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# MATERIALS OF TO-MORROW



# MATERIALS OF TO-MORROW

*by*

PAUL I. SMITH

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## PREFACE TO FIRST EDITION

THIS BOOK CATERS FOR THOSE WHO WANT TO KNOW SOMETHING about the new materials handled by British industry to-day, and those substances now in the embryo state of development which are likely to be produced to-morrow. It attempts, within the compass of a few chapters, to give a simple but factual account of various key industries and to indicate the opportunities that exist in those industries.

The story of modern industry is a fascinating and even exciting one, touching as it does many of the facets of national progress and the life of the individual. The discovery of new products; the birth of new industries and the exploitation for good or evil of strategic materials made possible by science, these facts alone, without the embroidery of imaginative writing, make absorbing reading.

There is nothing dry or academic about the materials of industry; on the contrary, they have a direct influence on our lives. Everyone with a stake in industry, it may be his work or the future employment of his children, should know something of their development, both present and future. We cannot leave these things to the expert. The materials of industry, coal, oil and minerals, these concern us all in a personal kind of way. It is now our responsibility to ensure that we make the best possible use of our resources, slender though they are, and mobilise industry even more efficiently than we do our armed forces. There is a fight ahead for markets, for industrial security and for good opportunities for our children.

IPSTONES, STAFFS.  
*March, 1945.*

PAUL I. SMITH.



## PREFACE TO SECOND EDITION

SINCE THE PUBLICATION OF THE FIRST EDITION OF "MATERIALS OF TOMORROW" three major events have occurred: victory in Europe, victory in the Pacific, and the development of atomic power as a lethal weapon in war.

It is my opinion that the unleashing of atomic energy will bring about an Industrial Revolution of a magnitude far surpassing the one which took place in Britain in the late eighteenth and early nineteenth centuries. One regards the future with serious misgivings, if not with actual alarm, as, apart from the possibility of a premature end to our so-called civilisation, the development of cheap and inexhaustible atomic power must inevitably upset all our values, both economic and moral. It may well be, as the late Dr. Alfred Russell Wallace has said: "That man's scientific discoveries have outstripped his moral development," but what is more to the point is that so far our scientific discoveries have outstripped our intelligence.

Our economic system, industry and the lives of the people appear to be ill prepared to receive this gift of limitless cheap energy. There is no part of our national life that will not be affected by this amazing development. Cheap, abundant power may be a blessing, but it has a greater chance of proving a curse unless there is complete co-ordination of economic and industrial efforts and central planning.

The immediate effects of atomic energy, once it has been industrialised, may be felt in those industries responsible for the production and transportation of fuels. Millions of men now engaged in mining, related industries, oilfields, refineries, railways, etc., might well become redundant. Even before atomic power replaces coal and oil there is a danger that an economic blizzard may affect these industries, owing to the withdrawal of capital or to financial chicanery.

Cheap and inexhaustible energy geared to industry will eventually give a tremendous boost to all synthetic processes formerly handicapped owing to the high cost of power. Coal and oil, no longer used as fuels, will become raw materials for vast new chemical industries producing plastics, rubber, synthetic fibres, synthetic foods, dyestuffs, building materials, etc. Processes now considered to be uneconomical owing to the high cost of electrical power may be operated cheaply to extract old and new metals from low-grade ores, utilise small quantities of reactive gases from industrial effluents and the air, and carry through long series of organic synthesis with simple gases, such as carbon dioxide.

It is possible that metals regarded to-day as mere laboratory curiosities will, in the age of atomic power, become of great industrial importance. It is not always appreciated that some of the so-called rare metals, such as gallium, are only rare in the sense that no satisfactory method has yet been developed for their economical recovery from the earth's crust. Scandium is a common constituent of certain rocks; germanium is known to be present in coal ash, and haforium, and zirconium are fairly plentiful.

Countries which to-day appear to be bankrupt of minerals and natural

resources may, through the availability of abundant cheap power, find it possible to build up metallurgical and chemical industries based on low yield raw materials formerly considered to be uneconomical to handle.

It is no exaggeration to talk of the new Industrial Revolution ; rather is it an understatement. The great dread is that without central planning, that is world control or direction of atomic power, we shall not be prepared to meet the new and unpredictable emergencies that will arise with any greater prospect of success than we faced the economic crisis.

PAUL I. SMITH.

IPSTONES,  
*March, 1946.*

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## INTRODUCTION

THIS BOOK IS AN ATTEMPT TO PRESENT TO THE YOUTH OF BRITAIN SOME of the new materials likely to assume great importance during the years of reconstruction. It is not intended to be a write-up of British achievements, although these have been considerable, nor does it constitute a pat on the back for British industrialists and scientists, rather is it a critical survey of opportunities and a pointer to the future development of industry. If realism has been preferred to ballyhoo and plain speaking to pious hopes it is because the author feels that now is the moment when British industry needs a new charter. This is the crucial point in our history and future generations will either say: "the industrial development of Great Britain declined from this period due to public apathy," or "this marks the beginning of the 20th century industrial Renaissance."

To make secure Britain's industrial future demands three things :

- (1) Improved technological education.
- (2) Expansion of industrial research.
- (3) Continuance of State interest in industry.

Great Britain is lagging behind America and even the U.S.S.R. in the provision of technological educational facilities, in consequence, the home industry suffers a severe handicap, and youth is denied a ready opportunity to qualify for industry. What is needed is the grafting, under the gentle anæsthetic provided by State funds, of a system of technological education on to the existing system of standard and academic education. True there are some excellent technical colleges in this country, but the number is inadequate and those that are in use are overcrowded and ill-equipped. Britain requires a chain of technical institutions devoted to such subjects as aerodynamics, radio, chemical engineering, plastics, light metals, etc., which could be fed by ancillary technical colleges or such-like institutions. It is part of the debt we owe to youth to provide these facilities, and it is a debt that should be paid in full and promptly.

It has been said that a nation with strong metallurgical industries must always be greatly superior, and therefore, more dangerous, than a nation with strong agricultural industries. This is becoming less true as we now realise that out of such comparatively harmless substances as starch or sugar can be obtained the alcohol to make synthetic rubber, plastics, explosives, drugs and many other vital sinews of war. The peoples will continue to regard with uneasiness all nations which increase their capital equipment out of all proportion to their national requirements. These nations constitute potential aggressors irrespective of their manpower.

In future wars manpower will undoubtedly play a less important part, and nations may well be vanquished without invasion. The men who menace the future of civilisation are not the soldiers, but the specialists in various branches of technology and science. True, we cannot stifle the inventiveness of man, but the people are asking if it is not possible to exercise some control and so harness that inventiveness to construction as opposed to destruction. In the war of to-morrow which we all dread,

an idea is likely to be more important than a division ; a theory more dangerous than an army. The development of the atomic bomb renders the so-called fighting services as useless as the dodo.

What of research in Britain ? Whilst it is a common platitude to say that the highest measure of productive efficiency is only possible if industrial research and development are fostered to the nth degree, the growth of industrial research in this country is not in any way commensurate with industrial expansion on a capital basis. One company alone in the U.S.A. spends more money in a year on research than all the British concerns put together. It is reported that to-day American organizations engaged in the manufacture of synthetic products, particularly plastics, are spending as much as 10-20 per cent of their gross profit on research. According to the 1943 Report of the Federation of British Industries, 566 firms spent £5,442,000 on industrial research and development in 1938 against £2,696,000 expended by 484 firms in 1935. It is estimated that the various research associations spent £850,000 in 1943, and these represent all the most important and wealthiest industries in the country. Research in Great Britain is a direct charge on capital, whereas in the U.S.A. it is financed from revenue. The British method constitutes a financial anomaly that should be removed, particularly during the years when income tax soars to dizzy heights. By levelling up British and American methods of financing research the home Government could do much to stimulate both private and publicly sponsored research.

The above figures are pitifully small in comparison with the £500,000,000 that was spent from 1941 to 1945 on research in connection with the atomic bomb. It will be remembered that in a statement to the press made by Sir John Anderson on August 7th, 1945, this statesman said : "Realise that in four years scientists have solved a problem which in peace-time would have taken 25 to 50 years. Look at the figure of £500,000,000 that has been spent on research in those four years and compare it with the fact that in ordinary times no more than £10,000,000 would be spent on any one line of scientific development."

Without the new products and new methods suggested and developed by research, both pure and applied, real progress cannot be maintained. During the years of fierce international competition, which must inevitably follow the brief period of industrial readjustment, markets will only be won and retained by those nations possessing the most efficient machinery and the most productive research organisations, public and private. One of America's leading market experts, Mr. J. George Frederick, recently told the American Marketing Association that sometime between 1945 and 1950 the American public will be inundated with the greatest deluge of new products that the world has ever known. He has listed 324 complete new products already advertised, 500 more ready to be launched, and 2,000 forthcoming logical developments of new technology, many of which are in the synthetics field.

Modern industrial research is not a leisurely business conducted during conveniently brief hours at some central laboratory, not too well equipped but all very cosy and comfortable. It is, if really successful, a kind of commando venture into the realm of the unknown. Imagination harnessed to scientific competence is essential ; leadership and teamwork. The problems facing any industry to-day are so complex that no one man can be expected to solve them, shock tactics have to be

employed, attacks undertaken by teams of workers planned and co-ordinated with all the ingenuity and completeness of an invasion. An instance of this is the work carried out by British, American, Danish and German scientists on the development of the atomic bomb for the use of the United Nations. This does not imply that quality of effort is less important than quantity, and that no premium is paid for genius. The Michael Faraday of to-day is the scientist who initiates, plans and co-ordinates research, the master mind behind the effort to produce new light alloys or synthetic rubbers.

The State has a great responsibility towards industry, the responsibility of a trustee who should ensure that the resources of the country in terms of materials and man-power are used for the common good, as distinct from the interests of the State. This is not thinly veiled communism, but common sense. It is not suggested for a moment that the State should set up a new trade D.O.R.A., or a vast army of inspectors and officials with all the attendant official forms. There should, however, be a revitalised Board of Trade to decide on major points of policy, such as how far trusts can be allowed to exist, bearing in mind that big combines mean mass production and low prices, and how far cartels or international agreements can be permitted, considering that a free market for all nations would be ruinous to Britain with her heavy overheads. It is, moreover, the duty of the State to ensure that the youth of the country is properly trained and equipped to make the maximum contributions to the social life and prosperity of the country.

The Services could have made a substantial contribution to Britain's industrial prosperity by means of really progressive and workable Pre-vocational Educational Schemes aimed at genuine industrial rehabilitation of the soldier. What an opportunity has been presented to the Services, and what a great pity it is that this opportunity has been allowed to slip by through lack of enthusiasm, lack of proper co-ordination with industry and lack of experienced and fully qualified instructors.

The Service educational authorities do not yet appear to have a clear conception of technical (non-military) education, or a thorough understanding of the mechanism of industry. Unfortunately many of the authorities responsible for implementing Service educational schemes are drawn more to the classics than science, and they know little about industry. Moreover, those officers who organise and administer these schemes are not yet impressed by the urgency of technical education and seem somewhat reluctant to tackle problems in any original or unorthodox manner.

There has been no real driving force behind the Pre-vocational Educational Schemes and one wonders if they are not just mild sedatives prescribed mainly to pacify the Service personnel during their last few restless weeks in uniform.

It is extremely difficult to rehabilitate the sailor, soldier or airman unless an organisation is developed which operates in full collaboration with industry, and here it must, in fairness to the Service authorities, be pointed out that industry has so far shown little genuine interest in rehabilitation schemes. No one can doubt that these various schemes do achieve some useful purpose, but how much more valuable would they have been if there had been full co-operation between the Services and industry.

