THE LIGHT METALS INDUSTRY

1825 The Danish chemist Oersted produced the element aluminium by reduction of the chloride with potassium amalgam.

1827 – 1845 The German scientist Wöhler tried the reduction of aluminium chloride with potassium and succeeded in separating small globules from which he determined essential properties.

1854 The French scientist Saint-Claire Deville reduced aluminium chloride with sodium.

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In the same year, Bunsen and Deville produced.... the first aluminium by electrolysis, using fused..... sodium chloride as electrolyte.

1856 Deville erected works at Nanterre which started industrial production of aluminium.

1886 Hall in America and Héroult in France, independently developed the fused electrolysis method of producing aluminium from alumina dissolved in a fused bath.

1888 America took up industrial production of aluminium by the new electrolytic method. (Pittsburgh Reduction Company).

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In the same year, industrial production started in Switzerland, at Neuhausen.

France also commenced producing by the electrolytic method at Froges.

....

1890 This country started production by the Hall process in a pilot plant at Patricroft............ (Metal Reduction Syndicate).

1894 Full-scale working of the Hall-Héroult process was undertaken by the newly formed British Aluminium Company at Foyers, in Scotland.

Frontispiece. The Main Dates in the Early History of Aluminium.

THE
LIGHT METALS
INDUSTRY

By

WINIFRED LEWIS, B.Sc.

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DEDICATION

To the new era dawning
where the conflicts of history will give place
to peace.

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FOREWORD

THIS book appears at a very interesting point in the history of the light metals industry. In the case of aluminium—the principal light metal—its half-centenary is already receding into the past and there is an impressive record of solid progress inside the industry despite the breath-taking speed of its development from a minor to a major metal industry. On the other hand, a quivering of the old structure of the established industry is evident on the production side, as shortened supplies of high-grade raw materials make inevitable sufficient changes to threaten the old omnipotence of the processes used practically unmodified so far in its history. The magnesium industry, still in its infancy, has surmounted huge difficulties in production, but has not yet succeeded in establishing a peace-time consumer industry on any scale: whilst beryllium, cherished child of promise in the light metals family, has not yet become available as a pure metal industrially.

Partly as a result of war there are in the industrialized world of to-day many far-reaching problems of shortages: steel is at least a short-time problem in this island and elsewhere, and aluminium has to step into the breach to some extent. It has also become important as a replacement material for other metals in short supply and it has at the same time to meet the rationally expanding demand resulting from its own unique properties and from the industry's energetic past research and development programmes, which have in the main been remarkably scientific.

The outstanding feature of contemporary metallurgy as a whole is its fluidity, and on the manufacturing side of the light metals industry the whole field of working and fabricating has undergone revolutionary changes. In fact, the light metals industry and particularly the aluminium industry—which is one of the first great integrated producing industries to come into being during the scientific phase of industrialization, with its whole structure organized on sensitive lines accordingly—has reflected all the stresses and strains of the strenuous politico-economic developments of the past epochs of history.

The main technical features of the production processes are now well known and little can be added to any textbook reiteration of them since the critical factors of operation are known only to the individual producers and are jealously guarded secrets: even the research literature does not reveal any of the detail regarding the central works processes as actually operated and contains at the most expository ideas which can throw light on established techniques to an experienced technician. This book does not therefore cover the technical ground of the main operational processes of the light metals industry in any detail, but rather sets out from a different angle to view the industry of light metals from a technico-economic approach, attempting to relate it in perspective to the whole structure of modern industry which has the great metal industries as its base.

Again on the fabricating side of the industry this book does not try to give an account so much of the processes involved as of the special factors affecting the application of processes in themselves known—whose variety of forms, ancient and modern, is, incidentally, astonishingly large—to aluminium and magnesium materials. This point of view accounts for the brief treatment of some of the fabrication methods touched on where they are subject-matter for discussion on general engineering lines only and do not call for any special consideration as affecting light metals.

Little reference has been made in the text to patents and it is perhaps appropriate here to explain this omission as a deliberate one since, although the whole field of the industry is literally littered with patents, the contemporary position is that, with few exceptions, they afford no real hindrance to free development of any vital process in any country. This is in sharp contrast to the earlier position when the main process patents were able to dominate development and orient expansion.

Perhaps if viewed as the "progress report" of the light metals industry which this book attempts to be, rather than one more textbook on the light metals, the critical spirit in which some of the aspects of the industry are appraised or interpreted will be regarded as admissible.

It has been particularly interesting to verify in practice how much of human history is written through the lines of a review of an unfolding industry.

It is necessary to add that, whilst I have drawn widely on the world literature and official statistics of many countries for my facts, the interpretations and views of the industry are entirely my own, developed during my service in it since 1930. This book was conceived and partly written in a period of enforced leisure while I was recovering from a serious injury and as I have since rejoined the British Aluminium Company as Information Officer in their Intelligence Department I feel I should definitely disclaim that my ideas about the Light Metals Industry represent the Company's views: they are, in fact, wholly personal. I would further make it clear that the Company has in no way been associated with the supply of data or information.

WINIFRED LEWIS.

17th March, 1949.

CHAPTER I

A GENERAL ACCOUNT OF THE HISTORY, PRODUCTION, PROPERTIES AND USES OF ALUMINIUM

Historical Outline

OWING to the nature of aluminium considered as a chemical element there is no "classical" history of the metal: even as a chemical curiosity there is no record of its being known before the 19th Century. Following Sir Humphrey Davy's separation of metallic sodium and potassium by electrolysis (and an abortive attempt to produce aluminium by a similar method) the Danish chemist Oersted succeeded, in 1825, in producing a small lump of metallic aluminium by heating the chloride, formed chemically, with potassium amalgam and distilling the aluminium amalgam resulting from the interaction without contact with air. The German scientist Wöhler repeated Oersted's experiments with some variations in 1827, producing globules of metallic aluminium, from which he was able to determine some of the properties of the remarkable newly isolated element, notably its most characteristic property of lightness.

After another decade, the French scientist Saint Claire Deville discovered a method, based on Wöhler's procedure but using sodium instead of potassium, which promised to be the forerunner of production methods which would make possible the large-scale production of the new metal: Saint Claire Deville's name is generally associated with the foundation of the aluminium industry. The French Academy and later the Emperor Napoleon III lent financial support and encouragement to Saint Claire Deville to further his researches and French scientists offered their personal assistance, so that France has some claim to being the cradle of the Industry. The famous Javel works produced the first bars of aluminium and the Paris Exposition of 1855 gave an opportunity for the first public appearance of the latest comer among the metals.

Manufacture of the metal was started near Paris, but Deville's method, involving as it did chlorine, was found noxious and a new factory was erected at Nanterre where aluminium was produced in small quantities at a cost of some £7 per pound. The double chloride of aluminium and sodium was employed instead of the aluminium chloride formerly used and fluorspar (or later cryolite) was used as flux. The process was carried out in reverberatory furnaces with hearths about 1 metre square, closed to the atmosphere, up to 10 kilograms of aluminium (of average purity 97%) being run off from each reaction.

The cost of production by this early method proved to be too great to accord to the new metal aluminium the anticipated expansion warranted by its exceptionally favourable properties: and for a quarter of a century no industrial progress was made. The next step forward was taken in this country, when the Aluminium Company, Limited, erected near Birmingham a plant for operating a process based on the earlier used method but making use of the metallic sodium then recently introduced as a commercial product by Castner's method. Production started in 1888 and by the following year reached 500 pounds per day at a cost which made possible a selling price of 16s. per pound.

At this stage the New World was taking a big stride forward in the development of what has proved a new metal age. Charles Martin Hall, whose name is still associated with the modern process of production, on the 23rd February, 1886, discovered the possibility of applying the electrolytic method, using a fused bath to act as solvent for the alumina. Two years later production of aluminium was started at Pittsburg and the cheapness of the new process closed down the crop of works, distributed in Western Europe, which had essayed and implemented improvements in the chemical production process. Aluminium came on the market at the revolutionary price of a dollar a pound and a new era of the metal world began.

Practically simultaneously with Hall, Paul Héroult in France was working on a similar fused electrolysis method: his patent was applied for independently in the April of 1886, two months after Hall's invention had been claimed in America. Héroult also extended the electrolytic method to the production of aluminium alloys and to some extent sidetracked French production of the pure metal at that time in the interest of alloy production. A Swiss company acquired Héroult's patents and also started production of alloys by his method under the direction of Killiani at Neuhausen, the success of the venture leading to the founding of a new Company and an enlarged works and to the establishment of a French production centre at Froges—also for alloys.

When the success of Hall's process in America was apparent, Héroult and Killiani returned to the production of pure metal in Europe; and in this country simultaneous developments were taking place. In 1890 the Metal Reduction Syndicate, associated with Johnson Matthey, erected what would now be called a pilot plant to operate the Hall process at a works near Manchester, at Patricroft, this plant putting out about 5 tons a day. In 1894, under the auspices of Lord Kelvin, the British Aluminium Company was formed and acquired the rights for the Héroult process, which was operated at the Company's first works at Foyers, which opened in 1895. (The Patricroft works had closed the previous year.)

This is the skeleton history of aluminium: the Industry as it is known to-day commenced with the simultaneous discovery of Hall in America and Héroult in Europe of the electrolytic process. Of course there were many contributions to the development of the essential features of production by the electrolytic method and other suggested processes also played a passing part but the modern Industry chiefly recalls the names of Deville, Hall and Héroult as its godfathers.

The frontispiece shows the main dates in the early history of aluminium.

Production of Aluminium

As the preceding paragraphs have indicated, aluminium came late into the world of major metals for the reason that it was an electrolytic process product and required the electric furnace at a process of aluminium production based on the Hall-Héroult process and on bauxite has involved one main dichotomy, it having been found more economical to produce the alumina for reduction close to coal rather than to bauxite, whilst the electrolytic reduction plants must, of course, be located close to the source of power. This dichotomy immediately introduces the factor of transport, which becomes a further vital " raw material."

In Europe, France and the U.S.S.R. are the most advantageously situated in respect of aluminium production and the United States is probably placed about equally with the U.S.S.R. (except that the ore position is not so satisfactory in the United States). Apart from political considerations, the purely technico-economic position in Europe, excluding Russia, would have made France, Switzerland and Norway the largest European producers of aluminium, using French bauxite converted to alumina in Germany or England for the electrolytic process. In the last period before Europe began to head for the recent War, there did in fact exist a unified economic unit between the French, Swiss and German industries, French bauxite being converted into alumina in Germany, where coal (brown coal) was cheap, the aluminium being then manufactured in Switzerland where water power was freely available: low freights were charged for carrying French ore to German coal. Because of political implications and the consequent necessity for the development of national industries—for example, in this country—dichotomy has not always been adequate and the industry has had to work on a triangular basis of (imported) ore, alumina production and aluminium reduction. The question of transport then virtually resolves itself into the question of sea transport so far as favourable ore supply is concerned.

AVAILABILITY OF POWER

In the early days of the aluminium industry power was almost universally construed in terms of water power; hydro-electric energy was then becoming an important factor in industrial economy and strenuous efforts were made by the major industrial nations to secure favourable locations and development of water power. At that time the modern conception of electric power stations with alternative sources of energy based on alternative fuels such as powdered coal, mineral oil, or even peat on a large scale (as used in certain regions of the U.S.S.R.) was non-existent and hydraulic power represented a unique advantage in the newly developing electrolytic process industries in which aluminium was one of the major products. Capital investment in hydraulic power stations varied greatly with the natural resources but viewed as a long-term project it was always a good economic proposition and in favourable instances it provided remarkably cheap power, as for instance, on the Saguenay river or at Niagara. In Europe, conditions were, of course, at their best in Switzerland and Norway. Since the situation of the source of power is nearly always unfavourable for the location of a major industrial undertaking, power derived from hydraulic stations was commonly relayed to selected centres which could serve as the foci for assembly of the other raw materials and for the erection of works and their concomitant towns and satellite industries.

These factors, with their geographic and economic background, are complementary to the technical aspects of the use of water power in the cheapest manner. An important consideration in all electrolytic processing is the necessity for a continuous supply of electric energy (in contrast with part-time utilization for engineering and municipal requirements, e.g., for lighting and heating) which implies a very high load factor. From this angle the needs of an electrolytic industry such as aluminium are both favourable and unfavourable as regards power consumption: on the one hand, the power undertaking can count on disposing of an otherwise unused capacity and on the other hand, it is essential that the production cost of the energy shall be low and the power supply steady. A hydro-electric system normally expects to provide for commitments for a certain amount of firm power which has to be based upon the lowest level of water during the year, taking into account normal storage provision. Due to irregular volume of water flow, both annual and seasonal, the minimum may be exceeded during certain years and for certain months in every year and this excess power, known as secondary power, has been utilized successfully in the electrolytic industry and to some extent in the aluminium industry. In this industry, however, most of the big producers have their own power undertakings or own at least a controlling interest in them.

Coal and Fuel

Fuel is one of the most important materials consumed in the production of aluminium, being essential to fire the kilns in the production of alumina. Until the outbreak of the second world war, the only fuel used in the manufacture of alumina was coal; but during the war years and particularly in America, some shift has taken place towards other fuel sources, for example, natural gas. Oil or electricity may also be used in the production processes according to the situation of the works relative to a supply at a favourable cost.

In Europe the most favourably situated countries from the angle of coal supply for alumina production were Germany and England, with Italy as a runner-up. In the United States a good supply of high-quality coal is available in the State of Washington and there is plenty of lower grade bituminous coal for most of the plants producing alumina, although oil was substituted for coal at four or five plants distributed through the States in recent years.

Caustic Soda

In general the aluminium industry has concerned itself only with the mining of bauxite and the manufacture of alumina and metallic aluminium and has not entered into the production of the caustic soda utilized in the alumina process. Both the processes used on a large scale for the production of caustic soda, namely the soda-ammonia and the electrolytic process, belong essentially to the heavy chemical industry and large quantities are available at a low price. The raw material for caustic soda production, which is chiefly soda ash, is available in abundant supply. This material also enters directly into the process of alumina production by the Bayer method in some instances.

ELECTRODE CARBON

The anodes used in the electrolysis cells are prepared from a mixture of petroleum coke and ordinary pitch, roughly in 70-30 ratio, but this figure varies according to the quality of the coke. Petroleum coke is a by-product of petroleum refining, being actually the residue after the volatile and fuel oils have been withdrawn. Before it is ready for service for the production of anodes, the crude materials from the petroleum stills have to be calcined and this process requires special plant and consumes one-fifth to one-quarter of the weight of crude coke processed in fuel supply.

BAUXITE

Bauxite is the raw material peculiar to the aluminium industry, and the chief producers prior to the First World War were France and the United States. With the coming of that war and afterwards, when the status of the aluminium industry rose from a minor to a major industry, a scramble took place for the hitherto undeveloped deposits of bauxite in Europe (the best being in Hungary, Dalmatia, Istria, smaller deposits occurring in Yugoslavia, Rumania and Greece) and in the Guianas (the most important though not the only deposits in South America). Ore availability was not, of course, uncontrolled; the Great War Peace Settlement made reference to the European deposits and the British Colonial Office attempted to restrict grants for the British Guiana ore to British capital and enterprise.

By the latter part of the post-First War decade, the position was roughly that a very large part of the better ore in the Guianas was in the hands of the American aluminium-producing industry which had also acquired Istrian and Yugoslavian ore. In Europe the Germans acquired about 20 million tons of bauxite in Hungary, Yugoslavia and Rumania (principally the former); whilst the rest of the then explored deposits were distributed between British, French and Canadian producers.

In the next ten years, before the Second World War, the exploitation of the bauxite mines developed full swing, the total world output in 1940 being over 4½ million tons. The chief producers are shown in the next chapter. The immediate position of the aluminium industry at the outbreak of and during the Second War, tied as it was to the high-grade bauxite production process in the majority of producing countries, was very closely linked with the acquisition of the ore reserves and this situation had considerable influence in barring new entrants to the producing industry.

More recently attempts have been made to open up hitherto untouched supplies of bauxite. The ore is fairly widely distributed but the grades suitable for the Hall-Héroult process are not inexhaustible and may prove to be rather limited. There has been, for instance, some concern about the surprisingly rapid exhaustion of the Guiana deposits worked in the interests of the American aluminium industry: whilst this country has interested itself in newly worked deposits in Australia (New South Wales and Victoria) and has acquired new reserves in Africa (Gold Coast). Substantial reserves are reported to be available in India, but production of bauxite has until recently been restricted to a small output of high-grade ore near Bombay and in Madras.

In view of the political implications of the aluminium industry and of the geographical availability of bauxite, attempts have recently been made to consider possible substitutes for bauxite, chief of which are clay and leucite. Next to bauxite the kaolinite clays are the richest source of aluminium, containing some 39% of alumina; and in view of their almost ubiquitous distribution in unlimited supply a great variety of processes for the extraction of the alumina have been tried out. The difficulties inherent in the production of a pure alumina from clay are bound up with the silicious nature of the matrix material which renders the removal of all the impurities extremely cumbersome and expensive even where a particular process has proved it possible.

Another mineral which has attained some importance in the production of aluminium ores alternative to bauxite is leucite, on which the Italian industry before the recent War was branching out on a large scale. Leucite is a silicate of alumina and potassium and processing of this ore is faced with the same difficulty as the production of alumina of a grade suitable for aluminium production from clay.

One further ore has been tried and utilized with some success in Manchuria and in U.S.S.R., namely alunite, which is a hydrous potassium aluminium sulphate.

Some details of the various processes developed for the working of these alternative ores will be found in subsequent references.

The Production Process

It has already been noted above that there are two essential stages in the production of ingot aluminium from the ore—which is normally bauxite but may be alternatively clay, leucite, alunite, nephelin or other minerals giving rise to aluminium oxide. These two essential stages are the production of pure aluminium oxide from the ore: and the reduction, by fused electrolysis, of the oxide to yield pure aluminium.

In addition to these main processes, there are ancillary operations such as the manufacture of synthetic cryolite for the molten electrolysis bath and the production of anodes for the electrolysis cells.

ORE PROCESSING

About 90% of the world production of aluminium from bauxite for the aluminium industry was carried out, prior to the last war, by the Bayer process. The essential features of this process are shown in the accompanying Figure (see Fig. I on p. 12). Modifications of the process in different producers' procedures are many and varied, but the main outlines of the process remain the same. The crushed, ground bauxite is subjected to calcining, with the threefold objective of (1) partial dehydration, (2) further, finer grinding, (3) removal of any organic matter present in the ore, which would accumulate in the aluminate liquors and interfere with the separation of the hydrated oxide. Calcining is usually carried out in rotary furnaces, from which the product is transported mechanically by elevators to the fine-grinding mills. From the mills it passes to storage containers.

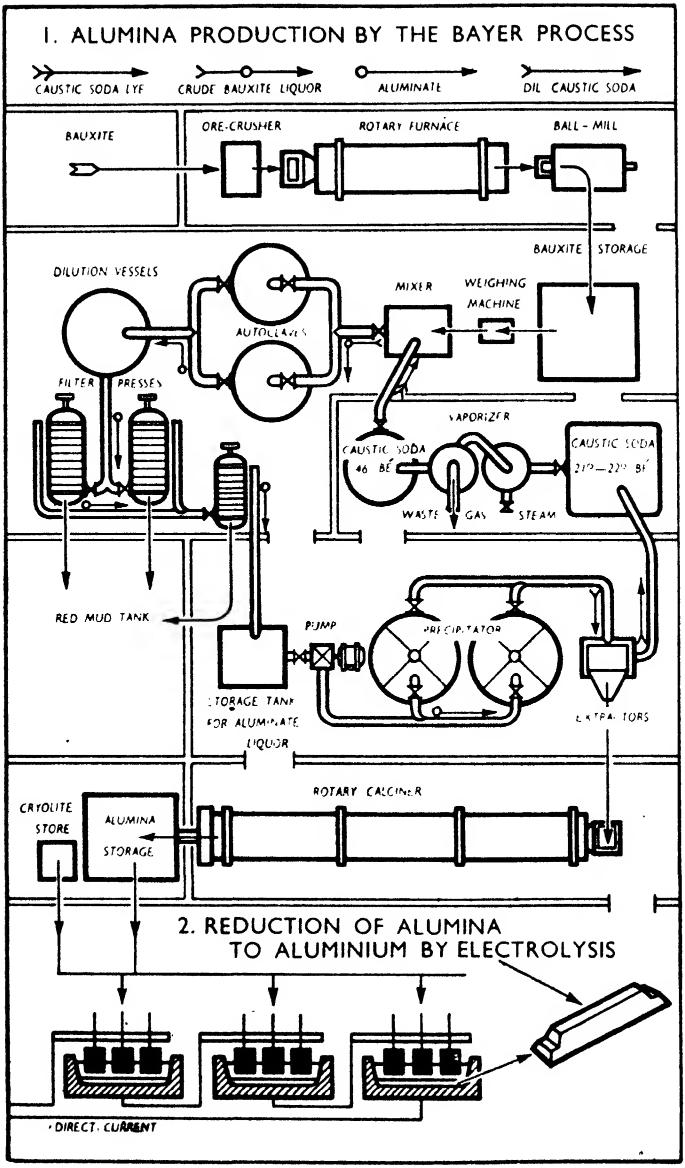

Fig. I. **Diagrammatic Representation of the Main Processes of Production of Alumina and its Subsequent Reduction.**

Exactly weighed amounts of this product are treated in large mixers with caustic soda liquor of about 46° Bé concentration and fed into autoclaves in which the reaction proceeds under pressure and at controlled temperature. The resulting sodium aluminate liquor is immediately pumped into presses for filtration under pressure, where the liquor is separated from the insoluble residue (the so-called " red mud "). The clear aluminate liquor is ultimately pumped into the precipitating tanks where it is mixed with a " seed " charge of aluminium hydrate from a previous cycle: the precipitators are provided with efficient agitators and controlled cooling is applied to aid the precipitation of coarsely crystalline aluminium hydrate. With properly controlled concentrations and cooling temperatures a yield of about 60% of hydrate is precipitated and continuously removed from the solution, washed and sent to the calciners. Calcination is carried out in rotary kilns in which the alumina passes from top to bottom in contra-direction to the heating gases: the temperature required is over 1,200° C., as the alumina has to be " dead-burned " in order to withstand subsequent tendencies to deliquescence during storage. Modern calciners are sometimes also equipped with electric dust-extractors which continuously withdraw the fully calcined product.

Apart from the Bayer process, many alternative methods have been from time to time proposed for the extraction of alumina, as shown in the Table on pp. 14 and 15.

Reduction of Alumina

The reduction of alumina to aluminium is universally undertaken by the electrolytic process originally developed by Hall and Héroult. The electrolyte is a mixture of sodium-aluminium fluoride (cryolite) and alumina with a melting point lying between 900° C.—950° C. This mixture is fused in the electrolysis vats which are provided with carbon linings which function as cathode. The anodes are made from very low-ash pitch-coke or petroleum-coke mass (see p. 9) bound together with a highly viscous tar as agglutinant. The operating voltage is 5-6 volts, the amperage load of a furnace being in the region of 10,000 to 30,000 amps. The

TABLE I

PROPOSED METHODS FOR THE EXTRACTION OF ALUMINA

Ore or raw material	Name of process or inventor	Principle of process	Intermediate product	Commercial exploitation
		A. Alkaline Decomposition Processes		
Bauxite ..	Pechiney ..	Fusing with Na_2CO_3	Sodium aluminate	Tried in France
Bauxite ..	Pederson ..	Fusing with alkaline earth carbonate	Calcium aluminate	Tried in U.S., operated in Norway and Sweden
Bauxite ..	Peniakoff	Fusing with sodium sulphate	Soluble alkali aluminates	Operated in Belgium in early days of Al industry
Bauxite and other ores	Various ..	Fusing with alkali and/or alkaline earth chlorides	Aluminates	—
Cryolite ..	Various ..	Calcining with bauxite and lime	Aluminates	Obsolete
Alunite ..	Tanaka ..	Treatment with caustic soda	Crude alumina cake	Full plant scale tried in Japan
		B. Acid Decomposition Processes		
Clay ..	Buchner/ " Aloton "	Fusing with ammonium sulphate	Alums/ sulphates	Considerable development in Germany before war, and tried in U.S. during war
Clay/ feldspar	Various ..	Fusing with SO_2 and sulphurous acid	Sulphite	Tried in Germany
Clay/ feldspar	Various ..	Fusing with H_2SO_4	Alums/ sulphates	Tried in U.S.

Table I—Continued

Ore or raw material	Name of process or inventor	Principle of process	Intermediate product	Commercial exploitation
Alunite ..	Various ..	Partial or total decomposition by heating	Sulphate	Pilot-scale operation during war in Japan
Alunite ..	Various ..	Digestion with H_2SO_4	Sulphate	Development in U.S.S.R.
Leucite ..	Blanc ..	Leaching with HCl	Chloride	Extensively used in Italy
Different ores	Various ..	Treatment with HNO_3	Nitrate	—
		C. Electrothermal Processes		
Bauxite ..	Hall/Frary	Smelting with coke	No intermediate cpd : direct to alumina	Commercially operated in U.S. in the '20s
Bauxite ..	Haglund ..	Smelting with coke and pyrites	Slag with 20% Al sulphide	Semi-commercial scale in Germany and Italy
Bauxite ..	Serpek ..	Smelting with coke and N	Nitride ..	Semi-commercial devel. in France and U.S., but not successful
Ores, alloys or cpds.	Various ..	Smelting with coke and pyrites or with iron sulphide alone	Sulphide ..	—
Ores or cpds.	Various ..	Smelting with coke	Carbide ..	—
Clay or colliery waste	Seailles/ Dyckerhoff	Smelting with limestone	Calcium Al clinker	Tried in Germany during war

molten aluminium collects at the bottom of the furnace and is tapped off at intervals. The oxygen of the alumina is liberated at the anode and burns to carbon dioxide.

THE REDUCTION FURNACE

The older furnaces in use are circular in shape and provided with a single anode: the need for larger furnaces and increased anode section has led to the development of multiple-anode rectangular-shaped cells or " pots," as they are commonly called in the aluminium industry, which are now nearly universal, although oval cells have been designed as part of the newer equipment in some modern Continental works. Interior dimensions of the common rectangular furnaces now in use are about 8 × 4 ft. by 2-2½ ft. in depth: larger furnaces with cross section increased to double or treble the capacity are being introduced in newer works. The furnace hearth, constructed of baked carbon block, is slanted downwards to a tapping hole at one end of the cell.

Anodes are of two main types, the older pre-baked anode and the modern so-called continuous anode of which the best-known and most widely used is the Soderberg anode. In the continuous anode the carbon is fed continuously in the form of paste, baking being accomplished within the furnace itself. The current is fed through flexible conductors to steel stubs inserted into the anode container, the anode consumption being compensated by the rise in level of the bath: when metal is removed from the furnace by tapping, the anode has to be lowered to regain its proper working distance and as the anode descends the conductors are transferred from the lowest stub rows (which are removed) and connected to a higher stub row. Improvements are constantly being introduced into the design of the continuous anodes and their mechanized manipulation.

According to the size of the furnace different numbers of anodes may be employed. Furnaces are commonly connected in series and arranged (often diagonally, to facilitate tapping operations) in two opposite banks with the electrodes mounted in pairs. The electrodes are carried on some form of jack, which, in the newest plants, may be individually motor-operated and controlled by a separate switch at each furnace. A modern furnace room may contain up to fifty pairs of furnaces and it is customary to leave a few pairs unconnected as "spares" for bringing into operation when furnaces have to be dismantled or taken out of action for any reason.

The technical control of the reduction furnaces in action is very exacting: proper regulation of temperature, depending on the maintenance of optimum working distance of anodes, depth of bath, metal content and flux composition, requires careful control. Anode polarization, known as "anode effect" and popularly referred to as an "up," which is caused by impoverishment of alumina in solution in the flux is of frequent occurrence—every few hours—in each furnace and requires the attention of skilled furnace operators to stir the solid alumina risen into the solid crust back into solution. Warning of this polarization effect, which is accompanied by a very rapid and steep rise in voltage, is arranged by signal lights. The changing of the anodes in the older type of furnace is also a routine operation calling for skill and care.

Reduction furnaces are normally enclosed and provided with exhaust systems to remove flux fumes and, in the case of continuous electrodes, the escape of tar pitch volatiles arising from the baking of the anodes. The exhaust systems in modern plants are equipped with scrubbing plants from which cryolite is recovered as a by-product.

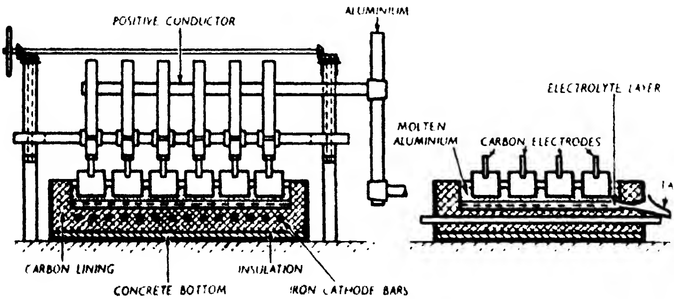

Fig. II. Diagram of an Aluminium Reduction Furnace.

The life of a reduction furnace is dependent on the life of the carbon lining: it averages 2-4 years in the older type of furnace and may reach 5 or 6 years in furnaces of good up-to-date design.

CRYOLITE

Originally all the cryolite used for aluminium production was the natural ore drawn from Greenland. Although the natural product has certain slight advantages which make it a more acceptable product to most aluminium producers, the bulk of the material in use to-day is the synthetic product prepared from hydrofluoric acid derived from fluorspar. The acid is made to react with sodium aluminate in stoichiometric proportions to produce the double fluoride of sodium and aluminium.

INGOT CASTING: REMELTING

The aluminium tapped from the electrolytic cells may contain traces of electrolyte or of metallic sodium and the solidifying metal is usually first cast directly into crude pigs which are then remelted either in an electric or reverberatory furnace before casting into ingots. Large ingots are mostly cast plain in form; they may weigh up to 50 lb., but the normal size in this country is about 22 lb. Smaller ingots are put on the market in the familiar form of the notched bar, which is also sometimes known as a " ten-notcher " or otherwise according to the number of notches. This type of ingot is very practical in use, since properly chosen notch dimensions allow of nesting for stacking; and in the case of small ingots they may be conveniently made into bundles without risk of slipping. Further, the notches allow of conveniently breaking into fractional parts. Sizes of commercial ingots vary widely in different countries: the commonest size in this country is the 15-in. bar with ten notches, weighing between 2 and 2¼ lb.

The actual process of ingot casting is elaborate and is usually now done in so-called continuous casting machines in which the ingot moulds are arranged in the form of a continuous band which moves mechanically under the pouring spout of the crucible or furnace.

INGOT TO FABRICATED PRODUCT

Aluminium appears in its final form of fabricated products by way of two main channels of manufacture, depending on whether the metal is worked by forging or is cast. Wrought products are first semi-manufactured into sheet or strip by rolling, into sections by extrusion, or into wire by drawing (these are the main categories, but there are also other methods of semi-manufacture). Cast products are produced directly from ingot in the foundries, which are not necessarily connected with the primary producing works. The forged "semis," as they are called, go on to the fabricators for further manufacturing processes, e.g., by spinning, pressing, impact extrusion or deep-drawing: or they may find themselves in other industries in direct use as constructional materials or units.

THE ALLOYS OF ALUMINIUM

It should be noted here that aluminium as a pure metal is comparatively soft, with a relatively low tensile strength; and although it finds a wide outlet in those industries where its natural chemical and physical properties make it of value in its virgin condition as it comes from the electrolytic reduction plant via the casting shop or rolling mills, it finds the majority of its applications in the role of structural material in the form of alloys. Huge and confusing as is the number of alloys of aluminium which have in the course of industrial development been put on the market, the main alloys are limited in number and type; the best of these have established themselves firmly as engineering materials of outstanding importance and not infrequently find themselves in loose colloquial usage described as "aluminium," which has become in lay circles a generic name for the metal plus its major alloys.

The most important alloying constituents are copper, magnesium, silicon, zinc, manganese, iron, nickel, cadmium and antimony. The straight binary alloys are not of such great commercial importance, outside the casting industry, as the ternary alloys, which in some cases can be given heat-treatment further to increase their mechanical strength.

Appropriate information about the alloys of aluminium is given in later sections: the present chapter is concerned chiefly with the pure metal.[1]

Cost of Production

The cost of production of commercial ingot involves (a) the costs of several basic raw materials, of which the chief items are controlled by the aluminium industry, (b) the cost of power and fuel, of which the former may or may not be controlled by the aluminium producer and (c) the costs of three distinct operations for the conversion respectively of (i) bauxite to alumina by a chemical process, (ii) alumina to crude aluminium by electro-chemical reduction and (iii) crude aluminium to commercial ingot by a mechanical casting process (see p. 18).

(a) COST OF RAW MATERIALS

The principal raw material is, of course, bauxite, of which, in the grades usually employed in the aluminium industry, two tons are required for the production of one ton of calcined alumina and four tons go to each ton of aluminium metal. Most of the large producers, as will be seen in Chapter II, own their own bauxite deposits and mine the ore themselves or contract for its mining: the cost at the aluminium plant is dependent on the cost of mining, which is obviously very variable, depending as it does on the nature and location of the mines and the labour conditions there pertaining, and on the cost of transport *ex* mine to the plant. Some typical figures for the cost of bauxite at the mine head have been published in the United States recently:

Bauxite at the mine, Dutch Guiana	$5.80 per long ton
Bauxite at the mine, Bintan	$4.00 per long ton
Bauxite at European mines, pre-War	10s. per long ton

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[1] Though from the point of view of the chemist or physicist, the so-called pure aluminium of commerce is strictly an alloy, with small quantities of iron and silicon and "trace elements" present in it, from the technological stand-point, compared with other metals of commerce, industrial grades of aluminium are pure, with a content not lower than 99.2% and averaging 99.3%-99.4%.

The cost of transport of the ore is again clearly widely variable; in general it may be said that with intra-continental freights as they operated, for instance, in Europe before the recent War, bauxite at the European producers' alumina plants cost on a rough average 23/- per ton: while in the United States, alumina plants, dependent on bauxite supplies outside the North American continent, had to reckon more than double this figure, averaging very roughly $10 per ton.

Caustic soda, as soda ash, is consumed to the extent of about 170 lb. (0.08 ton) per ton of alumina produced: the price, at the alumina plant, is again variable, being lowest at or near centres of electro-chemical production (as in Canada and in certain of the United States plants) where the price is of the order of £8 per ton.

Carbon for anodes is an expensive raw material; some figures of American origin are shown in Table II on p. 22.

(b) Power and Fuel Costs

These naturally vary widely. Typical figures, so far as they exist, are included in the schedules given below.

(c) i. Processing of Bauxite to Alumina

Few figures have been published but representative cost sheets for operating the Bayer process (p. 11) in a typical large European plant and in a United States plant of comparable annual output appear to be somewhat as follows:—

	Europe			United States
Cost Items per ton of Alumina	**£**	**s**	**d**	**$**
Bauxite, 2 short tons	2	6	0	25
Soda ash, 0.085 short tons	2	8	0	3
Fuel (coal or equivalent in oil or gas)	4	2	0	2
Electric energy		13	0	1
Miscellaneous Supplies		11	0	1
	£10	0	0	$32
Other Costs				
Wages		12	0	5
Administration and other Expenses		8	0	1.5
Amortization, Taxation, etc.	1	0	0	2.5
Total Costs	£12	0	0	$41

ii. Reduction of Alumina to Crude Aluminium Metal

The data given below are for the United States and were furnished from Alcoa's books in the course of the U.S. Government suit against them in the Courts:

TABLE II

U.S. PRE-WAR COST OF REDUCTION OF CRUDE ALUMINIUM (CENTS PER POUND OF METAL)

	1926	1927	1928	1929	1930	1931	1932
Pot Lining	0.12	0.10	0.10	0.11	0.11	0.08	0.09
Carbon Rodding:							
Electrodes	1.91	2.07	1.72	1.68	1.54	1.47	1.40
Electrode Rods ..	0.12	0.12	0.05	0.03	—	—	—
Labour	0.08	0.08	0.07	0.06	0.05	0.04	0.03
Power	3.49	3.19	2.33	2.30	2.24	2.13	2.08
Pot Rooms:							
Ore	6.69	6.61	5.41	5.38	5.37	5.35	5.35
Electrolyte	0.47	0.52	0.50	0.40	0.45	0.32	0.27
Alloys	0.13	0.09	0.07	0.06	0.05	0.04	0.11
Labour	2.03	1.57	1.03	0.99	0.92	0.74	0.49
Miscellaneous Plant Expenses	0.22	0.28	0.19	0.19	0.20	0.18	0.16
Transport on Consigned Aluminium	0.15	0.15	0.17	0.20	0.12	0.10	0.13
Depreciation	0.27	0.25	0.21	0.18	0.19	0.26	0.40
Plant Administration ..	0.32	0.26	0.18	0.18	0.18	0.17	0.19
Repairs and Maintenance	0.32	0.30	0.24	0.24	0.21	0.17	0.16
TOTAL plant expense ..	16.32	15.59	12.27	12.00	11.63	11.05	10.86
DEDUCT:							
Carbon differential ..	0.38	0.51	0.34	0.38	0.34	0.40	0.39
Power differential ..	1.16	1.33	0.75	0.78	0.85	0.64	0.06
Ore differential ..	0.80	1.53	0.54	0.78	0.81	0.80	0.79
ACTUAL COST .. Cents	13.98	12.22	10.64	10.06	9.63	9.21	9.62

iii. Conversion of Crude Aluminium to Commercial Ingot

Over the same period as that covered in Table II above, the American costs of conversion of crude aluminium to commercial ingot were supplied from the same source as ranging from $13-20 per ton.

The Properties of Aluminium

It has been said that any account of the properties of aluminium tends to savour of the disingenuous by exhausting the superlatives. On the one hand, due to its position among the elements, it is a metal characterized by great reactivity and its chemical affinity to oxygen is the most valuable example of this: the oxide film which is invariably present on aluminium contributes to the versatility of the pure metal since the oxide film can be controlled and exploited to serve many and varying physical or chemical uses. On the other hand, the wide range of alloys which aluminium is capable of forming gives it a corresponding range of mechanical properties which rank it as a structural or engineering material of importance comparable to that of steel.

Aluminium has an attractive silvery-white colour. Its low specific weight (approximately 2.7 as compared with iron 7.86 and copper 8.93) is only about one-third that of steel or copper.

The tensile strength of the high-strength alloys (30 tons/sq. in. to 36 tons/sq. in.) is equal to—and may even in exceptional instances exceed—that of ordinary structural steels.

The oxide film on aluminium, which is not ordinarily visible to the naked eye, imparts to the metal a good chemical resistance to corrosion by atmospheric influences and to the effect of a wide range of products in the chemical and food-processing industries.

Aluminium itself, its alloys and the chemical compounds to which it gives rise in ordinary use, are all completely non-toxic.

Of outstanding importance is the high electrical conductivity of aluminium which places it next to copper as a conductor: the specific resistance is 1.119 to 1.131 microhms/in. cube.

The heat conductivity is also high, lying between that of iron and copper: 0.51 to 0.53 cal/cm^3/sec/°C. is the figure for aluminium as compared with 0.113 for iron and 0.938 for copper.

The optical properties (reflectivity) are outstandingly good.

Aluminium and its alloys are moreover possessed of the capacity to make excellent castings and to undergo any of the normal forging and machining operations: they can also be joined by any of the known methods, being amenable to welding and soft soldering, riveting, etc.

Surface treatment of aluminium and its alloys offers unusual possibilities, since in addition to a full range of electro-plated finishes on the metal, the oxide film can be reinforced by chemical or anodic oxidation and given numberless subsequent treatments serving special chemical or physical requirements as well as purely decorative ends.

The Table on p. 26 (Table III) lists the more important properties of aluminium of ordinary commercial purity (averaging 99.3%-99.4%—see footnote, p. 20).

GRADES (OR QUALITIES) OF ALUMINIUM

In England the official standard specifications (B.S.S.359 and 360)[2] for the commercial grades of aluminium actually admit of impurities being present to the extent respectively of 2% and 1%: but the industrial virgin ingot is generally of much higher quality than that covered by the official standard (which sets out to define a liberal minimum) and although post-war grades of aluminium fall slightly below the quality which was common prior to 1939, current virgin products marketed rarely contain less than 99.3-99.4% Al. and in practice never contain less than 99.2% Al.

The chief impurities are iron and silicon. Traces of copper, zinc, titanium or calcium, sodium and carbon are sometimes present due to contamination from the furnace linings, electrodes, etc.

The iron-silicon ratio is of some importance. For forging products the iron should preponderate, to give the best results: whilst for casting, metal in which the silicon content exceeds the iron pours more easily. The reason for this is connected with the complexes or compounds which may form between the two constituents and the aluminium matrix: since the alloy which results from the presence of the iron and silicon is by no means a simple ternary alloy.

The official standards of other countries (particularly U.S. and

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[2] See pp. 168-169 for details.

pre-war German standards) differ in detail from the British standards but the industrial output in all countries is not notably different.

In addition to the ordinary grades of so-called "commercial" purity, the main producers all market special high-purity grades for special uses. Of these the most interesting is known as "super-purity aluminium" in this country or "refined aluminium" in the U.S. and (by translation) "aluminium raffiné" in France, where the output of this special metal is considerable.

SUPER-PURITY ALUMINIUM

This grade of aluminium, which is produced by an electrolytic refining process described in a later chapter on p. 294, in normal output contains only 0.002% or less of foreign elements. The cost of production limits its use to special applications, usually those calling for small quantities or for very exacting conditions of corrosion-resistance or surface-finish quality.

SECONDARY ALUMINIUM

Before World War II, there was not a large British market for secondary aluminium (metal obtained from scrap by remelting) which was produced only on a small scale and principally exported. In the early part of the war, however, it became apparent that secondary metal must play its part to amplify the supplies of virgin metal produced by the domestic producers or imported. The Government sponsored the erection of several reclamation plants and as the war went on quite important tonnages of secondary metal were obtained from recovery of scrapped aircraft. The process and some of the principal plants are described in Chapter XV on p. 310.

Even with the most up-to-date sorting and production control, the purity of reclaimed metal falls considerably below that derived from virgin production and in consequence, its use has been directed mainly into channels where issues of purity in the case of non-alloyed metal and of strict composition in the case of alloys are relatively unimportant. In view of prevailing shortages both

TABLE III

THE PROPERTIES OF ALUMINIUM *

Property	Unit of measurement or other data	Value
A.—Physical		
1. Atomic weight	(taking oxygen = 16)	27 (no isotopes)
2. Electronic charge	—	13
3. Specific gravity	—	2.7
4. Melting point..	°C.: 99.97% purity °C.: 99.7% purity	659.8 658.7
5. Boiling point	°C.	1,800
6. Specific heat	20°–400°C. cals.	0.24
7. Specific thermal conductivity	cals./cm.^{3}/°C./sec. at 0°C.	0.502
8. Relative heat conductivity ..	(taking silver = 100%)	51.8
9. Latent heat of fusion ..	cals./grm.	92.4
10. Heat of combustion	to Al_2O_3 per grm. mol. in cals.	383,900
11. Coefficient of linear expansion :		
20°–100°C.	per °C. × 10^6	24.0
20°–300°C.	per °C. × 10^6	26.7
20°–600°C.	per °C. × 10^6	28.6
12. Vapour pressure	at 658.7°C.: mm. of mercury × 10^{43}	1.0
B.—Optical		
13. Reflecting power (normal incidence) of ordinary polished aluminium	%: Wavelength—	
	23,000 A.U. ..	100
	22,000 A.U. ..	96
	18,000 A.U. ..	97
	16,000 A.U. ..	98
	10,000 A.U. ..	93
	5,000 A.U. ..	88
Reflecting power (normal incidence) of special surface-treated aluminium	% : Visible light	87
14. Refractive index	Wavelength—	
	6,570 A.U. ..	1.48
	5,890 A.U. ..	1.28
	5,270 A.U. ..	1.10
	4,860 A.U. ..	0.93
	4,310 A.U. ..	0.78

* See also detailed Schedules in Chapter VII.

Table III—Continued

Property	Unit of measurement or other data	Value
15. Absorption index	Wavelength—	
	6,570 A.U. ..	3.92
	5,890 A.U. ..	3.66
	5,270 A.U. ..	3.39
	4,860 A.U. ..	3.15
	4,310 A.U. ..	2.85
C. *Electrical*		
16. Electrolytic solution potential	(against normal hydrogen electrode in *N.* aluminium sulphate) in volts	1.3
17. Electro-chemical equivalent..	grms. per coulomb	0.00009316
18. Specific resistance	microhms/in. cube at 20°C.	1.12 to 1.13
19. Temperature coefficient of resistance	per °C. at 15.6°C.	0.00407
20. Magnetic susceptibility ..	at 18°C.: $\times 10^6$	0.63
21. Thermo-e.m.f.	99.97% purity Al against pure Pt at 100°C.: in millivolts	+0.416
D.—*Mechanical*		
22. Hardness :		
(i) Brinell	1 mm./5 kg.	Cast : 20–28 Annealed sheet : 19–23 Hard sheet : 38–45
(ii) Scleroscope	(magnetic hammer)	Cast : 5–5½ Hard sheet : 15–22
23. Modulus of elasticity ..	lb./sq. in. $\times 10^{-6}$	9.9
24. Torsion modulus	lb./sq. in. $\times 10^{-6}$	3.87
25. Poisson's ratio	—	0.36
26. Tensile strength of wrought aluminium of 99% purity	tons/sq. in.	Annealed : 5–6.5 Half-hard : 7–8.5 Hard : 9 or greater
27. Percentage elongation ..	in 2 ins.	Sand cast : 20–30 Chill cast : 30–40 Wrought, annealed : 12–40 Wrought, half-hard : 5–12 Wrought, hard : 2–8 Wire, hard-drawn : 4–7
28. Notch strength	mkg./cm.^{2}	>10
29. Fatigue limit, Schenk ..	kg./mm.^{2}	5–10 $\times 10^6$

of virgin aluminium and of other metals there is still, in the post-war period, a not inconsiderable market for the lower-grade secondary aluminium.

The Uses of Aluminium

A great change has taken place in the shape of the industrial applications of aluminium in the space of its lifetime of fifty years, changes which it has been curious to watch even in the span of a normal career spent in the industry. Born at the end of last Century at the peak of the Industrial Age so far as Europe, at least, is concerned, the history of aluminium runs coincidentally with the later stages of Mechanization that have been bound up with the tragedy of mechanized destruction which has disfigured Western civilization. When aluminium made a shy debut as a maiden metal in a world dominated by the dowager steel industry and its filial associates among the new alloy steels and older heavier metals, the applications of the new material were entirely restricted to small fabricated articles—mostly the pots and pans with which the name of aluminium is still associated in the lay mind, which can hardly grasp the changes that a short life-time has wrought in the products of scientific development. The features which were noticeable were the lightness and whiteness of the new metal—an attractive combination in the kitchen, where the Twentieth Century spirit of emancipation from the gloom and drudgery of the Nineteenth was also beginning to struggle for expression. Coy advances were made in related spheres and much was anticipated of the new "Light Metal" which in its infancy had been a "bibelot" treasure metal whose actual future was hardly then foreshadowed even by the dreamers among scientists.

The cost of the new metal, as a metal, was of course high; and on this account, in the palmy days of cheap living before the Great War of 1914-1918, even the obvious advantages of lightness and brightness did not produce any spectacular advances in the early markets. The next stage of aluminium, interestingly enough the stage which foreshadowed the great future of aluminium as an engineering material, was dependent on its electrical properties. Transmission line engineering, undergoing vast development, was attracted by the combination of an electrical conductivity which compared favourably with that of copper and the lightness of a material a third the weight of copper: and aluminium became a competitor among electrical engineering metals.

This adult emergence from the hollow-ware and fancy goods trades was first beginning to shape seriously when the Great War broke the illusions of Western European peace and prosperity. Armaments took the place of ploughshares and the mind of so-called civilized man bent its energies to creating destructive mechanisms. To the scientists of that time the omens went unheeded and, accepting the "war to end wars" plea of the idealists, he gave unstinting, if unmeaning, aid in forging the weapons which were ultimately to destroy what Europe had stood for. Early in the war the importance of aircraft development, then in its infancy and handicapped by the lack of suitable materials, was appreciated. Throughout the world research was undertaken on an unprecedented scale to develop aircraft construction, and many minds turned to the obvious factor of "lightness" of the little-known metal aluminium. In this country the brilliant work of the war-time Light Alloys Sub-committee of the Advisory Committee for Aeronautics, headed by Rosenhain, discovered the key to the development of strong aluminium alloys by heat-treatment. Wilm, in Germany, perfected the first great constructional alloy, duralumin; and simultaneous researches in different centres brought about the creation of a new metal age, the age of light alloys.

Born of war, the alloys of aluminium throve on it. By the 'twenties they were weaving their way into the fabric of that materialistic inter-war period when Western civilization was drawing breath and sharpening its sword for the next great conflict. It is questionable whether aluminium, a luxury metal among its drabber companions, could have won so soon against the economic pressure in the struggle amongst its competitors if the urges of war had not overruled the rational problems of cost. For aluminium is still an expensive commodity.

Expense did not count, however, in the strategic conceptions of the inter-war period, and thus we find the necessitous development of many national industries for the production of aluminium which no national economic factors could justify. The larger production of the metal spelt larger research to develop its uses: and vast sums have been devoted to this purpose in an age where every development has been breath-takingly rapid. From the position of a nonenity among engineering metals in 1912, by 1932 aluminium was taking its place among its major competitors in the field of constructional engineering—first and foremost, of course, in the aircraft industry which sponsored its introduction in this sphere but also in architecture; in the transportation industry (where it even entered the Steel Age's holy-of-holies, the railway rolling-stock workshops) and in the ship-building industry; in some branches of heavy engineering where light weight is advantageous; in light engineering; and of course in a vast congregation of minor light-weight components and small objects in every industry under the sun. It maintained and extended its early-won position in the electrical industry and expanded its influence as a material of chemical engineering where its high corrosion-resistance is of interest. It entered new fields after certain surface-treatments such as anodizing and electrolytic brightening increased its interest to the physicist as a material for instruments and reflectors, and fulfilled the most exotic dream of the most exigeant industrial designer as a material capable, as foil or as metal, of taking on all the hues of the rainbow. It became a medium *par excellence* for light-weight insulation and for heat exchange. In fact, it is difficult to list the uses and applications of aluminium without feeling that it is a material too extravagantly endowed by nature with every known desirable quality. The scientist, of course, can regard this state of affairs with complacence, since he is aware not only of giving essential obstetric aid to Nature in the birth of this remarkable metal but of his further contribution in shaping its future by exploiting all the inherent qualities of a well-endowed element—which properties, moreover, no more than fulfil his expectations in the place he assigned to it before it was born as an industrial material.

This brief review has attempted to give a perspective of the development of the consumer industry of aluminium: the following factual lists of major applications fill in some of the details. (It should be noted that the items listed are only *headings*, as it would be tedious to name the half-million currently-used individual objects.)

HEAVY ENGINEERING

In this field aluminium features the strength characteristics of the high-duty alloys, for the most part the heat-treatable ones. Corrosion-resistance is of high importance, appearance and other properties of less interest. In this as in the other applications where aluminium is used as an engineering material for all types of structural and mechanical components, the importance of the *variety* of structural forms of aluminium, particularly of the extruded sections (where aluminium can compete on most favourable terms with ferrous sections, which have to be produced mainly by forging) and press products, is of prime significance in controlling the economic balance in competition where lightness is practically the only special attribute of aluminium among other available materials. The chief heavy engineering applications which have reached significant proportions are the following:—

Travelling cranes; crane jibs
Bridges
Building framework
Railings
Ladders
Bulkheads; lock gates
Roofs

LIGHT ENGINEERING

Aluminium is an established components of machines of all types, where it can compete on more easy terms with rival materials. Its uses may be briefly indicated by the headings:—

Machine tools
Textile industry mechanical components

Mining machinery: excavating scoops
Conveyors
Lifts
Agricultural machinery
Military equipment
Veneering cauls
Metallurgical apparatus

Here the influence of light-weight is an obvious factor and it brings the transportation constructional industries into line with the other light engineering applications. First and foremost in this field is the aircraft industry, the oldest user of structural light alloys. Aluminium materials are essential and standard for such applications as:—

AIRCRAFT:

Airships }
Balloons } body components
Aeroplanes }
Engine components
Fuel tanks: oil systems
Propellers
Wheels
Furniture: fittings

The lightening of dead weight is not less important in the different forms of land transport where cost of operative motivation is determined by load. Aluminium alloys have long ceased to be novel as main structural components and chassis or body-work of:—

LAND TRANSPORT:

Motor Traction:	Automobile vehicles of all descriptions, including buses, motorcars and all types of commercial vehicles, racing cars, motorcycles, etc.

Rail Traction:	Tram cars
	Electric locomotives
	Steam locomotives
	Passenger railway rolling stock—railcars, coaches, etc.
	Goods trucks: Tankers
	Trolley buses
Miscellaneous Transport:	Handcarts: wheelbarrows
	Perambulators
	Bicycles: tricycles
	Aerial railways: cage railways
Military Transport:	All types of military rail, road and amphibious transport units.

Apart from the use as structural components and body-work of the foregoing vehicles, aluminium enters universally into engine construction and in motor traction the light-alloy piston has revolutionized the industry. In electric traction, aluminium also enters into the current collection system as a result of its excellent electrical properties.

MARINE TRANSPORT:

In the case of the ship-building industry, the emphasis on lightness is generally of less outstanding importance than in air or land transport units: and the corrosion-resistance is called upon as a more significant factor. In the case of small craft, lightness may be an added advantage to strength: and for marine architecture, the qualities of lightness and strength are second only to fire-resistance, good appearance (calling upon a great variety of surface finishes) and preservation of good appearance under the exacting conditions of exposure to marine atmospheres. Special alloys have been developed to meet these difficult requirements of marine engineering and architecture, and aluminium is now familiar in the construction of:

- Hulls of small vessels and craft of all description, particularly life-boats, cruisers, motor boats, sailing yachts, rowing boats, racing craft, canoes, etc.
- Upper-work components of naval vessels, passenger liners and cargo vessels
- Trawler holds
- Portholes: scuttles
- Marine engine components and machinery
- Ship's instruments
- Fishing floats

Lloyd's have recently issued specifications for aluminium alloys.

Companion to these developments in the field of light engineering is the great contribution of aluminium and its alloys in architecture. Making its entry into this sphere by way of modest ornamental work and statuary which demonstrated to the architect and layman more forcibly than any preaching or teaching by the industry or by scientists its remarkable weather-stability (Eros can only be inappropriately described as the " grand old man " of this experiment), aluminium then firmly established its position as an ideal modern building material wherever a *metal* is required—and in many cases where a non-metal functioned formerly. In the epoch of pre-fabricated all-light-metal houses, it is hardly necessary to labour the position of aluminium as an " old hand " in the construction of:—

ARCHITECTURE:

- Buildings of all types, permanent and pre-fabricated
- Roofs and gutterings
- Windows: skylights
- Doors: gates
- Floors
- Kitchen fittings; bathroom fittings
- Shop-fronts; showcases
- Lifts
- Street-signs; road studs, etc.

CHEMICAL PLANT:

Closely allied are the uses of aluminium and its alloys (in many cases here the pure, commercial metal) in plant construction in the chemical and food industries. Apart from the structural features of the material, its chemical inertness or corrosion-resistance is obviously the prime factor in these applications; and, close to it, the colourlessness (and consequent freedom from staining) of the light metals. The chemical industry, as would be expected, was not backward in taking stock of the special characteristics with which its own prodigious efforts had endowed aluminium, partly at birth and partly subsequently, and aluminium is extensively used in plant in the following chemical industries:—

Heavy chemicals; acids
Resins; varnishes; alcohol products
Fats; oils; toilet preparations
Perfumery; cosmetics; tooth pastes
Water engineering
Bleaching; dyeing
Rubber; vulcanite
Petroleum; hydrogenated products
Sewerage
Gelatine; glues
Paper
Leather

Aluminium is also used in the production of pressure vessels.

FOOD INDUSTRY AND ALLIED:

In the food-processing industries aluminium is utilized very extensively because its high chemical corrosion-resistance is coupled with the psychological appeal of its hygienic, attractive surface whiteness and brightness and with the fact of its complete innocuity (extending also to any of the compounds which could form as traces during processing—in contradistinction to traces of similar compounds of certain other metals which have toxic properties).

Aluminium plant features in:

- Milk processing; dairy products
- Brewery; fermentation industry
- Sugar manufacture; sugar confectionery production
- Bakery; farinaceous products manufacture
- Canning of meat and fish
- Vegetable and fruit processing; jam manufacture
- Tea drying
- Tobacco drying and processing; cigar manufacture

In addition to the uses of aluminium as *metal*, it is extensively used as *foil* for wrapping and for linings of containers; and as *foil-coated paper* in the manufacture of all sorts of boxes. Aluminium foil, alone or backed, serves a multitude of uses for seals, labels, bottle caps.

As a material for canning, aluminium has started its career as a most important substitute for tin-plate, particularly during the recent war; and its probable future in this direction is undoubtedly one of major developments.

Also as the material for collapsible tubes, aluminium has challenged the older-established tin.

HEATING—LIGHTING—CLEANING:

Next in line of descent from the engineering and chemical aspects of the applications of aluminium is its use in the heating, lighting and cleaning industries where, in addition, some of its important physical properties of good heat conductivity, high emissivity, etc., come into play. Aluminium is used in a multitude of appliances belonging to the following industries:

- Gas appliances
- Washing machines; mangles
- Flat irons
- Boilers
- Radiators
- Domestic fires
- Hot water bottles
- Refrigerators
- Immersion heaters; electric water heaters

Hot plates
Lamps
Infra-red and heating reflectors
Heat exchangers.

Electrical Engineering Industry

Before leaving the engineering field and proceeding to the uses of aluminium in the world of small objects, the old-established applications in the realm of electrical engineering, depending primarily on its outstanding qualities as a conductor, may be summarized as follows:—

Transmission lines
Overhead conductors: aluminium
    aluminium alloy
    steel-cored aluminium
Overhead line insulators
Overhead line accessories: suspension clamps
    anchor clamps
    Pairard joints
    arrestors
Trolley wire
Insulated cable
Lighting leads
Telephone wires
Busbars
Switchboards
Switch gear and busbar casings.
Fuse wire
Windings of all descriptions
Rotors
Electrolytic condensers
Housing for all types of electrical plant
Wireless components; radar

Tools and Instruments, etc.

Getting back to the applications where the electrical properties are not the main consideration, there is an immense field of uses for aluminium in tools and instruments of all descriptions. Only an outline of the many industries in which aluminium figures for small objects can be given:—

Reflectors
Hand tools; portable tools
Scientific instrument parts and housings
Office appliances
Medical equipment
Musical instruments
Gramophones; records
Wireless and radio equipment
Photography
Printing and intaglio plates
Toys and models
Articles for personal use
Flashlights; torches
Coins
Fire-fighting appliances
Metallic fabrics
Photographic bases

ALUMINIUM COATINGS:

It remains to consider the many applications which aluminium finds as a *coating* on other metals or materials. It has a huge outlet as *paint* alone. The following uses may be listed in addition to paint:—

Ink; aluminized paper
Spraying; aluminizing
Calorizing
Immersion coating
Mechanical coating; armoured plywood
Foil coatings
Mirrors; astronomical mirrors
Ceramic decoration
Electrodeposition

CHEMICAL AND MISCELLANEOUS USES:
The final field of applications of aluminium is that in which it figures not as a metal, not as an electrical conductor and not as a material dependent on any of its solid properties, but as a chemical element. It is used extensively in the following connections:—

Deoxidation; siderugical and other
Alumino-thermics
Zinc production; plating and galvanizing
Cyanide precipitation
Metal processing industries, various
Explosives production
Pyrotechnics
Aerocrete
Silver and other metal cleaning
Decoration of textile materials

The foregoing résumé of present established applications should give an impression of the vastness of the ramifications of the aluminium consumer industry. Details of the economic aspects and of the proportions of metal which enter into the different categories of applications will be found in a later chapter (see p. 127).

CHAPTER II

BAUXITE AND OTHER ORES AND THEIR TREATMENT

BAUXITE, the higher grades of which ore have served almost exclusively for the industrial production of aluminium metal during the first period of the industry's development, is the term used rather loosely as a generic title for various hydrated forms of aluminium oxide as it occurs in nature, where it is invariably intimately associated with certain impurities of which the most abundant are iron oxide, silica and titanium oxide. The name is derived from the village of Les Baux, in Provence, France, where large deposits occur and where the mineral was first produced. Berthier's analysis of this material in 1821 showed that the reddish-coloured ore, which at first had been regarded as clay, contained practically no silica. His analysis showed 52% alumina, 27.5% iron oxide and 20.4% chemically combined water. The deposits were worked originally for the production of aluminium sulphate; as was also the case with American deposits, principally in Georgia, Arkansas and Alabama, the exploitation of which was not commenced until the last decade of the Nineteenth Century. When the Hall-Héroult process for the electrolytic production of aluminium was shortly afterwards put into commercial development, utilizing the Bayer method of extracting the aluminium hydrate from bauxite, the major importance of the ore was established; and at the same time the discovery of methods for preparing artificial abrasives from fused bauxite extended the demand for the new material. Prospecting for new deposits and commercial exploitation of known deposits received a great stimulus and by the time of World War I production was in full swing in many parts of the world. In Europe, Italy took up production from the valuable Istrian deposits in 1905, Germany in 1914 (the German deposits are of little value), Yugoslavia in 1915 and Hungary and Rumania opened mines during the war to supply Germany, then cut off from her former source of supplies in France. India started mining bauxite in 1908. American interests, seeking large-scale supplies for the aluminium and chemical industries, opened up the extensive South American deposits in British Guiana in 1914 and in Surinam in 1916; ore from these sources has been supplied steadily to the United States since 1917 and 1922 respectively, and by 1929 the output from the Guianas reaching the U.S. exceeded the domestic supply, which from the time of the 1914-18 war had topped even the French production. Before 1915, and again by 1930, France was the biggest world producer. Italy's production also climbed rapidly and the Hungarian output increased similarly, so that by 1930 the five main producers (France, Guianas, Hungary, U.S. and Italy, in that year in that order) were responsible for 95% of the world output, then figuring at over two million tons. After 1930 the influence of Germany's economic development was seen in the rapidly mounting figures for middle-European bauxite output, principally in Hungary but also in newly opened workings in Greece and in Rumania; and Soviet Russia came into the picture as a major producer whilst British interests—up till then chiefly concerned with French ore (and having failed in the Peace Settlements to oust American capital from her Guiana ore)—took up developments in Asia, in Malaya and in India; Holland also started exploiting Asiatic deposits in the Dutch East Indies. A new impetus to South American bauxite mining was given by the Brazilian development of her domestic resources of this ore in conjunction with the birth of her national aluminium industry. Australia also started to exploit her deposits.

During the recent war, the fall of France closed the French bauxite mines for all practical purposes and this country, dependent on overseas ore and with her Malayan resources jeopardized, turned to West Africa as a more convenient open source of supply than South America. The ore is plentiful in the Gold Coast area, which has the largest known resources in the world. Chart II illustrates the main phases of bauxite production in different areas of the world; and statistics are given on pp. 144-151.

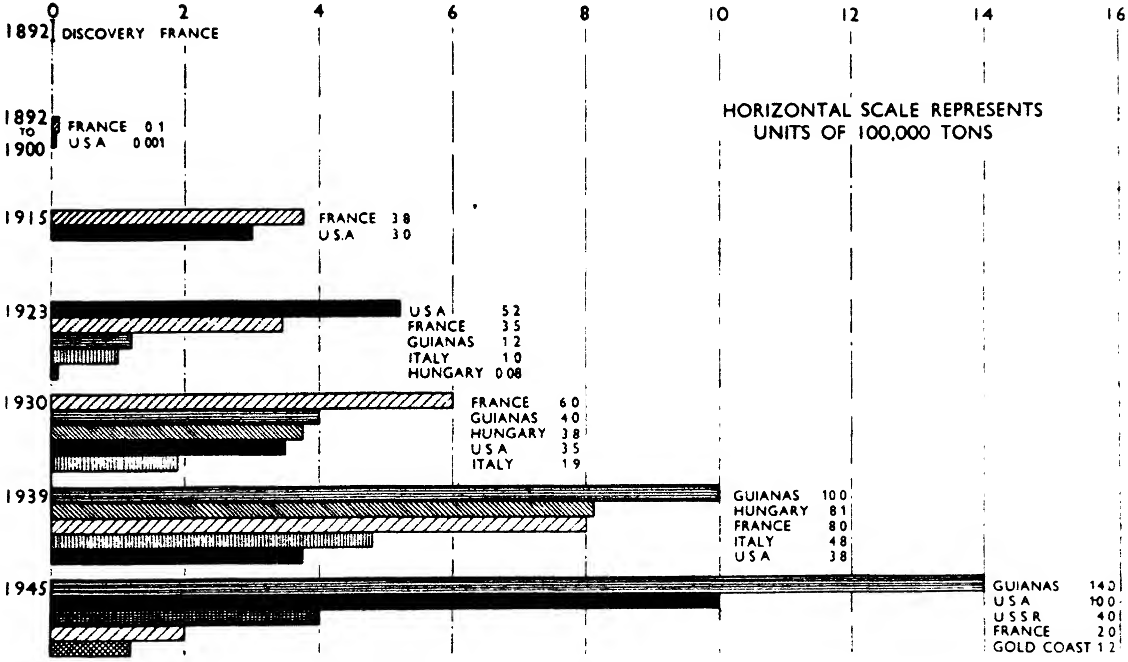


Chart II. The Main Phases of Bauxite Production in Different Areas of the World.

CHEMICAL AND PHYSICAL PROPERTIES

The original French bauxite, which began the world's industry, was generally taken by contemporary chemists to be the di-hydrated form of alumina, $Al_2O_3.2H_2O$, and there has been considerable controversy among experts regarding the extension of the term bauxite to include any of the hydrated forms. However, in industrial practice, any of the clay-like ores low in silica and with the aluminium oxide in chemical composition with water of hydration, whether in the proportion of the mono-, di- or tri-hydrate, are universally known as bauxite. This ore always contains substantial amounts of iron oxide and, usually, smaller proportions of silica. Titanium oxide is also a normal constituent. European bauxite is predominantly the mono-hydrate form; with the exception of French bauxite which has been claimed as the di-hydrate and is probably an admixture of mono- and tri-hydrate. The tropical bauxites of Africa, Asia and South America occur predominantly in the form of the tri-hydrate $Al_2O_3.3H_2O$; and this form is common to the North American ores also.

Whilst the mineralogical characteristics vary, the chemical composition of bauxite falls within a fairly narrow range (in reference, that is, to the high-grade ores; a note on the low-grade bauxites is given on p. 49) and the main constituents' range is as follows:—

Al_2O_3: Aluminium oxide (alumina) ...	52%-65%
Fe_2O_3: Iron oxide	0.5%-20%
TiO_2: Titanium oxide	1.2%-10%
SiO_2: Silica	1%-15%
Chemically combined H_2O	12%-32%

In addition, most bauxites contain small quantities of lime, magnesia, zirconia, and fluorine, phosphorus, sulphur and manganese compounds.

The ratio of the three main impurities, the oxides of iron, titanium and silicon, is of importance in determining the value of the ore for different uses. The silica is chiefly present as a mixture of aluminium silicates and free quartz (or silica); the iron as the carbonate, or less commonly the sulphide, of both the ferrous and ferric oxides; the titanium may be present as rutile or ilmenite, or as a combined titanite. For aluminium production, the ore of greatest value is that with lowest silica, but the iron-silica ratio is important for certain uses.

In appearance, bauxites of different provenance vary very greatly. The colour may range from white to dark red but is commonly reddish-brown in the European deposits and pinkish in the tropical ores. The texture may be hard, spongy or chalky.

MINING AND TREATMENT

According to the geological nature of the deposits, bauxite is mined by either underground or open-cast methods. In some cases, for example in France, the methods are combined. The economical limit of open-cast earth removal has been extended by modern improvements in mining machinery and at the present times ore deposits which would formerly have required underground mining are worked from the surface. Special problems are presented by many deposits on account of variation in analysis of the ore or unevenness in the beds; and some underground mining is rendered difficult by the nature of the overlying clay or sand. The machinery of bauxite mining is not highly specialized and this fact has had important repercussions on the industry, which has been characterized by remarkable fluctuations and shift in accordance with such factors as discovery of new deposits or political or economic changes. Production of the ore can be relatively easily expanded or contracted in any working.

So far, with fairly large available supplies of high-grade ore, treatment of the mined product at the workings does not normally extend beyond blending and selective mining. A great deal of research has been carried out on beneficiation methods, particularly in America, but widespread use has not yet been made of these methods, of which flotation is the most attractive; and is not likely to become necessary until the exhaustion of the best grades makes such processing desirable and economic.

The bauxite is shipped in a number of different forms from different mines. At some, notably in European mines, where the ore is very dense, it is shipped undried; at others it is first dried or may even be partially or wholly calcined or sintered. In cases where the bauxite is "loose," to save transport costs the ore is dried to a moisture content in the region of 1.5% free moisture, and it may also be rough screened or graded after crushing. In some cases washing is first carried out to remove surplus silica.

An Opencast Bauxite Mine in Southern France.

PROSPECTING

The prospecting of bauxite is, except in the case of the surface deposit, not particularly easy and it is comparatively costly. There is only one geophysical method applicable to deep deposits, and drilling is expensive.

RESERVES

Bauxite is extremely widely dispersed over the globe. It is common to latitudes as far remote as the Arctic circle (quite large deposits occur in the Norwegian-owned island of Jan Meyen) and tropical Africa and South America.

A recent estimate of world reserves of bauxite, based on the assessment of major known deposits prior to the war is as follows:

	Millions of Tons.
Gold Coast	234
U.S.S.R.	150
Hungary	150
Jugoslavia	80
British Guiana	60
France	60
India (Hindustan)	60
United States	37
Malaya	30
Jan Meyen (Arctic)	30
World Major Deposits	891

These figures feature estimates of a very rough character for the U.S.S.R. and for Hindustan, whose resources are probably much greater. They concern only the deposits known and measured as surface or near-surface deposits and do not take account of deep-lying deposits; and they do not include the huge deposits known to exist in South-East Asia (Borneo and Indo-China), in Africa (French Guinea and Nyasaland), in Australia and China; nor the minor deposits, known and exploited, in many parts of the world. Even this conservative estimate indicates the plentiful nature of the world supplies.

USES OF BAUXITE

Bauxite finds its main applications in the production of the following commodities, in the approximate order given:

Aluminium metal
Abrasives

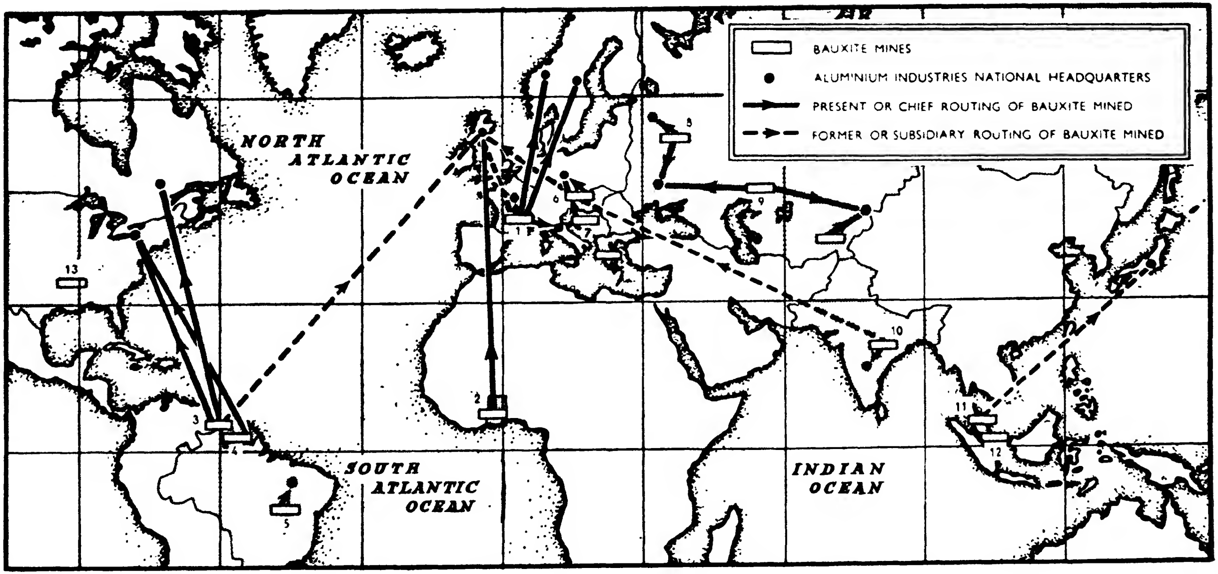


Chart III. Bauxite: Principal Present-day Production Centres and Routes.

Chemical products
Aluminous cement
Absorbent and bleaching mass for petroleum purification
Insulating materials
Siderurgical blast furnace charges
Pigments.

The main use, for the production of aluminium, requires a bauxite with the maximum of aluminium oxide and the minimum of silica, which is the most objectionable impurity; in the Bayer process any silica present in the raw material as combined silicates reacts with the caustic soda and the aluminium oxide to form a complex, stable and undecomposable silicate, with attendant loss of soda and alumina, and a consequent increase in production costs. It is for economic reasons, therefore, that high silica is regarded as objectionable; chemically, the presence of silica does not interfere with the quality of the processed alumina since the caustic soda reacts selectively to dissolve the hydrated oxide of aluminium.

Various abrasives, chiefly synthetic corundum, are prepared from bauxite by electric furnace sintering. For economic production, again, the ore should have minimal silica adulteration. In the chemical industry bauxite is the raw material for a large number of aluminium salts, the sulphate being of great importance in a number of industries, notably for water purification. The alums are also important and the chloride and fluoride of aluminium and sodium aluminate are produced directly or indirectly from bauxite. Aluminous cement, produced by the fusion of bauxite and limestone, has the special advantages, as compared with ordinary Portland cement of quick hardening, high resistance to chemical attack by acids and chemical reagents and ceramic resistance to high temperatures. Again, the bauxite grades most suitable for the aluminous cement are those low in silica. For oil purification, part of the chemically combined water is removed from bauxite by controlled calcining; the resultant mass is active in the removal of sulphur products from crude oil and certain petroleum products, and recent developments in the United States have also shown its potential value as a bleaching agent for lubricating oils in place of Fuller's earth. For the production of refractories certain bauxites are capable of yielding low-density products which are of value where a low iron content is desirable. Bauxite has also found recent use as an addition to blast-furnace slag in the steel industry. The residues from the processing of bauxite by the Bayer process find a market, in the form of the so-called red oxide, as an important pigment.

The low-grade bauxites, not suited for economic reasons to the production of aluminium or the other uses where high alumina content and low silica contamination are requisite, are also utilized for the making of such products as refractory bricks.

Alumina, as a derivative of bauxite, has many uses of its own apart from its major interest as the source of metallic aluminium.

Other Ores

In considering ores alternative to bauxite as sources of alumina, the question of *availability* hardly arises, since aluminous ores of some type or other form roughly a one-third basis of practically the whole crust of the Earth (elemental Al being present in that crust to the extent of 7%) and are in that sense universally available. The real problem faced is that of finding a workable process for extracting the alumina contained in the ores by a method technologically not too cumbersome to make its cost prohibitive. In this problem there are two factors. The first is that the aluminium industry in its established form in the major producing countries (with a few exceptions referred to hereafter) has concentrated on the Bayer process (see p. 11) applied to high-grade bauxite and, so long as supplies of this high-grade ore have lasted, has found nothing to supersede it from the technological and economic standpoint, so that in consequence, the whole of the modern industry is designed for the Bayer process in respect both of plant for alumina production and of plant for the further stages of working on the product of this process (with narrowly-defined limits for the metallurgical-quality alumina in question) in the subsequent reduction to metal. The second factor is this closely-tied-up problem of ore grade—which ultimately resolves into the two problems of the commercial separation of silica and siliceous products as contaminants and the handling of greatly increased quantities of raw ore (in the probable ratio of up to 3 : 1).

There are two possibilities in approaching this problem. One is to tackle low-grade ores by double processing, that is, to interpolate an additional extraction method to arrive at a product which can then be processed by the Bayer method in the existing set-up. The other is to scrap the existing chemical plant, modify the electrochemical plant and redesign the whole industry to work with the alternative ores. Obviously neither of these alternatives is palatable in competitive industry and only sheer realism has forced it on those national aluminium industries which have turned attention to it, notably Germany before and during the early part of the recent war, Japan during the period she was cut off from bauxite supplies and the United States, concerned about her dependence on (perhaps not too dependable) extra-territorial supplies of high-grade ores. The U.S.S.R. turned attention to the same problem as part of her general policy—made possible by non-competitive internal economics—to utilize all possible resources in the interest of maximum overall production.

LEUCITE

There is one single exception to rating ores alternative to bauxite in terms of their relative grade, which arises in the case of leucite, a high-grade potassium-aluminium silicate which occurs in sufficient quantity in Italy, near Rome and Naples, to have made its processing by the Italian industry, utilizing the Blanc method, a considerable success. The Blanc HCl process utilizes the presence of a large amount of potash in this ore to remove it by fractional crystallization after leaching with hydrochloric acid, before precipitating the aluminium chloride. The HCl used for extraction is obtained by calcination of the aluminium chloride, the process thus being cyclic and self-contained.

CLAY, ALUNITE, NEPHELIN

Clay and the related alumina-bearing minerals such as kaolin, shales, siliceous bauxites and diaspores; and also the aluminosilicates such as nephelin, kyanite and anorthosite have all been investigated as aluminium ores. A host of processing methods has been tried and, in the slang of the comedian, " the answer is a lemon." Acid as this " lemon " may be, there are signs that it may be sucked dry by the less fortunate competitors in the aluminium production race—which is becoming, in point of fact, a much more strenuous race as on the one hand the high-grade aluminium ore supplies become restricted for geopolitical or other reasons, and on the other hand the demand for aluminium is heightened by shortages of different structural engineering materials which aluminium has been promoted to alternate.

The pioneer work on the processing of clays for alumina production was carried out in Germany as an essential part of her self-sufficiency drive before and during the recent War; in the United States, this German development was watched with interest as the bauxite supply problems were considered in relation to the American position in the event of and during the war. The two countries worked on roughly similar lines. In practice the only valid process for the treatment of clay is the lime-sinter process which in essence consists of six stages: the preparing of the clay and limestone raw materials, furnacing, leaching, purification of the solution, recovery of alumina tri-hydrate from solution and calcination of the hydrate to alumina. The process is worked continuously; close control is absolutely necessary. Nearly two-and-a-half times the weight of the aluminous ore in limestone is required; and a considerable amount of fuel and electrical energy is used.

It has been pointed out above that the problem of processing is the conversion of silica (to the tune of 45% or more in the case of many ores) into a separate form; the economics of the lime-sinter process or of any of the others tabulated on pp. 52-53 depend essentially on the chemical composition of this separated product in relation to its utility as a marketable by-product. The product of the lime-sinter process is a dicalcium silicate with a small admixture of calcium carbonate, a material which is of value in the manufacture of cements of the Portland type, and it may prove that the value of this by-product will offset the cost of the clay-processing.

The alumina product of the lime-sinter process is not fit for direct reduction to aluminium in the existing furnaces and it has either to be Bayerized or recrystallized under pressure, re-precipitated and then again calcined.

Three American pilot-scale plants are operating the lime-sinter process at the present time.

The following table indicates the alternative processes which have been tried:

TABLE IV

PROCESSES PROPOSED FOR THE EXTRACTION OF ALUMINA FROM LOW-GRADE ORES

Ore type	Process	Name of process	Alumina product requires Bayerizing	Exploitation
Clay	Pressure extraction with HNO_3	Nuvalon	—	Industrial-scale output in Germany.
Clay	H_2SO_4 digestion	Goldschmidt	—	Industrial-scale output in Germany.
Clay	H_2SO_3 digestion	—	—	Small-scale operation in Japan.
Clay	Pressure-solution in HCl	—	—	Pilot-scale operation in Japan
Clay	Calcium sulphate	—	Yes	Research in Japan.
Alunite	H_2SO_4 digestion	—	—	Industrial output in Azerbaijan, U.S.S.R.
Alunite	H_2SO_4–K_2SO_4	Kalunite	—	Pilot-scale plant in Utah (U.S.) unsuccessful—now abandoned.
Alunite	NaOH–sod. aluminate, steam digestion	—	Yes	Small-scale output in Japan.
Alunite	Roasting with magnesite	—	Yes	Research in Japan.
Alunite	Heating with ammonia	—	Yes	Research in Japan.
Alunite	Steam-heating with $Mg(OH)_2$	—	Yes	Research in Japan.