## CHAPTER I

### RAW MATERIALS

THE NATURAL RESOURCES OF THE WORLD ARE KNOWN BY ALL ECONOMISTS, and they can usually be assessed with a fair degree of accuracy. What cannot easily be assessed is the influence of science on those resources, some of which may appear to be of little practical value. Who would have thought that sea water with its small mineral content could be utilised to produce a large tonnage of magnesium metal, as well as bromine, iodine, etc. In the early days of the Ministry of Economic Warfare many estimates of Germany's ability to carry on with limited natural resources were made, and all of them proved hopelessly inaccurate, mainly because they failed to take fully into account the ability of science to work industrial miracles.

A country rich in coal can be largely self-sufficient in oil, rubber, plastics, synthetic fibres, drugs, dyes, perfumes and many other chemicals, and a country rich in petroleum is even more independent, as crude oil can, by modern refining technique involving cracking, produce not only fuels and lubricating oils, but hundreds of organic chemicals necessary for the manufacture of the products named above. Coal and petroleum are the most versatile raw materials in the world, and it is only now, after decades of waste, that we are beginning to realise that they are far too precious to consume as fuels. In 1938 some 227 million tons of coal were mined in this country, and out of this 144 million tons were burned in the raw state, whilst 46 million tons were exported. In fifteen years' time, so experts claim, the known oil resources of the United States will have become exhausted. This is hardly surprising in view of the fact that out of a total world consumption of 265 million tons in 1939, three-quarters of which was produced on the American Continent, the U.S.A. used 160 million tons, an increase of over 8% over consumption in 1938. (This does not necessarily mean that the United States will be short of oil in fifteen years' time, as new fields will undoubtedly be discovered, and there is always plenty of oil to be recovered from shale rock at a somewhat higher rate of extraction.)

It is worth recording that oilfields in England are now yielding worthwhile quantities of high-grade oils. According to reliable figures (July, 1945) oilfields near Eakring in Nottinghamshire and Kelham hills, Duke's Wood and Caunton have accounted for a production of substantial quantities of oil. The British Oil Control Board reported in September, 1944, that 78,000,000 gallons of British oil were produced since September, 1939. The average depth of these wells is a little more than 2,200 feet.

The home production of petroleum proved of considerable strategic importance during the war. It enabled the R.A.F. to draw upon readily accessible supplies of high octane spirit at a time when U-boats and Junkers were taking a heavy toll of tankers and threatening to ground our heavy bombers through lack of fuel. In peace the presence of even



relatively small amounts of oil in Britain may prove of considerable assistance to the organic chemical industry as it has been shown that the oil refinery more than the carbonisation plant at the coalfield can produce a larger number of potentially valuable intermediates.

The thorough geophysical survey of Britain made prior to the outbreak of war has, besides revealing the presence of worthwhile quantities of oil in the Millstone Grit under cover of Coal Measures, also produced other



Coal derived from the primeval forest forms the raw material for plastics, synthetic rubber, textile fibres, adhesives, drugs and dyes. There are between 2,000 and 3,000 derivatives from coal in addition to gas and coke.

evidence of unsuspected mineral wealth in this country. New rich coal seams have been discovered in the East Midlands and valuable potash salts at Eskdale.

Waste, a practical confession of ignorance, is anathema to science, which for years has been mobilised to husband resources and produce alternative materials and methods of manufacture. Admitted the stimulus has been the need for self-sufficiency at a time of national

emergency, but there is no denying the fact that some miracles of production have been achieved. In Germany, about 43% of the military requirements of petroleum was obtained by the hydrogenation of coal and the Fischer Tropsch process which entails the passing of carbon monoxide (derived from coal or coke) admixed with hydrogen over special metal catalysts at moderately low temperature and pressure. The Fischer Tropsch process supplies not only petrol (low octane number) but valuable waxes and even edible fats. The carbonisation of coal was developed in Germany to supply a greatly expanded chemical industry engaged in the manufacture of many vital materials cut off from the Reich by the British blockade. It was early realised by the leaders of Germany's chemical industry that coal and lignite were assets of the greatest strategic value as raw materials and that use of them in the unprocessed or crude state as fuels had to be subject to rigid control.

Modern British industry is depending more and more on coal, but it is still used with great extravagance. In 1938 only 38·7 million tons of coal were carbonised and 144 million tons burned in the raw state. Whilst the industrial and, incidentally, the domestic demand for coal is increasing yearly, the output is steadily dropping. In 1937 the yield from British mines was 240 million tons and in 1938 only 227 million tons. In spite of increased wages the output per man-shift overall has gone down year by year. In 1941 the figure was 21·62 cwt.; in 1942 this had decreased to 21·28 cwt. and in 1943 to 20·83 cwt., a fall of just under half a hundredweight per shift in one year. In comparison with Continental and American coal mining practices the British output is extremely costly from the labour standpoint. The main weakness in our system would appear to be the excessive labour needed for haulage from the coal face to the shaft bottom. According to the 1945 report of the Technical Advisory Committee on Coal Mining set up by the Minister of Fuel and Power, one haulage worker is required for 5 tons of coal in Britain in comparison with 20-25 tons in Holland and 50 tons in the U.S.A.

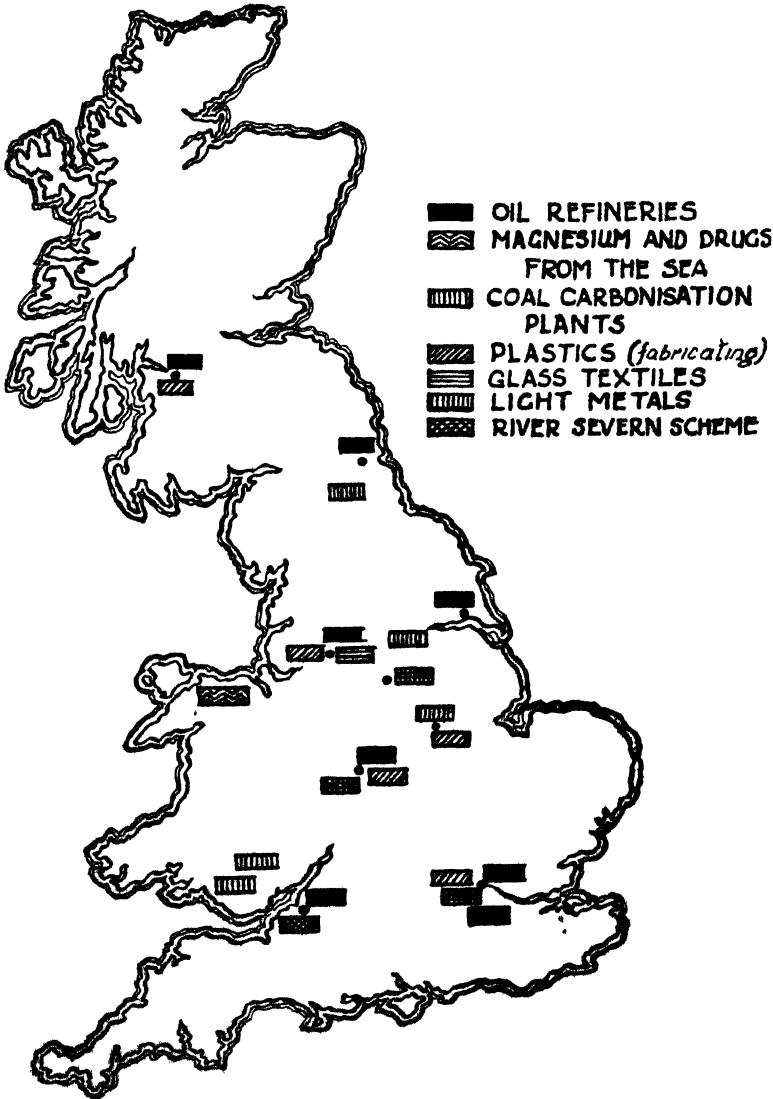
The coal reserves in this country are claimed by scientists to be capable of lasting less than 100 years, indeed, some experts predict exhaustion within 70 years.

In view of the potential value of coal as a national asset the time will come when raw coal will no longer be available for the domestic consumer or even for steam-raising in industry. Certainly it will soon become necessary to restrict the sale of highly volatile coal for fuel purposes and to insist on the more extensive use of smokeless fuels, gas and electricity. Only in this way can we conserve resources and build up new industries based on coal products. Carbonisation of coal as carried out in the modern gas works would appear to yield the richest dividends, as before the war it produced nearly 60% of the total benzol and coal tar production and, moreover, had an overall efficiency of over 79%.

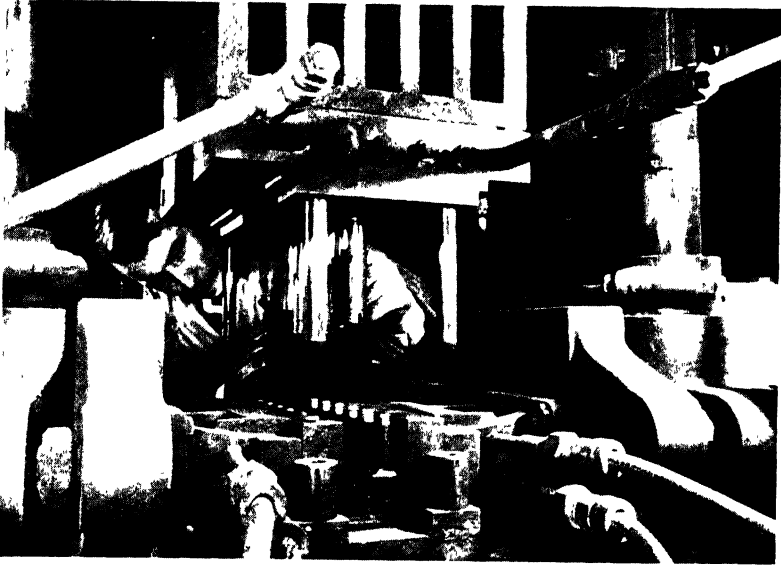
Unremitting research is revealing many ways in which Britain might utilise coal reserves more profitably. It has been suggested that underground gasification might be applied to unprofitable seams and so provide cheap fuel as well as potentially valuable gases for organic synthesis. Experiments carried out on the complete gasification of coal above ground also open up interesting possibilities as large quantities of valuable hydrocarbons can be produced. Incidentally methane obtained by any of the gasification processes might profitably be used for internal combustion

engines instead of petroleum fractions and ethylene and propylene recovered for use in the synthesis of various plastics. Polythene is obtained from ethylene by subjecting it to very high pressure.

It is not always appreciated that both the hydrogenation and the



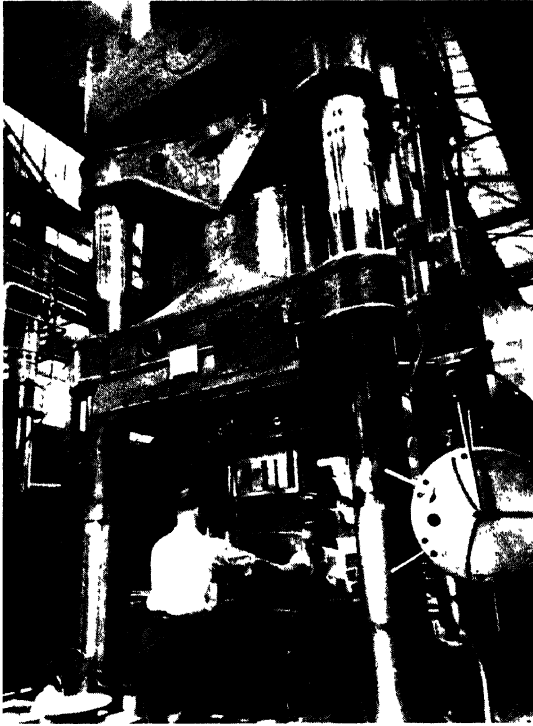
This sketch gives a general idea of some possible new industries for Great Britain and shows approximate locations. The industries are those which can utilise the country's raw materials, and, by the importation of raw petroleum instead of finished spirit the main refineries can feed new and prosperous chemical trades supplying plastics, synthetic rubbers, drugs, solvents, etc.



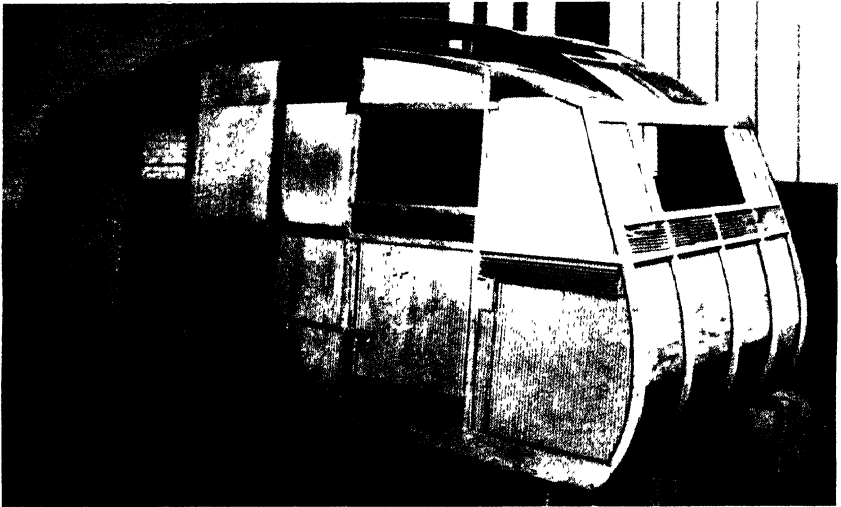
Moulding torch cases at the works of the Streetly Manufacturing Co Ltd ,  
England



World's largest drop-hammer working on light alloy has a falling load of 20 tons  
and produces a crank case in 9 blows Taken from the film "Forgings in  
Hyduminium Aluminum Alloys "



One of the massive hydraulic presses in the Ekco works used for the mass production of moulded radio cabinets



Caravan insulated throughout with Isoflex cellulose acetate light-weight insulating material

Fischer Tropsch processes of producing oil from coal are uneconomical to operate except at a time of national emergency. According to figures given by Harold Moore, M.Sc., F.Inst.P., before the Institute of Petroleum, February 1st, 1944, over 3 tons of coal are consumed by the hydrogenation process to produce 1 ton of liquid hydrocarbons, and the thermal efficiency is only 43%. The Billingham hydrogenation plant works at a loss and has to be heavily subsidised in the form of tax exemption by over 200% on the f.o.b. of the product. By the Fischer Tropsch reaction about  $5\frac{1}{2}$  tons of coal are required for 1 ton of oil, and the thermal efficiency of the process is 40%.

Mr. Moore suggested that to ease our pressing industrial problems connected with the maintenance of high yields of coal from the mines, some of which are uneconomical to work, the following recommendations should be considered :

1. Reduction in the total coal mined so as to conserve resources.
2. Reduction in employment underground with increase in the employment in the carbonising industries.
3. Reduction in atmospheric pollution.
4. Increase in the liquid products, particularly liquid fuels for internal combustion engines and materials for organic synthesis.

As a preliminary to any change in our industrial policy towards coal it will be necessary to make the public realise the real value of coal as a raw material, and the waste that ensues when it is used as a fuel for the domestic hearth or the boiler furnace. Apart from the loss of valuable by-products, out of each ton of coal consumed one hundredweight goes up the chimney in smoke (domestic use), and in industry the waste of fuel due to unconsumed smoke amounts to one stone per ton. Around A.D. 1240 it was a capital offence to burn coal in the city of London, and perhaps in 1994 the old Act may be suitably modified and re-introduced in a last attempt to save these dwindling tons.

It is no exaggeration to say that coal has become an Aladdin's lamp which, when rubbed by the modern chemist, yields a thousand different products, ranging from surgical sutures to motor tyres, drugs to fertilisers and poisonous gases to perfumes. Coal may well be called the Black Diamond, but it is far more useful than any precious stone.

### *Plastics*

The most important raw materials for the manufacture of thermo-setting resins are phenol or carbolic acid, urea, formaldehyde and furfural, together with various filling substances, such as wood flour, previously imported from the Scandinavian countries, cotton, asbestos, etc. Phenol is a by-product of coal tar distillation, and it is interesting to note that to obtain 1 ton of coal tar necessitates the carbonisation of 10-20 tons of coal. This important raw material, phenol, which is required by several branches of the chemical industry, is also manufactured synthetically from coal tar benzene and to a growing extent from petroleum by a process known as aromatisation, which means the conversion of ordinary (so-called paraffin) hydrocarbons into aromatic hydrocarbons, such as benzene. During the war the supply of phenol available to the British plastics industry was greatly reduced, and use had to be made of cresylic

acid. Urea is prepared synthetically from ammonia, derived from the nitrogen of the air, and carbon dioxide. Formaldehyde, which is a gas, although used as a 40% solution in water (formalin), is made from the gases given off by coke ovens and producer gas, and, to a small extent, from wood tar. Furfural is a by-product manufactured from oat hulls and also from sawdust and wood shavings. Incidentally, large amounts of furfural are used in the production of intermediates for synthetic rubber.

The thermo-plastic or heat-softening resins, such as cellulose acetate, cellulose nitrate or celluloid, and the new vinyl products, are made from a variety of raw materials. The cellulose plastics require cellulose in the form of cotton linters (imported from U.S.), or specially processed wood cellulose as a starting point, and the vinyl resins are prepared from acetylene made from coal and lime, natural gas and the products of the petroleum refinery. Methyl methacrylate is another resin which is manufactured from the by-products of the coal industry and also of the petroleum refinery.

Although it has been shown that coal is the key to the plastics industry in Great Britain and Europe, it is by no means as economical to process as petroleum, which is pure hydrocarbon, or natural gas (mostly methane or marsh gas). These products on cracking and heating under pressure produce practically all the intermediate chemicals required by the plastics and synthetic rubber industries. Crude oil can be made to produce more economically than coal many hundreds of valuable chemicals required by the chemical industries. A study of the economics of the subject clearly shows that it is cheaper to import crude oil than finished products, and in the modern refinery the yields of finished products and usable gases are 95% to 97½%. For a processing figure of 5 million tons of crude oil, 4 million tons of liquid and solid products and between 240,000 and 500,000 tons of gases could be produced. From these gases alone, many tens of thousands of tons of synthetic rubber, vinyl resins, polystyrene, methyl methacrylate, benzol for phenols, glyptal resins for paints, formaldehyde, could be manufactured.

The raw materials of the plastics industry are relatively expensive, but the fact that they are readily adaptable to mass production methods of fabrication enables them to compete very favourably with metals, ceramics, glass, etc. If there is to be a 'Plastics Age' it must come via the coal or petroleum industries, or possibly both. These will have to be very generously exploited to provide the chemicals.

### *Synthetic rubber*

Coal and petroleum are the most important sources of intermediate organic chemicals used for the formation of rubber-like bodies. The German Buna was produced mainly from acetylene formed by the action of water on calcium carbide made from coke and lime. American Buna rubbers are prepared mainly from petroleum and natural gas, also acetylene, and alcohol distilled from fermented grain. An interesting sidelight on the economics of the synthetic rubber industry is afforded by the fact that to produce some 90,000 tons of Buna S. rubber a year requires 197,000 U.S. gallons of alcohol a day and the cultivation of 720,000 acres of land. Soviet synthetic rubber is manufactured from

grain alcohol. Neoprene, another most important grade of synthetic rubber, is prepared from acetylene made from coke and lime, and Thiokol, the first industrial type to be made in the U.S.A., uses three simple raw materials, salt, natural gas and sulphur. Other types of synthetic rubber are derived from the by-products of the petroleum industry, thus the well-known Butyl Rubber, usually regarded as the second most important type, is produced from petroleum and natural gas, the starting-off point being the gas isobutylene.

It is interesting to speculate on the position of the synthetic rubber industry when natural rubber gets on its feet again. Whilst it is likely that there will always be a limited market for synthetic rubber for specialised applications involving resistance to oils, solvents, heat and light, it is difficult to predict its future for major uses, such as tyres for the automobile industry. So far even the best synthetic rubber still lacks some of the most desirable physical properties of natural rubber, such as high elasticity, and tyres made solely of G.R.S. rubber have not the life of the old pre-war rubber tyres. The future of synthetic rubber is not, however, bound up so much in its properties, because science can be trusted to improve these, but in hard economics, in other words, how cheaply can it be produced? The American chemical and petroleum industries have invested heavily in plant for the manufacture of synthetic rubber, and a huge tonnage of commercial rubbers is now turned out. When the natural rubber plantations are fully recovered what will be the position of the vast synthetic rubber industry in the United States? Backed by Government subsidies it could, no doubt, compete with the rubber planters, but the cut-throat competition would be disastrous for both sides. In this country very little synthetic rubber is manufactured, this being due primarily to lack of cheap and plentiful raw materials and plant.

#### *New woods*

The most important contribution made to the wise conservancy of timber resources is the use of wood veneers or plies, which, with modern synthetic glues, enable many different kinds of laminates to be built up. New plywoods have one of the highest strength factors of modern building materials, and have a higher specific strength than solid steel. The joints effected by means of synthetic adhesives are not only stronger than the wood itself, but are water resistant and also resistant to fungi and bacteria.

In addition to resin-bonded plywoods, which in production are so amenable to new methods of fabrication involving the use of novel moulding methods, there are also the high-density or high-duty woods consisting of veneers which have been impregnated or coated with fairly large quantities of synthetic resins and pressed together under high pressure. These special woods are to-day used mainly for aeroplane propeller blades, and to a small extent for press tools required by the light metals fabricating trades, and for electrical insulating uses, such as fish-plates required for electrified lines. It is somewhat difficult to say how these high-duty woods will fare now that the war is over, and their manufacturers are carrying out some vigorous sales research to find new markets.

One of the most promising of the new uses of this improved wood is in the textile industry where it is at present being employed for making



shuttles, picking sticks, bobbins and loom frames in place of natural woods, such as boxwood, cornel, persimmon, Spanish oak, etc. The great advantage of the improved wood over the natural type is that it is more resistant to abrasion and shock and therefore lasts much longer.

Another very interesting development in the field of new woods is the sandwich construction consisting of thin plywood skins resin bonded to a low density expanded plastic or rubber core. It resembles, therefore, a meat sandwich, the part of the two slices of bread being taken by the sheets of plywood, and the meat, or centre of the sandwich by the layer of expanded plastic which has a thermal insulating value some 33% better than high-grade cork. Panels of the material known as Jicwood X are made to meet specific requirements and they can be supplied in various thicknesses and sizes. These can be rapidly assembled by the use of normal joinery methods and different types of buildings erected and fitted up with considerable speed.