Table IV—Continued

Ore type	Process	Name of process	Alumina product requires Bayerizing	Exploitation
Aluminous shales, Kaolin	Sintering with soda-lime		Yes	Pilot-scale output in U.S. Considerable development in Japan, Korea, Manchuria and North China.
Aluminous shales, Kaolin	NaOH digestion		Yes	Research in Japan.
Aluminous shales, Kaolin	Semi-fusion with NaOH–sod. aluminate		Yes	Research in Japan.
Nephelin, Anorthosite	Sintering with lime-soda			Pilot-scale output in U.S. Considerable development in U.S.S.R.
Siliceous (i.e. low-grade Bauxites)	Sintering with lime-soda		Yes	Considerable development in U.S.S.R. ; some output in China.

CHAPTER III

ELECTRICAL ENERGY: WATER POWER

ELECTRICAL energy figures in the aluminium industry as an essential factor for which there is no alternative. The main, central process of the production of the metal is the electrolytic reduction of the prepared oxide in a fused bath, which reduction requires some 20,000 to 25,000 kWh of electrical energy per ton of ingot produced (see pp. 4 and 13). In addition, electrical energy features, as in other heavy industries and in modern chemical industries, as the most convenient method of furnishing power for all the stages of processing involved from the actual mining of the bauxite ore to the final remelting of the crude pig; for all the ancillary operations; and, of course, for the subsequent semi-manufacturing and working of the commercial ingot, right down to fabrication and finishing.

Some process of conversion is always implied by electrical energy and in view of its essential contribution in relatively large amounts in the production of metallic aluminium, the first requirement in considering the possible sources of origin is that of cheapness. The position in general regarding electrical power generation has undergone an interesting evolution in the comparatively short period of time contemporaneous with the adolescent growth and later development of the aluminium industry. At the time when aluminium production was showing signs of taking its place as a major metal industry, hydro-electric power rates were definitely low, hydro-stations required comparatively small investment and something of a scramble took place to secure the best locations. Since that time, however, the cost of new installations has become more and more prohibitive and power rates have steadily increased to a point where it is probably true to say that very little cheap hydro-electric power is available to-day; certainly there is very little in locations otherwise attractive. Meanwhile the operation of steam power plants has improved to a point where such plants can equal or even surpass all but the most exceptional hydro-electrical performances. In the last years before the recent war the use of improved fuels such as powdered coal was steadily decreasing the operating costs. When it is remembered that the efficiency of conversion of fuel energy into electrical energy is still not far in advance of 20%, it is obvious that improvement and corresponding reduction of cost must steadily take place; whereas there is little or no room for equivalent improvement in the efficiency of conversion of hydro-energy, where the limit has almost been reached. Diesel developments have also been important. In the United States, diesel engine installations have gained ground and can compete economically with steam units in areas where oil is very cheap. In the U.S.S.R. immense collateral developments have simultaneously taken place with regard to powdered fuel-fired, peat-fired and diesel-driven stations.

Aluminium production in the major established national industries has almost solely derived its electrical energy from water power, except in the U.S.S.R. and to some extent in Germany, due primarily to the fact that its period of expansion synchronized with the period when hydro-electric development was at its height, before the later, more recent trends in alternative forms of generation became significant. The Table on p. 57 shows some estimated costs of water power at major centres, with some other figures which are of interest for comparison. Unfortunately, no very recent figures are available and certain modifications require to be taken into account for estimating contemporary costs. On the one hand, the hydro-power figures at the older works are by now reduced, since the chief factors in cost of production, namely interest and amortization charges on capital expenditure, are partly or wholly written off; on the other hand, improvements have taken place in steam-produced power costs. In both cases altered rates of exchanges have to be allowed for, the figures given being based on the pre-war dollar to pound (sterling) exchange.

As they stand, the figures give a rough idea of the relative costs of hydro-electric power throughout the world, with comparative figures for steam-generated power. Brown coal, of the German type, has been until recently the cheapest source of steam-produced electricity but recent developments with powdered fuels have changed the favourable position which brown coal enjoyed formerly in this respect.

TECHNICAL FACTORS

Modern water-power schemes utilizing maximum flow and long ranges of streams may be divided into four categories:—

1. Hydro-stations where water can be stored and is controlled to yield a continuous output.
2. Stations where only partial storage (or even no storage) is possible.
3. Stations where partial water storage is combined with alternative generating stations to undertake pumping to reservoirs as required.
4. Water-power schemes based on tidal variations.

The aluminium industry is only concerned, so far, with the first three categories; and of these the first is by far the most important since a water-power scheme which provides complete control of flow to enable the power station to operate throughout the year on 100% load factor is essentially to be desired both from the technical and from the economic aspects. Where the plant operates continuously on a constant flow from the reservoir, the sizes of the tunnels and pipe-lines can be chosen minimum to suit this flow; whereas seasonal loads require the upkeep of larger cross-section aqueducts. The same principle applies to all the power house plant. Since the heaviest cost in the generation of electric energy from water power is the cost of plant and upkeep, these considerations are material.

The life of a hydro-station works is usually assessed for financial purposes as 75 years, but the power dams, aqueducts and other masonry structures have an indefinitely long life. The average life of the steel pipe-lines and engineering plant is assessed at 30 years but reasonable upkeep and replacement of such running parts as turbine wheels probably extends this estimated lifetime to equal the 75 years assessed for the permanent structure as the life of the sinking fund. Naturally the works continue to

TABLE V

ESTIMATED COSTS OF WATER-POWER AT MAJOR CENTRES

Location	Year	Estimated cost of water power	Cost of electrical energy based on hydro power	Cost of electrical energy based on steam coal†	Cost of electrical energy based on steam/brown coal†	Cost of electrical energy based on Diesel power†	Cost of electrical energy based on peat†
		pence/kWh	pence/kWh	pence/kWh	pence/kWh	pence/kWh	pence/kWh
Europe—							
Kinlochleven (1) ..	1933	0.19	0.30	—	—	—	—
Lochaber (1)* ..	1933	0.12	0.18	—	—		
France (2)	1934	—	0.10–0.18	—	—		
Neuhausen (1) ..	1925	0.13	0.18	—	—		
Rheinfelden (1) ..	1925	0.15	0.18	—	—		
Germany (1), (2) ..	1926	—	—	—	0.23		
Norway (1)	1925	0.07	0.09	—	—		
Sweden (2)	1934	—	0.09	—	—		
U.S./Canada—							
New York Harbour (2)	1934	—	—	0.40–0.78	—		
Niagara (2)	1934	—	0.18	—	—		
Tennessee (2)	1934	—	—	0.23–0.36	—		
Arvida/Saguenay (1) ..	1925	0.046	0.06	—	—		
Southern States (5), (3)	1943	—	—	—	—	0.36‡ 0.59 0.54	— — —
Asia/U.S.S.R.	—	—	—	—	—	—	§(4)

(1) Wallace, pp. 143/44.
(2) Perry, p. 2400.
(3) A.S.M.E. Ann. Rep. 1943.
(4) Probst *et al*, Third World Power Conference, Rep. 1936, II, 486.
(5) Perry, p. 2406.
(6) Powel and Bodea, Third World Power Conference, Rep. 1937, II, 335.

* Estimated on full development: figure nearly double for first stage.

† The following figures show the comparative values of thermic energy resources (6), the calorific power being in cal./kg. :—

Black coal	7,000	Petroleum	10,000
Brown coal	5,500	Petroleum gas ..	5,700
Lignite	3,500	Methane	9,000
Peat	3,000		

1 kWh necessitates 4,300 cals. on basis of efficiency factor of 0.2.

‡ Where fuel oil is about 2d. gallon.

§ Figures for cost are not available, but it is worth noting that 24.8 per cent. of all regional stations, representing 14.3 per cent. of all electric power stations in the U.S.S.R., were peat-fired in 1935 (4).

exist at the end of this period and the named period of amortization charges is established rather as a prudent matter of insurance precedent to cover such unforeseen factors as the abandonment of the project or completed scheme in the event of discovery of a cheaper alternative source of power.

One important feature of hydro-power is that the ultimate cost is known when the station starts to operate; another is that the labour of operation and maintenance is quite small. In the case of the aluminium industry, a special factor is the peculiar possibility of using secondary hydro-electric power while it is available during periods of high water which would otherwise flow away to waste.

Water-power Plants in Different Aluminium-producing Countries

The following notes outline the development of water-power and describe the more important hydro-electric stations owned and operated by the aluminium industry in the countries possessed of old-established national centres of aluminium production.

GREAT BRITAIN

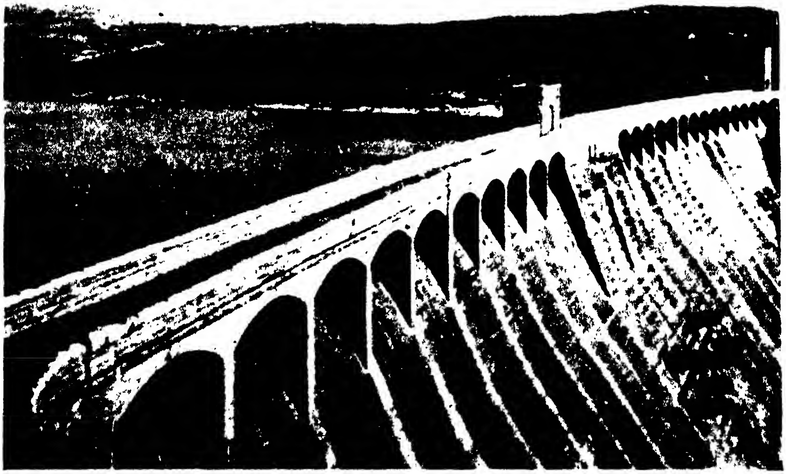
Hydro-electric development is centred in the Highlands of Scotland and in North Wales. In Scotland in particular the conditions are favourable to a large potential output. With prevailing wet south-westerly winds meeting mountain ranges 2,000-4,000 ft. high to the north and west of central Scotland, the annual rainfall at the higher levels averages high—with the disadvantage, however, of wide variations above the average, both annual and seasonal. At the top of Ben Nevis (4,406 ft. above sea-level) the average rainfall is estimated at 164 inches.

Due partly to the geographical and economic isolation of the Highlands, and partly to other factors (such as the uncertainty of a good economic return alongside the high-yield industries in the early part of the Century and the intervention of the wealthy land-owning aristocracy, jealous of its rights to preserve large sections of Scottish territory for their ancient stalking and sporting rights) there was, until recently, when in less prosperous times the Grid scheme was initiated, no general development of highland water-power for central distribution, and the early history of Scottish hydro-development is bound up with the aluminium industry and is associated with the name of Sir W. Murray Morrison (himself a native of Inverness-shire) whose inspiration was at the back of the British aluminium industry throughout its entire history until 1947.

The first hydro-electric scheme was initiated in connection with the newly formed British Aluminium Co.'s reduction works at Foyers on Loch Ness in 1896. The estate of Lower Foyers, comprising about 8,000 acres, was purchased with neighbouring water-power rights from the Stratherrick catchment area. A concrete and masonry dam and an earth embankment formed an artificial lake—Loch Mhor—4½ miles in length. A half-mile tunnel carries the water to a point above the Falls of Foyers; and a thirty-inch diameter (cast iron) pipe-line carries the water to the power house (static head 350 ft.) equipped with five turbines and D.C. vertical-shaft generators. The power station has an installed capacity of 6,700 h.p. at the present time.

In 1909, a second larger hydro-station was erected by the British Aluminium Co. at Kinlochleven in Argyllshire. This involved the erection of a half-mile-long dam, 85 ft. high and 62 ft. broad at the base. The artificial lake created is 8 miles in length. The conduit is of reinforced concrete, 4 miles long, with internal dimensions 8 ft. × 8 ft. and feeds additionally from a number of diverted side streams. A 1¼-mile-long pipe-line, with six lines of 39-inch diameter (steel) pipes conveys the water to the power house (static head 935 ft.) which is equipped with eleven 3,200 h.p. hydro-electric units for the production of aluminium. The first Great War extended the development to include an additional catchment area and the present total is about 66 square miles. The installed capacity is 30,000 h.p.

In 1921 the Company obtained an Act of Parliament to allow it to undertake extensive developments at Lochaber to utilize the waters from a vast catchment area of over 303 square miles, which includes the flow of water from a section of the Ben Nevis range,



The Laggan Dam.

the waters of Loch Treig and Loch Laggan, as well as diverted upper waters of the River Spey. In view of the complexity of the catchment terrain, the Lochaber scheme involved three stages, the first of which required the drilling of a 15-mile-long tunnel (15 ft. in final diameter) through Ben Nevis. From the end of the tunnel, two half-mile pipe-lines were laid to the first power house. The second stage (requiring a further Act in 1930) required the erection of dams to raise the levels of the two Lochs and the drilling of a second tunnel three miles long to divert Loch Laggan waters into Loch Treig. Three further pipe-lines (of steel) 69 inches in diameter connect the tunnel to the power house, whose present equipment consists of ten 10,000 h.p. hydro-electric units, for aluminium production. The third stage, responsible for diverting the head waters of the River Spey into the existing artificial lake, was commenced in 1938: progress was made during the War and the work was completed in 1942. The installed capacity now exceeds 120,000 h.p. (See also p. 78.)

In Wales the position has differed somewhat from that which applied in the Highlands since the needs of the municipal suppliers of electrical energy for Welsh and adjacent English towns in a crowded industrial area of this island was responsible for the main Welsh hydro-development. In 1908, however, an aluminium reduction works was installed by the Aluminium Corporation at Dolgarrog, who erected an independent hydro-electric station with installed capacity of about 5,000 h.p., since increased to exceed 7,000 h.p.

UNITED STATES

The attraction of the great natural resources of the United States not only proved a powerful stimulus to domestic development in the interest of private enterprise, but must be considered as responsible for much of the pioneer interest in the development of water power as a source of generating electricity throughout the entire world. So important to industry are these immense native resources of power that the second phase of American hydro-electric development, since 1932, has been the curtailment by Federal Authority in the interest of the State, of private ownership and private initiative. The first American aluminium reduction works used power derived from the Niagara Falls development, which was inaugurated in 1893, the aluminium industry being the first customer. The original power contract called for 1,500 h.p. with an option of 1,000 h.p. additional. With increasing industrial development in the Niagara Falls district and increased power costs, the aluminium industry turned towards cheaper power for its own requirements, abandoning the first two works constructed at Niagara and only maintaining a third, modern plant, which is still in operation. In 1912 the American aluminium industry embarked on the policy of undertaking its own hydro-electric development and the hydro-stations on the Little Tennessee River, now State-owned, was initially undertaken by the Aluminum Company of

America solely to provide power for its reduction works at the new township named Alcoa. This reduction plant in its present greatly enlarged condition draws its power to the tune of nearly 400,000 h.p. from five hydro-electric power plants on the Little Tennessee River and its tributaries the Nantahala. Glenville, Calderwood, Santeetlah and Checah Rivers. The latter, which is the latest development, has a 230-ft.-high arched dam, and the power house is equipped with four 30,000 h.p. turbines. The power from this station has to be transmitted 28 miles to the Alcoa reduction works. The Santeetlah Dam is 205 ft. high and a 5-mile-long tunnel and pipe-line conduct the water to the power house, which is equipped with two 33,000 h.p. turbines (maximum head 660 ft.).

The Calderwood Dam is 230 ft. high, and a pressure tunnel nearly a half-mile long carries the water to the power house, which originally had two 56,000 h.p. turbines, with provision for installation of a third. The Nantahala station has a very high static head of 1,005 ft. and employs a single reaction turbine. With the Glenville plant, 90,000 h.p. are added to the total Tennessee capacity utilized by the Aluminum Company of America.

Recent politico-economic factors in the United States' newly oriented post-war aluminium industry are responsible for pressure on the Government to begin a new power development programme with short-term concentration on a new transmission distribution network and long-term planning for additional hydro-electric capacity on the Columbia River and in the already projected but controversial St. Lawrence Seaway scheme.

CANADA

In Canada, as in the United States, water power has mainly been developed on centralized hydro-station lines for general distribution to industry and municipal suppliers. The huge power development on the Saguenay River, Quebec, however, exists chiefly to supply the vast aluminium reduction works at Arvida. The Saguenay has a potential power capacity of 2,500,000 h.p. The hydro-development is by way of three main power plants at Ile Maligne, Chute-à-Caron and the Shipshaw Rivers. The first of these plants has been in operation since 1925 (and, incidentally, supplies some power outside the aluminium industry). At the second station, a dam is built across the Saguenay River to control the waters but not to implement storage. The original installed capacity was four 65,000 h.p. turbines, but during the recent war the output was increased by the addition of two further 65,000 h.p. units and by extending the capacity of three of the existing turbines to 70,000 h.p. each. The Shipshaw development was extensively furthered during the recent war. A power canal is fed from the Saguenay Dam to a point above the new Shipshaw power house. The present output of the first six turbines exceeds 500,000 h.p. and when fully developed the station will be capable of producing 1,000,000 h.p.

EUROPE

Alongside the American Continent's hydro-developments those of Europe are modest. The aluminium industry's development has been largely associated with the major water-power developments in many different European countries, as the following notes show.

SWITZERLAND

Switzerland was early forced to turn her attention to water-power development to meet industrial needs as a result of her lack of coal. The Swiss chemical industry depends partly on privately-owned water-power, but the metal industries tend to buy their supplies from public companies. The largest consumers are the aluminium reduction works. The Aluminium Industrie A-G., Neuhausen, has its own hydro-electric stations on the Rhone and on a tributary of this river, the Navizence, which supply the Neuhausen works: two of the stations are at Chippis at the confluence of the two rivers. The Rhone scheme is in two sections: one with a low head of capacity 52,200 h.p. and the other with a high (2,285 ft.) head, with 20,000 h.p. capacity. The Navizence scheme has an installed capacity of 33,000 h.p.

FRANCE

France has exploited her naturally rich water-power resources to a point where she can supply 60% of her electricity requirements by hydro-electric generation. The aluminium industry either produces its own electricity or draws supplies from existing stations.

The first producer of aluminium in France derived its hydro-electric power from the Arve River which was utilized for aluminium electrolysis in 1906. A second station was built on the four-hundred metres fall at Auzat, which provided annually a few hundred h.p.; and the operating companies turned their attention to additional power in the high falls of the Alps. The next installation was at La Praz in Savoie in 1908. In 1910, new aluminium plants were erected in conjunction with their supplying hydro-electric stations on La Saussa and Argentière.

After the somewhat complex network of small producers was rationalized by merger into two great aluminium companies during the 1914-1918 War, the existing plants were modernized and extended, and new hydro-electric undertakings were initiated. In 1924-1925 important developments took place in the Pyrenees and on the Romanche river, and since that time hydro-stations have been installed at Sabart in the Pyrenees, at Bonne-et-Drac in the Alps, and at San Guilherme on the Romanche River. To-day the great stations at La Girotte (Savoie), Bissorte in the upper valley of the Arc, Le Sautet on the Drac and Le Chambon on the Romanche supply more particularly the neighbouring aluminium works and largely remain outside the French grid system.

The war saw no military damage to the French stations but some sabotage was done to the Argentière pipe-line on one or two occasions.

ITALY

Italy ranks high among the European nations which have utilized hydro-electric resources and has some claim to being the first to generate electricity from purely hydro-development schemes. Roughly 11% of its total power was utilized in the electro-chemical and electro-metallurgical industries during the inter-war period and at the present time Italy ranks as the fourth largest World producer of hydro-electric power with an output of the order of 20,000,000 kWh. Italy entered the aluminium industry later than the other large producers and the first plant was opened at Bussi in 1907 and supplied with power from a small station on the Pescara River (Aquila province). The next development in aluminium reduction did not take place until the Great War, when a second plant was opened at Nera Montuoro and drew its power from the hydro-electric station erected by the Ville Nueve Company on the River Nera.

The present-day installations owned by the aluminium producers comprise only one large station and a number of smaller ones, and all the aluminium producers have to buy part of their power from outside supply companies. The large hydro-station is that at Bolzano, whose established capacity is about 40,000 h.p., which supplies about half the power required by the chief domestic aluminium producer, Industria Nazionale Alluminio, at their northern reduction plant. The same concern has a smaller (about 20,000 h.p.) station at their more southerly Mori plant. There are three small hydro-stations at Borgofranco, two low-head and one high-head, with a total installed capacity of 23,000 h.p., all owned by the (Canadian controlled) Società dell'Alluminio Italiano and three at Porto Marghera supplying together 40,000 h.p. as part of the power used by the Soc. Alluminio Veneto (Swiss interest).

The architectural excellence of Italian hydro-electric projects has been the subject of much admiration.

NORWAY

Norway, rich in mineral ores but not possessed of large coal deposits, has many facilities for the development of water-power. The electro-chemical industry, initiated with the production of carbide at the end of the last century, led to the production of metals, and the electro-metallurgical industry started in Norway in 1908. The available resources of water power have widely varying conditions and require many different types of water-power plants, some of which operate with high heads and some with heads as low as 3 ft. The Tyssedal plant was originally constructed to serve a carbide works, but it was taken over to supply power also to an aluminium works on the opposite side of the Sørfjord; and continued to do so until it was damaged by enemy action during the war. The scheme utilizes the waters of the River Tysse which rises in the lake of Ringedal. A 108-ft. high dam regulates the flow, and a tunnel and pipe-line convey the water to the power house which is equipped with fifteen impulse turbines with an installed capacity of 153,000 h.p. Reconstruction work is in progress.

SWEDEN

In Sweden, the water-power developments are parallel to those in Norway, except that the greater number of developments are in low-head schemes. The control of the resources of water-power has been closely organized on semi-socialistic lines which have been responsible for most efficient development of water power, both from the technical and economic points of view. The aluminium industry is not a private owner of any water-power development, the chief aluminium reduction works at Mansbo drawing its electric energy to the tune of 6,000 h.p. from a public power company in the neighbourhood. The Kubikenborg works, which started operations in 1942, also draws its power from a distribution centre.

GERMANY

In Germany water-power resources are comparatively poor in relation to the needs of a country which had such a highly concentrated industrial structure, and most of the generation of electrical power was undertaken in steam plants fired by brown coal, the German supplies of which are the richest in the world. The aluminium industry, in common with other industries, therefore used mostly steam-driven power stations, but there are two examples of water-power serving the production of aluminium at the Falls of the Rhine and at the Töging works on the Inn River in Bavaria. The Rhine hydro-station is the oldest large station in Europe: it was started in 1896 and the first stage, costing eight-and-a-half million Reichmarks and making available 24,000 h.p., was opened two years later. This hydro-electric station feeds, *inter alia*, the Rheinfeld aluminium works, the oldest in Germany and originally Swiss-owned. The Inn hydro-electric plant is fed from a low-head dam controlling a large canal, and short pipelines convey the water to the power house, the established capacity of which before the war was 100,000 h.p. The station is still operating at the present time.

U.S.S.R.

Most of what can be said about the development of water-power in the U.S.S.R.—as of the aluminium industry and any other major industry—relates to the pre-war situation. The Soviet Union had undertaken vast development of her great natural resources in water-power in European Russia and, among other achievements in this direction, had constructed one of the largest power dams in the world across the Dnieper in connection with the erection of the Dniesprostroy power-works, which served the electro-chemical and electro-metallurgical industries in the neighbourhood as well as transmitting power to other areas in the vicinity. The enormous curved dam, 2,200 ft. in length, was blown up by the Soviet army when the German invasion reached this territory, but since the war it has been partially reconstructed and the original power output of 1,200,000 h.p. will ultimately be increased. The Ural aluminium plant at Kamensk utilizes power from the Iset River, whilst the first aluminium producer in the Soviet, the Wolchow concern, draws its power from the Zvanka hydro-electric plant on the opposite bank of the river. The Wolchow plant was to some extent involved in war damage and the present position is not fully known.

In connection with the policy rapidly put into practice during the early days of the war, any equipment which was mobile was transferred from the threatened Western zones to safer areas in the Eastern States, and this policy was co-ordinated with the extension of the original schemes for new hydro-electric developments in Asiatic Russia. The Armenian station on the Sewansanga was originally erected to dispose of 536,000 h.p. The Taschkent aluminium works is based on the Tschidschik power station with a capacity of 368,000 h.p. The Kusnetz aluminium works draws its power from the Kemerovo power station. Post-war development in the production of aluminium include the erection of hydro-stations on the Angara River in Eastern Siberia, and on the Irtysh River in Western Siberia.

SPAIN

Spanish interest has not ignored the development of the power resources of the Pyrenees and has undertaken extensive application of this power for use in the electro-metallurgical and electro-chemical industries. A large Aragon concern has power stations at various points; the station which serves the aluminium industry being at Sabinanigo in the Huesca Province, where aluminium has been produced since 1929. In 1944 a second larger aluminium producing works has been established close to Valladolid with a power station on the Pisuerga River.

AUSTRIA

There is a quite important aluminium producing industry in Austria, with two older-established reduction works; one at Lend, Gastein (Swiss interests) which operates a small hydro-electric station on one of the tributaries of the Inn. The second works are in Upper Austria, at Gmunden, which are controlled by a domestic Group and utilize surplus power left from two lakes in the Dachstein Mountains after the public utility requirements are supplied by this Group.' A third more recent aluminium plant at Ranshofen utilizes power from the Inn River.

YUGOSLAVIA

The only aluminium producing works in Yugoslavia is that near Sibenik at Ljubljana, which derives its electric energy from a hydro-electric station on the Sava River.

SOUTH AMERICA—BRAZIL

The development of the aluminium industry in Brazil, which is very recent, is based on the possession of large native supplies of bauxite and extensive resources of water-power, which are practically virgin for development. A large hydro-electric station at Ouro Preto has an installed capacity of 40,000 h.p. at present. A second aluminium reduction works (partly owned by Canadian interests) is in the Sao Paulo State: the hydro-electric development, at Serra de Cubatao, which has recently been developed at an initial cost of over £2,000,000, has an installed capacity of 88,000 h.p. This power station also operates a public supply.

ASIA—JAPAN

Japan is richly endowed with rivers capable of developing water-power, with thirty-seven principal streams to tap, and if she started late to utilize her resources she made up for lost time by employing the latest techniques of engineering and science. The industrial revolution period between the wars saw water-power harnessed on a large scale at many sites, the development being undertaken on the most advanced lines, utilizing high-dam and long-conduit schemes with full supplementing storage reservoirs for regulation. By the mid-'thirties over a thousand sites were developed in the forty-seven Japanese administrative districts, with a theoretical kW power output of 4,000,000; and nearly half this number of further sites were being rapidly developed to utilize to the full the total estimated available water power of 10,000,000 or more theoretical kW. The chief hydro-stations are in the Nagano, Niigata, Toyama, Gifu and Fukushima prefectures. Post-war reports show that Japan's power resources are integrated and interconnected to a greater degree even than in the United States, a higher proportion of industrial plants being served with electricity than in any other country in the world. The present Five Year Plan fixed by the Far Eastern Commission authorizes the continuation of hydro-electric engineering projects, ninety-three further plants being scheduled for completion by 1952.

INDIA

Under British Rule, little was done to develop the enormous potential hydro-power of India. This was due in the main to the policy of keeping India undeveloped industrially to ensure a market for Western-produced goods and to strengthen the effective force of the Rule: a minor factor was the attempt to favour coal-produced electricity to increase the royalties on coal—no royalty could be charged on water-power—and the Indian public was generally encouraged to react against schemes for developing power from water on the misleading grounds that the Indian resources of water were sacrosanct for irrigation in the interests of agriculture. After the 1914-1918 War the total developed water-power in British India was well under 70,000 theoretical kW and that of the Indian States under 5,000 kW, out of a conservatively estimated 13,000,000 kW available for development in the—even then obsolete—contemporary Survey. There were only five small hydro-stations in British India, in Mysore, Bombay, the U.P., Madras and the Punjab, of which the Mysore scheme (17,000 kW) was the largest: of the States schemes, only the Jammu/Jhelum development in Kashmir (5,000 kW) was at all important. Effectively these hydro-electric stations, which were for the most part privately owned, served municipal supplies for lighting and power and little of the one per cent. of water-power developed went to establish industry.

In the inter-War period, additional development was undertaken in Bombay, Mysore and the Punjab: and since Independence and Partition the Hindustan Government has given prompt attention to the vast undeveloped water-power resources, particularly of Northern India, whilst Pakistan has also set up a statutory authority to be responsible for hydro-electric projects in the West Punjab and in East Bengal and Sind.

In Hindustan the important project for the Wainganga River hydro-station, planned to yield 600,000 kW, links with the big scheme for producing aluminium in the Central Provinces and Berar (see p. 116).

CHINA

Until just before the recent War, little was even known of Chinese water-power resources, but some preliminary investigations carried out between 1935 and 1938 estimate that the potential power available for exploitation is about 22,000,000 h.p. available continuously and 40,000,000 available six months in the year. This grades China as a country with potentially very great water-power. The majority of water-power resources are in the south-western part of China, whose rivers are characterized by cataracts and which has an abundant rainfall.

CHAPTER IV

THE ALUMINIUM PRODUCING INDUSTRY

THE ECONOMIC history of the aluminium industry has demonstrated that the conditions for free competition in production costs, with an Exchange acting as a barometer of the failures and successes as in the case of other non-ferrous metals, did not obtain; for reasons connected with the technological features of the producing industry. The Hall-Héroult process is complicated and requires a highly integrated industrial structure controlling economical ore and power, and requiring investment of large sums of the order of several million pounds for a moderate-size industry. Moreover, the industry is subject to the disadvantage of limited natural resources, e.g., bauxite and cheap power. Obsolescence raises uncertainties. There is no scope for the use of large specialized units of production except insofar as improved design permits of larger furnaces, large-scale output being simply dependent on multiplication of small producing units with proportional multiplication of labour and energy requirements and with virtually no proportional economies.

For the first fifty years of its history, the above-mentioned factors tended to give rise to single-firm monopolies in the various national industries, which have been characteristic of the aluminium producing industry up to the Second World War. The post-war tendencies are by no means yet clear, but it may be said that the expanding market for aluminium and its increasing importance as a basic engineering material will allow for an increase in the number of large-scale producers in those countries which have extensive natural resources and territory, although the limiting technological factors still weigh against true competition inside the producing industry.

PRE-WAR POSITION

Before the Second World War there were about 25 large independent companies engaged in the reduction of aluminium. These were distributed between the principal nations of the world and rather more than 25% of the world output was accounted for by Germany, closely followed by the United States. The remaining 50% of production was under the direction of Great Britain, Norway, France, Switzerland, Italy, Russia, Canada, etc.

POST-WAR POSITION

The war has completely changed this position and has moved—finally, it would seem—the centre of gravity of the aluminium-producing industry right out of Western Europe. During the actual period of the war the Allied centre of gravity was firmly established in the North American dualism of the United States and Canada: but there was an Axis output which, at least for the early years of the war, between Germany, Japan and Italy alone exceeded the American and Canadian output combined. Now the German industry is practically gone, the Italian industry is under Anglo-American control and the Japanese industry is finished. Germany's place in Europe, however, is likely to be taken by that of a great combine between the Central European States, Hungary, Czechoslovakia and Yugoslavia, under Soviet influence and with supporting industries in Rumania and Poland. The Soviet herself, with her new aluminium industry stretching eastwards from the Urals, will be a dominant factor in the World industry: and in Asia, whilst Japan's sun has temporarily been eclipsed, India's star is rising fast in the modern world and great developments in her industry in a short space of time may be looked for.

The Western European producers, France, Switzerland and Norway and the small units in the Low Countries will have to seek new export outlets to keep their aluminium-producing capacities operating after the immediate post-war sellers' market (where ingot is literally rationed to old customers) declines; and economic competition from the Central European group will be formidable. The British aluminium industry has still a special position, with possibilities of expansion in Africa and in the Far East in collaboration with other Commonwealth members, and her domestic working and fabricating industry is steadily developing—with German competition absent.

The South American market has changed with the development of at least one major indigenous producing industry (in Brazil): and the Australasian continent is establishing its own production, though the effects of this will hardly be felt for some years to come.

As an addition sum which has to be added up, the total remains enigmatic because there are too many blanks in the entries in Asia and in Eastern Europe inside the Soviet sphere of influence: but one thing is clear—the old cartel monopoly is gone and the second phase of the aluminium industry has begun and must make for a greatly increased world production, with all the implications this must inevitably mean.

The influence which the world bauxite position will have on the producing industry is extremely important and the following paragraphs summarize the present-day situation.

Economics of Bauxite: The Present-day Situation

Chapter II, which discusses this ore, draws attention to world supplies and national bauxite mining industries. In the light of the fact that bauxite is, for the aluminium producing industry in its present form, technologically indispensable, it is interesting to summarize the present economic position as it affects the various national aluminium industries.

The first obvious point to note is that, whilst abundant and widely distributed reserves of bauxite ore are available, there is no present geographical correlation between the main centres of ore production and the old-established national industries for aluminium production,—with two exceptions, France and Soviet Russia. This position, the outcome of disproportionate and unnatural concentration of industrialization in Western Europe and America last century, is not likely to prevail in the future; the newcomers among the national aluminium producers are those countries like Brazil and India, which have access to effectively unlimited domestic supplies of bauxite.

The second point to note is that the aluminium industry is not a monopolist consumer of bauxite and the question of supplies is dependent on competitive buying.

Of the present great World aluminium producers, Canada is entirely dependent on external ore: the United States is dangerously low in domestic bauxite following the depletion of her home mines to meet the vast output of aluminium in the recent War: supplies in Northern Ireland which at present count as British are useless for aluminium production (though not entirely negligible for other uses) and Great Britain is wholly dependent on the resources of bauxite in what remains of her Empire, where a new drive is taking place to develop particularly the supplies in West Africa (Gold Coast) and South-Eastern Asia (Malaya and the larger Polynesian islands): Switzerland has no national supplies of ore: Norway has so far been unsuccessful in developing her domestic and Arctic supplies: Yugoslavia has up to the present been mainly an exporter of bauxite but she has a small national aluminium industry which is almost certain to see intense development in the future: Italy has been in the past and is again in the post-War period an important exporter of bauxite—following the Anglo-American assumption of control of her national industries which include a major aluminium producing industry (in which, however, Italy once elected to use partly her large native supplies of leucite as the raw material, processing it by the Blanc method) she may well continue to figure as a large-scale exporter: Germany has no bauxite worth consideration: Japan-Manchuria is out of the picture at the moment (and in any case the Japanese aluminium industry was based mainly on imported bauxite and Manchurian supplies of alunite).

These are the old aluminium producers: France and the Soviet Union have not been included because they are both in the position of being adequately supplied with large ore reserves to meet any present and future requirements of their aluminium industries, large though these are. France is not yet back to pre-War level in her bauxite output. The Soviet Union is actively expanding production of both alumina-bearing ores, including bauxite, and aluminium to a new high level.

The new aluminium producers are in a separate camp because, as mentioned above, they are based on the exploitation of plentiful domestic deposits of bauxite.

So the old producers in this post-War period have to face a new situation. The economic structure of the first industrial world which held together only loosely after the First Great War has been profoundly disrupted by the stresses of the Second: the old organization of an order which made economically feasible the transport of crude bauxite as a ballast load from across the oceans for conversion to aluminium in the home industry cannot easily face the competition of the younger industries erected in sites chosen for their proximity or favourable transport orientation in reference to home ore locations. This problem is partly bound up with the question of modernized power generation (q.v. in Chapter III, p. 54).

EXTERNAL ACTIVITIES OF ALUMINIUM PRODUCERS

As distinct from activities representing integration inside the Industry (most producers have integrated to the point of semi-manufacturing but have kept out of fabricating and finishing processes) certain of the World producers have external activities relating to water-power-produced products and for the past fifteen years all the major aluminium producers have interested themselves in the development of the magnesium industry.

Review of the Aluminium Industry by Countries

The following part of this Chapter gives brief accounts of the development of the various national industries throughout the world.

Statistics of Production, Bauxite Production, Consumption, and in some instances of Imports and Exports, are given in Chapter VI.

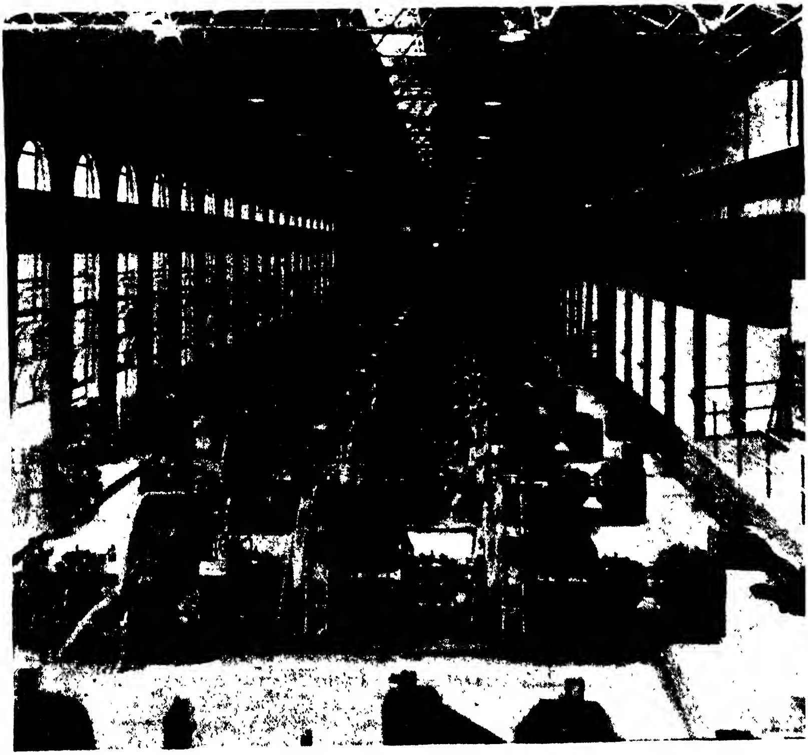
Great Britain

The case of the aluminium industry in Great Britain is a somewhat special one. Because of her sea-power, both mercantile and naval, when the industry was formed at the end of last Century it found no difficulty in basing itself on sea-borne imports of ore. Domestic coal was available in adequate supply and power was to some extent potentially available but not on a footing to render this country an equal competitor with nations possessed of great natural resources. On a strictly economic basis, as the following paragraphs will show, Great Britain's aluminium industry could not keep pace with foreign producing interests, but the industry has nevertheless thrived on its limited basis—limited, that is, by comparison with the leading World producers. Before the recent war it shared the privileged position of a member industry of the international cartel: and also benefited from its imperial relationship with, on the one hand, Canada (a huge producer) and on the other hand, India (with a large undeveloped market). The post-war situation finds this country with a small but healthy domestic industry: whose external relationships have, however, to be completely reorientated in the light of the great changes, international and imperial, which have taken place.

THE BRITISH ALUMINIUM COMPANY

Apart from early experiments in commercial production by the Deville process, which date back as long ago as 1860, the modern aluminium industry in Great Britain dates effectively from 1896, when the British Aluminium Company was formed, with the active interest of Lord Kelvin, and began operations in a 3,500 h.p. plant at Foyers, Scotland, using Héroult Patents under licence from the Swiss. Though the Company was originally small (with a Share Capital of £300,000 divided as to £100,000 in Ordinary Shares and £200,000 in Preference Shares) it was highly integrated from the start. It acquired bauxite mines in Northern Ireland, as well as water-power rights in Scotland and in North Wales. (The latter, however, have never been developed.) An alumina factory was constructed at Larne Harbour. French ore deposits were also purchased, and arrangements were made for low transport rates as return loads in vessels carrying coal to Mediterranean ports. An electrode plant was established at Greenock; rolling mills were erected at Milton.

In 1903, an additional and slightly larger reduction works was erected at Kinlochleven, and in 1905 a further extension of this was undertaken, and was completed in 1907. By this time it was recognized that aluminium reduction in Great Britain was uneconomical on account principally of the high cost of the water power under the conditions obtaining in the Scottish Lakes, where very large dams are required; and the British Aluminium



Interior of Power House Supplying Lochaber Reduction Works.

Co. accordingly turned to Norway for expansion, acquiring works at Stangfjord in 1908 and at Vigelands in the following year.

During the First World War, Government support was forthcoming for extensive hydro-electric development near Lochaber in Scotland, the necessary legislation being passed through Parliament in 1921, and the actual development undertaken about 1925, with the aid of a Government loan of £2,500,000. This development added about 45,000 h.p. at the completion of the first stage of the development in 1929, and a further 30,000 h.p. at the second stage in 1938. The Lochaber plant was further extended during 1940-1942. The latest furnaces are of 40,000 amperes—as compared with 8,000-ampere furnaces originally erected at the first Foyers plant.

The following table roughly indicates the progress of production capacity in terms of h.p. at the British Aluminium Co.'s plant:—

BRITISH ALUMINIUM COMPANY'S POWER

Date	Foyers	Kinlochleven	Lochaber	Stangfjord	Vigelands
	h.p.	h.p.	h.p.	h.p.	h.p.
1896	3,500	—	—	—	—
1903	3,500 plus	5,000	—	—	—
1907	3,500 plus	20,000	—	5,000	14,000
1914	6,000 plus	20,000	—	20,000*	
1929	6,000 plus	20,000 plus	45,000	—	—
1938	6,000 plus	20,000 plus	75,000	—	—
1940-43	6,700 plus	30,000 plus	120,000	(liquidated)	

* The B.A., the French and American interests took up, in 1912, one-third shares each in the Det Norske Company, which produced aluminium at large water-power stations at Kinsarvik and Tysse.

At the present time the British Aluminium Company's power resources, so far as domestic works are concerned, are thus in excess of 150,000 horse-power. During the last war, two other temporary reduction works were erected at Kinlochleven and at Swansea, utilizing power from the Grid. Both of these have now ceased production. The Foyers works, too small to meet modern competition, is being converted to produce other electrochemical products.

Alumina was first produced at Larne, whose works were extended to the limit of the land available, and Burntisland in Fifeshire was chosen as the second site for alumina production which started in 1917 and was progressively extended to the maximum capacity. A third factory was opened at Newport, Mon., in 1939, and this plant has been considerably extended during the recent war.

General view of the Lochaber hydro-electric aluminium reduction works, showing the pipe line and Ben Nevis in the background.

As has been mentioned, the Company owned fabricating plant from the very start, the first mills being at Milton and at Greenock. Just prior to the Great War, further rolling facilities were acquired at Warrington, and extrusion processes were put into large scale production at the same works. During the recent war a large up-to-date rolling mill was erected at Falkirk in Scotland on behalf of the Ministry of Aircraft Production. The Company designed and erected this mill and has since the War acquired it. A final war-time development on the fabricating side was the production of secondary ingot metal which has been undertaken at Latchford Locks, originally for the Government and now in the interests of the Company.

The Company also controls a number of ancillary works for production of certain chemicals, carbon electrodes, and aluminous products, and it has interests in a number of subsidiary concerns and Empire producers.

THE ALUMINIUM CORPORATION

The only other producing company in the British Isles is a much smaller undertaking which operated originally as the Aluminium Corporation, with a small (5,000 to 7,000 h.p.) reduction works at Dolgarrog, Wales, and alumina factory at Hebburn-on-Tyne. This company was formed in 1908 but failed shortly afterwards. It refused an offer to purchase by the British Aluminium Company and reorganized and continued, in association with the International Aluminium Company, Ltd., which controlled rolling mills in Wales, independently as a small producer, until, in 1928, it undertook the development of 50,000 h.p. at the Haugvik smelters' plant at Glomfjord in Norway. The economic conditions were unfavourable and precipitated a second failure and the Corporation sold out to the Alliance Aluminium Cartel (of which an account is given below) in December, 1931. The Dolgarrog capacity is still small, but the Company has a small rolling mill. Since the liquidation of the Cartel, the Aluminium Corporation has been managed by the British Aluminium Company.

The market policy of the British industry has been closely influenced by its association with the European Cartel, of which the British Aluminium Company was a member firm since the inception of the Cartel in 1901.

THE CARTEL

The following notes give a skeleton chronological history of the Aluminium Cartel:—

1901: The "Alliance Cartel" was formed by the four European producers and the Northern Aluminium Company (a completely owned subsidiary of the American concern, the Aluminum Company of America). Details of its structure are not known but its functions included reservation of the home markets, apportionment of the member firms' sales quotas for the competitive markets and the fixing of minimum prices. This first Cartel was not a strongly centralized instrument: it had no central sales agency or central administration. The Swiss Company (Neuhausen) assumed the leadership and this position gave rise to French distrust. As the French companies began to overtake the Swiss producers in output, the friction increased and the Cartel was dissolved in 1908.

1910: The Cartel was reconstituted.

1913: The "Aluminium Association" was formed as a new Cartel and included the new British producer, the Aluminium Corporation, and the Italian producer. The term was fixed for ten years but was actually terminated by the First World War. The Contract Deed provided for regulation of all sales by its members of aluminium, aluminium alloys, semi-manufactures and manufactured finished goods in all markets except the U.S. Output was not limited directly but sales quotas were allotted to each member company on fixed proportionate percentage as follows:—

The French Company	38.9%
The Swiss Company	21.4%
The British Aluminium Company	19.9%
The Northern Aluminium Company	16.0%
The Italian Company	1.9%
The Aluminium Corporation	1.9%

A firm which exceeded its quota could either pass some of its orders to those who were still below their quotas or buy from the latter at the standard price the amount of metal by which it had surpassed its allotment: a member in arrears who was unable to fulfil its orders quota had to surrender them for division among the others. Each member was free to sell his quota where he chose. Since there was no definite control of output and no central sales agency, administrative instrumentality was inadequate to prevent evasions and constant disputes arose.

1923: A Price Agreement was drawn up between the French, British and Swiss producers, to remain in force for two years.

1926: A new, formal Cartel was constituted between the French, British and Swiss producers and certain German producers: it did not include the Aluminum Company of America and the latter's Canadian subsidiary but there was a working agreement by which the Cartel prices were respected by Alcoa until 1928.

This Cartel was based on three objectives:

1. Exchange of patents and information
2. Co-operative cultivation of markets.
3. Reduction of costs and stabilization of prices for ingot metal only, the prices being fixed quarterly.

The Sales were worked out on a Quota basis:—

The French members	30
The German members	27
The Swiss members	23
The British members	20

This Cartel strengthened the monopolistic market control by supplanting private agreements but it did not eliminate competition. It exerted no control over the investment policy of the member firms.

1928: The British quota was increased and the French quota decreased.

1931: The " Alliance Aluminium Compagnie " was formed as a highly centralized Cartel between the European producers, excluding the U.S.S.R. and Italy, and excluding Alcoa. It regulated production, sales and prices and financed the pool of accumulated stocks. In the new quota basis, the British quotas were increased once more and the Swiss quotas were decreased.

In the same year, an agreement was made between Aluminium Limited (Canada), and the British, French, Swiss and German companies regarding the Japanese market and sales in India, but it is not clear whether this agreement was inside or outside the Cartel jurisdiction.

1934: The Germans "kicked" against the provisions of the Cartel, claiming special favour on the score of their "domestic" needs and demanded a separate price reduction. The 1935 producing capacity of the member firms was as follows:

The French members	23.3%
The German members	32.4%
The Swiss members	27.1%
The British member	17.1%

Until the Second World War, the Cartel strengthened monopolistic control in all markets of the world (excluding consideration of the U.S.S.R. and its unpredictable influence in European and Asian markets), delineating four separate areas—the U.S., Germany, Italy and the rest of the world—in each of which market control was largely co-extensive with the activities of producers. The Italian group of producers were chiefly interested in the domestic market; whilst the Americans obtained a position of greater power than they formerly enjoyed (the American tariff permitted of considerable freedom in planning price, investment and output policy and, unhampered by quota restriction, it did not have to share the home market with foreign competition).

France

France is generally considered the cradle of the aluminium industry. One of the master patents for the production process on which the modern industry is based is that of Héroult, a Frenchman, which was taken out in 1886. Although this patent was first of all utilized in Switzerland, Héroult opened up a French plant at Froges in 1888, employing 4,000-ampere furnaces. This works was to become one of the major producing plants in Europe: by 1910 the hydro-electric station was enlarged to give some 50,000 horse-power. In the early years of the Century, four other French manufacturers entered the aluminium production field. The then Cie des Produits Chimiques d'Alais et de la Camargue operated the Froges works: the Société des Forces Motrices et Usines de l'Arve, the Soc. des Produits Electrochimiques et Electrométallurgiques des Pyrénées, the Soc. Electrométallurgique Francaise and the Soc.d'Electrochimie joined with the Froges group to form a new company, the Aluminium Francais, in 1911. The new company was not only a Selling Organization for all the member firms but had its own plants at Selzaete (Belgium) and Mennessis, whilst it immediately opened up new works at Chambéry and at Arrean in the Pyrenees, the former for foundry and fabricating operations. The French industry was highly integrated early in its development and the fabricating plants for production of cooking utensils and decorated articles were among the finest in Europe.

France entered the Cartel with the other major producers and domestic production was rationalized by a large measure of unification due to the distribution of output by l'Aluminium Francais. Prior to the Second World War, there were only two major producers, with the following alumina and reduction works:—

	Alumina Works	Reduction Works
Alais, Froges et Camargue (Pechiney concern) ..	Gardannes St. Auban Salindres	St. Jean de Maurienne La Saussaz Riouperoux L'Argentière Chedde Sabart Auzat Beyrede
Soc. d'Ugine	La Barasse	Les Clavaux Venthon Prémont

The total output of the combined reduction works before the war was about 45,000 tons p.a. of ingot. With the outbreak of war the output was stepped up to 70,000 tons in 1940. With State aid the capacity was increased still further to give a planned production of 90,000 tons.

During the Occupation, the French industry had to meet German demands to some extent and it also had to supply the domestic market with enough metal to replace imported metals: but in spite of relatively small damage to works (partly sabotage, e.g., at the Argentière works in 1943, where the pipe-lines were more than once blown up and partly destruction by the Germans during their Retreat, particularly in the Maurienne region in 1944) the output of ingot has fallen off continuously from 1942 onwards. By 1944 the annual production was only 26,000 tons: and during the following year it rose only slightly to about 36,000 tons. The pre-war output has not yet been re-attained.

BAUXITE

France has always been an important producer of bauxite ore, which takes its name from the little village of Les Baux—to-day still suffering from war-time destruction—although the main French output is from the Bouchées du Rhône, Var, Héroult and Ariège districts. On an average, more than half-a-million tons of bauxite were extracted annually from French soil before the war—until very recently about a third of the World output. The labour force in the bauxite mines (formerly chiefly Italian, now mostly French) is about 1,500 strong.

Switzerland

Switzerland has a definite claim to be regarded as the nursery of the modern aluminium industry in Europe. The process discovered by Héroult in France was actually first operated in Switzerland at Neuhausen, near Schaffhausen, on the falls of the Rhine, and in 1887 a Swiss domestic company with a large capital set up an experimental plant for developing the Héroult process. At first the plant was devoted exclusively to the production of aluminium-bronze and ferro-aluminium, but a year later a new company, the Aluminium Industrie A.-G., was formed to take over the existing plant for the production of pure aluminium. The capacity of this first European production plant, as long ago as 1889, was 4,000 h.p. and the large-scale production which was possible allowed of reducing the production costs to such a point that aluminium could compete in price with other common metals. The new light metal found an important market in Germany at a time when German industry was immensely productive and after ten years' operation the Swiss company decided that it would be profitable to undertake the construction of new producing units actually in German territory. The A.I.A.G. therefore established a second aluminium plant at Rheinfelden in 1897 and a third works at Lend in the Austrian province of Gastein between 1898 and 1901. By the early years of this Century, Swiss water-power developments were being more fully exploited, and the A.I.A.G. put down its fourth plant at Chippis in the Canton of Valais to utilize water-power based on the Rhone. The section on water-power (p. 63) mentions the power stations with which the great Chippis works is associated and the following table indicates the development of the Swiss aluminium works between 1908 and 1926:—

Navizance works	1908	32,000 h.p.
Rhône works	1911	53,000 h.p.
Borgne works	1913	33,000 h.p.
Illsee-Turtmann works ...	1926	32,000 h.p.

In addition to the works of the A.I.A.G., a small independent company set up a less important aluminium producing works at Martigny-Bourg.

Switzerland does not possess either bauxite or coal and has therefore been compelled to import either the raw materials or alumina manufactured from them from foreign sources. The Swiss producer from the beginning organized its ownership of foreign subsidiaries to control both bauxite and alumina, the former in France and the latter in Germany and Italy. The domestic industry was fully integrated from ingot production onwards, but since Swiss industry has always been largely dependent on its export trade a considerable proportion of its ingot output was exported before fabrication.

The A.I.A.G. has some of the finest plant in Europe for the manufacture of rolled and pressed products and it also controls various foundries, some of which specialize, for example, in piston production.

The Swiss producer has always been a member of the aluminium cartel and in the early days assumed its leadership, until French production began to overtake Swiss output. when the Swiss producer took second and ultimately third place in the allocations of proportionate quotas.

In the inter-war period, Switzerland maintained her position as a major producing country with a fairly steady output of the order of 20,000 tons, and she suffered comparatively little in the bad years of the early thirties. By 1939 she was producing nearly 30,000 tons per annum.

The Swiss industry was essentially an exporting industry, selling both ingot metal and nearly the whole of its semi-manufactured and fabricated products and, since the quality of output was high, the industry had practically an unbroken prosperity until the Second World War broke into this state of affairs. The early part of the war did not greatly affect Swiss production, but during the later years immense difficulties were encountered in the supply of imported alumina, the Swiss subsidiaries—mostly in German-controlled territories—being unable to deliver, and the Chippis reduction works had to close down.

Since the end of the war, the Swiss aluminium industry has again been operating to meet a large and constant demand for aluminium goods both in the domestic and foreign markets, and only hampering factors, such as the unsatisfactory water-power supplies and persisting transport difficulties, have marred its complete recovery so far as domestic works are concerned: the Swiss foreign subsidiaries, in ex-Axis territories, have in some instances been damaged and, in all cases, output has been greatly decreased.

Germany

Born in France and suckled in Switzerland, the aluminium industry yet owes a great deal of its nurture at a tender age and much of its vital growth at later phases to Germany, in whose economy the industry has had a very special position. The German aluminium industry came into being originally through Swiss initiative on the crowded stage of industrial development in the over-peopled Germany of the two decades before the Great War—a Germany beginning to struggle against the bonds imposed by her inability to assimilate in time the Western European political form of life with its concomitant expansive imperialism. Germany had no bauxite. She had no adequate sources of water-power for hydro-electric development. But she had unlimited supplies of brown coal and unlimited labour; and the energy born of the sense of inequality with her more powerful imperial neighbours to find its expression, aside from intellectual and scientific achievement, in technical skill and militant industrial efficiency. Germany had to live, and insofar as aluminium had to be made a vital element in her non-ferrous metal industry which, with poor imperial resources, had little or no favoured access to the world's major ore reserves of, for example, copper, Germany had to produce aluminium and produce it on the grand scale.

The first aluminium reduction works in Germany was of Swiss origin, at Rheinfelden, which was opened in 1897 and had an annual output of some 800 tons. The 1914-1918 war saw the initiation of the first serious undertakings to foster a large domestic industry. Two rather small temporary War Emergency reduction works were opened up at Rummelsberg (4,300 tons p.a.) and Horrem (3,000 tons p.a.) in 1915 and 1916 and a third permanent small plant of 3,000 tons capacity at Bitterfeld was also erected in 1916: a newly-formed Aluminium Trust, the Vereinigte Aluminium-Werke (V.A.W.), half-capitalized by the German Government which also supplied funds for the erection of plant, undertook the organization of the war-time output and of planning for a big permanent future production. Large integrated alumina and reduction works were laid down at Lauta, near Dresden, and at Grevenbroich (the Erftwerk) on the lower reaches of the Rhine, both works drawing their power largely from steam-generated electricity from brown coal. Yet another plant was founded in 1917, at Töging, in Bavaria, for which a hydro-electric station was built on the Inn (see p. 66), the only aluminium works in Germany apart from the small Swiss works at Rheinfelden to draw its power from hydro-generation. During the early part of the inter-war period, the domestic output from these three V.A.W.-controlled works and from the Bitterfeld works of the Griesheim Elektron concern (exclusive of the small Swiss-controlled output at Rheinfelden) was about 30,000 tons annually, rating Germany second among world producers for the period 1925-1930. German research and development work within the aluminium industry was foremost in the world at that time; and the quality of German aluminium products was uniformly high. Entry into the Aluminium cartel (p. 80 *et seq*) was made in 1926 and Germany played a leading part in the expansion of the world market, particularly the Far Eastern market, for aluminium goods and hollow-ware. Bauxite supplies were drawn at first from France and subsequently more and more from Hungary and Istria.

The third phase of the German aluminium industry was entered on with the coming to power of the Nazi regime. The Four-Year Plan stepped up the domestic aluminium capacity to 130,000 tons in 1937 and 160,000 tons in 1938 (largest world producer). It undertook extensive research to develop production methods based on domestic raw materials to replace bauxite, meanwhile garnering the utmost obtainable stocks of bauxite from the territories under German control or influence. A large secondary metal production potential was organized with a view to war needs, a big plant for scrap reclamation being laid down at Lünen, in Westphalia, and smaller plants strategically scattered.

The new reduction and alumina works installed in 1938 at Lippe were equipped with the first pilot plant for clay-processing by the lime-soda method (see p. 51) and further plants for processing clay and blast furnace slags were planned and put in hand as the programme for self-sufficiency developed and as inevitable inroads were made into the accumulated stocks of bauxite due to the rapidly rising output of " the German metal," as aluminium came to be called at this time. This final pre-war period was indeed one of Aluminium Age for Germany, when her technicians thought in terms of aluminium as *ersatz* for every engineering material in short supply; and it must be added that the research and development work which the State had fostered bore such good fruit that the claim of ubiquity applied to aluminium was no empty pretension. Light alloys did usefully replace other traditionally used metals in nearly every sphere.

After the war broke out, even greater efforts were made to expand aluminium production. The V.A.W. put down a fine modern plant at Ranshofen, in Austria, in 1941-1943 (see p. 91) and extended the Innwerke and Lippewerke plants. Annual output exceeded the 200,000-ton level in 1939 and passed the 250,000-ton level in 1942, the peak year of German aluminium production.

As the war entered the later phases, the aluminium industry reflected the general pressure on German resources, at first adequate and then gradually cracking under the strain. While the stocks of good bauxite which had been collected lasted, the quality of aluminium and light alloys remained high; as the plans to switch over to lower-grade ores and to German domestic raw materials (clay and furnace slag were the only ones available) were put into operation it became difficult to maintain quality. Above all, as man-power was inevitably drawn into the military machine the skilled labour available to the works and foundries became more and more attenuated and overstrained. The psychology of despair, after the almost superhuman efforts of a generation to raise its head from defeat to victory and to raise the status of the nation from a "have-not" to a "have" economy failed to achieve their purpose, overtook the whole of German activity even before the physical invasion of their victors; and this attitude became apparent in the output at all levels.

At the end of the war the biggest V.A.W. works at Lauta were dismantled by Soviet technicians for removal to the U.S.S.R. The Western Powers at first completely prohibited the production of all light metals and permitted only the melting-down of aircraft aluminium scrap; but a limited operation of the reduction plants at the Erftwerk (7,000 tons), the Innwerke and the Lippewerke of the V.A.W. was allowed by the American and British Bizone authorities in a revised plan for controlling German industry in August, 1947. In 1948 a new schedule provided for 11,000 tons output at the Lippewerke. Old stocks of bauxite (probably amounting in all to not more than 300,000 tons) will be used up. Reopening of the Rheinfelden and Töging Works is also permitted (the output proposed being about 15,000 tons) and the Martinswerke at Köln are being put into working order.

Austria

The aluminium industry in Austria dates back to last century although the first works, at Lend, in the Gastein province, south of Salzburg, was operated by Swiss interests, who started this works in 1897. A small hydro-electric station was erected on a tributary of the Inn River to feed the reduction works.

The first Austrian works operated by a domestic group was built during the First World War, with Government aid; in 1916 an alumina works, reduction plant and electrode factory were erected at Steeg, near Gmund, in Upper Austria. Power was drawn from the Gosanwerke group of power plants based on two lakes in the Dachstein Mountains. Istrian bauxite was at first available but when the Peace Settlements passed Istria to Yugoslavia, orc supplies had to be obtained from the Käraten district of Austria. The original capacity of the plant was about 1,300 tons per annum, which fully covered the consumption requirements of Austria prior to the Anschluss.

The most important works in Austria was erected by the V.A.W. during the recent war. This Mattigwerk plant at Ranshofen (near Braunau) started production in 1941; it utilizes power from the Inn River. All the latest improvements known at the parent Lauta works were incorporated in this very fine and up-to-date plant, whose initial production of 12,000 tons in 1941 was doubled, trebled and quadrupled in the following three years.

The Mattigwerk was allowed to resume operation after the war and restarted production on a token scale (785 tons) in 1946. Shortage of electricity prevented large-scale resumption of work and again in 1947 it was only possible to produce during about five months of the year (3,600 tons total output). Early in 1948 it was announced that sufficient power would be available for continuous operation and the plant will operate on a pay-its-way basis of half the production being allocated to finance the necessary raw materials.

Norway

The aluminium industry of Norway reflects very clearly her position as a small satellite nation without adequate resources of wealth to capitalize even her own considerable natural assets on a scale capable of holding its own in the Western industrial world's economy. Norway is possessed of large water-power resources, situated near to deep ice-free harbours on the Atlantic Coast, which provide excellent sea-transport facilities: and this fact attracted all the pioneer aluminium producers in search of cheap power. It is particularly interesting to note the early penetration of Canadian and American capital alongside British and French: this became necessary, not so much because of the economic conditions—which were not, in all cases, relatively advantageous alongside conditions in the North American continent—but as a result of the policy of tariff restrictions after the Great War, designed to protect the North American market but necessitating overseas production to supply overseas markets.

The first aluminium works in Norway was erected with British capital at Vigelands in 1906, when the British Aluminium Company was expanding and requiring cheaper power than the Scottish hydro-electric schemes could produce. The original power station had a capacity of 12,000 h.p. and the Vigeland Brug works' original output was of the order of 2,000 tons per annum. The following year a second reduction works was laid down by the same British concern at Stangfjord: this was a smaller plant with an initial power capacity of some 3,000 h.p. and an output of about 500 tons per annum.

In 1912 a first attempt was made by Norwegian domestic interests to take a hand in the development of a national aluminium industry and a plant was erected in conjunction with an existing works owned by the Det Norske Nitridaktieselskap (D.N.N.) and operated for nitride production at Eydehavn, utilizing power from the important Arendal hydro-electric station. When the 1914-18 war broke out, French interests (the Alais, Froges et Camargue concern) took over control of this plant and made considerable enlargements, bringing power supply up to 25,000 h.p. and aluminium output up to 8,000 tons per annum. The same French group put down another 8,000 tons per annum works at Tyssedal, near Odda, on Hardangerfjord, utilizing for the war effort plant from an American works which had been bought by Alcoa interests. Meanwhile, with the war bringing pressure on aluminium supply, the British works at Vigelands and Stangfjord were enlarged, the former having its power supply increased to some 15,000 h.p. (output about 3,400 tons annually) and the latter being extended to 5,000 h.p. supply and 1,000 tons output.

The foreign interests were, of course, concerned only with the policy of cheap ingot production, and Norwegian industry was anxious to foster a complete, integrated aluminium home producer: so once again, in 1915, a domestic company, the Norske Aluminium Co., erected a reduction works at Høyanger on the Sognefjord, purchased French bauxite through a subsidiary company, and initiated alumina production on Norwegian soil, using the Pederson method developed by a Norwegian national. The Norske company formed also subsidiary companies for rolling and semi-fabricating and for the manufacture of finished goods.

As the slump developed in the years after the war, the poor capital resources of these Norwegian companies and of the French-controlled works at Eydehavn and Tyssedal were inadequate to meet their commitments: and Canadian and Swiss capital acquired interests in the Høyanger concern (the Norske Company) whilst Canadian and American capital took up controlling interests in the French-owned concerns. Later, with the resuscitation of the Cartel, the British, French and Canadian-American interests shared the control of the D.N.N. With enlarged capital, the Høyanger works was successively expanded to bring its capacity up to 30,000 h.p. and aluminium output up to 11,000 tons per annum.

In 1927 the small British producer, the Aluminium Corporation, was finding it difficult to weather the slump and turned to development of the A/S Haugwik Smeltewerk's plant at Glomfjord for production of aluminium with 50,000 h.p. hydro-capacity: the economic conditions made this venture a failure also and once again American interests stepped in to capitalize the Glomfjord works and to establish additional works at Kinsarvik. Both of these works were extended successively, the planned output being increased to 10,000 tons per annum.

Before the outbreak of the recent war the total Norwegian capacity was of the order of 40,000 tons p.a. with power resources far in excess of this capacity, and it was intended by the British and American aluminium interests to extend the output very much further.

This intent failed completely in the early days of the war, and the war-time history of the aluminium industry in Norway was that of German endeavour to utilize the existing resources and Allied effort to stop German output by blockading imports of the necessary shipments of bauxite from Yugoslavia, France and other European sources and by destroying production plant. The Norske works, under German guidance, turned to the production of alumina from Norwegian labradorite ore at a new factory at Heroya (destroyed during the war) and a new aluminium company was created in co-operation with the I.G. Farbenindustrie, who held a controlling interest, to absorb the former British works. Most of the Norwegian reduction and alumina works suffered severe damage by British and American bombing raids, and production of aluminium in Norway had come to a standstill before the final collapse of Germany.

Since the war, a new reduction works, the erection of which was started during the Occupation, has been completed with Norwegian (60% State and 40% private) and Canadian capital by the A/S Aardal Verk at Aardal. The present capacity is about 12,000 tons per annum, and production on half this scale actually started in March, 1948. Two further extensions to the Aardal works are planned, the first raising the output to 24,000 tons per annum and the final extension creating a total capacity of 50,000 tons per annum, which will make Aardal Norway's biggest aluminium plant. A third of the output is earmarked for Canadian overseas sales (in return for supplies of alumina) and the balance will create a Norwegian export market.

By 1946, the Eydehavn and Tyssedal works were able to resume limited production, utilizing French alumina and operating in the interest of the French A.F.C. group.

Exports were resumed by Norway in 1946 on a small scale (11,000 tons as compared with 30,000 tons in 1938).

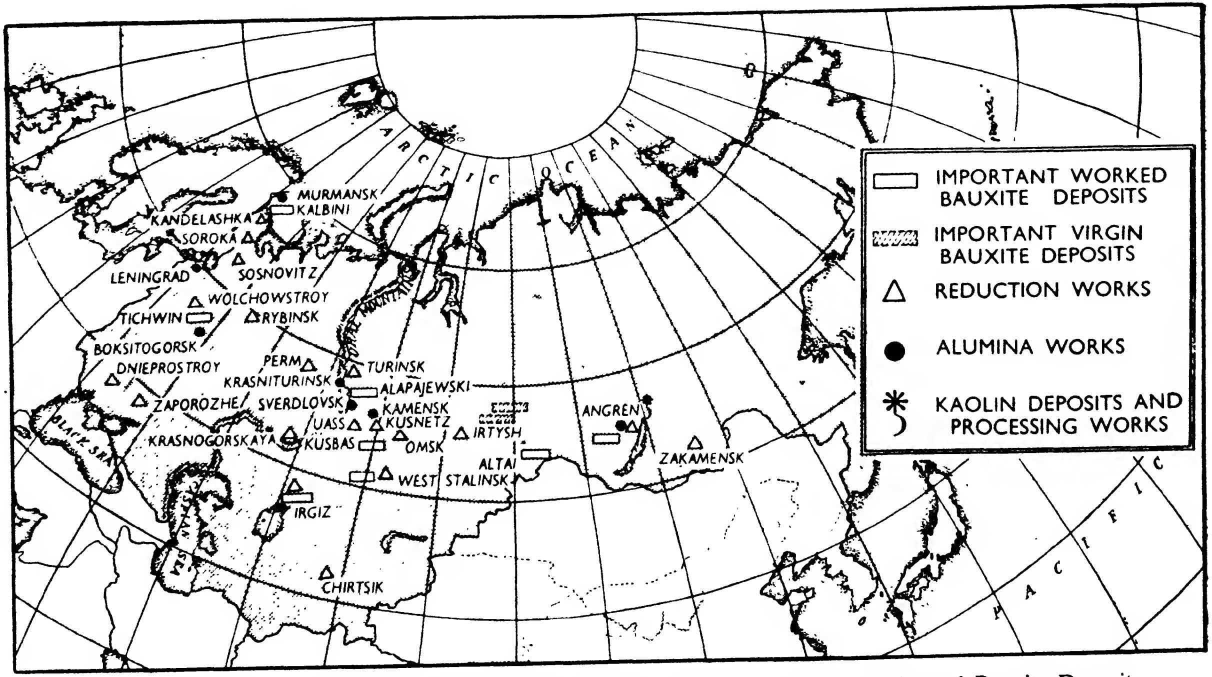
U.S.S.R.

The history of the Soviet Aluminium industry is striking in many respects. Industrial production of ingot metal only started in 1932, when the output was a mere 855 tons; by 1936 it had risen spectacularly to 37,900 tons, with further increases in 1937 and 1938 to 52,500 and 63,000 tons. The Third Five Year Plan catered for a four-fold increase of the 1937 production and the peak pre-war production actually reached a figure nearing 100,000 tons. This output was drawn in the main from three reduction works, the Ural Aluminium Combine (about 40,000 tons) at Kamensk, the Dnieprostroy Works (35,000), and the Wolchow Works. Each of these works was associated with a corresponding alumina works and there was an additional alumina plant working on a very large-scale output at Tichwin. The Dnieprostroy and Ural works also had electrode factories and further electrode production was undertaken at Moscow and Tscheljabinsk.

At the time of the German attack, six new works were under erection at Kusnetz, Kandalakscha, Rybinsk, Stalinsk, Sungait and Taschkent. The Sungait works was based on the Sewansanga hydro-electric station in Armenia, and could dispose of 400,000 kW, with a planned ingot output of 50,000 tons. The Taschkent works operates in connection with the Tschidschik Power Station, whose capacity is 275,000 kW, the planned aluminium output being 30,000 tons. The Kutsnetzk works is in the coal area, where cheap power is available from the Kemerovo power station and alumina is drawn from the Kamensk works, whose capacity is scheduled as 250,000 tons.

The early days of the war saw huge destruction and huge transfers of equipment from the threatened western zones to safer areas farther east. The Dnieper works was captured by the Germans in the summer of 1940 in a wholly or partly destroyed condition, the great dam being blown up by the retreating Russians. The whole equipment of factories in the threatened military zones was removed to the new reduction plants rapidly erected at Stalino and Bogoslovsk. The bauxite mines in the northern Urals and at Sokolov were enlarged and equipped with modern plant to provide the reduction works with raw material and the Krasnogorsk Diesel power station was built to supply electric energy. The Kamensk plant in the Urals increased its output, which by 1945 reached 72,500 tons, and additional new works were constructed on the Angara river in Eastern Siberia, on the Irtysh river in Western Siberia, and at Nievietaisk and Kemerov.

The post-war picture is not yet clear. The Dnieper dam has been repaired and the power station is partly functioning again. The Zaporozhe and Leningrad works have been reconstructed. The Wolchow plant produced 8,000 tons in 1946 and the Bogoslovsk plant about 40,000 tons. There are no figures for recent total outputs, but in view of the Soviet policy to rate the light metals industry high in importance and in view of the known comeback in the chemical industries to a level in excess of pre-war achievements it seems a fairly good certainty that the Russian output of aluminium and organization of the industry are established at an ambitious level. The Soviet industry was, from the beginning, on a sound financial basis without over-capitalization. The actual capital sunk in connection with the Second Five-Year Plan (1933-1937) was 660,000 roubles and the Third Plan (1938-1942) disposed of nearly 2,000,000,000 roubles. The ore position is probably more favourable than that of any other aluminium-producing country, with the Ural deposits alone accounting for 65 million tons of rich bauxite. There are also the valuable Tichwin deposits and others in Central Siberia and in the Altai region. Apart from bauxite, there are immense reserves of alunite and nephelin and these ores have been utilized in specially developed processes for conversion to alumina.



Map 1. Location in the U.S.S.R. of Aluminium Reduction Works, Alumina Works and Bauxite Deposits.

Italy

Italy entered the aluminium production field later than the other large Western European industrial nations. The first reduction works was erected at Bussi in the province of Aquila in 1907 and drew its power from the Pescara River and its bauxite supply from the neighbouring deposits at Lecci de Marsi. Italy remained a small producer until the Great War of 1914-1918 brought the impetus for expansion. A second small reduction works was erected at Nera Montuoro during the war. The war settlements gave to Italy the rich bauxite reserves of Istria and in the inter-war period the new phase of Italian political resurgence was accompanied by great development of the national resources of water-power in Northern and Central Italy. The aluminium industry figured largely in the plans for industrial expansion and new reduction works were erected in the vicinity of two of the new large hydro-electric undertakings in the Northern Alpine watersheds, at Mori (1927) and at Bolzano (1937, enlarged 1941). On the alumina production side the Regime fostered the development of the important leucite deposits in the volcanic Rocca Monfina district behind Naples and the Blanc process attained considerable importance. (See p. 50.)

Italy's national development in the 'twenties was complicated by the entry of foreign capital into the exploitation of her indigenous and annexed bauxite resources. Previous to the Fascist political phase, Swiss interests entered the alumina production field (with an eye to Swiss requirements of alumina) and also put down a reduction works. American capital entered the bauxite production industry through the Canadian subsidiary: the Canadians further put down a small reduction works at Borgofranco which is still operating. German capital joined Italian to form the great bauxite subsidiary of the German V.A.W. These outside interests sought to make Italy a great exporter of bauxite and were not quite identifiable with the Fascist attempt to raise the domestic aluminium industry to greater stature and conserve her bauxite reserves as a long-term policy.

The post-Fascist history of the Italian aluminium producing industry is concerned with the four reduction works referred to at Bolzano, Mori, Porto Marghera and Borgofranco and their associated alumina and ancillary plants. The nationally capitalized Montecatini concern, Industria Nazionale Alluminio (I.N.A.), controlled about 60% of the output at Bolzano and Mori and the Swiss subsidiary, Società Alluminio Veneto Anonima (S.A.V.A.), at Porto Marghera was responsible for roughly another 35%, the small balance being accounted for by the Canadian Borgofranco works of the Società dell'Alluminio Italiano (S.A.I.). German technical advice and administrative guidance were available to the industry during the Axis phase of Italian history but did not always integrate well with the Italian outlook.

The expansionist period saw output raised from 800 tons in 1922 to 50,000 tons in 1941. The total output during the Second War for the four years 1939-1943 was 200,000 tons, with Italy ranking only seventh or eighth among world producers for this period; an indication of the immense difficulties which the Fascist order had to contend with in its attempt to rouse Italy from her decadence. For the aluminium industry had very favourable chances in Italy from the angles of supply of raw materials, power resources and help with plant; and its troubles were mainly associated with poor labour and administration.

In general, alumina extraction was more successful in Italy than the production of metal. The Blanc alumina from leucite was surprisingly good and the Aurelia alumina produced near Rome by the Prodotti Chimici Nazionale (P.C.N.) for the Canadian producer at Borgofranco was of very high quality, superior to the average Bayer product. Alumina production was mostly in excess of what the reduction works could handle and a large surplus went to Germany all through the war, even the Swiss-controlled output at Porto Marghera being side-tracked from its intended destination, Neuhausen. The important centres of alumina production were the greatly enlarged original works of the Società Nazionale dell'Alluminio at Bussi (reduction was transferred to the more modern northern plants) operated for the Montecatini (Industria Nazionale Alluminio) group, who also owned a large (72,000 tons p.a.) plant at Porto Marghera alongside the (76,000 tons p.a.) Swiss S.A.V.A. subsidiary's works.

The Italian industry was fully integrated, and its fabricating side was highly developed. Italian foundry work has traditionally been excellent and her light-metal foundry work has proved no exception. On the production side her technical efficiency was poor but this is perhaps a question of overstrained administration. There is, however, another aspect of the Italian industrial revival adventure which it may be of interest to note, where Italian character could assert itself; which was the care taken in the architecture of its industrial buildings and structures. It has already been mentioned that the Fascist-inspired hydro-electric projects are remarkable for their great architectural beauty; the power house at the Mori works in the style of a mediæval church with " Michel-Angelo " ceiling is certainly unique, even if opinions may differ about its appropriateness or consider it a reflection of the abortive Italian experiment.

Sweden

Aluminium production started in Sweden only a few years before the outbreak of the recent war and only on a modest scale intended to supply the home market and render it effectively independent of imports. The A.B. Svenska Aluminium Kompaniet erected in 1934 a reduction works at Mansbo, near Avesta, with an initial capacity of about 2,000 tons per annum, which output was steadily achieved between the years 1934 and 1939. Planned extensions provided for double this capacity and some extensions have actually been made during the war. An alumina factory was erected by the same company acting in co-operation with Norwegian and American interests at Kubikenborg in 1939, the intention being to utilize domestic aluminium-bearing ores to make the Scandinavian aluminium industry independent of imported bauxite which, until war broke out, was drawn from Greece and France. A small (1,100 tons) reduction works was also planned at Kubikenborg to utilize part of the proposed 6,000 tons of alumina.

Yugoslavia

The first aluminium-producing company in Yugoslavia (Fabrika Aluminium A.D.) started operations in 1937 with a production of 1,500 tons per annum at the reduction works at Lozovac near Sibenik. Alumina was at first supplied by the Yugoslavia Chemical Trust from a works at Ljubljana but the Fabrika Aluminium A.D. later erected their own alumina plant.

During the war the German Aluminium Trust started the construction of a fairly large works at Sterntal, near Maribor. Both reduction and alumina factories were nearing completion by the end of 1941.

Recent events in the post-war years indicate the amalgamation of Yugoslavian and Hungarian aluminium-producing interests, with large-scale expansion of output. Technical aid and capital are forthcoming from the Soviet Union.

Spain

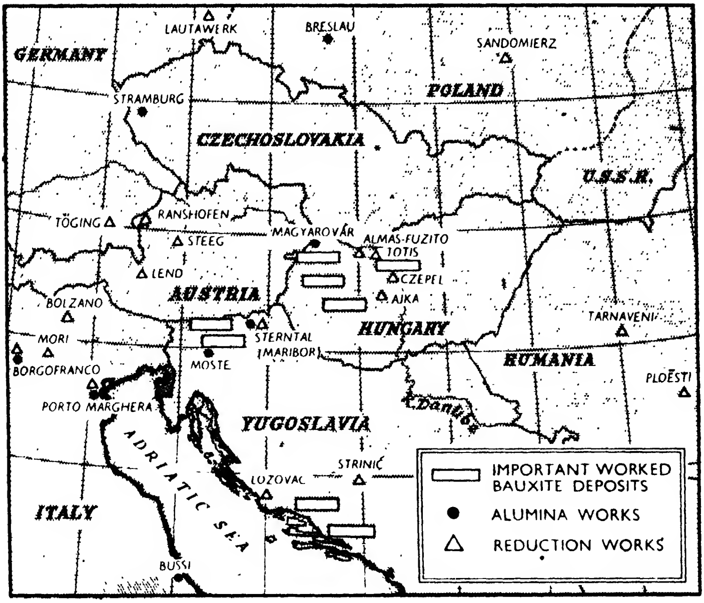
Production in Spain of aluminium ingot was commenced in 1928, though the semi-manufacturing and manufacturing industries are older. The first reduction works, equipped with very high-class plant, was erected by the Aluminio Espanol S.A. at Sabinanigo, in the Huesca region of Aragon, drawing power from the Aragon hydro-electric stations based on six falls in the Pyrenees. The original plans of the Spanish company were to import alumina from France, and the reduction works were situated conveniently near the frontier for this purpose; but the difficulties arising from the Civil War, in the first place, and from the recent world war made it necessary to revise the planned organization, and a Spanish alumina factory was established near Barcelona to work up the native bauxites—which are of rather low grade—from the deposits in Catalona in north-east Spain, with the objective of rendering the domestic industry independent of foreign supplies of raw material. The Sabinanigo reduction works were extended in the later part of the world war, the capacity being increased from

1,300 to 2,000 tons per annum. In 1944, moreover, a second large reduction plant was established by Empresa Nacional del Aluminio near Valladolid: the planned capacity of this works was 8,000 tons per annum. Erection of yet another reduction works was also undertaken in 1944 by the Sociedad General Espanol del Aluminio in Santander province, with planned capacity of 10,000 tons per annum. This company intended to establish its own alumina works.

Spain has always had a fairly important semi-manufacturing and fabricating industry, and Spanish foundry work has been of notably high quality and, with a total potential ingot production of the order of 20,000 tons per annum and a domestic consumption of about a tenth of this amount, it is obvious that the Spanish industry will be in a position to establish an export market. During the war the actual output of 1,000 tons per annum was sufficient to meet the reduced requirements of the home market.