Whilst it might be thought likely that in view of the devastation and ruthless stripping of some forest areas in Europe during the war, there may well be a shortage of timber, this, according to experts, is not likely to be the case. Before the end of the war the Timber Development Association, Ltd., claimed that there would be no shortage of standing timber; no lack of production; no lack of shipping space and no excessive demand likely. It is likely that Canada with her 781,000,000 acres of forest will be one of Britain's greatest suppliers when trading conditions return fully to normal.

It is considered probable that an effort will be made to popularise the use of resin-bonded plywood for pre-fabricated houses, of which some millions are required. Luxury houses, five rooms, were built at Lake Oswego, an exclusive Portland, Oregon, suburb, in 1938, entirely of resin-impregnated wood at a cost of a little over £700 sterling.

### *High alloy steels*

The raw materials of the steel industry are iron ore, scrap, coal, ferro-silicon, and non-ferrous alloys. Unfortunately, the British ore is low grade and uneconomical to work unless heavily supplemented by large imports of high-grade ore. Before the war the British foundries depended very largely on Norway for rich ore (Narvik) and on Sweden for steel billets. Practically three-quarters of the raw materials of the industry were imported prior to the outbreak of war. This country lacks all the non-ferrous metals, such as nickel, manganese, chrome ore, cobalt, titanium, vanadium, tungsten, etc., but fortunately the Empire is rich in many of these, particularly nickel, manganese and tungsten. Ferro-silicon is available in large quantities in this country, although formerly a large tonnage came from Norway.

Before the war a large number of alloy steels were produced for specialised applications involving a high resistance to chemical corrosion, heat, etc., but considerable rationalisation was carried out to reduce the range and to conserve dwindling stocks of vital alloying metals.

Many important developments have taken place during the war in the manufacture of special steels, but in peace-time a good deal of interest is taken in steels that resist high temperature and pressure and also steels coloured through their cross section. Already one British firm has pro-

duced a special black stainless steel, and there is good reason to believe that coloured steels will be on the market during the next twelve months.

Of interest also is the use of plastic cements for bonding together light gauge metal sheets. Employment of these cements enables manufacturers to dispense with riveting and welding for many light structures.

### *Light metals*

The most important source of aluminium is bauxite, imported from British Guiana and the Gold Coast. This mineral is a form of the hydrated oxide. Another raw material of great importance is cryolite (sodium aluminium fluoride), which is used as a flux or solvent for the alumina (aluminium oxide). Cryolite is found in very large masses in Greenland.

Magnesium is produced from magnesite or magnesium carbonate, dolomite, a magnesium and calcium double carbonate, magnesium chloride prepared from sea water and special brines, and brucite or magnesium hydroxide. There are some deposits of magnesite in this country, but the magnesium industry in Great Britain is relatively small in comparison with that in the U.S.A. and Canada, the latter country boasting the largest magnesium plant in the world.

A most interesting and successful departure from standard ore mining and extraction processes is the production of magnesium from sea water. The plant now in operation at Freeport, Texas, is scheduled to recover 50,000 tons of pure metal from sea water. The water is filtered, mixed with milk of lime and the insoluble magnesium salt collected and treated with hydrochloric acid. The salt formed, namely magnesium chloride, is evaporated and when dry is electrolysed at about 700 deg. C. The metal, which is 99.9% pure magnesium, is skimmed off the surface of the melting crucible and cast in pig form.

During the war the light metal industry put all its eggs into one large basket, namely, the aircraft industry, and now that peace has returned it will be necessary to make a fresh start. The fortunes of the British manufacturers depend to a large extent on the policy to be adopted by Canada, and, also, by the U.S.A. The Canadian light metal industry is in an enviable position as it has abundant natural resources and a newly developed manufacturing capacity, both virgin metal production and fabrication. If the Canadian industry decides to fabricate its metals on a large scale and so compete with the Mother Country in overseas markets then our own prospects are somewhat bleak, as it is not possible to rely entirely on the home requirements. It is highly probable, however, that some arrangements will be made which will ensure a reasonable division of profits between the greatest base metal exporting country in the world, Canada, and the second largest fabricating country in the world, Britain.

### *Cements and ceramics*

The basic constituents of cements are limestone or chalk and clay, and there are abundant supplies of these materials in this country, particularly along the banks of the Thames, where the cement industry flourishes. Asbestos cement, now known the world over as a building material, possessing very valuable characteristics, including lightness in weight, sturdiness in service, ease of assembly and economy, is a combination of asbestos fibres, which act as reinforcements, and Portland cement,

Canada exports something like 75% of the asbestos of the world. Great Britain is well supplied with natural resources for her ceramic industry with the possible exception of the highest quality felspar and talc, and British clays are some of the best in the world. New materials are being utilised for electrical porcelains and high-frequency ceramics. During recent years interest has centred round cordierite, rutile, etc., for the making of condensers, coil formers, etc., and they are claimed to show a great improvement over the steatite productions.

### *Glass*

The most important ingredient of glass, silica, present as sand, is one of the most plentiful raw materials in the world. Nevertheless, it is not always easy to find sources of supply to meet all glass requirements. The sand must possess a low iron content, especially for optical work, and be regular in grain size and shape. Other raw materials used in glass manufacture include alkalies, barytes and various metallic oxides, most of which are in abundant supply in this country.

There is no doubt that the glass industry is in a particularly fortunate position, as the demand for its commodity will be considerable for several years immediately after the war. Glass will be used to a much greater extent than previously for constructional purposes, and for interior fittings we are likely to see tempered-glass doors, bookcases, shelves for kitchen and living-rooms, glass sinks, glass washing-machines and baths.

The modern treatment of certain types of sheet glass prevents glare by means of a thin etched film of molecular dimensions. This film reduces the loss due to reflection by about half. This improvement will, undoubtedly, go a long way towards the greater use of glass in building practice.

Of future interest is the relationships of silicon to carbon and the production of new silicon substituted plastics, that is, organic and inorganic combinations. It is likely that entirely new ranges of glass-like plastics capable of easy fabrication and greatly improved plastics properties will be produced. Silicon is a raw material which is cheap and plentiful, and it offers the greatest scope to research workers looking for entirely new types of plastics. In America several large organizations, such as General Motors, Corning Glass, Libby-Owens-Ford Glass Company, General Electric and Pittsburgh Plate Glass Company are vitally concerned in the development of glass plastics.

### *Synthetic fibres*

The synthetic fibres owe their origin in most cases to the same sources as plastics and synthetic rubber. Nylon, which is somewhat similar in chemical structure to natural silk, can be manufactured from chemicals produced by the coal, petroleum and natural gas industries. Nylon is a polymer, or large molecular body, formed by the association of simple chemical compounds, known as monomers, and in patent literature covering its manufacture an example is given as the combination under strict conditions of the two relatively simple chemicals tetramethylene diamine and adipic acid. This new synthetic fibre, which, incidentally, is synthesised in a number of different forms, is not only used for hosiery and knitted fabrics, but also worked up with acetate

rayon to produce special effects. The finest toothbrushes and bristles used for industrial purposes are made of nylon.

Vinyl resins produced as textile fibres for moth-proof rugs, raincoats, and dress fabrics, are manufactured from hydrogen chloride (gas used for making hydrochloric acid) and acetylene, which are by-products of the coal tar and petroleum industries. Acetate and viscose rayon, although not exactly new synthetic fibres (or indeed truly synthetic as cellulose derived from natural sources is used), have been developed along new lines and will be used to a much greater extent in association with natural and true synthetic fibres. The textile industry will, undoubtedly, work more with mixtures than hitherto owing to the very much wider range of fabrics which can be turned out.

Germany has excelled in the production of new synthetic fibres, particularly in the utilisation of the non-cellulose constituents of wood, such as xylan, lignin, etc. Other fibres are being manufactured from milk casein, e.g., the famous Lanital wool, pea-nuts, e.g., "Ardil," fish waste and seaweed. The last-named appears to have many interesting and potentially valuable possibilities.

#### *Glass textiles*

Glass textiles have captured the public imagination and will certainly find many important uses. In 1931 the Fiberglas Corporation of America produced only one type of product, whereas in 1938 this concern turned out 380 separate Fiberglas products. The two basic forms are, of course, glass wool which is used as an air filter, retainer mat in electric storage batteries and for thermal insulation, and glass textile. This is available in two standard types, continuous and staple fibres, both of which are used in the production of numerous yarns, tapes, fabrics, etc., mainly for electrical insulation and chemical filtration. It has been suggested that apart from direct textile applications, glass fabric may be used for low temperature insulation in the form of an asphalt enclosed rigid bat, also for making new laminated building boards in combination with plastics.

Glass textiles woven from continuous or staple fibres promise to give competition to the organic type for soft furnishings, particularly where fire-proof and moth-proof qualities are required, such as for the theatre, hotel and cinema. Glass fibre has been used with great success as the reinforcing agent in rubber tyres.

#### *New adhesives*

The new synthetic glues are all plastic in origin; most of them are heat-hardening, but a few are thermo-plastic. The range is covered by phenol formaldehyde resins, used as thin deposits on tissue paper (called dry glue film) or as solutions of the resin in alcohol and in water, and urea formaldehyde resin which is also employed as a water solution. Melamine, a comparatively new organic resin and used for allied purposes, is similar to the urea formaldehyde type but possesses improved properties.

In effect, the glues are made up of three main constituents, the resin itself, a chemical accelerator or hardener, and the solvent or thinning medium, which may be water or a spirit, such as alcohol. As mentioned

previously, the phenol required for making the resin is a by-product of coal tar distillation or it may be derived from the petroleum industry, and formaldehyde is obtained from coke oven gases. Urea is a simple and cheap chemical prepared indirectly from the nitrogen of the air. The thermo-plastics, or heat-softening adhesives, of which the vinyl type is the most important, are made either from coal or petroleum by-products.

The use of synthetic adhesives has revolutionised the plywood industry by speeding up production (plastic glues set in a fraction of the time required for hide glues or casein) and enabling wood to be used for applications where moisture and fungi resistance of the glue line is essential.

### *New drugs*

The relationship of modern chemical synthesis to chemotherapy, or the new science devoted to the treatment of disease by means of chemical bodies, is very close. Whenever a new drug is found to be efficacious in the alleviation of pain and the saving of life and limb, one of the first considerations is its synthesis if it is of natural origin, or the development of alternative methods of producing it in commercial quantities if it is a synthetic product. The work of the chemist follows as a natural sequence on the research undertaken by physiologists, bacteriologists and biochemists.

Many of the latest drugs now in regular use in our hospitals and clinics were originally derived from natural products, but the ways of Nature are often obscure and devious, and she releases her secrets with the greatest reluctance. To produce sufficient quantities of natural penicillin to satisfy all medical requirements would severely tax the entire production facilities of the fine drug industry, but no doubt the synthetic equivalent would present comparatively few major difficulties. It is claimed that synthetic penicillin will be on the market in the course of a few years, also, perhaps, an entirely new range of bactericides closely related to notatin, patulin and other drugs now derived from natural fungi.

There is reason to believe that antibacterial substances may also be obtained from green plants. According to one report, inhibitory substances have been found in 70 genera belonging to 30 different families of plants.

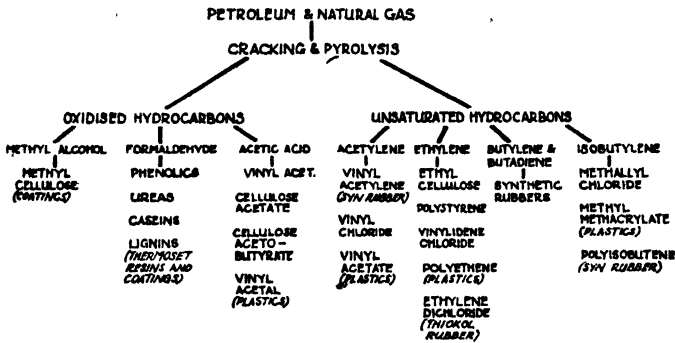
The benefits to be derived by suffering humanity from the use of cheap and plentiful drugs made possible by the application of chemical synthesis to medical research must inevitably be considerable. Thousands of lives have already been saved by the use of the sulphonamides, particularly the famous M. and B. 693 (sulphapyridine) used so successfully for the treatment of pneumococcal infections, and the diamidines for sleeping sickness and wound antiseptics. Of recent interest is the use of the synthetic chemical diethylstilbœstrol for the treatment of cancer of the prostate gland.

British scientists have taken a great part in the development of the new science of chemotherapy, and the home chemical industry has made notable strides in the building up of a healthy fine drug trade. Many instances could be quoted of the success achieved by Britain in making good urgent deficiencies of vital drugs, but one will be sufficient. When

the Japanese invaded the Dutch East Indies supplies of quinine were cut off, which meant British troops in the East were exposed to ravages of malaria, which history has proved to be a far more deadly enemy than armies. To make good this gap in our medicine chest the I.C.I. produced the now famous mepacrine, which is claimed to be superior to the German synthetic substitute 'Atebrin,' for natural quinine. In 1944 over one thousand million tablets of mepacrine were turned out to fight malaria.

### Conclusion

The two raw materials mentioned so frequently throughout this chapter are coal and petroleum. Upon these depend the chemical and allied industries which produce plastics, synthetic rubber, synthetic



Possible intermediate chemicals and plastics produced from petroleum suggested by W. G. Goggin, Dow Chemical Co., U.S.A.

fibres, adhesives, drugs, dyes, etc. Coal is reasonably cheap and plentiful, but processing costs are heavy, whereas petroleum and natural gas, being pure hydrocarbons, are more readily converted into organic chemicals. It is claimed that the yields of finished products and usable gases from crude petroleum and natural gas are from 95–97½%. Over 300 well-known chemicals are being produced from petroleum, and in 1943 the petroleum industry undertook to produce the ingredients, butadiene and styrene, for nearly 600,000 tons of the 700,000 tons of synthetic rubber required by the United States. The gases formerly considered to be waste products of the refinery are now essential for the production of high-grade aviation fuel and some hundreds of chemicals.

The United States chemical industry stands in a most enviable position, as it is supported on two firm legs, coal and petroleum, and with the latter is included natural gas. Faced with dwindling resources of petroleum the United States will probably import crudes from South America and the Near East, but no matter the source, the refineries already in existence are now closely geared to the chemical industry, and petroleum is rightly regarded as a raw material capable of being exploited to the greatest advantage to produce synthetic resins, solvents, fine drugs, dyes, etc., as well as fuel and lubricants.

For some strange reason Great Britain has steadfastly refused to build up a refinery industry capable of feeding her chemical trades and has

been content to import finished products rather than crude oil. There is an urgent necessity to review the whole position, as refineries set up at our large ports and able to handle roughly ten million tons a year would render us increasingly independent of foreign imports and provide employment for many thousands of workers in connected industries.

In addition to cheap and plentiful raw materials, a nation needs ideas, ideas born of research and developed to practical commercial propositions in the laboratories and pilot plants of industry. It is claimed that some twelve hundred scientists were employed in the German dye industry before World War No. 1. Only 5% of the researches undertaken were productive, and yet the various dye firms were able to pay dividends of more than 20% on their capital investment.

Great Britain spends money niggardly, almost suspiciously, on research, as if doubtful of it ever paying a dividend. The British Coal Utilisation Research Association is to spend £200,000 a year for the next five years on research. This sum seems rather paltry in view of the magnitude of its task! The total number of subscribers to grant-aided research associations was, in 1941, over 7,100, but the expenditure of twenty-one of the grant-aided associations on research was just short of £450,000 in 1938, and in 1941 was £477,000. According to figures given by the Federation of British Industries Industrial Research Committee, the total provision for 1943 is estimated at £850,000, and a recommendation is being made that this should be increased to one million pounds!

The United States spent 220,000,000 dollars on production research in 1940, an increase of 120,000,000 dollars over the figure spent in 1937. Out of this total, ten firms (four chemical firms) spent 10% of their gross income on finding new products, new methods of manufacture and new applications. The F.B.I. report states that in Great Britain in 1935 some 484 firms were spending £2,696,000, while in 1938, 566 firms were spending £5,442,000.

In relation to the expenditure on research it is now being strongly advocated that all expenditure on research and development should be chargeable against revenue either immediately or over the commercial life of any asset created. The present policy of the British Inland Revenue is that whilst some items of expenditure are chargeable against revenue, development work and plant construction for experimental purposes are disallowed. In America, research and development are charged directly against revenue, not against profits, as here, and the advantage to America is obvious.

It should be remembered that a considerable leeway has to be made up before we can meet American competition in the overseas markets. During the war British export trade declined drastically and in 1943 the figure was only 49% that of the 1936-38 figures. In comparison with this American commercial exports totalled in 1943 some 88% of the 1936-38 figures.

Lend-Lease has undoubtedly contributed most generously to our victory, but we shall have to pay very dearly for our indebtedness. It should be remembered that apart from sacrificing all our foreign securities (655 millions in 1944), Britain has also sacrificed her goodwill. Through the medium of Lend-Lease goods, America has been able to make her products known throughout the world. The potential market built up

by American manufacturers of foodstuffs, plastics, synthetic rubber, engineering equipment, etc., is likely to prove of immense value to Uncle Sam when the fight is really on for overseas markets.

It is becoming increasingly apparent that Great Britain will have to depend for its commercial security to a greater extent than ever before on the Empire. There are Empire markets for most British-manufactured goods and the pity is that prior to the outbreak of war these were seized by American interests without much of a fight from British manufacturers. The home Board of Trade seemed to regard with equanimity the loss of these most valuable export markets, and little effort appeared to be taken to reduce the heavy tariffs on British goods imposed by some of the Dominions.

Before the war Australia imported only 41% machinery from the U.K. against 59% from the remainder of the world (largest percentage coming from the U.S.A.). The figures for rayon goods (piece) were 21% from U.K. and the remainder from other countries.

New Zealand imported some 40% machinery, 50% drugs and chemicals, 40% rayon (piece goods) and 21½% printing paper from the U.K.

One need not be a follower of Lord Beaverbrook's Empire Free Trade Crusade to realise that the British Empire does itself offer to the U.K. immense potentialities for prosperity—a common prosperity.

## CHAPTER II

### THE NEW TRANSMUTATION

IF WAR IS AN OPEN CONFESSION OF MAN'S SOCIOLOGICAL FAILURES IT IS also a revelation of his greatest scientific triumphs. It is the one period in human history when the scientist is given every possible encouragement and practical assistance provided he is willing to gear science to the wheels of war. Witness the astronomical sum of £500,000,000 spent by Britain and America on the development of the atomic bomb—the most frightful weapon of war ever conceived.

During the uneasy years preceding any great war when nationalistic drives for self-sufficiency are made, and, of course, during the actual conflict, the impetus given to applied science is such that nothing is stinted the scientist; men, apparatus, material and honours for results, all are made readily available by an anxious Government. In consequence progress made in pure and applied science during a war lasting but a few years is so appreciable that it takes civilisation a decade or more to absorb it, sufficient time to plan another holocaust.

War presents the only real opportunity for large-scale experiment. In medicine there are mass tests of chemotherapeutic drugs; in dietetics entire nations are the guinea-pigs, and in metallurgy thousands of tanks and aeroplanes provide data on the behaviour of new alloys. Secrets denied peace-time workers because of the lack of equipment, facilities and funds are discovered in months, instead of years, through the munificence of service departments.

It is a tragic anomaly that the materials which scientists labour so hard to produce are destined to be wasted with almost maniacal extra-



gance. Fortunately, however, their efforts are not entirely wasted, as knowledge is accumulated during the war years which forms a rich legacy for future generations. The cynic might well say that war is the price modern civilisation is willing to pay for scientific progress.

It may even be that research devoted to the development of the atomic bomb will one day be made to contribute to the peace and happiness of the world.

#### *Miracles of production*

Many instances could be quoted from history where a national emergency has created the necessary stimulus for the Government to organise through applied science the rapid development of new materials and new processes. The embargo of 1806 and the war of 1812 gave the necessary stimulus to American scientists and technologists to develop home industries and so become independent of future imports of manufactured goods. In consequence, during the years 1806-1814, America changed from a purely agricultural and raw material producing country into an industrial nation. Such was the feeling of urgency born of necessity and independence that the United States was soon exporting manufactured goods instead of importing foreign materials. To bring this right up to date, since the entry of America into the second World War the progress made in the development of home industries has been astronomical; increased output of petroleum by 66%, bituminous coal by 40%, chemicals by 30%, iron ore by 40%, hydro-electric power by 79%, and steel by 106%.

Prior to the outbreak of the European War of 1914, Great Britain had practically no dye industry and was wholly dependent on imports of coal tar dyes from Germany, which then produced some 80% of the world's total tonnage. (This in spite of the fact that an Englishman, William Henry Perkins, was the real founder of the synthetic dye industry. In 1856 he made the first synthetic aniline dye.)

The war, which cut off all supplies of German dyes and drugs from Great Britain, forced the Government to mobilise scientists to create a fine chemical industry, but this took several difficult years to organise and build. During the early years of that war the fighting services suffered from a paucity of drugs, many of which were German monopolies. Arsphenamine (salvarsan), discovered by Ehrlich and recognised as essential for the treatment of syphilis, provided a knotty problem for both British and American chemists owing to the great toxicity of the early synthetic products. It was found that many of the German patents were entirely unworkable, frequently because the patent did not fully describe the process.

The lethargy and indifference of the pre-1914 Government towards industrial research and their failure to realise the menace of the cartel system so cunningly exploited by the German I.G. (Interessen Gemeinschaft Farbenindustrie) cost this country some hundreds of thousands of lives and resulted in a considerable prolongation of the misery of war. Yet born of national incompetence with all the agony of a difficult delivery during the dark days of war, a home chemical industry took shape which years later was to prove the salvation of the country.

The most outstanding examples of the miracles which scientists can perform when the stimulus is powerful enough are afforded by Nazi Germany. By regimentation of science and industry the Nazi regime

built up an industrial system in complete harmony with her war machine. This industrial system was devised and organised to convert the national raw materials: coal, lignite, wood, magnesium chloride, bauxite and iron ore into the munitions of war; oil, rubber, explosives, non-ferrous alloys and steels for aeroplanes and tanks. At the dictates of the German High Command, industrialists waged their own war for technological supremacy and the sums expended for research far exceeded the total figures for Great Britain and America.

Whilst Great Britain had profited from her bitter experience in 1914, the outbreak of the 1939 World War saw her chemical and metallurgical industries in phase A of industrial mobilisation instead of phase B. The immediate weakness was twofold. First, dependency on imports of raw materials; bauxite from France, rubber and tin from the Malay Peninsula (out of the total annual world supply of rubber amounting to 1,400,000 tons, 1,100,000 tons was of British Malaya or Dutch East Indies origin); oil from America and the Middle and Far East, etc. Second, lack of a shadow synthetic industry ready to supply the deficiencies made by the exigencies of war within a few months. To compensate matters there was a most valuable collaboration between British, American and Canadian scientists and industrialists and this proved of the greatest practical value to the Allies.