Hungary

Hungary's aluminium industry is of recent origin: the first reduction works at Csepel (an island near Budapest), owned originally by the Mannfred Weiss steel concern, started production of ingot on the scale of 1,200 tons per annum in 1935. The works was designed to utilize cheap power based on brown coal, and was equipped with very modern plant: alumina supplies were available from a (partly Swiss-owned) works at Magyarovar, whose capacity was initially 15,000 tons per annum. During the war the sale of ingot production at Csepel was greatly increased (reaching 4,000 tons per annum in 1944) and, under German influence, two new aluminium reduction works were erected at Ajka (the controlling company being the large bauxite mining trust Magyar Bauxitbanya R.T.) and at Totis (4,800 tons per annum capacity) in the Tata district of Transdanubia (in conjunction with a large Hungarian colliery group) and started production early in the war. The Ajka works (10,000 tons p.a.) had its own alumina plant and the Bauxite Trust erected a further alumina plant in the Danube Valley to supplement the



Map 2. Location in the central European countries of Aluminium Reduction Works, Alumina Works and Bauxite Deposits.

output drawn from Magyarovar. Additional alumina was also drawn from the Stramburg works in Czechoslovakia.

Little information is available regarding post-War developments but there is some evidence that Hungary will join forces with Yugoslavia under Soviet influence to create a large and integrated Central European aluminium-producing industry with an output of some 200,000 tons p.a. The bauxite industry has been nationalized to this end. The Csepel works was damaged rather seriously late in the war but has started nearly full-scale working again.

Poland

The first aluminium-producing works in Poland was erected in 1938 by a newly formed company, the Huta Aluminium S.A., in the neighbourhood of Sandomir. Half the capital was subscribed by

Polish interests and half by German. Hungarian bauxite was to be utilized.

No information is at present available regarding post-war developments.

Belgium

French aluminium interests were planning, before the war, to erect a reduction works in conjunction with the Belgian firm Métallurgie de l'Escaut. In 1946 the Société Industrielle de l'Aluminium (" Sidal ") was formed in Brussels with a capital of fifty-two million francs. In 1947 some ingot output was notified.

North America—United States

Until the recent war, the Aluminum Co. of America, which started business as the Pittsburgh Reduction Co., was effectively the only producer of virgin aluminium in the U.S. since 1888, when the P.R.C. started to work at New Kensington (Pa.) the original Hall patents covering the electrolytic process of producing aluminium. During the early period of the industry, it was difficult to get existing metalworking concerns to fabricate the new metal and introduce its products into industry, and the producing company found it necessary at an early stage to integrate its organization in a very comprehensive manner. By 1910, the Aluminum Co. had purchased its own mines, invested heavily in water-power at Niagara and elsewhere, manufactured its own carbon anodes and furnace linings, and controlled its own sheet rolling and fabricating plants for the production of tubes and sections, and finally formed separate concerns to manufacture finished goods having aluminium as the principal material.

The first development of water-power took place at the Shawinigan, St. Maurice River, the power house and reduction plant being operated by a totally owned subsidiary, the Northern Aluminium Co. of Canada. A third great reduction plant was constructed at Niagara Falls, and a large reduction works was built at Massena.

During the inter-war period, the Aluminum Co. of America occupied a more or less monopolistic position, and laid itself open to repeated attack under the Anti-trust legislation of the United States. Litigation was carried through different courts, and as recently as 1939 the Government of the U.S. filed a suit asking for dissolution of the Aluminum Co. of America on the charge that it was a monopoly in violation of the Anti-trust Laws. The Company lost the suit in 1945.

During the last war, the position of the Aluminum Co. as a monopoly concern was more effectively challenged by the war-time policy of the Administration in operating Government-owned plants to swell the production of aluminium for the war effort, and the post-war policy of the Administration has been to give first choice to Alcoa's competitors when disposing of surplus aluminium facilities. At the present time, the industry in America is on a competitive footing as opposed to the monopoly position characterizing Alcoa's hold on the aluminium industry for roughly forty years. The chief new commercial concerns in the American Aluminium Industry are now Reynolds Metal Co. and the Kaiser interest, The Permanente Metal Corporation. The former company has a lease from the War Assets Administration of the smelting and casting works at Newark, Ohio, whose war-time output reached some 55,000 metric tons of virgin ingot and nearly 100,000 tons of rods per annum. The Permanente Metal Corp. is building up a completely integrated industry, producing alumina at the Baton Rouge plant, reducing to aluminium at Spokane, Washington, and rolling at Trentwood. A further reduction plant is nearing readiness for production after rehabilitation at Takona, and is expected to produce some 20,000 metric tons of ingot per annum. The Company is also sponsoring mining operations in Surinam.

The position in the first quarter of 1947 is shown by the following tabulated statement:—

Interest	Alumina production in per cent.	Aluminium production in per cent.
Alcoa	44	54
Reynolds	36	29
Permanente	20	17

Alcoa is still attempting to extend its plant and operations.

In addition to the major interests serving America as sources of virgin aluminium, many manufacturers throughout the country became fabricators of aluminium products during and since the war. Production of aluminium was in early 1944 four times as great as in the highest pre-war year, and the 1947 near capacity production is estimated to reach nearly 600,000 metric tons. The basic price of aluminium in the U.S. has been reduced by 25% since 1939, and this actual price reduction represents a relatively greater reduction in the face of the general rise in prices of competitive metals. The contemporary production of aluminium, which is more than seven times that of 1939, places it as the second ranking metal of peace-time industry on a volume basis; and makes the United States by far the world's largest producer and fabricator of aluminium. Viewed from the angle of capital investment, the industry accounts for nearly two billion dollars.

As regards raw material reserves, most of the domestic high-grade bauxite is held by the Aluminum Co. and this group, with the Aluminium Co. of Canada, control the most economical of the bauxites developed in South America. Reynolds control bauxite supplies in Jamaica and Haiti, whose quality and quantity have not yet been fully described.

The Special Committee which was set up by the Senate to study industrial problems considered that new sources for a permanent supply of bauxite would have to be sought abroad, and it was also considered desirable that imports of ore might be Government-subsidized. The U.S. Government has also sponsored some researches in connection with the production of aluminium from domestic clays and ores other than bauxite, and built four semi-commercial-scale experimental plants in the latter part of the war at Salt Lake City, Utah; Laramie, Wyo.; Salem, Oreg.; and Harleyville, S.C.

On the development side, the United States are confident of new and expanded peace-time uses of light metals on a scale exceeding that so far known in the history of the American industry. The unique qualities of light weight, combined with strength, easy workability, high electrical conductivity, good corrosion-resistance, insulation against heat and cold, and the new developments which combine light metals with heavy metals, wood, paper, and plastics, are regarded as certain to increase the net usefulness and marketability of the light metals. Alcoa submitted a list of over two thousand articles which can be made of aluminium for a post-war programme. One interesting feature is the major shift in the application of aluminium from the transportation industries to the architectural field.

Since the beginning of 1948, a campaign has been run by the new U.S. aluminium producers to bring pressure on the Government to increase the power facilities available to the aluminium industry (see p. 62) to enable the current production of 643,000 tons per annum to be increased quickly by a further quarter-of-a-million tons: which is the output of the pot-lines made idle by lack of power. This connects, on the politico-economic plane, with the U.S. producers' dissatisfaction with the Government's import contract with Canada, under which over half-a-million tons of aluminium was purchased in 1943, when frantic efforts had to be made to get aluminium at home and abroad, at 15 cents per pound, a sum of $68,000,000 being paid in advance to construct a dam at Shipshaw.

A development which links with the efforts of the new producers to clip Alcoa's wings occurred in the late part of 1948 when the U.S. Department of Justice filed a court action designed to force Alcoa to " reduce its power and size." It will be interesting to see the outcome of this oligopolist phase of the American aluminium industry—whether it will share the fate of others which reverted to a still stronger monopolist position in the long run.

Canada

The Canadian aluminium industry has always linked closely with the United States industry. In 1928, the American enterprise, the Aluminum Company of America, had become so vast an undertaking that it organized a Canadian Corporation, Aluminium, Ltd., to act as a holding company for the foreign interests of Alcoa. Aluminium, Ltd., has a wholly-owned Canadian subsidiary, the Aluminium Company of Canada, which is a large producer of aluminium and a completely integrated unit. The Aluminium Company of Canada owns important bauxite deposits in British Guiana: has vast reduction works at Arvida (Saguenay River) and at Shawinigan Falls, Quebec: alumina works and electrode works in association with the Arvida reduction works; and fabricating plant at Kingston and Toronto, Ontario. Pre-war production figures were of the order of 35,000-40,000 tons of aluminium (about one-tenth of the world output) but these were greatly stepped up in the war effort expansion and a vast capacity of up to 350,000 tons of ingot was reached. By the end of the war more than 1,000 Canadian works were concerned with semi-manufacturing and fabricating aluminium and its alloys.

The holding company, Aluminium, Ltd., has wholly or partly owned operating subsidiaries in twenty or more countries: among the most important subsidiaries are the following (those marked with as asterisk producing ingot aluminium):—

Australian Aluminium Co. Pty., Ltd.
Companiha Brasileira de Aluminio (Brazil)
Demerara Bauxite Co., Ltd. (British Guiana)
Northern Aluminium Co., Ltd. (U.K.)
*Indian Aluminium Co., Ltd.
Teewanlal (1929) Ltd. (India)
Jamaica Bauxites, Ltd.
Aluminio Industria Mexicano (S. America).
Newfoundland Fluorspar, Ltd.
*Svenska Aluminiumkompaniet A-B (Sweden)
Aluminiumwerke A-G Rorschach (Switzerland)
*Norsk Aluminium Co. A/S (Norway)

The net assets of the Company, according to their 1947 Report, were divided up as 64% in Canada, 21% elsewhere in the British Commonwealth, 11% in Continental Europe and 4% in other parts of the world.

South America—Brazil

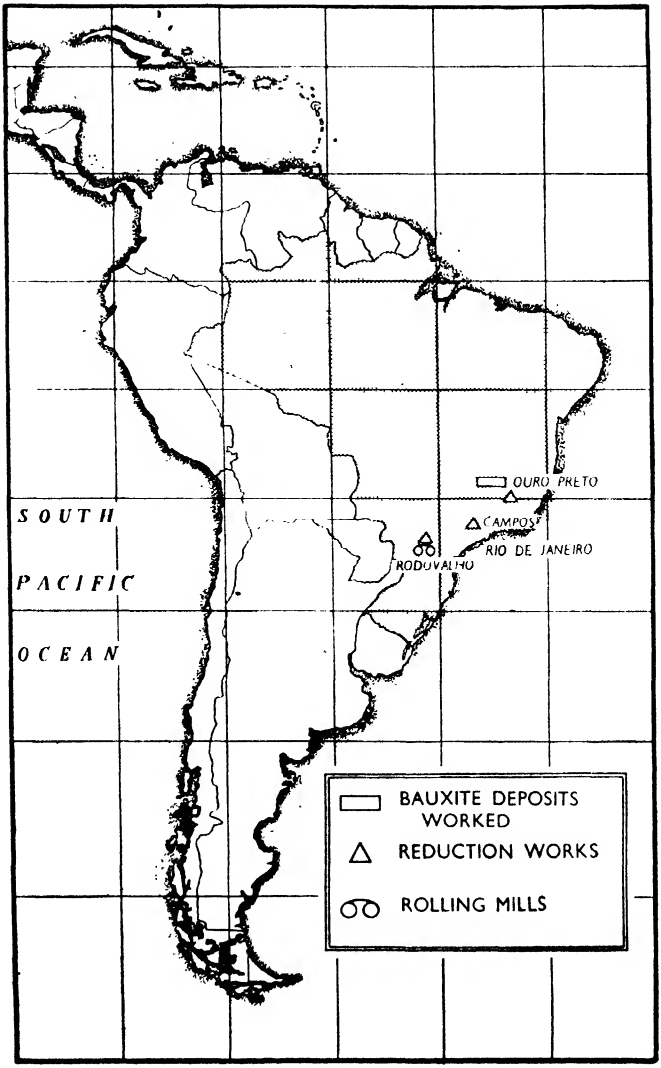
The Brazilian aluminium industry is of very recent origin, none of the producing works being more than five years old. The first of these, Electro-Quimica Brasileira, has important works at Ouro Preto, where the hydro-electric capacity is estimated at 40,000 h.p. The installation comprises 44 furnaces each of 24,000 amperes. The works is situated close to three bauxite deposits and controls, in its immediate vicinity, a reserve of 1,500,000 tons. The alumina plant has a capacity of 12,000 tons, and the reduction plant can accordingly cater for an output of 6,000 tons of ingot, though the actual contemporary output is about half this amount.

A second company, Companiha Brasileira de Aluminio, is jointly owned by Aluminium, Ltd., of Montreal, and Mr. Pignatari, one of Brazil's leading industrialists, with total assets in excess of £2,500,000. Plants have already been erected and are in operation at Rodovalho, in the State of Sao Paulo. The enterprise plans a fully integrated industry, with a modern high-speed rolling mill with an ultimate capacity of 15,000 tons p.a. of aluminium sheet. Modern facilities and low-cost production are expected to enable the Company's products to enter Brazil's growing utensil, transport construction and container industries on a competitive basis. The latest figures from Brazil show the 1946 consumption to have been in the region of 5,000 to 6,000 tons, an amount considerably in excess of pre-war levels.

A third company, Cia Industrial Brasil-Aluminio, has planned a works at Campos (State of Rio).

Asia—Japan

The case of Japan is of special interest in any review of the aluminium industry because it indicates in a rather striking way



Map 3. Location in Brazil of Aluminium Reduction Works, Alumina Works and Bauxite Deposits.

the full significance of what can be done in such an industry, modern in conception and scientific in its whole outline, if full advantage is taken of its accumulated experience and example. Stripped of the political prejudices which now colour the circumstances of its history, the Japanese aluminium industry affords an example of an unusually creditable technical performance in organizing and operating a highly-geared production programme in record time.

Japan necessarily entered very late into the aluminium production industry since her development of electric power was not sufficiently advanced until well into the 'thirties and since her home islands have no deposits of bauxite of suitable quality. During the period of Japanese expansion, however, and with the support initially of American advice and plant and later of German technological assistance, the remarkable Western Industrialist revolution produced among its other progeny a notably successful aluminium industry, outstanding alike for the very rapid growth and the quality of its production and for its efforts (attended with a distinct measure of technical success) to deal with untried and low-grade alumina-bearing ores of indigenous origin.

Production was only started in 1933: within ten years the Japanese aluminium industry achieved the position of fourth-ranking World producer, with an output in 1943 of 150,000 tons of good quality virgin metal. (This figure includes 36,000 tons from the then Imperial territories of Korea, Formosa and Manchuria.) Aluminium was Japan's most important non-ferrous metal during the war years from the angle of economic value and the output of very close on half-a-million tons during the four-and-a-half years of 1941-45 constitutes no mean production record, even in the strenuous history of the aluminium industry, for so young a unit.

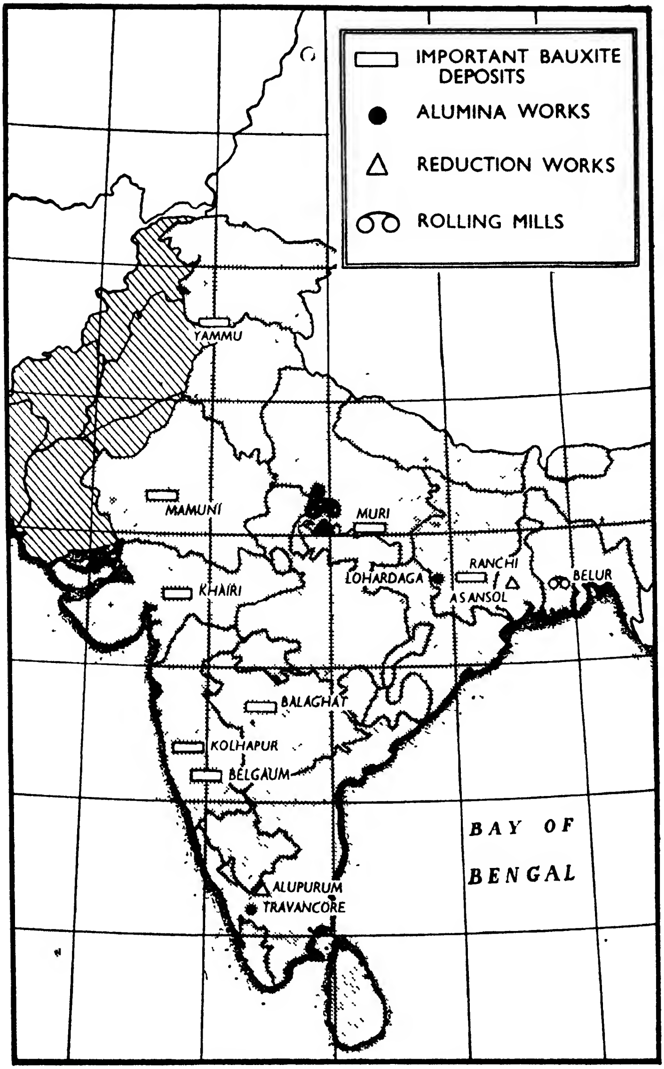
Production ceased at the end of the war: so that the history of the Japanese aluminium industry so far is brief and related effectively to the period of the war, which thus orientated its entire policy and in the process was responsible both for the difficulties and successes of the industry.

The difficulties related to maintaining a supply of suitable

As the Indian market actually developed into one of the chief consumer markets for aluminium semi-manufacturers, which reached the proportions of 8,500 tons of sheet and circles in 1929, it became more and more jealously sought after by the cartelized European exporter-producers: Indian workmanship in the production of fabricated goods, particularly hollow-ware, was encouraged, however, as it was more profitable to export sheets and circles. Successive proposals by Indian nationals and industrial interests for the production of aluminium, particularly after a modern hydro-electric Survey of India was made, were turned down (including the projected Koyna Valley project, the Rewa State proposal and the Kolhapur State and Bombay plans) and even semi-manufacturing facilities were refused.

With this historic background, the aluminium-producing industry in India was born very belatedly, during the recent war, due partly to the pressure which the war itself brought on Britain and partly to the growing strength of the Nationalist movement which could no longer be frustrated. The first ingot was actually produced in 1943, by the Indian Aluminium Co., Ltd., which was then owned jointly by the Canadian holding company Aluminium, Ltd., and by the British Aluminium Co., Ltd., and shareholders in India. The company's works for treatment of domestic bauxite from the Muri deposits in Bihar are in Travancore and have a planned capacity of 40,000 tons per annum of alumina. The reduction works are at Alupuram (Travancore), with an output capacity of 5,000 tons per annum of ingot aluminium. Rolling mills owned by the Company are situated in Belur, Calcutta, where other fabricating plant is also available. An electrode works is operating in Travancore.

A second producing company is the Aluminium Corporation of India, Ltd., of whose capital of 50,000,000 rupees the Dalmia Group originally had a considerable holding (now increased). Bauxite from Ranchi is mined by this Group for the reduction works at Asansol, which were designed for an ultimate capacity of 8,000 tons per annum of ingot metal. Output in the last two years has passed the 1,000 tons level. The Asansol works are in



Map 4. Location in India (Hindustan) of Aluminium Reduction Works, Alumina Works and Bauxite Deposits.

the neighbourhood of important coal seams: the works were designed and erected by Skoda.

The whole industrial outlook has, of course, changed in India since the Declaration of Independence, and great developments are planned in the aluminium industry.

It now seems fairly certain that the projected scheme for producing aluminium in the Central Provinces and Berar will go forward: it is anticipated that eventually the new works, whose present capacity is planned as 5,000 tons per annum, will be the centre of the largest producing region in India and may be the largest in the world. Power will be drawn from the projected Wainganga River hydro-electric station and the power rates are expected to be so favourable that the cost of producing aluminium will be very considerably reduced from that ruling at present.

The National Aluminium Co. of India, Ltd., plans to install plants for the initial production of 25,000 tons of aluminium annually.

China

There is no aluminium industry in China proper: but the Kaosiung (Taiwan) aluminium reduction plant in Formosa, which was constructed (in 1936) and operated by the Japanese during the war, when it was damaged by enemy air offensive, is to be repaired and enlarged with the aid of (40%) American capital. This follows an agreement between the Chinese Metal Resources Commission and the Reynolds Metal Co. (United States). The Kaosiung works had an annual capacity of 12,000 tons and maintained this output up to 1945.

A second smaller works in Taiwan Province, at Hualien, with capacity 8,000 tons per annum, closed down in 1944 and it is not known whether this will be reopened by Chinese or American interests.

OTHER COUNTRIES IN WHICH NEW ALUMINIUM INDUSTRIES ARE PLANNED OR PROPOSED

Europe

GREECE. Just prior to the war, a British company was negotiating with the Greek Government to establish a reduction works based on the bauxite deposits in the Achelostal region and on nearby water-power from the Acheloos, Fidaris and Mornos rivers flowing into the Gulf of Corinth.

HOLLAND. Before the war, consideration was being given to plans for the establishment, with State aid, of a Dutch metropolitan aluminium industry, based on bauxite from the Dutch Indies and low-cost electrical development in the Limburg district.

RUMANIA. Before the war plans were in hand for the erection by the Concordia concern, of an aluminium reduction works at Plösti. A small producing works is also starting up at Tarnaveni in Central Transylvania.

Asia

DUTCH EAST INDIES. The Billiton Concern had plans extensively advanced before the war for a fully integrated producing aluminium industry in the Dutch East Indies, with reduction plant in Central Sumatra, based on hydro-electric power from the Asahan falls, and semi-manufacturing and fabrication plants in Java. The parent Bauxite Mining Group was already a large producer of ore before the War.

PHILIPPINES. The Fifteen Year Industrialization Plan of 1947 provides for aluminium production.

UNFEDERATED MALAY STATES. Some consideration was given in the years before Singapore fell to the establishment of an integrated aluminium industry in its vicinity: bauxite is plentifully available and Malaya has important resources of low-grade coal and is also relatively near the oil fields from the angle of power provision.

Africa

GOLD COAST. The exploitation of the rich bauxite deposits in the Gold Coast was being undertaken by a company, West African Aluminium, Ltd., formed shortly before the war broke out, which obtained a Concession from the Gold Coast Government and considered plans to establish an aluminium-producing industry. These plans have been revived since the war and are still in the investigatory stage, in consultation with the Imperial and local Governments and with British industrial participants. The project suggested would involve a hydro-electric scheme on the Volta River and the dam and works would be situated not too far from the Mt. Ejuanema bauxite workings from which the supplies would initially be drawn, being added to later by output from the Yenahin districts deposits.

Australasia

TASMANIA. British (British Aluminium Co., Ltd.) and Australian (Electrolytic Zinc Company of Australia) interests formed jointly in 1936 a company to undertake production of aluminium at an existing works at Risdon, utilizing power from the Tamar River scheme at Launceston. Nothing was done during the war, but the Australian and Tasmanian Governments are now jointly financing a 6,000 tons p.a. capacity plant, with provision for extensions to 10,000 tons annual output, and erection is being proceeded with.

NEW ZEALAND. Negotiations are going on between the New Zealand Government and British and Canadian industrial interests to establish a large aluminium reduction works at Lake Manipouri in the South Island of New Zealand, with projected annual output 60,000 tons. This will involve the erection of a hydro-electric station.

South America

CHILE. The installation of a reduction works, financed largely by U.S. capital, has been under discussion in the last few months.

North America

BRITISH COLUMBIA. At the invitation of the British Columbian Government in 1948, the Aluminium Co. of Canada is planning to start production of aluminium in British Columbia.

CHAPTER V

THE ALUMINIUM CONSUMER INDUSTRY

WHEN we turn to the Consumer Industry, the whole complex of economics rises up like the hydra-headed monster it is. In considering the advent of a new material it is generally assumed that it will find its market—the question of technical merit being presupposed—in relation to its price. It is particularly obvious, however, in the case of aluminium, that the great expansions of markets which have twice occurred in its short career coincided with the two world wars which took place during this period. It then becomes apparent that price, as such, is not necessarily an overriding factor.

It may not be wrong even if it is unorthodox to examine the economics of any industry in the light of the sociological background to which industry in any form belongs. In the first place such an examination is intended to throw light on the nature and relationship of the conflicting elements involved. In every period of history there have been—and the oppositions are glaringly clear to-day—two forms of society in the true sociological sense. In one of these the group is the unit and in the other the individual. By " group " is not meant the Marxian conception of " primitive " or " undeveloped " individualism but the strict unit of society of the Asiatic—including Bolshevistic—type, which developed on Caste or autonomous group lines. The contrasting form of individualistic society, which produced the Class structure, is of course most highly developed in Western Europe and in the New World whose social form is directly derived from it. Both forms of society develop in turn two phases, the feudal (hierarchic arrangements of the units) and the democratic (equalitarian arrangement of the units): and in both the forms contemporary society is developing the democratic phase in the present stage of the movement of history.[1]

The economies corresponding to these two fundamentally contrasted forms of society are also fundamentally opposite. The " autonomous group " society has developed communalism (with an immensely long history in India and a short but outstanding history in its—partly hybridized—modern form of communism in the Soviet Union). Communalism is essentially a decentralized economy, preserving all the multiple forms: which, by contrast, compete with and eliminate each other by competition in the centralized, capitalist economy of the individualistic society of the West, leaving the temporary winner in a state approaching monopolistic glory. Price, which is the symbol of competition in the West, has not the same significance inside the " autonomous group " society, whose present preoccupation in both the great nations, the Soviet and Hindustan, embraced in it is concerned, in the immediate building-up phase following victorious emergence from the period of suppression by the individualistic form, only with maximum *production* to satisfy the needs of a long-destituted home economy and to be able to meet the capitalist society on equal terms. This maximum production is achieved by what may be called the structural principles apposite to the " autonomous group " concept of multiple contribution. As an instance, the note added to Table III is of interest: it indicates that the Soviet found it natural to preserve the turf economy existing in some parts of Siberia and utilized turf for electric generation although it had available quite unsaturated and effectively unlimited supplies of higher-grade fuels and water-power. Such a development could not have taken place in a capitalist economy unless there was an overriding factor of shortage, in other words, unless the true competitive factor were in abeyance.

The first opposition of interests in the economy of a newly

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[1] In the Western society the democratic principle has been established in the political sphere, but has not yet been completely established in the economic sphere, where the capitalist system, which is hierarchic, still in the main prevails, though it is slowly moving in the direction of socialization.

emergent industry is therefore the large background opposition of the conflicting economies: and this is now appearing, in the post-war period, in the aluminium industry, where, it has been pointed out p. 72), the Western producers have to face new competition from the Eastern European nations in the Soviet sphere of influence.

In this opposition, the price factor which will symbolize the market will not be dictated by purely Western—that is, capitalist—considerations but will be influenced by the *fact of opposition* from the conflicting economy and " price "[2] accordingly loses its true significance which is relevant only to internal competition in the capitalist society.

After this primary opposition, there come into play (in both economies, autonomous group and individualistic capitalist, but we need only consider the latter for the moment) what may be called the internal oppositions: which are ultimately concerned with the constituents of *technique*, in the broad historic sense where the word is used, for instance, to differentiate between the Stone Age and the 20th Century. Technique here takes account of human society plus its non-human environment, the inorganic and animal worlds. Both the opposing sociological forms of society develop techniques; which are relevant to the particular phase of history being worked out at a particular time. The techniques of the two forms may be parallel or different or they may borrow from one another. The technique of contemporary Western society is the mechanistic technique developed at high pressure to pursue the materialistic objective which characterizes the Economic Age of Western democracy. In these domestic oppositions inside the capitalist economy, the technological factors weigh, and price then becomes a true symbol of comparative merit at any period. This

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[2] Price has actually two significances. In the autonomous group society it is a measure of the *contribution* of the entity priced to the general pool of entities ; whereas in the individualistic society it is a measure of the *unique* feature or features which allow the entity to compete. The latter is the meaning usually applied to the term " price," and is, indeed, the only significance familiar to the West, where price is effectively a " determining factor." (N.B.—An illustration of the difference between the two definitions is that of so-called " bargaining " in the East, which draws from the Westerner the comment that there is " no price.")

" merit " has to take account both of the production factors of the industry and of the consumption " value," which is based on some unique or outstanding property owned by the entity which entitles it to compete. In the case of aluminium, lightness is the key words: whole new industries such as the aircraft industry have sprung up because of this fact of lightness (other merits, such as strength, of course cancelling out as equal in the competition) and this results in the effect that the new material which created these new industries has a temporarily heightened market—which is probably the origin of what is referred to by economists when comparing the steeper upward trend of aluminium output as compared with that of the general commodity index as its " youth factor." This " youth " will naturally pass away as the new industries in question establish in their turn standards relevant to their novel features where aluminium, their progenitor, will have to enter into competition with yet newer materials.

It is a work of supererogation to appraise such expansion of markets in terms of successful research and development effort, because this effort is inevitable and incidental at a certain stage in the history of any commodity to whatever may be the necessity of the contemporary environment for preserving or extending the existence of the commodity; and in fact simply represents a stage of technique. According as to whether the technique or research and development is applied " at the flood " or not, it will succeed or fail; but it does not control the " flood." No amount of research and development could now, it is imagined, re-create a Stone Age: because history has its own say in the matter of technique (which is nothing other than the fortune of the human species at a given time in its involvement with its environment in the larger universe) though it certainly does not follow from this that the difference between the Stone Age and the Atomic Age represents Progress, as has been light-heartedly assumed by the protagonists of the mechanistic age.

In general, the factor of lightness (aluminium's unique " divine right " until very recently) translates into money-saving: saving of fuel consumption of vehicles and aircraft, saving of energy supplied to moving parts, saving of work involved in conveyance and erection of fixed components, and so on. The energy-saving and money-saving factors form an endless cycle and generate new forms of techniques such as, for example, speed. Speed then becomes in its turn essential to " save money " or " save energy," and the age can be interpreted as the age of speed. And the money-saving or energy-saving or the machine which incarnates speed, in application, is taken into account in the prime price of the material.

All the factors at different " levels " or in different spheres which enter into the symbolism of price in its Western sense finally boil down to a *fact of opposition:* whatever emerges from a particular opposition as the balance of merit left over in favour of one of the commodities in opposition contributes to its price. Lightness may be the prime merit in the case of aluminium generally but, as has been pointed out in the account given of its applications in Chapter I, there are many other merits relevant to different fields of application in which aluminium competes on different grounds.

As regards the production factors of the industry, referred to above, exactly the same sort of competitive factors or oppositions enter into the production costs. The prices of the necessary raw materials are dictated by the oppositions relevant to their markets and even the cost of labour is controlled in the long run by similar factors.

So that in the huge complex of oppositions from which a new commodity emerges on to the market, its price at any moment labels its degree of victoriousness in the oppositions, on the large plane as between societies or on the small plane as representing internecine oppositions which are engrossing the society into whose environment it enters. The price is not related to any intrinsic merits of the material, because there are, strictly speaking, no " intrinsic merits " in the sense of permanent survival (the merits relevant to one period of history being usually the demerits of the next).

Price is, in fact, the symbolism of the right to exist, which right is gained (in the West) by beating the opponent. It measures, in the largest sense, the market: in other words it is the index of the existence of the commodity as an active component of society's environment.

The degree of victoriousness which can be ascribed to aluminium in its opposition to or competition with other materials makes it clear that the term " Aluminium Age " is not simply a propagandist extravaganza. The present age is, in fact, an age of supreme mechanization, whose objective could not be served by steel, which was adequate only for the precedent industrial age whose degree of mechanization was only partial.

The oppositions which formed the life-history of the development of steel necessarily in course of time gave rise to the birth of aluminium. This is the essence of the principle of survival by victory and part of the way it is in accord with the Marxist doctrine of dialectical contradiction. Marx's theory was incomplete and cannot be regarded as valid, however, for the reason that, because of his obsession with the materialistic hypothesis, he missed the fact that the components or constituents of the environment are just as much a part of society as the human species: the components of the scientist's " objective world," the so-called commodities, actually get involved in oppositions at all levels, including the opposition, even, between different forms of human society, as has been pointed out above. The relationship between the human and the non-human constituents of society is complete, each being dependent on the other.

In the case of steel, its victorious emergence from one series of oppositions made possible—or, more accurately, for the sake of survival made it necessary to procreate—the electric furnace: in turn, the electric furnace, for survival, had to develop electro-metallurgy: and ultimately aluminium's emergence became due. This fact is repeated as a commonplace statement: but the irony of it and its exact illustration of the hard nature of the profound historic phenomenon of opposition is hardly noted.

With aluminium established as a new material and with the evidence, from the degree of supremacy in a great variety of fields of application, that it is in actuality the material of a new age, one looks around also for the evidence of its newness in the sphere of its treatment as a material in the engineering sense, and one finds at once that aluminium has, in fact, brought about innovations on the scale of revolution in the methods of semi-manufacturing and fabrication on the one hand and in the field of design on the other hand. Out of its newness have sprung new versions of the principles of forging and new co-ordinates for the creation of engineering structures and components. For instance, extrusion, as a method of forging, is the direct outcome of the emergence of the new metal: and what are called aircraft construction principles, applied to design, are the direct product of having aluminium as a constructional material to design for. The new methods emergent with the new material to enable it to compete for its existence are, of course, " money-saving." Extrusion dies are relatively much cheaper than the forging dies used in the traditional methods that evolved in the reign of steel, whilst by utilizing so-called aircraft construction principles of design new economies are effected in structures which have nothing to do with flying.

In the historic process of opposition, of course, these methods will have to create sharp new competitors for aluminium, but the supremacy of the latter in these competitions will be, for a period, established and the future of defeat in the face of new opposition is not yet.

This perpetual opposition theme is what is known as life: and there is certainly plenty of " living " in the aluminium industry! Aluminium has challenged nearly every constructional material in nearly every industry in the first fifty years of its life and it has not yet lost its so-called " youth " impetus. The Chairman of the great Canadian producer stated that of the 1947 domestic output of aluminium, ten per cent. was absorbed in new methods of utilization. This is evidence of a new age which even the most reactionary-minded must note.

In the immediate pre-War years, world consumption of aluminium was of the order of half-a-million tons: Europe accounted for seventy-five per cent. of this quantity (Germany alone consumed thirty-four per cent. of the total). The United Kingdom consumption was 70,000 to 75,000 tons per annum. Distribution between different industries varied slightly in different territories, roughly in accordance with the following figures:—

TABLE VI

ANALYSIS OF APPLICATIONS OF ALUMINIUM BY INDUSTRIES (IN PERCENTAGES)

Industry	U.K.	European Continent	U.S.
	%	%	%
Transport, marine and land	33	20	29
Transport, air		15	
Cooking utensils	16	5	14
Electrical conductors	12	10	10
Machinery and electrical appliances	11	5	15
Architecture	6	10	8
Chemical industry (plant)	6	5	5
Food industry (plant)	4		6
Metallurgy, ferrous and non-ferrous	4	15	5
Foundry and metal-working	5		4
Foil and powder	—		—
Military uses (excluding air)	—	10	—
Unclassified residue	3	5	4
	100	100	100

The war-geared aluminium industries raised the aggregate output of aluminium to four times the 1938 figure, the peak year being 1943, with a world production topping the two-million ton level. Since the war, with the production reshuffle described in the preceding chapter and with the disappearance of the Axis producers (who, during the war peak, were producing two-thirds of the new post-war pattern's aggregate) the output decreased in 1947 to about 40% of the 1943 figure: or in other words the post-war output is roughly double the pre-war production.

The distribution of this new peace-time high-level of output has also been somewhat modified in post-war markets; in the United States architectural and building uses have definitely supplanted transport as the chief consumption market (accounting for perhaps one-third of the total consumption) and the same trend is noticeable here in Britain, where aluminium is for the first time seriously entering the heavy engineering field and taking its place, both at home and for export, in large structures. With this trend is coupled the growing interest in the medium-strength aluminium alloys which are now in the foreground rather than the very high-strength alloys which acted as pioneers in forcing entry into the engineering industries in competition with steel. The working of the medium-strength alloys offers certain advantages: and in the field of structural engineering conversion from steel to light alloys has proved less costly and technically more attractive than designers were prepared to believe. With the slow conversion of the technical experts has also come—inevitably still more gradually—the legal sanctions with which the industrial State controls the changing factors affecting the community's interests, namely the Materials Specifications, the Codes of Practice and the Draft Rules which define the terms of legal contracts and cover the responsibilities of Public Authorities. This is the final act of the initiation of aluminium. The first stage was over when the engineering shops were equipped for light-alloy construction, for they do not like to revert to steel or older media. Labour, generally, favours light metals; and every successive generation of technically educated entrants to industry swells the ranks which belong to the age of aluminium.

Partnering the widening industrial acceptance of aluminium and its future hold on markets has been the general downward trend of its price course and its steadiness within recent years in a world whose general price level has risen sharply since the early days of the War. In 1948 tin costs nearly 18 times as much as aluminium on a volume basis, copper costs 5½ times, lead nearly 3 times and zinc 2½ times as much; these materials being mostly, moreover, in short supply. With these disparities to turn the scale where the demand for aluminium is elastic, the growth in demand for aluminium has every expectation of being very rapid in the immediate future.

The great technological advances which the war-time efforts spurred on in the methods of fabrication has followed somewhat different lines of development on the two sides of the Atlantic.

In this country the outstanding achievements have been in sheet and plate production, whilst in America the chief interest has centred in the development of larger and stronger forgings and extrusions and in the evolution of better methods for precision die-casting. The quantitative balance of the working and fabricating side of the international industry in relation to production is also greatly changed, and in particular the case of this country is of interest. As a comparatively small domestic primary producer which could not expand to take her place progressively alongside the national industries of countries more favourably placed with regard to natural resources or indigenous supplies of ore, Britain during the war organized huge imports of virgin ingot (chiefly derived from Canada) for her military needs and increased the capacity of the manufacturing and fabricating side of the aluminium industry to a point which completely reversed the balance of the former structure of her light-metal industry. From the seventy-odd thousand tons of the immediate pre-war capacity, a five-fold increase was reached at the war peak fabrication output of nearly 400,000 tons, and the post-war output is being established at a new peace-time record level of about a quarter of a million tons which makes the country a leading fabricator in line with the old "workshop of the world" tradition of palmier national days but in a new situation in which German competition in Europe is absent. Supplies of ingot will continue to be drawn from Canada and some will derive from Norwegian subsidiaries. Sheet and strip production leads in the new level, a rough analysis for a typical 12-month period in the years 1946-47 being as follows:—

BRITAIN

Sheet and strip	136,000 tons, roughly 58%
Rod, sections, tubes ...	42,000 tons, roughly 18%
Castings	48,000 tons, roughly 20%
Forgings	2,500 tons, roughly 1%
Foil	6,500 tons, roughly 3%

By comparison, American fabricated products arrange themselves with a notably bigger allocation for forgings and rolled products and a corresponding reduction in the proportion of sheet and strip, thus:—

UNITED STATES

Sheet and strip	40%
Rods, sections, tubes	21%
Castings	23%
Forgings	13%
Foil	3%

Of the new peace-time markets for aluminium sheet in this country corrugated sheet for building purposes is an important item in the export trade. In the transportation field aluminium is greatly extending its use, particularly in marine applications. In domestic architectural uses rain-water goods have become an important development. New entries into many industries using elaborate machinery, such as the textile industry, are constantly being established. Uses for wire are increasing, important new developments being linked-chain fencing and barbed wire. In the older-established markets, for instance in the food processing and packaging industries, the displacement of other materials is paralleled by the introduction of new uses—for example, that of foil for packing butter. Houses, prefabricated and permanent, bungalow and two-storey, have found about a dozen different favoured forms in the rebuilding programme but much of this development has been held up for reasons not connected with the industry.

Nothing in the way of detail can add to—or detract from—the general position discussed in the beginning of this chapter and frequently indicated in different contexts throughout this whole book: namely, that aluminium is the material of an age hardly yet in its adulthood. So that markets are expanding and will continue to expand; the price is falling relatively and will continue to fall; and production is increasing and will continue to increase. These are synonymous formulations of the fact that the Aluminium Age is born.

CHAPTER VI

STATISTICS RELATING TO THE ALUMINIUM INDUSTRY

IT HAS generally been the custom in the aluminium industry to give returns of metal in metric tons and of ore in long tons, but there are numerous exceptions to this rule in the published statistics from different sources. In the following Tables all the figures are given as metric tons.

Equivalents:

1 long ton[1] = 2,240 lb.
1 short ton = 2,000 lb.
1 metric ton = 2,205 lb.

Conversions:

1 long ton = 1.01605 metric tons
1 short ton = 0.90719 metric tons

The figures quoted are the latest edited figures for any given year: they are derived mostly from the official publications of the respective countries. Prices are taken from trade organs and reference works.

This Chapter does not include any statistics on secondary aluminium, some figures relating to which are given in Chapter XV on p. 316.

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[1] Generally referred to simply as *ton*.

TABLE VII.—NINETEENTH CENTURY

Country	1854-6	1859	1865	1869	1872
Austria	—	—	—	—	—
Belgium	—	—	—	—	—
Brazil	—	—	—	—	—
Canada	—	—	—	—	—
China : Formosa	—	—	—	—	—
Manchuria	—	—	—	—	—
France	55 (c)	3,696 (c)	2,398 (c)	1,001 (c)	3,960 (c)
Germany	—	—	—	—	—
Hungary	—	—	—	—	—
India	—	—	—	—	—
Italy	—	—	—	—	—
Japan	—	—	—	—	—
Korea	—	—	—	—	—
Norway	—	—	—	—	—
Russia	—	—	—	—	—
Spain	—	—	—	—	—
Sweden	—	—	—	—	—
Switzerland	—	—	—	—	—
U.S.S.R. (Russia)	—	—	—	—	—
U.K.	—	—	—	—	1,650 (c)
U.S.A.	—	—	—	—	—
Yugoslavia	—	—	—	—	—
WORLD : Annual total (estimated)	—	—	—	—	—
WORLD : Horizontal grand total (estimated)	—	—	—	—	—

Country	1890	1891	1892	1893
Austria	—	—	—	—
Belgium	—	—	—	—
Brazil	—	—	—	—
Canada	—	—	—	—
China : Formosa	—	—	—	—
Manchuria	—	—	—	—
France	81,400 (c)	79,200 (c)	88,000 (c)	88,000
Germany	*	*	*	*
Hungary	—	—	—	—
India	—	—	—	—
Italy	—	—	—	—
Japan	—	—	—	—
Korea	—	—	—	—
Norway	—	—	—	—
Russia	—	—	—	—
Spain	—	—	—	—
Sweden	—	—	—	—
Switzerland	89,190	371,100	660,000	1,056,000
U.S.S.R. (Russia)	—	—	—	—
U.K.	*	90,000	90,000	*
U.S.A.	61,281	150,000	259,885	333,629
Yugoslavia	—	—	—	—
WORLD : Annual total (estimated)	231,871 †120 tons	690,300 †350 tons	1,097,885 †500 tons	1,474,000 †700 tons
WORLD : Horizontal grand total (estimated)	—	—	2,586,000 1,155 tons	—

c=Chemically produced. * Some produc

PRODUCTION OF ALUMINIUM (IN POUNDS)

1882	1883	1884	1887	1888	1889
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
5,170 (c)	—	5,280 (c)	7,700 (c)	9,900 (c)	32,650 (c)
—	—	—	*	*	*
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
*	*	*	*	*	50,000 (c)
—	70 (c)	125	17,800	19,000	47,468
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—

1894	1895	1896	1897	1898	1899
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
220,000	792,000	814,000	1,034,000	1,254,000	2,200,000
*	*	*	*	*	*
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
—	—	—	—	—	—
1,320,000	1,430,000	1,540,000	1,760,000	1,760,000	3,520,000
—	—	—	—	—	—
*	*	286,000	682,000	682,000	1,210,000
706,000	924,000	1,298,000	4,400,000	5,280,000	6,380,000
—	—	—	—	—	—
2,244,000	—	—	—	—	
†1,100 tons	†1,800 tons	†2,500 tons	†4,000 tons	†7,000 tons	10,000 tons
—	—	—	—	—	—
					†28,500 tons

tion, amount unknown. † Approximately.

TABLE VIII.—ANNUAL PRODUCTION OF VIRGIN ALUMINIUM, 1900–1918 (IN METRIC TONS)

Country	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912
Austria	—	—	—	—	—	—	—	—	—	—	—	—	—
Belgium	—	—	—	—	—	—	—	—	—	—	—	—	—
Brazil	—	—	—	—	—	—	—	—	—	—	—	—	—
Canada	—	—	—	—	—	—	—	—	—	2,800	3,500	2,300	8,300
China : Formosa	—	—	—	—	—	—	—	—	—	—	—	—	—
Manchuria	—	—	—	—	—	—	—	—	—	—	—	—	—
France	1,000	1,200	1,400	1,600	1,700	3,000	4,000	6,000	6,000	6,000	9,500	10,000	13,000
Germany	—	—	—	—	—	—	—	—	—	—	—	—	—
Hungary	—	—	—	—	—	—	—	—	—	—	—	—	—
India	—	—	—	—	—	—	—	—	—	—	—	—	—
Italy	—	—	—	—	—	—	—	—	600	800	800	800	800
Japan	—	—	—	—	—	—	—	—	—	—	—	—	—
Korea	—	—	—	—	—	—	—	—	—	—	—	—	—
Norway	—	—	—	—	—	—	—	—	—	600	900	900	1,500
Rumania	—	—	—	—	—	—	—	—	—	—	—	—	—
Spain	—	—	—	—	—	—	—	—	—	—	—	—	—
Sweden	—	—	—	—	—	—	—	—	—	—	—	—	—
Switzerland	2,500	2,500	2,500	2,500	3,000	3,000	3,500	4,000	4,000	5,000	8,000	8,000	12,000
U.S.S.R. (Russia)	—	—	—	—	—	—	—	—	—	—	—	—	—
U.K.	600	600	600	700	700	1,000	1,000	1,800	2,000	2,800	5,000	5,000	7,500
U.S.A.	3,200	3,200	3,300	3,400	3,500	5,100	6,500	11,800	5,900	6,800	15,400	16,800	18,100
Yugoslavia	—	—	—	—	—	—	—	—	—	—	—	—	—
World total	7,300	7,500	7,800	8,200	8,900	12,100	15,000	23,600	18,500	24,800	43,100	43,800	61,200

Country	1913	First World War				
		1914	1915	1916	1917	1918
Austria	5,000	4,000	2,500	5,000	5,000	8,000
Belgium	—	—	—	—	—	—
Brazil	—	—	—	—	—	—
Canada	5,916	6,820	8,490	8,800	11,800	15,000
China : Formosa	—	—	—	—	—	—
Manchuria	—	—	—	—	—	—
France	15,000	12,000	7,500	20,000	20,000	20,000
Germany	800	800	2,000	8,000	15,000	25,000
Hungary	—	—	—	—	—	—
India	—	—	—	—	—	—
Italy	874	937	904	1,126	1,740	1,715
Japan	—	—	—	—	—	—
Korea	—	—	—	—	—	—
Norway	2,500	2,500	3,500	6,000	8,000	7,500
Rumania	—	—	—	—	—	—
Spain	—	—	—	—	—	—
Sweden	—	—	—	—	—	—
Switzerland	10,000	10,000	12,500	15,000	15,000	15,000
U.S.S.R. (Russia)	—	—	—	—	—	—
U.K.	10,000	8,000	6,000	4,000	6,000	14,000
U.S.A.	29,500	40,500	45,000	63,000	90,700	102,000
Yugoslavia	—	—	—	—	—	—
World total	79,590	84,957	88,394	130,626	173,240	208,215

The Price of Aluminium Ingot Throughout Its Lifetime

TABLE X

PRICE IN 19th CENTURY

Date	England	France	Germany	Switzerland	U.S.A.	Price per lb. in English currency where no English figure given		
	per lb. £	per kg. fr.	per kg. RM.	per kg. Sw. mks.	per lb. cents	£	s.	d.
1854	56	—	—	—	—		—	
1856, March	—	1,000	—	—	—	23	0	0
1856, August	—	300	—	—	—	7	0	0
1859	—	200	—	—	—	4	10	0
1862	3	130	—	—	—		—	
1886	—	130	—	—	—	3	0	0
1887	—	—	100	—	—	2	0	0
1888	1-5	—	—	—	—		—	
1889	—	—	—	—	200		10	0
1890	—	—	25	—	—		10	0
1891	—	—	—	—	—		7	6
1892	—	—	—	—	—		5	0
1893	—	—	—	—	—		4	3
1894	—	—	—	—	—		2	6
1895	—	—	—	3	—		1	9

TABLE XI

PRICE IN THE 20th CENTURY

	England	Germany	U.S.A.
	per ton £ s.	per kg. RM.	per metric ton $
1900	—	2.0	721 (about £180)
1913	80 0	1.7	521
1914	82 0	1.65	411
1915, January	81 0	3.25	749
April	95 0	—	—
May	90 0	—	—
June	100 0	—	—
July	140 0	—	—
August	160 0	—	—
September	180 0	—	—
October	190 0	—	—
November	195 0	—	—
December	200 0	—	—
1916, January	215 0	3.25	1,338
February	155 0	—	—
1917, January	155 0	3.25	1,137
February	225 0	—	—

Table XI— Continued

	England		Germany	U.S.A.
	per ton £	s.	per kg. RM.	per metric ton $
1918, January	225	0	3.42	739
December	200	0	—	—
1919, January	200	0	11.80	709
February	150	0	—	—
1920, January	150	0	35.91	675
February	165	0	—	—
1921, January	165	0	41.88	468
March	150	0	—	—
September	125	0	—	—
October	120	0	—	—
1922, January	120	0	743.8	412
May	100	0	—	—
November	92	10	—	—
1923, January	95	0	—	560
February	100	0	—	—
April	110	0	—	—
June	115	0	—	—
1924, January	115	0	2.24	596
April	120	0	—	—
May	125	0	—	—
December	122	10	—	—
1925, January	122	10	2.37	600
February	122	0	—	—
April	121	0	—	—
May	118	0	—	—
1926, January	118	0	2.29	595
September	107	0	—	—
1930, January	95	0	1.86	516
November	85	0	—	514
1931, January	85	0	1.70	514
September	95	0	—	—
1932, January	95	0	1.60	514
October	100	0	—	—
1933	100	0	1.60	514
1934	100	0	1.57	476
1935	100	0	1.44	451
1936	100	0	—	451
1937	100	0	1.33	440
1938, January	100	0	—	440
August	94	0	—	—
1939, January	94	0	—	440
December	110	0	—	440
1940	110	0	—	414
1941	110	0	—	363
1942	110	0	—	330
1943	110	0	—	330
1944	110	0	—	330

Table XI—Continued

	England		Germany	U.S.A.
	per ton		per kg.	per metric ton
	£	s.	RM.	$
1945, January	110	0	—	330
March	85	0	—	330
1946, January	85	0	—	330
April	67	0	—	330
September	72	15	—	330
1947, January	72	15	—	330
March	80	0	—	330
1948, October	87	0	—	375

TABLE XII

VOLUME RATIOS OF WORLD PRODUCTION OF ALUMINIUM TO WORLD PRODUCTION OF OTHER METALS* AT INTERVALS THIS CENTURY

Year	Aluminium to Zinc	Aluminium to Copper	Aluminium to Lead	Aluminium to Tin	Aluminium to Steel†
1900	0.04	0.05	0.03	0.23	—
1910	0.14	0.16	0.16	1.02	—
1920	0.47	0.44	0.62	2.76	—
1930	0.49	0.55	0.69	3.97	—
1940	1.25	0.98	2.06	9.26	0.02
1943 . ..	2.88	2.42	5.99	46.58	0.04

* See below. † Ingot steel and castings.

Consumption of Aluminium

In considering the consumption of aluminium, it is important to take into account its low specific gravity. For most practical applications the bulk of metal used is a fixed quantity. The following shows the volumes of certain other metals equivalent to 1,000 tons aluminium.

1,000 tons of aluminium equals 4,600 tons lead
4,000 tons silver
3,500 tons nickel
3,300 tons copper
2,800 tons tin
2,700 tons zinc
} non-ferrous metals
3,300 tons (approx.) ferrous metals

TABLE XIII

INDEX OF PRICES OF METALS FROM 1936 to 1947 IN TERMS OF AVERAGE PRICE, 1925–1934 = 100: NEW YORK AND LONDON

Year	Aluminium : Average price, 1925–34		Zinc : Average price, 1925–34		Copper : Average price, 1925–34	
	24.27 c. per lb. New York	£101.3 per ton London	5.31 c. per lb. New York	£22.2 per ton London	11.8 c. per lb. New York	£56.2 per ton London
1936	84.5	98.7	92.3	67.9	82.3	76.4
1937	82.7	98.7	122.9	100.9	113.5	107.0
1938	82.4	96.9	86.9	63.5	86.6	81.7
1939	82.4	96.2	96.5	64.5	94.9	88.0
1940	77.0	110.8	119.4	116.2	97.7	110.5
1941	68.0	110.8	140.9	116.2	101.7	110.5
1942	61.8	110.8	155.4	116.2	101.7	110.5
1943	61.8	110.8	155.4	116.2	101.7	110.5
1944	61.8	110.8	155.4	116.2	101.7	110.5
1945	61.8	89.8	155.4	130.7	101.7	110.5
1946	61.8	74.2	164.4	194.7	119.1	137.6
1947	61.8	78.9	197.9	316.0	180.3	232.5

Table XIII—Continued

Year	Lead : Average price, 1925–34		Tin : Average price, 1925–34		Steel : Average price, 1925–34	
	5.64 c. per lb. New York	£20.2 per ton London	45.3 c. per lb. New York	£209.4 per ton London	$31 per ton New York	£5.7 per ton London
1936	80.8	87.4	102.5	97.7	127.6	106.0
1937	103.8	115.5	119.8	115.7	117.2	128.8
1938	81.3	75.9	93.4	90.6	114.0	138.3
1939	86.8	76.0	110.9	108.1	109.3	130.7
1940	89.0	123.9	110.0	122.6	109.3	158.3
1941	100.0	123.9	114.9	125.0	109.3	180.0
1942	112.6	123.9	114.9	132.1	109.3	181.4
1943	112.6	123.9	114.9	132.1	109.3	181.7
1944	112.6	123.9	114.9	144.0	109.3	183.0
1945	112.6	138.4	114.9	144.0	113.1	187.7
1946	141.0	239.8	120.5	154.1	124.2	208.0
1947	256.9	421.5	172.3	202.2	139.1	220.2

TABLE XIV

CONSUMPTION OF ALUMINIUM FROM 1925* ONWARDS (IN THOUSANDS OF METRIC TONS)

	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935	1936
Germany	33.6	23.6	38.8	39.0	39.0	28.0	24.0	19.1	28.3	52.5	87.0	104.2
Switzerland	7.5	5.8	7.0	6.0	8.0	7.0	5.0	4.5	5.5	6.5	7.0	9.0
France	20.0	24.0	18.0	24.4	25.0	20.0	18.0	15.0	14.0	18.0	24.0	27.0
Great Britain	16.1	15.0	18.0	17.0	30.0	24.0	20.0	17.5	19.0	23.0	28.4	35.0
Italy	8.4	4.7	5.8	4.2	9.3	8.2	7.4	5.5	7.3	9.4	15.0	17.0
Russia	5.0	5.0	6.0	13.0	6.0	10.0	20.0	11.5	15.0	19.5	25.0	38.0
Rest of Europe					8.0	7.0	7.0	6.0	9.0	10.0	12.2	15.0
Europe	90.6	78.1	93.6	103.6	125.3	104.2	101.4	79.1	98.1	138.9	198.6	245.2
Asia	5.0	8.0	6.0	10.0	13.0	11.0	5.0	6.0	4.6	6.6	13.3	18.2
Australia	0.3	0.4	0.3	0.4	0.7	0.3	0.1	0.2	0.2	0.4	0.8	0.5
United States	80.0	100.0	100.0	124.0	137.0	95.0	70.0	53.0	55.5	81.0	94.3	143.5
Canada												
Rest of America												
WORLD	175.9	186.5	199.9	238.0	276.0	210.5	176.7	138.3	158.4	226.9	307.0	407.4

	1937	1938	1939	1940†	1941	1942	1943	1944	1945	1946	1947
Germany	125.0	176.6	210.0	252.0	273.8	273.4	286.2	267.3	—	—	—
Switzerland	11.0	11.5	12.0	12.0	—	—	—	—	—	—	—
France	30.0	27.0	50.0	50.0	—	—	—	—	—	—	—
Great Britain	42.0	66.0	90.0	135.0	—	—	—	—	—	—	—
Italy	20.0	26.0	26.0	30.0	—	—	—	—	—	—	—
Russia	41.0	55.0	60.0	65.0	—	—	—	—	—	—	—
Rest of Europe	18.0	21.3	24.0	21.0	—	—	—	—	—	—	—
Europe	287.0	383.4	472.0	565.0	—	—	—	—	—	—	—
Asia	26.4	41.3	46.5	46.8	—	—	—	—	—	—	—
Australia	0.6	0.5	0.75	—	—	—	—	—	—	—	—
United States	150.8	89.8	168.5	190.5	272.0	530.0	789.0	681.0	716.0	415.0	—
Canada					—	—	—	—	—	—	—
Rest of America					—	—	—	—	—	—	—
WORLD	463.8	515.1	688.0	802.3†	1,000.0†	1,300.0†	1,800.0†	1,500.0†	900.0†	650.0†	—

* There are no reliable earlier figures. † Estimate.

TABLE XV.—PRODUCTION OF BAUXITE IN THOUSANDS OF METRIC TONS IN PRINCIPAL COUNTRIES AND (PARTLY ESTIMATED) WORLD PRODUCTION, 1914–1947

Country	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929
Australia	—	—	—	—	—	—	—	—	—	—	—	—	—	0.9	0.2	0.5
Austria	—	—	—	—	—	—	0.4	2.6	4.0	2.7	3.0	4.0	5.0	1.8	6.3	—
Brazil	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
British Guiana . .	—	—	—	2.0	4.2	—	—	—	—	135.8	188.2	194.3	219.0	189.9	201.0	220.2
Dutch Guiana . .	—	—	—	—	—	—	—	—	13.1	12.7	60.0	85.4	45.7	176.0	206.9	215.9
France	—	55.6	104.5	119.0	—	160.8	221.9	131.7	147.1	354.3	374.6	502.0	506.0	655.0	636.0	666.0
French Indo-China . .	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
French W. Africa . .	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Germany	—	—	—	—	—	—	13.2	10.0	14.9	6.6	3.0	1.8	15.1	2.4	5.0	2.0
Gold Coast	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Greece	—	—	—	—	—	—	—	—	—	—	1.3	3.6	2.3	1.3	0.3	6.3
Hungary	—	58.1	—	—	—	—	—	—	—	0.5	0.2	0.4	3.7	339.5	396.0	389.2
India	0.5	0.9	0.8	1.4	1.2	1.7	6.3	6.7	5.0	6.5	23.2	10.2	5.0	4.4	14.9	9.2
Italy	3.8	5.8	8.7	7.7	2.7	—	12.9	48.3	65.6	96.5	138.6	195.2	90.6	95.4	162.3	192.9
Malaya, Union . .	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Malaya, Unfederated	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Portuguese East Africa (Mozambique) . .	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rumania	0.2	58.1	—	—	—	—	—	—	3.7	4.1	—	7.1	0.7	1.8	0.7	0.9
Spain	—	—	—	—	0.5	1.8	0.5	0.2	—	—	—	—	—	—	0.2	1.0
Ulster, N. Ireland . .	8.2	11.7	10.3	14.7	9.6	9.2	4.0	2.3	5.9	3.5	5.2	5.2	6.2	5.3	2.4	2.5
U.S.S.R.	—	—	—	—	—	—	—	—	—	—	—	—	20.0	35.0	52.2	58.7
United States* . .	223.0	302.0	431.0	577.0	605.7	376.6	521.3	139.6	309.6	522.7	347.6	316.5	392.3	320.9	375.4	365.8
Yugoslavia	—	—	—	—	—	—	18.9	9.9	30.8	26.2	18.2	79.0	129.7	100.3	49.3	103.4
World total† . .	520.0	540.0	800.0	1,000.0	1,050.0	650.0	900.0	338.0	702.0	1,198.0	1,155.0	1,383.0	1,379.0	1,880.0	2,032.0	2,149.0

Country	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942
Australia	0.8	1.6	1.1	0.7	1.1	1.2	0.7	1.8	1.8	2.5	3.5	5.4	3.4
Austria	—	—	—	—	—	—	—	—	5.0	—	—	—	—
Brazil	—	—	—	—	—	—	7.0	8.8	12.7	18.0	—	—	—
British Guiana	147.0	157.1	83.5	—	—	—	—	—	447.4	470.1	604.4	1,094.8	1,159.6
Dutch Guiana	260.4	170.4	124.5	—	—	—	—	—	—	—	—	1,108.0	1,226.0
France	609.0	403.0	401.0	490.0	528.4	512.9	649.5	688.2	673.0	697.3	481.3	578.1	629.5
French Indo-China	—	—	—	—	—	—	0.03	7.0	0.2	2.3	0.2	10.0	12.6
French W. Africa	—	—	—	—	—	—	—	—	—	—	3.3	—	—
Germany	1.4	—	1.4	1.1	6.6	8.5	12.4	18.2	19.1	15.5	10.0	12.7	16.0
Gold Coast	—	—	—	—	—	—	—	—	—	0.02	0.05	2.0	48.0
Greece	2.3	1.2	0.6	—	—	9.5	129.9	137.4	177.0	184.0	50.0	50.0	50.0
Hungary	31.7	89.6	111.6	72.4	185.0	211.1	329.1	532.7	532.2	492.3	552.8	810.4	972.9
India	2.6	4.4	4.5	1.1	—	7.8	3.7	15.4	14.7	9.0	8.0	13.0	18.3
Italy	161.3	67.4	86.7	94.9	131.3	170.1	278.6	386.5	355.1	476.0	540.0	492.0	393.0
Malaya, Union	—	—	—	—	—	—	0.03	19.3	55.1	92.3	62.8	50.8	100.0
Malaya, Unfederated	—	—	—	—	—	—	—	—	—	—	—	65.0	65.0

* Dried bauxite equivalent. † Not equivalent to the addition of the countries given : in some cases estimates.

Table XV — Continued

Country	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942
Portuguese East Africa (Mozambique)	—	—	—	—	—	—	—	—	0.4	0.2	1.0	1.3	1.8
Rumania	0.7	0.4	0.6	1.3	1.5	6.2	10.8	10.7	11.8	10.5	10.5	10.3	20.0
Spain	0.3	—	1.3	2.5	—	—	—	—	—	0.3	1.4	2.2	2.4
Ulster, N. Ireland..	2.1	3.5	1.6	0.8	0.06	—	—	—	—	—	—	12.9	95.7
U.S.S.R.	—	11.6	37.4	50.6	61.0	132.0	203.2	230.0	250.0	300.0	300.0	250.0	270.0
United States*	330.6	195.8	96.3	154.2	169.4	247.4	382.8	425.0	310.9	375.3	446.3	899.0	2,648.0
Yugoslavia	94.7	64.8	67.1	80.9	84.8	216.2	292.2	354.2	396.4	318.8	290.0	395.0	195.0
World total†	1,629.0	1,136.0	969.0	1,095.0	1,32.70	1,769.0	2,830.0	3,746.0	3,849.0	4,306.0	4,627.0	5,900.0	8,100.0

Country	1943	1944	1945	1946	1947
Australia	2.5	3.8	—	—	—
Austria	—	19.5	—	—	—
Brazil	—	—	—	—	—
British Guiana	1,941.8	913.5	1,190.0	—	—
Dutch Guiana	1,635.0	625.0	1,100.0	—	—
France	901.9	655.1	250.0	48.0	—
French Indo-China..	—	0.4	—	—	—
French W. Africa	—	—	—	—	—
Germany	25.0	25.0	—	—	—
Gold Coast	104.9	107.2	—	—	—
Greece	50.0	10.0	—	—	—
Hungary	985.6	900.0	—	—	—
India	24.2	12.1	—	—	—
Italy	350.0	150.0	—	65.0	—
Malaya, Union	100.0	100.0	—	—	—
Malaya, Unfederated	60.0	50.0	—	—	—
Portuguese East Africa (Mozambique)	3.2	6.1	—	—	—
Rumania	15.0	—	40.0	—	—
Spain	2.9	3.5	—	4.9	—
Ulster, N. Ireland	107.9	43.8	—	—	—
U.S.S.R.	350.0	375.0	—	—	—
United States*	6,273.0	2,986.0	1,001.0	1,072.0	1,215.0
Yugoslavia	120.0	150.0	—	—	—
World total†	13,700.0	7,300.0	—	—	—

* Dried bauxite equivalent. † Not equivalent to the addition of the countries given : in some cases estimates.

TABLE XVI
WORLD CONSUMPTION OF BAUXITE IN THE ALUMINIUM INDUSTRY IN TYPICAL YEARS

Year	Bauxite consumed, in thousands of metric tons	Consumption as a percentage of bauxite output
1914	340	65
1920	592	66
1925	712	51
1930	1,064	65
1935	1,040	59
1939	2,884	67
1943	7,784	59

TABLE XVII
ALLOCATION OF UNITED STATES BAUXITE BY USES IN TYPICAL YEARS

Year	Aluminium Industry	Chemical Industry	Abrasive Industry	Refractory Industry
	%	%	%	%
1914	73.0	—	—	—
1920	73.5	16.3	10.0	—
1925	54.7	21.2	23.1	0.1
1930	54.2	20.3	24.8	0.1
1935	48.0	28.3	23.0	0.7
1939	46.1	22.6	23.4	7.5
1943	53.0	—	—	—

Table XVIII—Continued

		1914		1920		1925	
		Imports	Exports	Imports	Exports	Imports	Exports
C—SOUTH AMERICA							
Argentina	Aluminium ..					109	
	Bauxite ..					—	
Brazil	Aluminium ..						
	Bauxite ..						
British Guiana ..	Aluminium						
	Bauxite .						174,999
Chile	Aluminium ..						
	Bauxite ..						
Colombia ..	Aluminium ..						
Dutch Guiana ..	Aluminium .						
	Bauxite ..						84,150
Peru..	Aluminium ..						
	Bauxite ..						
Uruguay	Aluminium ..						
	Bauxite ..						
Venezuela	Aluminium ..						
	Bauxite ..						
D—ASIA							
Burma	Aluminium ..						
	Bauxite .						
Ceylon	Aluminium .						
	Bauxite ..						
China	Aluminium .						
	Bauxite .						
Dutch East Indies ..	Aluminium .					15	
	Bauxite .						
French Indo-China..	Aluminium					33	
	Bauxite .						
India	Aluminium .					3,946	
	Bauxite .						
Iran	Aluminium ..						
	Bauxite						
Iraq	Aluminium .						
	Bauxite .						
Japan	Aluminium .					4,612	
	Bauxite .						
Malaya	Bauxite ..						
Palestine	Aluminium ..						
	Bauxite ..						
Turkey	Aluminium ..						
	Bauxite ..						
E—AFRICA							
Algeria	Aluminium ..						
	Bauxite ..						
Egypt	Aluminium ..						
	Bauxite ..						
Gold Coast ..	Aluminium ..						
	Bauxite ..						
Tunis	Aluminium ..						
	Bauxite ..						
F—AUSTRALASIA							
Australia	Aluminium ..					981	
	Bauxite ..						
New Zealand ..	Aluminium ..						
	Bauxite ..						

1930		1935		1939		1943	
Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
409		565		859		—	
				—		224	
512		1,088		15,000§		480	
					17,990		75,549
	119,616		111,500		476,013		1,901,393
50		56		77		—	
		121		294		14	
	260,377		113,370				
				83		8	
				134		6	
		6		10		—	
				331		—	
		198		221		—	
435		711		1,823		—	
		668		914		—	
			9,766		242,262		
		138	4	59		—	
7,307		3,055		1,684		1	
					2,156		
				4			
		37		48		—	
10,792	684	9,861	1,002		562		—
				347,000		805,000	
					56,000§		
		105		169		—	
18	24	116		144		—	
		15	139	100§	300§	—	
				200§			
		105		117		—	
					16		104,819
				10§		11	
1,101	(£1,203)	1,439		1,590	(£724)	8,779	(£18)
243		51		41		44	

§ Estimated.

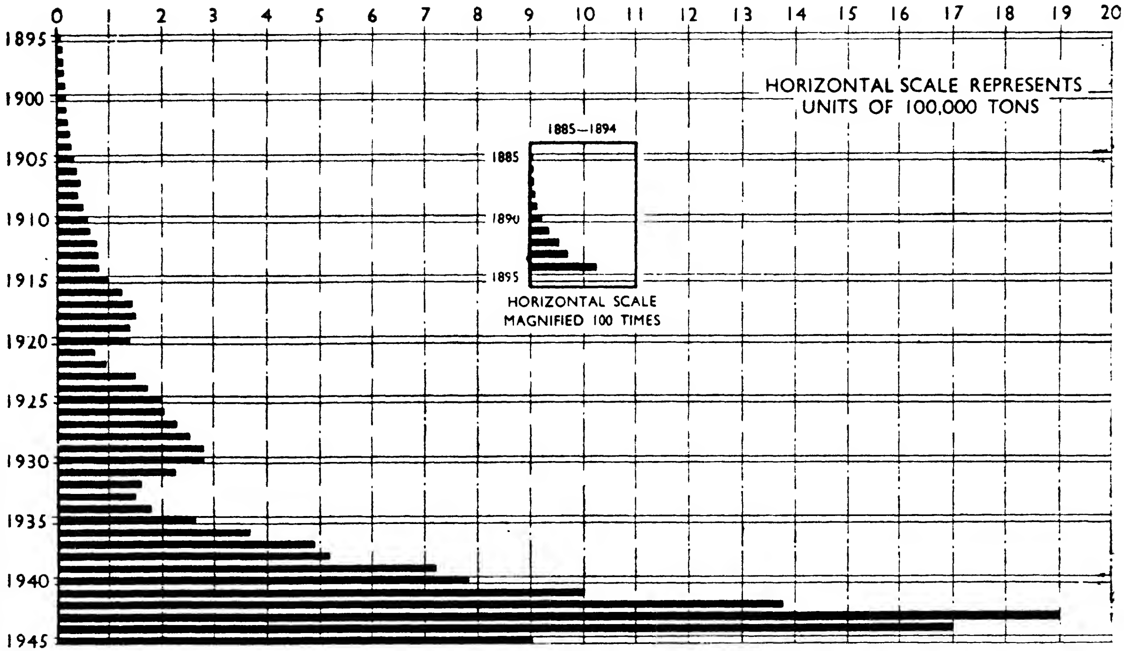

Chart IV. Fifty Years' Production of Aluminium.

CHAPTER VII

THE ALLOYS OF ALUMINIUM

THIS chapter is devoted to some Schedules giving in Tabular form the chemical composition of the light alloys and heavy alloys of aluminium, alphabetically listed under their proprietary names; the British Standards relating to aluminium alloys; the mechanical properties of the alloys listed in the alphabetic schedules; the collated physical and electrical properties of some of the best-known alloys; and corrosion data. Some general information on the casting alloys of aluminium and the forging alloys of aluminium will be found in Chapters VIII and IX, on pp. 194 and 212. In Schedule III the mechanical properties are given in units of lb./sq. in., conversion tables to tons/sq. in. and metric units being supplied on p. 179.

During the first phase of expansion of the aluminium industry the intensive interest in alloy research, which the then popular cliché "the future of aluminium lies in its light alloys" reflected, gave rise to a multitude of proprietary alloys, a large number of which overlapped as regards composition. This position has gradually changed; from the very nature of alloying technology there was bound to be a slowing-down of this confusing reproduction, and standardization of composition by the various bodies responsible in different countries has also acted in the same direction. With the exception of certain alloy types whose names are firmly established in the international industry, the modern tendency is to refer to alloys by Standards designations rather than by trade names. Schedule I lists those of the latter which are still in use in various parts of the world and Schedule II gives first the titles of the British Standards current, D.T.D., Aircraft, B.S. and STA 7. being included; and second the compositions of the alloys covered.

SCHEDULE I

THE LIGHT ALLOYS OF ALUMINIUM : ORIGIN AND COMPOSITION

Name of alloy	C or F*	Origin†	Composition in %						
			Cu	Fe	Mg	Mn	Si	Zn	Other elements
Aeral	C	French	4.5	—	1.2	0.25	—	—	Cd 1–2
Aeron	F	German	1.5–2	—	—	0.75	1	—	—
Albondur	F	German			(Bondur plated with aluminium)				
Alclad	F	American			(Duralumin plated with aluminium)				
Alcoa alloys	—				(See " S " series)				
Aldrey	—	Swiss and German	—	—	0.43	—	0.55	—	—
Aldural	F	Jas. Booth and Co.			(English equivalent to Alclad)				
Allautal	F	German			(Lautal plated with aluminium)				
Almag	F	French	2.75	—	0.7	—	0.6	—	—
Almasilium	F	French	—	—	1	—	2	—	—
Almelec		French	—	—	0.7	—	0.6	—	—
Alneon	C	Swiss	2.5	—	—	—	—	7–22	—
Alpax	C or F	French	—	—	—	—	13	—	—
Alucable		French	—	—	0.43	—	0.55	—	—
Aludur 533	F	German	—	—	0.9	0.5	0.6	—	—
Aludur 570	F	German	4.5	—	0.5	0.6	0.4	—	—
Aludur 580	F	German							
Aludur 630	F	German							
Alufont (hard)	C	Swiss	2	1.4	0.15	—	—	12	—
Alufont (soft)	C	Swiss	2	—	—	0.5	2	12	—
Alufont 2	C	Swiss	4	—	0.2	0.6	2	—	Ti 0.15
Alumag	F	French	—	—	7	(0.45)	—	—	—
Alunite		—	0.1	0.6	—	0.5	0.2	—	—
Anticorodal	C or F	Swiss	—	—	0.65	0.7	2 or 1	—	Ti 0.15
Ardal		Ardal, Ltd.	2	1.7	—	—	—	—	Ni 0.6
Argental		American	5	—	—	—	—	20	Ag +
Argilite		French	6	—	—	—	2	—	Bi 2 (optional)
Aviol	F	Russian	—	—	0.6	—	0.7	—	—
Avional D	F	Swiss	3.8	—	0.55	0.5	—	—	—
Avional Z	F	Swiss	4.5	0.3	0.75	0.6	0.4	—	—
Avional 411	F	Swiss	4.8	—	0.5	0.8	1	—	—
B.S. Seewasser	—				(See B.S.S.)				
Birmabright	F or C	Birmingham Al. Casting Co.	—	—	3.5	0.5	—	—	—
Birmasil		Birmingham Al. Casting Co.	—	—	—	—	10–13	—	Ni 2.5–3.5
Bondur	F	German	3.5–5.5	—	0.2–0.7	0.25–1	0.3–0.5	—	—
British Aluminium alloys	—				(See B.A. series)				
Ceralumin B	C	J. Stone and Co., Ltd.	1–1.75	0.3–1	0.05–0.2	—	0.75–2.5	—	Ni 1–1.75 ; Ce 0.05–0.2
Ceralumin C and D	C	J. Stone and Co., Ltd.	2	1–1.4	0.5–1	—	1–1.4	—	Ni 1–2 ; Ce 0.05–0.2
Chlumin	F	Japanese	—	+	+	—	—	—	Cr +
Chromal	F or C	Swedish			(Very variable composition)				
Cindal E 11 A		D. and J. Tullis, Ltd.	—	0.4	—	—	0.4	14	Cr 0.5

Cindal E 11 B		D. and J. Tullis, Ltd.	—	0.4	—	—	3.5	14	Cr 0.5 ; Ca 0.1
Cindal L 8/8		D. and J. Tullis, Ltd.	—	0.3	—	—	8.5	8	Cr 0.3 ; Ca 0.1
Cindal L 5/12		D. and J. Tullis, Ltd.	—	0.3	—	—	5	12	Cr 0.3 ; Ca 0.1
Cindal L 3/16		D. and J. Tullis, Ltd.	—	—	—	—	3	16	Cr 0.3 ; Ca 0.1
Constructal 2	F	German	1.5	—	0.9	—	0.55	—	Ti 0.5
Constructal 8	F	German	—	—	2.5	1	0.2	7	—
Cupal		German			(Aluminium plated with copper)				
Dural H	F	French	—	—	7	—	—	—	—
Dural K	F	French	—	—	9	—	—	—	—
Dural P	F	French	—	—	12	—	—	—	—
Duralumin G	F	German, also manufactured by J. Booth and Co., A.L.C.O.A., and Soc. du Duralumin	4.2	—	1.5	0.6	—	—	—
Duralumin W	F		4	—	0.5	0.5	—	—	Ni +
Duralumin 681 A and B ..	F		4.5	—	0.5	0.6	—	—	—
Duralumin 681 H ..	F		2.5	—	0.5	—	—	—	—
Duralumin 681 K ..	F		—	—	0.2	—	—	—	—
Duralumin 681 ZB ..	F		4.5	—	0.5	0.8	0.6	—	—
Duralumin DM 31 ..	F		4.0	—	1	1.2	0.6	—	—
Duranalium 3–5	F	German	—	—	3.5	0.4	—	—	—
Duranalium 7	F	German	—	—	7	—	—	—	—
Durcilium	C or F	E. and E. Kaye, Ltd.	4	—	0.5	0.5	—	—	—
Eutectal		French	1.5	—	—	0.8	0.25	—	Ti 0.35
Hiduminium 40	C	High Duty Alloys, Ltd. ..	—	—	0.6–0.8	0.6–0.8	4.5–5.5	—	Ti 0.1–0.2
Hiduminium 45	F	High Duty Alloys, Ltd. ..	—	—	0.5–1	0.5–1	0.5–1.5	—	—
Hiduminium DU Brand ..	F	High Duty Alloys, Ltd. ..	3.5–4.5	<0.7	0.4–0.8	0.4–0.7	<0.7	—	(Ti <0.3)
Hiduminium RR	—					(See RR series)			
Hiduminium Y	—					(See Y alloys)			
Hyb-lum	F	American	0.63	1.0	0.3	—	0.27	—	Ni 1.06 : Cr +
Hydronalium 5	F	German	—	—	5	0 3	—	—	—
Hydronalium 7	F	German	—	—	7	0.45	—	—	—
Hydronalium 9	C	German	—	—	9	0.5	—	—	—
Hydronalium 10	F or C	German	—	—	10	0.5	0.2–1.5	—	—
Hydronalium 51, 71 ..	C	German	—	—	5–12	0.2–0.5	0.2–1.5	—	—
noxalium	F	French	—	—	1	—	2	—	—
Italsil	C	Italian	—	—	—	—	13	—	—
K.S. Seewasser	—					(See K.S.S.)			
Kolchugalumin	F	Soviet	4	—	0.5	0.5	—	—	Ni +
Kupfersilumin	C	German	0.8	—	—	0.3	13	—	—
Lautal	F	German	5	—	—	—	0.4	—	—
Legal I		German	—	0.3	0.45	—	0.5	—	—
Legal II		German	—	0.3	1	0.8	1	—	—
Lo-Ex	C	American	0.8–0.9	1	1	—	14	—	Ni 2.5
Lynite	C and F	American	10	1.2	0.2	—	—	—	—
Magaluma	F	Belgian	—	—	3.4	0.15	—	—	—
Magdal	F	French	—	—	1	1.25	—	—	—
Magnalium	F	German	—	—	3–30	—	—	—	—
Maluminium	C	German	6.5	1.5	—	—	—	5	Pb 0.15
Mangal	F	German	—	—	—	1.5	—	—	—
Manganal	F	French	—	—	—	1.25	—	—	—
Miralite	C or F	Miralite, Ltd.	—	—	—	—	—	—	Ni 4 ; Na + ; Pb +

* Casting or forging † Name of producer given if British.

Schedule I—Continued

Name of alloy	C or F*	Origin†	Composition in %						
			Cu	Fe	Mg	Mn	Si	Zn	Other elements
Navalium			0.1	0.6	—	2.3	0.24	—	Sn 0.7
Nelson Bohnalite	C	American	10	—	0.5	—	0.4	—	—
Neonalumin		Swiss	6–14	—	+	—	—	—	—
Nicral	C	American	0.2–1	—	0.2–0.5	—	—	—	Ni 0.3; Ti 0.05. Cr 0.3
Nüral 200	C	German	14–16	0.5–1	0.15–0.35	—	—	—	—
Nüral 122	C	German	9–12	—	0.8	1	0.6	—	Ni 0.5
Nüremberg Gold		German	—	—	—	—	—	—	Au 25
Pantal	F	German	—	—	1.4	0.9	0.7	—	Ti 0.3
Pantal 5	F	German	—	—	0.6	0.7	5	—	Ti + Fe <0.6
Peraluman	F	Swiss	—	—	2.2	1.4	—	—	—
Peraluman 7	F	Swiss	—	—	7	0.45	—	—	—
Permite 1004	C	American	6–8	1.5	0.2	0.2	2.0	2.5	—
Polital	F	German	—	0.19	0.75	0.42	1.1	—	Ni 0.14
Quartzal		German	15	—	—	—	0.5	—	Iron group +
Redulith		Metal Alloys (S. Wales), Ltd.	—	—	—	—	—	—	Li 1–5
Savoye	C	French	2.2–2.8	0.7	—	—	0.2–0.3	—	Ni 3; Ag 1; Sn 1.5–2.5
Scleral M		French	—	—	7	—	—	—	—
Scleron	F	German	3	—	—	0.6	0.5	12	Li +
Silmalec		British Aluminium Co., Ltd.	—	—	0.43	—	0.55	—	—
Silumin	C	German	—	—	—	—	12–13.5	—	—
Silumin Beta	C	German	—	—	0.3	0.5	13	—	—
Silumin Gamma	C	German	—	—	0.3	0.5	13	—	—
Studal	F	French	—	—	1	1.25	—	—	—
Studal TT	F	French	—	—	1	—	1	—	—
Superduralumin	F	American	4.5	—	0.5	0.5	0.75	—	—
Thalassal	F	French	—	—	2	1.4	0.8	—	Sb 0.2
Uginal		French	—	—	—	—	32	—	—
Ultralumin		German	4.7	—	—	0.75	—	—	Ni 0.2
Vedal	F	French			(Duralumin coated with aluminium)				
Wilmil	C	William Mills, Ltd.	—	—	—	—	12–13.5	—	—
Wilmil M	C	William Mills, Ltd.	—	—	0.3	0.5	13	—	—
Zinnal	F	German			(Aluminium plated with tin)				
A.S.T.M. D		American standard alloys	6–8	—	—	—	—	—	(Si + Mn + Sn) <0.75
A.S.T.M. E			11–13	<1.2	<0.05	<0.3	<1	<0.2	(Si + Mn + Sn) <0.3
A.S.T.M. F			9–10.75	0.9–1.5	0.15–0.35	—	—	—	(Si + Mn + Sn) <0.75
A.S.T.M. G			4–5	1.2	<0.3	<0.3	<1.2	<0.2	(Si + Mn + Sn) <0.2
A.S.T.M. H			3.5–4.5	<0.8	1.2–1.7	<0.3	<0.7	<0.1	Ni 1.8–2.3
A.S.T.M. J			<0.6	<1	—	<0.3	4.5–6	<0.2	Ni <0.3
A.S.T.M. K			<0.3	<0.8	+	<0.5	12–13	<0.2	Ni <0.3
AW 15	F	German	—	—	—	1.5	—	—	—
AW 160	F	German	—	—	0.65	0.7	1	—	—
AW 421	F	German	—	—	7	0.45	—	—	—
BA 20	F	British Aluminium Co., Ltd.	—	—	1–6	1.25	—	—	—
BA 23	C	British Aluminium Co., Ltd.	—	—	1.25	—	0.6	—	—

BA 24	F	British Aluminium Co., Ltd.	—	—	0.5	—	0.5	—	—
BA 25	F	British Aluminium Co., Ltd.	—	—	1.0	—	1.0	—	—
BA 31	C	British Aluminium Co., Ltd.	5–6	—	—	—	—	—	—
BA 35	F	British Aluminium Co., Ltd.	2.5–4	0.75	0.4–0.8	—	—	—	Sn + ; Sb +
BA 37	C	British Aluminium Co., Ltd.	6–8	—	—	—	2	—	—
BA 40D	C or F	British Aluminium Co., Ltd.	—	—	—	—	10–13	—	—
BA 40J	C	British Aluminium Co., Ltd.	—	—	—	—	7.5–8.5	—	—
BA 40M	C	British Aluminium Co., Ltd.	—	—	0.4	0.35	12	—	—
BA 42	C	British Aluminium Co., Ltd.	1.0	0.5	1.0	—	12	—	Ni 2.5
BA 60A	F	British Aluminium Co., Ltd.	<0.15	—	—	1.25	—	—	—
B.S.S.	F	German	—	—	5–10	0.2–0.6	—	—	—
B.S.S. alloys	—	—			(British Standard Alloys : see separate table)				
D.T.D. alloys	—	—			(British Standard Alloys : see separate table)				
K.S. 245		German	4.5	—	0.7	1.2	12	—	Ni 1.5
K.S. 280		German	1.5	0.6	1.5	1.5	20–22	—	Ni 1 ; Cr 0.2 ; Sb 0.5
K.S.S.		German	—	—	2	1.4	0.7	—	Sb 0.2
L alloys	—	—			(British Standard Alloys : see separate table)				
L.A.C. alloys	—	—			(British Standard Alloys : see separate table)				
MG.5		Jas. Booth and Co.	—	<0.5	4.5–5.5	0.6	<0.5	—	—
MG.7	F	Jas. Booth and Co.	—	—	7	<0.6	—	—	—
M.V.C.	F	Metropolitan Vickers Electrical Co.	—	—	—	—	13	—	—
NA 3S	F	Northern Aluminium Co., Ltd.	—	—	—	1.5	—	—	—
NA 17S	F	Northern Aluminium Co., Ltd.	3–4	—	0.4–0.7	0.4–0.7	—	—	—
NA 22S	F	Northern Aluminium Co., Ltd.	3.5–4.7	—	0.4–1	0.4–1.5	0.7–1.5	—	—
NA 24S	F	Northern Aluminium Co., Ltd.	3.5–4.8	—	0.8–1.8	0.3–1.5	—	—	—
NA 35S	F	Northern Aluminium Co., Ltd.	—	—	—	—	10–13	—	—
NA 51S	F	Northern Aluminium Co., Ltd.	—	—	0.5–1.5	—	0.5–1.5	—	—
NA 57S	F	Northern Aluminium Co., Ltd.	—	—	1.5–3	—	—	—	Cr 0.1–0.35
NA 125	C	Northern Aluminium Co., Ltd.	1–1.5	—	0.4–0.6	—	4.5–5.5	—	—
NA 162	C	Northern Aluminium Co., Ltd.	0.5–1	—	0.75–1.25	—	12–15	—	Ni 1.5–2.5
NA 225	C	Northern Aluminium Co., Ltd.	4–4.6	<0.7	—	—	<0.9	—	—
NA 226	C	Northern Aluminium Co., Ltd.	4–4.6	<0.7	—	—	<0.9	—	Ti <0.25
NA 244	C	Northern Aluminium Co., Ltd.	8	—	—	—	2	—	—
NA 250	C	Northern Aluminium Co., Ltd.	9–11	0.9–1.5	0.15–0.35	—	—	—	—
NA 305	C	Northern Aluminium Co., Ltd.	—	—	0.75–2	—	0.25–1.5	—	—
NA 350	C	Northern Aluminium Co., Ltd.	—	—	9.5–10.5	—	—	—	—
N.C.A. alloy	F or C	Haywoods, Ltd.	3	—	0.25	0.25	—	—	Ni 2.25
P.2	C	Birmingham Al. Casting Co., Ltd.	3–4.5	2–4	<0.5		4.5	—	Ni 1.75–2.5
RR 50	C	High Duty Alloys, Ltd	0.8–2.0	0.8–1.4	0.05–0.3	—	1.5–2.8	—	Ni 0.8–1.75 ; Ti 0.05–0.25
RR 53B	C	High Duty Alloys, Ltd.	1.3–2.5	0.8–1.3	0.7–1.7	—	<2	—	Ti <0.25 ; Ni 0.5–1.1
RR 56	F	High Duty Alloys, Ltd.	1.8–2.5	0.6–1.2	0.65–1.2	—	0.55–1.25	—	Ti 0.05–0.15 ; Ni 0.6–1.4
RR 59	C or F	High Duty Alloys, Ltd.	1.5–3	1–1.5	1.2–1.8	—	<1.3	—	Ti <0.2 ; Ni 0.5–1.5
RR 77	F	High Duty Alloys Ltd.	3	<0.6	2–4	<1	<0.6	4–6	Ti <0.3

* Casting or forging. † Name of producer given if British.

Schedule I—Continued

Name of alloy	C or F*	Origin†	Composition in %						
			Cu	Fe	Mg	Mn	Si	Zn	Other elements
3S	F	American (A.L.C.O.A.)	—	—	—	1.25	—	—	—
4S	F	American (A.L.C.O.A.)	—	—	1	1.25	—	—	—
12	C	American (A.L.C.O.A.)	8	—	—	—	—	—	—
13	C	American (A.L.C.O.A.)	—	—	—	—	12	—	—
14	C	American (A.L.C.O.A.)	14	—	—	—	2	—	—
14S	F	American (A.L.C.O.A.)	4.4	—	0.4	0.8	0.8	—	—
17S	F	American (A.L.C.O.A.)	4	—	0.5	0.5	—	—	—
A17S	F	American (A.L.C.O.A.)	2.5	—	0.3	—	—	—	—
B17S	F	American (A.L.C.O.A.)	3.5	—	0.3	—	—	—	—
C17S	F	American (A.L.C.O.A.)	4	—	0.5	0.5	1.3	—	—
18S	F	American (A.L.C.O.A.)	4	—	0.5	—	—	—	Ni 2
24S	F	American (A.L.C.O.A.)	4.2	—	1.5	0.6	—	—	—
25S	F	American (A.L.C.O.A.)	4.5	—	—	0.8	0.8	—	—
32S	F	American (A.L.C.O.A.)	—	—	1	—	12	—	Ni 0.8
43	C	American (A.L.C.O.A.)	—	—	—	—	5	—	—
43S	F	American (A.L.C.O.A.)	—	—	—	—	5	—	—
45	C	American (A.L.C.O.A.)	—	—	—	—	10	—	—
47	C	American (A.L.C.O.A.)	—	—	—	—	12.5	—	—
51S	F	American (A.L.C.O.A.)	—	—	0.6	—	1	—	—
A51S	F	American (A.L.C.O.A.)	—	—	0.6	—	1	—	Cr 0.25
53S	F	American (A.L.C.O.A.)	—	—	1.25	—	0.7	—	Cr 0.25
70S	F	American (A.L.C.O.A.)	1	—	0.4	0.7	—	10	—
73	F	American (A.L.C.O.A.)	2.5	—	—	—	8.5	—	—
83	C	American (A.L.C.O.A.)	2	—	—	—	3	—	—
85	C	American (A.L.C.O.A.)	4	—	—	—	5	—	—
93	C	American (A.L.C.O.A.)	4	—	—	—	2	—	Ni 4
106	F	American (A.L.C.O.A.)	—	—	—	2	—	—	Ni <1.5
108	C	American (A.L.C.O.A.)	4	—	—	—	3	—	—
109	C	American (A.L.C.O.A.)	12	—	—	—	—	—	—
112	C	American (A.L.C.O.A.)	7.5	1.2	—	—	—	1.5	—
113	C	American (A.L.C.O.A.)	7.5	1.2	—	—	1.5	1.5	—
121	C	American (A.L.C.O.A.)	12	—	—	1	—	—	—
122	C	American (A.L.C.O.A.)	10	1.2	0.2	—	—	—	—
122–70	C	American (A.L.C.O.A.)	12	—	0.1	—	—	—	—
132	C	American (A.L.C.O.A.)	0.9	1	1	—	14	—	Ni 2.5
134	C	American (A.L.C.O.A.)	4	—	—	—	13	—	—
142	C	American (A.L.C.O.A.)	4	—	1.5	—	—	—	Ni 2
144	C	American (A.L.C.O.A.)	10	—	0.2	—	4	—	—
145	C	American (A.L.C.O.A.)	2.5	1.2	—	—	—	10	—
195	C	American (A.L.C.O.A.)	4	—	—	—	—	—	—
195–60	C	American (A.L.C.O.A.)	4.5	—	—	—	2.8	—	—
195–80	C	American (A.L.C.O.A.)	5.5	—	—	—	0.7	—	—
196	C	American (A.L.C.O.A.)	4	—	0.2	—	—	—	—

212..	C	American (A.L.C.O.A.) ..	7–8.5	0.8–1.2	—	—	1–1.5	—	—
214..	C	American (A.L.C.O.A.) ..	—	—	3.8	—	—	—	—
A214	C	American (A.L.C.O.A.) ..	—	—	3.8	—	—	2	—
215..	C or F	American (A.L.C.O.A.) ..	—	—	0.65	0.7	1	—	—
216..	C	American (A.L.C.O.A.) ..	—	—	6	—	—	—	—
220..	C	American (A.L.C.O.A.) ..	—	—	10	—	—	—	—
A334	C	American (A.L.C.O.A.) ..	3	—	0.3	—	4	—	—
355..	C	American (A.L.C.O.A.) ..	1.2	—	0.5	—	5	—	—
A355	C	American (A.L.C.O.A.) ..	1.4	—	0.5	0.8	5	—	Ni 0.8
356..	C	American (A.L.C.O.A.) ..	—	—	0.3	—	7	—	—
406..	C	American (A.L.C.O.A.) ..	—	—	—	2	—	—	—
427..	C	American (A.L.C.O.A.) ..	4.4	—	0.35	0.75	0.8	—	—
645..	C	American (A.L.C.O.A.) ..	2.5	1.5	—	—	—	11	—
V.L.W.	—			(German manufacturer's proprietary mark for light alloys)					
Y alloy	C or F	Jas. Booth and Co.	4	—	1.5	—	—	—	Ni 2
Z3	C	Birmingham Al. Casting Co. ..	6–8	—	—	—	2–3	2–4	—

* Casting or forging. † Name of producer given if British.

THE HEAVY ALLOYS OF ALUMINIUM : ORIGIN AND COMPOSITION

(The table also includes other alloys in which aluminium is a constituent)

Name of alloy	Base metal	Origin*	Composition in %						
			Al	Cu	Fe	Mn	Zn	Ni	Other elements
Alcumite	Cu	American	6–7	87–90	3–4	1–2	—	—	—
Alcunic	Cu	American	2	80	—	—	17	1	—
Aldurbra	Cu	Chas. Clifford and Son, Ltd. ..	2	76	—	—	22	—	—
Alni	Fe	Darwin's, Ltd.	13.5	—	Bal.	—	—	29	—
Alnico	Fe	—	12	—	Bal.	—	—	20	Co 5
Alsifer	Fe–Si	American	20	—	40	—	—	—	Si 40
Alumbro	Cu	I.C.I. Metals. Ltd.	2	76	—	—	22	—	—
Alumel	Ni	—	2	—	0.5	2.5	—	94	Si 1
Aluminium Brasses ..	Cu	—	1–6	55–71	—	—	24–42	—	—
Aluminium Bronzes ..	Cu	—	4–12	87.5	1–4	∼	—	—	Sn ∼
Aluminium Iron Bronzes	Cu	—	6–9.5	85–89	3.5–7.5	—	—	—	—
Aluminium Solders ..	Sn–Zn	—	6–15	∼	—	—	16–40	—	Sn 50–70
Aluminium Steels ..	Fe	—			(Very varying compositions)				
Aluminium Tin Bronzes ..	Cu	—	2.5	86	—	—	2	—	Sn 10
Avialite	Cu	American	9.5	90	0.5	—	—	—	—
Batalbra	Cu	B'ham Battery and Metal Co. ..	2	76	—	—	22	—	—

* Name of producer given if British.

Schedule I—Continued

Name of alloy	Base metal	Origin*	Composition in %						
			Al	Cu	Fe	Mn	Zn	Ni	Other elements
Batterium	Cu	Batterium Metal and Vislok, Ltd.	9	89	—	—	—	1	Other elements ⁓
Calite	Fe–Ni	—	4.1	—	50	—	—	40	Cr 5.5
Calmet	Fe	Calorizing Corpn. of Gt. Britain, Ltd.	(Cr–Ni–Fe–Al austenitic alloy)						
Chromax	Cu	—	3	66.7	—	—	12.1	15.2	Cr 3
Crotorite	Cu	Manganese Bronze and Brass Co., Ltd.	2.5–3.5 9–9.75	 88–90	— 0.2–2	0.2–0.4 0.2–0.6	— —	6.5–7.5 —	— —
Doler-Zinc	Zn	American	3.75–4.3	2.5–3	—	—	Bal.	—	—
Durana	Cu	—	1.5	65	1.5	—	30	—	Sn 2
Elektron alloys	Mg	—	(See separate table of Mg-base alloys)						
Feran	—	—	(Sheet iron coated with Al and rolled together)						
Frontier alloy	Cu	American	10	89	1	—	—	—	Ti +
Hibbo alloys	Cu	American	(Straight Cu–Al alloys)						
Hidurax	Cu	Langley Alloys. Ltd.	<12	Bal.	<6	<2.5	—	<6	—
Hytensil	Cu	American	4.7	67.6	2	3.2	22.4	—	—
Illium	Ni	—	1	6.5	1	1	—	62.5	Cr 21 ; Mo 5 ; W+
Immadium	Cu	Manganese Bronze and Brass Co., Ltd.	0.3–6.5	54–71	1.5–2.25	+–3.25	⁓40	—	Sn ⁓
Insuluminium	—	—	(Steel with a surface impregnating Al)						
Kanthal	Fe	Swedish	6–7	—	60	—	—	—	Co + Cr 33–4
Kunial A	Cu	I.C.I.	2.5	84	—	—	—	13.5	—
Kunial B	Cu	I.C.I.	1.5	92.5	—	—	—	6	—
Lumen	Cu	American	10.75	79.75	6	3.5	—	—	—
Mazak	Zn	National Alloys, Ltd.	4.1	⁓	—	—	Bal.	—	Mg ⁓
McGill Metal	Cu	—	9.0	89	2.0	—	—	—	—
Monel K	Ni	Henry Wiggin and Co.	2.75	29	0.9	0.4	—	66	C 0.15 ; Si 0.25
Nicral "C"	Fe–Ni	American	—	—	—	—	—	—	—
Nitralloy	Fe	Firth Brown	1–2	(Nitriding steels of varying compositions)					
Nuremberg Gold	Cu	—	7.5	90	—	—	—	—	Au 2.5
Oranium Bronze	Cu	—	3–8	92–97	—	—	—	—	—
Rosin	Ni	—	30	—	—	—	—	40	Sn 20 ; Ag 10
Superston	Cu	J. Stone and Co., Ltd.	8–12	Bal.	4–6	—	—	4–6	—
Texas Metal	Zn	—	4.42	2.56	<0.35	—	Bal.	—	Pb <1.2
Tungum	Cu	Tungum Alloy Co., Ltd.	0.7–1.2	81–86	—	—	Bal.	0.8–1.4	Si 0.8–1.3
Turbiston	Cu–Zn	J. Stone and Co., Ltd.	1	55	0.84	0.16	41	2	—
Turbo	Cu	German	10	77	—	—	—	1	—
White Brass	Zn	—	<5	4–10	—	—	Bal.	—	Pb, Fe +
Yorkalbro	Cu	Yorkshire Copper Works, Ltd.	2	76	—	—	22	—	—
Zamak	Zn	American	4.1	⁓	—	—	Bal.	—	Mg ⁓
Zantal	Cu	Italian	9	87.2	3	0.8	—	—	—
Zimal	Zn	Birmingham Al. Casting Co., Ltd.	3.8–4.3	2.75–3.25	—	0.03–0.15	Bal.	—	Pb, Cd ⁓

* Name of producer given if British.

SCHEDULE II

CURRENT LIGHT-ALLOY SPECIFICATIONS

D.T.D. Specifications
Aluminium-base Alloys

128	Aluminium alloy forgings (for sealing rings for cylinders).
130A	Aluminium alloy bars, extruded sections and forgings (not exceeding 3 ins. diameter or minor sectional dimension).
131B	Aluminium alloy sand or die castings (heat-treated)—suitable for pistons, etc.
133C	Aluminium alloy sand or die castings (heat-treated)—not suitable for pistons.
147	Light alloy airscrew forgings (Fairey Reed type).
150A	Light alloy airscrew forgings (detachable blades).
165	Aluminium-magnesium alloy castings
180B	Soft aluminium alloy sheets and coils (3½% magnesium).
182A	7% magnesium-aluminium alloy sheets and strips (annealed).
184	Light alloy airscrew forgings and stampings (detachable blades and complete airscrews).
186A	7% magnesium-aluminium alloy tubes (hard).
190	7% magnesium-aluminium alloy tubes (annealed).
213A	Aluminium-manganese alloy sheets and coils.
231	10% silicon-aluminium alloy castings.
238	Aluminium alloy sand or die castings (as cast)—suitable for pistons, etc.
240	Silicon-aluminium alloy castings (heat-treated).
245	Silicon-aluminium alloy castings (fully heat-treated).
246A	Aluminium alloy crankcase forgings (softened).
250	Aluminium alloy sand or die castings—not suitable for pistons.
255	Aluminium alloy die castings—suitable for pistons.
264	Aluminium alloy sand or die castings—not suitable for pistons.
269	Aluminium alloy sand or die castings.
272	Aluminium-silicon alloy sand or die castings—not suitable for pistons.
273	Aluminium alloy tubes.
276	Aluminium-silicon alloy sand or die castings—not suitable for pistons.
287	Aluminium alloy sand or die castings—not suitable for pistons.
294	Aluminium alloy sand or die castings—not suitable for pistons.
297	7% magnesium-aluminium alloy bars, extruded sections and forgings (softened).
298	Aluminium alloy sand or die castings—not suitable for pistons.
300A	Aluminium alloy sand or die castings (heat-treated)—not suitable for pistons.
303	5% magnesium-aluminium alloy wire and rivets.
304	Aluminium alloy sand or die castings—not suitable for pistons.
309	Aluminium alloy sand or die castings (heat-treated)—not suitable for pistons.
310C	Soft aluminium alloy tubes—suitable for oil, petrol, gas starters and general low-pressure purposes.
313	Aluminium alloy sand or die castings (as cast)—not suitable for pistons.
324	Silicon-aluminium alloy forgings for engine cylinders and pistons.
327	Aluminium alloy wire and rivets.
346	Soft aluminium alloy sheets and strip.
361	Aluminium alloy sand castings (heat-treated)—not suitable for pistons.
363A	Aluminium alloy extruded bars and sections. (Bars and extruded sections up to 6 ins. diameter or width across flats.)

Schedule II—Continued

364B	Aluminium alloy bars, extruded sections and forgings (not exceeding 6 ins. diameter or minor sectional dimensions).
390	Aluminium-coated aluminium alloy sheets and coils.
404	Hard-drawn high-tensile 7% magnesium-aluminium alloy wire and rivets.
410	Aluminium alloy bars and forgings (greater than 3 ins. diameter or minor sectional dimensions).
423B	Aluminium alloy bars, extruded sections and forgings.
424	Aluminium alloy castings for general purposes.
428	Aluminium alloy castings for low-stressed parts.
440	11/15 aluminium alloy tubes—suitable for structural and high-pressure use.
443	10/17 aluminium alloy bars, extruded sections and forgings.
450	10/17 aluminium alloy tubes—suitable for structural purposes.
460	18/22 aluminium alloy tubes—suitable for structural purposes.
464A	Aluminium alloy tubes.
478	99% secondary aluminium notched bars and ingots for re-melting.
479	Secondary aluminium alloy notched bars and ingots for re-melting.
520	23/27 aluminium alloy tubes.
523	Cold-headed aluminium alloy bolts (not exceeding ⅜-in. diameter).
543	Aluminium alloy sand or die castings (heat-treated)—suitable for cylinder heads.
546B	Aluminium-coated high-tensile aluminium alloy sheets and coils (solution-treated and artificially aged).
603B	Aluminium alloy sheets and coils (solution-treated).
606	Half-hard aluminium alloy sheets and coils (2% magnesium).
610B	Aluminium-coated aluminium alloy sheets and coils (solution-treated).
634	Soft aluminium alloy sheets and coils (2% magnesium).
635	Aluminium alloy sand or die castings (heat-treated)—not suitable for pistons.
646B	High-tensile aluminium alloy sheets and coils (solution-treated and artificially aged).
653	Aluminium alloy sheets and coils (1¼% manganese).
683	Aluminium alloy bars, extruded sections and forgings.
687	Aluminium-alloy-coated aluminium alloy sheets and coils.
693	Aluminium alloy tubes
706	Aluminium-coated high-tensile aluminium sheets of special flatness (solution-treated and artificially aged).
710	Aluminium-coated aluminium alloy sheets and coils to close tolerances (solution-treated).
746	Aluminium-coated aluminium alloy sheets and coils to close tolerances (solution-treated and artificially aged).

B.S.I. Aircraft Materials

6L 1	Aluminium alloy bars, extruded sections and forgings (not greater than 3 ins. diameter or minor sectional dimensions).
5L 3	Aluminium alloy sheets and coils.
2L 4	Aluminium sheets (hard).
3L 5	Aluminium–zinc–copper alloy castings.
3L 8	12% copper–aluminium alloy castings.
4L11	7/1 aluminium alloy castings.
2L16	Aluminium sheets (half-hard).
2L17	Aluminium sheets (soft).
2L24	"Y" aluminium alloy castings.
4L25	Aluminium alloy forgings (including pistons and cylinder heads).
2L30	98% aluminium notched bars and ingots for re-melting purposes.

Schedule II—Continued

3L31	99% aluminium notched bars and ingots for re-melting.
2L33	Silicon-aluminium alloy castings.
L34	99% aluminium bars and sections.
L35	" Y " aluminium alloy castings (heat-treated).
L36	Aluminium rivets.
2L37	Aluminium alloy rivets.
2L38	Aluminium-coated aluminium alloy sheets and coils.
2L39	Aluminium alloy bars and forgings (greater than 3 ins. diameter or width across flats or minor sectional dimensions).
2L40	Aluminium alloy bars, extruded sections and forgings (not greater than 3 ins. diameter or minor sectional dimensions).
2L42	Aluminium alloy forgings—including pistons and cylinder heads.
L44	Soft aluminium alloy extruded bars and sections (not greater than 3 ins. diameter or minor sectional dimensions).
L45	Aluminium alloy bars and forgings (greater than 3 ins. diameter across flats or minor sectional dimensions).
L47	Aluminium-coated aluminium alloy sheets and coils.
5T 4	Aluminium alloy tubes.
4T 9	Aluminium tubes.

B.S. Specifications

359	98% aluminium : (1) notched bars and ingots (for re-melting purposes) ; (2) rolling slabs and billets.
360	99% aluminium notched bars and ingots (for re-melting purposes).
361	7% aluminium alloy castings for general engineering purposes.
362	12% copper-aluminium alloy castings for general engineering purposes.
363	Zinc-copper-aluminium alloy castings—suitable for crankcases and general use.
385	Pure aluminium tubes for general engineering purposes.
386	Pure aluminium bars and sections for general engineering purposes (excluding wire bars).
395	Wrought light aluminium alloy (duralumin) sheets and strips for general engineering purposes.
396	Wrought light aluminium alloy (duralumin) tubes for general engineering purposes.
414	Wrought light aluminium alloy sheets and strip (heat-treated) for general engineering purposes. (This specification covers the alloy generally known as Y-alloy.)
477	Wrought light aluminium alloy bars for general engineering purposes.
478	Wrought Y-alloy bars for general engineering purposes.
532	Light aluminium alloy forgings for general engineering purposes.
533	Y-alloy forgings for general engineering purposes.
702	Silicon-aluminium alloy castings for general engineering purposes.
703	Y-alloy castings (as cast) for general engineering purposes.
704	Y-alloy castings (heat-treated) for general engineering purposes.
1080	Aluminium alloy bars for the manufacture of fuses and fuse parts. (War emergency issue.)

British Standards STA 7 Schedule

A1	99.99% aluminium sheet and strip.
A2	99.8% aluminium sheet, strip and foil.
A3	99.6% aluminium wrought bars, sections, sheet, strip, foil and wire.

Schedule II—Continued.

A4A	99% aluminium ingot.
B	99% aluminium wrought bars and sections.
C	99% aluminium wrought tubes.
D	99% aluminium sheet and strip.
E	99% aluminium wire and rivets.
AC 1	Gravity die castings.
AC 2	Pressure die castings.
AC 3	Sand castings.
AC 4	Sand, gravity and pressure die castings.
AC 5	Sand and gravity die castings.
AC 6	Sand, gravity and pressure die castings.
AC 7	Sand and gravity die castings (artificially aged).
AC 8A	Sand and gravity die castings (special heat-treated).
B	Sand and gravity die castings (solution heat-treated).
AC 9A	Sand and gravity die castings (artificially aged).
B	Sand and gravity die castings (fully heat-treated).
AC10	Sand and gravity die castings.
AC11A	Sand and gravity die castings (solution heat-treated).
B	Sand and gravity die castings (fully heat-treated).
AC12	Sand and gravity die castings—suitable for pistons.
AC13A	Sand and gravity die castings—suitable for pistons.
B	Special quality die castings for pistons.
AC14A	Sand and gravity die castings—suitable for pistons.
B	Special quality die castings for pistons.
AC15	Sand and gravity die castings—suitable for pistons.
AW 1	Wire and welding rod.
AW 2A	Bars and sections.
B	Sheet and strip.
C	Welding rod and wire.
D	Rivets.
AW 3A	Bars and sections
B	Tubes.
C	Sheet and strip.
AW 4A	Bars and sections.
B	Tubes.
C	Sheet and strip.
AW 5A	Bars and sections.
B	Tubes.
C	Sheet and strip.
AW 6A	Bars, sections and forgings.
B	Tubes.
C	Sheet and strip.
D	Wire, welding rod and rivets.
AW 7A	Bars, sections and forgings.
B	Tubes.
C	Sheet and strip.
AW 8	Bars for machining (free-cutting).
AW 9A	Bars and sections (solution heat-treated).
B	Bars and sections (fully heat-treated).
AW10A	Bars, sections and forgings (solution heat-treated).
B	Bars, sections and forgings (fully heat-treated).
C	Tubes.
D	Sheet and strip.

Schedule II—Continued.

E	Sheet and strip (fully heat-treated).
F	Wire, welding rod and rivets.
AW11A	Bars and sections (solution heat-treated).
B	Bars and sections (fully heat-treated).
AW12	Forgings.
AW13	Wire and rivets.
AW14	Wire and rivets.
AW15A	Bars, sections and forgings (solution heat-treated).
B	Bars, sections and forgings (fully heat-treated).
C	Tubes (solution heat-treated).
D	Tubes (fully heat-treated).
E	Sheet and strip (solution heat-treated).
F	Sheet and strip (fully heat-treated).
G	Aluminium-coated sheet and strip (solution heat-treated).
H	Aluminium-coated sheet and strip (fully heat-treated).
AW16A	Bars and sections.
B	Coated sheet and strip.
AW17A	Forgings and stampings.
B	Forgings and stampings—suitable for pistons and cylinder heads.
AW18	Forgings and stampings—suitable for pistons and cylinder heads.

Light Metals Control L.A.C. Specifications

LAC 10	Secondary aluminium alloy—suitable for pistons other than aero and heavy-duty pistons.
LAC112A	Secondary aluminium casting alloy—especially suitable for pressed and gravity die castings.
LAC113B	General-purpose secondary aluminium sand-casting alloy—suitable for use where ductility is not important—e.g., gearboxes and casings.

Schedule II—Continued

CURRENT LIGHT-ALLOY SPECIFICATIONS

	Al	Mg	Si	Cu	Mn	Ni	Fe	Cr	Zn	Ti	Pb	Sn	Remarks
D.T.D. Specifications, Aluminium-base Alloys													
128	R	0.05–0.15	0.5 max.	2.0 –3.0	—	0.5 –1.0	0.8 –1.2	—	—	0.02–0.1	—	—	—
130A	R	0.65–1.2	0.55–1.25	1.8 –2.5	—	0.6 –1.4	0.6 –1.2	—	—	0.05–0.15	—	—	—
131B	R	0.7 –1.7	2.0 max.	1.3 –2.5	—	0.5 –1.7	0.8 –1.3	—	—	0.25 max.	—	—	—
133C	R	0.05–0.2	1.5 –2.8	0.8 –2.0	—	0.8 –1.75	0.8 –1.4	—	—	0.05–0.25	—	—	—
147	R	0.4 –0.7	—	3.5 –4.5	0.4 –0.7	—	0.75 max.*	—	—	—	—	—	—
150A	R	0.4 –0.9	0.7 max.	3.5 –4.5	0.4 –0.7	—	0.7 max.	—	—	—	—	—	Ti 0.3 max. (if present).
165	R	3.0 –6.0	—	—	0.25–0.75	—	0.6 max.*	—	—	—	—	—	Total impurities (including Fe), 1.0 max.
180B	R	3.0 –4.0	0.6 max.	0.15 max.	1.0 max.	—	0.75 max.	0.5 max.	—	—	—	—	—
182A	R	6.5 –10.0	0.5 max.	—	0.6 max.	—	0.75 max.	—	—	—	—	—	—
184	R	0.4 –1.0	1.0 max.	1.5 –3.0	—	0.5 –1.5	0.8 –1.4	—	—	0.02–0.12	—	—	—
186A	R	6.5 –10.0	0.5 max.	—	0.6 max.	—	0.75 max.	—	—	—	—	—	—
190	R	6.5 –10.0	—	—	0.6 max.	—	0.75 max.	—	—	—	—	—	—
213A	R	—	0.6 max.	0.15 max.	1.5 max.	—	0.75 max.	—	—	—	—	—	—
231	R	—	8.0 –12.0	—	0.5 max.	—	0.6 max.	—	0.1 max.	0.2 max.	—	—	Other elements, excl. mod. agents, 0.1 max. Total mod. agents (Na, W, Cr, Co, B, Ca), 0.3 max.
238	R	1.4 –1.8	2.0 max.	1.5 –2.5	—	0.5 –2.0	1.2 –1.5	—	—	0.02–0.12	—	—	—
240	R	0.6 max.	10.0–13.0	—	0.6 max.	—	0.6 max.	—	—	—	—	—	Total other metallic impurities, 0.2 max.
245	R	0.6 max.	10.0 –13.0	—	0.6 max.	—	0.6 max.	—	—	—	—	—	Total other metallic impurities, 0.2 max.
246A	R	0.6 –1.2	1.0 max.	1.5 –2.5	—	0.5 –1.5	0.8 –1.5	—	—	0.12 max.	—	—	—
250	R	0.5 –1.0	1.0 –1.4	2.0 –3.0	—	1.0 –2.0	1.0 –1.4	—	—	—	—	—	Ce 0.05–0.2. Cb 0.05–0.3 (if present). Cr 0.05–0.2 (if present).
255	R	0.5 –1.0	1.0 –1.4	2.0 –3.0	—	1.0 –2.0	1.0 –1.4	—	—	—	—	—	Ce 0.05–0.2. Cb 0.05–0.3 (if present). Cr 0.05–0.2 (if present).
264	R	—	10.0 –13.0	0.1 max.*	0.5 max.*	2.5 –3.5	0.6 max.*	—	0.1 max.*	0.2 max.*	—	—	—
269	R	0.1 –0.3	0.7 –0.9	4.0 –4.6	0.3 max.*	—	0.5 –0.7	—	—	0.25 max.	—	—	—
272	R	0.4 –0.6	4.5 –5.5	1.0 –1.5	—	—	0.6 max.	—	—	0.25 max.	—	—	—
273	R	0.8 –1.8	0.5 max.	3.5 –4.8	0.3 –1.5	—	0.4 max.	—	—	—	—	—	—
276	R	0.4 –0.6	4.5 –5.5	1.0 –1.5	—	—	0.6 max.	—	—	0.25 max.	—	—	—
287	R	0.05–0.2	0.75–2.5	1.0 –2.0	—	1.0 –1.75	0.25–1.3	—	—	—	—	—	Ce 0.05–0.3 (if present). Cr 0.05–0.3 (if present.) Cb 0.05–0.3 (if present).
294	R	0.2 –1.5	2.5 max.	2.0 –4.5	0.5 max.	—	0.8 max.	—	—	0.4 max.	—	—	Cd 0.5–2.5.
297	R	6.5 –10.0	0.5 max.	—	0.6 max.	—	0.75 max.	—	—	—	—	—	—
298	R	—	0.25 max.	4.0 –5.0	—	—	0.25 max.	—	—	0.25 max.	—	—	Impurities (Ni, Mg, Mn, Zn), 0.2 max.
300A	R	9.5 –11.0	0.35 max.*	0.15 max.*	—	—	0.35 max.*	—	—	—	—	—	—
303	R	4.5 –5.5	0.5 max.*	—	0.6 max.*	—	0.5 max.*	—	—	—	—	—	—
304	R	—	0.25 max.	4.0 –5.0	—	—	0.25 max.	—	—	0.25 max.	—	—	Impurities (Ni, Mg, Mn, Zn), 0.2 max.
309	R	0.3 –0.8	2.0 –3.0	0.8 –2.0	—	0.5 –1.5	0.8 –1.4	—	—	—	—	—	Ti 0.3 max. (if present).
310C	R	1.5 –3.0	0.6 max.	0.15 max.	0.5 max.	—	0.75 max.	0.5 max.	—	—	—	—	—
313	R	0.3 –0.8	2.0 –3.0	0.8 –2.0	—	0.5 –1.5	0.8 –1.4	—	—	—	—	—	Ti 0.3 max. (if present).
324	R	0.8 –1.5	10.5 –13.0	0.7 –1.3	—	0.7 –1.3	—	—	—	—	—	—	Impurities (Fe, Mn, Ti), 0.6 max.
327	R	0.2 –0.5	0.7 max.*	1.5 –3.0	0.5 max.*	0.7 max.*	0.7 max.*	—	—	0.3 max.*	—	—	—
346	R	0.5 –1.25	0.75–1.25	—	0.5 –1.0	—	0.75 max.	—	—	—	—	—	—
361	R	—	0.25 max.	4.0 –5.0	—	—	0.25 max.	—	—	—	—	—	Ti 0.25 max. (if present). Total impurities (Ni, Mg, Mn, Zn), 0.2 max.
363A	R	4.0 max.	0.6 max.	3.0 max.	1.0 max.	—	0.6 max.	1.0 max.	4.0 –8.5	0.3 max.	—	—	When Zn content is in excess of 8.0 Mg content shall not exceed 2.5.
364B	R	0.6 max.	1.5 max.	3.5 –4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	—
390	R	0.6 –1.8	0.7 max.	3.5 –5.0	0.3 –1.2	—	0.7 max.	—	—	—	—	—	Coating, Al 99.7 min.
404	R	6.5 –10.0	0.5 max.*	—	0.6 max.*	—	0.5 max.*	—	—	—	—	—	—
410	R	0.65–1.2	0.55–1.25	1.8 –2.5	—	0.6 –1.4	0.6 –1.2	—	—	0.05–0.15	—	—	—
423B	R	0.5 –1.25	0.75–1.25	1.0 –2.0	1.0 max.	0.3 max.	0.75 max.	—	—	—	—	—	—
424	R	0.15 max.	3.0 –6.0	2.0 –4.0	0.3 –0.7	0.35 max.	0.8 max.	—	0.3 max.	0.2 max.	—	—	Mn+Fe 1.3 max.
428	R	0.1 max.*	2.0 –4.0	6.0 –8.0	—	—	1.0 max.*	—	2.0 –4.0	—	—	—	Ni+Sn+Pb+Mn 1.0 max.*
440	R	1.0 –3.0	0.7 max.*	—	1.5 max.	0.5†	0.7 max.*	1.5 max.†	—	0.2 max.*	—	—	—
443	R	0.5 –1.25	0.75–1.25	1.0 –2.0	1.0 max.	0.3 max.	0.75 max.	—	—	—	—	—	—

* Denotes elements classified as impurities. † Denotes elements which may be present at option of manufacturer.

Schedule II—Continued.

	Al	Mg	Si	Cu	Mn	Ni	Fe	Cr	Zn	Ti	Pb	Sn	Remarks
D.T.D. Specifications, Aluminium-base Alloys—Continued													
450	R	0.5 –1.25	0.75–1.25	1.0 –2.0	1.0 max.	0.3 max.	0.75 max.	—	—	—	—	—	—
460	R	0.5 –1.25	0.75–1.25	1.0 max.	1.0 max.	0.3 max.	0.75 max.	—	—	—	—	—	—
464A	R	0.6 max.	1.5 max.	3.5 –4.8	1.2 max.	—	1.0 max.	—	—	—	—	—	—
478	99 min.	—	0.5 max.	0.2 max.	—	0.25 max.	0.6 max.	—	0.1 max.	—	—	Nil	—
479	R	0.4 –1.0	0.7 max.	3.5 –4.5	0.4 –0.7	0.25 max.	0.8 max.	—	0.2 max.	—	0.05 max.	Nil	—
520	R	0.4 –0.9	0.7 max.	3.5 –4.5	0.4 –0.7	—	0.7 max.	—	—	—	—	—	Ti 0.3 max. (if present).
523	*Material to latest B.S. Specification L.1 or D.T.D. 423A*												
543	R	1.3 –1.7	2.0 max.	1.5 –2.5	—	0.5 –2.0	0.8 –1.3	—	—	0.02–0.12	—	—	—
546B	R	0.6 max.	1.5 max.	3.5 –4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	Coating, Al 99.7 min.
603B	R	0.6 max.	1.5 max.	3.5 –4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	—
606	R	1.75–2.75	0.6 max.	0.15 max.	0.5 max.	—	0.75 max.	—	—	—	—	—	—
61CB	R	0.6 max.	1.5 max.	3.5 –4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	Coating Al 99.7 min.
634	R	1.75–2.75	0.6 max.	0.15 max.	0.5 max.	—	0.75 max.	0.5 max.	—	—	—	—	—
635	R	0.4–0.8	0.7 –1.3	1.0 –2.0	—	0.25–1.0	0.5 max.	—	—	—	—	—	Cb 0.03–0.3.
646B	R	0.6 max.	1.5 max.	3.5 –4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	—
653	R	—	0.6 max.	0.15 max.	1.0 –1.5	—	0.75 max.	—	—	—	—	—	—
683	R	2.0 –3.5	0.5 max.	1.5 max.	0.25–1.0	—	0.5 max.	—	4.5 –6.5	—	—	—	Ti 0.3 max. (if present). Cr 0.5 max. (if present).
687	R	2.0 –3.5	0.5 max.	1.5 max.	0.25–1.0	—	0.5 max.	—	4.5 –6.5	—	—	—	Ti 0.3 max (if present). Cr 0.5 max. (if present). Coating, Zn 0.75–1.25. Al R.
693	R	2.0 –3.5	0.5 max.	1.5 max.	0.25–1.0	—	0.5 max.	—	4.5 –6.5	—	—	—	Ti 0.3 max. (if present). Cr 0.5 max. (if present).
706	R	0.6 max.	1.5 max.	3.5 –4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	Coating, Al 99.7 min.
710	R	0.6 max.	1.5 max.	3.5 –4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	Coating, Al 99.7 min.
746	R	0.6 max.	1.5 max.	3.5 –4.8	1.2 max.	—	1.0 max.	—	—	0.3 max.	—	—	Coating, Al 99.7 min.
B.S.I. Aircraft Materials													
6L 1	R	0.4 –0.9	0.7 max.	3.5 –4.5	0.4 –0.7	—	0.7 max.	—	—	—	—	—	Ti (if present) 0.3 max.
5L 3	R	0.4 –0.9	0.7 max.	3.5 –4.5	0.4 –0.7	0.25 max.	0.7 max.	—	0.1 max.	0.3 max.	0.05 max.	0.04 max.	—
2L 4	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	Fe + Si 1.75 max. Other metallic impurities 0.25 max.
3L 5	R	—	0.7 max.*	2.5 –3.0	—	—	0.8 max.*	—	12.5–14.5	0.2 max.*	0.1 max.*	—	—
3L 8	R	—	0.7 max.*	11.0 –13.0	—	—	0.8 max.*	—	0.1 max.*	0.2 max.*	0.1 max.*	—	—
4L11	R	—	0.7 max.*	6.0 –8.0	—	—	0.8 max.*	—	0.1 max.	0.2 max.*	0.1 max.*	1.0 max.†	—
2L16	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	Fe + Si 1.75 max. Other metallic impurities 0.25 max.
2L17	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	Fe + Si 1.75 max. Other metallic impurities 0.25 max.
2L24	R	1.2 –1.7	0.6 max.*	3.5 –4.5	—	1.8 –2.3	0.6 max.*	—	—	0.2 max.*	0.05 max.*	—	Si + Fe 1.0 max.* Sn + Zn 0.1 max.*
4L25	R	1.2 –1.7	0.6 max.	3.5 –4.5	—	1.8 –2.3	0.6 max.	—	—	0.3 max.	—	—	Si + Fe 1.0 max.
2L30	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	Fe + Si 1.75 max. Other metallic impurities 0.25 max.
3L31	99 min.	—	0.5 max.	0.03 max.	—	—	0.6 max.	—	0.03 max.	—	—	—	—
2L33	R	—	10.0 –13.0	0.1 max.*	0.5 max.*	—	0.6 max.*	—	0.1 max.*	0.2 max.*	0.1 max.*	—	—
L34	99 min.	—	0.5 max.	—	—	—	0.6 max.	—	—	—	—	—	Fe + Si 0.9 max. Other metallic impurities 0.1 max.
L35	R	1.2 –1.7	0.6 max.*	3.5 –4.5	—	1.8 –2.3	0.6 max.*	—	—	0.2 max.*	0.05 max.*	—	Si + Fe 1.0 max.* Sn + Zn 0.1 max.*
L36	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	0.2 max.	—	—	Fe + Si 1.7 max. Other impurities 0.2 max.
2L37	R	0.4 –0.9	0.7 max.	3.5 –4.5	0.4 –0.7	0.25 max.	0.7 max.	—	0.1 max.	—	0.05 max.	Nil	Ti (if present) 0.3 max.
2L38	R	0.4 –0.8	0.7 max.	3.5 –4.5	0.4 –0.7	0.25 max.	0.7 max.	—	0.1 max.	0.3 max.	0.05 max.	Nil	Coating, Al 99.5 min.
2L39	R	0.4 –0.9	0.7 max.	3.5 –4.5	0.4 –0.7	—	0.7 max.	—	—	—	—	—	Ti (if present) 0.3 max.
2L40	R	0.3 –1.5	1.5 max.†	1.5 –4.5	1.0 max.†	2.0 max.†	0.15–1.5	0.2 max.†	—	0.2 max.†	—	—	Ce 0.3 max.† Nb 0.3 max.†
2L42	R	1.2 –1.8	1.3 max.	1.5 –3.0	—	0.5 –1.5	1.0 –1.5	—	—	0.2 max.	—	—	—
L44	R	1.0 –3.0	0.7 max.*	—	1.5 max.	0.35 max.†	0.7 max.*	0.5 max.†	0.1 max.	02. max.*	0.05 max.	Nil	—
L45	R	0.3 –1.5	1.5 max.†	1.5 –4.5	1.0 max.†	2.0 max.†	0.15–1.5	0.2 max.†	—	0.2 max.†	—	—	Ce 0.3 max.† Nb 0.3 max.†
L47	R	0.3 –1.0	1.0 max.†	1.5 –4.5	1.2 max.†	1.5 max.†	0.3 –1.0	0.2 max.†	0.1 max.	0.2 max.†	0.05 max.	Nil	Ce 0.3 max.† Nb 0.3 max.† Coating, Al 99.5 min.
5T 4	R	0.4 –0.9	0.7 max.	3.5 –4.5	0.4 –0.7	—	0.7 max.	—	—	—	—	—	Ti (if present) 0.3.
4T 9	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	Fe + Si 1.7 max.

* Denotes elements classified as impurities. † Denotes elements which may be present at option of manufacturer.

Schedule II—Continued

	Al	Mg	Si	Cu	Mn	Ni	Fe	Cr	Zn	Ti	Pb	Sn	Remarks
B.S. Specifications													
359	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	Fe+Si 1.75 max. Other metallic impurities 0.25 max.
360	99 min.	—	0.5 max.	—	—	—	0.6 max.	—	—	—	—	—	Fe+Si 0.9 max. Other metallic impurities 0.1 max.
361	R	—	1.0 max.*	6.0 –8.0	—	—	1.0 max.*	—	0.1 max.*	—	—	—	Other metallic impurities 0.1 max.
362	R	—	1.0 max.*	11.0 –13.0	—	—	1.0 max.*	—	0.1 max.*	—	—	—	Other metallic impurities 0.1 max.
363	R	—	1.0 max.*	2.5 –3.0	—	—	1.0 max.*	—	12.5–14.5	—	—	—	Other metallic impurities 0.1 max.
385	98 min.	—	1.0 max	—	—	—	1.0 max.	—	—	—	—	—	Fe+Si 1.75 max. Other metallic impurities 0.25 max.
386	98 min.	—	1.0 max.	—	—	—	1.0 max.	—	—	—	—	—	Fe+Si 1.75 max. Other metallic impurities 0.25 max.
395	R	0.4 –0.7	—	3.5 –4.5	0.4 –0.7	—	0.75 max.*	—	—	—	—	—	—
396	R	0.4 –0.7	—	3.5 –4.5	0.4 –0.7	—	0.75 max.*	—	—	—	—	—	—
414	R	1.2 –1.7	0.6 max.	3.5 –4.5	—	1.8 –2.3	0.5 max.	—	—	—	—	—	—
477	R	0.4 –0.7	—	3.5 –4.5	0.4 –0.7	—	0.75 max.*	—	—	—	—	—	—
478	R	1.2 –1.7	0.6 max.*	3.5 –4.5	—	1.8 –2.3	0.5 max.*	—	—	—	—	—	—
532	R	0.4 –0.7	—	3.5 –4.5	0.4 –0.7	—	0.75 max.*	—	—	—	—	—	—
533	R	1.2 –1.7	0.6 max.*	3.5 –4.5	—	1.8 –2.3	0.5 max.*	—	—	—	—	—	—
702	R	—	10.0 –13.0	0.1 max.	0.5 max.	—	0.6 max.	—	0.2 max.	0.1 max.	—	—	Other metallic constituents (excluding Na) 0.1 max.
703	R	1.2 –1.7	0.6 max.*	3.5 –4.5	—	1.8 –2.3	0.6 max.*	—	—	—	0.05 max.*	—	Sn+Zn 0.1 max. Si+Fe 1.0 max. Total other impurities 0.2 max.
704	R	1.2 –1.7	0.6 max.*	3.5 –4.5	—	1.8 –2.3	0.6 max.*	—	—	—	0.05 max.*	—	Sn+Zn 0.1 max. Si+Fe 1.0 max. Total other impurities 0.2 max.
1080	R	0.25–0.75	—	2.5 –4.0	0.2 max.*	0.05 max.*	0.75 max.*	—	0.2 max.*	—	—	0.1 –0.5	Sb 0.3–1.0. Fe+Si 1.2 max.
BS/STA7 Specifications													
A1	99.99 min.	—	—	—	—	—	—	—	—	—	—	—	—
A2	99.8 min.	—	—	—	—	—	—	—	—	—	—	—	—
A3	99.6 min.	—	—	—	—	—	—	—	—	—	—	—	—
A4A B C D E	99 min.	—	0.5 max.	0.03 max.	—	—	0.6 max.	—	0.03 max.	—	—	—	—
AC1	R	0.1 max.	2.0 –4.0	6.0 –8.0	—	—	1.0 max.	—	2.0 –4.0	—	—	—	Ni+Sn+Pb+Mn 1.0 max.
AC2	R	0.3 max.	9.0 –11.5	0.75–2.5	0.5 max.	1.5 max.	1.0 max.	—	1.2 max.	—	—	—	Other constituents 0.5 max. Ni+Cu 3.0 max.
AC 3	R	0.1 max.	1.3 max.	2.5 –4.5	0.5 max.	0.5 max.	1.0 max.	—	9.0 –13.0	—	—	—	Ni+Sn+Pb+Mn 1.0 max.
AC 4	R	0.15 max.	3.0 –6.0	2.0 –4.0	0.3 –0.7	0.35 max.	0.8 max.	—	0.5 max.	0.2 max.	—	—	For ingot Zn=0.2 max. Mn+Fe 1.3 max.
AC 5	R	3.0 –6.0	—	—	0.25–0.75	—	0.6 max.	—	—	—	—	—	Total other elements (including Fe) 1.0 max.
AC 6	R	—	10.0 –13.0	0.1 max.	0.5 max.	0.1 max.	0.6 max.	—	0.1 max.	0.2 max.	0.05 max.	0.04 max.	—
AC 7	R	0.05–0.2	0.75–2.8	0.8 –2.0	—	0.8 –1.75	0.25–1.4	—	0.1 max.	—	0.05 max.	0.04 max.	Ti+Cb+Ce+Cr 0.05–0.30.
AC 8A B	R	0.3 –0.8	4.5 –6.0	—	0.25–0.8	0.1 max.	0.6 max.	—	0.1 max.	0.1 –0.2	0.05 max.	0.04 max.	—
AC 9A B	R	0.6 max.	10.0 –13.0	—	0.6 max.	0.1 max.	0.6 max.	—	0.1 max.	—	0.05 max.	0.04 max.	Total other constituents (including Ni, Zn, Sn, Pb), 0.2 max.
AC10	R	9.5 –11.0	0.25 max.	0.15 max.	—	—	0.3 max.	—	—	—	—	—	Ti+Mn+Ca 0.25 max.
AC11A B	R	—	0.25 max.	4.0 –5.0	—	—	0.25 max.	—	—	0.25 max.	—	—	Ni+Mg+Mn+Zn 0.2 max.
AC12	R	0.15–0.35	0.6 max.	9.0 –10.5	0.6 max.	0.5 max.	0.3 –1.0	—	0.1 max.	—	—	0.1 max.	Zn+Sn+Pb 0.2 max. Fe+Mn 1.4 max. In approved cases max. Si content may be increased to 2.0.
AC13A B	R	0.75–1.5	12.0 –14.0	0.5 –1.3	—	1.0 –2.5	0.6 max.	—	0.1 max.	—	0.05 max.	0.04 max.	Total other constituents (including Zn+Sn+Pb), 0.6 max.
AC14A B	R	1.2 –1.7	0.6 max.	3.5 –4.5	—	1.8 –2.3	0.6 max.	—	—	0.2 max.	0.05 max.	—	Fe+Si 1.0 max. Sn+Zn 0.1 max.
AC15	R	0.5 –1.7	2.0 max.	1.3 –3.0	—	0.5 –2.0	0.8 –1.4	—	—	—	—	—	Ti+Ce+Cb+Cr 0.05–0.30.
AW 1	R	—	4.5 –5.5	—	—	—	—	—	—	—	—	—	—

* Denotes elements classified as impurities.

Schedule II—Continued

	Al	Mg	Si	Cu	Mn	Ni	Fe	Cr	Zn	Ti	Pb	Sn	Remarks
BS/STA7 Specifications—Continued													
AW 2A B C D	R	—	9.0 –14.0	—	—	—	0.6 max.	—	—	—	—	—	Other constituents, 0.6 max.
AW 3A B C	R	—	0.6 max.	0.15 max.	1.0 –1.5	—	0.75 max.	—	—	—	—	—	—
AW 4A B C	R	1.5 –2.5	0.6 max.	0.15 max.	0.5 max.	—	0.75 max.	0.5 max.	—	—	—	—	—
AW 5A B C	R	3.0 –4.0	0.6 max.	0.15 max.	1.0 max.	—	0.75 max.	0.5 max.	—	—	—	—	—
AW 6A B C D	R	4.5 –5.5	0.6 max.	0.15 max.	1.0 max.	—	0.75 max.	0.5 max.	—	—	—	—	—
AW 7A B C	R	6.5 –7.5	0.6 max.	0.15 max.	1.0 max.	—	0.75 max.	—	—	—	—	—	—
AW 8	R	0.5 –0.75	—	2.5 –4.0	0.2 max.	0.05 max.	0.75 max.	—	0.2 max.	—	—	0.1 –0.5	Fe+Si 1.2 max. Sb 0.3–1.0.
AW 9A B	R	0.4 –0.8	0.3 –0.6	—	—	—	0.6 max.	—	—	—	—	—	—
AW10A B C D E F	R	0.5 –1.25	0.75–1.3	—	1.0 max.	—	0.6 max.	—	—	—	—	—	—
AW11A B	R	0.5 –1.25	0.75–1.25	2.0 max.	1.0 max.	0.25 max.	0.75 max.	—	0.1 max.	—	0.05 max.	0.04 max.	—
AW12	R	0.65–1.2	0.55–1.25	1.8 –2.5	—	0.6 –1.4	0.6 –1.2	—	0.1 max.	0.3 max.	0.05 max.	0.04 max.	—
AW13	R	0.2 –0.5	0.7 max.	1.5 –3.0	0.5 max.	0.7 max.	0.7 max.	—	0.1 max.	0.3 max.	0.05 max.	0.04 max.	—
AW14	R	0.4 –0.9	0.7 max.	3.5 –4.5	0.4 –0.7	0.25 max.	0.7 max.	—	0.1 max.	0.3 max.	0.05 max.	0.04 max.	—
AW15A B C D E F G H	R	1.0 max.	1.5 max.	3.5 –4.8	1.2 max.	0.25 max.	1.0 max.	—	0.1 max.	0.3 max.	0.05 max.	0.04 max.	— For G and H coating, Al 99.5 min.
AW16A B	R	4.0 max.	0.6 max.	3.0 max.	1.0 max.	—	0.6 max.	1.0 max.	4.0 –8.0	0 3 max.	—	—	—
AW17A B	R	1.2 –1.7	0.6 max.	3.5 –4.5	—	1.8 –2.3	0.6 max.	—	0.1 max.	0.3 max.	0.05 max.	0.04 max.	Fe+Si 1.0 max.
AW18	R	1.2 –1.8	1.3 max.	1.5 –3.0	—	0.5 –1.5	1.0 –1.5	—	0.1 max.	0.2 max.	0.05 max.	0.04 max.	—
Light Metals Control.		*L.A.C. Specifications*											
10	R	0.15–0.35	0.6 max.*	9.0 –10.5	0.6 max.*	0.5 max.*	0.3 –1.0	—	0.1 max.*	—	0.1 max.*	0.1 max.*	Fe+Mn 1.4 max. Zn+Sn+Pb 0.2 max.
112A	R	0.3 max.	9.0 –11.4	0.75–2.5	0.5 max.	1.5 max.	1.0 max.	—	1.2 max.	—	—	—	Cu+Ni 3.0 max. Total other impurities 0.5 max
113B	R	0.1 max.	1.3 max.	2.5 –4.5	0.5 max.	0.5 max.	1.0 max.	—	9.0 –13.0	—	—	—	Ni+Sn+Pb+Mn 1.0 max.

* Denotes elements classified as impurities.

SCHEDULE III

A.—MECHANICAL PROPERTIES OF THE LIGHT ALLOYS OF ALUMINIUM

Name of Alloy	Condition	Tensile strength, lb./sq. in.	Yield point, lb./sq. in.	% Elongation	Brinell hardness
Aeral	—	56,000–75,000	30,000–55,000	10–20	—
Aeron	Annealed	23,000–35,000	7,000–12,000	12–20	45–55
	Quenched	45,000–53,000	15,000–30,000	15–22	68–85
Aldrey	Annealed	44,000–49,000	38,000–43,000	9–5	90
Allautal	—	20,000–60,000	—	18–25	—
Almag	—	38,000–54,000	—	22–25	100–110
Almasilium	—	31,000–64,000	—	6–26	90
Almelec	—	44,600	—	6–8	90–100
Alneon	—	28,000–48,500	10,700–17,000	Up to 3	100–150
Alpax	—	21,000	8,500	2–5	60–80
Alucable	Annealed	44,000–49,000	38,000–43,000	5–9	90
Aludur 533	—	45,000–50,000	—	8–10	90–100
Aludur 570	—	60,000	—	17	90–100
Aludur 580	—	60,000–68,000	—	17–22	110–125
Aludur 630	—	60,000	—	17	90–100
Alufont (hard)	Sandcast	43,000	36,000	0.5	100–160
	Chillcast	44,000	42,000	1.5	
Alufont (soft)	Sandcast	35,000	20,000	3.5	85–100
	Chillcast	40,000	35,000	3.5	
Alumag	—	57,000–60,000	—	28	—
Anticorodal	Soft	15,000	9,000	25	60
	Hard	45,000–55,000	35,000–45,000	11–18	75–110
	Springhard	50,000–60,000	30,000–40,000	2–10	70–105
	Forged	40,000–50,000	35,000–45,000	10–15	75–110
Ardal	—	33,000	—	—	—
Avial	Annealed	17,000	700	27	40
Avional D	Normal	55,000–65,000	35,000–43,000	16–22	—
	Hard	78,000–87,000	—	2–4	—
Avional Z	—	62,700–71,500	37,000–46,000	12–15	—
Avional 411	—	65,000–74,000	—	8–12	115–130

Schedule III—Continued

Name of Alloy	Condition	Tensile strength, lb./sq. in.	Yield point, lb./sq. in.	% Elongation	Brinell hardness
B.S. Seewasser	Heat-treated	30,000	20,600	4	80
	Rolled	64,000–79,650	45,000–52,625	8–20	120
Birmabright	Sandcast	20,000–22,000	11,000–15,000	3–5.5	54–58
	Drawn	34,000–43,000	20,000–27,000	15–25	70–80
Birmasil	Chillcast	36,000–42,000	16,000–22,000	3–6	70–80
	Sandcast	28,000–29,000	14,000–16,000	2–4	52–60
Bondur	Annealed	31,000	—	15	—
	Heat-treated	65,000	43,000	16	125
Ceralumin C and D	—	63,000	55,000	9	—
Chlumin	—	26,000–31,000	—	4–10	80
Chromal	—	55,000–60,000	—	—	—
Cindal E 11A	—	31,500	1,4000	5–8	66
Cindal E 11B	—	36,000	18,500	4–6	72
Cindal L3/16	—	29,000	16,000	2–4	68
Constructal 2	—	54,000–60,000	—	18–25	95–115
Constructal 8	—	67,000–72,000	—	15–18	120–140
Dural H	—	47,000–50,000	—	16–25	—
Dural K	—	51,000–54,000			
Dural P	—	57,000–63,000			
Duralumin G	Sheet	65,000	40,000	8–15	—
	Extruded	69,000	45,000	15	—
Duralumin 681 B	—	64,000–68,000	—	10–12	120–130
Duralumin 681 H	—	50,000–55,000	—	10–16	—
Duralumin 681 K	—	31,000	—	20	—
Duralumin 681 ZB	—	65,000–68,000	—	10–12	130–140
Duralumin DM 31	—	71,000–74,000	—	10–12	134–146
Duranalium 3.5		(cf. Birmabright)			
Duranalium 7	—	57,000–64,000	—	4–10	110–130
Dursilium		(cf. Duralumin)			
Eutectal	—	38,000	—	4	98
Hiduminium 40	—	34,000–38,000	—	2.5	90–105
Hiduminium 44	—	40,000–52,000	—	10–15	90–110

Name of Alloy	Condition	Tensile strength, lb./sq. in.	Yield point, lb./sq. in.	% Elongation	Brinell hardness
Hiduminium DU Brand	—	56,000–60,000	—	15–20	110–130
Hiduminium RR alloys	—	Up to 90,000	—	—	Up to 180
Hiduminium Y	Wrought	54,000–60,000	—	15–20	100–130
	Cast	40,000	—	*3	105–130
Hyblum	—	40,000–64,000	—	0–10	—
Hydronalium 5	—	—	—	16–22	55–60
Hydronalium 7	—	52,000	32,000	12	—
Hydronalium 9	Rolled	60,000	40,000	10	—
	Extruded	54,000	24,500	20	82
Hydronalium 10	Forged	54,000	32,000	15	93
Hydronalium 51 and 71	—	40,000–64,000	—	2–5	*60
Inoxalium	—	31,000–64,000	—	6–26	90
Italsil		(Italian Alpax)			
K.S. Seewasser	Sandcast	26,000	12,800	2.5	60
	Diecast	32,720	12,800*	1.6	81
	Rolled	45,500	36,000	2	83
Kolchugalumin		(Soviet Ni-Duralumin)			
Kupfersilumin	—	25,000	14,000	2–4	60
Lautal	—	35,000	18,000	25	65
Lo-Ex	Annealed	30,000	- -	0–1	90
	Hard	38,000	—	1	120
Magaluma	Soft	29,000–36,000	10,000–14,500	15–20	—
	Hard	42,500–50,000	36,000–42,500	2–6	—
Magdal	—	34,000	—	8	—
Magnalium	—	41,800	—	34	29
		14,900	—	31	69
Maluminium	—	21,000	—	1.5	—
Mangal	—	17,000	—	20	—
Manganal	—	16,000–17,000	—	30	30
Miralite	Cast	24,000	—	—	—
	Drawn	54,000	—	—	—
Nelson Bohnalite	—	25,500	23,400	0.2	110
Neonalium	—	22,800	—	0–1	100–120
Nicral	—	—	—	—	40–120
Nural 200	—	20,000–28,000	—	0.3–0.5	90–120
Nural 122	—	22,000–30,000	—	0.3–1.5	90–120
Nuremberg gold	—	—	—	—	—
Pantal	—	50,000–60,000	—	2–10	100–120
Peraluman	Soft	31,000–36,000	15,000–21,000	—	—

* Approximately

Schedule III—Continued

Name of Alloy	Condition	Tensile strength, lb./sq. in.	Yield point, lb./sq. in.	% Elongation	Brinell hardness
Peraluman	Hard	50,000–65,000	45,000–58,000	—	—
Peraluman 7	Half-hard	60,000	43,000	15–20	90–95
	Annealed	43,000	29,000	26–30	80–90
Permite 1004	Chillcast	23,000	—	1.0	80
	Sandcast	20,000	—	1.0	60
Polital	—	40,000–46,000	—	10–12	80–100
Quarzal	—	21,000	—	0.5–1	160–180
Savoye		(Coinage	metal)		
Scleron	—	64,000	38,000	—	—
	Aged	57,000	—	15	110–135
Silmalec	—	44,000–49,000	38,000–43,000	9–5	90
Silumin	—	21,000	8,500	20	50
Silumin Beta	—	25,000	14,000	2–4	60
Silumin Gamma	—	28,000	16,000	—	85–110
Studal	—	34,000	—	8	—
Superduralumin	—	59,000	—	8–12	160–170
Thalassal	—	38,000–43,000	—	3	70
Ultralumin	—	54,000–60,000	—	14–24	—
Wilmil	—	26,000–28,000	—	5–14	—
Wilmil M	—	25,000–28,000	14,000–16,000	2–4	60–110
AW15	Hard-worked	37,000	—	3	59
	Annealed	17,000	—	27	32
BA 20	—	31,000–36,000	—	5	—
BA 23	—	29,000–39,000	—	3–20	80–85
BA 24	—	25,000–36,000	—	12–20	52–90
BA 25	—	37,000	—	25	75
BA 30	—	20,000	—	30	40–50
BA 31	—	35,000–47,000	—	3–13	85–90
BA 35	—	41,000	—	27	78
BA 37	—	21,000–28,000	—	1.5–30	75
BA 40D	—	25,000–31,000	—	8–15	55–60
BA 40J	—	22,000–27,000	—	11–20	47–50
BA 40M	—	40,000–50,000	—	1–1.5	105–115
BA 42	—	24,000–39,000	—	0.5	140
BA 60A	—	17,000	—	40	30
B.S.S.	Soft	47,000	22,000	25	—

Schedule III—Continued

Name of Alloy	Condition	Tensile strength, lb./sq. in.	Yield point, lb./sq. in.	% Elongation	Brinell hardness
B.S.S.	Hard	78,000	65,000	3	—
KS 245	—	29,000	25,000	0.2	130
KS 280	—	27,000	26,000	0.25	120
KSS	Sandcast	26,000	12,800	2.5	60
	Diecast	32,720	12,800	1.6	81
	Rolled	45,500	36,000	2	83
M.G.5	—	—	—	16	—
M.G.7	Soft sheet	50,000	24,000	26	—
	Hard-rolled	70,000	62,000	4	115
M.V.C.	Sandcast	18,000–27,000	10,000–11,000	5–15	50
	Chillcast	22,000–30,000	—	10	—
NA 3 S	—	13,000–17,000	—	20–25	—
NA 17 S	—	56,000	—	15	—
NA 22 S	—	—	—	—	—
NA 24 S	—	—	—	—	—
NA 23 S	—	56,000	—	15	—
NA 25 S	—	—	—	—	—
NA 26 S	—	60,000	—	8	—
NA 51 S	—	31,000–45,000	—	8–15	—
NA 57 S	—	25,000	—	18	—
NA 75 S	—	72,000	—	8	—
NA 125	—	29,000–38,000	—	—	—
NA 160	—	21,000	8,500	2–5	60–80
NA 161 A	—	34,000–43,000	—	2	—
NA 162	—	29,000–36,000	—	—	—
NA 226	—	38,000–45,000	—	9–13	—
NA 350	—	40,000	—	12	—
NCA alloy	Rolled	45,000	—	—	—
	Sandcast	24,000–31,000	12,000–15,000	5–7	63
RR 50	Sandcast	20,000–25,000	18,000–20,000	4	65
	Heat-treated	25,000–30,000	—	3	72
RR 53B	Die-cast	31,300	28,000	3	80
	Heat-treated	56,000	50,400	1	130
RR 56	—	60,000–72,000	54,000–58,000	10–20	120–160
RR 59	Heat-treated	55,000	47,000	8	127
	Forged	52,000–65,000	50,000–56,000	6–10	120–150
RR 77	—	73,000	—	8	—

STRENGTH CONVERSION TABLE

Tons/sq. in.	Lb./sq. in.	Kg./mm.^{2}
1	2,240	1.575
25	56,000	39.37
26	58,240	40.95
27	60,480	42.52
28	62,720	44.10
29	64,960	45.67
30	67,200	47.25
31	69,440	48.82
32	71,680	50.40
33	73,920	51.97
34	76,160	53.55
35	78,400	55.12
36	80,640	56.70
37	82,880	58.27
38	85,120	59.85
39	87,360	61.42
40	89,600	63.00

STRENGTH CONVERSION TABLE

Kilograms/square millimetre to tons/sq. in.

10	6.35	26	16.51
11	6.99	27	17.15
12	7.62	28	17.78
13	8.26	29	18.41
14	8.89	30	19.05
15	9.53	31	19.68
16	10.16	32	20.32
17	10.80	33	20.95
18	11.43	34	21.59
19	12.07	35	22.22
20	12.70	36	22.86
21	13.34	37	23.49
22	13.97	38	24.13
23	14.61	39	24.76
24	15.24	40	25.40
25	15.88		

SCHEDULE IV

THE PHYSICAL AND ELECTRICAL PROPERTIES OF ALUMINIUM AND THE BEST-KNOWN ALLOYS

The Physical and Electrical Properties of Aluminium

ATOMIC WEIGHT

26.97.

Seventh Rep. Int. Atomic Wt. Comm.

SPECIFIC GRAVITY

2.70 (varies according to the purity of the metal and the treatment it has undergone).

J. D. Edwards. Trans. Amer. Electrochem. Soc., 1925, XLVII, p. 287.

MELTING POINT

659.8°C.—Aluminium 99.97%.
658.7°C.—Aluminium 99.66%.

J. D. Edwards. Trans. Amer. Electrochem. Soc., 1925, XLVII, p. 287.

BOILING POINT

1,800°C.

H. Greenwood. Proc. Phys. Soc., 1910, A LXXXIII, p. 483.

MAGNETIC SUSCEPTIBILITY

0.65×10^{-6}.

K. Honda. Ann. Physik, 1910, XXXII, 4, p. 1027.

STANDARD ELECTRODE POTENTIAL

$Al, Al^{\cdot\cdot\cdot}$ -1.33 volts at 25°C.

S. Glasstone. "The Electrochemistry of Solutions," p. 296.

LATENT HEAT OF FUSION

92.4 cal./gm.

Awbery and Griffiths. Proc. Phys. Soc., 1926, XXXVIII, p. 5.

HEAT CONTENT

The following figures are referred to 20°C. :—

400°C.— 88 cal./gm.
600°C.—146 cal./gm.
700°C.—267 cal./gm.

Awbery and Griffiths. Proc. Phys. Soc., 1926, XXXVIII, p. 5.

COEFFICIENT OF LINEAR EXPANSION

The following table shows the average coefficients of expansion per °C. $\times 10^{-6}$:—

Temp. range, °C.	Cast Al, 99.95%	Cast Al, 99.74%	Rolled Al, 99.15%
20–100	23.8	23.8	24.0
20–200	24.7	—	25.9
20–300	25.7	25.6	26.7
20–400	26.7	—	27.2
20–500	27.7	—	27.9
20–600	28.7	29.4	28.6
100–200	25.5		
200–300	27.5		
300–400	29.5		
400–500	31.5		
500–600	33.5		
300–600	31.5		

Hidnert. Sci. Pap. Bur. Stand., 1925, 497.

THERMAL CONDUCTIVITY

The following table shows the thermal conductivity at various temperatures expressed in c.g.s. units :—

Temp. °C.	k
109	0.528
129	0.532
154	0.528
254	0.536
375	0.542

F. H. Schofield. Proc. Roy. Soc., 1927, A CXV, p. 236.

ELECTRICAL PROPERTIES

(1) *Annealed Wire :*

The following table shows the resistivity and temperature coefficient for annealed wire :—

Purity, %	Resistivity at 20°C.	Temp. coefficient at 20°C.
99.997	2.62	0.00433
99.55	2.767	0.0040
99.10	2.78	0.00413
98.61	2.835	0.0040

Gauthier. J. Inst. Metals, 1936, LIX.

(2) *Wire, Drawn and Annealed :*

This table shows the influence of annealing on the resistivity at 20°C. :—

Purity, %	Hard-drawn	Annealed
99.68	2.82	2.75
99.48	2.89	2.77
99.36	2.91	2.78
99.19	2.94	2.80

British Aluminium Co. Ltd.

The above figures, while representative, must not be taken as limiting values, since a considerable influence is exerted by the treatment the material has undergone.

The Physical and Electrical Properties(¹) of Duralumin

NOMINAL COMPOSITION

Copper	4%
Magnesium	0.6%
Manganese	0.6%
Aluminium	The balance

(Impurities : Iron not more than 0.75%.)

SPECIFIC GRAVITY

2.85 maximum.(²)

British Standard Specifications 395, 396, 477 and 532.

MELTING RANGE

560–650°C.

ANNEALING RANGE

350-400°C.

British Standard Specifications 395, 396, 477 and 532.

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(1) All the figures given must be regarded as merely representative on account of the inevitable variations in the composition and properties of all manufactured alloys.

(2) Nominally 2.79.

Normalizing Temperature

480–490°C.

British Standard Specifications 395, 396, 477 and 532.

Forging Range

400–470°C.

Coefficient of Linear Expansion

The following table shows the average coefficients of expansion per °C. × 10^{-6} :—

Temp. range °C.	Coefficient
20–100	22.0
20–200	23.5
20–300	25.0

L. W. Kempf. Trans. A.I.M.M.E., Feb., 1933.

Thermal Conductivity

The following table shows the thermal conductivity at various temperatures expressed in c.g.s. units for the alloy in the extruded and heat-treated condition(3) :—

Temp. °C.	k
87	0.212
273	0.383
373	0.432
476	0.465

W. Männchen. Z. Metallk., 1931, XXIII, 7, p. 193.

Electrical Resistivity

4.9–5.2 microhms/cm.^{3} for the alloy in the heat-treated condition.(4)

The Physical and Electrical Properties of 10-13% Aluminium-Silicon Alloy ("Silumin," "Alpax," "Wilmil," "B.A.40D")(5)

Nominal Composition

Silicon	10–13%
Iron	Not more than 0.60%
Manganese	Not more than 0.50%
Zinc	Not more than 0.20%
Copper	Not more than 0.10%
Titanium	Not more than 0.10%
Aluminium	The balance

Total other metallic constituents (excluding sodium) not more than 0.10%.

British Standard Specification No. 702 (1936).

Specific Gravity

Normal	2.67–2.66	According to Si content
Modified	2.66–2.65	

Eutectic Composition

11.6–15.1%, according to degree of modification.

Melting Point

577°C.

Freezing Point (Solidus Extremes)

577–560°C., according to composition and degree of modification.

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(3) *Circa* 0.40 for annealed material at 100°C.

(4) *Circa* 3.8 for annealed material.

(5) A number of the above figures, for which no source has been given, have been taken from commercial literature.

LIMITING TEMPERATURES OF SOLIDIFICATION RANGES

590°C. and 560°C. for composition and modification limits.(6)

COEFFICIENT OF LINEAR EXPANSION

The following table shows the average coefficients of expansion per °C. × 10^{-6} :—

Temp. range °C.	Coefficient
20–100	19.4
20–200	21.0
20–500	24.0
300–500	24.0

P. Hidnert. Sci. Pap. Bur. Stand., 1925, 714.

THERMAL CONDUCTIVITY

The following table shows the calculated values of the thermal conductivity *k* at 25°C. expressed in c.g.s. units for the alloy in different conditions :—

Condition of alloy		k
Normal :	As cast	0.29
	Annealed	0.31
Modified :	As cast	0.37
	Annealed	0.39

L. W. Kempf, C. S. Smith and C. S. Taylor. Trans. A.I.M.M.E., 1937, 124, p. 287.

ELECTRICAL RESISTIVITY

The following table shows the electrical resistivity at 250°C. expressed in microhms/cm.^{3} for the alloy in different conditions :—

Condition of alloy		Elect. resistivity	Conductivity (7)
			%
Normal :	As cast	5.706	30.2
	Annealed	5.423	31.7
Modified :	As cast	4.352	39.6
	Annealed	4.186	41.2

L. W. Kempf, C. S. Smith and C. S. Taylor. Trans. A.I.M.M.E., 1937, 124, p. 287.

The Physical and Electrical Properties of " Birmabright "

CHEMICAL COMPOSITION

The theoretical composition of standard " Birmabright " is 3.5% magnesium, 0.5% manganese and the remainder high-purity aluminium.

SPECIFIC GRAVITY

2.68.

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(6) The supercooling effect of modification is lost on re-melting.

(7) Percentage of annealed copper standard.

FREEZING RANGE

580–635°C.

HEAT TREATMENT

Annealing range 360–380°C.

COEFFICIENT OF LINEAR EXPANSION

0.0000229 (approximate) per °C. for extruded material, determined between the temperatures of 0°C. and 30°C.

THERMAL CONDUCTIVITY

Approximately 0.4 c.g.s. units.

ELECTRICAL RESISTANCE

Specific resistance with hard-drawn wire at 20°C.—5.35 microhms per c.c.

The Physical and Electrical Properties of Y-Alloy

NOMINAL COMPOSITION (8)

Copper	4%
Nickel	2%
Magnesium	1.5%
Aluminium	The balance

SPECIFIC GRAVITY

Maximum 2.85.

British Standard Specifications 478, 533, 2L24, L35, 3L25, L43. Nominal 2.78.

FREEZING RANGE

490–630°C.

S. L. Archbutt. Nickel Bull., III, 7, 211.

COEFFICIENT OF LINEAR EXPANSION

Temp. range °C.	Coefficient $\times 10^{-6}$
20–100	22.5
20–200	23.5
20–300	24.5

L. W. Kempf. Trans. A.I.M.M.E., Feb., 1933.

(8) The composition range and permissible impurities according to British Standard and Aircraft Specifications are :—

Composition range	Maximum permissible impurities			
	B.S.S. 478 and 533	B.S.S. 703 and 704	2L24 and L35	3L25 and L43
% Cu, 3.5–4.5 Ni, 1.8–2.3 Mg, 1.2–1.7 Al, remainder	% Fe, ≯ 0.5 Si, ≯ 0.6	% Fe, ≯ 0.6 Si, ≯ 0.6 Fe+Si, ≯ 1.0 Pb, ≯ 0.05 Sn+Zn, ≯ 0.1 Other impurities, ≯ 0.2	% Fe, ≯ 0.6 Si, ≯ 0.6 Fe+Si, ≯ 1.0 Pb, ≯ 0.05 Sn+Zn, ≯ 0.1 Ti, ≯ 0.2	% Si, ≯ 0.6 Fe, ≯ 0.6 Other impurities, ≯ 0.5

HEAT-TREATMENT TEMPERATURES

The following table shows the heat-treatment temperatures given in the different specifications :—

	B.S.S. 478	**B.S.S. 533**	**B.S.S. 704 and L.35**	**3L25 and L.43**
	°C.	°C.	°C.	°C.
Heat-treatment ..	505–515	505–520	500–520	490–525
Annealing	350–400			
Artificial ageing ..	100	100	100	100–200

FORGING RANGE

350–500°C.

S. L. Archbutt. Machinery, 16/1/30.

THERMAL CONDUCTIVITY

As cast	0.33 cal./cm.^{2}/cm./sec./°C.
Heat-treated	0.30 cal./cm.^{2}/cm./sec./°C.
Annealed	0.42 cal./cm.^{2}/cm./sec./°C.

Kempf, Smith and Taylor. Metals Technology, Jan., 1937.

ELECTRICAL RESISTIVITY

As cast	4.9 microhms per cm.^{3}
Heat-treated	5.583 microhms per cm.^{3}
Annealed	3.874 microhms per cm.^{3}

Kempf, Smith and Taylor. Metals Technology, Jan., 1937.

SCHEDULE V

CORROSION OF ALUMINIUM, ALUMINIUM-SILICON ALLOY AND ANODIZED ALUMINIUM BY SOME TYPICAL COMMON CHEMICAL SUBSTANCES

This Schedule indicates in three broad classes the reaction of aluminium to the substances listed (in alphabetical order) :—

+ is used to indicate that aluminium is ordinarily not attacked by the reagent in question.

— is used to indicate that aluminium is attacked to a degree or in a manner (e.g., by pitting) which ordinarily renders it unsuitable for use with the reagent in question.

In column 3 indications are given of the behaviour of aluminium in special circumstances, using the same broad + and — symbols qualified by concentration and temperature conditions, etc. (separated by colons).

Column 5 shows, with the same broad symbolization, the behaviour of aluminium-silicon alloy or anodized aluminium.