After Pearl Harbour, when the United Nations faced an immediate shortage of rubber, veritable miracles were effected in the development of synthetic rubber from coal, petroleum, corn, molasses, etc. It is no exaggeration to say that everything depended upon the speed with which the rapidly dwindling reserves of raw rubber could be made good. In 1942 the Baruch Committee reported the imminence of 'a civilian and military collapse' unless the synthetic rubber problem was promptly solved. Thanks to the enterprise and skill of American chemical engineers the problem was solved in time, and before the end of the war U.S.A. produced more than 870,000 long tons of factory-made rubber (755,000 long tons of Buna S., 75,000 tons of Butyl and 40,000 tons of Neoprene).

Canada with its vast resources of minerals was industrialised to a relatively high degree with remarkable skill and efficiency in the early days of 1939 World War, and a new chemical industry developed to supplement the already overtaxed British plants. The dollar value of the output of the chemical industry jumped from 2 million during the period 1939-40 to 121 million in 1942. Synthetic rubber was produced in large quantities, the largest magnesium plant in the world operated at full pressure, and many new electro-chemical and electro-metallurgical factories built. Canadian nylon was exported, as well as the American material, to meet Britain's need for an efficient silk substitute. (Japan supplied 80% of the world supply of raw silk, some 120,000,000 lb. per annum, the balance by occupied China and Italy.) It should also be borne in mind that there are immensely valuable deposits of uranium ores in Canada and this radio-active mineral is at present essential for the explosion of the atom.

In the field of medicine, the Allied scientists, and particularly British workers, made great progress. Penicillin and the sulphonamides, especially sulphathiazole and sulphathiazole, promamidine and the amino acridine compounds, these owed their rapid development and clinical acceptance to the genius of British workers operating under the stimulus of war.

It is not always realised that it was the shortage of pyrethrum flowers (*Chrysanthemum cinerariifolium*) during the war which compelled the U.S.A. and Britain to speed up research directed towards the production of new and powerful synthetic insecticides. Pyrethrum, formerly exported in large quantities from Japan, has for a number of years been justly famed as an insecticide with very rapid knock-out properties, it is, in fact, much more deadly to the common fly than D.D.T.

### *The Trend of Modern Industrial Progress*

It is now fully realised that the industrial future of a nation depends on research, pure and applied. Only those nations willing to invest heavily in science can possibly draw the dividends in terms of trade, particularly export trade, and security.

The trend of modern industrial progress is towards the more efficient utilisation of natural resources and waste products of industry. It is often claimed that the recipe for national prosperity is cheap power, abundant raw materials and a plentiful supply of skilled labour. There is, however, one major ingredient left out, namely, the inspiration of science, which alone makes possible the economical transmutation of resources into commodities. The profitable disposal of these commodities really depends upon the co-ordination of a number of factors, and, in the future, this might well be ensured by some kind of State Economic Advisory Council. Such a body could prove of the greatest assistance by ensuring that industry operated at the greatest efficiency with no wasteful overlapping, and that market research (home and export) was made available by means of a first-class trade investigation service. It is obvious that the old power-raising methods using raw coal, fuel oils and natural gas, stand in urgent need of revision, as these are the very raw materials required to produce the new synthetic products feeding commodity-producing factories. At present the synthetic industries could not absorb anything like the tonnage of coal produced in a year, but the question might well be asked, do we need to draw so heavily on our national capital of coal? Extension of our electrification and gas-supplying systems with their great benefits to industry are means to hand of reducing coal consumption in the domestic hearths and in factories for raising steam.

There are enormous resources of water-power still untapped, and one authority, W. T. Halcrow, *J. Inst. Metals*, 1942, 68, 145, has estimated that in the British Empire alone some 107,000,000 h.p. is available, of which, so far, only 6% has been developed. In Great Britain water-power has been badly neglected, although there is sufficient to supply our electro-chemical and electro-metallurgical industries and to enable such materials as calcium carbide to be made in large quantities. This vital chemical is the key to synthetic rubber and plastics production. Incidentally a mixture of 78% ammonia and 22% acetylene forms a very satisfactory alternative to petrol. Atomic energy promises to supersede all other sources of energy, and although official opinion is very reserved concerning the probable date when it may be harnessed for explosive power in industry, there is good reason to believe that this may not be long delayed, probably within 10 years. Solar energy offers great promise as a cheap source of electricity, and it is considered not unlikely that the sun's energy will be exploited in the tropics during the next decade. There is also

the harnessing of the tides to consider, and maybe the Severn River Scheme will emerge from its blue-print stage into a practical proposition.

Although abundant indigenous raw materials are denied Great Britain with the exception of coal, low-grade iron ore and lime, there are very large resources in her Dominions and Colonies. Provided this country retains a strong mercantile marine and is able to import cheaply the basic raw materials from the Empire, then there need be little fear of industrial starvation. (In 1939 Great Britain had about 18,000,000 tons gross of shipping, which was considerably less than in 1914.) On the other hand, it must not be forgotten that the 1939 World War has converted some of the Dominions, particularly Canada, into a manufacturing country instead of a raw material producing Dominion. The manufacturing potentialities of that country are immeasurably greater than of Great Britain, and the migration of a large proportion of our skilled workers to Canada is clearly indicated.

The supply of skilled labour calls for greatly improved technical training facilities through the medium of technological colleges and universities. In Great Britain the technical side of our educational system has been badly neglected and lags far behind those of America and Germany. If this island is to become the training school for its Empire, then there is urgent need of a great improvement in technical education.

#### *Modern synthesis*

The new transmutation is primarily a process of synthesis and semi-synthesis made possible by the great advances in chemistry and chemical engineering. The basic raw materials, such as coal, lignite, petroleum, natural gas, sea water, air, etc., and the very large family of chemurgic materials, particularly wood, corn, soya bean, fibrous matters are converted by chemical means into the materials of the processing industries.

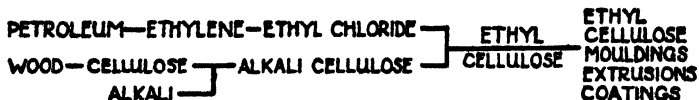
Coal is the first example. By a combination of low temperature carbonisation and Fischer-Tropsch synthesis liquid fuels and by-products for the heavy and fine chemical industry can be produced at an economical figure. Phenol and cresol for the plastics, dyestuff and pharmaceutical industries are essentially products of coke ovens. (Synthetic phenol from benzene formed during one or other of these processes.) Calcium carbide made in the electric furnace from coke and lime gives acetylene so necessary for synthetic rubber and the thermo-plastics, including the synthetic fibres. These are all coal utilisation processes and they offer their best chances of large-scale development at the coal centres, such as South Wales, Nottingham, etc., where freight charges do not eat into profits and where cheap power could be made from surplus coal to serve ancillary industries and heavily populated dormitory areas.

Petroleum, oil shale and natural gas are essentially raw materials of the chemical industry, and the various producing firms spend very large amounts each year in finding new uses for the hundreds of different organic materials produced. High octane spirit for aviation, motor fuel, diesel fuel, synthetic rubber, plastics, pharmaceuticals, synthetic fibres, fertilisers, paints, dyes, solvents, etc.; these are some of the main products to be made from crude oil and natural gas. The latter consists largely of methane or marsh gas (the gas responsible for explosions in mines) with small quantities of ethane, propane and even higher hydrocarbons. So-called wet gas is rich in pentanes, hexanes, and heptanes which are so

necessary for the enrichment of petroleum fuels to produce high-grade aviation spirit. These various types of natural gas contain the basic raw materials for synthetic rubber, plastics and a wide range of organic chemicals, besides, of course, carbon black for pigments and rubber compounding. (All natural gas is first treated to recover any free petroleum.)

Sea water, which contains  $3\frac{1}{2}\%$  mineral matter, is now a recognised source of metallic magnesium, and the Dow plant at Freeport, Texas, is designed to yield 50,000 tons of 99.9% metal a year. Bromine, which is used for making ethylene dibromide to be used with lead tetra-ethyl

#### ETHYL CELLULOSE 1935



#### METHYL METHACRYLATE 1936



#### POLYSTYRENE 1937



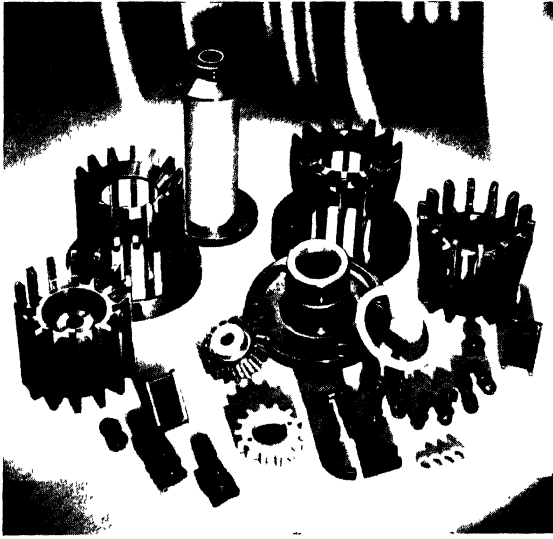
#### POLYVINYLIDENE CHLORIDE 1939



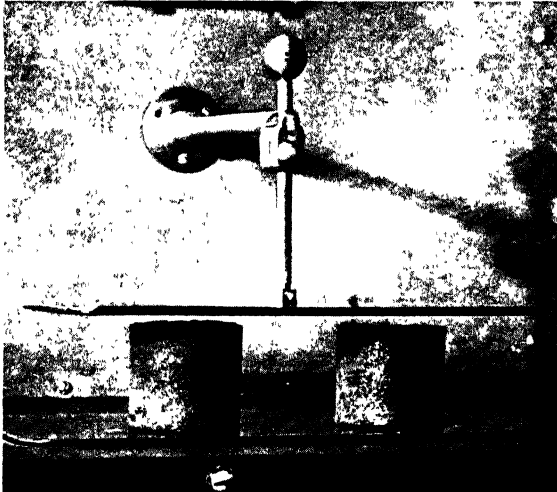
Some of the latest plastics associated with petroleum, suggested by W. G. Goggin, Dow Chemical Co., U.S.A.

for anti-knock compounds, iodine and many other salts, as well as small quantities of gold, are also recovered from ocean waters. It is to be hoped that a sea-water industry will be developed on a large scale in this country so as to render Great Britain independent of foreign imports of magnesium and thus to facilitate the rapid expansion of our home light metal industry. The fabricating industry, of which the automobile and aeronautical industries form an integral part, depends on the availability of large quantities of aluminium and magnesium. Other types of sea water, particularly the waters of the Dead Sea which contain 25% mineral matter, offer enormous possibilities for development. The Dead Sea, length about 50 miles, average breadth 9 miles and maximum depth 1300 feet, could supply the entire world with potash and other chemicals for 2000 years. Experts claim that it contains 1,000,000,000 tons of potash, over 800,000,000 tons of bromine and other salts.