Reagent	99.0–99.5% aluminium generally resistant	Behaviour of 99.0–99.5% aluminium in special circumstances. (Concentrations and temperatures relate to reagent)	99.0–99.5% aluminium non-resistant	Behaviour of anodized aluminium or Al–Si alloy. (Concentrations and temperatures relate to reagent)
Acetanilide	+			
Acetic acid		+ :: 95% : 20°C. + :: 98–99.5% : b.p. + :: vapours		+ : Al-Si :: 50% : 20°C. + : Al-Si :: 100% : 20°C. — : Al-Si :: 30% : 118°C. + : Al-Si :: 100% : 120°C.
Acetic ether	+			
Acetone	+			
Acetyl oxide	+	+ :: vapours at 500°C.		
Acetylene	+			
Albumen	+			
Alum				+ : Al-Si :: 5% : 20°C.
Aluminium chloride (soln.) ..			—	
Aluminium chloride (dry) ..	+			
Aluminium sulphate			—	+ : Al-Si :: 25% : 20°C.
Ammonia (ammonium hydroxide)		+ :: chloride-free		+ : Al-Si :: 10% : 20°C.
Ammonium carbonate	+			
Ammonium chloride			—	
Ammonium diphosphate ..		+ :: 3%		

Ammonium nitrate	+			
Ammonium sulphate		+ :: H_2SO_4-free : 70°C.		
Amyl acetate	+			
Aniline		+ :: 20°C. — :: boiling		
Aqua Regia			—	— : Al-Si
Barium chloride			—	
Benzaldehyde	+			
Benzenesulphonic acid			—	— : Al-Si
Benzoic acid	+			
Benzol (benzene)	+	1% H_2O permissible 20% alcohol permissible		+ : Al-Si
Boric acid		+ :: 20°C.		
Bromine			—	
Butyl acetate		+ :: 20°C.		
Butyl alcohol	+			
Butyric acid	Slight attack : not precluding use			
Calcium carbide	+			
Calcium chloride		+ :: dil. soln. : 20°C. — :: hot soln.		+ : Al-Si :: 25% : 20°C.
Calcium hydroxide			—	
Calcium hypochlorite			—	
Calcium oxalate			—	
Calcium sulphate	+ (anodizing desirable)			+ : Al-Si
Camphor	+			
Carbon dioxide	+	Anodizing desirable for solutions		+ : Al-Si :: CO_2 — : Al-Si :: H_2CO_3
Carbohydrates	+			
Carbon disulphide	+	Even at b.p.		
Carbon monoxide	+			+ : Al-Si
Carbon tetrachloride		+ :: 20°C. : dry — :: hot : moisture present		
Chloracetic acid			—	— : Al-Si
Chloric acid			—	— : Al-Si

Schedule V—Continued

Reagent	99.0–99.5% aluminium generally resistant	Behaviour of 99.0–99.5% aluminium in special circumstances. (Concentrations and temperatures relate to reagent)	99.0–99.5% aluminium non-resistant	Behaviour of anodized aluminium or Al–Si alloy. (Concentrations and temperatures relate to reagent)
Chlorine		+ :: dry : 20°C. — :: otherwise		
Chloroform		+ :: no moisture		
Creosote			—	+ : anodized
Chromates	+			
Chromic acid			—	
Citric acid		+ :: 20°C. — :: hot solutions		
Coal gas	+			
Copper acetate			—	— : Al-Si
Copper sulphate			—	— : Al-Si
Dyestuffs		+ :: Cotton dyes + :: Linen dyes — :: Vat dyes + :: Acid wool dyes (colour may be slightly modified)		
Essential oils	+			+ : Al-Si
Ether		+ :: acid-free		
Ethyl alcohol		+ :: 90–100%		+ : Anodized Al :: ≳90% + : Al-Si
Ethylene glycol	+			
Ferric chloride			—	— : Al-Si
Ferrous sulphate		+ :: 20°C.		+ : Al-Si :: 10% : 20°C.
Fluorine			—	
Fluosilicic acid			—	— : Al-Si
Formaldehyde	Slight attack : not precluding use			+ : Al-Si :: 50%, 100% : 20°C.
Formic acid			—	

Gallic acid	+	SO_2 content gives rise to attack		
Gelatine	+			
Glycerine	+			
Hydriodic acid			—	— : Al-Si
Hydrobromic acid			—	
Hydrocarbons	+			
Hydrochloric acid			—	— : Al-Si
Hydrocyanic acid	+			
Hydrofluoric acid			—	
Hydrogen	+	Even at high temperatures		
Hydrogen peroxide		+ :: if sodium metasilicate added		
Hydrogen sulphide	+			
Iodine			—	— : Al-Si
Iodoform	+			
Lactic acid	+	Should be anhydrous		+ : Al-Si :: 80% : 20°C.
Lead acetate			—	
Linseed oil	+			
Magnesium chloride			—	+ : Anodized + : Al-Si :: sat. d. soln. : 20°C.
Magnesium sulphate	+			+ : Al-Si :: 20°C.
Mercuric chloride			—	
Methyl alcohol		+ :: >80% — :: <75%		
Methyl chloride			—	
Methylamine		Slight attack not precluding use		
Naphthalene	+			
Napthylamine			—	
Nicotine	+			
Nitric acid		+ :: >40% : cold		+ : Al-Si :: conc. : 20°C. — : Al-Si :: hot
Nitrocellulose	+			
Nitrophenols		Presence of any water starts attack	—	

Schedule V—Continued

Reagent	99.0–99.5% aluminium generally resistant	Behaviour of 99.0–99.5% aluminium in special circumstances. (Concentrations and temperatures relate to reagent)	99.0–99.5% aluminium non-resistant	Behaviour of anodized aluminium or Al–Si alloy. (Concentrations and temperatures relate to reagent)
Nitrose gases		+ :: dry — :: damp		
Oils..	+			+ : Al-Si
Oleic acid	+	Completely anhydrous acid attacks		
Oxalic acid		+ :: 20°C.		— : Al-Si
Oxygen	+			+ : Al-Si
Ozone	+			
Phthalic acid	+			
Phenols		+ :: alcoholic or aqueous solutions — :: anhydrous at b.p.		+ : Al-Si
Phosphoric acids			—	
Phosphorus chloride			—	
Picric acid		— :: aqueous solutions + :: fused		
Potassium bromide			—	
Potassium carbonate			—	— : Al-Si
Potassium chlorate	+			+ : Al-Si :: 5% : 20°C.
Potassium chloride			—	
Potassium chromate	+			
Potassium cyanide		Sod. metasilicate inhibits attack	—	— : Al-Si
Potassium ferricyanide				+ : Al-Si :: 10% : 20°C.
Potassium ferrocyanide				+ : Al-Si :: 10% : 20°C.
Potassium hydroxide			—	— : Al-Si
Potassium nitrate..	+			+ : Al-Si :: 5% : 20°C. — : Al-Si :: fused salt
Potassium peroxide			—	— : Al-Si
Potassium persulphate			—	— : Al-Si
Potassium sulphate	+			+ : Al-Si

Potassium sulphide			—	— : Al-Si
Salicylic acid		+ :: anhydrous. Slight attack aqueous solutions		
Sodium bisulphate			—	— : Al-Si
Sodium borate	+			
Sodium chloride		+ :: attack dry does not preclude use — :: dilute solutions		
Sodium chromate..	+			
Sodium hydroxide			—	— : Al-Si
Sodium hypochlorite			—	
Sodium nitrite	+			
Sodium sulphite				+ : Al-Si :: 10%: 20°C. + : Anodized
Sodium tartrate	+			
Sodium thiosulphate				+ : Anodized
Sulphonal	+			
Sulphur	+	Even at b.p.		+ : Al-Si + : Al-Si :: molten
Sulphur dioxide		+ :: gaseous : hot — :: H_2SO_3		+ : Al-Si :: dry — : Al-Si :: H_2SO_3
Sulphuric acid		Some attack : not precluding all uses		
Sulphurous acid			—	
Sulphur chloride			—	— : Al-Si
Sulphuryl chloride	+	Even at b.p.		
Tannin (*see* Gallic acid)				
Tartaric acid		+ :: slight attack not precluding use at 20°C. — :: hot		
Town gas (*see* Coal gas)				
Trichlorethylene	+	Slight attack at high temp. in presence of H_2O		
Turpentine	+			
Zinc chloride			—	+ : Anodized :: 5% : 20°C.
Zinc sulphate		Slight attack : not precluding use		

CHAPTER VIII

THE FABRICATING INDUSTRY: SEMI-MANUFACTURING, PART I

CASTING

THE use of aluminium for casting is older than its application in the form of wrought products and the light alloy casting industry has to some extent developed along independent lines, particularly in those countries which have the oldest-established aluminium producing industries. In countries whose aluminium industries are more modern, signs of integration into the structure of the primary industry are apparent; in Germany, for instance, the pre-war grouping of the light alloy foundries was closely knit into the virgin and secondary metal production framework, and in the short-lived most modern and highly integrated aluminium industry of all in Japan the aluminium foundries were a well-co-ordinated sub-section of the mother industry. In the United States, however, and in this country, the light alloy foundry industry has not been too closely tied to the aluminium producing industry and has tended to grow along lines more closely related to the traditional structure of the foundry industry, with its main development along two lines, foundry development as such and foundry problems as subsidiary to and linked with the problems and interests of the big users of specialized cast components, such as the aircraft and automotive engine industries. The line of growth inside the aluminium industry proper, where casting is regarded as one process alongside other semi-manufacturing processes and the objective is the development of aluminium alloy products, has taken only third place in these countries.

The magnitude of the light metal casting industry is now considerable. In the United States there are well over three thousand foundries and die-casters turning out aluminium products, the volume of castings handled representing nearly a quarter (23%)

of the total tonnage of aluminium produced—that is, a castings figure in the hundred-thousand ton level at the present time. In Germany the aluminium castings output rose steadily from 36,000 tons in 1937 (representing 21% of total output of aluminium) to 90,000 tons in the peak year, 1943. In this country the war-time peak output rose to the order of 65,000 tons, in 1944, from the pre-war figure of 20,000 to 30,000 tons; and the post-war output has stabilized around the 40,000-ton level.

The light alloy foundry industry in Great Britain is very complicated, comprising a wide range of all types of foundries from the very large firms and groups of firms, few in number, to the smallest casting shops carrying on as individual firms; all these varieties being duplicated in the main dichotomy between the independent foundries and those forming part of the structure of the owner-user industries, and appearing in triplicate to some extent in the concerns concentrating on output of light metal products of all types. It may be estimated that at the present time more than six hundred foundries in Great Britain make aluminium castings, but of this total only comparatively few are devoted to light metal casting on any scale. Three firms have a large output of the order of 5,000 tons a year; eight or nine firms rank their production between the 1,000 and 5,000 mark; another hundred and thirty foundries specialize in light alloy casting with an aggregate peak capacity for an output of 20,000 tons; and the other five hundred foundries, including the very small shops and the jobbing foundries of large engineering firms produce occasional aluminium products.

This non-compact structure of the casting industry is the direct outcome of the technical aspects of casting aluminium and its alloys, which are versatile and easy casting materials to handle and do not necessarily depend upon an organization replete with elaborate equipment and technical control; even a shortage of skilled workers has not vitally hampered the industry in its expansion. The larger and specialized medium-sized foundries employ mechanization to a high degree whilst the small independent shops prove useful in taking up the great variety of castings required in quantities insufficient to justify major expenditure on specialized equipment and machines.

The war-time output of the aluminium foundries in this country was chiefly in the form of sand castings, but in the post-war years this position has been reversed and at the present time the output of die castings exceeds that of sand castings by about 40%. Improved technique is having an influence on prices and it is particularly interesting to note the lower prices as compared with pre-war figures quoted in the United States for large castings.

The two factors which have had perhaps the most significant bearing on foundry work in aluminium alloys are the development of the low-frequency induction furnace and the improvements in methods and techniques for degasification. The aluminium foundries have also, of course, benefited equally with those concerned with other metals from the introduction of X-rays into everyday shop working, which has been responsible for an enormous improvement in the quality of castings in general.

The Casting Alloys and Their Properties

The principal basic types of casting alloys of aluminium are shown in the Table opposite.

Apart from these typical straightforward binary and tenary compositions—allowance being made for the normal presence of the impurities ordinarily present in the aluminium forming the basis of the alloy—there are many special alloys, for example compositions suited particularly for fine die-casting, which are often very complex; and elaborate compositions for piston alloys, of which the RR series, for instance, have very numerous small alloying additions (see Schedule I on p. 157). Different trends and even "fashions" tend to develop in different countries—thus antimony has been a favourite addition in German and Swiss alloys for castings used in marine atmospheres, and cerium has given its name to the Ceralumin group of English alloys in which it functions as a grain-refiner in place of the titanium more commonly used.

TABLE XIX.—ALUMINIUM CASTING ALLOYS

Alloy type	Examples (trade names)	Nominal Composition							
		Si	Mg	Mn	Cu	Ti	Sb*	Ni	Al
Al–Si	Aipax, Silumin, Wilmil, L.33	10–13	—	—	—	—	—	—	Remainder
Al–Mg 3 . .	—	0–1.3	1.8–3.5	0.3–1.3	—	(0–0.3)	(0–0.3)	—	Remainder
Al–Mg 5 . .	Birmabright	—	3.6	0.25–0.75	—	—	—	—	Remainder
Al–Mg 7 . .	MG7	0.6–1.5	6–7.5	0.1–0.5	—	(0–0.3)	(0–0.3)	—	Remainder
Al–Mg 10† . .	—	0.35	9.5–11	—	<0.15	—	—	—	Remainder
Al–Cu 7 . .	4L11	—	—	—	6–8	—	—	Sn 0–1	Remainder
Al–Cu 12 . .	3L8	—	—	—	11–13	—	—	—	Remainder
Al–Si–Mg . .	Alpax beta	10–13	0.2–0.6	0.3–0.6	—	—	—	—	Remainder
Al–Si–Ni . .	Birmasil special	10–13	—	—	—	—	—	2.5–3.5	Remainder
Al–Mg–Si . .	—	2–5.5	0.5–3	0–1	—	—	—	—	Remainder
Al–Cu–Zn . .	3L5	—	—	—	2.5–3.0	—	—	Zn 12.5–14.5	Remainder
Al–Cu–Ni . .	" Y " Alloy†	0.1–0.5	1.2–1.7	—	3.8–4.2	—	Fe 0.2–0.9	1.7–2.2	Remainder

* Addition more common on the Continent than in England. † Heat-treatable (see p. 213).

GENERAL QUALITIES TO BE LOOKED FOR IN LIGHT ALLOYS FOR CASTING

The essential qualities required from a good casting alloy are that it shall have good mould-filling properties to avoid blow-hole and cavity formations, cracking or shrinking and the setting up of internal stresses; these requirements are mainly conditioned by high fluidity and the timing of shrinkage and hot-shortness factors in relation to the type of casting by suitable choice of alloy composition so that, ideally, they occur in the stage just at the instant of solidification, and are minimum.

GENERAL CASTING PROPERTIES OF ALUMINIUM

The essential requirements of the metal when it is poured into the mould is that it shall be fluid enough to run freely and fill every outline of the mould. The more fluid the alloy the more perfect will be the resulting casting. This quality of fluidity varies to quite a large degree among the aluminium alloys. Generally speaking, the Al-Si alloys head the list, followed by the Al-Mg-Si alloys and the binary Al-Mg alloys.

The fluidity of the alloy is in practice measured by the same method as that employed for determining the same quality in grey iron for casting in sand, namely the pouring of the metal into spiral moulds, a measure of the fluidity being the length of spiral which can be filled. Comparative figures for pure aluminium and the binary Al-Si alloys of the eutectic type are of the order of

Al-Si alloy	730 mm.
Commercial aluminium	400 mm.

The metal in each case being poured at 680° C. and the spiral mould being heated to 300° C.

Remelting, unless proper fluxing or refining is used, has a definite influence on the quality of the fluidity and the following figures give an indication of the deleterious influence on commercial-grade aluminium; the spiral length obtained for first, second and third melting (using the same pouring temperature and mould temperature as above) are:—

First melting—400 mm. spiral length;
Second „ —330 „ „
Third „ —290 „ „

The more slowly the metal can solidify in the mould the longer will its less viscous, fluid state be retained, that is to say, where the pouring temperatures are high, sand moulds should have a carefully controlled moisture content and metal moulds should be heated. There is, however, an optimum relationship between the pouring and mould temperatures and the latter must be determined by experience for a particular alloy to be on the one hand high enough to prevent premature cooling and on the other hand not too high to cause slowing-down of solidification and consequent coarse grain.

A rough figure for the shrinkage of aluminium and its alloys on solidification is 7%. This shrinkage is the chief cause of large draws. If the shrinkage takes place other than at the gates and risers the resulting casting may have quite serious internal cavities or external blowholes which render it effectively useless.

Proper design and technique of casting can, in general, prevent the formation of large internal cavities, but it is more difficult to avoid the formation of small pinhole cavities on solidification, particularly in the case of the alloys of aluminium which do not solidify at a fixed temperature as does the pure metal, but solidify in a number of stages, becoming first partially solid or thickly viscous or "pasty" before they finally solidify at the end of the solidification temperature range. During the solidification interval processes intervene which may give rise to the formation of fine so-called pores between the metal crystals in the casting. The binary eutectic aluminium-silicon alloy with 13% Si is the only alloy of aluminium which has a definite solidification point (570 degrees) and does not solidify over a temperature interval.

The hot-shortness which is an inevitable phenomenon in the process of casting alloys of certain composition may, if it occurs at an unfavourable time point, give rise to hot-cracking, particularly at certain portions of the casting. The most sensitive alloys from the angle of hot-crack formation are those with zinc, and the least sensitive are the binary silicon alloys, particularly the eutectic alloy with 13%. After the casting has passed through the solidification zone in which hot-shortness occurs, further shrinkage takes place and may give rise to the so-called shrinkage cracks, or alternatively to internal stressing of the solidifying casting if the design of the cores and the casting conditions are not closely controlled. In general, it may be said that to prevent ill effects from hot-shortness and contraction, care must be exercised not to remove alloys subject to hot-shortness too soon from the moulds; but this, of course, raises difficulties, particularly when dealing with metal moulds, if the contraction is considerable and the casting rapidly shrinks about the core. The actual contraction depends not only on the precise composition of a given alloy but on casting factors and is not a true physical constant.

Neither fluidity nor contraction are so important in the case of sand castings—except for very large castings—as in the case of chill castings. Hot-shortness can be very largely counteracted since there is no difficulty about allowing the metal to remain in the mould until it is sufficiently cool. Sand castings, however, are at a greater disadvantage with reference to the formation of cavities in consequence of the slower solidification across thick cross-sections; the cavities are generally not external draws but inner cavities. The binary Al-Si alloy has little tendency to form draws, but may form internal blowholes and cavities, particularly those of what the Germans call the " earthworm " type. All the other aluminium casting alloys have more or less tendency to form draws, and they also form pinholes and pores, particularly intercrystalline pores.

In selecting alloys for chill casting, it is essential to take into account low shrinkage, good fluidity, and small tendency to hot-shortness.

The following paragraphs indicate the main features of the different casting-alloy groups from the angle of foundry technique.

Details of the properties of the alloys may be found in Schedule III on p. 174.

THE AL-SI ALLOYS

The common binary alloy is the eutectic mixture with 10-13% Si. The aluminium-silicon alloys are generally treated by the so-called " modification " process which consists in fluxing the melt with metallic sodium or certain salts before pouring to control the grain size and structure. With careful management this treatment gives excellent properties to the finished casting, both in respect of mechanical strength and high elongation. The alloys of this group are characterized by excellent corrosion-resistance and are good subjects for welding; their chief disadvantage is their comparative softness which makes them rather troublesome to machine. They are good " general purpose " alloys suitable for most types of castings, particularly those of intricate design or thin section and for castings subject to shock.

THE AL-MG ALLOYS

The binary aluminium-magnesium alloys are met with in four main types, with roughly 3, 5, 7 or 10% of Mg. They have high mechanical strength and good corrosion-resistance towards a fairly wide range of atmospheres and substances commonly met with. They also cut well with machining tools and take a good polish.

THE AL-CU ALLOYS

The commonest of the binary aluminium-copper alloys is that with 6-8% copper which can be widely used as a " general purpose " alloy, either sand-cast or chill-cast. The other binary alloy with 12% Cu has a greater hardness but its strength characteristics are not greatly affected and it suffers from a rather low elongation value.

THE AL-SI-MG ALLOYS

The ternary alloys of aluminium with Si and Mg bring the casting alloys into the heat-treatable category;[1] the simplest is the alloy

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[1] See p. 213.

with 1.25% Mg and 0.6% Si which has good strength properties coupled with high elongation and very good elastic limit; and is notably good in corrosion-resistance and surface qualities. The latter characteristic makes it one of the few castings amenable to such after-treatment as anodizing. The actual foundry properties of the alloy are not too good and it is therefore limited in application to simple castings.

THE AL-CU-ZN ALLOYS

The most useful of this alloy group is that with 13½% Zn and 2½% Cu, which is in the first place cheap and in the second place a good alloy to utilize secondary aluminium. It is a medium-strength alloy but does not possess very good mechanical properties at high temperatures, and it suffers from the disadvantage of cracking during storage after casting.

THE AL-CU-NI ALLOYS

These alloys are amenable to heat-treatment and are used where high strength at higher temperatures is desirable. "Y" alloy, which contains in addition magnesium, can be made by heat-treatment to develop very outstanding mechanical strength.

PREPARATION OF ALLOYS

Pure aluminium melts, as is known, at 658° C.; the addition of alloying elements of course lowers the melting point below that of the pure aluminium and this principle is particularly advantageous in the case of the light alloys since it is undesirable for the aluminium to undergo overheating. In general an aluminium melt should not be allowed to reach a temperature above 750° C.; above this temperature a coarse grain is produced.

In the production of alloys where major quantities of high-melting constituents have to be added it is inconvenient to proceed with the direct addition of metal and it is usual to employ the so-called "hardeners" or key alloys containing known high proportions of the desired constituent. Thus, copper is usually added in this country to form hardeners with 50% (a 32% Cu key alloy is more usual on the Continent), nickel hardeners are available in different ranges from 20% Ni upwards, silicon hardeners are commonly those with 20% or 50%, manganese key alloy has up to 10% Mn and Ti or other grain-refining additions which are added in small amount are derived from 1% rich alloys. Zinc and tin can be added directly to the molten aluminium, being simply stirred into the melt held at below 700° C.; magnesium is introduced directly but requires a special perforated " spoon " to thrust it under the surface and prevent burning. Such additions as iron, chromium or cobalt are first heated with fluxes and are then added in small quantities at a time to prevent local over-heating of the aluminium melt. If complex alloys with multiple constituents are being mixed, several appropriate hardeners may be selected, or, preferably, a special key alloy is prepared with the constituents in the correct ratios in richer concentrations.

USE OF SECONDARY ALUMINIUM

It is not in all cases necessary to use virgin ingot of aluminium in the production of alloy castings; good secondary ingot is adequate for many purposes where castings are not exposed to special high duty as stressed engineering components or are not required to fulfil a high standard of corrosion-resistance. Foundries which utilize secondary aluminium necessarily have to have their own laboratory control of the composition of the metal employed. The use of secondary metal is largely determined by the supply position of virgin ingot and of course by the question of price in relation to the requirements of the particular casting. The cost of production of an intricate, high-duty sand casting in a heat-treated alloy of the highest grade in mass production is of the order of 2.5 times the cost of the same weight of virgin aluminium; and in times of scrap availability this figure would be roughly halved for castings produced from high-quality secondary ingot. (See also Chapter XV on Secondary Aluminium.)

Metallurgical Factors in Casting Aluminium Alloys

There are four main problems from the metallurgical point of view in the casting of aluminium:

1. The prevention of contamination by solid inclusions,

including oxides, gaining entry from the melting crucibles or from the paraphernalia such as stirrers used in the process of casting.

2. The prevention of gas absorption.
3. The avoidance of overheating.
4. The production of fine and uniform grain.

The first problem is ultimately one of control to ensure clean working and proper choice of crucible and implements. The prevention of gas (mainly hydrogen) absorption, with its attendant " pinholing " or " speckling " depends upon the elimination of all possible sources of water vapour in the furnace atmosphere; that is, upon thorough drying out of the furnace linings, of the coke used for firing and upon the use of high-grade gas-free hardeners or metals of addition as well as avoiding too high temperatures, which links with the problem of overheating. This is not so difficult to prevent, and it is good general practice to set 750° C. as a maximum heating temperature, although with careful working temperatures may be allowed to reach 800° C. without much risk of gas absorption, even in gas-fired or oil-fired furnaces. Overheating is not solely of interest from the angle of preventing gas absorption, however, but has an important influence on the grain-size, producing a tendency to coarser grain. The problem of grain-size is a most important one since the foundry properties of aluminium alloys are altogether improved when the metal is fine-grained—intercrystalline cracking during cooling is minimized and shrinkage porosity is greatly reduced. In addition the mechanical properties of the finished casting are rendered more uniform throughout its different parts and at varying cross-sections; and the tensile strength and shock-resistance are actually increased. The necessity for the achievement of fine grain has given rise to a special branch of foundry processing in the light alloy castings industry, depending on the incorporation in alloys of elements inducing small grain size. Notable among these elements are titanium, boron and niobium, though a host of others have been proposed and form the subject-matter of patented processes. (See also the section on choice of furnaces on p. 204.)

CHOICE OF CASTING METHOD: PRINCIPLES INVOLVED

Sand Casting is the method of most " universal " application and puts virtually no limit on the size of casting to be produced. Sand can be used for castings of complicated shape and for hollow ones (for this purpose sand is the only casting medium possible if the hollow product has an opening of smaller cross-section than the body). The disadvantages of sand-casting, apart from its poorer surface, are that the highest mechanical properties cannot be ensured, dimensional control is not precise and, from the foundry angle, a new mould has to be made for each casting. However, the introduction of machine moulding for intricate work greatly facilitates the production of such sand castings as lend themselves to this method; and the improvement in accuracy of patterns, the development of gating systems integral with patterns and the mechanization of core-removal by pneumatic equipment are all factors which have revolutionized sand-casting in modern foundries.

Gravity Die Casting, or " chill " casting, consists in pouring the molten metal into a metal mould and allowing it to fill by gravity. The moulds, or dies, are usually made of close-grained iron and are made in parts (sometimes very numerous indeed) fitted together and clamped to ensure correct registration. The mould is heated before the melt is poured into it and good foundry technique consists in determining the optimum temperature and solidification time cycle to produce a sound casting from a given alloy. A die-coating preparation is generally used—a range of proprietary coatings based on whiting and sodium silicate are available. In modern foundries suction is sometimes applied to the mould to withdraw air and ensure proper filling of narrow sections.

Gravity die-castings allow of much more refined control of solidification than sand-castings and have accordingly better mechanical properties and a much reduced tendency to form pinholes; they are dimensionally accurate and uniform in shape and have a good surface finish particularly suited for anodizing. The chief limitation from the angle of foundry practice is the economic limit to the size of castings which can be produced, since the iron moulds are very heavy to manipulate.

An offshoot of chill casting is the so-called "slush" casting, in which the two halves of a mould (for making a tea-pot spout, for instance, in pure aluminium) are hinged together, one half being attached to a support; molten metal (which must be a metal or a eutectic alloy with a definite melting point, not a melting range) is passed into the die which is then inverted to return surplus molten metal not immediately solidified on the walls to the melt.

Pressure Die Casting is an operation which involves injection into massive steel moulds under pressure so that the molten metal solidifies rapidly instead of crystallizing normally. There are two types of pressure machines; in one, the "gooseneck" type, which is not much used in this country for aluminium, comparatively low pressures (of the order of 400 lb./sq. in.) are employed and in the other, the "cold chamber" type, very high pressures (about 3 tons/sq. in.) are used in a mould clamped under a pressure of at least 50 tons. New developments are taking place in prefill methods with feed at initially low pressure.

The pressure process is best suited to small castings of simple shape and thin section. Remarkable dimensional accuracy is the outstanding feature of pressure-cast products, together with highly developed mechanical properties and rapidity of production. The method is, however, fairly costly because of the necessity of using high-grade alloy steels for the dies, which have to withstand big pressure and temperature changes. Also, where castings such as pistons have to be undercut, hand operation becomes essential and puts pressure casting out of court. Gravity die casting still accounts for a larger output than pressure casting where light metals are concerned.

Pressure castings cannot be anodized satisfactorily (see p. 205).

CHOICE OF MELTING FURNACE

A wide variety of furnaces fired by oil, gas, coke or electricity is nowadays available. The main considerations are the efficiency from the point of view of maximum output coupled with maximum heat usage: flexible temperature control coupled with even heating of the melt: avoidance of contamination (see p. 202) of the melt and the avoidance of unnecessary splashing and turbulence of the melt during pouring.

Processing of Aluminium Alloy Castings

After the castings leave the moulds they are given a series of preparatory treatments—chipping, grinding and snagging—before proceeding to the machine shops. In up-to-date foundries this processing is mechanized on conveyor lines. After finishing operations and shot or grit blasting the castings are given preliminary inspection before going to the heat-treatment departments which are under laboratory control. The heat-treated products are then subjected to final testing and inspection.

Surface treatment of castings, particularly by anodizing, poses considerable difficulties. Anodizing can only be applied to the casting alloys with suitable composition to stand up to the constituents of the anodizing bath: the most successful alloy from this point of view is the 1.25% Mg.-0.6% Si alloy (which is, however, a difficult alloy to cast). Where anodizing has to be undertaken with a view to decorative finish, the first essential requirement is that the casting shall be a good, sound product free from surface flaws or irregularities and possessed of even, fine grain-size. The next prerequisite is that the greatest care must be exercised in the mechanical finishing of the casting and in its subsequent cleaning by chemical means so that the casting skin is completely removed. The surface should preferably be polished or shot- or grit-blasted. After anodizing the most careful cleansing is necessary to ensure that no traces from the bath are entrapped in any surface pores. Dyeing of anodized castings is successful only in a limited range of colours and colour-matching with similarly treated sheet products is difficult with all but a very few dyes.

CHAPTER IX

THE FABRICATING INDUSTRY: SEMI-MANUFACTURING, PART II

MILL, PRESS AND FORGE PRODUCTS: POWDER PRODUCTION

THERE are a number of features about the aluminium fabricating industry dealing with semi-manufacturing in the form of wrought products produced in the rolling-mill, forge or press which are of special interest, being peculiar to the light metal industry and indicative of its position as an industry of modern birth and scientific conception and control. In the first place, semi-manufacturing of wrought products (in contradistinction to semi-manufacturing by casting) has customarily been integrated into the production industry: that is to say, it is the producers of virgin aluminium ingot who have undertaken the conversion of the ingot into mill, forge and press products, drawn tubes and profiles. This feature is particularly significant since it reflects the whole outlook of the newly developing science of metallurgy, which essentially relates the ultimate properties of metals to their ultimate structure or "morphological" characteristics: by unifying the control of processing and research on processing from the molten virgin metal *via* cast ingot and cast or extruded mill or forging billet (or in some modern developments direct) to the semi-manufactured product, a very important step forward has been taken in relating the requirements of metal products to their production and a very important long-term integration of the research and development functions of the light metal industry has been accomplished.

The second outstanding feature of the aluminium fabricating industry, again embodying the important principle of integration or unification—rationalization in the economic sense—is its flexibility viewed from the angle of quantity control. Some of the most advanced examples of attainment of quantity production in factories originally planned and equipped for much smaller manufacturing schedules have come from the aircraft industry in connection with the forging of aluminium alloys.

Because of the unification of the fabricating side of the industry concerned with semi-manufacturing processes with the parent aluminium reduction industry, all the aspects of its development show the interweaving of many factors not directly concerned with, or the product of research on, forging and working processes as such. The history of the light metal fabricating industry has gone through two main phases. Effectively it came into being in the First World War with the birth of the aircraft industry and the simultaneous outcrop of the important new ideas of aluminium alloy technology. In its first score of years the industry was on a workshop basis: since about 1938 it entered its second phase as a mass producer of sheet, extrusions and forgings. The great expansion during the recent War was again centred in the aircraft industry, but the achievements of the industry, born of the exigencies of all-out warfare in the modern age, remain translated into other terms in the mammoth structure of the post-war aluminium industry which is fast creating a new metal age.

Closely knit with the expansion of the fabricating industry are the advances in light alloy technology: the improvement in purity of the parent metal aluminium and the bearing of modernized production control on its quality and industrial position based on output capacity and cost of production: developments in ingot casting, which allow of the production of larger and better ingots: the introduction of trends which revolutionize the traditional conceptions of fabrication, such as the important development of strip-rolling straight from the molten metal and the parallel tendency to cut out the transition from "cast structure" to "forged structure" by replacing ingot with forged or extruded billets. These may be regarded as advances in principle, partly the product of the integral place which fabrication enjoys in the production industry viewed as a whole. There are contemporaneous advances in technique available as part of the generally advancing science of metal technology and not born of the aluminium industry alone: thus furnace technology has undergone great advances: equipment is available to allow of much higher rolling speeds and larger, heavier forged products: the size of extrusion presses has increased: forging presses, more economical than hammers, have been developed and contribute towards lower costs of production, whilst at the same time improved hammers for small and medium work are available. Such development keeps pace with the modern, still-evolving basic theories of plastic working to interpret into practice the objective of producing metal shapes in which the work done in forging is distributed as uniformly as possible over the whole forging die.

Again, the development of the principle of pre-fabrication, which came to the fore largely as a result of the war-time necessity to accelerate production, to save time and shipping space and to speed the reclamation of scrap metal in application to the light metal aircraft industry, brought into the aluminium fabrication industry several new and essential concepts, and taught the producer of aluminium a good deal not previously known about the fabrication of light metal products, particularly in suiting the right alloy to the right production job.

Viewed industrially, the second phase of the semi-manufacturing of wrought light alloy products shows spectacular growth. In the United States the number of fabricators, big and small, of aluminium and its alloys in the post-War period exceeds 7,500: this figure includes, of course, factories and workshops occupied with working and processing aluminium end products as well as semi-manufacturing. The largest American producer, the Aluminum Company of America, undertook a war-time expansion programme of its capacity for making sheet, extrusions, tubing, wire, rod, bar, rivets, forgings and other fabricated forms representing increases from two to six hundred per cent. A second big American fabricator, the Bohn Aluminum and Brass Company, operated during the war $25,000,000 of new Government aluminium fabricating plants and invested a further $3,000,000 of its own funds in such plant. In Europe, similar huge expansions were undertaken. In Greater Germany the peak figures during the war years represented an annual output capacity by the aluminium fabricating industry in excess of 400,000 metric tons. In post-War

Czechoslovakia the output of sheet, strip and sections is more than triple the 1937 figure and the output of wire is more than twenty times as great. In Japan, in spite of the comparative infantility of its aluminium industry, the ten years' output of aluminium and aluminium alloy mill products alone from 1936 to 1945 was well over 800,000 tons, the peak year 1944 having an output in excess of 137,000 tons of light metal sheet (this came mainly from twenty-one mills devoted to the rolling of light alloy and aluminium products but was supplemented to the extent of about seventeen per cent. from mills also engaged in rolling copper). In this country, during the recent War the all-round capacity for fabricating light metals was increased roughly fivefold, surpassing the 350,000-ton annual output mark at the peak in 1944. The most remarkable output has been achieved in rolling sheet and strip and the post-War rate of production has even exceeded the war-time peak output (in connection, primarily, with the temporary aluminium house programme). Even so, to meet the urgent need for further expansion it has been necessary to undertake the erection of new rolling mills sufficiently large to double the existing capacity. The post-War demand for forgings and pressings at first underwent a fall, due to the time lag in adjusting from the change-over from aircraft to general uses, which was naturally more marked in the case of the specialized products than in the case of sheet: but from the early part of 1948 the ground initially lost has been steadily regained. The official statistics show the 1947 output in the United Kingdom of sheet, strip, foil, bars, tubes, wire and forgings as nearly 179,000 long tons: and a modest estimate for the requirements of the British fabricating industry in 1948 puts it at a level where 200,000 tons of ingot have to be imported—full capacity operations would require much more metal than even this figure.

As the international aluminium industry stands to-day, the fabricating side of the industry, which includes not only semi-manufacturing but also the subsequent working processes carried out on the products of semi-manufacturing, is economically, by a considerable margin, the largest and most important side of the industry. The value of its output appreciably exceeds that of the virgin metal reduction industry: it employs more labour and pays more wages. This position is especially marked in Great Britain where the fabricating industry has of necessity far outstripped the small parent producing industry, a large proportion of the metal rolled and manufactured being based on imported virgin metal.

As between the two great main branches of semi-manufacturing in the aluminium industry, viz., casting and fabrication of wrought products, technologically the smooth, sound, uniform surface of a forging or pressing produced in a well-made die offers appreciable advantages over that of the best casting, particularly when the cost of finishing operations on the latter is taken into account. The general trend in those countries which have well-equipped, modern fabricating plant, is to use forgings for highly stressed parts and large components. Even in some of the fields where formerly castings had a monopoly, for example for pistons, highly stressed units are now being made as forgings or stampings rather than as castings. This tendency is bound up with the evolution of the highly developed high-duty modern alloys of the heat-treatable type on the one hand: and on the other with the development of forging and press technique and the evolution of larger products.

The outstanding problems which remain to be dealt with by the aluminium fabricating industry are connected mainly with surface-finishing and joining methods: in the former connection, a finish equivalent to vitreous enamel has yet to be forthcoming; and in the field of joining methods, although great advances have been made in, for instance, welding and brazing, techniques are still far from final. Probably the most important contribution of the aluminium industry to joining technique has consisted in the great development of extruded sections, whose design can contribute vastly to the problem of interlocking joints.

As far as the industrial market external to the aluminium industry influences the situation, the outstanding direct factor is the current shortage of light gauge steel sheets both here and in America: this is naturally turning attention to the possibilities of substituting aluminium sheet. Gauge for gauge, one ton of aluminium releases almost three tons of steel: and cost differential is to some extent ironed out where production can be substantially increased with little or no increase in overheads.

Another factor—an indirect one—is the experience now gained in fabricating aluminium alloys. During the recent War, many plants with little or no prior experience in working aluminium alloys were called upon to produce aircraft parts, for example heavy forgings or drawn sheet parts, of light alloy: the natural initial reaction was to use the same tool design and shop techniques that were familiar in handling steel or other materials, but over a period of years considerable modifications in the sequence and number of operations have established themselves and familiarity with the handling of the new materials has created a bias in favour of working with them rather than with, for example, steel. Obviously, the factor of light weight strengthens this bias where any non-mechanical handling operations are involved.

Apart also from the usual methods of forging, rolling, drawing, etc., the wrought alloys of aluminium offer an additional attraction to designers by virtue of their special aptitude to the new process of extrusion—which in fact is virtually a product of the aluminium age. The extrusion process provides an almost unlimited range of intricate sections, heavy or light, tubular or solid. The big extrusion shops now possess extrusion dies running into literally thousands of designs: the dies cost relatively little in relation to their service life and enormous output, and the dimensional accuracy of extruded products is of a very high order.

Step by step with the expansion of the light metal fabricating industry improvements in equipment have taken place. Rolling speeds are transformed and the plant is heavier: the size of extrusion presses and the number in use have increased: forging presses have been greatly developed. Better and bigger ingots are available: better technique and equipment have been evolved for the heat-treatment of the light alloys. These and other factors all work together to rationalize the economy of the light metal fabricating industry.

These, at least are the long-term technical factors. The immediate position of the semi-manufacturing side of the aluminium industry since the War is beset with short-term difficulties, the fruits, in the main, of war shortages affecting both production conditions and consumer demand, in its delivery schedules. The major producers in the United States, Canada and this country find themselves in the unprecedented condition of having to quote anything up to forty-odd weeks between placing an order and delivery for the most popular classes of sheet and anything up to about half this period for standard extruded shapes. The delay on wire is less and the most satisfactory item from the point of view of delivery is probably rod. With virgin ingot in so short supply that it is being rationed to old customers only, and with the demand for sheet products about six times the supply this situation is by no means astonishing in the general welter of post-War disorganization, but it makes short-term difficulties on the sales side acute. In this respect there are, too, curious anomalies as between primary and secondary metal products and as between semi-manufactures and fabricated end products, against the general background of priorities dictated by national needs. Some of the mass-produced products from the big ex-War converted factories are offered on a much shorter delivery schedule —for instance, in mid-1948, one producer was able to offer erection of aluminium prefabricated schools within three-four weeks from the date of placing the order.

The Materials of the Light Metal Fabricating Industry: Aluminium and the Wrought Alloys

With few exceptions, the fabricated products of the aluminium industry are produced in three classes of material, pure aluminium, the non-heat-treated and the heat-treated alloys respectively of the so-called wrought alloy class. The wrought alloys fall into several groups, each of which is distinguished by one main alloying constituent:—

1. The copper group.
2. The silicon group.
3. The manganese group.
4. The magnesium and magnesium silicide group.
5. The zinc group.

In the case of the non-heat-treated alloys the mechanical properties are developed by the cold work carried out on them after the final annealing operation; the properties thus obtained are destroyed by subsequent heating and cannot be restored except by new cold work. The alloy producers generally supply these non-heat-treated alloys in different tempers ranging from the soft or annealed temper to the full hard temper which is produced by the maximum amount of cold work which is commercially practicable. Sometimes, also, the temper known as "fabricated," i.e., that resulting when products are derived from ingot without any subsequent controlled amount of cold work, is met with; this temper corresponds to varying strain-hardening and is not strictly a uniform temper.

The heat-treated alloys have their mechanical properties improved by heat-treatment; and, contrary to what happens with strain-hardening in the case of the non-heat-treated alloys, the increased strength is obtained with little sacrifice of ductility. There is the further advantage that the alloys can be re-heat-treated after annealing to restore their high-strength properties.

THE PRINCIPLE OF HEAT-TREATMENT

Essentially, heat-treatment is a method by which even dispersal of the soluble alloying constituents in the aluminium matrix is arrived at, based on exploitation of the fact of differential mutual solubilities at high temperatures of certain elements and compounds. The mechanism whereby the uniform dispersion of the finely divided precipitated alloying constituents furthers strain-hardening and integrates the mechanical strength of the alloys is the subject of different metallurgical theories which have not yet conceived a final or a satisfying exegesis.

The actual process of precipitation or dispersal of the alloying constituents depends on a number of factors inherent in the nature of different alloys (whose chemical inter-solubilities for different temperature ranges may be very complicated) and on the control of the heating, cooling, quenching and ageing operations comprised by the general term heat-treatment. Ageing, or age-hardening, is the process of attaining ultimate, stable dispersion; in the case of some alloys this can be accelerated by low-temperature heating, known as "artificial ageing," following the so-called solution heat-treatment or precipitation heat-treatment which initially produces the supersaturation or dispersion stages.

Effectively the heat-treatable alloys can be regarded as two groups, according as to whether they age-harden spontaneously and do not require precipitation heat-treatment, or age-harden at room temperature but require precipitation heat-treatment to attain maximum mechanical strength.

THE CARRYING-OUT OF HEAT-TREATMENT

The fused salt bath is the most common and, in many ways, the most effective method of treatment since it combines a high capacity for heat with uniformity of temperature, and provides the simplest possible method of establishing direct contact between the metal to be treated and the heating medium. The salt bath generally employs a mixture of sodium nitrite with sodium or potassium nitrate (10%/90% and 50%/50% mixtures respectively, with melting points 290° C. and 220° C.). For the treatment of small parts the salt bath resembles a crucible furnace, with steel pots in a brick-lined chamber heated by oil burners. Larger parts require treatment in sheet iron tanks, gas- or oil-heated, or in the most up-to-date plants electrically heated by resistance elements encased in tubing on the walls or bottom of the tanks. Solution heat-treatment is usually applied in hot-air furnaces with forced draught.

Up-to-date equipment for heat-treatment provides for mass production by using mechanical conveyor-belt types of furnace in which the products to be treated are carried through the preheating and heating chambers at the required temperature and speed and pass straight over a ramp into the quenching tank. Where, because of size or shape, parts are not suitable for container carriage, overhead chain conveyors may provide mechanization or it may be necessary to utilize supporting cradles or jigs.

Quenching must follow solution heat-treatment without any delay. Sheet and tube, because of their proportionately large surface, cool rapidly and it is necessary to pass such material from the heat-treatment furnace instantaneously into the quenching tank below. Quenching is carried out, according to the alloy and the shape and size of product, in cold or in boiling water or in oil: but oil-quenching, used necessarily, for example, with the alloys with higher Mg content, must never follow salt-bath treatment, because of the explosion risk. Spray quenching and air-blast quenching are also utilized in modern heat-treatment shops.

All heat-treatment equipment requires automatic temperature control and recording devices to maintain accurate temperatures within the specified heat-treatment limits. These limits are normally closely set by the producers of the proprietary heat-treatable alloys and careful attention has to be paid to the exact carrying out of prescribed procedures.

The cost of heat-treatment is, of course, considerable: but this fact is very largely offset by the results obtained. As compared with the highest attainable strength of the non-heat-treated alloys of, say, 25 tons/sq. in., an equivalent heat-treated alloy would show an ultimate strength of 28 tons/sq. in.: further, in the case of the former alloy the elongation would be of the order of 6% whilst the heat-treated alloy would show an average value of 20%. This factor of ductility is of the utmost importance in fabricating and working the alloys and the cost of heat-treatment is compensated for to a very large extent by the subsequent ease with which deformation by plastic working can be carried out on the heat-treated alloys.

Heat-treated alloys are supplied in a wide range of tempers: fully annealed; solution heat-treated; solution heat-treated and aged; solution heat-treated, aged and cold worked; solution heat-treated and cold worked; as fabricated (see p. 213); quenched and aged; and simply quenched. All the tempers are not, of course, applicable to any one alloy.

The Main Groups of Wrought Aluminium Alloys

THE COPPER GROUP

The alloys with copper as a main constituent are chiefly ternary or quarternary alloys and these two classes cover some of the most important types of forging alloys. Foremost among them are the high-strength and super-high-strength ternary and quaternary alloys of the duraluminium type, with magnesium (giving rise to magnesium silicide) as the third element and varying quantities of Mn (see below): the duralumins, historically the first and still the most important of the heat-treatable alloys which develop very high strength after suitable thermal processing, offer a wide range of valuable properties, as the table on pp. 218-219 shows.

In sheet form, some of the duralumin alloys are used as " Alclad " sheet, consisting of the alloy as core coated on both sides with high-purity pure aluminium to provide maximum corrosion-resistance.

Another important forging alloy composition group in which copper is the chief constituent is the quaternary " Y " alloy, with Cu, Ni and Mg. This heat-treatable alloy preserves its tensile properties to a large extent when hot (250°C.) and is a valuable material for hot-forging, rolling or extrusion.

THE SILICON GROUP

The wrought alloys in which Si is the main constituent added are again ternary or quaternary heat-treatable alloys depending on the formation of magnesium silicide. They are in reality copper-free duralumins, the best known being Duralumin H (see Table XX p. 218), which is known under a variety of names (51 S in the United States, Anticorodal, Aldrey, Almelec, Aludur 533 and other manufacturers' names in European countries. (See Schedule III on p. 174.)

THE MANGANESE GROUP

Manganese increases the strength of pure aluminium to a moderate degree without much sacrifice of ductility, and the binary alloy with 2% Mn finds a wide application where a non-heat-treatable alloy of greater strength and rigidity than commercial aluminium is required, particularly where good corrosion-resistance, which characterizes this alloy, is concerned.

THE MAGNESIUM GROUP

There are three main alloys in the forging range of the magnesium alloys, depending on Mg additions roughly 2%, 5% and 7%. The alloys are non-heat-treatable. The Table on pp. 220-221 shows their main properties, the hard tempers being developed on working.

THE ZINC GROUP

The outstanding alloys containing zinc for forging and extruding are the complex alloys of the RR type (see Schedule I, p. 157) which include alloys in the highest strength range of light alloys available at the present day. The Table on p. 222 (Table XXII) shows the remarkable properties of alloys of this type to D.T.D. 683 in the extruded or forged form after heat-treatment (which depends on the formation of the constituent $MgZn_2$).

This alloy is relatively free from the disadvantages associated with zinc due to the comparatively low percentage and the compensating effects of the other alloying additions.

Rolling Aluminium and Its Alloys

Where rolling is concerned, the aluminium industry has (with one important exception which will be discussed later) borrowed almost wholly from the established techniques employed in the ferrous and heavy metal industries. There are, of course, necessary modifications dependent on the inherent qualities of light metal, but these may be regarded as modifications in detail rather than organic changes in principle. And in the matter of principle it is an interesting reflection that the methods of rolling metal have remained essentially unchanged for a century; that this stationary position should apply even to such vital factors as the bearings of the rolls would be surprising if it were not possible to trace its causation to the background of the Industrial Revolution, with its emphasis on output at any cost and the consequent " victimization," from the point of view of scientific or rational consolidation, of the great siderurgical industries which gave the chief impetus to the early advances of the modern industrial age. Quantity production was achieved in Europe in the Nineteenth-Century days

TABLE XX.—THE

Alloy	British Specifications		Temper	Annealing and heat-treatment temperatures (1)
	B.S.S.	D.T.D.		
A—SINGLE HEAT-TREATED ALLOYS				
Duralumin M		327	Soft Heat-treated (5)	A=360°C. S=490°C.
Duralumin B	2L.37 5T.4 6L.1 5L.3	150A	Soft Heat-treated (5)	A=360°C. S=490°C.
Duralumin Q		273 390	Soft Heat-treated (5)	A=360°C. S=490°C.
B—DOUBLE HEAT-TREATED ALLOYS				
Duralumin H(6) ..		346	Soft Solution-treated Fully treated	A=360°C. S=520°C. P=185°C.
Duralumin E		443 423B	Soft Solution-treated Fully treated	A=360°C. S=520°C. P=185°C.
Duralumin S	2L.40	603B 610B 364B 546B 646B	Soft Solution-treated Fully treated	A=360°C. S=505°C. P=185°C.
Duralumin L		683 687 693	Soft Solution-treated Fully treated	A=300°C. S=460°C. P=135°C.
Duralumin K		363A	Soft Solution-treated Fully treated	A=300°C. S=460°C. P=135°C.

Footnotes

of good profit-making by multiplicity of unit machines and of labour—which was cheap. In America, where scale-planning has been given more thought because of the nature of her larger-unit

DURALUMIN ALLOYS

Average mechanical properties (2)				
Proof stress tons/sq. in.[3]	U.T.S. tons/sq. in.	Elongation % (on 2 ins.)	Fatigue limit (4)	Remarks
8 12	12 18	20 20	— 7	A soft form of the alloy, of high ductility ; rivets can be headed in the heat-treated condition.
10 17	15 27	20 20	— 9	The original Duralumin, a "general-utility" strong alloy.
12 19	6 29	15 12	— 9.5	A stronger variant of Duralumin B ; less easily worked.
5 13 16	11 17 23	25 20 10	— — 8	Useful for products of intricate shape, since easy to work. Good corrosion resistance. Weldable.
9 12 21	13 18 26	25 20 10	— — 8	Stronger than Duralumin H, decreased ductility and corrosion resistance. High proof stress. Chiefly for extrusion.
10 16 27	15 26 32	20 15 8	— — 10	The strongest of the "general-purpose" alloys after full heat-treatment. High proof stress.
11 — 30	17 — 35	15 — 8	— — 10.5	The strongest alloy available in all forms ; less easy to work.
11 — 34	17 — 39	15 — 8	— — 10.5	In the highest strength range of present-day aluminium alloys. Available as bars and sections, fully heat-treated and ready for use.

on pp. 220-221.

TABLE XXI.—THE ALUMINIUM

Alloy	British Specifications		Temper	Annealing and heat-treatment temperatures (1)
	B.S.S.	D.T.D.		
MG 2	L.44 L.46		Soft Half-hard Hard	A=360°C.
MG 5	L.46	303	Soft Half-hard	A=360°C.
MG 7		182 190 297 186 404	Soft Half-hard Hard	A=360°C.

(1) A is the annealing temperature to which the metal is heated for softening after cold-working. S is the solution treatment temperature from which the metal is quenched for primary hardening. P is the precipitation temperature to which the metal is re-heated after quenching to induce secondary hardening.

(2) Average mechanical properties quoted are from manufacturers' literature for material not less than ½-in. thick.

industry which, coming later into the field, had to face an organized battery of established European industries in the world markets, some attempts have been made to introduce improvements into the process of rolling by developing better and larger rolls, improved design arrangement of mills and better lubricants; but still, essentially, the technique of rolling has not undergone radical change. Although the recent war made it a necessity to increase rolling speeds for light metals, for instance, to a point where quantity change almost seems to imply a change in method, this improvement is offset by the fact that the power consumption has not effectually changed its *pro rata* value, because of the still enormous wastage of power absorbed in bearing friction, so that the advance is not actually one of principle.

MAGNESIUM FORGING ALLOYS

Average mechanical properties (2)				**Remarks**
Proof stress tons/sq. in. (3)	**U.T.S. tons/sq. in.**	**Elongation % (on 2 ins.)**	**Fatigue limit (4)**	
5	12	20	6	Works very easily; weldable. Excellent corrosion resistance.
10	14	10	6	
13	16	6	6	
8	17	20	8	The best "general-purpose" alloy of the Mg range; good ductility and good strength qualities. Excellent corrosion resistance.
15	20	10	8	
17	23	6	8	
10	21	20	10	The strongest of the Mg range; good ductility; weldable. Excellent corrosion resistance.
17	24	10	10	
19	26	6	10	

(3) The proof stress gives a permanent extension of 0.1% to the material.
(4) The fatigue limit is based on 50 million stress reversals.
(5) The mechanical properties develop fully about four days after quenching; ageing is spontaneous at room temperature during that period. Immediately after quenching the material is not much harder than in the soft temper.
(6) Contains no copper: see under silicon group, p. 216.

With this proviso, it can be said that in the international aluminium industry the most advanced improvements in technique and plant for rolling light metals are American and British; the equipment of the mills in European countries generally and even in Germany up to and during the war was in general less modern by ten or twenty years, but German practice in some processes differed materially from English and American methods.

The expansion during the last decade of the light metal rolling industry has brought it up to a huge-scale industry. The United States was operating twelve major mills during the war as well as a host of smaller ones; the largest Alcoa mill covers 55 acres. The war-time peak capacity was well over three-quarters of a million tons per annum. In Germany the peak war-time output

TABLE XXII

ALLOYS TO D.T.D. 683

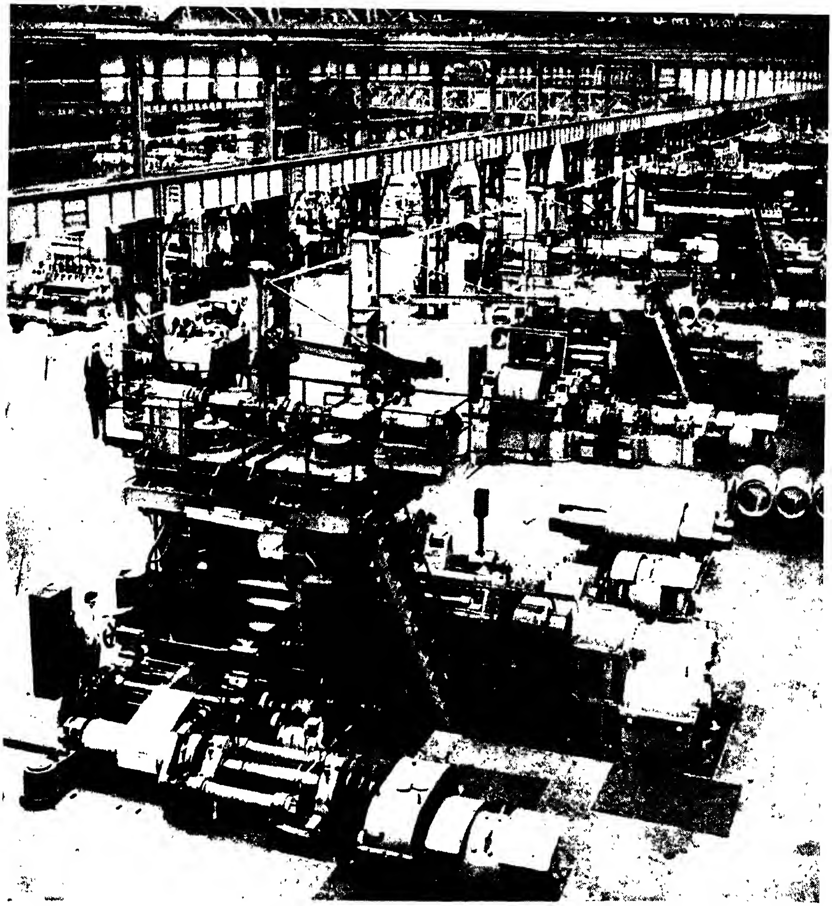
Composition range	**Percentages**	**Proof stress**	**U.T.S.**	**Elongation**	**Brinell hardness**
		tons/sq. in.	**tons/sq. in.**	%	
Zinc	4.5–6.5	28–30	35–38	10	In the region of 160
Copper ..	1.5 max.				
Magnesium ..	2.0–3.5				
Manganese ..	0.25–1.0				
Iron	0.5				
Silicon ..	0.5				
Titanium* ..	0.3 max.				
Chromium* ..	0.5 max.				

* If present.

in 1944 produced 150,000 tons of rolled products. The scale of the Japanese output of light metal mill products has been already referred to on p. 209. In this country the important light metal rolling mills are the three great mills of the British Aluminium Company at Milton, Warrington and Falkirk, the latter being the largest and most modern (it covers nearly a score of acres at present and plans for extension will develop the 50-odd-acre site fully), and the Banbury and Rogerstone mills of the Northern Aluminium Company, the British fabricating subsidiary of the Canadian producer. In addition there are quite a large number of important alloy rolling mills owned and operated by the chief light alloy producers in this country. The war-time peak output of light metal mill products was reached in 1944 with a figure of the order of 100,000 tons and the post-war sheet and strip output in the United Kingdom reached, in 1947, nearly 130,000 tons.

ROLLING MILL OPERATIONS

Essentially the operation of rolling light metals in a modern mill involves the preliminary stage of melting the ingot (or ingot plus treated scrap); two main stages of rolling proper, comprising hot rolling or breaking down and cold rolling or roughing; a third optional stage of final rolling or planishing to surface the sheet produced in the first two stages; and finishing operations such as



A Strip-Rolling Mill Bay at Falkirk.

flattening, stretching, coil slitting, rewinding and shearing. Heat-treatment plant is, of course, a major part of the equipment of a rolling mill.

In the first stage, rolling slabs are produced in continuous melting furnaces, usually of the fixed hearth reverberatory type; the solid metal charges of ingot or scrap are mechanically charged to the furnaces at the end opposite to the firing burners at regular intervals by screw-operated gear, being pre-heated by the " waste " combustion gases. The molten metal is transferred by launders to holding furnaces for casting, which is now almost universally carried out by the semi-continuous method. Slabs are currently cast in sizes of 10 ft. by up to 48 ins. wide by 8 ins. thick, but improvements in casting and rolling methods are in the direction of larger slabs. After sawing and scalping or machining to remove any surface flaws the slabs pass on mechanical conveyor rails to the preheating furnaces and thence to the rolling plant.

In the older mills, flat sheet rolling was usual, but in modern plant most of the production is rolled in coil form, the finished coil being subsequently passed through levellers and automatic shears for cutting into sheets. The width of sheet at present being rolled in this country is up to 6 ft. wide; to obtain the requisite width it is, in some plants, necessary to cross roll at some stage during the break-down operation. The breaking-down or hot-rolling stage is now carried out in 2-high or American-type 4-high reversing mills, where the slab is rolled down to the required blank gauge, the blanks being edge-trimmed and coiled for annealing and further rolling. According to the width of sheet being rolled, one or more mills in line may be required for the breaking-down rolling operations, intermediate annealing being necessary for wide sheet. Where two mills are employed the second is usually more powerful and may be a 4-high type. Continental practice generally favours the 3-high type.

The next stage of so-called " roughing " or intermediate rolling is carried out in cold rolling single-stand 2-high or 2-stand tandem 4-high strip mills. With modern equipment, the cold-rolling mills may terminate the process of rolling proper, depending partly on the composition of the alloy being rolled and the quality of sheet required. In the case of strong alloys or for thick-gauge sheet or special grades it may be necessary after further intermediate annealing to proceed to a third stage of rolling to give a planishing treatment. This is not properly a rolling treatment in the sense that it gives very little reduction; it usually consists of a series of passes between very smooth-finished rolls which result in producing a hard, brilliant surface to the sheet and a uniform gauge thickness.

After passing through all the stages of rolling, the finished coils are cut into flat sheet, which then either goes to the heat-treatment shop or to the final finishing department. The work of the finishing shop consists in flattening and cutting off, strip slitting and coiling. In the older-equipped mills, flattening of sheet is mostly done by roller levellers: in more modern plants hydraulic stretching machines are employed. Different but definite ranges of sheet thicknesses are catered for in either type of levelling or flattening plant by separate groups of machinery. Continuously operated flattening-cum-cutting-off machines with flying shears are now considered superior to the older intermittent type as there is less risk of giving rise to surface damage by the stopping and starting of rollers.

The strip-slitting and coiling machines usually form part of the flattening equipment, which can be used for different operations. Shearing plant consists of either the guillotine type or the American so-called gang shears, which is fully mechanized and is provided with automatic feed and delivery controls.

ANNEALING AND HEAT-TREATING

The whole operation of rolling is dependent on heat-treatment. Annealing and heat-treating is carried out in a wide variety of furnaces, ranging from salt baths to electric and producer-gas air furnaces. Hot-rolling is carried out between 400° C. and 450° C.: if more than one breaking-down rolling operation is undertaken, intermediate re-heating has to be provided for. The annealing furnaces of conventional type are those with box hearths. Where alloys are being rolled, annealing has to be carried out with particular care to ensure a safe margin below the solution heat-treatment temperature, the overstepping of which would seriously affect the working properties of the material. Solution heat-treatment is applied at the end of rolling operations and for this it is current practice to employ either electrically heated salt baths or gas-fired air circulatory furnaces. The sheet may be treated flat or in coils and the sizes and shapes of furnace chambers are generally very diverse and numerous in a large modern mill. Cold rolling takes place at temperatures below 350° C.

ROLLING PLANT

A typical present-day breaking-down hot mill has rolls of forged steel of composition of the type carbon 0.85%, manganese 0.35%, silicon 0.25%, nickel 2.00% and small additions of vanadium and molybdenum. Advances in rolling technique have largely been related to advances in the roll-carrying bearings. In a modern mill high pressure bearings (some development has taken place with laminated plastic bearings) with automatic film lubrication may be used or in some mills the more conventional type of self-aligning roller bearings are employed for the largest diameter rolls, which measure perhaps 34 inches for a roll width of 84 inches. The mill housings and the sole plates are of heavy steel construction. The rolls are coupled by gearing and are normally driven by a high-pressure low-speed d.c. motor, with an energizer motor generator to provide a range of power, quick reversing and sensitive control. Some of the largest motors of this type ever made, of 5,000 h.p. rating, weighing nearly 215 tons and designed to operate at 30 r.p.m., have been supplied to the Aluminum Company of America's latest light metal rolling mills: the generator sets are rated at 4,000 kW and are driven by synchronous, 6,500 h.p. motors.

In the case of 2-high breaking-down mills, the larger units have the upper roll or roll sets hydraulically balanced. Automatic roll-setting devices have been fitted to some recent German mills: and another German development favoured the use of high permeability magnetic-type pressure gauges for the routine control of roll pressures.

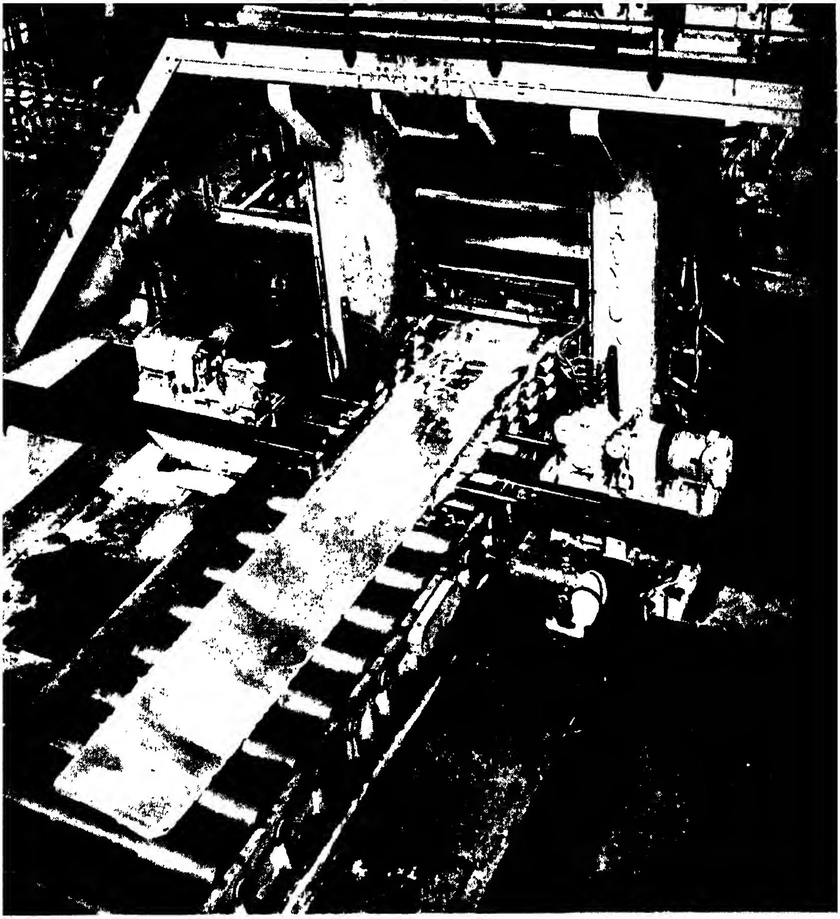
TECHNICAL FACTORS IN LIGHT METAL ROLLING

The rolling of aluminium differs from steel, brass and copper rolling in at least two marked particulars: in the first place relatively low working temperatures are employed for hot-rolling and in the second place finishing to final gauge is usually performed by cold-rolling. The actual hot-rolling or breaking-down temperature range may be very restricted in the case of aluminium alloys because of the two factors of hot shortness and cold shortness.

Being less plastic at hot-rolling temperatures than steel, aluminium and its alloys require very heavy pressure for rolling and the mills are therefore of a heavier build than in the case of most other metals. Where the rolling operation involves a heavy reduction the actual working roll has to be of small diameter to keep down hardening to the minimum, but this involves great risk of cambering, with consequent variation in gauge, so that roll design has evolved on the principle of using backing-up rolls of large diameter to introduce rigidity. Thus, development of mills has been in the direction of 3-high (Continental type) or 4-high (American type) mills. The 4-high mills are of the reversing pattern and long roller "tables" are usually provided behind and in front of the mill: the longer these tables, the larger the slab which can be run out before reversing, with consequent saving of power. In addition the use of such roller tables eliminates the necessity for elevator tables, which are necessary with the Continental 3-high type of mill.

Vertical edging rolls are provided in some modern mills to roll the edges but more commonly the edges are unsupported, and some edge cracking may tend to occur, particularly in the case of the harder light alloys.

Plate is defined as material ¼ in. or more in thickness. Light alloy plate is usually hot-rolled to gauge unless finishing cold-rolling is specially called for by the nature of the alloy. Sheet is defined as material ranging from 0.005 to 0.249 in.; if sheet is rolled flat, i.e., in relatively short lengths, it is often finish-rolled in packs, particularly where lighter-gauge sheet is concerned. In strip-rolling, where long lengths are rolled and intermediately



Hot Rolling a Strong Alloy on a 4-High Mill.

wound in coils; the flatness is controlled by " bridling " the tension with steel bars equipped with guides or by means of brakes. Because of the fact that tension plays a part in controlling the flatness of strip, much heavier reductions per pass are possible than in flat rolling. It is common practice to effect the heaviest reduction on the first pass after annealing. The actual reductions in common practice are from the rolling slab to ¼ in. to ½ in. thickness on the breaking-down hot rolls: and subsequent rolling down in series of ten or twelve passes to gauge thickness in the cold-rolling operation. In the new continuous hot-rolling mills, slabs nearly one inch in thickness can be rolled straight down to gauges between 0.080 and 0.200 in. In these mills the speed of rolling has been increased nearly fifty times.

The degree of reduction per rolling operation has a far-reaching effect on the structural properties of the finished sheet, the quality of which for deep-drawing purposes, for instance, is largely dependent on random grain orientation. This is dependent in turn on proper control of recrystallization and cold work and the proper amount of reduction by cold rolling between annealing is a matter of ultimate importance to the end product.

Flow lines are sometimes produced in the surface of certain alloys following rolling, being particularly evident in the annealed material. This tendency may be overcome by introducing compression forces by intermediate cold-rolling or levelling.

The final surface of rolled products is affected by a large number of factors, such as lubricant, condition of the rolls, the proper proportion of cold working introduced at intermediate and final stages, and the type of grind applied to the rolls, as well as by the actual working temperatures and methods of annealing and heat-treatment. The production of high-quality sheet grades of good surface calls for a close degree of control and inspection of all operations down to the auxiliary operations not directly part of the rolling process.

POWER AND COSTS FACTORS

The power required to drive a rolling mill is directly related to the width of the metal being rolled, the speed of rolling and the resistance of the metal being rolled to displacement. The third factor varies for different metals and is also dependent on the amount of strain-hardening supplied prior to and during the rolling process. Aluminium and its alloys roughly group with the hard steels in their resistance to displacement, which is of the order of 70,000 lb. per sq. in. when rolling from the annealed state to 25% reduction: by comparison the resistance of medium-strength steel is of the order of 60,000 lb. per sq. in., that of soft steel is 50,000, that of brass 40,000 and that of copper, the easiest of all metals to roll, 30,000 lb. per sq. in. The influence of the speed factor is very marked: when the old-fashioned type of slow-speed strip mill in the steel industry was replaced by the moderately high-speed mill, the power consumption was halved: with a pre-war British high-speed mill (300 f.p.m.) it was reduced to nearly a quarter. The best pre-war power consumption figure was of the order of 25 kW per ton; but American practice has advanced this figure during the war years considerably and present-day figures are reduced well below 20 kW. The trend of rolling costs, of course, follows closely the reduction in power costs and general efficiency: but it has to be taken into account in considering the costs of rolling aluminium that the scale of production and standardization of product, as in the steel industry, are factors exercising great influence. From the American side the claim is made that the average mill cost has been reduced, in light metal rolling, since the beginning of the war, to about 3 cents per lb. (roughly £17 per ton at par) for the older mills and to as low a figure as 2.0 to 2.25 cents (just over £11 to £14 per ton) for the more efficient new continuous strip mills: these figures relate to the actual rolling costs in the production of finished sheet of different types of commercial aluminium from virgin ingot but they do not include any overhead, amortization or interest charges. It is of interest to note that, as long ago as 1925, R. G. Anderson, the American specialist, in his " Metallurgy of Aluminium," calculated the same nominal conversion costs, 3 cents down to 2.25 cents, apart from cost of metal and overheads, as being reasonable for what was then large-scale production: the devaluation of the dollar judged in terms of purchasing power and the greatly increased costs of labour and materials since 1925 have between them, accordingly, nullified the apparent economic gains resulting from the technical improvements. This is one more example of the common paradox that so-called technical advances only keep pace with the economic changes which they themselves endow. This paradox has been variously interpreted and the Marxist school sees in it a clear instance of "contradiction."

The cost of rolling alloys is, of course, higher.

Whilst the power consumption and production costs for actual fabrication are of a comparable order, it must nevertheless be taken into account that, at fabrication level, the total power consumption represented in finished aluminium sheet is still nearly five times as great as that in electric steel sheets, due to the very heavy power consumption in the electrolytic reduction process. The factor of relative weight, however, redresses this balance to a large extent.

FUTURE DEVELOPMENTS

The tendency in the industrial structure of the light metal rolling industry is for two-fold development to take place. In the first place there will be the rollers manufacturing large quantities of standard products; these will necessarily be the large producers of metal. Their development on the rolling side will be in the direction of the large continuous wide strip mill products. The large modern continuous wide strip mill can achieve something like a 75% saving in labour, a 65% saving in power consumption, a 45% saving in material and a general plus overhead cost saving of 55% as compared with smaller sheet mills: but there is a much greater first cost of plant and a higher rate of depreciation and successful operation depends upon a smooth-flowing output of products of standard dimensions in standard materials, which can only be effectively achieved by the big virgin metal producers. In the second place there is room for the development of mills which can increase their output by installing modern equipment and will produce especially high-quality sheets in special alloys and non-standard sizes: in general these smaller producers will retain speciality features. The second group will be competitive because of their smaller capital outlay and will exploit their tradition of trained operatives; which will add to the competitive features of the fabricating industry referred to on p. 250.

Technically, there is room for revolutionary developments in the field of rolling: such developments are already foreshadowed in the methods of melting, for instance by the development of the electric induction furnace, but so far this development is technically in its infancy and the cost is as yet prohibitive for large-scale application. Cast slabs for rolling are still regarded as standard for large-scale production, as extruded slabs are not yet produced in large enough sizes: extruded billets are used extensively for alloys and for small-scale production. Future developments are all tending towards the use of bigger slabs, however, so that the extrusion process has a long leeway to catch up. Improvements are continually forthcoming in the direction of higher rolling speeds due to the use of improved lubricants and methods of lubrication on the one hand and to bearing design on the other hand. Where lubricating methods are concerned revolutionizing of present-day methods may be foreseen in such fertile ideas as the passing of high-voltage discharges through vaporized oil, recently applied in America with remarkable results in tin rolling. The future of bearings may be linked with the development of plastics.

The future of alloy technology seems to be coupled with that of fabrication in general and sheet products in particular in the contemporary tendency to develop the medium-strength alloys rather than the super-high-strength alloys, for which so much was claimed when they first emerged.

DIRECT ROLLING OF STRIP: THE HAZELETT PROCESS

The method by which aluminium strip is directly rolled from molten metal is an important departure from the traditional principles of rolling: and although the idea was mooted as long ago as 1857 in connection with ferrous metals (Sir Henry Bessemer actually took out a patent on the subject, which was never utilized) the Hazelett process may be considered a very significant exception to the borrowing from established practice which has otherwise dominated the light metals rolling industry. In the direct rolling method the metal is poured, molten, between a pair of rotating cooled rolls, where it is converted into rolled strip which is withdrawn on the exit side. The rolls are, of course, at a lower temperature than the metal. The pouring temperature and the diameter and speed of the rolls are critical factors in determining the success of the operation: and the control of the temperature of the rolls by external cooling to maintain uniformity presents a fourth problem. Comparatively small variations in the temperature of the metal, for instance, give rise to corresponding variations in the thickness of the solidifying layer: the compensatory factor is the control of the roll speed which is in turn controlled by the power requirements. The actual thickness of the strip is determined to a greater extent by the speed of the rolls than by the roll gap.

The early difficulties associated with Hazelett's method were mainly the " edge effect " due to preferential solidification of the metal on the flanges of the roll; segregation, in the case of alloys, and a certain amount of trouble due to oxidation. Just before the war, Hazelett had, however, improved on the methods of feeding the molten metal and operating the rolls to an extent whereby remarkable uniformity of thickness and complete prevention of roll-checking and heat cracking had been overcome. The process has been in commercial operation by the Crown Cork and Seal Company of Baltimore since 1936: performance by 1939 was such that strip of 24-in. width could be produced in 500-ft. length of 0.120-in. thickness, with a gauge variation of less than 0.001 in., at the rate of 3,800 lb. per hour. In appearance the strip is uniformly matte and has smooth edges as clean as those produced in a conventional mill on strip of this thickness.

There are some extremely valuable features in the direct rolling process. Essentially it meets the metallurgical problem of changing over from " cast " to " wrought " structure as an intermediate material for further rolling-down or ultimate working processes such as deep drawing. In fact, the properties of the direct-rolled strip are such as to endow it with characteristics eminently suited for fabrication: its tensile strength is double that of cast aluminium and half as much again as that of hot-rolled annealed aluminium, and both the ductility and hardness are excellent. From the commercial angle an important point is that scrap is negligible.

ROLLING OF CLAD SHEET

Quite a large proportion of light alloy sheet and strip produced currently is in the clad form, the most familiar alloy name being Alclad. This is material with a strong alloy core and an outer plate of high-purity aluminium: in the rolling process the pure sheets are laid on each side of the rolling block before preheating and the composite " sandwich " goes through the roughing mill. The pressure of this mill is sufficient to give complete adhesion between the plating and the core after two passes and the subsequent rolling procedure is exactly the same as if the material were a straightforward aluminium or alloy slab. Due to the fact that the material actually in contact with the roller is pure aluminium, the rolling operations are in point of fact simpler than in the case of many alloys.

SECTION ROLLING

The rolling of aluminium rod, chiefly for electrical uses, has been developed on a considerable scale on the Continent, in America and in this country, where the British Insulated Cable Company were pioneers. A recent war-time development is the American production of special rolled light alloy structural shapes, with cross sections up to 30 sq. ins., weighing as much as 1,200 lb. each. The obvious commercial advantage of such sections is their great length, up to 100 ft.; but the development is promising from more than one technical aspect. In a representative light alloy section mill, which closely resembles a mill for similar steel products, the ingots of 1,000 lb. to 3,000 lb. are melted in reverberatory furnaces: the prepared rolling billets are then pre-heated in soaking pits and then go through reversing-type breaking-down hot mills with rolls grooved in such a way as to control the changes in form. After heat-treatment, final rolling is carried out in a structural mill.

EMBOSSED SHEET ROLLING

The manufacture of such products as light-gauge tread plates is undertaken in sheet embossing mills. These machines are very similar to foil embossing mills except that they are much heavier-built and are not equipped with unwinding and rewinding drums. The two rolls used are usually of the same size and are cut with the male and female designs respectively. Alignment is by means of special gears mounted on the end of the rolls.

A purely ornamental form of sheet patterning is obtained by a method developed in England by the British Aluminium Company and marketed as " Imprest " sheet: the pattern is first cut on a paper or metal stencil (alternatively a metal pattern such as wire gauze, mesh, netting, etc., or a fabric with a relief design may be employed) and this stencil or pattern is simply inserted between the rolls and the metal in the finishing mill. The sheet emerges with the pattern permanently impressed, down to the finest detail such as the texture of the transfer material or stencil.

Foil Rolling

THE FOIL INDUSTRY

The aluminium foil industry has occupied a rather special position: it grew up not as a branch of the aluminium semi-manufacturing industry so much as a separate industry, pursuing its own objectives and forming its own independent structure. Germany took a leading part in developing the production and new uses of aluminium foil: other Central European countries followed the German lead and by the early 'thirties a strong European Aluminium Foil Convention had been organized to protect the interests of the eighteen German, four Swiss, two Austrian, two Czechoslovakian, one Dutch and one Belgian foil makers and working-up plants. This association controlled exports and arranged price agreements in an industry where competition was exceedingly keen and large markets existed in East Asia, the British Empire and America. American production of foil lagged far behind the German output, whch, as early as 1929, was consuming 4,000 tons of aluminium per annum and by 1936 was utilizing ten per cent. of the national output, or nearly 10,000 tons. The United States foil output for the corresponding years was only 1,500 tons and 2,500 tons respectively. Japanese production came into the picture about 1930 and rapidly developed to a point where it could not only cover the needs of the domestic market but export on a fairly large scale to China. This upset the German export market: and about the same time an independent German producer, Tscheulin, started production outside the ægis of the Convention organization. The wide margin indulged in by the Convention between its selling prices and the actual cost of the metal made it possible for Tscheulin to undersell the Convention in the world market and still make a handsome profit. The French foil-rollers, three in number, remained outside the Convention. Aluminium foil-rolling mills were also started up in Poland and in the Soviet during the middle 'thirties.

In this country, aluminium foil-rolling was not developed on a large scale until later than in Central Europe. The first aluminium foil-rolling plant in the United Kingdom was laid down in 1910 by the Empire Aluminium Company. Fishers Foils, Ltd., took up production after the First War, but the aluminium foil industry in Great Britain was greatly hampered in the years prior to the recent War by the dumping policy of the Continental producers. The post-war light foil-rolling industry is rapidly expanding and the 1947 output was well over 6,000 tons.

World production to-day is chiefly in the hands of the American and Canadian producers, with a developing industry in this country. It is of some interest to note that the famous German Tscheulin mills have been shipped, as part of war reparations, to the United States, where Reynolds will utilize them.

PRODUCTION OF ALUMINIUM FOIL

The early development of foil production was undertaken in Switzerland. The first sheets of aluminium foil were rolled by Gautschi between the years 1902-1905, using rolls heated internally by hot water: he used the pack rolling process and annealed the foil in a vacuum. The pack rolling process was taken up in Germany and developed in actual use for nearly a quarter of a century until it was possible to evolve the continuous single-band rolling process favoured by Tscheulin. This depended on the development of strip rolling.