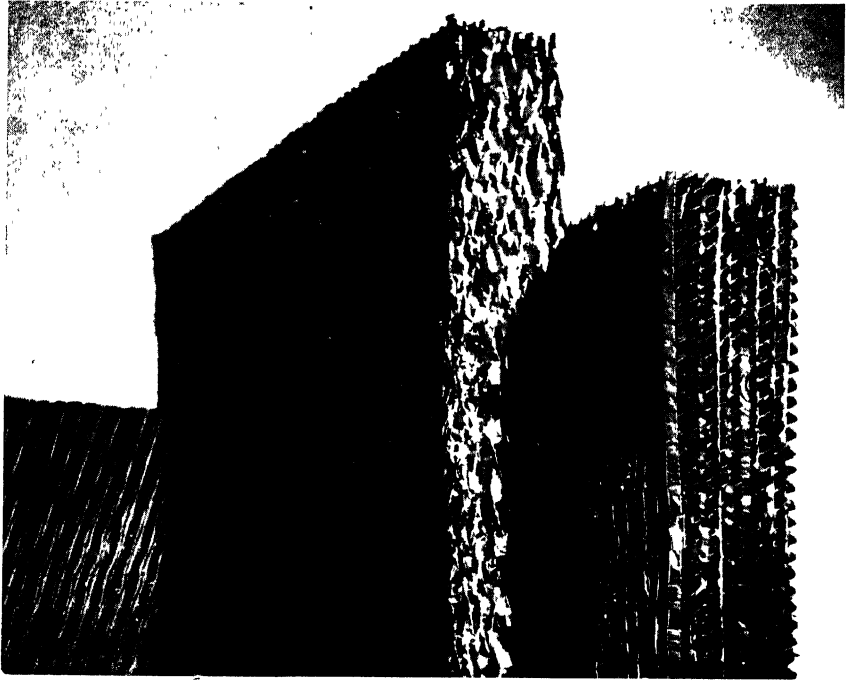
It has been suggested that by the use of atomic energy the icefields around the North and South Pole could be broken up and the seas made safe for shipping. In this way the enormous mineral wealth of the Polar regions could be tapped and made available to industry. It is claimed that there are enormous deposits of iron ore, nickel, manganese, copper, etc., in those ice-bound lands.



These moulded parts form the new thread-advancing reel developed for the continuous spinning and processing of viscose rayon yarn by the Rayon Machinery Corp



Preforms of phenol formaldehyde moulding powder being pre-heated by means of radio-frequency heating



This layered type of cellulose acetate sheet insulating material, known as Isoflex, has a thermal conductivity of 0.32 B Th U and a density of 0.75 lb per cubic foot. It is suggested for the insulation of the Portal type of steel house.



Polystyrene ("Distrene") moulded and turned goods, are both strong and highly transparent. Owing to the excellent dielectric properties of this plastic it is particularly suitable for important electrical applications.

*Chemurgy*

The comparatively new science of chemurgy or the use of agricultural products, particularly farm surpluses, as raw materials of the chemical industry, has a great future. Intensive research has been carried out in Great Britain and America to find new uses for soya beans, flax (linseed), sunflower, rape seed, fibre flax, hemp flax, bagasse (stalks of sugar-cane), coffee, milkweed floss and other rubber-producing plants, molasses, cereals, artichokes, wood, etc. Of the greatest interest is the use of corn to produce such important organic chemicals as ethyl alcohol and butylene glycol, both of which can be used for making butadiene for synthetic rubber. New processes employing wheat flour as a starting-off point in fermentation ensure a yield of 2.8 wine gallons of alcohol per 56 lb. of granular wheat flour, which compares favourably with 2.6 wine gallons from whole corn and 2.4 from whole wheat. By selective fermentation of grain, molasses, etc., with various ferments it is possible to produce badly needed organic chemicals. Thus by employing the *Aerobacillus* type of fermentation 2,3 butylene glycol can be formed in addition to alcohol and later separated by fractional distillation. Butylene glycol is in great demand for making new plastics, solvents, various types of coatings, drugs, etc.

Wood is a material which has been widely exploited by German chemists, who have produced such diverse materials as fibres, fats, food-stuffs, drugs, rubber and plastics from sawdust. One of the most sensational and important processes is the production of alcohol from sawdust by the Scholler-Tornesch method. This consists of treating the wood waste under pressure with solutions of either sulphuric or hydrochloric acid and so converting the cellulose into fermentable sugars. The latter are then purified and fermented. The alcohol is removed by distillation and purified by fractional distillation. Alcohol is also being made from sulphite paper waste, which is available in very large quantities and finds little real use in modern industry.

Chemurgy offers some promise to the world as a means of reducing surpluses and affording farmers an outlet, other than the bonfire, for produce not required for food purposes. It also provides the means of converting purely agricultural countries into manufacturing communities.

## CHAPTER III

## WHAT ARE PLASTICS

PLASTICS HAVE MADE AVAILABLE TO INDUSTRY A WIDE RANGE OF NEW materials; materials able to satisfy some of the most exacting requirements of the electrical, engineering and chemical trades. When mobilised for war, plastics made immediate and vital contributions to the speed and efficiency of aircraft production, the building and fitting up of ships and the vast armament programme generally. They helped to replace non-ferrous metals in short supply and satisfied many industrial requirements formerly using large quantities of natural rubber. In times of peace plastics will be found even more important than in war-time, particularly in the electrical, building and engineering industries, and the experience gained during the period of emergency, enriched as it is by



intensive research and experiment, must pay handsome dividends in the form of new materials, new properties and new markets.

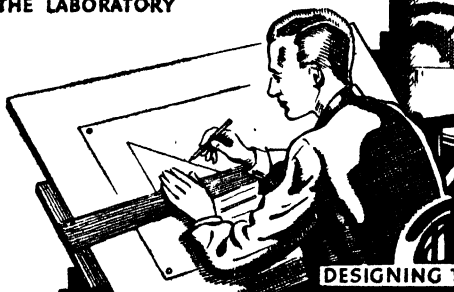
In 1939 Great Britain was third in the world production for plastics with a total of 30,000 tons. America was first with 125,000 tons and Germany second with an estimated 75,000 tons. There is good reason to



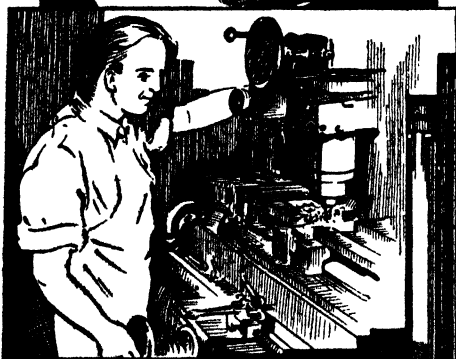
IN THE LABORATORY



MAKING THE PLASTIC



DESIGNING THE MOULD



TOOLING THE MOULD



ACTUAL MOULDING

The moulded or fabricated plastic article is born in the laboratory where the plastic is first produced and thoroughly tested, later it is manufactured in a pilot plant, and, if finally approved, produced on a commercial scale.

believe that all these figures were greatly exceeded during the war, and it has been disclosed that in 1944 America produced about 400,000 tons of miscellaneous plastics.

The materials produced to-day by the plastics industry are, in many cases, 'tailor made' for specific industrial needs. There are, for instance, plastics possessing very high resistance to shock or impact; plastics with high tensile and compressive strength for mechanical purposes; plastics with high dielectric strength to solve electrical insulation problems; plastics of great beauty and even more transparent than glass. The fact that plastics can be made to measure, within certain limits of strength, is one of their most important assets and the engineer of the future is likely to be the first to appreciate this.

#### *Definitions and explanations*

A simple and yet comprehensive definition of a plastic is not easy to find. The dictionary definition, 'something capable of being moulded and modelled,' is far too vague to be useful, as it naturally includes rubber, clay, glass and metals, none of which are true plastics as we understand them to-day.

The popular view of plastics is that they are the products of chemical synthesis. Here again this is only partially correct, as a number of plastics are not true synthetic compounds. Celluloid, for instance, which was the earliest commercial plastic, is prepared by treating the cellulose from cotton linters with nitric and sulphuric acids. Whilst the latter chemicals are certainly synthetic, the cellulose is a natural compound of a most complex nature and has so far not been produced synthetically.

It would be wrong to say that all plastics are organic compounds, that is, chemical compounds in which carbon is an integral part, as some of the latest plastics are derived from silicon, the element widely present in nature as an oxide (sand). The new plastic known as Mycalex is an example of an inorganic plastic. It is manufactured from ground mica and lead borate and is finding many important applications in Britain, where high arc resistance and high dielectric strength are required.

When considered on all grounds, the term 'plastics' is a most unfortunate one. It creates a good deal of confusion and not a little irritation when attempts are made to distinguish between plastics and non-plastics. Probably the easiest way out is to regard plastics as materials made from synthetic or semi-synthetic substances which can easily be moulded or formed to shape.

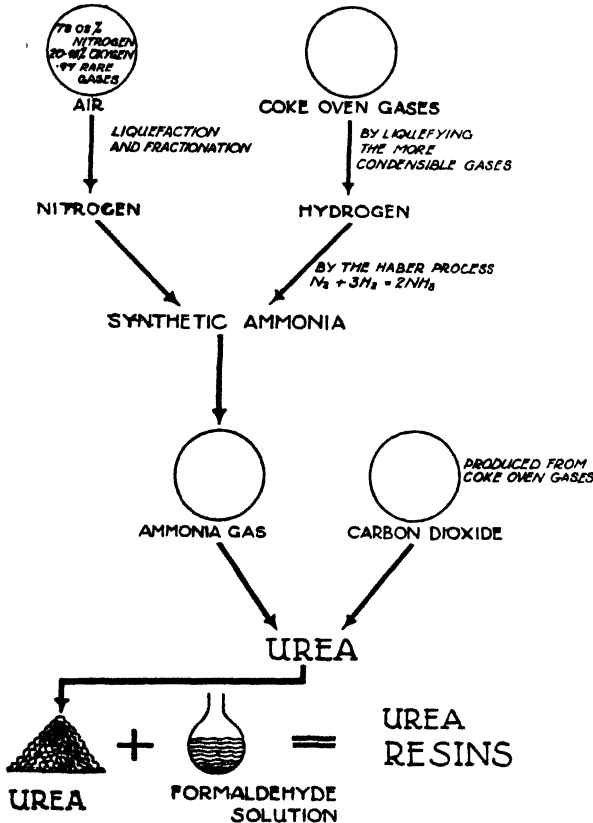
#### *The main types of plastics*

There are two main types of plastics, thermo-setting and thermo-plastic resins. The first-named include all those materials capable of momentarily softening or fusing under the action of heat and pressure and subsequently hardening to form an infusible and extremely hard product that is resistant to heat, water and many chemicals. The thermo-plastics, of which celluloid is probably the best example, can be softened by heating and moulded or extruded to shape, and, if required, re-softened by heat and re-moulded. This procedure may be repeated indefinitely without changing the properties of the material. When Bakelite moulding powder is subjected to heat and pressure a chemical and irreversible change takes place, but when celluloid is softened and shaped the change is a physical and reversible one.

Apart from the above general classification, it is also possible to consider plastics under various headings, such as : materials suitable for fabrication, materials used in paint and varnish manufacture and materials employed as adhesives or glues. In this particular chapter only those plastics capable of being shaped by one of the standard methods of fabrication will be described. Another useful classification of plastics is based on their chemical origin, and synthetic resins, cellulose plastics derived basically from natural cellulose and protein plastics are the best-known types.