There have been different specifications for foil thickness in different countries. In the early days the European foil-rollers defined foil as sheet between 0.1 and 0.001 millimetre (0.004 and 0.00004 in.). The English specification for foil started at the upper thickness 0.006 in., whilst American practice favours 0.005 in. as the dividing line. Probably the most popular thickness for aluminium foil is about 0.00035 in. Aluminium leaf, thinner than 0.00004 in., is produced from foil by pneumatic hammering operations, similar to gold beating, on piles of foil interleaved with sheet zinc to soften the effects of hammering.

The ingot metal required for rolling to foil has to meet fairly stringent specifications, the minimum standard of purity being 99.2% and its ordinary grade being 99.5% purity (99.8% purity for special applications such as electrolytic condensers). Special care has to be taken in melting and pouring and it is usual to undertake gas-removal by methods such as those employing carbon tetrachloride or nitrogen-chlorine mixtures. The ingot moulds are specially prepared and the ingots are machined after casting. The first rolling operation is a hot-rolling (420° C.) reduction from the original ingot thickness to about 0.12 in.: the rolls are lubricated with special lubricants. The first plate product is divided into strips which are annealed and then subjected to cold rolling in multiple stages down to foil strip of thickness 0.0016 in., which is subsequently rolled down in one continuous operation in special foil-making machinery in long bands up to 3,000 odd ft.

This, roughly, was the German method. The British method differs somewhat in the thickness grading of the different operations; the foil stock supplied by the producers is 0.018-0.012 in. thick, down to 0.0006 in., after which the foil-rolling machines take the material in double thickness, and roll it down to 0.0004 in. or even 0.0002 in., in widths up to 30 ins. A roll may be as long as 1,200 yds. After removal the double layer is run through a separating machine.

Where double-thickness rolling is employed, since the interior surfaces of the foil do not derive any polishing action from the steel rolls the ultimate product emerges with one matt and one polished face. In recent times new high-speed aluminium foil rolling mills have been developed in Canada which can roll coils up to 32 ins. wide and 1,200 pounds in weight down to foil 0.00025 in. at speeds up to 1,200 ft. per minute: three mills, a 4-high, 2-high and doubler, form the mill train. At such high rolling speeds, the tension control is of great importance and air-operated braking devices are used in the Canadian mills. The finishing rolls for foil-rolling are very highly polished.

One of the most important developments in foil-rolling is that used by the Crown Cork and Seal Company, an American corporation, in conjunction with the Hazelett direct rolling method to produce the strip. The advantages which the direct-rolled strip offers are considerable and the output of foil from this source is now large.

The subsequent treatment of the finish-rolled foil depends upon the use for which it is intended. In some cases no further processing is undertaken and the foil is simply trimmed up in guillotines. In other cases the foil is given coloured decorative treatment by printing or Batik methods or a raised effect by embossing.

Much of the foil marketed is also lacquered or backed with gummed or wax-paper backings. All these decorative operations are carried out in subsidiary roll-type machinery, which forms part of the equipment of a modern foil-rolling mill.

Extrusion

The significance of the method of extrusion, essentially developed with the aluminium alloys as the chief medium and as a direct result of the particular fabricating characteristics of aluminium and the light alloys, has been touched upon in the introductory section of this chapter. The importance of the extrusion industry has grown rapidly. In the United States sixteen large plants were operated during the recent War, with a peak annual capacity of close on ¼ million tons: the U.S. Government expended more than $107,000,000 in capital outlay on war-time plants. The post-war output has been maintained around the 100,000-ton level. In Germany the war-time peak output of extrusions was reached in 1944 when more than 103,000 tons were supplied. In this country the war-time output peak was about 42,000 tons p.a. and the 1947 production of extrusions reached the 40,000-ton level after the immediate post-war decline.

Although, quantitatively, the development of extrusions has been mainly directed to finished sections, great technical significance attaches to the method as a semi-manufacturing process whereby intermediate stock such as billets and slabs for forging and rolling and tube stock for drawing operations are produced. The elimination of the intermediacy of a cast structure is of the utmost importance in the modern trend of metallurgical development and the extrusion process is potentially one of the greatest interest for all forged products.

The basic principle of extrusion is the forcing of a block of solid metal heated to the semi-plastic state through an orifice of smaller cross-sectional area whereby the metal is forced to take the shape of the orifice along its length. Extrusion presses comprise essentially three elements: the extrusion cylinder, fitted with a ram and plunger (the cylinder may be either horizontal or vertical); a thick-walled container into which the metal is charged and through which the plunger travels; and the die assembly. Extrusion presses are now almost invariably hydraulically operated. In modern light metal fabricating plants they are often worked in conjunction with hydraulic forging presses. The capacity of the majority of presses is in the region of 1,000 to 6,000 tons, but some presses have now been designed with capacities as high as 15,000 tons: and there are, of course, a large number of small presses operating at 350 tons onwards.

There is practically no limitation in theory to the type of section which may be extruded: practical limitations for medium size press work may be roughly considered as cross-sectional area between 0.035 in. and 25 ins. and maximum length about 40 ft. or even 65 ft. in the latest high-powered presses. The maximum weight of extrusion products of medium size presses does not greatly exceed 400 lb.

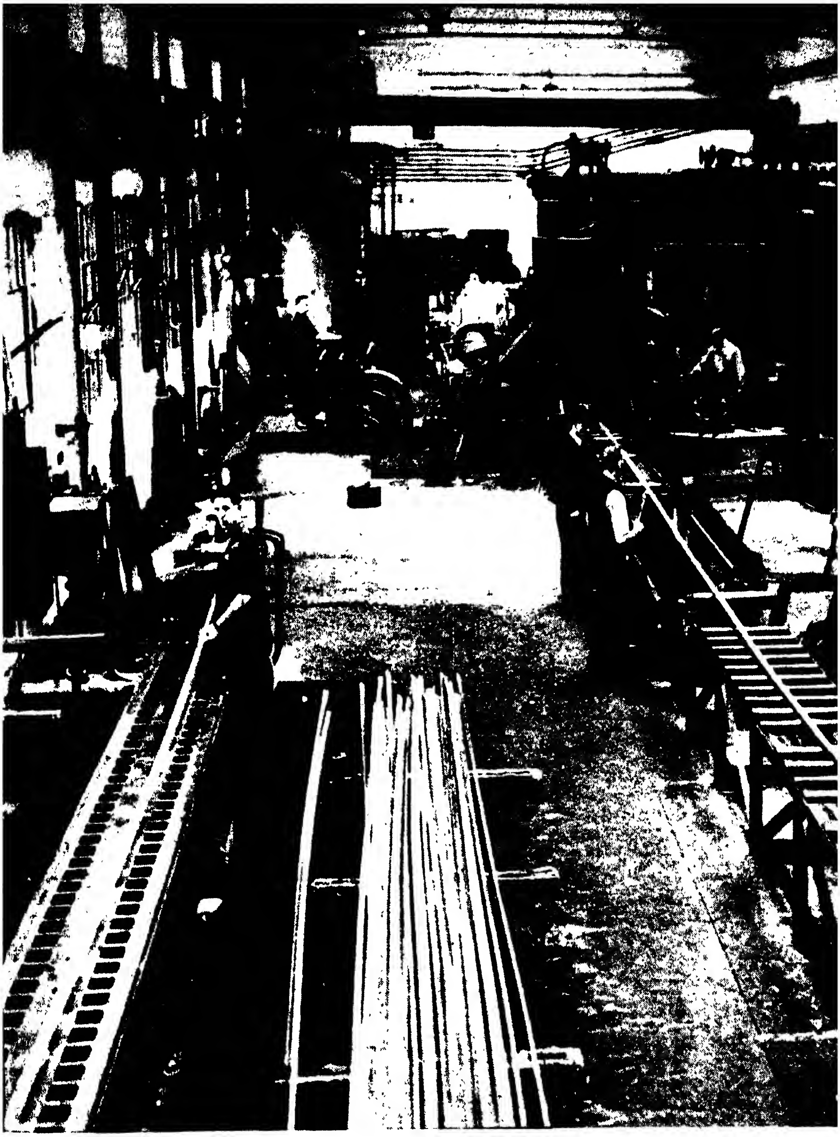
The metallurgical problems involved in the process of extrusion are exceedingly complex. The plunger movement first involves compression before movement takes place in front of the die: flow then occurs along the central axis and it is only after the stroke is well advanced that the outer layers of metal begin to fill in to the centre. In essence the extrusion process is equivalent to turning the metal inside out and, because of this feature, many problems arise, notably the problem of oxide skin inclusions.

The speed of extrusion is limited on the one hand by the working characteristics of the metal being processed and by the temperature at which it has to be worked (with regard to hot-shortness); and on the other hand by the available power. A high rate of extrusion is desirable because of generation of heat, but any increase in the rate of flow of the metal has to be produced by an increase in the tool pressure causing the flow. Although the theory of plastic flow is not very highly developed, by analogy with the laws of fluids the increase in pressure required may be taken to be of the order of the square of the velocity for a given orifice and a given plastic state (corresponding roughly to the yield point of the metal being extruded). In a small press handling billets of 12-24 ins. long the rate of extrusion may be one billet per minute, whilst larger presses may handle billets up to 36 ins. long at the rate of 20 or 30 an hour.

EXTRUSION PLANT

There are two methods of extrusion—the direct and the indirect (sometimes called inverted). In the direct process the container and the die are stationary and the billet to be extruded is pushed by the ram through the container. In the inverted process the ram is stationary and the container and die are pushed against the ram, which in this case is hollow; so that the billet does not itself move during the process of extrusion.

A modern extrusion press is a complicated hydraulic machine, provided with separate cylinders for forwards and backwards movement in several directions. The main pressure is utilized in the extrusion thrust proper: and a separate hydraulic system, much



Extrusion Press Producing Aluminium Sections.

less powerful, retracts the ram or the container. During extrusion the heated metal is under very heavy pressure and to prevent escape between the container and the die, a subsidiary hydraulic power system is operated to hold the container and the die together in a sealing cylinder: again, a smaller hydraulic system is employed to unseal the cylinder in reverse motion. After extrusion the sections are separated from the metal which remains in and behind the die by a hydraulically operated shear.

In the older extrusion plants the hydraulic power was supplied by gravity or high-pressure hydraulic pumps. In modern presses the hydraulic power system is based on air-hydraulic accumulators, either of the weighted type or hydro-pneumatic type which accelerates the speeds at opening and approach.

The actual pressure exerted in the billet ranges from 3,500 lb./sq. in. in a small press up to 100,000 lb. and over in the largest presses.

The container is of forged steel with a liner of high-grade heat-resisting steel of nickel-chrome-tungsten type. The container in position in the press is surrounded by a gas-heated or electrically heated chamber.

The die plate is the most vital part of the extrusion press. It is prepared from a template made to the exact shape of the section required, with allowances for contraction. The actual die is of nickel-chrome-tungsten steel of high grade: it may be partly machine cut but all extrusion dies are finished by hand to extremely fine tolerances and are then highly polished.

For the extrusion of aluminium, the die plate is cut square, without any radiusing as in the case of some metals: it is supported in a die-holder and, in large presses, in a special bolster, both of forged nickel-chrome-tungsten steel cut to the same contour as the die plant, but slightly larger to allow of free passage to the extrusion. The die and die holders are given special hardening and tempering: the finished assembly fits accurately into the die-head attached to the slide.

In some modern extrusion plants provision is made for quenching the extruded section as it emerges from the die.

As in the case of rolling mills, heat-treatment furnaces form an essential part of the equipment of the modern extrusion works.

HOLLOW EXTRUSIONS

One of the advantages of the extrusion process lies in the possibility of producing by it the most complex cross-sections, including hollow sections. Where tubes or more complicated hollow sections are to be extruded a mandrel is fixed in position in the centre of the stem of the press, being held central by the pressure of the metal being extruded during the actual process, through the annular space between the mandrel and the die. The hollow bore of the section may be of any reasonable shape, the original billet having been first pierced by the mandrel or alternatively pre-drilled, or cast-cored with a water-cooled core. In modern technique the " bridge mandrel " system developed in Germany late in the War has been brought to a high degree of perfection to produce hollow aluminium alloy sections. The bridge mandrel consists essentially of a die to give the external form of the section required backed by a so-called spider which holds in position, projecting into the die orifice, a short mandrel, shaped to the required contour of the bore. The actual die assembly may consist of several parts.

TAPERED SECTIONS

The extrusion process can be applied to the production of both hollow and solid sections in which the wall thickness tapers along the entire length, not necessarily in a straight taper.

CLAD SECTIONS

A recent development whose ultimate importance may be very considerable is in the production of clad extrusions (on the same principle as the rolling of clad sheet referred to on p. 234). Not only is the clad product available for use where severe corrosion conditions apply: the pure aluminium used for cladding acts as a lubricant for the extrusion process, giving rise to products of better finish and causing less wear on the dies as well as increasing the speed of extrusion.

FINISHING OPERATIONS

After extrusion the sections produced have to be heat-treated (in some modern plants quenching is automatic as the section emerges from the die) and subsequently straightened and cut to length. Whilst the extruded products emerge perfectly true, heat-treatment introduces distortion, sometimes very great: preliminary straightening is done by means of hydraulic stretching machines and any sections which require further trueing are corrected by hand operations or in special trueing presses.

Forging

Hot hammer forging, using mechanical or steam hammers, has been increasingly developed for light metal products. The hammers employed are similar to those used for steel and weigh up to 35,000 lb. With the necessity for development on mass production lines during the recent war, the aluminium industry has seen a rapid increase in the use of hydraulic forging presses and fast-acting forging machines. The size and quality of equipment have been continually improved and technique has also made forward strides, to a point where large forgings up to 1,000 lb. weight were regularly produced, for instance for gas turbine drum components and other highly stressed parts, during the war on large-scale output. Forgings up to 8 ft. long and over 6 ins. thick, weighing well over 750 lb., are produced by at least one important firm in this country.

Billets or slugs for forging may be either cast or extruded. Cast billets are usual for the largest work but the extrusion of billets for smaller products is being extensively developed. Forging temperatures are usually slightly below the solution temperature for any given alloy (e.g., RR 56 is forged at about 480°C., duralumin at 450° C. and Y-alloy at 470° C.) and preheating of the slugs is carried out in forced-draught, thermo-controlled furnaces in the case of larger sizes or in a salt-bath for small billets.

Forging proper is carried out in two or more stages: the first stage consists of " upsetting " the slug by power hammering or by a hydraulic press operation, liberal lubrication being essential. The "dummy" resulting from this operation is then given a re-heating treatment and sent on to the second stage of forming, which may require two or three operations between special dies, again with lubricants such as graphite suspensions, tallow or other special types. Press forgings are turned out to close tolerances. The characteristic shapes are round and fairly simple. After final forging, a clipping press removes any flash before final heat-treatment.

Compared with the common steels, aluminium alloys require about 30% more energy or power to produce a final forging from a billet of given size.

Powder Production

Aluminium powder manufacture until comparatively recently did not count as a fabricating process inside the aluminium industry: it was undertaken by the so-called bronze powder industry, the chief manufacturers in which in the early days were German and Central European. The manufacture of bronze powder had its origin in the manufacture of real gold bronze, or comminuted gold derived from the trimmings of gold-beaters' leaf, and is an industry of considerable antiquity. From the earliest availability of aluminium ingot, it joined gold, copper, brass, tin and other metals as material suitable for conversion into powder.

The discovery of the pyrotechnic properties of finely divided aluminium was soon known and aluminium powder joined the ranks of materials manufactured for the fire-works and munitions industries. Its production was taken up in this country in the later part of the second half of the Nineteenth Century but only on a small scale compared with the German industry.

For printing and as paint pigment, aluminium powder (or aluminium bronze, as it is frequently still called from its early associations) soon came to the fore and even before the First World War aluminium paint was well established in usage as a non-corrosive and heat-resisting protective paint: exports to America from the European manufacturers were on quite a considerable scale by 1915 when the United States first turned attention to the commercial manufacture of aluminium powder among other metal powders and, by 1938, the United States consumption of aluminium powder for paint alone reached the 5,000-ton level. About half this amount was imported into the United Kingdom in 1930 (chiefly from Germany, with a small supplement from Canada) to swell the modest output of the domestic manufacturers, of which the two chief ones were S. Fry and Company and the English Metal Powder Company. The necessity for large-scale imports and the growing importance of aluminium powder products caused the Canadian, American and British aluminium producers in turn to give their attention to the production of aluminium powder, to break what was up till then virtually a German monopoly in the bronze-powder market. Existing patented processes of major importance were bought up by the parent companies and production of powder was finally integrated into the general control of the aluminium industry on a par with other semi-fabricating processes. In this country the British Aluminium Company has started production of powder at Latchford Locks and the Northern Aluminium Company operates a paste plant at Banbury for their parent Canadian aluminium concern, which also has large domestic works for powder production. In the United States, the biggest aluminimum producer (Alcoa) has three plants now producing powder and paste and has reduced her imports to a nominal minimum (for the three years 1944, 1945 and 1946 they totalled less than 2,000 tons).

The modern industry distinguishes between two main classes of powder—granules and flake. Granules are coarser than flake and irregular in shape: flake powder, as its name implies, consists of very fine, thin flakes of thickness one-fifth to one-tenth the flat dimensions.

GRANULES PRODUCTION

The chief methods of production are five in number, each giving rise to a product possessed of characteristic properties in regard to shape, size, lustre, etc.

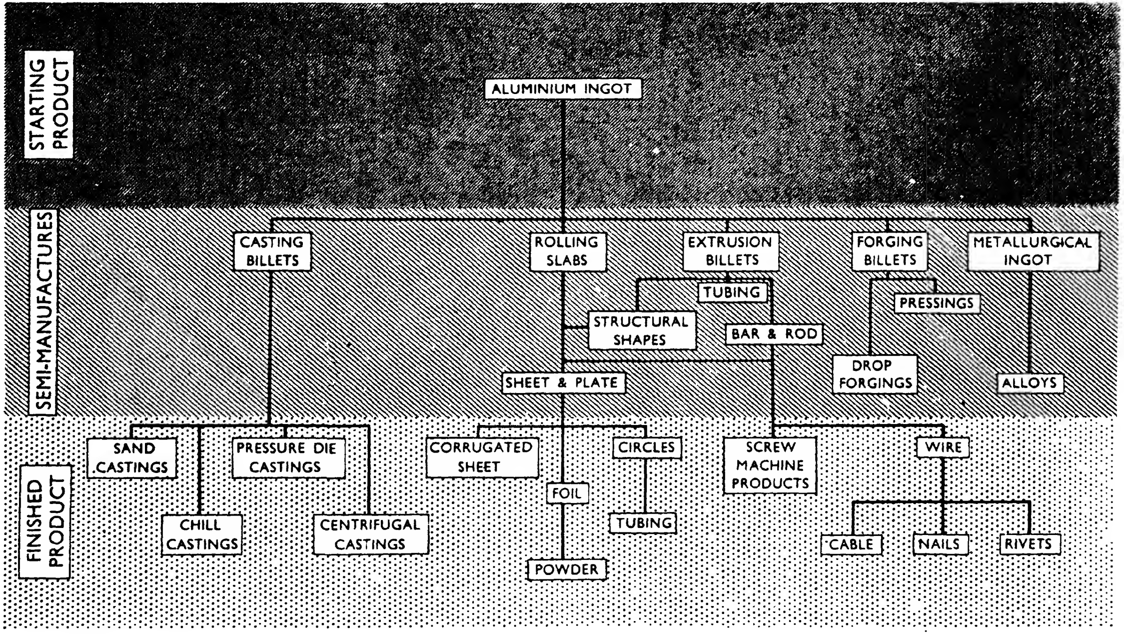


CHART V. The " Family Tree " of the Products of Semi-Manufacture in the Aluminium Industry.

Grinding in special mills, of ball-mill type, is the oldest, now the least used, method of manufacturing coarse granules of fairly uniform grain size.

Centrifuging is applied to granules production: molten aluminium is directed through a narrow slot on to a corrugated drum revolving at high speed.

Stirring is applied to semi-molten metal to produce a spongy form of very coarse powder.

Sieving also utilizes molten metal, which is poured through a sieve into water.

Blowing is the most important present-day method for producing granules of the type used in explosives manufacture and in pyrotechnics. A stream of molten metal is directed against a blast of air or steam produced by a nozzle or assembly of nozzles, the shapes and arrangement of which determine the characteristics of the comminuted metal.

FLAKE POWDER PRODUCTION

Flake is produced either from thin sheet or foil cuttings (foil scrap) or from granules. Four main methods of manufacture are in use at the present day. Lubrication plays an important part in all of them and most flake powders require subsequent polishing in special brush drums.

Stamping

This is the oldest and still the commonest method used in Europe. Stamping is carried out in a series of special mills in which cam-actuated steel hammers crush the aluminium material on steel anvils: the risk of explosion being very great, the stamping-mills have to be totally enclosed and the drives earthed to prevent sparking, whilst remote control, outside the mill room, makes it possible to exclude personnel completely during the period the machinery is running.

Wet Milling

Ordinary ball-mills, with steel balls, are used, the risk of explosion being countered by wetting the material with either water or oil which is subsequently evaporated.

Dry Milling

This is accomplished in one well-known German process, the Hametag process, by operating in an atmosphere of inert gas to which is added just sufficient air or oxygen to allow of the formation of the natural oxide film on the surface of the aluminium particles in order to counter the risk of spontaneous combustion when the powder emerges into the ordinary atmosphere.

Paste Process

In the production of aluminium powder for paste, the raw foil and sheet cuttings are mixed with mineral spirits and a lubricating and leafing agent and are fine-ground in a ball mill to produce direct a paste with 60%-70% aluminium powder.

A good paste has flake of thickness down to 0.00007-0.00001 in. (the latter figure for the finest grades), corresponding to about $10-20\times 10^9$ (thousand millions) flakes per gram. Ordinary powder passes through 150 mesh and about half through 300 mesh: extra fine grades pass entirely through 300 mesh.

CHAPTER X

THE FABRICATING INDUSTRY: WORKING

THE characteristic feature of aluminium, frequently referred to in the earlier chapters of this book, of being one of the most workable of metals, has already borne remarkable fruit in establishing a huge variety of available methods for forming it from semi-manufactured products into fabricated articles. Every conceivable method from hand-forming or hand-tooling up to the most ingenious mechanical forming methods yet devised, like impact extrusion, succeeds with aluminium because of its good ductility and general mechanical characteristics. The aircraft industry has fathered not a few of the present-day fabricating methods—many borrowed, with scant ceremony in transition, from the methods developed for sheet steel, but the main advances in technique owe much to the special qualities of aluminium, whose versatility is outstanding. Side by side with the new mass production methods, involving the use of high-powered presses and machinery, there still exist the older small-scale methods, even the hand-forming methods where the skill of the operator is responsible for the quality of the product.

In view of this great diversity of working and manufacturing operations, although the manufacturing-fabricating side of the aluminium industry is in the line of direct descent from the semi-manufacturing industry, at this stage the economic pattern of the industry becomes much more complex than is the case at either the semi-manufacturing stage or the parent reduction stage. Ownership of plant ranges through a much larger variety of interests and is no longer closely knit with the structure of the aluminium industry, whose integration in general stops at semi-manufacturing level although, through the medium of subsidiaries, many of the great contemporary aluminium producers throughout the world hold a large, if not controlling, influence in light metal manufacturing concerns, and keep a watchful eye on technical developments. Development associations, with members representing equally the producers and the fabricators of light metals, further the latter objective.

Hot Pressing and Sheet Forming

Hot pressing is in reality forging reduced to its simplest terms. It is being widely developed on account of its usefulness for producing small components at low cost. The pressing blanks are commonly cut from extruded rod stock and, after heating in a simple furnace of the muffle type, inserted one by one in a hand-fed press, usually of the screw type provided with compensatory friction drive. The commonest alloys for this type of work are the aluminium-silicon alloys which do not require heat-treatment and which react well to the die.

Roll pressing is akin to section rolling and the press employed is effectively like a rolling mill which makes only one revolution before reversing. The blank for this kind of work is an extruded bar or rod which is machined and then heated before insertion in the rolls, which are large in diameter and are provided with cavities of the required shape to act as a die assembly. This method has been applied with success in the forging of aircraft propeller blades: finishing of these blades is carried out in a light hydraulic press before trimming, to give them the necessary spiral pitch.

Sheet forming operations of all types are particularly successful on aluminium and its alloys. The pure, commercial metal can be cold worked without intermediate annealing. Alloys which do not require heat-treatment are commonly worked in the soft or quarter-hard condition, sometimes in the half-hard condition. Alloys which are heat-treatable are usually worked immediately following solution treatment and quenching to avoid solution heat-treatment operations and consequent distortion after forming.

In two important respects aluminium differs from other metals in its sheet-forming properties. Its coefficient of surface friction is high and it has a tendency to thicken when exposed to compression forces. Whilst the principles of sheet deformation are basically the same as for other metals, therefore, allowance has to be made for these factors in designing blanks and tools and in calculating deformations, clearances and permissible pressures.

Drawing of light metals is carried out in the same type of equipment as is used for other metals. Shallow drawing may be made on single-action high-speed presses: if the sheet is thick enough to escape any risk of wrinkling, a blank holder may be dispensed with, but in the case of thin sheet a holder is requisite and in addition an air cushion or spring assembly may be necessary to control the pressure sufficiently to prevent wrinkling. Wrinkling cannot be removed successfully by subsequent ironing in the case of aluminium as it can with other metals.

Deep-drawing necessitates the use of the double-action press. This has three essential components: a vertically moving ram and punch assembly, driven by an overhead crankshaft; the blank holder or pressure plate, fixed to an outer ram; and the die. When a deep-drawing operation is in process the outer ram plus blank-holder assembly descends first and exerts pressure on the edges of the blank, whilst the inner ram, which subsequently descends, forces the metal into the die, which is provided with an opening through which the punch travels, carrying the workpiece. The formed shell is stripped off the blank holder on the return stroke.

The success of a deep-drawing operation in aluminium depends largely on careful adjustment of the pressure and on proper lubrication. For ordinary drawing a light lubricating oil is satisfactory but for deep drawing operations it is usual to add animal fat to the mineral oil: suitable mixtures are 50 or 30% mutton tallow and 50 or 70% paraffin or heavy lubricating oil.

The tools for drawing aluminium may be made of cast iron, plain or alloyed, carbon steel or tungsten carbide, choice depending on the quantities in production and on the desired finish. Tool faces require to be highly polished, to prevent any risk of retarding the flow of the aluminium or scarring or flawing of the metal to give rise to ultimate fracture.

Tool clearances vary according to the shapes being drawn. The percentage reduction attempted in the drawing operation must not be too great: the following figures show optimum successive reductions for drawing cylindrical shells:—

First draw	0.40 blank diameter	(d_1)
2nd „	0.20 d_1	(d_2)
3rd „	0.15 d_2	(d_3)
4th „	0.15 d_3	

The optimum range for the die radius is 4-15 times the thickness of the sheet to be formed: whilst the radius of the punch should be not less than four times the sheet thickness. Finally, in draw-aluminium it is desirable to design the drawing tools so that the sheet undergoes very little change in thickness during the operation.

In general it may be said that if the deep-drawing operations required to produce a given component are severe (requiring, for comparison, the use of special quality deep-drawing steel) an additional operation as compared with steel is requisite.

STRETCHER-PRESSING OR STRETCH-FORMING

This method of sheet forming, originally German, has been greatly developed here and in America in recent years and has proved of great value in the production of aircraft light alloy sheet metal components because, first, of the greater possibilities it offers technically to form in the quenched condition and, second, because both the tools and the operation of the method are cheap. The stretcher machine, operated by hydraulic power, clamps the edges of the horizontally stretched sheet tightly: and the punch or former, which may be of any softly contoured shape, is then forced vertically up against the sheet which is actually purely stretched to take the required shape. Recent modifications of the stretcher-forming process render it capable of application to mouldings and extrusions, the ends of which are clamped in jaws attached to pneumatic or hydraulic cylinders: the pressure can be varied in the forming without giving rise to any wrinkling.

FORMING BY THE DROP-STAMP OR DROP-HAMMER

Where only small production rams are required for aluminium or aluminium alloy components, the drop-hammer method, one of the oldest working methods in existence, is still one of the best and in a revised form has been extensively revived by the aircraft industry in recent times. Both plant and tools are cheap and the work is easily controlled. A representative drop-hammer or drop-stamp consists of a heavy frame which carries an overhead shaft, a suspended hammer and punch attachment and a die-bed. In operation the hammer can be raised to any height and dropped by tension-controlled, manually operated gear: the usual practice is to commence with light blows and finish off with successively heavier stampings.

Components suitable for drop-stamping are those which are shallow and have liberal radii.

FORMING WITH RUBBER: THE GUERIN PROCESS

In the Guerin process, developed in aircraft production methods, a series of flat rubber pads is used on the blank, the pads being removed one by one after successive impacts of the drop-stamp, and the final blow delivered direct, without any pad, to sharpen the contour. The process is very useful for forming shallow parts or flanges.

Compressed-Air Hammers replace manual operation by pneumatic force. In addition they add the possibility of performing squeezing as well as stamping operations.

IMPACT EXTRUSION

The method of impact extrusion, originally and principally developed in Germany, has attained great importance in the case of aluminium, with which, for certain operations, it possesses outstanding advantages and is less costly than deep-drawing. Essentially impact extrusion consists in the nearly instantaneous application of sufficient pressure to a flat blank of metal to force it to flow through the die. Single action presses are employed, operating with a descending punch which has a very short drop, driven at high pressure. After the initial impact, the punch stroke is then accelerated.

The critical factors in the method are many: and tool material and design have to be first-class. The punch usually has a hardened chromium steel body with a working head of softer steel: to prevent skidding on impact the centre is left rough or may even have a skid-resisting stud. The so-called extrusion edge at the end of the punch controls the inside diameter of the product and its width is critical in controlling the frictional forces set up. The head is generally about 0.12 in. greater in diameter than the body of the punch, the edge being sharply radiused and highly polished. The relationship between the depth of the die cavity and the depth of the blank is of the order of 2 : 1. The maximum diameter of the impact extrusions produced in the latest German machines was as great as 10 in., but most of the impact-extruded products do not exceed 3 in. The maximum depth obtainable is up to 6-8 times the diameter. The base thickness is of the order of 1-2 times the wall thickness and should not be reduced below one-tenth the original blank thickness.

The pressure required for impact extrusion depends on all the size factors and on the nature of the metal (whether pure aluminium or alloy), the working temperature and the lubricant used. It increases with increasing depth and diameter of the product and decreases as the wall thickness of the extrusion increases and as the temperature rises. It is directly affected by the ductility of the metal.

The extrusion process has so far been chiefly applied to high-purity aluminium, of minimum purity specification 99.7%. This grade of metal is requisite for thin-walled collapsible tubes, but a somewhat lower grade (99.5%) can be successfully used for rigid-sided containers: and even alloys of the high-strength type like duralumin can be impact-extruded.

The rate of production is very high. With a good modern press up to 4,000 products an hour may be turned out.

SPINNING

This is a method old-established and still very extensively used and undergoing development in the aluminium industry for the fabrication of symmetrical circular shapes, particularly simple hollow shapes and those of re-entrant curvature. Apart from the fact that it is cheaper than press production on account of the much less costly tools employed, it offers definite advantages in production for such forms as variations of the potter's " Greek vase " and reflector shades or hollow bowls with concentric convolutions, among smaller objects: and since there is practically no limitation to size, it is also extensively used for very large simple shapes up to 6 ft. or more in diameter which it would be very expensive to produce by press methods. Aluminium spins very easily: the 2% manganese alloy is also very successful in spinning production but the silicon alloys harden rather too rapidly to allow of much change in form. Alclad sheet can be spun successfully for shallow parts.

Spinning is carried out on a form of lathe, usually quite elementary in design but of fairly heavy construction. A circular blank equal in size to the finished article is pressed against a chuck or former shaped to the contours of the desired product and rigidly fixed. The blank is held in position by a disc which is rotated rapidly in the lathe, pressure being applied so as to deflect the unsupported portion of the blank on to the former. Modern spinning lathes are usually driven electrically, the spindle being carried in ball or roller bearings: for heavy work, lathes are generally provided with a pressure bearing to take the thrust of the work. Chucks are of hard aluminium alloys, steel or cast iron, or hardwood such as lignum vitæ or maple. Hand tools are of steel and exist in a great variety of forms suitable for shaping and planishing work.

Hand spinning lathes are frequently employed for finishing operations, such as beading, on press products: or machine lathes may be used in conjunction with press-work to do certain forming.

The speed at which aluminium can be spun is much higher than is possible with other metals, and for small spinnings in the pure, ductile metal the spindle speed may reach 2,000 r.p.m. The peripheral speed is of the order of 3,000 ft. per minute. Spinning generally involves a reduction of the order of up to one-third in the thickness of the metal: the limits to the gauge thickness of pure aluminium or manganese alloy, suitable for spinning, depending on the size of articles, are roughly from 26 s.w.g. for products up to 2½ in. depth to 18 c.w.g. for products up to 12 in. in depth.

The lubricants used are important: for small spinnings a mixture of animal fat such as lard, oil or tallow (or even beeswax) with solid paraffin is used, but for large spinnings a low-alkali soap gives better results.

PANEL BEATING

One of the most ancient of forging arts, this is still a method essential to the production of special parts which cannot as yet be formed mechanically and to the hand-finishing of shapes roughed out by press work. It consists in hand-hammering with wooden mallets of special shape and of different sizes. Aluminium is possessed of sufficiently high malleability to allow of its being beaten with such wooden mallets into double curvature forms. The metal is beaten to shape in a recessed wood block or against a sandbag to form the hollowing operation, or it may be formed in a wood block hollowed to the required shape or over wood formers.

The method requires a skilled craftsman for its execution. Its application is of great value in the production of prototypes and for the production of throat-shaped bends, for example for aircraft ducting.

The mallets used to do the main shaping are commonly round-headed or pear-shaped and are preferably made of holly wood or boxwood: finishing mallets and dressing tools, which form an essential part of the panel-beater's kit and are actually fine precision instruments, may be made of apple or pear wood. A tendency is developing to use steel finishing tools but the finest craftsmen consider wooden tools definitely superior.

The Aluminium Hollow-ware Industry

Although it is a very long cry from the days when the chief use of aluminium was for domestic pots and pans, the hollow-ware industry is still an important one and merits some interest because although it is an entirely separate industry within the confines of the aluminium fabricating industry, with an independent history, it is nevertheless closely bound up with the development of the parent aluminium industry. As a result of being the chief handmaiden of the primary producers in their pioneering days, the aluminium hollow-ware industry was given much help and backing by them and it never pursued a course divergent in its interests to those of the main industry.

In the early days of aluminium production at the turn of the Century the hollow-ware industry was struggling in the throes of intense internecine competition in the world markets between the hollow-ware producers both of Western Europe and America. In this economic contest rival materials were played off against each other. Iron cooking utensils were becoming obsolete, copper was going out of fashion (except where the gastronomy of a more leisurely age was clung to) and of the new materials enamel-ware, aluminium, nickel and stainless steel, the most strenuous rivalry was between the former two. Both were relatively much cheaper than the others and the struggle between them was carried to the point where prices were cut-throat, against a background of sweated labour and even child labour in this industry in some European countries in the first decade of the 20th Century. Germany and Bohemia, first in the field with mass production of cheap enamel and aluminium hollow-ware competed fiercely with Sheffield goods in the markets of the East and in Europe, driven by the necessity for bare survival in the first exhausting industrial expansion period. American producers of hollow-ware fought the same battle in their own preserves on a scale only slightly less intense.

Aluminium hollow-ware production had two main trends, based on casting and on sheet fabrication, but both methods did not enter into the production of the cheap-grade goods which far outnumbered the better-quality utensils in the early days. The bulk of production was based on aluminium circles as the raw material, which the hollow-ware industry processed in sheet presses, with spinning as an auxiliary or subsidiary fabrication method. With profit margins cut to a fraction, much of the cheap stuff which flooded both the lower-class domestic European markets and especially the bazaars supplying the poverty-stricken populations of Asia and Africa, was made with the prime objective of putting as little metal as possible into the utensils: pressings were made marginally thin, temporary stiffness being produced by beading over the edges. Better quality utensils were spun or, according to shape, first formed in a power press and then given treatment on a spinning lathe or in an automatic machine to produce alterations in shape such as necking or refinements in wall structure. In the highest grades of all, cast utensils, particularly for cooking, competed with the best spun vessels—interesting, as much of the metal which went into the castings was remelt product in those days.

The first aluminium saucepan was stamped experimentally from sheet in 1890 by the Avery Stamping Company, of Cleveland, Ohio. The British industry dates from about the end of last Century and by 1905 there were two or three producers of pressed and spun utensils and one producer of cast saucepans. These numbers were already substantially increased by the time the First World War broke out in spite of the formidable competition from the European producers. With the changed position at the end of the war, the industry commenced to flourish in this country and the formation of the British Aluminium Hollow-ware Manufacturers' Association, in October 1918, was the first attempt to introduce an organized structure into the industry on the German model. As the industries in the Allied countries gained ground during the period of partial paralysis of the ex-enemy industries after the war, the difficulties which beset these even when they were re-formed were severe and by the end of the 'twenties a definite decline had set in in the German aluminium hollow-ware industry. Overproduction in the home industry and increasing foreign competition in the best markets, with prices cut very low, made the German producers' outlook for aluminium hollow-ware almost uniformly pessimistic, in spite of the fact that the German industry was a long way ahead in production technique and in standardization. In fact it was a meeting between the German and British Hollow-ware Associations in 1927 which gave rise to the first serious attempt in this country to control and up-grade the standard.

During the 'thirties the prosperity of the British industry steadily mounted. In 1932 a nation-wide and well-organized campaign to boost the home market was initiated in the form of an "Aluminium Week," and exports of aluminium hollow-ware greatly increased. Output was concentrated in the hands of some forty manufacturers, two-thirds of whom were in the Midlands close to the allied Sheffield hardware industries, who carried between them some 80% of the total production, and the industry was well-knit and sufficiently competitive.

Shortly after the war broke out in 1939, manufacture of aluminium hollow-ware was prohibited, and this restriction remained in force until 1945, but plans were made by many newcomers, in the period of extreme scarcity during the war, to enter the production field. More than 250 Government licences were granted to new producers, some tenth of the licensees being sizeable concerns who erected plants in the vicinity of the older-established manufacturers after the war. Through the first of the boom period in the immediate post-war years the new manufacturers did well, but after the inevitable falling-off of sales set in the older established companies overhauled their new rivals and by the middle of 1947 the position was roughly that the output of the former firms both for home and export trade was three times as much as that of the latter. The greatest overall falling-off of sales has been in the export market.

In recent years production of cast products has been on the increase and there no longer exists the old quality line distinction between the two types of vessels, particularly as hot-plate cooking has become almost universalized for modern solid fuel and electric stoves, thicker-gauge saucepans and utensils have become more common in the Western markets, so that castings are the natural rival of thick-walled pressings.

It has been estimated that, from the forming of the first saucepan in 1890, over 400,000,000 saucepans had been produced in the aluminium hollow-ware industry by its half-centenary year 1940: and the scale of the contemporary industry is indicated from the example of one American aluminium hollow-ware producer who runs over 2,500 lines of articles in his production schedule.

CHAPTER XI

FABRICATION: JOINING

THE methods in use for joining aluminium and its alloys cover as wide a range as the entry of the metal into all industrial spheres from heavy engineering to the smallest fabricated objects necessitates: from riveting of large structures down to bonding and soldering methods and simple folding. Few of the methods are new to the general metal industry and the tendency to borrow and adapt is as apparent as in sheet-working, but there is one notable exception which is the product of the exceptional development of the extrusion of light metals. By virtue of the intricacy and precision possible with extruded sections they can be designed to provide inter-locking by the use of simple shop equipment and need not be dependent entirely on any joining method.

The main function of a join in an engineering structure built up of heavy sections or heavy sheet is to provide a union of components which will allow of the exploitation of their full stress values. Appearance is here secondary in importance. Riveting is the chief method in use; interlocking as a principle is utilized where possible. Next in the field of joining come the methods applicable to sheet fabricated parts, and here, where the vital factor is homogeneity, welding (particularly oxy-acetylene welding, so far) comes into its own as a highly favoured method. Brazing methods are being developed to some extent in America. For small objects bonding by diffusion or utilizing plastic resins and joining by soldering can be applied to aluminium. Screw joints are possible as with other metals, for jointing tubular components.

Adaptation of method is often slower in developing a sound technique than are methods embodying new principles or outlook: and this is noticeable in the case both of riveting and of welding aluminium, where much of the best equipment has been primarily developed in highly specialized industries for steel sheet-parts and is relatively inflexible except for detailed changes in geometry of the parts.

Riveting

For the early development of the technique of riveting the strong alloys of aluminium much of the credit goes to German research. Rivets of the non-heat-treatable alloys and certain heat-treated rivets in ordinary size are always driven cold; and early German research established the essential divergences in design and practice of cold-riveting light alloys, where the forces are almost exclusively compressive in the rivet hole and shear in the rivets, as compared with the hot riveting of steel where the rivet is principally subject to tensile stress from the friction forces resulting from compression of the seam.

In general, structures assembled with aluminium alloy rivets require a larger number of smaller-diameter rivets than is the case with joints in steel. Most of the traditional types of rivet can be used in aluminium—round or pan head, mushroom or flat head, countersunk rivets of different included angle. Light metal rivets for use on light metal joints are available in sizes from $\frac{1}{16}$ in. to $\frac{3}{8}$ in. (in addition there are available small rivets for joining non-metallic materials). Rivets with small heads are manufactured in single-blow, cold-heading machines but larger types involve three-stage fabrication comprising the wire blank-cutting, coning of the head and final shaping. Single lap joints are commonly made in sheet up to 22 s.w.g. in thickness whilst double and treble lap joints are necessary for sheet of thickness range 22-16 s.w.g. and 16-6 s.w.g. respectively. Double or treble rows of rivets may be employed equidistantly and diagonally placed. The minimum edge allowance should be 1.5-2 times the rivet hole diameter.

Rivets are commonly supplied in five materials: commercial aluminium (for use on non-structural joints only), heat-treated duralumin, which age-hardens *in situ*, the Mg-Mn alloys to D.T.D.303 and D.T.D.404 and a special heat-treatable alloy developed to allow of riveting in the fully heat-treated condition (to D.T.D.327). Wherever possible the composition of the rivet metal should correspond to that of the workpiece.

Rivet holes are drilled or punched (which is cheaper) and it is common practice to punch undersize and then ream to size during assembly. Location before assembly may be necessary with large sheet parts and drill plates or template jigs are employed for this purpose. Any burrs or chips are carefully removed before the rivets are driven. Countersunk holes are often drilled in thicker parts, either with hand tools or with a lever punch or pneumatic compression riveter. Thin sheets are sometimes " dimpled " by squeezing the rivet into the material with special dollies.

Aluminium or aluminium alloy rivets require driving with a few heavy blows on the (dolly-supported) shank: practically all light metal rivets are driven with a flat upset. Small rivets can be driven by hand but portable hydro-pneumatic squeeze riveting units or pedestal power riveting machines, air operated or hydro-pneumatic, are used for medium work and air-operated rivet hammers of different types are employed for riveting large assemblies.

A number of special developments in riveting are applicable to aluminium. Of particular interest are the hollow rivets developed for blind riveting of inaccessible places: these so-called " Pop " rivets are also now used for general riveting in place of the more usual solid rivets. " Pop " rivets have cup-shaped " shanks " with a hole through which a mandrel is threaded: they are set with hand tools, the rivet being pushed into a pre-drilled hole, and forward pressure is exerted on the rivet whilst the mandrel is simultaneously pulled in the opposite direction. Different designs of rivet-head and mandrel are available. A feature of " Pop " riveting is its speed—such rivets can be set at up to 1,200 an hour.

Explosive rivets, for assemblies where one side of the joint is completely inaccessible, have also been developed in Germany: the heading power of the rivet is supplied by a small explosive charge inserted in a small hole at the end of an ordinary aluminium alloy rivet.

Recent developments in light metal riveting include automatic riveting methods which operate on the same principle as the press:

simple types of presses such as the brake press can in fact be adapted to automatic flush riveting of straightforward assemblies.

For the storage of rivets of the heat-treatable duralumin alloys which have to be driven in the as-quenched condition to age-harden in position, special portable refrigerators are used to hold the rivets at about 0°C. in order to delay age-hardening until they are driven into the work-piece.

Welding

Welding of aluminium and aluminium alloys has been considerably developed but it still has a good way to go before techniques can be said to be on a par with the high degree of efficiency arrived at in the welding of steel. All types of welding are applicable in principle to the light metals—autogenous, arc and resistance welding, but all have not been equally developed. In welding, as in riveting, practice and equipment are still largely adaptations from the steel industry.

There are one or two fundamental differences as between light metals and steel in relation to welding problems as a whole. First is the characteristic high oxidizability of aluminium and its alloys; the invariable presence of an oxide skin which forms so rapidly that fluxing, in the ordinary sense, is mostly inefficient, is perhaps the chief problem in any method of welding aluminium products. Second, in the case of the strong aluminium alloys, is the fact that a higher percentage of alloying constituents is present than in the common steels and hence a wider melting range is encountered, with consequent increasing tendency to cracking when the weld cools. Another general problem is the rather lower ductility of welded joints in light metal as compared with steels. In the case of the heat-treatable aluminium alloys, any of the fusion welding methods reduce the strength of the welded joint to the strength of the annealed metal (irrespective of any strain hardening), but where methods can be devised for heat-treating the parts after welding this particular difficulty can be met to give at least partial (60% up to 90% in exceptional cases) restoration of strength:

sometimes hammering of the welded seam may replace or precede heat-treatment.

AUTOGENOUS WELDING

This is one of the oldest and most successful methods of welding aluminium. Mechanically and in corrosion-resistance oxy-acetylene welds behave excellently. Much the same technique and equipment as are used with ferrous materials can be employed for light metals: the process is commonly used manually, though recent developments are in the direction of mechanized operations where long straight butt joints are to be dealt with.

Fluxing is of first importance: proprietary fluxes, preferably for use dry, are available in variety and require application with care to prevent using excess. A welding rod, wherever possible of the same composition as the sheet to be welded and of diameter in general approximately equal to the sheet thickness (practical limitations are about 14 s.w.g. to $\frac{5}{16}$ in. for the rod diameter even where the sheet thickness is outside these ranges) is invariably necessary.

The rate of welding is more rapid in the case of aluminium than with the common steels, and it is not uniform since it increases as the sheet becomes heated. For very thick sheet, over $\frac{3}{8}$ in. thick, pre-heating is desirable to economize gas, prevent warping and speed up the welding process.

On completing the weld any residual flux must be scrupulously removed by boiling water or acid dips (warm 5% nitric acid) followed by washing.

Autogenous welding may be applied in repair work on castings: such work should always be undertaken on pre-heated parts.

Oxy-hydrogen mixtures can be used in place of oxy-acetylene and may be favoured for light-gauge steel or tubular parts on account of the lower flame temperature. Larger-nozzled apparatus is required and welding is slower.

Autogenous welding is essentially a skilled operation, calling for dexterity and experience. During the war a large number of operatives were trained to use oxy-acetylene welding equipment on aluminium alloys in the aircraft industry and it was found that the rate of acquirement of skill was about even with that in welding steel.

ARC WELDING

Three types of arc welding are applied to joining light metals: those depending on the metal arc, the carbon arc and, the most recent, the argon shielded tungsten arc. Whilst all methods are possessed of characteristics which make them specially suited to repetitive work for mass production, frequently on fully automatic lines, their use on aluminium alloys is limited because of the characteristics of arc welded joints in the usual sheet thickness range dealt with in sheet work assembly. The melting point of aluminium being lower than that of steel, the rate at which the smaller-size electrodes burn is extremely rapid and it is difficult, accordingly, with equipment as yet available, to control the deposition of the weld metal so as to make a smooth sound joint.

Metallic arc welding is at present, therefore, only applicable to sheet of $\frac{3}{16}$-$\frac{1}{4}$ in. thickness and over. It is carried out with d.c. equipment, the flux-coated electrode (of the same composition as the workpiece, or, in America, 5% Al-Si alloy) forming the positive pole. The function of the flux in metal arc welding is twofold: to react with the oxide skin on the aluminium and to stabilize the arc. In manipulating the arc the electrode is held nearly vertical and the arc is kept as short as possible.

The potential advantages of the metallic arc method of welding light metals are considerable because of the greater localization of the heating effect, which reduces physical buckling and distortion tendencies and also decreases cracking due to hot-shortness. In the present state of technique, however, the method is restricted in use in application to aluminium alloys: attempts are being made to develop electrodes for use with a.c. which would simplify operative control, but these are not yet far advanced.

Carbon arc welding has certain advantages over the metallic arc method but it has nevertheless not "caught on" widely in the joining of aluminium alloys. A separate feeding rod is required for carbon arc welding and the method is usually applied in mechanized equipment where the electrode, feeding rod and flux supply travel horizontally and at a uniform rate along the work piece. Direct current is used as with the metallic arc, but the joints obtained are smoother and it is possible by the carbon arc to weld sheet of any thickness down to about 1/32nd in.

The only fusion welding process proved suitable for welding aluminium alloys without the use of a welding flux is **Tungsten-arc Welding** in an atmosphere of argon (American practice) or hydrogen (British practice), a method introduced during the recent war which has remarkable potentialities. The main features of the process are the production of a smooth, sound weld without fluxing; preservation of mechanical strength in the welded join; improved ductility of the welded seam; and, finally, good appearance. In technique the method is superior to the other arc methods as a.c. equipment can be used and h.f. current can be superimposed to stabilize the arc. It is possible, because of the smooth flowing of the weld metal, to apply the arc to seams in the overhead and vertical positions as well as downwards. And, finally, the method is adaptable to mechanization.

At the present stage of development the advantages of the method are largely offset by its comparatively high cost, occasioned by the feeding of the costly high-purity argon or hydrogen gas through a cup surrounding the tungsten electrode to " blanket " the arc and the molten metal.

Improvements in and reduction of the cost of this new and promising method are looked for in America, where its wider application in modern light metal fabricating shops is anticipated. The fact of the independence of the arc makes the latter a more flexible subject for manual operation: it may be handled very much in the same way as a welding torch and moved away from or towards the join as the situation demands. This same fact makes the method one calling for greater skill in operation, however: and the very high temperature of the arc (of the order of 4,000°C.) creates added difficulties such as dross formation on the weld surface if high dexterity in operating technique is not available.

ELECTRIC RESISTANCE WELDING

All the developed forms of electric resistance welding, namely spot, seam and flash welding are applicable to aluminium, but considerable differences in technique and equipment, as compared with welding steel, are made essential by the quite divergent relevant properties of the two metals. Aluminium is possessed of a very high electrical conductivity and of very high heat-conducting properties, both of which factors directly influence the welding process. Again the oxide film invariably present on aluminium materials varies in thickness and surface resistance on different alloys and from workpiece to workpiece of the same alloy, depending on its history and treatment, which directly affects the quality of the electric weld and the cost of the process.

Spot Welding is closely comparable, from the angle of the finished seam type, to a riveted joint and good welds can be made provided proper control can be exercised on the current, pressure and time factor and provided the design of the electrode tip is good and the alignment of the upper and lower electrodes is perfect. Different welding circuits have been developed, the main attempt being to offset the demand of the very high current consumption with aluminium on the works mains; modern developments are oriented towards either storage of energy in the periods between welds by the use of condensers or batteries or transformers, or in the independent generation of the required current inside or ancillary to the welding equipment proper. In designing the electrode set-up allowance must be made for the much greater pressure—roughly double, as compared with welding steel—required and for the difficulty of getting uniform pressure distribution to obtain consistent strength and size of the welded seam. Either hydraulic or pneumatic pressure systems give good results: synchronization with the welding must be perfect. So far as actual electrode-design is concerned, spherically tipped interchangeable ends of hard copper or copper alloys with electric conductivity not less than 80%-85% that of copper, have given the best results: the use of special tip shapes to deal with welding under flanges or in grooves is practically out of court with aluminium on account of the difficulty of applying adequately high pressure and by reason of the high cost.

Aluminium and its alloys essentially require good precleaning before welding by the spot method: common methods are based on either mechanical methods like wire-brushing or chemical etching. The electrode tips also require redressing at intervals and these two cleaning operations are inter-related. Good cleaning of the aluminium surface reduces the interval between redressing of the tips. Figures quoted for maximum surface resistance of the surface are of the order of 50 microhms, with which resistance tip-redressing is only necessary after 200-400 spot welds have been made.

Seam Welding. Whilst the seam-welding process is only in effect a variation of spot-welding, revolving electrode tips being employed to produce a continuous series of spot-welds by analogy with stitching, the current consumption is disproportionately increased because of the short-circuiting influence of the close preceding weld. In the case of pure aluminium and of the aluminium manganese alloys this increase may be as low as one-quarter, but with the light alloys with larger proportions of alloying constituents, it may be a hundred or even two hundred per cent. increase: and the temperature increase resulting from the electrical effects may reach solution heat-treatment point. Seam-welding of aluminium products must therefore be undertaken with care and provision for subsequent hardening of the weld by hammering or mechanical working is usually necessary. Apart from deterioration in mechanical strength, a seam-weld may be very sensitive to corrosion effects as a result of physico-structural changes and scrupulous technique in pre-cleaning and after-cleaning must be employed.

Flash Welding represents an interesting departure in principle from the other forms of electrical resistance welding since it involves additionally a forging or strain-hardening action dependent on the use of what are effectively dies. It is particularly suited to the end-to-end welding of sections. Two clamps, one stationary, and the other movable, are fixed in position on the work-bench and when the two ends of the work piece are clamped in butt-ending relationship current instantaneously passes, fusing the metal, and the movable die rises and " forges " the material whilst simultaneously interrupting the current cycle. Travel of the work piece is mechanized to synchronize with the welding current. The current required is of very high amperage (up to 100,000 amps./sq. in.) and the temperature which flash-welding produces causes rapid oxidation of the aluminium, so that it is essential to reduce the flash and die-movement times to the absolute minimum: for sections up to ½ sq. in., the optimum cycle for the flashing period is 35-45 followed by a 3-6 cycle for the " forging " period. The pressure exerted by the die clamp may range from 12,000 to 22,000 p.s.i.

There are two main advantages of the flash-welding method: the first, related to its purely welding function as a butt method and the second, related partly to the die-forging principle embodied and partly to the elimination of a molten zone and the rapidity of the flash, is the excellent strength quality of the weld and surrounding area. The application of the method is determined by the geometry and shape of the parts to be welded since firm clamping is its central essential.

The standard flash-welding equipment for steel is not of direct use for aluminium on account of the different timing and cycles required.

BRAZING

Sometimes called hard soldering, this process depends essentially on the principle of adhesion and is therefore limited to lap joints. The filler materials used on light metals must necessarily, to avoid corrosion, be aluminium-base alloys and since none of these melt at a very low temperature, the brazing of aluminium materials has to be carried out at relatively high temperatures: whilst little or no melting of the parent material occurs, the annealing range of both cold-hardening and heat-treatment aluminium alloys is surpassed, so that, as in welding, the strength across the actual joint is equal to that in the annealed temper unless it is corrected subsequently by heat-treatment or working. The fillers most favoured for brazing light metals are the Al-Si or Al-Si-Cu alloys.

Three different techniques are in use for brazing. In **furnace**

brazing, the parts are assembled, the filler is applied in the form of wire and flux is sprayed or painted on: the entire assembly is then heated to a temperature of the order of 600°C. (585-615°C.) according to the class of alloy. In the case of heat-treatable alloys the brazing of an assembly may be combined with its heat-treatment, quenching being performed on removal from the furnace. **Dip-brazing** is carried out similarly, the furnace being replaced by a pre-heated molten salt bath which acts at the same time as flux, so that separate fluxing can be dispensed with. **Torch brazing** is carried out with the same sort of equipment and technique as gas welding: a low melting point flux and filler wire are used and torch-heating is applied to melt the flux and flow the molten filler to fill the join, which is frequently, in this joining method, a lapped join in sheet assemblies.

It is important in the furnace brazing method to heat the part uniformly to avoid buckling and distortion: the torch method has the advantage where small neat joins are required. All brazing operations require the use of flux and scrupulous removal of the flux subsequently is essential to the ultimate good condition of the brazed joins.

SOLDERING

This is scarcely a fabrication method for industrial application. A large variety of solders, mostly based on tin-zinc-aluminium compositions, has been developed but soldered joins in light metal are not very successful and tend to deteriorate after exposure due to their sensitivity to moisture: reasonable performance can only be obtained if protective paints or varnishes are applied to soldered parts.

PLASTIC BONDING

This is a recent development, in which synthetic resin components take the place of fillers. It is not intended for joining load-bearing assemblies although the actual sheer strength of such joins is appreciable. The low temperatures applicable to this type of bonding are at once its strong point and its weak point: for although the heating necessary is not such as to interfere with mechanical properties derived by heat-treatment, the join once formed cannot stand any degree of heating.

COLD WELDING

An interesting post-War innovation in the methods of joining aluminium, borrowed from the copper fabricating industry, is that of so-called cold welding, introduced, following research, by the G.E.C. It depends on the possibility afforded by highly ductile materials of inducing cold flow to cause fusion of lapped joints by the application of pure pressure. Surface cleanliness at the contact is necessarily a critical factor: and the central technical problem is that of applying heavy pressure over a narrow strip area in such a manner as to allow excess metal to be removed. This is accomplished by the use of special dies, applicable to straight plate welds and ring welds and the continuous seaming of tubes and standard dies suitable for aluminium have now been developed. The actual percentage reduction is high, of the order of 50%.

CHAPTER XII

FABRICATION: SURFACE TREATMENT

SURFACE treatment of aluminium and its alloys may comprise the machine finishing processes undertaken as the last stage in the factory production of a component as part of the normal and proper sequence of shop operations, or it may entail purely adscititious processing by mechanical, chemical or electrochemical methods intended to endow the metal with a special surface layer which, in the case of the latter groups, may or may not be metallic. Into the electrochemical class of surface treatments comes the extremely important process of anodic oxidation which in its remarkable range of possibilities is peculiar to aluminium materials and offers some of the most interesting combinations of properties yet available to metals.

Common to all the surface treatments is the necessity for cleaning pre-treatments, to remove any traces of dirt, oil or grease derived from fabrication processes and handling or any traces of loose oxide left behind as the product of corrosion during storage under adverse condition.

Cleaning Pre-Treatment

The degree of cleaning to be undertaken depends entirely on the condition of the workpiece. Wire-brushing or the use of abrasives may be necessary to deal with badly handled or badly stored components or objects which have, for instance, hard deposits of burnt-on lubricating oil or badly oxidized patches: simple brushing with a bristle brush is adequate to remove swarf. Subsequent to such rough cleaning where requisite and as starting operation in all other cases, some form of degreasing treatment is essential. For large components or parts unsuited to immersion or spraying this may have to be carried out by hand, first swabbing with a cloth soaked in an organic solvent and following up with a second "cleaner" swabbing and rubbing with a dry cloth. For objects of reasonable size and shape bath treatment is often the most effective: organic solvents or buffered alkaline degreasing solutions supplied specially for use with aluminium materials are used, singly or in bad cases both may be necessary. Alternative to bath treatment is the more modern spray application, but this requires a more elaborate set-up and control of ventilation, etc. Cleaning with alkaline degreasing agents usually renders necessary a subsequent dip or treatment with a dilute nitric acid-hydrofluoric acid (30% : 10%) solution to re-brighten the surface.

Mechanical Finishing

MACHINING OPERATIONS

Machine finishing is usually carried out in two stages, the first involving grinding operations and the second polishing operations. There is no remarkable difference in the technique suited to aluminium materials as compared with other metals other than the general "softening down" of operations requisite because of the much softer surface which aluminium, and even its alloys, possesses: abrasives require to be finer for the corresponding operations as compared with steels and heavy metals, and uniformity of grain-size is important; and the pressures used are much smaller. In buffing operations sticking or dragging must be guarded against with more watchfulness. Speeds are in general fairly high, steering between the two undesirable extremes producing tearing and overheating.

Routine Mechanical Finishes

GRINDING

This is usually only necessary in the case of castings: the flash is removed on muslin, linen or canvas wheels impregnated with emery or corundum (60 to 120 grades) run at about 6,000 f.p.m. Successive grinding operations with increasingly fine grades of abrasive may be necessary. In general dry-grinding is employed to avoid any risk of working lubricant substance into the surface pores.

POLISHING

A sequence of at least two operations is implied by the term polishing, which comprises:—

1. Buffing
2. Colour-buffing or "colouring" (American term)

American terminology includes another operation, "greasing" or "oiling," prior to buffing and following on grinding.

"GREASING"

An operation which resembles grinding, the abrasive being finer, 120-220 mesh, and in American practice a lubricant, usually tallow, is employed.

BUFFING

This is carried out with sewed muslin wheels, using tripoli or similar abrasive cake with a binder and a lubricant.

COLOUR-BUFFING

This requires an open muslin buffing wheel and a soft compound for polishing. English practice uses Vienna lime (a natural product from Viennese dolomite, which is calcium carbonate with a small admixture of magnesium carbonate): American practice favours soft silica compound. A lubricating binding medium is usual with either lime or silica cake white finishes.

AUTOMATIC POLISHING

Machines are now available in modern shops for the automatic polishing of aluminium strip, tubing and sections.

Non-Routine Mechanical Finishes

SATIN FINISHING

A process which may be carried out mechanically, after preliminary fine-grinding or " greasing," with certain cutting compounds such as pumice, emery-in-oil or steel wool-in-oil or in soapy water mixtures. Hand application or muslin wheels can be used, or, on flat surfaces, a belt sander.

SCRATCH-BRUSHING

This is achieved by the application of a rotating wire brush to the surface of the aluminium material. The wheels are about 10 in. in diameter and the brush wires are of stainless steel or German silver and are of diameter of the order of 0.015 in. The wheels revolve at high speed (1,500 r.p.m. in English practice, about half that rate in American practice) and require cleaning periodically to free them from oxide and metallic particles by rubbing a pumice-stone during rotation.

SAND-BLASTING

A process which is capable of imparting varying finishes to aluminium depending on the fineness and qualities of the abrasive applied, which may be washed silica-sand, steel grit or shot,[1] powdered silicon or silicon carbide, and the method of producing the blast, which may be controlled under gravity, by suction or by direct mixing under pressure in a column of compressed air. The nozzle should be inclined roughly at right angles to the surface being treated. Its distance depends on the fineness of the abrasive, ranging from 8 in. for very fine (200 mesh) up to 20 in. for coarse (6-20) grades, and on the desired effect.

TUMBLING AND BURNISHING

Applied to small articles of aluminium or its alloys this is sometimes carried out in wooden barrels revolving at 25-35 r.p.m., or by shaking in reciprocating tanks, with appropriate polishing or burnishing elements such as 5/32-in. steel shot or steel shot-sand mixtures. Twice as much shot as the objects treated should be present. Thin sheet may be treated with hard-wood balls or silica sand or a mixture of these elements.

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[7] Steel particles sometimes cause discoloration, however.

Chemical Surface-Treatment of Aluminium

Chemical surface treatment of aluminium depends essentially on reinforcing the natural oxide film on aluminium as is the case with anodic oxidation: but only thin films can be produced by chemical methods and their properties are correspondingly limited or "diluted." In some instances chemically produced films offer adequate resistance to mild corrosive conditions or environment—the chief *raison d'etre* for providing surface treatment—but in general they serve best as a means of preparing the surface for good keying of paint media. They tend, therefore, rather to fall between two stools—if painting is necessary in any case they may be a superfluous luxury, but if painting is not necessary, the protection they offer over and above the natural corrosion-resistance of aluminium is not very appreciable, except, possibly, in borderline cases (or, it may be frankly owned, as a psychological weapon in the hands of the producers to combat the frequently expressed fear of corrosion of aluminium arising out of ill-informed, antiquated prejudice). Chemical surface treatments have the merit of being simple and cheap—and, certainly, they "can do no harm," even if they cannot do all that is sometimes claimed for them. They generally consist in immersion treatment in hot, weakly alkaline baths containing an oxidizing agent: but to carry out any surface treatment effectively and well, the aluminium requires chemical pre-cleaning and even oxide-stripping first; and the relative costliness of these preparatory treatments weighs against the inherent cheapness of chemical surface treatment and, in view of the quantitatively rather low end protective value, makes justification doubtful. An important exception must be allowed in the case of preparative treatments for electro-plating on aluminium.

The best method developed so far is undoubtedly the M.B.V. process, in which the treatment bath is based on alkaline chromates. The process costs little and is easy to operate. It affords as high a degree of corrosion-resistance as can be anticipated from any chemical surface-treatment, due.to the added value of the chromium ion as a galvanic protective agent. M.B.V. treatment was carried out on quite a grand scale in Germany before the war, and has achieved some degree of favour in this country.

A selection from the large number of chemical surface treatments devised for aluminium is listed by name in the following Table for reference; but great importance does not, at the present time, attach to their use. Many are, or were, covered by patents: some are proprietary baths of unspecified composition.

Anodic Oxidation

INDUSTRIAL DEVELOPMENT

The early industrial treatment of the important process of anodic oxidation provides an example of a field where bad patents are a hindrance to development and the parent aluminium producing and fabricating industry cannot be completely exonerated from the charge of " bad housekeeping " in its neglect of the situation. The first work on anodic oxidation of aluminium which made any assessment of its potential scope and significance possible (following the academic researches of earlier workers on the peculiar film-forming behaviour of the so-called valve metals) was carried out in this country by Dr. G. D. Bengough and his co-worker, J. M. Stuart, at the Royal School of Mines. They used a chromic acid electrolyte and they were able successfully to anodize even quite large aircraft components. The value of the anodic film as a bulwark against the (then unnecessarily overrated) risk of corrosion of light metal structures was recognized by these workers and excellent work was done by Bengough, with different collaborators and under the ægis of responsible Government research organizations, which established the other valuable properties of anodic oxide films on aluminium materials. Two patents were taken out throughout the world to cover the process of anodic oxidation of aluminium in a chromic acid electrolyte, as such, and the subsequent dyeing of the film when formed. These were good patents. They belonged to the Government and were managed by the Department of Scientific and Industrial Research, who charged a not unreasonably high royalty for the use of the process. This

TABLE XXIII

TRADE NAMES APPLIED TO CHEMICAL SURFACE TREATMENT OF ALUMINIUM

Trade name of process	Proprietors	Description of Process
Acro	Dr. Finckh, G.m.b.H., Stuttgart, Germany	Chemical bath treatment preliminary to nickelling and chroming, etc.
Alocrom	I.C.I. (Paints Division) ..	Corrosion-protective and paint - bonding chemical treatment
Alrok	Alcoa (U.S.)	Hot treatment in Na_2CO_3/ $K_2(Na)$–Cr_2O_7 bath
Alumon	Enthone Co. (U.S.) ..	Sodium zincate with added copper salts form chemical bath
Alumox	Enthone Co. (U.S.) ..	Similar to Alumon
Anonising ..	Colonial Alloys Co. (U.S.)	Chemical bath treatment
E.W.	German	Bath like M.B.V. with added water-glass
Fescol	" Fescol," London ..	Electro-chemical deposition of metals
Jirotka (Jirotkizing)	O. Sprenger Patent-Verwertung Jirotka m.b.H., Germany ; and Paul Kettner, Berlin	Chemical-bath treatment in acid, alkaline or neutral baths of various compositions
L.P.W.	Langbein - Pfanhauser - Werke A.G., Leipzig	Pre-treatment for galvanic plating and/or galvanic plating
Pacz	(U.S. patent)	Chemical treatment in baths containing sodium-silicofluoride and Ni, Co or Mo salts
Panalumin ..	Protective Coatings Ltd., London	Chemical-bath treatment
Parker	Soc. Continentale Parker, France	Chemical-bath treatment in Cr, V, Mo, salt baths
Protal	Soc. Continentale Parker, France	Chemical-bath treatment in complex metal salt baths
Pylumin	Pyrene Co. Ltd., Brentford, Middx.	Chemical spray or chemical bath process (acid phosphate solution)
Saillerite	Possehl Erzgesellschaft m.b.H., Lubeck, Germany	Chemical-bath treatment
W.O. No. 1 ..	Turco Products Inc. (U.S.)	Paint-preparatory chemical treatment

came into extensive use for corrosion-protection, for which the chromic acid process is particularly suited and is still important. Because of certain difficulties experienced in dyeing the film produced in chromic acid, Bengough's electrolyte is not so much used for decorative purposes (see p. 284) but the fact remains that, in all main essentials, the properties of anodic films on aluminium were recognized by Bengough and his co-workers in this country by 1924 or 1925, and in retrospect it seemed astonishing that the aluminium industry did not immediately perceive the great significance of the anodic process and nurse it through its early stages instead of allowing its development to become hampered by patents more often obstructive than constructive and its authentic reputation to become tarnished by bad operation in the hands of inefficient jobbers.

The first serious recognition of the potential importance of the anodic oxidation process came, as might be expected, from Germany. A little later than Bengough's work in England (which was followed with the closest attention in Germany) German research workers experimented extensively on anodic films on aluminium produced in oxalic acid, following a line initiated by Küttner, who patented this electrolyte in 1930. The oxalic acid electrolyte proved to have remarkable possibilities, in respect both of the range of film thicknesses and hardnesses which could be produced by varying the controlling operative factors and in its general applicability to aluminium alloys. Fairly early, about 1932, the German Aluminium Combine bought up the electrolyte patent of Küttner and other relevant German patents and undertook an extensive research and production programme to systematize the process and its operation and, by patent control, to organize its industrial development. International patents were taken out and important collaboration on the technical end was established with the Siemens monopoly and with the experienced electroplating experts of concerns like Langbein-Pfannhauser and Schering. Dr. Jenny, of Siemens-Halske, directed the first large-scale investigations into the nature of the anodic film, the mechanism of its formation and its behaviour as an electrical insulator; and also pursued investigations along original lines in developing the use of the anodic film on aluminium as a base for photo-sensitisation. The oxalic acid film is less opaque than the chromic acid film and dyeing of the film, particularly with strong colours, proved very successful; the German dye industry lent its enormous capacity to the new problems of developing the best dyes for anodizing purposes and the best waxes for sealing the anodic films and, with the State interest in aluminium as a background, very thorough work was done on anodic oxidation in Germany—the only country where the patent field of this development in its early stages was made rigorously tidy by the aluminium interests, who also kept a strict eye on the actual commercial operation of the process to ensure a reputable and uniform quality of anodized products.

In America, after the pioneer work of Bengough and the German consolidatory research, such a fertile field for invention soon attracted scientific workers and technicians alike. With chromic acid and oxalic acid as electrolytes already patented, attention was first turned to discovering new electrolytes. Already in 1928 C. H. R. Gower, a chemist working in England, with the help of Stafford O'Brien, had patented the use of sulphuric acid of certain concentrations as an electrolyte for anodizing aluminium materials. The great advantages of sulphuric acid proved to be the complete colourlessness of the film and the remarkable flexibility of the process, and as soon as these facts were perceived, numerous attempts were made both in the United States and in England to get round Gower's patent—which was not altogether a good patent because of its too great specificity—by taking out new ones for different concentration ranges of sulphuric acid, mixed electrolytes in which sulphuric acid was in reality the only effective component, and so on. Gower sold his basic patent to an Indiana (U.S.) corporation, partly financed by Alcoa, which was formed to exploit it; and this company proceeded to take out a number of new patents and international patents and invest licensees (on a reciprocal technical development responsibility basis) with exclusive rights of operation in other countries. This situation proved extremely unsatisfactory in operation since the licensees, whose interest was usually financial rather than technical, could sub-license to unsuitable small-shop operators who, by bad processing, brought the name of anodic oxidation into bad repute. It also added a gratuitous and often disproportionately high cost factor to the overheads, which in small-scale operations were already burdensome.

In fact, the period of anodic oxidation developments from about 1931 or 1932 up to just before the recent war was characterized in this country and, to a somewhat less extent in the United States, by a scramble for patents which were of extremely doubtful worth in many cases. Apart from a few *bona fide* improvements or inventions, many were procured either with the idea of establishing some sort of proprietary right to a " new " or " improved " process as a cover for operating the valid processes of competitors or with the still less laudable aim of obstructing a particular line of development with a view to ultimate infringement claims. The eagerness with which the commercial operation of the processes was undertaken in the early days, in advance, in the main, of solid technical work on the processes devised and on the nature of the anodic film and the mechanism of its formation in given conditions, led to many commercial failures and the financial condition of the small-shop industry in this country, with the cross-currents of licence dues and infringement risks, has been discreditably unsound to be the background of such a really important process.

There is, as it now seems clear, sufficient ground for viewing the anodic oxidation process as one of the great developments associated with the emergence of aluminium as a major metal—perhaps as important in its way as the discovery of tinplating or priming paints was to the iron and steel industry. That it should take its place as a legitimate end-fabricating process inside the parent industry seems evident; and, in fact, just before the recent war this outlook was beginning to impress itself on the big producers here and in the United States in particular. The American producer Alcoa is doing its utmost to clean up the patent field and straighten out the international licence position connected with American patents. In this country, the British Aluminium Company has entered the patent field to clear the way for legitimate development and has a watchful eye on commercial exploitation of the anodic oxidation process. Several of the most important basic British patents have now expired and others which hold up free development have not long to last.

All the big international producers now sponsor research on anodic oxidation as part of their major programmes. They are also taking an active part in the preparation of standards for anodized products. The necessity for their undertaking the production of special sheet grades for decorative or exacting anodizing treatments became apparent some ten or twelve years ago when the so-called reflector or brightening processes were developed in the laboratories of Alcoa in the United States and of the British Aluminium Company in Great Britain; the direct experience gained in their work on these reflector processes did much to bring home to the producers the necessity for controlling surface-treatments of major importance, at least during their incubative period. There are signs very close on the horizon, moreover, of the emergence of fully mechanized anodizing, on the lines of automatic electroplating: and as soon as this development becomes an accomplished fact, the mass-finishing of sheet by anodizing will undoubtedly be integrated, along with such other " lost sheep " returned to the fold as granules manufacture and foil rolling, into the semi-manufacturing interests of the parent aluminium industry—where, incidentally, the cost of the process will have a chance of assuming its true proportions and will not be distorted quite irrationally by the present wasteful small-interest structure of the anodizing industry, which bears the characteristic features of disproportionate overheads and profit-making and in some instances very heavy costs of licence dues.

This is not to say that there will not be room for the small anodizing concerns specializing either in the craft of producing artistic metal objects of high quality, utilizing the large range of decorative possibilities which anodizing offers for this purpose, or in the production of special films for scientific purposes. Such factories, more in the line of *ateliers* than engineering workshops, cannot properly enter the large-scale production field without wastefully duplicating the light-fabricating and finishing plant already available in the shops of the large semi-manufacturers, to whom the first cost and depreciation of such plant assumes much more rational proportions than it does to the small interest; and without a " flow " of materials which it is not in a position to control or guarantee. Since, however, mass production methods of anodizing can only be applied to such raw materials as sheet, strip, wire, etc., or to the production of a standardized article in large quantities, and since there will always remain a large number of aluminium manufacturers producing fabricated articles which cannot be anodized before fabrication and the quantities of which do not justify the installation of their own plants, there will always be a demand for independent anodizers, who fulfil a definite role in the industry. The position is closely analogous to that which exists in respect to electro-plating and the " jobbing " anodizer of repute will continue to serve a very useful purpose.

At the present time the independent anodizing concerns are being forced to put their houses in order as far as possible. The aluminium producers supply to them sheet of special purity and are doing their best to provide a flawless rolling surface, whilst they keep a stringent watch on the licensees who operate their own processes.

The Bengough process was used, just prior to and during the recent war, on a much larger scale than any other process in this country until the Aeronautical Inspection Department gave general approval, in the shape of Aircraft Specification D.T.D.910' B., to the use of the sulphuric acid electrolytes, in 1944. Since then the sulphuric acid processes have been widely applied and for coloured anodizing are much more successful than the Bengough process, difficulty being experienced in arriving at uniform dyeing of chromic acid films and the colours when obtained being fugitive.

THE MARKET FOR ANODIZING: AND COSTS

Prior to the recent war, anodizing as a process had only effectively penetrated four of the main consumer markets for aluminium—the transport industry, domestic products, the light engineering industry and architecture. Allocations between these different industries was roughly as follows:

Transport:	
Aircraft	55%
Miscellaneous	3%
Domestic products:	
Utensils	2%
Light Engineering:	
Fancy goods	15%
Reflectors, etc.	10%
Scientific instruments	5%
Architecture:	
Sheet metal work and sections, furniture and small ware	10%
	100%

In this country it has been estimated that ten to twelve thousand tons of aluminium was annually treated by anodizing just before the war. On this basis, some five or six thousand tons were anodized for the transport industry, chiefly aircraft, representing roughly a quarter of the aluminium used in that industry: about 200 tons, out of a total tonnage of eleven or twelve thousand, were anodized for the domestic utensils industry: nearly three thousand tons of aluminium were anodized for fancy goods, reflectors, light-equipment and scientific instruments out of an estimated total of eight thousand tons consumed in the light engineering industry: and about one thousand tons of aluminium were anodized for architectural work, furniture and small-ware, representing less than one-fifth of the aluminium used for these applications.

The post-war market for anodizing is not easily assessed, but it is apparent on the one hand that there is a somewhat different inter-industry allocation and on the other hand that there is an all-round increase in the amount of metal anodized. This is to be expected from the fact that not only does anodizing rank as an established process which is more than an ordinary " finishing " process, on account of which it would at least share the general trend of increased consumption of aluminium: it also, by virtue of its own possibilities and flexibility as a process, tends in its own expansion to outpace the general rate of expansion of aluminium consumption. Whether in the future, given technical development to mass production scale, it can exert a steepening effect on the curve of aluminium expansion is largely related to the question of the cost of the process as such.

A great deal has been said and written about the cost of anodizing; but much if not most of this information is conflicting[2] and a large part of it is nonsense. An attempt has been made in the preceding paragraphs to show how the unfortunate situation which developed in the anodizing industry, with its essentially small-shop industrial structure—more suited to plumbing than anodizing—and its background of patent "racket" and shaky small-scale finance, has had the effect of creating a quite false price position. Technically, the last word has not been said on price: the range is probably from as low as one penny to as high as one shilling per square foot, depending on the process and electrolyte. An average market price for a finished sulphuric-acid film before the war was about 7d. per sq. ft. This probably represents about 5d. per sq. ft. in terms of the same output scale stripped of licence dues. In other words the actual market price of an anodic film, pre-war, was even with small-scale output well below half the price of the aluminium sheet (taking 16 s.w.g. as the average thickness treated by anodizing). This ratio is obviously capable of quite considerable reduction in larger-scale, better-equipped production conditions: added to which technical improvements and the introduction of continuous operation on mechanized lines can be expected to create still further and substantial cuts. There is a serious prospect that anodizing can be cheapened to a fraction where, its advantages being taken into consideration, it becomes an automatic quotation. This, of course, only applies to routine and probably mass treatment. Special processing to produce special films for special purposes is outside this category and will

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[2] Much of this confusion has arisen because of non-separation of the costs of mechanical polishing prior to anodizing (e.g., after fabrication by spinning, etc.). Mechanical polishing is a very costly operation, and in some cases may account for two-thirds, or even as much as four-fifths, of the end charge made by the anodizer, since the jobber is expected, and generally prefers, to do the polishing—from most points of view it is desirable that he should.

always remain in the price-range of specialist treatment, mostly for applications where the bulk is small and absolute cost therefore not a material one or for such applications as scientific instruments where cost does not count if a particular result has to be achieved.

An interesting case of the large-scale application of anodizing for a specialized use is provided by the post-war Norwegian canning industry, which is anodizing three tons of aluminium sheet a day.

THE PROCESS

Anodic oxidation (in which, as is known, the aluminium is made the anode in an electrolyte which is generally of low pH) essentially results in a reinforcement of the natural oxide film. By varying the five main controlling factors:

(1) the nature of the electrolyte
(2) the nature of the current (a.c. or d.c. or a combination),
(3) the operating current density,
(4) the temperature,
(5) the time of treatment,

it is possible to produce anodic films of widely varying properties in respect of their thickness, hardness and abrasion-resistance, corrosion-resistance and electrical insulating properties, as well as in their capacity to absorb dyestuffs or other impregnants such as photo-sensitising preparations, lubricants, paint and lacquer bases, and so on. The growth of the oxide film is conditioned, in electrolytic production methods, by a complex of factors whose net effect is that the growth progressively decreases with the time of treatment and finally stops after a certain maximum thickness, corresponding to the equilibrium between electro-chemical formative forces and chemical solution forces, is attained. The hardness of the film is chiefly conditioned by the operating voltage, higher voltages in general producing harder films. In structure, the anodic film consists mainly of (initially amorphous) oxide or oxides of aluminium: as formed the film is possessed of fine pore which frequently entrap basic compounds formed from the electrolyte during anodizing. Ageing of the film under natural conditions or by means of special treatments may induce at least partial crystallinity. In its arrangement the structure of the film is not uniform but is stratified.

After the film is produced its properties may be modified by a number of physical or chemical treatments. In commercial practice the commonest treatments are heating; dyeing; sealing (or closing the outermost pores) in hot water or with certain chemical solutions and waxing, which complements sealing.

Contemporary research is directed towards the general betterment of control of the properties of anodic films, particularly dyed films; the development of an opaque porcelain-like finish; the production of flexible films which will permit of some deformation by light working operations on already anodized products; the continuous anodizing of wire; and the development of continuous anodizing processes in general with a view to fully automatic operation.

At the present time Standard Specifications are actually in course of preparation by a Committee of the British Standards Institution with the objective of controlling the quality of commercially anodized products.

COMMERCIAL PROCESSES OPERATED

Whilst a very large number of electrolytes have been tried out, there are only three of any real importance in commercial operation: chromic acid, as used in the Bengough process and in modified American processes; oxalic acid, used extensively on the Continent where the process is commonly known by its original German name of Eloxal or by the Swiss name Ematal, applied to a modified oxalic acid bath; and sulphuric acid, the electrolyte of the Alumilite process and of a modified process developed in the Soviet Union. A fourth electrolyte of some promise which may be mentioned is an aqueous solution of certain sulphonated aromatic compounds used in the Peintal process in France.

The Bengough Process employs a bath containing 3% of chromic anhydride free from sulphuric acid and sulphates, maintained at 40° C. A carbon cathode or steel tank may be used. The voltage is gradually raised during 15 minutes to 40 volts, held at this value for 35 minutes and then raised to 50 volts during 5 minutes and held at this value for 5 minutes.

The films produced are at first somewhat soft and can readily be dyed. They possess a remarkable capacity to age-harden, becoming very hard after a time. Only relatively thin films can be produced in the chromic acid electrolyte and they are therefore usually further protected by loading with lanoline, which gives them an excellent corrosion-resistance; because of their thinness they are not suitable for electrical insulation.

The process can be applied to most alloys, including the copper-containing alloys with up to about 5% Cu.

The original patents, two in number, have now expired and the process is free to operate. Its chief disadvantage lies in the fact that because of the voltage variation it has to be run on the " batch " principle and is not amenable to continuous operation.

Two modifications of the chromic acid process have been introduced by American and Canadian workers; the American process uses a 2.5% CrO_3 bath and maintains its pH constant at 0.8-0.9 by addition of acid (density control), which allows of operating at a slightly lower voltage, 40 instead of 50. In the Canadian process developed by Boeing Aircraft, a slightly different bath is used, containing 3-5% hexavalent Cr and not less than 1.5% free chromic acid, the temperature being thermostatically controlled at 96° F.: the voltage cycle is 0 to 40 volts in 10 minutes, held at 40 for 5 minutes, then increased to 50 in 3 minutes and held for 2 minutes. The merits of this shorter-cycle process are regarded as its saving of power and of chromic acid.

The Eloxal Process uses an electrolyte of 3% oxalic acid or oxalates with or without addition of such oxidizing agents as chromic or sulphuric acid. The oxalic acid process affords remarkable flexibility; by comparatively slight changes in the concentration of the electrolyte, temperature of the bath or voltage, or by changing the nature of the current, considerable variations are produced in the resulting anodic films. The following figures show some representative operating conditions:—

d.c. treatment with voltage 60, c.d. 1.4 amp/dm^2 in a bath held at 18-20° C. requires 40-60 minutes.
d.c. „ with voltage 30.35, c.d. 1.8 amp/dm^2 in a bath held at 35° C. requires 20-30 minutes.
a.c. „ with voltage 40, c.d. 2-3 amp/dm^2 in a bath held at 35° C. requires 40 minutes.

a.c. and d.c. treatment with voltage 40-60, c.d. 1.5.-2 amp/dm^2
in a bath held at 20° C. requires 15-30 minutes.

The thickness and hardness of films produced by such typical treatments depend on the material treated; the oxalic acid process can be successfully applied to a wide range of aluminium alloys except those with high contents of heavy metal constituents such as copper or zinc.

The original German group of main patents covering the oxalic process numbered ten; apart from their expropriation, several have already expired and none have long to last.

An important modified oxalic acid process developed in Switzerland is the Ematal Process, which, by adding certain oxides such as titanium oxide to the bath, produces a milky film not unlike the much desired porcelain finish.

The Alumilite Process essentially depends upon the use of sulphuric acid as electrolyte, by itself or in combination or admixture with other substances. Since the admissible range of concentration of sulphuric acid is very much greater than in the case of any other electrolyte for anodic oxidation of aluminium so far discovered—in which respect sulphuric acid presents a remarkable exception to the general rule of low pH electrolytes—the process enjoys wider flexibility since each characteristic concentration range (5-12%, 10-20%, 15-35%, 35-60%, 60-77% and 90-100%, the higher ranges requiring the addition of such agents as glycerine) can be made to give varying results by changing its operating conditions. Furthermore the American proprietors have developed quite important treatments of the film during and subsequent to formation which are part and parcel of the process—and, incidentally, covered by the patents. Some of the most important treatments relate to the air agitation of the bath; the methods of impregnation with colourants or photosensitized preparations or deposition (actually within the pores of the film) of pigments by chemical reaction *in situ*; sealing of the film with hot water or nickel acetate; and production of multi-colour effects.

The sulphuric acid process is applicable almost without distinction to aluminium alloys, even those with higher percentages of heavy metal constituents. The film is quite colourless and transparent and dyes well in pale or deep colours—pastel shades being particularly effective. There are good prospects of developing a really flexible film, capable of withstanding bending and drawing operations of not too severe a character on the anodized aluminium. The working voltage for a given concentration range and type of film is constant, so that the process is amenable to continuous operation. Given careful and, essentially, clean working, the process presents no unusual difficulties.

Recent developments are in the direction of reducing the time of treatment, which roughly averages half an hour for a good film by the anodizing method of operation. Soviet research workers have developed an accelerated sulphuric acid process and a recently suggested process using a modified electrolyte may radically reduce the time of operation from tens of minutes to minutes.

The original Alumilite patents owned by the American proprietors numbered nearly forty—with the addition of the reflector patents, forty-five. Patents developed by the licensees of the process brought this number up to a formidable total in the seventies. About half the original patents, including, of course, Gower's basic patent for the sulphuric acid electrolyte, have now expired.

SEALING

One of the most important treatments in the sequence of operations comprising anodizing is that of sealing. The simplest method, and a very effective one, consists in simple plunging into hot or boiling water, or alternatively steam can be applied. For certain purposes, however, sealing with a solution of nickel acetate offers some advantages and this method has been extensively applied to sulphuric acid anodic films in particular. Cellulose acetate has been favoured in Continental practice, more especially in the Ematal Process, but is from some aspects undesirable and has not proved very popular in this country.

All the principal sealing methods have figured prominently in the patents covering anodic processes. The hot water and steam sealing patents have now expired.

OTHER ANODIZING PROCESSES

The table opposite provides an index of the proprietary names used for some other anodized coatings on aluminium.

The Reflector Processes

An important "by-product" of research on anodizing has been the development of the so-called reflector processes, Alzak, in the United States (inside the Alumilite patent group) and Brytal in this country (emanating independently from the British Aluminium Co.). Essentially the reflector processes consist in two-stage processing; electrolytic "polishing" or etching, in special baths, of the surface of pure aluminium—which must be of rather high grade—to give a very brilliant surface which is then immediately protected by anodizing so controlled as to produce a very thin, hard and absolutely transparent oxide film. The original American brightening bath consisted of hydrofluoboric acid; the original British bath was a mixed sodium carbonate—sodium orthophosphate bath. Both have undergone modifications, and improvements have been introduced into the technique at the important stage of electrolytic etching of the aluminium. The final surface, after anodizing, compares fairly closely in the two treatments: reflectivity in each case is very high, in the range of 80-85% according in the purity and quality of the aluminium, or even reaching 87% in the case of super-purity grades of metal.

The Brytal patents are five in number, as are the Alzak patents, which antedate the Brytal patents by a few years: both groups are near the end of their term, since they were developed before or early in the war.

TABLE XXIV

TRADE NAMES APPLIED TO ANODIZING OF ALUMINIUM

Trade name of process	Proprietors	Description of process
Aloxier	Friedr. Blasberg, Solingen-Merscheid, Germany	German name for one type of anodic process
Anochrom ..	London Aluminium Co. Ltd., Birmingham	Anodic oxidation
Anodium	James Gibbons Ltd., Wolverhampton	Anodic oxidation
Anodolex	Birmingham Aluminium Casting (1903) Co. Ltd. Birmingham	Anodic treatment for pistons
Anotints	Anotints Ltd.	Anodic oxidation
Cilium	(French)	Anodic oxidation in sodium silicate electrolyte
Coloral	U.S. Research Corporation	Anodic oxidation
Damien	(French)	Anodizing in alkali sulphate electrolyte
Decoral	E. S. and A. Robinson ..	Colour-printing on anodized aluminium
Deplating	Aluminum Co. of America	Anodic oxidation of castings in sulphuric acid electrolyte
Dialumin	Aluminium Protection Co. Ltd., London	Anodic oxidation
Elnural	(German)	Anodic oxidation of pistons
Elypol	(German)	Reflector process
Elytal	Siemens and Halske A.G., Berlin ; and Langbein-Pfanhauser-Werke A.G., Leipzig	Pre-treatment for galvanic plating by means of anodic oxidation in acid electrolyte
Kay-Met	British	Coloured anodic finishes
Lumium	British	Iridescent and/or coloured anodic finishes
Rainbonium ..	British	(Coloured) anodic proces
Seo-photo ..	Siemens and Halske A.G., Berlin	Anodic film produced by anodic oxidation in acid bath (under special conditions) is impregnated with light-sensitive salts to produce photographically sensitive surface
Solium	Ferranti Ltd., Manchester	Reflector finish

CHAPTER XIII

SUPER-PURITY ALUMINIUM

THE Hall-Héroult process (described briefly in Chapter I on pp 13, 16) used industrially for the electrolytic production of aluminium is capable ordinarily of yielding aluminium of purity at the most equal to 99.6% or, where special grades of alumina and of petroleum coke for the cell anodes are used, this figure may possibly be improved upon to reach values as high as 99.85%, which is about the utmost limit of purity attainable by direct electrolysis. Whilst the principle of electrolytic refining from aqueous solution can be applied to other industrial metals, this method is inapplicable to aluminium: and the efforts to develop an industrial process for refining aluminium had to be directed to fused electrolysis. The first attempt, by A. G. Betts, an American chemist, was made in 1905. He established the basic principle of the three-layer bath, with an aluminium alloy—or "impure" aluminium—forming the bottom layer, pure aluminium the top layer and a mixture of salts (chosen to adjust conductivity and density) the intermediate layer. During electrolysis, selective decomposition occurs, in conjunction with fluxing by the salt layer and gravitational effect, and the cathode top layer of pure aluminium is formed free from impurities to an almost cent. per cent. degree.

There are two modern descendants of the old Betts' refining process. One is the American Hoopes' method; and the other the A.F.C. method developed by the Alais, Froges et Camargue company in France, which is also used in this country and in Switzerland. Hoopes did not greatly vary Betts' method. The method utilizes an aluminium-copper alloy with a density of 3.0 or slightly over: the modern salt layer, or electrolyte proper, is composed of a mixture of cryolite with fluorides of aluminium and barium and is saturated with alumina to produce a density of 2.7.

The cell base is of carbon and graphite electrodes are employed for the cathode connections to the top layer of pure aluminium which is continuously formed. The operating voltage is 6-7 volts and the temperature of fused electrolysis in the region of 1,000° C. A typical Hoopes' cell has a capacity of 20,000 amperes.

The great difficulty experienced by both Betts and Hoopes was to find a material for the cell walls which will stand up to such strenuous operating conditions, carbon being ruled out and many normal refractory materials being attacked by the fluoride bath; the only workable method was to allow a solid crust of the salt mixture to form on the walls by providing external water-cooling but even this presented difficulties because of differences in composition between the solid and molten portions, with consequent interferences with density. The very high operating temperature is also an undesirable feature of Hoopes' method.

The A.F.C. process preserves the principle of the three molten layers of anode alloy, molten salts and cathode refined aluminium but by changing the composition of the electrolyte and by certain improvements in design and operation the difficulties associated with Hoopes' method are overcome.

The A.F.C. electrolyte is a chloride-fluoride mixture (a representative mixture being 60% barium chloride, 23% aluminium fluoride and 17% sodium fluoride) which is fluid below 750° C. and permits of operating in the range 700-750° C. The cell walls (which do not require cooling) are of magnesite brick composition, the cell base of carbon blocks and the cathode connections of graphite. The anode metal layer in the French process also contains a higher percentage of copper (33%), which lowers its melting point and increases the density gradation between layers.

The process is continuous, impure molten aluminium being fed to the bottom of the cell at intervals to replace the metal which has passed to the refined cathode layer, which is correspondingly tapped from time to time and cast immediately into ingot form.

Regular production on an industrial scale yields a super-purity metal of minimum 99.99% Al, the major portion being 99.995%

(impurities maximum Fe 0.005%, Si 0.004% and Cu 0.001% and average Fe 0.0002%, Si 0.0009% and Cu 0.003%).

INDUSTRIAL DEVELOPMENTS

Industrial production on varying small scales was already undertaken in the United States, in France, Germany, Switzerland, the U.S.S.R. and Japan and in this country (where it was started in 1936) before the War. Super-purity metal was then made available in semi-manufactured forms as well as ingot, in spite of the fact that rolling, tube-drawing and impact extrusion present some difficulties. The cost of production of super-purity metal is high and the selling price so far has not fallen below about three to four times the price of ordinary high-grade commercial metal.

The greatest industrial development has taken place in France, where production and consumption have both steadily increased, the 1947 output being of the order of several hundred tons per annum. In this country renewed interest has been taken in the possibilities of developing the market for super-purity metal in the post-war period and production will be stepped up.

PROPERTIES OF SUPER-PURITY ALUMINIUM

Super-purity aluminium is appreciably softer than ordinary aluminium; its ductility is very high and its tensile strength low. Typical figures for 99.99%-purity aluminium give the elongation of sand cast specimens as being in the region of 45% and the ultimate tensile strength as about 7,000 lb./sq. in., whilst fully annealed, worked metal may have an elongation as high as 55-60% with a tensile strength of 7,500 lb./sq. in. These figures compare with 30% elongation and 12,000 lb./sq. in. for 99.5%-purity aluminium.

The electrical conductivity of super-purity aluminium is outstandingly high, being in the region of 65% that of copper. Actual conductivity for 99.996%-purity aluminium are:—

Cold-worked	40.7 m/ohm/mm^2
Fully annealed	41.1 m/ohm/mm^2

and the temperature coefficient is 0.0043.

In the case of aluminium as in that of other metals the corrosion-resistance increases with the purity of the metal and super-purity aluminium is possessed of very high resistance to attack by both acid and alkaline reagents and to atmospheric and sea-water corrosion. As an extreme example, concentrated hydrochloric acid (12.5°Be) at 23°C., which completely dissolves 99.5%-purity aluminium 1 mm-thick sheet specimens in little over half an hour attacks 99.99%-purity aluminium sheet specimens of equal thickness only to the extent of 0.06 grm/dm^2 weight after sixteen hours' exposure.

This high resistance to corrosion has been found to be of great value in cases where surface treatment, particularly the so-called reflector treatments (see p. 292) or electrolytic polishing, is desired to give a very perfect bright surface for special purposes: super-purity aluminium when treated by any of these processes gives a yet more brilliant mirror finish than can be obtained on less pure metal.

THE APPLICATIONS OF SUPER-PURITY ALUMINIUM

The applications are so far based chiefly on these three outstanding properties of high corrosion-resistance, good electrical properties and the remarkable ductility of the annealed rolled metal, but the War came at a moment when the production of super-purity metal was just emerging from the primary stages and development of the market has been more or less in abeyance in this country and only partial, up to the present, in the United States and in France. In the latter country, where the process is operated on a larger scale than here, there are two main established applications: the use of super-purity foil for condensers and the use of super-purity metal for reflectors (which are then treated by the Brytal Process). There is also a considerable contemporary market for super-purity metal for small decorative metal-ware and particularly for costume jewellery and buttons treated by one of the brightening methods. Developments have also taken place in France on the use of super-purity foil for wrapping such products as certain cheeses and margarine where there is some evidence of discoloration with foil of ordinary commercial-grade aluminium; and for bottle capsules to seal bottles containing products which are exceptionally corrosive to ordinary aluminium.

Potential applications, on which work is being carried out both in France and in Great Britain, may develop for cable sheathing and for composite or clad-metal products, where the high corrosion-resistance of super-purity metal can be used to advantage on a stronger substratum.

CHAPTER XIV

POST-WAR APPLICATIONS OF ALUMINIUM

THE change in shape of the industrial applications of aluminium since it commenced to rank as a major non-ferrous metal has been referred to in the general review of its uses in Chapter I and in considering the consumer market in Chapter V, and in the present chapter it is only intended to particularize the most important developments of the post-war period.

In trying to get a perspective of the post-war applications of aluminium it must not be forgotten that, great though the production figures for this metal are, the predominating factor since the war has been inevitable shortage for the unnaturally swollen domestic requirements. Ore supply difficulties and water-power insufficiency, labour problems and other factors inherited from war disintegration combine, in different measure, in this country and even in America to create a situation where the current exceptional demand, following the war years' starvation of domestic as distinct from war-effort needs, is far in excess of current production. Certain uneven bottlenecks in fabricating plant availability aggravate this situation for particular applications requiring specialized products. In both America and England release of official controls has been followed by an automatic and unwilling " rationing " to the consumer market due to the producers' difficulties. This has been a particularly unwelcome circumstance where, for instance, the contemporary shortage of steel, in particular, and of some other metals and wood, would have encouraged important new outlets for aluminium.

This paradoxical situation is, of course, purely temporary, and is a not unfamiliar feature of post-war " sellers' markets."

With the above-mentioned reservations in mind, the following paragraphs give some account of the salient features of post-war applications in the aluminium industry.

ALUMINIUM FOR BUILDING CONSTRUCTION

In this country, as in the United States, the post-war shift in the fields of application puts architecture at the top of the list as the foremost user, in terms of tonnages, of aluminium materials: but there is naturally a considerable difference between the actual lines of development in this field in the two countries because of the different ways in which the war affected their territories. In America the outstanding need has been for repair of hundreds of thousands of rural and industrial buildings which during the war deteriorated because of shortage of labour and materials, and aluminium roofing sheet, for instance, has been applied to nearly half-a-million farm buildings throughout the States, according to a recently published figure. For similar reasons, window frames supplied in 1947 numbered somewhere about two million (representing over 10,000 tons of metal). Renewals of heating and ventilating ducts and fittings called for a greatly increased use of aluminium in this major new application in the building-construction industry; and a general expansion took place in the sales of aluminium porches, garage doors, gutters, water-pipes, awnings, shutters, sun-blinds, etc., for replacement. Pre-fabricated wall panels, particularly for large offices and factories, have been in great demand and the market for this product is steadily increasing.

At the same time the use of aluminium in more ambitious modern architectural projects has been noteworthy in the United States: at least five new buildings in the 1947 programme have featured aluminium in their construction, one of the most interesting being the Country Life Press in the Garden City of Long Island, where liberal use of aluminium windows and fluted aluminium wall facing, designed to resist corrosive fumes, is the main architectural feature and makes it a very striking building. In the American developments aluminium castings are not lacking: improved casting methods, resulting from war-time experience have made an appreciable price reduction possible for large castings and cast spandrels, copings, decorative wall facings, and so on, are frequently called for by architects and builders.

In this country the exigencies of the housing problem, following the devastations of enemy bombing in city and countryside alike, made it in the first place natural to turn to a metal whose constructional possibilities and scale of fabrication had so greatly advanced under the pressure of war-time necessity, and in the second place industrially desirable to provide a focus for converting some of the huge fabricating capacity built up for war-time production, principally in aircraft construction factories. The first great house-construction programme initiated in 1945 by the Ministry of Supply called for 54,500 aluminium prefabricated " temporary " houses, and this target was actually achieved by the middle of 1948, peak production rates being typified by the output at one factory alone of the Bristol Aeroplane Co.'s house-construction subsidiary which exceeded 200 per week—or a house every thirteen minutes. Nearly a dozen different types of prefabricated house were developed, some of which proved too expensive and are being reserved for future possible developments. The most generally successful has been the bungalow type of house, which has proved more comfortable for all-the-year-round living than any of the other types of pre-fab., and has certainly been better equipped. The category of " temporary " applied to the aluminium house has been revised, since the so-called temporary aluminium houses are proving good enough to offer prospects of a lifetime considerably greater than the ten years accepted in the original definition; which fact, incidentally, largely offsets the somewhat higher initial cost as compared with other prefabricated house types.

The success of the " Temporary " aluminium houses encouraged a second programme, in 1948, this time on the part of the Ministry of Health operating in the usual manner through local authorities, sponsoring the erection of 15,000 permanent aluminium houses as part of a priority scheme to provide houses in mining and industrial areas. These houses do not vary very greatly from their " temporary " forerunners but are modified in a few respects.

A two-storey semi-detached type of house, most attractive in style and quality, has been built as a prototype: and developments are taking place in the production of prefabricated aluminium houses of special design for export to other countries in Europe and in the tropics.

Following the urgent house programme came the almost equally urgent school building programme. The experience in designing the prefabricated house was of great benefit in the evolution of the unit construction designs, allowing for flexibility in size and type of building and single or two-storey construction, which have been produced for all-aluminium schools. In some local authorities' plans provision is made alternatively for addition of an aluminium storey to a ground floor construction of traditional type. Some of the all-aluminium schools erected are quite large, with up to twenty good-sized classrooms.

Prefabricated Kitchen Unit in the Aluminium House, Showing Refrigerator, Cooker, Wash-Unit, Cupboards, etc.
(*With acknowledgments to the Ministry of Works.*)

As the margin of aluminium sheet available for non-priority building construction has become a fraction wider, such erections as all-aluminium shelters for 'buses and trams are becoming popular throughout the country, and sheds, poultry houses, garages, green-houses, beach chalets and incidental buildings of aluminium are on the increase.

An excellent feature of the aluminium house has been the fine interior all-aluminium units, in some cases of kitchen equipment alone, in others combined with bathroom installations, and the call for such units independently is very great at the present time. Some of the designs are really good, combining maximum utility with space economy and admirable æsthetic appeal achieved by simple, unselfconscious treatment of line and colour. There is no doubt that the influence of pre-fabrication and factory-scale production, essentially involving uncomplicated, un-fussy lines, will be greatly to the good in combating the senseless tendencies in some modern designs prefaced by the warning and much-abused word " artistic."

Housing rain-water goods, flashings and roof fitments and other legacies inspired by the aluminium house such as sinks and draining boards and even gas-pipes are increasingly in demand. Scaffolding of aluminium is proving an even greater success than was anticipated and the market for it is large. Painters' trestles, equally prompted by the advantages to be gained by lightness, strength and clean handling, is a relatively new development which is fast becoming an established application.

The speciality nail field associated with aluminium building construction is proving an important growing market, both in the United States and in this country. Roofing nails, common nails, gutterspikes, tacks and other particular types of nail made of aluminium, are now in the manufacturer's lists as standard products.

TRANSPORT

In the road transport field, the American picture is that of a rapidly growing field of application for aluminium, with more units and more aluminium in each unit than in pre-war days. Whilst the actual rate of growth in this country has necessarily, for a number of reasons connected partly with the domestic problems of the transport industry and partly with the current shortage of aluminium products for many non-priority fields, been slower, the general position is similar. One outstanding attempt to mass-produce a revolutionary car, the all-aluminium £100 car, originally of French design, proved abortive in 1947 for reasons quite unconnected with its design or conception and has been postponed: but it has been noted as being an important sign of the times and the only noteworthy attempt at original departure from traditional pre-war tendencies in design in this country. In America some potential importance attaches to two new developments, the use of forged aluminium alloy wheels, both spoke and disc types, and of heavy-duty aluminium alloy axles and axle units equipped with housings, hubs and brake shoes as a standard assembly (weighing 220 pounds less than a steel unit).

In the railway transport field the utilization of aluminium is proceeding steadily, without any spectacular developments in the post-war years so far. American reports indicate a gradual extension of the percentage of all-light metal passenger coaches, following the comparatively early initiation of this development in the relatively favourable operating conditions of the American railway system: of post-war orders for new coaches about 10 per cent. specify construction principally of aluminium. In four seven-coach streamlined trains purchased by the Louisville and Nashville Railroad in 1946, all of whose bodywork except bolsters, cross-bearers and end sills is of aluminium, the interesting earlier-developed use of extruded aluminium sections for framing members was extended; and anodizing was applied to extruded window trim. For goods trucks and luggage vans American post-war orders also favour aluminium in an increasingly large number of cases: and the tank cars built of aluminium since the war equal in number the whole pre-war total since their introduction in 1928. Diesel-electric locomotives continue to use aluminium considerably and for an increasing number of components.

Conditions in the British railway system are not conducive to parallel developments in this country and the post-war changes in ownership and administration have in any case deferred any potential developments on the building side,[1] though ground is steadily being gained in introducing aluminium materials for fittings and furniture components.

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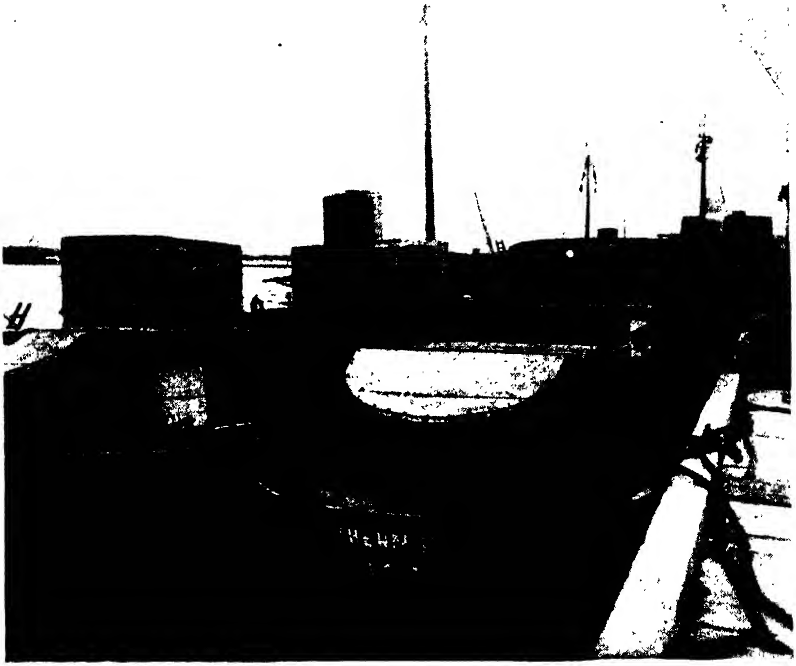
[1] Since this chapter was written, the London Transport Executive has placed an order for 90 light alloy Underground coaches—the first all-light metal coaches in this country.



Whale-boats Showing the Bridge Structure, Forward and Aft Deckhouses and Funnel Casings in Aluminium Alloys.
(*With acknowledgments to Smith's Dock Co., Ltd.*)

In the field of marine transport, however, some interesting developments have occurred here. It is significant of the times that Great Britain, the oldest ship-building nation in the modern world, with a great reputation and the world's most stringent codes and specifications, should be the first to introduce aluminium with official ceremony as an alternative material—not *ersatz*—for ship-construction by issuing in February, 1948, a Lloyd's tentative Rule on the " Quality and Testing of Aluminium Alloys for Shipbuilding Purposes." This amounts to pontifical benediction for the future of aluminium in marine construction and turns a page in ship-building history. Already tried out for small vessels and craft of all descriptions, aluminium now enters the post-war ship-building programme with a more ambitious outlook. The launching of a 75-foot motor torpedo boat of all-aluminium alloy construction in April, 1948, was the precurser of a series of post-war launchings of light alloy boats of many types built in shipyards distributed throughout Great Britain and great activity in the circles of naval architects and ship-builders is directed towards the large ship of the future, foreseen as a composite structure of steel and light metals. With a British post-war ship-building programme of the order of two million tons gross of finished ships per annum, of which roughly half is for tanker tonnage, and the serious shortage of steel, there are great hopes for aluminium.

The new St. Helier lifeboat launched in the second half of 1948 is the first shore-based lifeboat to carry a logical step forward the established pre-war development of light alloy ships lifeboats, which are now internationally accepted.

American developments on similar lines in the ship-building industry are well ahead and aluminium features widely in an extensive post-war building and rebuilding programme affecting all types of vessels, big and small.

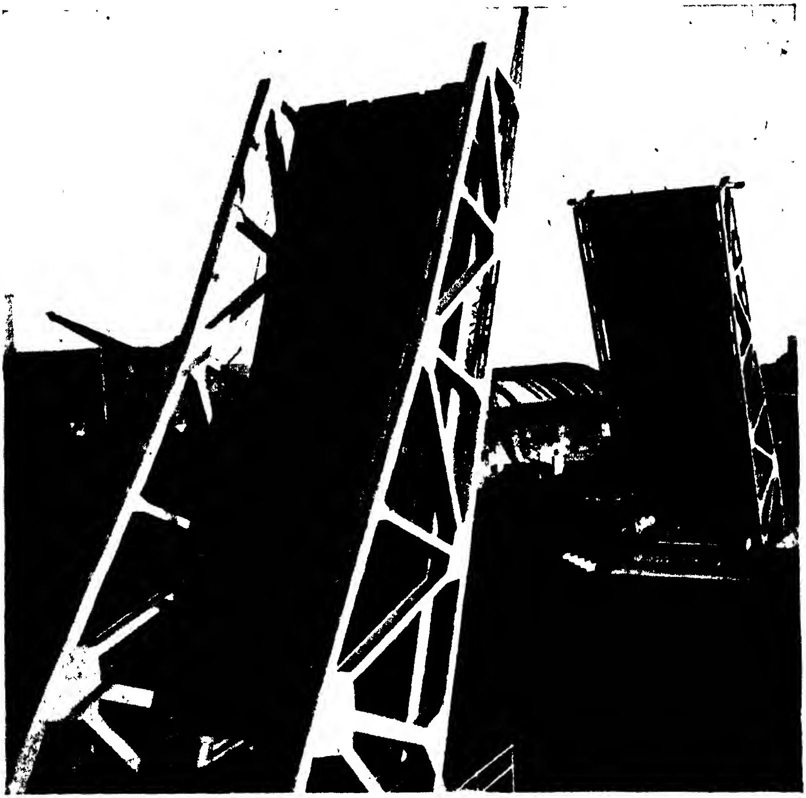
In the fisheries industry the introduction in this country of trawler otters of aluminium is an interesting new departure which is very promising in its early results.

The post-war aircraft-construction industry shows, of course, a much reduced tempo by comparison with the war-time scale of output, but the production of military aircraft continues—and in America is at a higher level than prior to 1939. An interesting post-war development in this field is the 1947 experimental United States rocket ship, Bell XS-1, of stressed-skin aluminium alloy construction, machine tapered, built to explore ultra-high speed flying (at velocities approaching the speed of sound). The turbo-jet engine development is also making calls upon aluminium, the forged impellers being made of this metal in American and British models.

OTHER INDUSTRIES

Parallel to the great changes in outlook about materials in the engineering industries concerned with mobile construction units is the more open-minded attitude towards aluminium in the civil and structural engineering fields. Whilst the economic factor here weighs more heavily against aluminium on a *prima facie* examination of the comparative merits of steel and aluminium, it is beginning to be recognized by structural engineers that design is the key to resolve the price difference. The whole field of civil and structural engineering, swathed in tradition though it may be and fed as it is by the steel industry, whose subsidiary it may be counted, by and large, is being obliged to change its creed and accustom itself to new formulæ in view of the great achievements already credited to the small vanguard of engineers, military and civil, who have sponsored the use of the new aluminium structural alloys. Two Canadian post-war developments, the Saguenay River bridge and a 15-ton overhead crane, both of all-aluminium construction, have excited world interest; and in this country the new 90-foot span aluminium alloy bascule bridge, commenced in 1948, across the junction of two docks at Sunderland, is also making history, since it is the first aluminium bridge in any part of the world to use aluminium alloy for the moving span. These are only a few high-lights out of many similar post-war news items in the field of heavy construction. In the world petroleum industry the years since the war have seen the large-scale initiation of light alloys for pipe-lines and engineering structures. Another new field of development for the aluminium industry is that of irrigation pipes, which have recently been tried out with great success.

In the field of light engineering products possibly the most noteworthy post-war interest lies in the textile industry, where, both in America and in this country, new uses of aluminium components are being actively developed as part of the essential programme of modernization. In England carding machines and heald frames are now being manufactured of aluminium and initial trials of lace machinery of light metal construction are in progress. In the United States in 1947 aluminium loom-beam barrels were intro-



The Wear Bridge, Sunderland—the First All-Aluminium Bascule Bridge, Showing the Spans in the Raised Position.
(*Contractors: Messrs. Head Wrightson Light Alloy Structures, Ltd.*)

duced and have been found a great improvement on the old traditional wood beam barrels.

In the electrical industry, new and superior aluminium bus-bars are available since the war, which gives them still further advantage over copper. In what post-war schemes for new transmission lines have been initiated, for instance in Sweden, steel-cored aluminium cable is finding new customers without difficulty.

Saturation point has not yet, in fact, been reached by a long way in many industries, even where aluminium has an established and large consumer interest. The constant emergence of new ideas dictated by modern needs and conditions in the post-war era brings out daily corresponding new uses for aluminium. To pick out a few random examples, the food processing and food packaging industry serves as an instance: aluminium foil for packing butter has been introduced in the post-war period in Denmark; aluminium fish-box linings are proving extremely valuable in the transport and marketing of fish in the new conditions in this country; containers of aluminium for fruit-juice and cocktail preparations are a new and useful item both here and in the United States; and fruit-picking trays are a helpful development in the agricultural side of the food industry under the new conditions where fruit spoliation cannot be permitted. An almost endless list of trivial-seeming applications, often interesting in technical respects and frequently accounting in the aggregate for large tonnages of aluminium, could be enumerated as post-war newcomers to the already cumbersome indexes to consumer goods. These range from umbrella ribs and knitting needles in the newly-explored markets for wire (at the other end of the scale from the equally new chain-link fencing) to foil for bandaging burns and wounds in the mill products market (at the opposite pole from the huge sales of corrugated aluminium sheet in the recent export drive from this country). Each new application in the post-war world is worthy of interest to the objective observer. Each is affording its mite of technical experience and offering its modicum of achievement. All are contributing their full quota to the consolidation of the vast and varied markets aluminium has already entered and the extension of the number of those aluminium has already won.

CHAPTER XV

SECONDARY ALUMINIUM SMELTING: SCRAP RECOVERY AND REMELTING

It has been pointed out in Chapter I (see p. 25) that secondary aluminium has had to play a quite important part recently in amplifying the supplies of virgin metal, even in Great Britain where formerly the secondary industry was a very small one. It is of some interest to consider the position of the international secondary aluminium industry in its changing relations to the aluminium industry proper as the status of aluminium among metals has changed.

Secondary aluminium is properly defined as metal obtained by remelting from scrap aluminium or from metal fabricating waste, skimmings or dross. This divides the product, secondary aluminium, into two initial categories depending on its origin from scrap metal correctly so called—that is, consumer goods discards; or from metal fabricating (including casting) waste, skimmings or residues.

The secondary metal industry, as an independent industry, is based on the former category of raw material. Secondary metal derived from the remelting of waste or trimmings produced inside the primary producers' casting shops or semi-manufacturing works is usually processed by the producers themselves and only enters the secondary aluminium industry at the marketing stage, if it is not consumed at source.

The inter-relations between secondary metal production proper and remelting of virgin metal waste inside the confines of the primary aluminium industry have been complicated and have given rise to much confusion about secondary aluminium which has actually been enhanced by the policy of the virgin producers to underrate, except in times of war, the value of secondary metal. On the one hand the very integration of the virgin aluminium producing industry with its semi-manufacturing interests and its consequent control of market prices (quite apart from cartelization in the international field) has been responsible for forcing into existence a secondary aluminium industry to feed the independent fabricators and casting shops which could not survive without independent—and cheaper—sources of metal. This involved, in normal times when the competitive structure of capitalistic industry was fully functioning, a direct conflict between the virgin producing industry and the secondary metal industry because of the challenge which the latter offered to the relative distribution of the profit margin as between the producer-cum-semi-fabricator to the fabricator and the fabricator to the consumer public. On the other hand, viewed from the angle of rational economics, the secondary metal industry, based on the recovery and utilization of what would otherwise be waste material, has not only been justifiable where the consumer market is concerned but could have been, and in many cases has actually proved to be, of great benefit to the primary producers in swelling the total of aluminium available and pushing its markets forward where a cheaper grade of metal, if less technically pure, could extend the general interest in the development of light metal products versus others.

As a matter of fact the technical issue of purity or quality of secondary aluminium is largely an artificial one. Given quality control of secondary metal production with appropriate safeguards in marketing it—features normal to the secondary metal industry from the angle of rational economics alone in a highly competitive industry, as this industry is—there is a clear field, not overlapping with the market interests of virgin metal in its different forms, for the utilization of secondary aluminium. It is not a question of secondary aluminium being an inferior product. Virgin aluminium and secondary aluminium are two distinct and different products. Equally it is invidious to discriminate between remelt metal produced in the shops of the primary producer, even if it is consumed at source, and remelt metal properly graded after production control by secondary smelters.

The relationship between the two industries of virgin aluminium production and secondary aluminium production is, in point of fact, one dictated purely by economic considerations. It has fluctuated between hostility in good times and uneasy co-operation in bad times. The two industries are totally different in their scale of operations and structure on the production side; they meet awkwardly on the marketing side where their scale is much less different, and where the influence of competitive secondary metal prices is definitely salutary. Technically, their problems are not unrelated and on the applications side, so far as rational utilization of their products goes, they are complementary.

THE SECONDARY INDUSTRY: HISTORICAL BACKGROUND

The secondary aluminium industry, which term covers the whole organization of collecting, sorting and baling, processing, melting and marketing scrap aluminium, dates from about the end of the first decade of this century. It first assumed importance, in Germany and in the United States in particular, during the Great War of 1914-18. The industry, once started, grew very rapidly in all the major aluminium-consuming countries. From the beginning, however, the secondary aluminium industry's career was quite separate from the primary aluminium industry's influence or sponsorship. In fact its existence was an embarrassment to the primary industry in the early days, partly on the technical score, because it was feared that the then hard-won markets for aluminium might be prejudiced by injudicious entry of ungraded material (and in the first stages of the secondary industry there was some genuine risk that remelted aluminium from scrap might contain undesirable constituents or be of unknown composition): but chiefly because, in the short-term view of the primary producers, the sales of secondary or "second generation" metal displaced an equal quantity of virgin metal in the days when the aluminium producers were up against a buyers' market.

The secondary aluminium industry, which on long-term considerations might have been legitimatized as the offspring of the virgin ingot producing industry, thus found itself instead ousted from the family and by reason of the similarity of some at least of its problems and the actual overlapping of some of its operations, such as collection, it found its lot thrown in with that of the secondary metal industry in general, alongside tin, zinc, and other heavy metals.

The following figures give an idea of the scale of the production side of the secondary aluminium industry in a few countries prior to the recent war. In most countries the official statistics did not then include any figures for the " shadowy " secondary metal industries' output, due probably to some sense of moral disapprobation applying, in the world of production, to the recrudescence of goods once already produced and decently done with, which warrants the kind of treatment accorded to some slightly disreputable and wholly unwanted ghost. A notable exception to this reticence is provided by the official statistics published by

TABLE XXV

PRODUCTION OF SECONDARY ALUMINIUM BETWEEN THE WARS
(IN METRIC TONS)

Year	United States	Germany	Italy
1920	15,000*	—	—
1921	9,000*	—	—
1922	16,000*	—	—
1923	21,000*	—	—
1924	27,000*	—	—
1925	44,000*	—	—
1926	44,000*	—	—
1927	46,000*	—	—
1928	48,000*	—	—
1929	48,000*	—	—
1930	—	—	—
	(in short tons)		
1931	30,300	—	—
1932	34,000	—	—
1933	33,500	6,000	—
1934	46,400	6,000	—
1935	51,400	6,000	1,334
1936	51,500	8,000	2,000
1937	62,560	14,800	—
1938	38,800	34,800	—
1939	—	48,400	—

* Approximately.

the United States, which presumably take a larger perspective of industrial activity, as including conservation, into account.

These figures alongside the virgin ingot production figures (see p. 136 *et seq.*) are significant. They show that in the United States the ratio of secondary to primary aluminium output rose from 1 : 6.4 in 1920 to 1 : 1.7 and 1 : 2.3 in the peak years 1927 and 1937 respectively. In Germany the ratio was much smaller, being 1 : 9 in 1937.

The price differential between virgin and secondary ingot was during this period fairly uniform and the price curves show rough parallellity. This is interesting in view of the fact that the secondary industry structure is highly competitive whilst the primary industry structure is practically monopolistic; it is accounted for by the existence of a large backlog of aluminium in the form of actual or potential scrap so that the immediate repercussion of any noticeable advance in the price of primary metal is to release an increased supply of scrap, with a consequent increase in the production of secondary metal, which has a stabilizing tendency on the primary market price. The actual price differential for secondary ingot depends on grade: in the period between the wars it ranged from 50% to 85% of primary ingot price.

An interesting development in the secondary aluminium industry during the period between the wars was the appearance of co-operative associations among the secondary producers in the United States and in Germany. This movement, overdue as it was, achieved some success in the U.S. by 1929, when the Aluminum Research Institute, comprising in its membership the principal producers of secondary aluminium, was formed. A similar reorganization, possibly more on the lines of cartelization, started in Germany in 1931, with the interest of the primary producers in the background. A " Code of Fair Competition for the Secondary Aluminium Industry " was approved by the N.R.A., Washington, early in 1934. On the technical side advances were occurring parallel to the developments in industrial structure: standard methods of analytical control and specifications were published both in America and in Germany by the new central organizing bodies and production control was well advanced in these two countries in the later pre-war years.

When the war broke out in 1939, the position of the secondary aluminium industry was completely changed: from being an unwanted offspring, it became overnight a respectable and well-cared-for member of the various national aluminium producing industries. As one large American smelting concern put it: " the ugly duckling has become a swan "; which was adopted as their advertising slogan. Each country sought to organize the existing secondary producers and to augment their output by Government support of collection of scrap through nation-wide appeals, and Government depots and smelting plants were laid down particularly to deal with war scrap such as aircraft. The primary producers were brought into the scheme to advise and to undertake their own share in the secondary metal production schedule. In this country the M.P.R.Ds. (Metal Produce Recovery Depots) were set up by the Ministry of Aircraft Production early in the war especially to deal with crashed and obsolete aircraft, their major responsibility being the collection, dismantling and breaking-up of crashed and captured aircraft. The chief depot was at Eaglescliff and the second at Cowley. The depots were managed for the Ministry by industrial concerns who took over the plant when the Ministry withdrew from control after the cessation of hostilities. In addition to the Government depots, war-time output was undertaken on a greatly enlarged scale by the existing secondary aluminium producing and refining companies and many of the most important producers of aluminium products—the great primary producers in the chief producing countries like the United States, Britain, Germany and Japan—took to remelting operation in their rolling mills and fabricating works and such light alloy firms in this country as R.R. subsidiaries and B.K.L. Alloys also turned to secondary ingot production.

During the war period the output of secondary aluminium thus soared to new high levels which would, earlier in the industry's development, have seemed fantastic. The following Table gives production figures taken from official statistics for the chief producing countries for the war years and the immediate post-war years where the output was still largely based on war scrap. Figures are not available for the M.P.R.Ds. output in this country while they were under Ministry control.

TABLE XXVI

PRODUCTION OF SECONDARY ALUMINIUM DURING THE SECOND WORLD WAR AND IMMEDIATE POST-WAR YEARS

<table>
<tr><th rowspan="2">Year</th><th rowspan="2">United States</th><th rowspan="2">Germany</th><th colspan="2">Great Britain</th></tr>
<tr><th>Secondary smelters</th><th>M.P.R.Ds.</th></tr>
<tr><td></td><td>short tons</td><td>metric tons</td><td>long tons</td><td>long tons</td></tr>
<tr><td>1940 .. ..</td><td>68,045</td><td>58,000</td><td>20,000*</td><td>—</td></tr>
<tr><td>1941 .. ..</td><td>106,857</td><td>85,600</td><td>50,347</td><td>—</td></tr>
<tr><td>1942 .. ..</td><td>196,464</td><td>93,600</td><td>75,279</td><td>—</td></tr>
<tr><td>1943 .. ..</td><td>313,961</td><td>114,000</td><td>87,746</td><td>—</td></tr>
<tr><td>1944 .. ..</td><td>325,645</td><td>163,200</td><td>95,897</td><td>—</td></tr>
<tr><td>1945 .. ..</td><td>298,387</td><td>—</td><td>61,912</td><td>—</td></tr>
<tr><td>1946 .. ..</td><td>278,073</td><td>—</td><td>48,590</td><td>—</td></tr>
<tr><td rowspan="2">1947 .. ..</td><td rowspan="2">—</td><td rowspan="2">—</td><td colspan="2">107,538</td></tr>
<tr><td>63,748</td><td>33,874</td></tr>
</table>

* Approximately.

In the post-war years, whilst the importance of secondary metal has not diminished in a world market characterized by shortage of primary aluminium and of other metals and other constructional materials, the increasing scarcity of scrap both in this country and in America as the spoils of war become depleted has created a tight market situation for scrap which, in conjunction with the delivery difficulties of the primary producers (who are obliged to ration ingot to old customers and can offer delivery only with very protracted delays of many months) has given rise to a remarkable anomaly where the price of good secondary metal—worth in normal times 50-85% of the value of virgin ingot—even exceeds that of primary metal. Scrap prices are correspondingly high.

From the intensive experience gained in secondary metal production during the war years, when all the resources of the parent aluminium industry (in regard particularly to research facilities and laboratory control of production) were laid open to the secondary smelters, secondary aluminium emerges with a very different status from its pre-war rating in the aluminium markets of the world. It has now won for itself a very definite position which does not overlap to any extent with that of primary aluminium. With established specifications for quality of secondary ingot and grading of the scrap used as raw material, and established procedures for control of production, the secondary metal now enters the aluminium market in its own right for its own applications where its utilization is complementary to that of the primary metal as some sort of rational economic planning has supervened under the stress of world shortages forced on the community by war wastage.

The post-war structure of the secondary aluminium industry is also very different from what it was pre-war. There is no longer any clear distinction corresponding to the pre-war classification of " remelters, smelters and refiners " as one class of scrap consumer and " manufacturers and foundries " covering all other consumers (except the large semi-manufacturing plants of the primary producers), to employ the American categories. With the primary producers still in the field of secondary production (29% of available scrap was used by the American primary producers in 1946 as compared with 71% used by the two classes referred to above) the old separatist tendencies between the primary and secondary industries are no more. Future tendencies are more likely to develop vertical rather than horizontal divisions.

The following paragraphs briefly outline the technical operations undertaken by secondary metal producers, using market scrap and equipped with modern, large-scale melting plant.

SCRAP COLLECTION, SORTING AND BALING

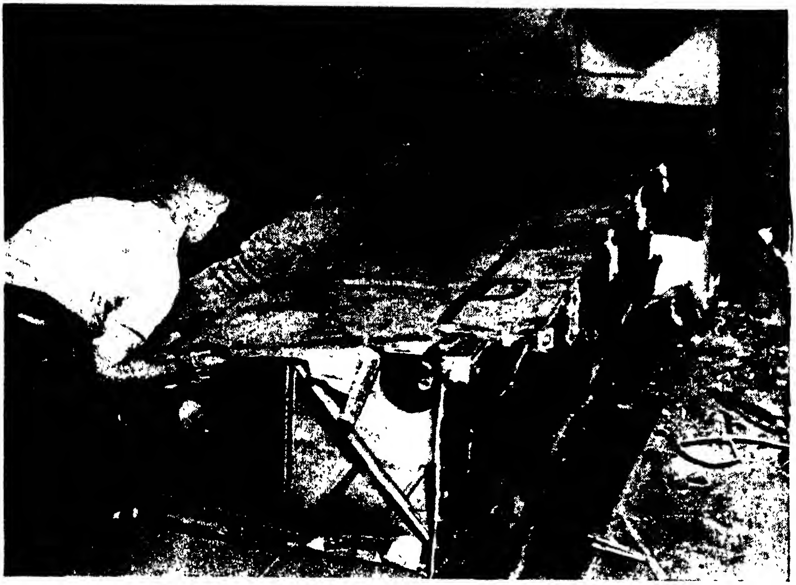
In pre-war days the classification of scrap for purchasing purposes was governed by trade specifications in the United States (1915) and in Germany (1926): there was no cut-and-dried classification operative in this country. Roughly, scrap aluminium proper (i.e., consumer goods discards) may be classified according to whether it is of origin cast or forged, painted or unpainted, mixed with or having fastened to it other metals or non-aluminium materials such as rubber, canvas, lead inserts, steel screws or bolts, and so on, or straightforward light metal scrap. In normal times scrap collection, from smaller dealers, wreckers, junk men, fabricating works, etc., is the business of the large scrap dealer, who gathers up smaller collections, sorts and classifies it and sells in lots or loads. Incidentally it has been a constant complaint that sorting and classifying is usually quite inadequate and quite oblivious of any existing specification or guiding standards issued by the trade.

Packing or loading of market scrap as supplied by scrap dealers varies greatly. Scrap may be loaded loose on to lorries or packed loosely in boxes, crates, sacks, etc.: modern methods, developed to a high degree in the handling of war-time scrap, utilize machine or hydraulic baling. Parcels of war scrap in this country released to the trade by the Ministry of Supply were largely cut-up aircraft scrap, broken down with very various techniques and very varying efficiency by intermediate contractors. Complete aircraft, crashed or obsolete, were later put up for disposal as such.

Sorting at the smelting or remelting works entails careful examination of the scrap to eliminate undesirable contaminants (particularly lead) and to limit the inevitable steel components such as bolts, stays, rivets, etc., to the order of 10-15% as a working estimate (allowing a wide margin up to the maximum admissible steel content of 30%). In the better-class smelting plants scrap is often further graded into first and second qualities and so on, after hand sorting and removal of any small attachments.

MELTING AND PROCESSING

The first stage in the processing of baled scrap is to separate the aluminium from the higher melting point materials constituting bolts, rivets and so on, by melting. This is usually accomplished in liquation hearth or inclined hearth furnaces. There are a number of different types of furnace designed for different heating methods (oil, gas, electric) but the essential principle in common is the provision of a sloping hearth, inclined at 5°-25° to the horizontal, so that when the scrap is melted the aluminium flows down the slope into a heating chamber separated from the melting compartment by a partition wall. The high-melting point contaminants or components remain behind and are raked off.



Charging Large Scrap Parts into a Secondary Smelting Furnace.

The charging of large scrap sections presents very considerable difficulties from the angle of necessitating large charging doors which give rise to uneconomic cooling. German practice developed the so-called " stack furnace " corresponding in height to two storeys with charging doors at ground or ramp level to feed the sunk furnace hearth in the scrap-melting building: scrap fed in from the charging entry slides down a slope to the melting hearth.

The main processing treatment is fluxing applied to the liquated aluminium bath in the heating chamber. Numberless fluxing methods and proprietary or patented flux mixtures have been developed. The most effective flux mixture generally consists of a mixture of chlorides and fluorides, with a melting point about 750° C. After fluxing, the surface scum layer is raked off the molten aluminium and the bath is tapped and cast into ingots in bucket-pouring machinery.

Whilst the procedure for dealing with works scrap such as trimmings, turnings or cuttings differs in scale and in detail, the broad principles outlined above apply to any miscellaneous scrap collection.

RECOVERY PERCENTAGE

Recoveries on scrap aluminium range from about 80% up to as much as 95%, depending on the amount of grease, dirt and other foreign matter present. Typical yields in remelting painted aluminium sheet, such as panelling, may vary between 80 and 87%. Discarded sheet or loose cuttings show a loss of the order of 3% as compared with baled weight after remelting.

ANALYTICAL CONTROL

Analytical control enters the secondary aluminium industry in its modern form at two stages: scrap collection and remelting. The former is the business of the scrap dealer in normal times. The latter is an essential feature of the secondary producer's operations and any remelting works must be equipped with a good laboratory. Routine work includes the sampling and assaying of incoming scrap loads, the sampling and analysis of all heats of metal poured and the analysis of any raw materials employed in the preparation of fluxes, etc. All blending to composition has to be closely controlled on the basis of chemical analysis and some works operate blending charts prepared by the laboratory.

In addition an up-to-date secondary aluminium producer makes provision for research into improved methods of analysis, improved fluxing methods, and so on.

STANDARD SPECIFICATIONS

The first British standards for secondary aluminium were issued during the recent war. The Air Ministry D.T.D. 424 and 428 appeared early in 1940. The war-time L.A.C (Light Alloy Castings Control, Ministry of Supply) standards 10, 112 and 113A were also much in use for casting alloys, chiefly pistons, during the peak years of scrap recovery. The following table shows the chemical compositions and chief mechanical properties of the secondary metal covered by these specifications:—

TABLE XXVII

	D.T.D. 424	L.A.C. 112	D.T.D. 428	L.A.C. 10	L.A.C. 113A
Chemical composition in percentages :					
Silicon	3.0–6.0	7.0–13.0	2.0–4.0	0.6	1.3
Copper	2.0–4.0	2.0–3.0	6.0–8.0	9.0–10.5	2.5–4.5
Magnesium	<0.15	<0.03	<0.1	0.15–0.35	<0.1
Zinc	<0.3	<1.2	2.0–4.0	<0.1	9.0–13.0
Lead	<0.05	—	—	<0.1	—
Nickel	<0.35	<1.5	—	<0.5	<0.5
Iron	<0.8	<1.0	<1.0	0.3–1.0	<1.0
Manganese	<0.7	<0.5	—	<0.6	<0.3
Titanium	<0.2	—	—	—	—
Other impurities	—	Total <0.5	Ni+Sn +Pb+ Mn <1.0	Fe+Mn <1.4 Zn+Sn +Pb <0.2	Ni+Sn +Pb+ Mn <1.0
Mechanical properties :					
Elongation % in 2 ins.	2	—	—	—	—
Ultimate tensile strength, p.s.i.	20,160	17,920	17,920	—	20,160

CHAPTER XVI

THE MAGNESIUM INDUSTRY

THE history of the magnesium industry so far has in it all the strange quality of the meteoric. The industry was first heard of in the early days of this Century. It appeared suddenly on the horizon in 1914, grew to quite appreciable dimensions with remarkable rapidity during the First World War and then as rapidly faded; to reappear with startling suddenness and great brilliance, assuming very large and imposing proportions, during the recent war, only to diminish in some countries and vanish in others with equal suddenness at the end of it. It would not, of course, be legitimate to press the analogy any further, except perhaps that it would be true to say the future of the industry is at present unpredictable equally to the economist and the technologist. It is admittedly difficult to assess the progress of the magnesium industry objectively, since its whole effective lifetime has been complicated by its war-time career, which has distorted its normal infant growth curve on the production side and has equally distorted what evidence is available regarding its prospects on the consumption side.

Many interacting factors and contradictory influences have to be considered in attempting to make any analysis of the industry. For a start the technical factors are complicated. The lightness of the metal—magnesium is a third lighter again than aluminium—is its obvious prime asset: but whereas aluminium in its alloyed forms owes its position as a structural material alongside steel to the fact that its greatly decreased weight is coupled with a mechanical strength of equal order to that of steel, magnesium's reduced weight vis-a-vis aluminium is at the expense of a roughly equal ratio of tensile strength (which in the best magnesium alloys is only about 75% of that of aluminium alloys: its compression strength does not lose proportionately so much). In corrosion-resistance magnesium products are again inferior to aluminium materials: and though it is open to question whether corrosion-resistance as an absolute factor is not greatly overrated in the case of either metal in a world where the annual wastage of steel due to corrosion, in the height of the Steel Age, has been conservatively estimated as approaching 30,000,000 tons and the annual expenditure on paint to protect exposed steel in this country alone in the inter-war period was of the order of £40,000,000, the relative advantage as between aluminium and magnesium still rests with aluminium. In its elastic qualities, also, magnesium is at a disadvantage, the relative ratings being 6,000,000 for magnesium as against 10,000,000 for aluminium and 30,000,000 for steel. The high coefficient of thermal expansion of magnesium is disadvantageous to its use in some applications and the high shrinkage factor may make casting a little more troublesome.

From the angle of its fabrication magnesium has the outstanding quality of being exceptionally machineable, in which respect it outpaces aluminium, but against this it is more difficult to form and difficult to bend. The risk of explosion in the molten condition and the fire hazard due to ignition of magnesium dust and swarf arising from the working of magnesium alloys are still awkward problems in that they necessitate constant alertness and careful precautionary measures in all shops dealing with magnesium casting and fabrication.

Of all these technical problems it is possible now to say that corresponding solutions and suitable techniques have been developed: but these techniques are still limited, are highly specialized and have not yet reached the calibre of the ordinary. For them to do so is a more difficult problem, psychologically, than was met with in the case of aluminium.

In the economic sphere strong counter-currents for and against magnesium are met with. Magnesium came into the world as the ward of the aluminium industry but the relationship between the two industries is not an easy one. In the first place the fear of future competition is operative. Magnesium is a metal in nearly as plentiful supply in nature as aluminium and—unlike aluminium—its commonest forms are those from which it can be derived without much difficulty; in other words the question of ore grade is less obtrusive than in the case of aluminium and other metals. For both these reasons all the politico-economic implications of most-favoured ore possession are by-passed. Moreover the chemical and physical properties of magnesium as an element are such as to render production from any of its ores or other sources possible and considerably less difficult than in the case of aluminium. Magnesium's low boiling point makes distillation methods of production feasible, its electro-chemical properties make it readily amenable to electrolytic production and its chemical relationship with carbon (magnesium carbide is unstable, in contrast to that of aluminium) renders applicable a whole range of smelting reduction methods. Thus whilst aluminium production (in the present state of the industry, at least) is tied to one extraction method, which is in use on a vast scale involving huge investments in plant and does not offer much scope for radical reduction in producing costs, magnesium production is in an interesting state of pregnancy where at any moment a revolutionary method for cheap and easy production might be born. This uncertainty is unwelcome to the prior-established light metal because of the potential threat on the basis of both price and scale of output.

In the second place some sort of " family solidarity " has to be given at least outward expression. If the case for light metals is made on behalf of aluminium it cannot be withheld with a good grace from the sister metal magnesium, and any competition in the field of applications, so far as the external world is concerned, must be kept within the bounds of sisterly rivalry. The history of the industry so far might suggest that jealousy is not wholly absent from the older sister's make-up but it is questionable whether this interpretation would go far enough in its analysis of the situation. The issue seems almost to be that magnesium was born either too late or too early: if the former, it is because aluminium has definitely established its pioneer rights to the exclusion of other claimants in the modern age and has no need of any complement, if the latter it may be that some time will elapse before the ultimate magnesium industry stages its advent for a permanent sojourn.

Certain it is that the contemporary world magnesium industry preserves its existence by a somewhat narrow margin alongside the robuster sister industry and that there is little sign of their being rationally necessary to each other. Whilst such technical characteristics of magnesium as that of lightness outclass the corresponding values for aluminium, pure extrapolation of the inherent significance of lightness as such as not achieved thereby, because of the associated disadvantages referred to above in the case of magnesium—which have in fact a nuisance value, in the abstract, even to aluminium because such damaging properties may be indiscriminately ascribed by unaccustomed users to all light metals as a class.

These are the economic factors affecting magnesium in relationship to aluminium, a relationship commonly presumed on account of there being the factor of light weight common to both metals and also because of the fact that magnesium was first produced under the ægis of the aluminium interests. If an attempt is made, however, to consider magnesium as an individual metal, aside from any accidental and possibly mistaken association with aluminium, it is still difficult to assess the position of the industry as it stands at the present time. Magnesium's chief consumption market has been as a war material: in its constructive field, as a structural material, it has been used mostly for war machines, notably war aircraft, where the emphasis has been on immediate performance rather than on life (or on a compromise between performance and life which ordinarily characterises peace-time applications). There has, as yet, been little opportunity for steady development in any significant civilian direction and it would therefore be difficult to make an accurate analysis of magnesium consumption growth at this stage. This is in spite of the facts that the pioneering work in overcoming the prejudice against new materials *versus* the traditional ferrous and heavy metals both in engineering fabrication and in design had already, in a measure, been accomplished by aluminium at an earlier stage and that the current shortage (which makes it even possible for a higher price to be obtained for short-delivery secondary metal than for long-delivery primary material) opens a ready-made market. The picture of magnesium applications flourishing in a few selected fields rather lacks the background of supporting evidence of steady, rational infiltration into multiple industries from a focal point, familiar in the early development of aluminium. On the production side the magnesium industry has not the same monopolistic character as the aluminium industry, so that there is no hampering on that score: and arguments advanced on the score of high price are not particularly convincing since the strength/weight ratio as an absolute factor operates in favour of magnesium in the comparative price differentials between aluminium and magnesium and aluminium and steel, except where the fabricating costs of magnesium are unduly high.

The facts are that, as it stands, the magnesium industry has developed a huge producing capacity (and there is no real limit on the score of availability of raw materials or practicability of methods to the amount which can be produced): but the consumption side, apart from war-time applications, is still disappointing. The question that remains is therefore whether the ectrogenic embryo industry can develop normalcy on the consumption side if the factor of war influences is eliminated. An affirmative answer may have to await a different economic order (see p. 121).

The Magnesium Industry: Historical Development

Magnesium was first isolated, in 1808, in this country by Sir Humphrey Davy, who reduced the oxide with potassium vapour. Twenty years later Bussy succeeded in reducing the chloride with potassium and thirty-five years later still, in 1863, Deville and another French chemist accomplished the same reduction with sodium. Meanwhile in 1852 Bunsen had experimented with the fused electrolysis method which proved successful with the anhydrous chloride. In 1857 the first commercial production of magnesium for flashlight photography was started in France, using the chemical method, and shortly afterwards, in 1864, a small company was formed in England to undertake production. This company—The Magnesium Metal Co.—set up works first at Salford and later at Patricroft in Lancashire (where aluminium was subsequently first produced in this country). Output was on a very small scale and the product was used chiefly as ribbon or powder for flashlights and pyrotechnics, to a very small extent also for chemical deoxidation in metallurgical operations.

The magnesium industry as a metal industry proper dates from the last years of last Century when the electrolytic method of production, following Bunsen's academic researches, was initiated at Bitterfeld in Germany. Griesheim Elektron, in which the I.G. later took a controlling interest, took over the Bitterfeld process shortly afterwards and continuously developed it to a point where, by the time of the First World War, commercial-scale production was already in swing in Germany, who maintained her position as the leading world producer right up to the recent war. The magnesium industry is in fact essentially German-inspired.

The United States took up production in 1915, the General Electric Company being the pioneer company. The 1915 output actually reached over 40 tons, the metal costing five dollars per pound. Other American concerns in the electro-chemical and aircraft production industries entered the production field, attracted by the possibilities of the new metal, but the difficulties experienced in the pioneering stages rapidly reduced the number of serious producers to two—Alcoa and the Dow Chemical Company of Midland, Michigan, who were alone in the field in the early 'twenties. (Alcoa later left the production side of the industry, in 1927, and retained only its interest in fabricating magnesium products.)

THE BRITISH INDUSTRY

In this country F. A. Hughes and Company, Ltd., started in 1920 to explore the possibilities of developing a magnesium industry. Investigation was undertaken by way of developing techniques for casting magnesium alloys, in which Sterling Metals, Ltd., played a pioneering role: contemporaneously research work on surface treatment to improve corrosion-resistance was sponsored by different concerns and institutions. Johnson Matthey entered the early production and casting field through subsidiaries, including British Maxium, which was at a later date taken over by High Duty Alloys and reformed as Magnesium Castings and Products, Ltd. Magnesium alloy castings were made under licence from the German producers by two further companies—The Birmingham Aluminium Casting Company and J. Stone and Company—in addition to Sterling Metals by the early 'thirties, and in 1931 a licence for the production of Elektron sheet extrusions and forgings was negotiated with James Booth and Company. The British market was then ready for the development of a domestic producing industry and in 1934 two companies were created for this purpose. Magnesium Elektron, Ltd., was formed to operate the German electrolytic process and a subsidiary of the Imperial Smelting Company formed a small company —Magnesium Metal and Alloys, Ltd.—to develop a thermal reduction process. Magnesium Elektron, Ltd., acquired a site at Clifton Junction, near Manchester, and a £250,000 plant to produce 1,500 tons per annum of magnesium was laid down and started production in 1936. This plant was rapidly enlarged under Air Ministry ægis, as war loomed nearer, extensions costing nearly £500,000 and increasing the capacity to 4,000 tons per annum being completed by the end of 1937.

Meanwhile the responsibility for the thermal reduction process was taken over by a new group in which the British aluminium producer played a leading part. In 1935 the Imperial Magnesium Corporation was jointly formed by Imperial Smelting, British Aluminium, I.C.I. and Murex interests and the operating company was charged with the commencement of production by 1938. This company operated first the Zinc Smelting's trial plant at Avonmouth and afterwards operated a new plant at Swansea, using a different carbothermic process. In 1936 the latter two members left the group and the new operating company was re-formed as Magnesium Metals Corporation, Ltd., under the control of Imperial Smelting and British Aluminium.

The raw material initially employed for both the electrolytic process of Magnesium Elektron and the carbothermic process of M.M.C. was imported magnesite (mostly from South-Eastern Europe), but strenuous efforts were made to find a domestic substitute. Magnesium Elektron successfully collaborated with the British Periclaese Company, of Hartlepool, in developing a suitable oxide for electrolytic reduction from domestic dolomite and sea water, and, in February, 1939, the modified process based on these materials was in actual output. This step put Magnesium Elektron in a position to extend her capacity indefinitely so far as raw materials were concerned; and since by 1940 war exigencies required further magnesium production capacity, a second plant, 25% larger than the extended original plant, was built on the same site at Clifton Junction and specially designed to operate with the new starting material. The original plant was afterwards adapted to permit also of production from the so-called sea-water magnesia: and during the war period these two plants accounted for a large output of magnesium metal, of the order of 50,000 tons.

The main plant of the Magnesium Metal Corporation, Ltd., operating the Hansgirg carbothermic process at Swansea, came into production and continued output during the war years. Murex successfully (but uneconomically) worked the carbide thermal reduction method to swell the war production, whilst a fourth production works established by the Lancashire Metal Subliming Corporation, Ltd., came into being in Burnleigh in North Lancashire, starting output in 1943; and this peak year of the war effort saw a total magnesium output in this country of nearly 19,000 tons.

Since the war, the uneconomic plants operated for strategic reasons have been closed down.

The onset of the war revolutionized the scale of the **United States** magnesium industry, where the existing pre-war industry was smaller in proportion to the needs of the nation than even in England. Several new enterprises were inaugurated with Government sponsorship to undertake production of magnesium and by 1943 sixteen new works were operating, the largest of these being the 50,000-ton Nevada "Big Job" plant of Basic Magnesium Incorporated, originally a joint subsidiary of Basic Refractories of Cleveland (whose interest was later bought out by Anaconda Copper) and the British company Magnesium Elektron, which employed the German electrolytic process, utilizing native magnesite and cheap power from Boulder Dam. The Dow Company extended greatly and operated two duplicate electrolytic plants of nearly equal combined capacity to that of the Nevada works in two sites in Michigan and Texas, these two plants accounting for a peak 1943 output of about 145,000 tons per annum, or some 56% of the total peak production in the United States. Of the remaining plants, three also operated the electrolytic process on a smaller scale; seven operated the silico-thermic process, with an aggregate 1943 peak output of some 65,000 tons, or about 25% of the total; and the Permanente concern operated the carbo-thermic process in California, with a peak output of 13,000 tons per annum, or 5% of the total, in 1913. With the exception of the latter plant, all the magnesium production units in the United States were owned (or part-owned in the case of the Dow plants) by the U.S. Government and operated under license for them during the war.

Although the actual annual output of the United States so far has not exceeded, even at the peak of the war effort, some quarter-of-a-million tons, it has been estimated that domestic resources of raw materials would enable this yearly output to be trebled.

Canada entered the production field, with one plant only, during the first half of the war, utilizing the Canadian-discovered Pidgeon process at the Government-owned works at Haleys (Renfrew) in Ontario province. Maximum output was reached in 1944 with 900 tons. Since the war ended this plant has been purchased by the operating company, Dominion Magnesium, Ltd., and extensive changes in equipment have been made.

Australia came into the war-time Empire magnesium production scheme in mid-1941, when the Broken Hill Proprietary Company laid down a 1,000-ton magnesium plant at Newcastle (N.S.W.). By the end of the following year, this plant was producing at half capacity and by 1944 full output was achieved.

Germany steadily expanded her magnesium industry—already well developed by 1939—and reached her peak production of 50,000 tons, from four (non-Government-owned) producing plants, late in the war. Three plants at Aken, Stassfurt and Bitterfeld (now all in the Russian zone) drew their raw materials from the Stassfurt salt deposits and from the Harz dolomite workings: the works at Heringen worked on carnallite found in the neighbourhood of the plant. Since the industry could base itself wholly on domestic and mostly local raw materials, no stock-piling programme had been undertaken before the war and the total magnesium capacity in 1940 was 25,000 tons, which was gradually extended each year up to 1944. In 1941, German interests erected a 10,000-ton magnesium-producing unit, based on sea water, in Norway, at Haren, but this works was partially destroyed by aerial bombing shortly before completion. Later in the war the I.G. started erection of a huge new plant in Austria, at Moosbierbaum, based on Styrian magnesite, but the project was abandoned because of different shortages; and a further plant partially erected in Hungary also failed to reach the production stage. Germany was in fact, due to her early control of the industry, never short of magnesium, whose supply was never inadequate for the war effort, and it was not therefore necessary for her to push new construction of magnesium plants.

Under Axis influence **Italy** gradually expanded her infant magnesium industry, which had only commenced production in 1937, utilizing native dolomite and sea-water, but development was slow and her peak output only reached 3,000 tons (in 1944).

In **France** the magnesium industry, initiated on a small scale in the early 'thirties, is in the hands of three concerns, Pechiney, Ugine and Bozel-Maletra, and is based on the plentiful domestic supply of dolomite and on sea-water, utilizing principally the electrolytic process. The industry was beginning to flourish on a moderate scale when the recent war was declared: during the Occupation it was fostered by the Germans, who even subsidized the French plants to keep them operating. Some 1,500 tons were exported from France to Germany in 1943 and 1944.

The industry in **Switzerland** is on a still more modest scale than the French industry, producing round about 1,000 tons per annum.

The only producer, the S.A. pour la Fabrication du Magnesium utilizes native magnesite and dolomite and employs both the electrolytic and thermal reduction methods at the Martigny-Bourg works. The industry is, as in the case of the aluminium industry, essentially an exporting industry, home consumption being very small.

Norway produced magnesium from sea-water on an experimental scale at the Stangfjord electro-chemical works as long ago as 1917. Industrial development was not pursued, however, until the recent War, when Norwegian plants were operated under German inspiration and control.

The **Soviet** magnesium industry was organized in 1929 initially, as part of the First Five-Year Plan, and it commenced industrial production in 1936, following extensive earlier trials on pilot-plant scale. Large deposits of carnallite are available at Solikamsk, there is abundance of magnesium chloride brine from salt lakes and the domestic resources of magnesite (and dolomite) are practically inexhaustible. The first Plan envisaged division of production between the Dnieper dam region of the Ukraine, the Urals and the Crimea: the second Five-Year Plan carried the magnesium industry, along with the general expansion of industry, further eastwards into Siberia and a plant was erected at Kichkas. There is some evidence that an improved electrolytic process has been worked in the Soviet Union, and with the excellent raw materials available, the Soviet plan foresaw no ultimate price differential between magnesium and aluminium. Production was gradually increased during the war years and post-war reorganization is intended still further to expand output, the Plan for which envisages the achievement by 1952 of 170% increase on the end-of-war capacity.

The history of **Japan's** magnesium industry, like her aluminium industry a product of her industrial revolution and drive for self-sufficiency, rapidly matured by preparation for the war, resembles the record of the sister industry also in its remarkable efficiency and achievement. Magnesium was produced on a small scale first in 1935. By 1939 production had risen to 2,000 tons per annum. During the war period there operated fifteen producing units, with a Government-consolidated, highly developed inter-organization:

supplies of raw material suitable for the electrolytic method were readily available from the immense magnesite reserves and from Japanese sea-water bitterns, and by 1943-44—ten years only after the industry was initiated—the annual production reached 17,000 tons, a figure nearly equalling the highest performance in this country. Two metropolitan plants were of more than 2,000 tons capacity and one operated in Manchuria (later completely destroyed by enemy action) was of 3,000 tons capacity.

Most of the great war-time magnesium plants in most countries now stand idle. World production fell from a quarter-of-a-million tons in 1943-44 to some 55,000 tons in 1945.

Figures for production in different countries and world totals are given in Table XXVIII at intervals from 1915 onwards. London and New York prices from 1915 to the present day are shown in Table XXIX.

Ores and Other Natural Sources of Magnesium

Magnesium is the third most plentiful metal used commercially in the earth's crust and the only one found on any scale in solution in natural waters. It occurs widely, almost universally, distributed on land in many varieties of its carbonate, magnesite, common forms being dolomite and breunnerite: and in sea water and other brine solutions chiefly as its chloride. Other frequently met ores are brucite (the hydrated oxide), serpentine (a silicate ore) and olivine (which contains iron). An important source is that of salt deposits.

The largest known reserves of high-grade magnesite ore are in Soviet territory in the Southern Urals. Next in importance so far are those in central Europe, in Austria and Czechoslovakia. Important reserves of good ore also occur in Germany (Silesia), Greece, Yugoslavia, Norway and Lapland, and Italy and Spain have some poorer but workable ores. Before the First World War Austria-Hungary was the largest world producer of magnesite, working chiefly from the important deposits in Styria. In recent years the U.S.S.R has been the world's greatest producer but practically none of the output has been made available for export.

TABLE

PRODUCTION OF MAGNESIUM METAL,
(IN METRIC

	1915	1920	1925	1930	1935	1936	1937	1938
Australia ..	—	—	—	—	—	—	—	—
Canada	—	—	—	—	—	—	—	—
France	—	—	—	130	—	—	1,500	1,800
Germany ..	—	—	—	1,880	*3,000	—	12,080	14,100
Italy	—	—	—	—	—	—	66	102
Japan	—	—	—	—	180	800	1,200	1,500
Norway	—	†	—	—	—	—	—	—
Switzerland ..	—	—	—	—	—	—	230	750
U.S.S.R. ..	—	—	—	—	—	—	500	500
United Kingdom	—	—	—	—	—	—	2,000	2,200
United States ..	44	62	123	280	2,120	2,000	2,059	2,918
World total ..	—	—	—	*2,500	*6,000	—	19,600	23,900

* Approximately.

Outside Europe there are large known reserves of magnesite in various parts of Canada, in Mexico, in Washington and in California in the North American Continent, and some fairly large occurrences in the islands off the Venezuelan coast in the South American Continent. In Asia very extensive deposits occur in India, Manchuria and Korea: Chinese reserves are known to exist and some ore is available in the Dutch East Indies and in Turkey.

Numerous small deposits occur in Australia and in New Zealand, and Africa has some known reserves, those worked being chiefly in the Transvaal.

Magnesite was formerly usually quarried or worked by opencast mining but underground working is now developing, particularly in Canada.

This country has no magnesite deposits of actual or even potential value and is entirely dependent on imports.

Dolomite ore occurs and is worked in this country, the inter-war annual output averaging some half-million tons. France also possesses widely distributed dolomite ore and works it in lieu of magnesite, which she does not possess.

XXVIII

BY COUNTRIES, IN SELECTED YEARS
TONS)

1939	1940	1941	1942	1943	1944	1945	1946 (Provisional)
—	—	200	430	800	900	—	—
—	—	5	367	3,245	4,799	3,380	146
2,500	2,000	1,908	1,332	1,741	842	—	1,040
16,500	25,000	25,000	35,000	40,000	50,000	—	—
360	500	1,504	2,494	2,800	3,000	—	1,005
2,000	3,000	8,000	12,000	15,000	17,000	—	—
—	—	100	2,000	2,000	2,000	—	500
750	750	700	1,500	1,500	1,000	—	200
1,000	1,500	4,000	5,000	5,000	5,000	2,170	3,000
4,831	6,500	9,232	14,630	18,794	12,887	6,000	1,200
3,039	5,680	14,782	44,418	166,544	142,518	29,748	4,823
30,900	44,900	65,400	119,200	257,400	239,900	55,000	—

† Some.

The Stassfurt salt deposits of Germany contain abundant reserves of raw material for the production of magnesium. Carnallite, a double chloride of potassium and magnesium, is the chief resource of these deposits.

Production Processes

The industrial processes for the production of magnesium fall into two main groups, electrolytic and electrothermic, the former being sub-divided into two classes according to the raw materials employed and the second group being again sub-divided into two types of process depending on whether the metal is collected by distillation or electrolysis of the reaction product. Figure III on p. 339 shows diagrammatically the family tree of the magnesium production processes.

1. Electrolytic Methods

All the industrial electrolytic processes use anhydrous magnesium chloride as the electrolyte but they differ widely in the methods used to produce the anhydrous $MgCl_2$ according to the raw material selected (see Figure III). The two chief processes are those developed in Germany and in the United States, respectively by Griesheim Elektron (an offshoot of the I.G. Farbenindustrie) and the Dow Chemical Company, the former depending on the synthesis of the chloride from magnesium oxide and chlorine, the latter on

TABLE XXIX

THE PRICE OF MAGNESIUM

Year	London Ingot Price*	New York Ingot Price†
	shillings/lb.	dollars/lb.
1915		5.00
1916		4.13
1917		2.02
1918		1.81
1919		1.83
1920		1.60
1921		1.30
1922		1.60
1923		1.25
1924		1.10
		cents/lb.
1925	4/0	86
1926	4/0	80
1927	4/0	68
1928	3/9 to 4/1½	55
1929	3/6 to 3/9	56
1930	2/10½ to 3/6	48
1931	2/7½ to 3/0	34
1932	2/5½ to 2/10½	29
1933	2/6½	28
1934	1/4½ to 2/6½	26
1935	1/3 to 1/6½	30
1936	1/3½ to 1/6½	30
1937	1/5½ to 1/6½	30
1938	1/5½	30
1939	1/5½ to 1/6½	27
1940	Controlled price 1/6	27
1941	Controlled price 1/6	24
1942	Controlled price 1/6	22.5
1943	Controlled price 1/6	20.5
1944	Controlled price 1/6	20.5
1945	Controlled price 1/6	20.5
1946	Controlled price 1/6	20.5
1947	1/6 to 1/2	20.5

* Delivered. † F.O.B. Midland (Mich.).

the dehydration of magnesium chloride brines. The electrolysis cells differ also in type.

The I.G. Cell is unheated and is refractory-lined. Multiple fixed sheet anodes are employed extending across the cell at intervals. The cells are about 100 cu. ft. in capacity and the current consumption is rated at about 9 kwh per pound of magnesium (c.d. 20,000 amps.).

The Dow Cell. The latest Dow cells are considerably larger than the German type, consisting of steel-walled containers 5 × 11 × 6 ft. deep. In contrast to the I.G. cell external heating is applied. The cell walls form the cathode and replaceable carbon rod anodes are employed. The current consumption has been reduced to about 8 kwh per pound of magnesium (c.d. 30,000-70,000, voltage 8). The operating temperature is 700° C.

2. Electrothermal Processes

Figure III shows the main industrial processes based on electrothermal reduction sub-divided into two categories according as to whether the reducing agent is carbon (which gives a volatile oxide) or is chosen to yield a non-volatile oxide.

The Carbothermic Processes depend on the reaction:

$$MgO + C = CO + Mg \quad . \; . \; . \quad \Delta H = 153.6 \text{ Kcal}$$

the reaction being reversible above 400° C. The vapour pressure of the right hand system increases rapidly at high temperatures, thus:—

at 1,527° C. the vapour pressure of (CO + Mg) is 0.042 atmospheres
1,727° C. the vapour pressure of (CO + Mg) is 0.333 atmospheres
1,927° C. the vapour pressure of (CO + Mg) is 1.77 atmospheres
2,127° C. the vapour pressure of (CO + Mg) is 7.03 atmospheres

The hot gas mixture requires shock-cooling to a temperature at which Mg and CO are stable and the main problem in operation is the dilution of the products. This is accomplished chiefly so far by using a large excess of inert gas for the shock-cooling: an alternative method tried out on pilot scale depends on the use of a liquid coolant.

Other Thermal Reduction Methods which depend on using reducing agents which give rise to non-volatile oxides are essentially two-stage, depending on the reactions:

$$C + MO = CO + M \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

$$MgO + M = Mg + MO \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

M and MO are chosen non-volatile so that Mg in Equation (2) can be liberated in the gaseous state. The conditions for M are that it must be economically priced, and that its oxide must have a high heat of formation and low vapour pressure: the substances so far employed industrially have been calcium carbide, aluminium scrap and silicon of electric furnace grade (i.e., ferro-silicon with 75% Si). All the methods used have certain common operations since they require to calcine dolomite or magnesia and they must be equipped with briquetting machines. The fundamental requisites of the thermal reduction method are continuous removal of magnesium vapour in order to displace the equilibrium to the right and the protection and condensation of the magnesium vapour. In order to arrive at a coherent form of the condensate the industrial processes employ vacuum plant. Since the reactions are endothermic heat must be continuously applied, the temperature being maintained over 1,100° C.

All the magnesium production methods are highly mechanized and the cost of labour is not, therefore, a very important item. The selection of sites for magnesium production units is mainly determined by availability of cheap power and access to raw materials except where political or strategic factors supervene.

As regards power the actual consumption in the electrolytic production of magnesium is about equal to that required for the production of aluminium, being in the region of 10 kwh per pound of metal. This means that on a volume basis 30% more magnesium can be produced with the same expenditure of electrical energy, the relative specific gravities being 1.7:2.7; a fact which might have potential importance if magnesium developed seriously as a competitor to aluminium in the future.

FIGURE IV

MAGNESIUM PRODUCTION

ELECTROLYTIC

Dehydration of $MgCl_2$ Brines

Dow Method 1 (seawater).	Synthetic brine from seawater evaporated to $MgCl_2.6H_2O$, then dehydrated to $MgCl_2.4H_2O$ and spray-dried.
Dow Method 2. (subterranean brines).	Dehydration of $MgCl_2.6H_2O$, derived by fractional crystallization of natural brines.
International Minerals and Chemicals Corp.	Potash plant sulphate brines reacted with KCl.
Diamond Alkali.	$CaCl_2$+slaked dolomite.
Mathieson Alkali	Ammonium chloride +slaked dolomite and CO_2 : $MgCl_2$ in solution recovered by dehydration.

Synthesis of $MgCl_2$

Griesham Elektron (I.G. Farb.).	Dry chlorination of magnesite.
Magnesium Elektron G.B. Method 1.	Ditto.
Magnesium Elektron Method 2.	Dry chlorination of magnesia from dolomite and seawater.
Basic Magnesium Inc. (Anaconda Copper).	Dry chlorination of magnesite.

Electrolytic Reduction

ELECTROTHERMIC

Carbon Reduction (Carbothermic)

Magnesium Metals Corp. (Hansgirg Process).	Electric furnace reduction of magnesium oxide with carbon, shock cooling with excess cold inert gas to act as diluent.
Permanente, California.	Ditto.
U.S. Bureau of Mines Method 1.	Ditto.
Method 2. (pilot-plant scale).	Dilution and quenching with cold inert volatile liquid.

Thermal Reduction to Produce Non-volatile Oxides

Murex Method.	Magnesia from dolomite and seawater reduced by calcium carbide in vacuum retort.
International Alloys, Ltd.	Aluminium scrap or Al–Si or Fe–Al–Si used as reducing agent (cold pressure shell furnace).
Electro-metallurgical Corp., Spokane, U.S.	Silicon used as reducing agent (cold pressure shell, internally heated).
New England Lime Co.	Silicon used as reducing agent (hot pressure-walled vacuum retort).
Magnesium Reduction Co. (U.S.).	Ditto.
Dominion Magnesium Ltd. (Canada) (Pidgeon Method)	Ditto.

So far there is no evidence that preference has been given to magnesium production on this score, even in the strained conditions of the power supply in war-time Germany, where magnesium extraction was developed to near perfection and could readily enough have been substituted for aluminium production (with advantages in other directions also) if magnesium had been regarded as *ersatz* for aluminium—which was not in fact the case. Nor is there any evidence that the power factor differential is influencing would-be producers in those countries which have as yet no light metals industries to put magnesium ahead of aluminium. Rather the contrary order is true.

The Properties of Pure Magnesium

Magnesium is a silvery-white metal whose outstanding characteristic is its lightness. Its thermal and electrical conductivities are moderately high, but the latter property is not commonly exploited because of the difficulty of making perfect contact, due to oxide formation: magnesium is chemically very reactive and rapidly acquires an oxide film in air. The following Table shows the chief physical characteristics of pure magnesium: since the metal is never used as a structural material in the pure state (being too soft), the mechanical properties are not listed, but the mechanical properties of the principal casting and wrought alloys are given in Tables XXXIII and XXXIV respectively.

Fabricated Cast and Wrought Products: the Magnesium Alloys

In its fabricated forms magnesium invariably contains alloying constituents, the strength of the pure metal being inadequate for structural purposes.

As a class the magnesium alloys are frequently referred to as the ultra-light alloys: in general their specific gravity lies between 1.80 and 1.82.

TABLE XXX

THE PROPERTIES OF PURE MAGNESIUM

Crystallographic form	Hexagonal holohedral (di-hexagonal di-pyramidal symmetry class).
Atomic weight	24.32.
Atomic number	12.
Valency	2.
Specific gravity	1.738.
Melting point	650°C.
Thermal conductivity	0.35 cal./cm.^{2}/°C./cm./sec. at 20°C.
Specific heat	0.246 cals./grm.
Coefficient of linear heat expansion	26×10^{-6}.
Specific electrical resistance	4.43 microhms per cm.^{3} at 20°C.
Coefficient of increase of resistance	0.00381 per °C. (range 0–100°C.).
Electro-chemical equivalent	0.45364 grams per ampere-hour.
Young's modulus of elasticity	6.5×10^6 pounds per sq. in.
Torsion modulus	2.42×10^6 pounds per sq. in.
Poisson's ratio	0.3.

The development of alloy technology in the magnesium industry has been somewhat fitful. Two important series of alloys—the Mg-Al-Zn-Mn series and the straight Mg-Mn series—were originally brought out in Germany, as the results of an arduous prior research programme extending over a long period, more than twenty years ago, forming the actual basis of the magnesium industry as a metal industry with its products entering the structural field. From then on until very recently virtually no development of alloys took place either in the mother industry in Germany or in the daughter industries established elsewhere. Towards the end of the recent war, however, Magnesium Elektron in this country were able to bring to fruition the results of intensive research (originally initiated in Germany before the war) on a new group of alloys containing zirconium, which have certain valuable new properties. There are now, therefore, three main types of magnesium alloys.

THE MAGNESIUM CASTING INDUSTRY

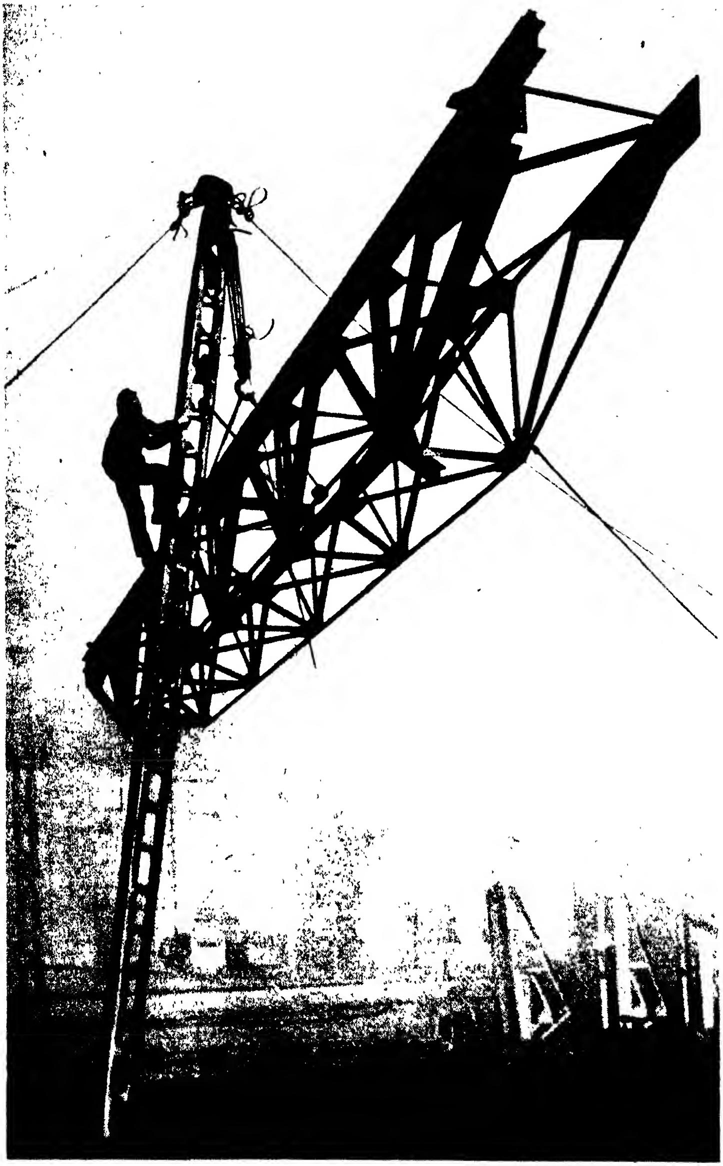
Magnesium is pre-eminently a casting material and at the present time 65-75% of the total magnesium production finds its way on to the market in that form. Magnesium cast structural products compare favourably with aluminium casting alloys because of the fact that cast magnesium alloys undergo considerable elastic and plastic deformation before failing. This is the chief reason for the successful introduction of magnesium into the aircraft constructions field. Magnesium alloys can be cast in any of the forms of sand, chill or pressure die castings. In the pre-war German industry sand castings predominated, accounting for between 67 and 78%, with chill castings 9 to 20% and pressure die castings about 13% of the casting output (aircraft landing wheels are included in the former two categories).

The American magnesium casting industry developed very rapidly during the war as ingot production increased by leaps and bounds; by the peak year 1944 as many as sixty-four foundries were turning out magnesium castings, which as a percentage of the total magnesium output rose from 65% in 1930 to 80% by 1940 and retained this percentage in the year of peak production, 1944, with a grand-scale output of castings totalling over 105,000 tons. Table XXXI shows the progress of the United States casting industry for the war years, the modest 1930 figures being included for comparison.

In Great Britain castings accounted for much the largest proportion of the total magnesium output. The Elektron factories, the biggest in the country, turned out 16,079 tons of sand castings for aero-engine and aircraft construction, and 4,247 tons of chill and pressure die castings. Sterling Metals made 700,000 landing wheels and the Birmingham Aluminium Casting Company made 230,000. The latter two companies jointly produced 47,000,000 incendiary bomb castings and J. Stone and Co. manufactured 28,000,000.

THE CASTING ALLOYS

Two of the main casting alloys of magnesium are in the magnesium-aluminium-zinc-manganese series of the composition and properties shown in Table XXXIII, both the alloys being heat-treatable. A third new alloy is in the recently developed zirconium series: this alloy is suitable for chill castings and is also heat-treatable. The important influence of the zirconium addition is as a grain-refining element, which effects great improvement in the proof stress value and in particular endows production castings with greater



32-ft. long magnesium-alloy hoist (comprising five spar sections bolted together and readily dismantled) shown in action with an 18-ton load: a recent French development.

TABLE XXXI

UNITED STATES CONSUMPTION OF MAGNESIUM METAL DURING THE WAR YEARS
(IN SHORT TONS)

	Compared with 1930	1939	1940	1941	1942	1943	1944	1945
CAST PRODUCTS								
Sand castings	50	938	1,987	5,972	16,012	29,561	44,773	18,405
Chill castings					5,400	35,910	59,181	8,307
Pressure die castings			350	384	673	1,432	1,165	803
Total castings		938	2,337	6,356	22,085	66,903	105,119	27,515
WROUGHT PRODUCTS								
Sheet	½	90	161	216	438	840	1,543	1,517
Extrusions	1	154	206	226	238	516	4,784	2,452
Forgings	3	9	13	13	22	113	344	157
Other	2	2	21	27	5	—	—	—
Total wrought products		255	401	482	703	1,469	6,671	4,126
Total structural		1,193	2,738	6,838	22,788	68,372	111,790	31,641
Non-structural uses	19	116	392	721	5,465	10,000	20,908	12,346
TOTAL	76	1,309	3,130	7,559	28,253	78,372	132,698	43,987

uniformity—the properties of the other alloys frequently show considerable scatter. The research which has been carried out on the whole series of zirconium-containing alloys and the early service results show that this group holds out great promise. Especially interesting are the compositions which contain additionally small rare earth percentages: in the cast form these alloys have shown themselves good for service at elevated temperatures up to 150-200° C.

TABLE XXXII

UNITED KINGDOM WARTIME AND POST-WAR FABRICATION OF MAGNESIUM (IN TONS)

	1941	1942	1943	1944	1945	1946	1947
Castings (not bombs) ..	3,997	4,834	5,927	7,656	4,219	993	
Sheet	131	165	148	204	99	68	
Extrusions..	148	285	293	274	113	37	
Forgings	102	114	45	39	8	1	
Powder, pure and alloy ..	—	1,617	2,953	3,162	1,752		
Bomb casings (in millions)	3.85	13.91	37.71	39.76	3.45		

Special techniques for the casting of magnesium alloys have been evolved and grain refining is universally undertaken. The older method of achieving this was to superheat the melts (850°-900° C.) but alternative methods have more recently been developed, including different types of carbon inoculation (which is effective and economical), and the latest depends on the zirconium alloying constituent. The Germans developed a method based on addition of ferric chloride which was very successful but is somewhat dangerous.

The outstanding property of the cast magnesium alloys is their good ductility, the 0.1% proof stress being one-third to one-half the ultimate stress. The compression strength of the alloys is from one-and-a-half times to twice the tensile strength whilst the compressive proof stress is almost identical with the tensile proof stress. Resistance to fatigue at ordinary temperatures is good. Magnesium casting alloys do not suffer from dimensional instability and do not grow appreciably in service: but they are as a general rule unsuitable for use at high temperatures (much in excess of 100° C.), although the zirconium-containing alloys are exceptional in this respect (see pp. 341, 345).

WROUGHT MAGNESIUM PRODUCTS

As a forging material magnesium is not uniformly successful. It presents quite different problems from those experienced with aluminium and has quite different prospects. Its alloys have a lower specific flow pressure than aluminium and magnesium materials are therefore easier to forge (for example in the hydraulic press): against this, magnesium is more difficult to roll than aluminium because of the preferred orientation set up in magnesium alloys due to the ultimate hexagonal lattice, and magnesium products for the same reason exhibit a certain disparity between the longitudinal and transverse properties. In fact directionality of properties is shown by forged products of magnesium in general.

Magnesium alloy sheet requires to be worked at higher temperatures than are necessary with aluminium materials, but at high temperatures working and drawing operations are particularly easy and successful, partly also on account of the low flow pressure exhibited by magnesium products.

Extrusion as a method is applicable to all the wrought alloys of magnesium.

Magnesium products machine admirably, representing almost the ideal from the point of view of a material, since the higher the cutting speed the better the results. In fact it has been said that magnesium as a material is waiting on better machines than have been devised up to the present time.

Joining is not in quite such a happy position and few would claim that magnesium can compare with aluminium from this point of view. Whilst workable techniques have been evolved for riveting, on the lines of riveting aluminium, the results have not been uniformly dependable; the Germans, for instance, considered riveting of magnesium precarious (due to trouble with local blistering) and it was partly on this account that the use of magnesium sheet was officially forbidden, in 1942, in the Reich. Welding affords safer ground and techniques for gas welding and, more recently, helium or argon arc welding, can be regarded as having reached a definitely successful stage in spite of the twofold difficulties of the low melting point and the high chemical reactivity. Spot welding techniques suited to magnesium are being developed in the United States. Magnesium cannot be soft-soldered but a method of brazing has been brought out.

Processes such as bending and shaping require in the case of magnesium rather high working temperatures (270-330° C.) and present certain difficulties.

THE SEMI-MANUFACTURING INDUSTRY: WROUGHT PRODUCTS

The magnesium fabricating industry for wrought products is on a smaller scale than the casting industry, as is evident from the discussion in previous paragraphs. The German output of wrought magnesium products before and even during the war was very small. In the United States only three firms produced extrusions and three forgings of magnesium as against more than ten times their joint number of casting concerns. The figures in Table XXXI show, however, that there is a steady overall growth in the American industry, even though the combined output of wrought products is only about one-quarter the output of castings, and this growth has naturally been accompanied by a general improvement in technique, with a concomitant reduction in costs. In the United States, for instance, the cost of conversion to sheet has been reduced to a point where the selling price of the latter is only twice the slab price, roughly. In this country progress in the wrought field has been slow by comparison and the equivalent conversion figure here is half as much again. (There is, however, a prospect of reduced rolling costs with the new zirconium series of alloys.) The British output of wrought magnesium products in 1947 was only 150 tons (as against a figure of 2,500 for the United States in the same year).

THE FORGING ALLOYS

The principal alloys of magnesium in the wrought group are the three old-established members of the Mg-Al-Zn-Mn and the Mg-Mn series. The new zirconium series of alloys also has two important members which are claimed to be much more easily worked or forged than the earlier alloys: the typical properties of these five main forging alloys are shown opposite in Tables XXXIII-XXXIV.

Magnesium wrought materials are characterized by good fatigue properties. Notch impact strength is somewhat low. The tendency to creep is more pronounced at corresponding temperatures than in the case of aluminium products and about 100° C. is the safe working limit for high-temperature stressing: above about 150° C. the strength decreases rapidly.

The Standard Specifications related to Magnesium are listed in Schedule VI on pages 350-351.

SURFACE TREATMENT

All magnesium surfaces require protection against corrosion under service conditions and it is routine practice to apply a chemical dip process in a chromate bath, followed by painting. In general, also, sheet and castings are chromated in the works of origin but other wrought products are frequently delivered untreated.

The chromate dip may take one of two forms:—

(a) a cold chromate bath containing:—

$$\left.\begin{array}{l}\text{15\% w/v sodium or potassium dichromate}\\ \text{20-25\% by volume nitric acid}\end{array}\right\}\ \text{in } H_2O$$

may be used for sheet or rough castings: immersion for 10-120 secs.

(b) a boiling alkaline chromate bath, commonly known as the R.A.E. half-hour bath, containing:—

$$\left.\begin{array}{l}\text{Ammonium sulphate 3\% w/v}\\ \text{Ammonium dichromate 1.5\% w/v}\\ \text{Potassium or sodium dichromate 1.5\% w/v}\\ \text{Ammonia solution (S.G. 0.88) 0.27-0.43 by vol}\end{array}\right\}\ \text{in } H_2O$$

(pH controlled between 5.90 and 6.18, according to the alloy composition)

TABLE XXXIII
THE MAIN CASTING ALLOYS OF MAGNESIUM

Name	Alloying composition %				B.S.S.	Condition	Mechanical properties*		
	Al	Zn	Mn	Zr			0.1% proof stress	U.T.S.	Elongation %
A 8	8.0	0.4	0.3		1277 1278	As cast . . . . Solution-treated . .	4.5–5.5 4.5–5.5	9–11 13–17	2–5 6–15
A 291	9.5	0.4	0.3		1273 1274 1275	As cast . . . . Solution-treated . . Fully heat-treated . .	4.5–6 5.6–6 6.5–8.5	8–10.5 13–16 13–16.5	2–4 4–8 1–4
Z5Z	—	4.5	—	0.65		Low temperature heat-treated . .	9.5–10	16–17	6–9

* For D.T.D. sand-cast bars.

TABLE XXXIV
THE MAIN FORGING ALLOYS OF MAGNESIUM

Name	Alloying composition %				B.S.S.	Condition	Mechanical properties		
	Al	Zn	Mn	Zr			0.1% proof stress	U.T.S.	Elongation %
AM 503	—	—	1.5	—	1353 1355	Rolled . . . . Extruded	6–10 8–13	13–18 15–20	5–14 4–10
AZM	6.0	1.0	3.0	—	1351 1354	Forged . . . . Extruded	10–13 9–14	18–20 14–22	8–14 8–18
AZ 855	8.0	0.4	0.3	—	1351	Press-forged . .	11–14	18–22	8–14
ZZ	—	3.0	Cd Max. 3	0.7	D.T.D. 626, 622 753, 622	Rolled . . . . Extruded	11 14–17	17 20–23	8 8–12
ZC	—	—	Max. 5	0.7	616, 613 613	Rolled . . . . Extruded	6–8 8	13–15 15	12–14 14

SCHED

MAGNESIUM-

	Al	Mg	Si	Cu	Mn	Ni	Fe
D.T.D. Specifications							
59B*i*	7.5 –8.5	R	0.2 max.*	0.15 max.*	0.2 –0.4	0.01 max.*	0.03 max.*
59B*ii*	7.5 –9.0	R	0.3 max.*	0.15 max.*	0.15–0.4	0.01 max.*	0.05 max.*
88C	5.5 –6.5	R	0.05 max.*	0.03 max.*	0.2 –0.4	0.005 max.*	0.03 max.*
88C	7.5 –8.5	R	0.05 max.*	0.03 max.*	0.2 –0.4	0.005 max.*	0.03 max.*
118A	0.05 max.*	R	0.02 max.*	0.02 max.*	1.0 –2.0	0.005 max.*	0.03 max.*
120A	9.0 max.	R	0.4 max.	0.3 max.	1.0 max.	—	—
136B*i*	9.0 –10.5	R	0.2 max.*	0.15 max.*	0.2 –0.4	0.01 max.*	0.03 max.*
136B*ii*	9.0 –10.5	R	0.3 max.*	0.15 max.*	0.15–0.4	0.01 max.*	0.05 max.*
140B*i*	0.05 max.*	R	0.02 max.*	0.02 max.*	1.5 –2.0	0.005 max.*	0.03 max.*
140B*ii*	0.08 max.*	R	0.05 max.*	0.02 max.*	1.0 –2.0	0.005 max.*	0.03 max.*
142A	0.05 max.*	R	0.02 max.*	0.02 max.*	1.0 –2.0	0.005 max.*	0.03 max.*
259A	5.5 –8.5	R	0.05 max.*	0.03 max.*	0.2 –0.4	0.005 max.*	0.03 max.*
281A*i*	9.0 –10.5	R	0.2 max.*	0.15 max.*	0.2 –0.4	0.01 max.*	0.03 max.*
281A*ii*	9.0 –10.5	R	0.3 max.*	0.15 max.*	0.15–0.4	0.01 max.*	0.05 max.*
285A*i*	9.0 –10.5	R	0.2 max.*	0.15 max.*	0.2 –0.4	0.01 max.*	0.03 max.*
285A*ii*	9.0 –10.5	R	0.3 max.*	0.15 max.*	0.15–0.4	0.01 max.*	0.05 max.*
289A*i*	7.5 –8.5	R	0.2 max.*	0.15 max.*	0.2 –0.4	0.01 max.*	0.03 max.*
289A*ii*	7.5 –9.0	R	0.3 max.*	0.15 max.*	0.15–0.4	0.01 max.*	0.05 max.*
325A*i*	3.5 –5.0	R	—	—	0.1 –0.4	—	—
348A	5.5 –6.5	R	0.05 max.*	0.03 max.*	0.2 –0.4	0.005 max.*	0.03 max.*
350A*i*	2.5 –4.5	R	0.2 max.*	0.1 max.*	0.2 –0.4	0.01 max.*	0.03 max.*
350A*ii*	2.5 –4.5	R	0.3 max.*	0.1 max.*	0.1 –0.4	0.01 max.*	0.05 max.*
628	5.75–7.25	R	—	—	0.1 –0.4	—	—
737	0.05 max.*	R	0.02 max.*	0.02 max.*	1.0 –2.0	0.005 max.*	0.03 max.*
749	5.5 –8.5	R	0.05 max.*	0.03 max.*	0.2 –0.4	0.005 max.*	0.03 max.*
B.S. Specifications. Magnesium Alloys, ingots and Castings							
1272§	9.0 –10.5	R	0.2 max.	0.2 max.	0.2 –0.4	—	0.05 max.
1273§	9.0 –10.5	R	0.4 max.	0.2 max.	0.2 –0.4	—	0.05 max.
1274§	9.0 –10.5	R	0.4 max.	0.2 max.	0.2 –0.4	—	0.05 max.
1275§	9.0 –10.5	R	0.4 max.	0.2 max.	0.2 –0.4	—	0.05 max.
1276§	7.5 –9.0	R	0.2 max.	0.2 max.	0.2 –0.4	—	0.05 max.
1277§	7.5 –9.0	R	0.4 max.	0.2 max.	0.2 –0.4	—	0.05 max.
1278§	7.5 –9.0	R	0.4 max.	0.2 max.	0.2 –0.4	—	0.05 max.
1279	0.05 max.	R	0.05 max.	0.05 max.	1.5 –2.5	—	0.05 max.
1280	0.1 max.	R	0.1 max.	0.05 max.	1.0 –2.5	—	0.05 max.
B.S. Specifications. Wrought Magnesium Alloys							
1350	3.0 –5.5	R	0.05 max.	0.05 max.	0.15–0.4	0.005 max.	0.03 max.
1351	5.5 –8.5	R	0.05 max.	0.05 max.	0.15–0.4	0.005 max.	0.03 max.
1352	0.05 max.	R	0.02 max.	0.02 max.	1.0 –2.0	0.005 max.	0.03 max.
1353	0.05 max.	R	0.02 max.	0.02 max.	1.0 –2.0	0.005 max.	0.03 max.
1354	5.5 –8.5	R	0.05 max.	0.05 max.	0.15–0.4	0.005 max.	0.03 max.
1355	0.05 max.	R	0.02 max.	0.02 max.	1.0 –2.0	0.005 max.	0.03 max.
1356	5.5 –8.5	R	0.05 max.	0.05 max.	0.15–0.4	0.005 max.	0.03 max.
1357	0.05 max.	R	0.02 max.	0.02 max.	1.0 –2.0	0.005 max.	0.03 max.

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* Denotes elements classified as impurities. § If Zn

ULE VI

BASE ALLOYS

Cr	Zn	Ti	Pb	Sn	Remarks
—	1.0 max.	—	—	0.1 max.*	Cu+Si+Fe+Ni 0.35 max.
—	1.0 max.	—	—	0.1 max.*	Cu+Si+Fe+Ni 0.4 max.
—	0.5 -1.5	—	—	—	Forgings made from extruded bars.
—	1.0 max.	—	—	—	Forgings made from billet in the as-cast and homogenized condition.
—	0.03 max.*	—	—	—	Ca 0.02 max.*
—	1.5 max.	—	—	—	—
—	1.0 max.	—	—	0.1 max.*	Cu+Si+Fe+Ni 0.35 max.
—	1.0 max.	—	—	0.1 max.*	Cu+Si+Fe+Ni 0.40 max.
—	0.03 max.*	—	—	—	Ca 0.02 max.*
—	0.03 max.*	—	—	—	—
—	0.03 max.*	—	—	—	Ca 0.02 max.*
—	1.5 max.	—	—	—	—
—	1.0 max.	—	—	0.1 max.*	Cu+Si+Fe+Ni 0.35 max.
—	1.0 max.	—	—	0.1 max.*	Cu+Si+Fe+Ni 0.4 max.
—	1.0 max.	—	—	0.1 max.*	Cu+Si+Fe+Ni 0.35 max.
—	1.0 max.	—	—	0.1 max.*	Cu+Si+Fe+Ni 0.4 max.
—	1.0 max.	—	—	0.1 max.*	Cu+Si+Fe+Ni 0.35 max.
—	1.0 max.	—	—	0.1 max.*	Cu+Si+Fe+Ni 0.4 max.
—	0.5 max.	—	—	—	Total impurities (including Cu+Fe+Si), 0.5 max.
—	0.5 -1.5	—	—	—	—
—	0.05 max.*	—	—	4.5 -7.5	Ag 2.0 max.
—	0.1 max.*	—	—	4.5 -7.5	Ag 2.0 max.
—	0.75-1.5	—	—	—	Total impurities (including Cu+Fe+Si), 0.5 max.
—	0.03 max.*	—	—	—	Ca 0.02 max.*
—	1.5 max.	—	—	—	—
—	1.0 max.	—	0.05 max.	0.2 max.	—
—	1.0 max.	—	0.1 max.	0.3 max.	—
—	1.0 max.	—	0.1 max.	0.3 max.	—
—	1.0 max.	—	0.1 max.	0.3 max.	—
—	1.0 max.	—	0.05 max.	0.2 max.	—
—	1.0 max.	—	0.1 max.	0.3 max.	—
—	1.0 max.	—	0.1 max.	0.3 max.	—
—	0.05 max.	—	—	—	—
—	0.05 max.	—	—	—	—
—	1.5 max.	—	—	—	—
—	1.5 max.	—	—	—	—
—	0.03 max.	—	—	—	Ca 0.02 max.
—	0.03 max.	—	—	—	Ca 0.02 max.
—	1.5 max.	—	—	—	—
—	0.03 max.	—	—	—	Ca 0.02 max.
—	1.5 max.	—	—	—	—
—	0.03 max.	—	—	—	Ca 0.02 max.

content less than 0.3, Cu content should be less than 0.1.

is more suitable for accurately machined or precision-dimensioned components: immersion for 30 minutes.

The degree of protection afforded by either of these chemical dips is only partial but they are essential to provide a good paint-bonding surface.

FIRE HAZARD

Whilst pure magnesium metal in thin or finely divided form is inflammable, the alloys of magnesium in solid form will not burn even if great heat is applied, in which case they melt first.

The fire risks associated with magnesium fabrication are therefore restricted to the machining shops and the foundries. In the case of the latter, normal precautions require some modification only; in the case of machining, careful provision must essentially be made for the continuous clearance of swarf and dust, for the exclusion of all damp from such collections and for the availability of special fire-extinguishing media (asbestos-graphite mixtures or dry sand or proprietary compositions).

Secondary Metal

Scrap recovery of magnesium was developed both in the United States and in this country during the War years. In the United States the output of secondary magnesium rose from 1,750 tons in 1941 to 14,000 tons in 1944, the peak year; and in the United Kingdom it started in 1940 with 400 tons and rose to its maximum of 5,000 tons in 1944.

The demand for secondary magnesium experienced the same decline after the cessation of hostilities as that for primary ingot; but there is some contemporary interest in the so-called " commercial grades " (in which primary metal is sometimes blended) where larger components of magnesium are concerned, for example for tractor parts.

The Uses and Consumption of Magnesium

The difficulty of appraising the non-war consumer uses of magnesium has been referred to earlier in this chapter. Little detailed information is available and practically no year-by-year analyses of the market for this very young and chiefly military metal. In Germany, where the magnesium industry was of longer standing and more highly developed than in any other country, the pre-war applications were divided into three roughly equal markets, 30% of the total (ingot plus secondary metal) going into military requirements, 35% into so-called civilian uses (mainly aircraft for conversion), the remaining 35% being exported. This is equivalent in the domestic market to 46% for military requirements and 54% for " civilian " uses (which also includes all the non-structural uses) whilst the percentage of metal exported was divided between different applications, mainly military, in the countries of reception.

In the United States (where available published information is rather more generous but not greatly detailed as yet) in the three years before the war the picture is fairly similar to that in Germany. The aircraft defence programme and large foreign orders for aeroplanes accounted for the major consumption of magnesium alloys with a smaller and largely experimental market for articles of portable and high speed equipment.

In Great Britain, also, the main pre-war fields of application were the aircraft and transport industries (in the latter industry there was a definite incentive in this country where the scale of taxation is based on the tare weight). There was a small entry into different industries including the cigarette manufacturing industry.

After the war broke out, the pattern of uses in the international industry changed completely, as would be expected. In war-time Germany the Luftwaffe took 90% of all the magnesium produced, which, including a rapidly growing return of secondary metal (rising from 3,600 tons in 1939 to 12,000 tons in 1944), was in the region of 135,000 tons over the war years; Army and Navy needs (including some use in artillery) came next; about 2-3% was exported for the war needs of her allies and a mere fractional percentage was left for true civilian uses. In the United States in the years 1940-1945, 60% of the total production of 429,000 tons went for structural uses, 5% was used in metallurgy, 7% for chemical uses (including flares) and 28% was employed for incendiary bomb casings. The analysis of the uses of the structural metal category is not available for the war period, but that published for 1946 shows that 45% of the structural magnesium consumed in the U.S. was used in the aircraft industry for engines, wheels, frames and accessories; 36% found its way into industrial applications in the manufacture of portable machine tools, and in the textile, printing and automobile industries; while 19% went into consumer products. Since as much as 45% of the available structural magnesium went into the aircraft industry in 1946, when the military aircraft building programme was already drastically curtailed, it is likely that a much larger proportion went into military aircraft during the war period and the German picture is probably again a fairly representative cross-section of the magnesium industry as a whole. In Great Britain 20,000 tons of Elektron castings went into airframes and aero-engines alone during the war period; 930,000 aircraft landing wheels were produced and 75,000,000 incendiary bomb casings were turned out, peak production being at the rate of more than 2,000,000 a month in two of three factories; so that here again, whilst the allocation differs slightly in detail the market picture was practically cent. per cent. for war applications.

POST-WAR USES

The immediate post-war market in both the United States and this country was greatly shrunken by comparison with the consumption of the precedent years. In the former country the 1947 consumption figure lags considerably behind the 8,000 tons of metal produced: in Great Britain it was 4,000 tons.

The American civilian market is concentrating on selected industries, principally the textile and printing industries, where high speed rotating and reciprocating parts handling delicate materials benefit particularly from any feasible reduction of inertia load: and on chosen categories of machine consumer goods, such as lawn-mowers and sewing-machines, and portable goods like ladders, folding furniture, cameras, binoculars, etc. The British development is on roughly parallel lines, but some interesting essays have also been made in the tobacco and confectionery processing industries, and more recently in the domestic cooking utensils field, which hold out some promising future possibilities.

In the aircraft field, where magnesium is primarily of military significance, the development of the jet-engine is being closely followed by the magnesium industry with an eye to the future.

Magnesium has some importance as a component in battery elements: and a new and potentially important development is the use of magnesium for cathodic protection of buried pipe-lines.

CHAPTER XVII

BERYLLIUM

ISOLATED only a year after Wöhler succeeded in separating aluminium by fused electrolysis, beryllium presents an interesting contrast in the history of its industrial development to that of its almost twin sibling which has given its name to an age. Twenty years ago, when German research seemed in sight of the solutions to the problems which had defeated chemists working on production of beryllium for more than half a century, high hopes were entertained of brilliant prospects for this youngest member of the light metal family, which was hailed as potentially perhaps the most promising. These great expectations have certainly not seen an early fulfilment and the future of beryllium is still enigmatic. The reasons for this are not at all parallel to those which have obtained in the case of magnesium, discussed in the last Chapter, and the character of the uncertainties is also different. Supplies of beryllium-bearing ores, so far as is known at present (and there are considerable difficulties in connection with prospecting and even with the analysis of ores), are not unlimited, in the first place. The only economic ore, that is to say the only ore which occurs in large enough local concentrations to rationalize utilization, is beryl, a compound silicate of beryllium and aluminium, and a second very important factor which has a far-reaching influence on industrial beryllium production is that this ore, whilst fairly widely distributed geographically, contains only a theoretical maximum of 5% beryllium and most varieties yield on an average only some 3.6% Be. As an ore it is usually, in fact, only a by-product of mica, lithium or feldspar mining (where perhaps 0.5 tons beryl per 100 tons ore is a good yield). There is as yet practically no direct beryl mining, which waits on the discovery of rich deposits or a " mountain " of beryl or comparable beryllium-bearing ore. Whilst there are in existence efficient processes for recovering the metal from beryl it is obvious, therefore, that overheads on mining and processing due to bulk of material are considerable; a recent estimate considered that, at the present stage of technique beryllium could not be marketed at much less than twenty-five shillings per pound to pay a commercially acceptable profit on actual production: whilst even this price would be dependent on there being a large enough volume of sales to carry the expenditure on production research, market development and general overheads. There is evidence that these items, which are a heavy drag on any infant industry in a competitive economy, have been particularly onerous in the case of beryllium. Equally there is evidence of a definitely expanding demand for beryllium and further evidence that this demand would increase much more rapidly if the price, especially the price to the ultimate consumer, could be reduced. With the price of beryl ore in the neighbourhood of £9 10s., equivalent to only three shillings per pound of Be, the onus of reduction of price reverts to the processing methods and essentially to far-reaching mechanization of ore-beneficiation and ore-treatment procedures.

Again, as a third factor affecting the fortunes of the industry, the metallic beryllium of commerce is only of 98% purity grade—the highest routine purity which the electrolytic process has so far been made to yield—and to arrive at final purification (without which many of the salient properties of the metal are not fully developed and markets based on the highest qualities are lost) is difficult and expensive. The question of ductility, a major determinant of the future of the beryllium industry, is probably bound up with this factor.

While the main problems of the magnesium industry are on the consumer side, the main problems of the beryllium industry, therefore, are on the production side.

History

Beryllium was isolated in 1828 by Bussy and Wöhler by reduction of molten beryllium chloride with potassium metal. The same method was utilized by other chemists in the early days of experimentation with the new metal and in particular Debray (about 1855) improved on the method.

Fused electrolysis was experimented with by a number of workers in Germany and in America and France, the names associated with this method being those of von Graetz, Nilson, Petterson and finally Lebeau, who in 1898 succeeded in obtaining globules of beryllium by electrolysis of a bath consisting of a double fluoride of beryllium and sodium.

In 1914 Fichter and Jablczynski took the fused electrolysis method a stage further and succeeded in preparing enough beryllium to remelt it as massive metal and study its properties.

In 1921 Stock and Goldschmidt were able to develop the method far enough in Germany to produce pure compact beryllium for the first time, by electrolysis, at temperatures in the region of 1,350°C., of a molten bath of $BeF_2.NaF$ and BaF_2.

The Beryllium Research Corporation was formed in 1923 under the ægis of Siemens and Halske A-G to exploit and develop the Stock-Goldschmidt method and by 1926 the results of their efforts were such that Siemens and Halske A-G laid down a plant for small-scale industrial production which commenced output about the year 1929.

Contemporaneously with the later stages of the German developments research on beryllium production was undertaken in the United States, where independent investigations on the fused electrolysis method were carried out; in this country, where research was undertaken in 1923 at the N.P.L. to develop the German method; and a little later in France, Austria, Hungary, Italy and the Soviet Union.

Commercial production was initiated in the United States in 1929, the Beryllium Corporation having been formed previously to take over the operation of the process developed by the Beryllium Development Corporation. This concern built its first plant at Marysville (Mich.), in 1932, and progressively enlarged it. In France, the Compagnie de Beryllium was formed in 1931 and in 1933 the Alais Froges et Camargue concern took up production of beryllium metal and alloys. At the outbreak of war, the United States, Germany and Italy were the chief world producers, with

France and Japan responsible for some output. By 1943 there were three companies in actual production of beryllium metal or alloys in the United States—the Beryllium Corporation, the Brush Beryllium Company, of Cleveland, and Clifton Products, Inc., of Painville, Ohio: the Defense Plant Corporation subsidized beryllium production throughout the war and also advanced a loan of $500,000 to the Beryllium Corporation. In war-time Germany, the Deutsche Gold und Silber Scheideanstalt (the commercial descendants of Siemens in the beryllium industry) operated five plants for production of beryllium metal, two being in Frankfurt and the others at Rheinfelden, Siebert (Hanau) and Stearstadt; and the Heraeus concern also operated three plants (two at Hanau and one at Sterbfritz) for production of beryllium alloys. In Italy a very large plant for production of beryllium oxide and beryllium-aluminium, beryllium-copper and other alloys was laid down by the Società Anonima Processi Privative Industriali at Chivasse (near Turin) in the mid-'thirties and was completed in 1937, coming into production early in the war. At the end of 1941 it was taken over by the Italian Government and remained in production throughout the war, after which it reverted to S.A.P.P.I. ownership.

It was not until 1942 that this country sought to enter the beryllium industry: in that year the Beryllium Smelting Company, Ltd., was formed in London to undertake refining and smelting of beryllium and beryllium compounds.

No information is available regarding recent developments in the Soviet Union, but it is known that increasing interest has been taken in beryllium-copper alloys and production is being stepped up. The beryl mine workings in Czechoslovakia and in Rumania are being reopened under Soviet influence.

Occurrence

Beryl ore has so far chiefly been drawn from the South American continent (Argentina and Brazil principally) which supplies the United States and before the Second World War also supplied Germany: and from Madagascar, which supplies the French producers of beryllium. The most important deposits of beryl are

The essential points of this process, which is nominally continuous, is that electrolysis of a beryllium oxyfluoride-barium fluoride bath is carried out at about 1,400° C., that is, definitely above the melting point of metallic beryllium, which therefore comes from the cell in compact form. The electrolyte is contained in a graphite crucible which forms the anode and is covered with a chromium-plated water-cooled iron ring to protect against burning. The crucible is supported on a graphite block and both are packed into a steel chamber with graphite fragments as packing. When the current passes, this packing behaves as a carbon resistance, which therefore heats the bath. The cathode is a water-cooled iron tube whose lower end reaches just below the level of the electrolyte: during electrolysis it is mechanically raised up to draw up the separated beryllium which solidifies in contact with its cooled surface. Fluorine, which is liberated at the anode, is converted at the operating temperature into gaseous carbon-tetrafluoride—an extremely valuable but exceedingly poisonous by-product. Provision is made for collection of this product, and of any volatile losses, by air-driven fans and lead scrubbers to dissolve the latter and to decompose the former to hydrofluoric acid in water (with a claimed recovery efficiency of more than 90%). The current yield of the process is high, current efficiency being up to 80% and metal yield about 90%: the operating voltage is about 80.

The difficulties associated with the method related chiefly to maintenance and starting up, apart from the liberation of highly toxic fumes, which in the long run led to the adoption in Germany of the Degussa (Deutsche Gold and Silber Scheideanstalt) method which depends on the use of the chloride for electrolysis. This product was produced from the hydroxide with 6-7% BeO by calcining a briquetted product of the hydroxide with powdered charcoal, wood-tar and water in a tunnel kiln for 45 minutes at 800° C. and chlorinating on the batch principle. The electrolytic reduction is carried out in two stages, each cell consisting of an electrically heated insulated nickel vessel which serves as cathode, graphite anodes being fixed centrally for each operation (lasting 24 hours). The initial cell melt is a 1 : 1 mixture of fused

NaCl and resublimed $BeCl_2$. At the end of electrolysis, carried out in alternate cells, the metal is removed and the residual electrolyte is sucked over to the next cell and again electrolysed for 24 hours. The crude metal is pressed and washed to remove electrolyte, then washed with sodium hydroxide and nitric acid and dried. The current density is 500 amps, the voltage drop across a series of five cells being initially 40 volts which falls to 24 volts at the end of the cycle. Efficiency of extractions from the ore is about 50%[1].

AMERICAN PROCESSES

For the first stage of processing the ore three different methods have been developed and are in commercial practice in the United States at the present time. The first two methods involve fusion of the ore at about 1,500° C. with or without addition of a flux, such as lime: or heat treatment at a little below this temperature followed by quenching in water. The product is then digested with sulphuric acid and subsequently, in one process, ammonium sulphate is added to separate the aluminium sulphate from the beryllium sulphate solution which is then evaporated to crystallization point, the crystals being finally decomposed by heating: whilst the second process depends on step-by-step separation of Be from Al and Fe by careful pH control. The third process is based on fluorides but differs from the old German method. The ground ore is briquetted with sodium ferric fluoride and heated at 75° C.; the ground product is leached out with water at ordinary temperature. The insolubles are filtered off and the solution is treated by a special procedure with caustic soda to precipitate the beryllium hydroxide as a granular product which is finally ignited at about 800° C. to convert it to the anhydrous oxide. The fluorine is recycled and used over again.

The American main stage reduction process preceded the modern German method in its use of beryllium chloride (produced as the anhydrous product from the oxide by chlorinating briquettes

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[1] This, at least, was the efficiency under wartime conditions in Germany, but the difficulties of operating secondhand and makeshift plant account in large measure for the low efficiency—in spite of which German output was stepped up to ten times the pre-war production.

formed with fine petroleum coke heated to about 800° C. and condensing the sublimate into a coarse powder) but the method otherwise differs from the Degussa process. The anhydrous chloride for electrolysis is fused with about five times its weight of NaCl in a special alloy-steel crucible which functions as cathode. The anode is a central graphite rod. The temperature of electrolysis is about 800° C. and the beryllium deposited on the walls of the crucible takes the form of loosely adherent flakes which are separated from the solid NaCl after cooling by washing and screening.

ITALIAN PROCESS

The S.A.P.P.I. process for treating the ore is a modified version of the old German process. The ground beryl is briquetted with twice its weight of sodium hydrogen fluoride and, after seasoning for some days, is heated in a muffle at 680° C. for two hours after attaining this temperature. The powdered roast is leached with hot (80-95° C.) potassium permanganate to separate the iron and aluminium compounds as insolubles, the residual liquor being concentrated and reacted with sodium hydroxide to precipitate beryllium hydroxide, which is then more than once filtered, washed by repulping and refiltered to remove sodium fluoride contamination. The hydroxide is dried at 350° C. for 12 hours to yield the oxide.

DIRECT PRODUCTION OF BERYLLIUM KEY ALLOYS

There are certain advantages in the direct production of beryllium-copper alloys as compared with production of pure beryllium, and all the producers have developed processes, some of which are electrolytic and some direct reduction methods.

In the early American electrolytic method, beryllium fluoride was mixed with sodium or calcium fluoride for the electrolyte, the beryllium being deposited on to a continuously consumed strip copper cathode and immediately absorbed to form a molten Be-Cu alloy.

This method later gave place to a direct reduction method which is in use at the present time. Beryllium oxide, powdered carbon and pulverized copper or copper oxide are mixed and charged in a 1 : 4 admixture with large copper pieces into a 3-phase 750 kWh arc furnace, capable of producing 7,500 pounds of 4% Be-Cu alloy (equivalent to 300 pounds of Be) per day. The chemical efficiency is over 90%.

The Italian method in use at the S.A.P.P.I. works is also electrothermic. Beryllium fluoride (produced from the dried oxide by heating bricks formed with ammonium hydrogen fluoride to 380° C. and fusing in an induction furnace at 800° C.) is mixed with copper and magnesium layers—the latter to reduce the fluoride—in a graphite crucible and heated to 1,100-1,200° C. in a high-frequency furnace. The capacity of the furnace is 25-30 kg. and the yield is in the neighbourhood of 70% Be-Cu.

German production of beryllium-copper and other alloys was not undertaken by the Degussa concern but at the Heraeus Vacuumschmelze plants. Originally the alloys were made by direct alloying of beryllium metal flake from the Degussa works with the copper or other heavy metal (Ni or Fe) in a vacuum melting furnace but it was found more economical to produce Be-Cu by direct reduction of beryllium oxide in an arc furnace.

The French producers use a method which resembles the Italian one. The double fluoride of sodium and beryllium is heated in a refractory crucible to 1,000° C., at which temperature ingots of copper-magnesium alloy with about 26.5% Mg are thrown in and stirred with a graphite spatula. After about twenty minutes the alloying process is complete but the alloy contains some 3% Mg in addition to about 11% Be and, since this magnesium content is undesirably high, the alloy is remelted in a fresh bath of the double fluoride and again held for about twenty minutes at 1,000° C. The French process is therefore worked in two stages.

Attempts have been made to utilize the more convenient method of direct production of alloys and carry processing further to the manufacture of beryllium metal from the alloy: it is possible to do so, for instance, by first making a zinc-beryllium alloy and then distilling for the zinc. There is no evidence of commercial success with this method, however.

Industrial Developments

BERYL

Tables XXXV and XXXVI show the available figures for the world production and for the consumption, in the three chief beryllium-producing countries, of beryl (or comparable beryllium ore).

Table XXXVI is very incomplete but it gives some picture, even if very rough, of the efforts made by the United States and the Axis powers to acquire beryllium ore. In the case of the latter, the ore brought from Brazil in 1940 and 1941 had to run the blockade of the Allies: up to the outbreak of war, Germany had taken more than one-third of the beryl available in the world markets.

The price of beryl has been reasonable and fairly steady since beryllium industrial production began, in the region of £10-12 per ton delivered to European ports. American prices have ranged between $30 and $50 per (short) ton at the mine during the same period.

BERYLLIUM METAL

There are as yet no official statistics relating to metallic beryllium and information about its production and consumption is almost non-existent. The latest uses of beryllium, in the field of atomic research, are likely to make for continued secrecy about production and consumption. The following figures, in Table XXXVII, provide a mere impression of the rapid growth of the industry in the two countries, Germany and the United States, which have principally developed it since the production of beryllium metal started on a semi-commercial scale. In the United States, in particular, the extent of output during the recent war has been respectably large. The German industry laboured under intense wartime difficulties, since it was not accorded priority facilities for plant and had to muster up makeshift equipment as best it could. In spite of this fact, observers have it on record that the German war-time output was increased tenfold compared with that of the immediately precedent years.

At the present time, with the German production plant in the

TABLE XXXV

WORLD BERYL PRODUCTION, 1935–1946
(IN METRIC TONS)

	1935	1936	1937	1938	1939	1940	1941	1942	1943	1944	1945	1946
Argentine	208	331	287	753	299	520	2,186	925	530	348	40	
Australia	—	—	—	—	6	2	3	—	534	417	—	19
Brazil (exports)	—	4	—	203	276	1,472	1,703	1,634	2,027	1,185	510	1,294
Canada	—	20	20	—	—	?	?	?	?	?	?	?
India	139	98	27	18	9	53	?	121	1,486	1,000	250	100
Madagascar	11	11	2	2	?	?	?	?	67	?	10	
Portugal	2	2	24	27	?	?	?	?	14	60	?	
Portuguese E. Africa ..	—	—	—	—	—	—	—	8	6	3	—	22
Spain	—	—	—	—	—	4	?	?	?	?	?	—
South-west Africa	—	—	—	—	—	—	20	39	36	1	5	—
Uganda	—	—	—	—	—	—	—	—	—	18	4	
Union of S. Africa	88	5	—	—	—	5	?	34	78	?	?	—
United States	—	—	75	23	86	110	143	244	323	352	35	91
Known total	448	471	435	1,026	676	2,166	4,090	3,005	5,101	3,384	854	1,526

Production in Finland, France, Italy, Kenya, Norway, Rumania and U.S.S.R. unknown.

Western Zones dismantled, the United States has a virtual monopoly of beryllium production in the world outside the U.S.S.R. (whose output is not known). French production is small and Italian production was discontinued at the end of the war, the S.A.P.P.I. process being regarded as rather a fancy one for industrial production purposes.

Prices for beryllium metals are not quoted on the open market in this country, but the 4% beryllium-copper alloy sells currently at £6 10s. per pound of Be plus 1s. 7d. per pound of alloy, delivered: fabricated beryllium-copper sells as follows:—

4% Beryllium-Copper Alloy:	*Price per pound (London)*
Strip	13s. 9d.-15s. 6d.
Rod (1 inch and over)	12s. 3d.-14s. 0d.
Wire (10 swg)	15s. 6d.-15s. 9d.

American prices for beryllium metal quoted as effective at the beginning of 1948 were as follows:—

Beryllium Metal:	*Price per pound (New York)*
Lump or pebbles (technical)	$56.00
Lump or pebbles (premium)	$85.00
Powder (technical)	$95.00
Powder (premium)	$103.00

whilst American beryllium-copper (4%) sells at $2.50 per pound for 1,000 pound lots or over.

Properties

It is of the greatest importance when considering the properties of beryllium metal to emphasize the difference between the commercial product with 96-98% and the pure metal of 99.7-99.8%, which is only obtained after special processes are undertaken to arrive at this titre, which is about the highest so far obtained even on a laboratory scale. The highest purity metal which has been tested for mechanical properties is about 99.5% purity.

Pure beryllium is a light metal of specific gravity 1.82, which lies between that of aluminium (2.7) and magnesium (1.74), but its

TABLE XXXVI

CONSUMPTION OF BERYL IN THE CHIEF BERYLLIUM-PRODUCING COUNTRIES, 1937–1945
(IN SHORT TONS)

Consumer country	Imports from	1937	1938	1939	1940	1941	1942	1943	1944	1945
UNITED STATES	Africa	—	10	—	6	—	38	86	23	29
	Argentine	152	78	384	422	861	703	1,162	229	—
	Australia	—	—	—	—	—	—	457	518	105
	Brazil	—	—	75	377	1,805	912	2,551	1,453	572
	India	30	58	—	—	—	397	509	892	484
	Madagascar	—	—	—	—	—	—	74	—	11
	Portugal	—	—	—	—	—	—	1	—	—
Total imports		182	146	459	805	2,666	2,050	4,840	3,115	1,201
Domestic production		75	25	95	121	158	269	356	388	39
Total U.S. consumption		257	171	554	926	2,824	2,319	5,196	3,503	1,240
GERMANY (estimated figures)	Brazil				200	200	—	—	—	
	Finland/Norway				20	20	20	20	20	
	France				60	60	—	—	—	
	Italy				—	—	—	470	—	
	Portugal				80	80	80	80	80	
Total imports					360	360	100	570	100	
Production in Greater Germany					?	?	?	?	?	
Total consumption					?	?	?	?	?	
ITALY Total consumption						353	128	141	29	

melting point, 1,287° C., greatly exceeds that of both these metals. Beryllium is remarkably hard but the specimens so far made available have been very brittle at ordinary temperatures: whether this lack of ductility is due to the limited purity factor (and/or the presence of intergranular films of oxide compounds or gas occlusions) or to the ultimate crystal structure is not yet clear, but the fact of its cold brittleness has, of course, far-reaching effects on the extent to which beryllium can find its place industrially as a metal. So far, whilst the balance of the theoretical evidence inclines to support the expectation that the really pure metal—when that can be produced—is in all probability ductile, no beryllium produced on a commercial or semi-commercial scale has shown ductility.

When hot, however, beryllium of the purities now available commercially can be forged and rolled. Rolling presents some difficulties in technique as cracking tends to occur along the crystal boundaries at the edges: but given rapidly cooled rolling blanks (to produce as fine a grain as possible) and a rolling temperature of 900-1,000° C., sheet can be produced successfully. Rolled products evidence brittleness once more on cooling but to a lessened extent and there is a very slight residual cold bendability.

The elastic properties of beryllium are very remarkable and particularly so for a light metal. Young's Modulus is in the region of 41,000 lb. per sq. in., more than 35% higher than that of steel: and there is almost no hysteresis effect. Both these properties are communicated in high degree to the beryllium-containing alloys.

Equally outstanding are the high fatigue endurance limit and especially the high corrosion fatigue limit with which small additions of beryllium endow its alloys, particularly in the copper-beryllium series. The former ranges in the Cu-Be alloys from 35,000-40,000 lb. per sq. in. (comparable with the values obtained for heat-treated low carbon steels): and the latter is far in excess of that obtained with any other known material.

Table XXXVIII lists the chief mechanical properties of 99.5% pure beryllium metal.

In its physical properties beryllium is not less well endowed. Its linear coefficient of heat expansion at ambient temperatures is in

TABLE XXXVII

AVAILABLE FIGURES RELATING TO THE PRODUCTION OF BERYLLIUM PRODUCTS

YEAR	GERMANY								UNITED STATES			
	Beryllium Metal		Be-Cu Alloy (2.4%)		Be Oxide (Comm.)		Total in terms of Be		Beryllium Metal		Total in terms of Be	
	Output met. tons	Price kg.	Output met. tons	Price kg.	Output met. tons	Price kg.	Output met. tons	Value	Output met. tons	Price lb.	Output short tons	Value
		RM.		RM.		RM.				$		$
1925	—	10,000	—	—	—	—	—	—	—	—	—	—
1930	12	900	—	26	—	—	—	—	<2	145	—	—
1939	<0.5	—	45	—	—	—	—	—	—	—	—	—
1940	<1	—	—	—	1	—	—	—	—	—	—	>500,000
1940 to 1944	4.1	385	317	13.5	18.8	57	18.8	?	—	—	*350†	—

* Approximate. † Calculated from the totals of ore available from imports and home production and deducting 4,815 tons, representing the published figures for stocks in hand of consumers, dealers and the Metals Reserve Fund at the end of 1944 (the 1939 stocks being assumed small); based on an average of 3.5 per cent. Be content.

TABLE XXXVIII

MECHANICAL PROPERTIES OF 99.5% BERYLLIUM

	As forged	Annealed 1,000°C. in H_2
TENSILE TESTS		
U.T.S., lb./sq. in.	29,850	27,000
Yield strength (0.2%), lb./sq. in.	—	26,400
Proportional limit, lb./sq. in.	9,400	8,700
Elongation on 4 diameters, per cent.	0.0	0.0
Reduction of area, per cent.	0.0	0.0
Modulus of elasticity, lb./sq. in.	40×10^6	36.8×10^6
COMPRESSION TESTS		
Yield strength (0.2%), lb./sq. in.	35,300	—
Proportional limit, lb./sq. in.	9,200	—
Modulus of elasticity, lb./sq. in.	42×10^6	—
Shear strength, lb./sq. in.	38,600	—
Density, gm./cm.^{3}	1.844	—
Electrical conductivity (per cent. that of copper)	43.1	—

the region of 12 x 10^{-6}: different workers, probably using metals of varying purities, have not agreed on the absolute determination but are agreed that the linear coefficient is close to that of iron and that it varies markedly with temperature.

The thermal conductivity of beryllium also compares favourably with that of aluminium and magnesium. Reliable values range it from 0.232 c.g.s. units at −176° C. to 0.508 at 190° C.

As regards the electrical properties of beryllium, the same confusion is noticeable in the published values because of the varying purity and sensitivity of electrical properties, in particular, to the presence of even small amounts of impurities. For the highest grades of metal so far available the conductivity has been found to reach 40 per cent. that of copper and this value may be expected to be improved on for the pure metal.

Corresponding to the very high elastic modulus value, the velocity of sound in beryllium is the highest known, being more than twice that of the nearest runner-up and two-and-a-half times that of steel.

The optical properties of beryllium are related to its ability to take a high polish, whose permanency is comparable with that of aluminium. The reflectivity for white light is of the order of 55%.

In reviewing the above properties it is apparent that, if beryllium could be produced in a state of purity or with an alloying constituent which would give it any useful degree of ductility, its other outstanding properties would place it in a position of eminence among the light metals and pre-eminence among metals in general. Its hardness coupled with its lightness, its stability and fatigue resistance at high temperatures and its remarkable elastic behaviour rank it in the forefront of engineering materials: and on the physical side it has potentialities linked with its good optical and acoustic qualities as well as in applications depending on its favourable thermal behaviour.

Beryllium Alloys

Beryllium alloys successfully with a number of metals to form ultra-light beryllium-rich, light and heavy low-beryllium products. In the series of ultra-light alloys the only important ones so far experimented with are those with aluminium: alloys with less than 70% Be are workable and can be rolled. An alloy developed in America with 28% Al and remainder beryllium of 99.5% purity (density 2.03) shows the following properties in the chill-cast condition:

Tensile strength	25,000 lb./sq. in.
Yield point	19,000 lb./sq. in.
Elongation	3%
Modulus of elasticity ...	29 × 10^6 lb./sq. in.
Brinell hardness	86
Endurance limit	11,000 lb./sq. in. at 20 × 10^7 cycles

The creep strength of the Al-Be alloy is, however, rather low.

With beryllium contents below 40% the Al-Be series has elongations of the order of 12-20%, with still high mechanical properties.

The heavy series of alloys, more especially those of copper base, have provided the main outlet for beryllium so far and have given it its present important place in the industrial world. In fact, beryllium is commonly said to fulfil the role with copper that carbon fulfils with steel. There are various favourite Cu-Be compositions, with or without other additions, but the most prominent is the alloy with 2-2.5% Be (the American version of this alloy having an added 0.3% cobalt). This alloy is heat-treatable and is an outstandingly good subject for working in the annealed condition while it regains a remarkable degree of hardness and tensile strength after precipitation hardening. The beryllium-copper alloys are characterized by high fatigue strength, high elastic limit and great hardness; relatively high tensile strength and electrical conductivity; outstandingly good corrosion-resistance; good wear resistance; good resistance to room temperature creep and to friction wear against steel; and good forming qualities. The following are representative values attained by the American alloy:

	Annealed	*H.t./Cold Rolled*
Ultimate tensile strength ..	66,000	190,000 lb./sq. in.
Percentage elongation ...	50	3
Electrical conductivity ...		good at high temp.
Elastic properties ...		no hysteresis.

Beryllium-copper is easy to cast by ordinary foundry methods and finds considerable application as a heat-treatable casting alloy. Plaster mould castings have shown excellent properties.

In the heavy series of alloys, beryllium-nickel is also a remarkable product and, although research on it had not reached finality before the war, the American producers expect to market it shortly. Its characteristics are of the following order:—

Ultimate tensile strength	270,000 lb./sq. in.
Percentage elongation	8-9
Brinell hardness	480

Beryllium-platinum for a short time replaced platinum-iridium in war-time Germany when iridium was in short supply.

Applications of Beryllium and Beryllium Products

Prior to the development of atomic energy, the chief use of so-called pure beryllium (96-98%) was as vacuum-tight windows for X-ray tubes to filter out stray or reflected electrons. Recently, however, beryllium has become important as a target for high-frequency deuteron beams in the production of neutrons. Its good thermal conductivity is valuable in this connection for dissipating heat. Beryllium-plated water-cooled targets have been used successfully and cast beryllium metal shows some promise. Beryllium has also been employed tentatively instead of graphite as a moderator for atomic piles, but this development would require larger available quantities of high-purity metal, apart from present difficulties in forming and fabricating.

Beryllium-Copper has wide applications, as the following list of heading shows:

- Springs (particularly calibrated springs).
- Diaphragms.
- Bellows.
- Sparkless tools, particularly:
  - wire brushes,
  - hammers,
  - axes,
  - pitchforks,
  - pliers,
  - wrenches,
  - wrecking bars.
- Seam welding wheels.
- Control instruments.
- Contact metals.
- Non-magnetic ball bearings.
- Bearings.
- Tubes for hydraulic drives.
- Bourdon tubes.
- Valve guides.
- Pitch propeller bearings.

aside from innumerable parts of aircraft, ships, tanks, gun, shells, engine components, radio and telephone parts and electrical control equipment for machinery and fire protection. Armour-plating of beryllium-copper excited some interest during the war, but it is believed that the reports of its extensive use by the German army are exaggerated.

Beryllium-nickel was used in Germany as the 2% alloy for sparkless chisel tools, which hold their edge better than beryllium-copper chisels. Radio engineers were also utilizing beryllium-nickel for wireless valve components.

Beryllium-aluminium is still more or less in the experimental stage but promising results for instrument parts have been noted as a basis for future developments.

The oxide and other non-metallic compounds of beryllium are of great value in the fluorescent lamp, X-ray, cathode ray and television industries and also in the ceramic and refractories industries.

Recent Trends and Future Developments in the Beryllium Industry

There are two recent developments from the American side which are symptomatic of the trend of present-day research on beryllium in different parts of the world and which may have far-reaching influences on the industry. One is the discovery that small additions of titanium or zirconium make beryllium somewhat ductile: the other the attempt to arrive at a high-purity metal by a new method, based on the reduction by means of magnesium of beryllium fluoride materials.

Research is being concentrated on these two main objectives of endowing beryllium with reasonable ductility and arriving at a routine production of a higher purity metal than can at present be manufactured under industrial conditions.

APPENDIX

SELECTED REFERENCE BOOKS

(The material of interest on light metals from the periodical and trade literature is so vast that it is not possible to deal with it adequately by selection.)

Note.—* indicates inclusion of historical data.
** indicates inclusion of economic data.
(———) enclosing the title indicates specialised treatment.

A. ALUMINIUM

I. Reference works with extensive bibliographies

GMELIN'S HANDBUCH DER ANORGANISCHEN CHEMIE, System-Nummer 35 : Aluminium. 8th ed. (1933-39) (Verlag Chemie, Berlin)

Teil A—Lieferung 1	History ; occurrence and geology of the ores ; production ; properties.
,, ,, 2	Electro-chemical and chemical behaviour in corrosion.
,, ,, 3	Surface treatment.
,, ,, 4	The alloys of Al with S—Ra.
,, ,, 5	The alloys of Al with Zn—U.
,, ,, 6	The alloys of Al with Mn—Au.
Supplement 1 to A	Patents of alloys of aluminium.
,, 2 ,, A	
Teil B—Lieferung 1	Compounds of Al with H—C.
,, ,, 2	Compounds of Al with Si—Fe.

ENGELHARDT, V.	1934	Handbuch der Technischen Elektrochemie : Vol. 3, Die Technische Elektrolyse im Schmelzfluss, has sections on aluminium, magnesium and beryllium. (Akademische Verlag, Leipzig.)
MELLOR, J. W.	1927	A comprehensive treatise on inorganic and theoretical chemistry. Vol. 5 : chapter on aluminium (224 pp.). (Longmans, Green & Co., London.)

II. Textbooks on the production, fabrication, properties and applications of Aluminium

AMERICAN SOCIETY FOR METALS.		Metals Handbook. (Published occasionally ; latest edition, 1948, has a 70 pp. section on aluminium and its alloys). (A.S.M., Cleveland.)
BROWN, Hiram, & KLEMIN, A.	1948	Aluminium and its applications. (Pitman, New York.)
SCHENK, Max.	1948	Werkstoff Aluminium und seine anodische Oxydation. (First two sections, 540 pp.) (A. Francke, Bern.)
BUDGEN, N. F.	1947	Aluminium and its alloys. 2nd ed.
	1933	do. 1st ed. * ** (Pitman, London.)
ZEERLEDER, A. von	1947	Technologie der Leichtmetalle. (Rascher, Zurich.)
(CARRINGTON, E.	1946	Aluminium alloy castings : their founding and finishing.) (Griffin, London.)
(IRMANN, Roland	1943	Aluminiumguss in Sand un Kokille. 3rd ed.) (Akademische Verlag, Leipzig.)
(HERMANN, E. & ZURBRUGG, E.	1943	Die Bearbeitung des Aluminiums. 3rd ed.) (Akademische Verlag, Leipzig.)
ZEERLEDER, A. von	1938	Technologie des Aluminiums und seiner Leichtlegierungen. 3rd ed. (Akademische Verlagsgesellschaft, Leipzig.)
	1936	do. 2nd ed. English translation by A. J. Field. (Nordemann Pub. Co., Amsterdam.)
(TEED, P. L.	1937	Duralumin and its heat-treatment.) (Griffin, London.)
EDWARDS, FRARY & JEFFRIES	1930	The aluminium industry. Part I, Aluminium and its production. * **
	1930	Part II, Aluminium products and their fabrication. ** (McGraw-Hill, New York.)
GUILLET, L.		Les métaux légers et leurs alliages :
	1936	I. Historique, métallurgie, propriétés, situations economiques. * **

	1940	II. Part 1—L'Aluminium et ses alliages. II. Part 2—Emplois de l'aluminium et de ses alliages. (Dunod, Paris.)
MAGNANI, U. & PANSERI, C.	1932	La tecnologia dell'alluminio. 2nd ed. (Stefano Pinelli, Milan.)
(ANDERSON, R. J.	1931	Secondary aluminium. **) (Sherwood Press Inc., Cleveland, Ohio.)
MELCHIOR, P.	1929	Aluminium : die Leichtmetalle und ihre Legierungen. (VDI—Verlag, Berlin.)
PAINTON, E. T.	1927	The working of aluminium. (Chapman & Hall, London.)
U.S. DEPT. OF COMMERCE	1927	Light metals and alloys : aluminium ; magnesium. Circular of the Bureau of Standards, No. 346. (U.S. Government Printing Office, Washington.)
ANDERSON, R. J.	1925	The metallurgy of aluminium and aluminium alloys. * (Henry Carey Baird & Co., New York.)
(ADVISORY COMMITTEE FOR AERONAUTICS	1921	Reports of the Light Alloys Subcommittee.) (H.M.S.O., London.)
RICHARDS, J. W.	1887	Aluminium : its history, occurrence, properties, metallurgy and applications including its alloys. *
	1896	do. 3rd ed. rev. enl. (Sampson, Low & Marston, London.)

III. Other books for general reading

HOBBS, D. B.	1947	Working with aluminium.
	1938	Aluminium : its history, metallurgy and uses, with projects for the school and home shop. * (Bruce Pub. Co., Milwaukee.) (Both.)
DEBAR, Rudolf	1937	Einfuhrung in die Leichtmetallkunde. (Max Janecke, Verlag., Leipzig.)

GRARD, C.	1921	Aluminium and its alloys: their properties, thermal treatment and industrial application. (Translation from the German.) (Constable, London.)

IV. Textbooks on special subjects with titular reference to aluminium or the light alloys

SCHENK, M.		See entry under II.
MONDOLFO, L. F.	1943	Metallography of aluminium alloys. (Chapman & Hall, London.)
FUSS, V.	1936	Metallography of aluminium and its alloys. (Translated by R. J. Anderson.) (Chapman & Hall, London.)
TEMPLE, J. E.	1947	Handbook of structural design in the aluminium alloys. (Jas. Booth, Birmingham.)
DUDLEY, L.	1947	Light metals in structural engineering. (Temple Press, London.)
EASTWOOD, L. W.	1946	Gas in the light alloys. (Chapman & Hall, London.)
BEHRENS, P.	1943	Aluminium - Freileitungen. Ein Hilfsbuch fur die Planung und den Bau von Starkstrom-Freileitungen. 6th ed. (Aluminium-Zentrale, Berlin.)
JENNY, A.	1940	The anodic oxidation of aluminium and its alloys. (Translated from the German by Winifred Lewis.) (Griffin, London.)
EDWARDS, J. D.	1936	Aluminium paint and powder. 2nd ed. rev. (Reinhold Publ. Co., New York.)
PLATT, W. H. H.	1922	Aluminium repairing. (Crosby Lockwood, London.)

V. Historical

PITAVAL, R.	1946	Histoire de l'Aluminium. ** (Pub. Minières et Mètallurgiques, Paris.)

VI. Economic

STOCKING, G. W. & WATKINS, M. W.	1948	Cartels or competition ? (Twentieth Century Fund. New York.)
DeMILLE, J. B.	1947	Strategic minerals. (McGraw-Hill. New York.)
MARLIO, L.	1947	The aluminium cartel. (Brookings Institution. Washington.)
ENGLE, N. H., GREGORY, H. E. & MOSSE, R.	1945	Aluminum. An industrial marketing. appraisal. (Richard D. Irwin, Chicago.)
ELLIOTT, W. Y., MAY, E. S., ROWE, J. W. F., SKELTON, A. & WALLACE, D. H.	1937	International control in the non-ferrous metals. (MacMillan. New York.)
WALLACE, D. H.	1937	Market control in the aluminum Industry. (Harvard University Press, Cambridge.)

B. MAGNESIUM

ELEKTRON MAGNESIUM ALLOYS	1947	" Elektron " magnesium alloys. (Elektron Magnesium, London.)
PIDGEON, L. M., and others.	1946	Magnesium. (American Society for Metals, Cleveland.)
BULIAN, W. & FAHRENHORST, E.	1944	Metallography of magnesium and its alloys. (F. A. Hughes & Co., London.)
BECK, E.h.A.	1940	The technology of magnesium and its alloys. (F. A. Hughes & Co., London.)

GMELIN'S HANDBUCH DER ANORGANISCHEN CHEMIE, System-Nummer 27 : Magnesium. 8th ed. (1937-39) (Verlag Chemie, Berlin).

Teil A	—Lieferung	1	Occurrence ; production.
„	„	2	Properties of the metal.
„ B	„	1	Compounds of magnesium, 1st part.
„	„	2	„ „ „ 2nd part.
„	„	3	„ „ „ 3rd part.

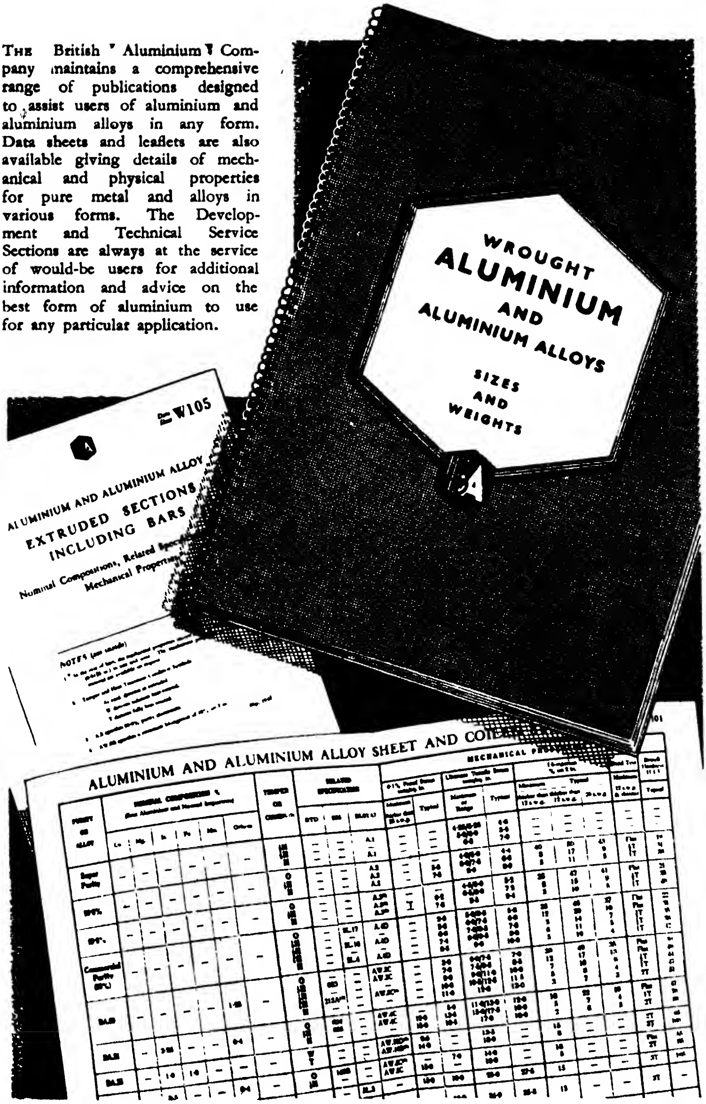
Teil B—Lieferung 4		Commercial production of magnesium compounds.
GRUTZNER, A. & others.	1937	Magnesium-Legierungen Patentsammlung. (Verlag Chemie, Berlin.)

C. BERYLLIUM

RIMBACH, R. & MICHEL, A. J.	1932	Beryllium: its production and application. (Reinhold Pub. Corp., New York.)

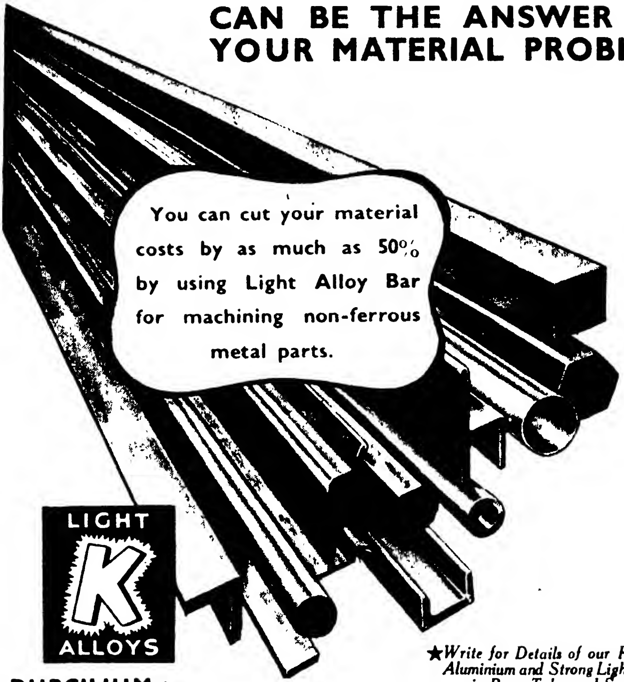
INDEX

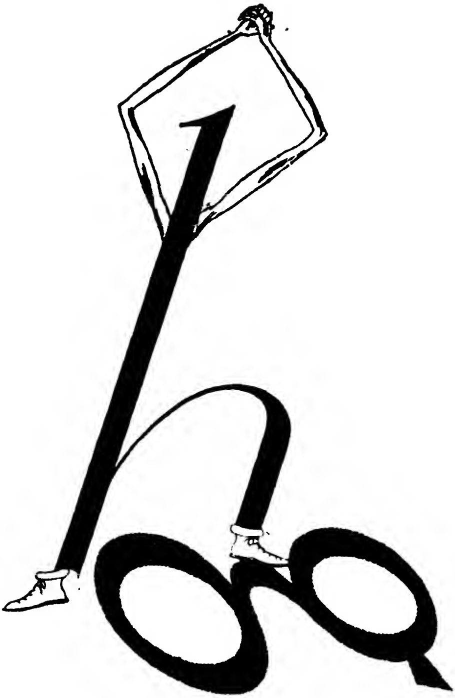
This Index does not analyse in detail items (such as trade names of alloys, processes, countries, etc.) already listed alphabetically in the various Tables and Schedules, which are referenced in terms of their headings only.

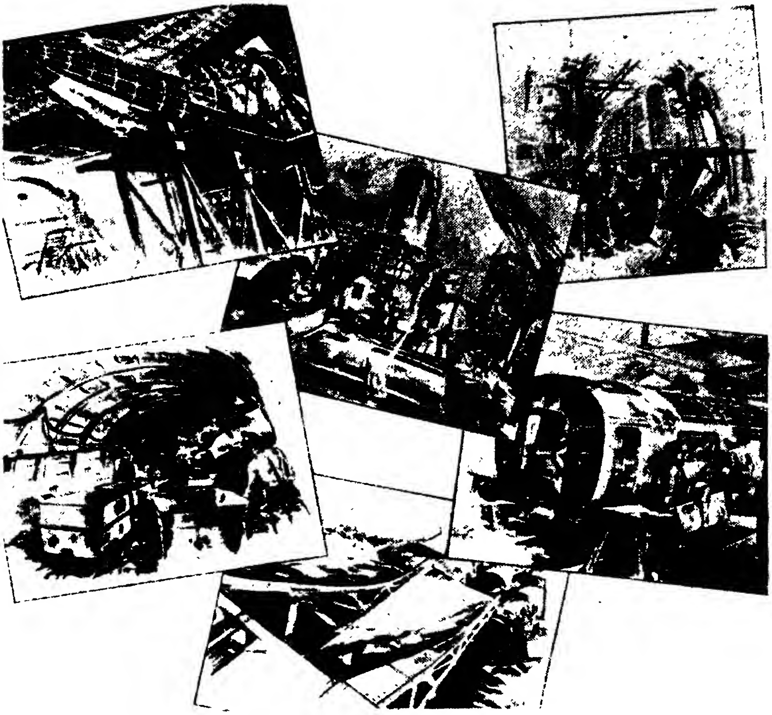

WROUGHT ALUMINIUM AND ALUMINIUM ALLOYS
SIZES AND WEIGHTS
W105
ALUMINIUM AND ALUMINIUM ALLOY
EXTRUDED SECTIONS INCLUDING BARS
Nominal Compositions, Related Specifications, Mechanical Properties
NOTES
ALUMINIUM AND ALUMINIUM ALLOY SHEET AND COIL
MECHANICAL PROPERTIES


DOLGAR ROG
Pure and Manganese

The Arvida plant of Aluminium Company of Canada, Ltd. This is the largest aluminium-producing plant in the world and can produce 813 tons, 9 cwt. of aluminium per day.








ALUMINIUM
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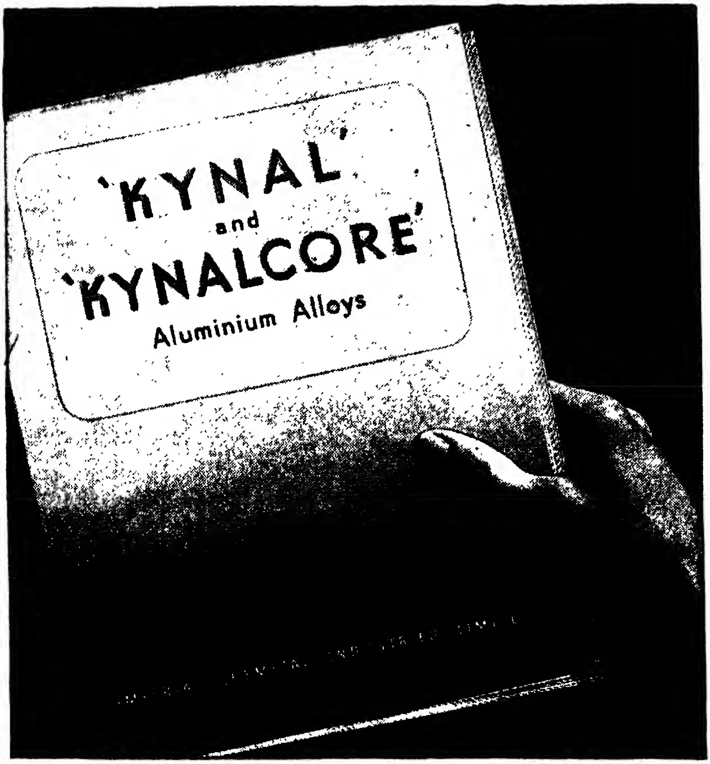
'KYNAL'
and
'KYNALCORE'
Aluminium Alloys