*Thermo-setting resins*

These are the best known, although by no means the most numerous plastics, and include phenol formaldehyde resins, of which Bakelite is the



classic example, urea formaldehyde resins, melamine and phenol furfuraldehyde. All these complex chemical compounds are polymers, or substances formed by the association or combination of simpler molecules known as monomers. A monomer is a single molecule substance which on multiplication to form a chain or group is converted into a polymer. The actual building up of polymers through the linking together of simple molecules or monomers is called polymerisation. Where this process takes place with loss of water, then it is referred to by chemists

Urea resins are important plastics and as the raw materials required for their manufacture are plentiful and cheap there is a great future for these plastics which find applications in the production of white and coloured mouldings (odourless and tasteless), adhesives and lacquers.

as condensation. The manufacture of plastics usually depends either on polymerisation or condensation.

*Bakelite*

The plastics industry is inseparably associated with the name of Bakelite, which was the first commercial resin to be produced from phenol (carbolic acid) and formaldehyde. In October, 1907, Dr. Leo Hendrik Baekeland filed in the United States his master patent covering the production of a synthetic resin, later known as Bakelite, from the reaction of phenol and formaldehyde. This American chemist of Belgian origin, who had already achieved fame by inventing the Velox photographic printing paper, found in his search for a cheap substitute for natural shellac that when formaldehyde and phenol were heated together under certain conditions of heat and pressure, and in the presence of small amounts of acids or alkalis, resinous materials could be produced. These resins were soluble in alcohol and fusible, but when once heated beyond a certain 'cure' temperature, they became cured or converted into a hard, infusible and insoluble substance, in other words the Bakelite of commerce.

*Production of the Bakelite type of moulding powder*

In a little more detail, the production of the Bakelite or phenol formaldehyde type of resin, is carried out in large, steam-heated steel kettles. The correct quantities of phenol and formaldehyde are pumped into the kettle and a small quantity of acid added to promote the desired chemical change. (This acid is known as a catalyst or substance capable of promoting a chemical action without itself taking part. Small quantities of alkali may also be used in place of acid to promote resinification.)

During the combination of the two chemicals a good deal of heat is evolved and the kettle has to be cooled. The process of resin-making, which is a form of condensation, necessitates the removal of water as it is formed in the kettle. This is done by means of powerful vacuum pumps.

The whole process of production is meticulously controlled as regards temperature, pressure, time and quantities of materials so as to produce a standard product, but even so, different batches of resin differ in their physical properties. The manufacturer overcomes this problem to a great extent by mixing several batches together.

The liquid resin, a clear amber in colour, is run out of the kettle into cooling pans, where it hardens into large crystalline lumps. This material, which is often known as resinoid, forms the starting-off point for varnish making, the manufacture of laminated sheets, and, most important of all, the production of moulding powders. These are made by crushing and grinding the lumps of resinoid and mixing the fine powder with various chemicals able to improve its moulding properties. The powdered resin mixture is finally mixed with dyes or other colouring matters and various fillers. The latter may consist of wood flour, which is a refined and uniform mesh form of sawdust; asbestos; mica or various cotton and chopped-up fabric mixtures. The function of the filler is most important. It is not just a means of cheapening the moulding powder, but it greatly improves the strength and usefulness of the finished moulding. An article moulded of the powdered resin without filler would be very brittle and so weak as to be quite unsuitable for commercial use. The addition of wood flour, which is termed a 'General



### *Cast phenolic resin*

The production of cast phenolic resins, of which Catalin is the best known proprietary form, is similar to the manufacture of phenolic resin for moulding powder. The main differences are that in the former case a little water is allowed to remain in the resin, and instead of using an acid catalyst, caustic soda is employed and later neutralised with lactic acid. Various dyes and pigments are added to the resin whilst it is still in the kettle.

The liquid resin from the kettle is poured into lead or glass moulds and allowed to cool. The hardened shapes are then placed in ovens for curing, which may take as long as ten days or more. During this period the resin becomes polymerised or thoroughly hardened. After oven treatment, the shaped pieces can be machined and fabricated in a similar manner to non-ferrous metals and hard woods. Tubes, rods and sheets can be sawn, drilled, tapped and generally worked on the lathe according to standard metal-working practice. Cast phenolic resins are produced in transparent, translucent and opaque colours of great beauty and permanence. It is commonly said that cast resin is the jewel of the plastics industry, and it certainly finds many applications where jewel-like qualities are needed, e.g., imitation stones. Incidentally, materials like Catalin find many important applications in the engineering industries for press tools and jigs which require good mechanical strength and dimensional stability.

### *Laminated plastics*

These are made by treating fibrous sheets, such as paper, woven cloth, asbestos and glass fabrics, with liquid synthetic resins, usually solutions of phenol formaldehyde resin in alcohol, and then subjecting the built-up layers of the treated materials to heat and pressure. Solid boards, tubes and shaped pieces are produced of laminated materials.

Giant impregnating machines are now in use which automatically impregnate the paper, fabric, etc., with liquid resin, remove excess so that there is no variation in the resinous content of the paper throughout a mile or so of its length, and then dry it. In the case of alcoholic solutions, the alcohol is drawn off, collected and re-distilled for use over again. Water solutions of urea formaldehyde resin may be employed instead of spirit solutions of the phenolic resins.

As laminated plastics are employed so extensively in the electrical industry where rigid specifications are laid down by manufacturers, every phase of production has to be most carefully controlled so as to ensure absolute uniformity of quality. A difference of 1% in the moisture content of batches of paper to be impregnated would be reflected in an appreciable difference in their resin contents after treatment, and consequent difference in electrical properties.

The resin-impregnated sheets of paper, fabric, etc., are piled up together in large hydraulic presses (multiple daylight presses, so-called because one can see the daylight between the steam or electrically heated platens). The platens are heated up to about 140–160 deg. C., and the pressure is in the region of 1,500 to 2,000 lb. per sq. in. The combined action of heat and pressure causes the resin to soften and flow, thus bonding the sheets together, and then after a few minutes (time depending

on thickness of pile) the resin hardens or polymerises to form an infusible and immensely strong assembly. Tubes and rods are either moulded in steel dies or rolled round heated mandrels.

For non-structural and semi-structural industrial units, such as aeroplane wing tips, air intakes, air conditioning and hot air heating ducts, etc., considerable use is now being made of low-pressure laminates. These differ from materials produced by use of high pressure, notably by their greater toughness, but they are far less resistant to moisture, and have a much lower compressive strength and modulus of elasticity. Low pressure laminates enjoy the unique advantage of retaining, to a greater degree than the high laminates, the natural structure and position of the fibres, and there is less rupture and distortion.

Thermo-plastic and thermo-setting resins are both employed, choice of resins being determined by the special requirements of the finished piece. Various kinds of paper are employed and usually this is specially milled for the purpose.

From the manufacturing angle, the production of low-pressure laminates permits a very considerable economy in manufacturing cost as very low pressure and little heat is necessary, and use can be made of light tools made from wood, papier mâché, concrete, plaster of Paris, etc. On the other hand, the process is essentially a hand-operated one and a good deal of skill is necessary to produce first-class results. Although shapes can be made, and many excellent ones are produced, by the use of contact pressure only, the best results are secured by the use of medium pressures, 30 to 100 lbs. per sq. in., using a flexible rubber bag or hydraulic press.

Forms are built up by wrapping adhesive or resin-coated paper in tape form round the wood mandrel or male former, etc., or alternatively, the layers of paper can be coated with resin solution and the solvent allowed to evaporate before applying a fresh layer. When the shape is built up in this way it can be dried out or stoved, or subjected to moderate (or low) pressure by means of a flexible rubber bag and autoclave.

Laminated plastics may be machined on the lathe in a similar manner to non-ferrous metals and hardwood.

#### *Urea formaldehyde resin*

This important plastic owes its origin to the research work of Hans John, Fritz Pollak and Kurt Ripper during the period 1920 to 1923. These chemists converted an academic experiment into a practical commercial process. It had long been known that when urea is heated with formaldehyde a white resinous substance is produced. In actual works practice to-day, fixed proportions of urea, which is a white, crystalline and odourless substance, and formaldehyde are heated together in large steel kettles in the presence of small amounts of alkali. As a result of polymerisation, which is stopped before reaching completion, a water-soluble and fusible, resinous body is produced. The resin solution is mixed with the filler, which may be a specially purified wood flour or mineral filler, and the mixture carefully dried, then mixed with dyes, pigments and various chemicals able to assist moulding.

Urea formaldehyde resin is one of the most attractive of the thermo-

setting plastics, and the well-known materials, such as Beetle and Scarab, are available in translucent, transparent and opaque colours.

### *Melamine*

This comparatively new industrial chemical produced from cyanamide and formaldehyde is, in many ways, similar to the urea formaldehyde resin, in fact mixtures of the two materials are often employed. The melamine resins are more resistant to heat and moisture than ordinary urea plastics and also possess superior electrical properties. Incidentally, melamine is now being extensively used in the chemical treatment of textile fibres to impart crease-resistance and waterproofness.

### *Wood Plastics*

Due mainly to research and development work carried out by the U.S. Forest Laboratory, several interesting wood plastics have been produced in America.

Most of the commercial wood plastics are based on ligno-cellulose derived from hardwood waste. The actual manufacture of wood plastics is achieved by first hydrolysing the wood so as to obtain the correct lignin-cellulose ratio and then treating this complex compound with aniline to obtain a satisfactory resinous product suitable for plasticising and modifying with furfural and other chemicals.

Various grades of moulding powder and sheets suitable for moulding are being produced, and these plastics are cheap, easy to make in large quantities and, when moulded, the various articles possess good mechanical strength, high shock resistance and also excellent resistance to abrasion, weather, etc. Although all the articles made from wood plastics are black, it is possible to cover the surface with a thin wood veneer. Paints, lacquers and enamels can also be applied to the moulded surface to produce novel colour effects.

It seems to be very probable that large quantities of wood plastics will be manufactured in America and Canada as they are much cheaper to make than synthetic resins and can be utilised for many purposes in industry. There is no difficulty in moulding wood plastics in thick sections and, where necessary, they can be moulded about heavy metal inserts.

### *Methods of moulding and pre-heating thermo-setting resins*

Compression moulding is the standard method adopted for the fabrication of articles to be made from phenolic and urea resin moulding powders. The principle of the method is relatively simple. The mould or die consists of two parts, the plunger or top component, and the cavity which is charged with moulding powder. In the actual moulding operation the cavity is charged with the correct volume or weight of powder, or, in many cases, pre-formed pellets, and the mould closed. When heat and pressure are applied (160-180 deg. C. and pressure in the order of 1 ton per sq. in.) the resin fuses and flows, thus filling all the available space in the mould. A period, known as the cure time, then elapses which the resinous mass begins to set or become cured and con-



verted into a rock-like and infusible material. When the resin is properly cured, the time being dependent on the size and thickness of the moulding, it is ejected hot from the steel mould.

In modern moulding practice the powder or pellets is pre-heated so as to reduce the cure time and so increase production figures. The usual method of pre-heating is by means of ovens, but recently radio frequency electrical methods have been used, also infra-red lamps.

### *Radio frequency method of pre-heating plastics*

The application of electronics to the moulding of plastics is an apt example of the way in which science can sometimes turn a fault into a virtue. In the early days of plastics, complaints were received by moulders from the electrical industry that certain mouldings when exposed to high frequency currents heated up to temperatures sufficient to cause blistering and charring. This proved a great nuisance and necessitated the employment of special low loss plastics able to withstand high frequencies without becoming heated. To-day this property of moulding powders and laminated sheets, also synthetic adhesives, to heat up when exposed to radio frequency currents is being utilised as a practical and economical means of pre-heating which ensures the even distribution of heat throughout the mass. As every particle of powder is heated to the same temperature there is no risk of uneven curing or softening, and when the heated and partially fused powder or pellets, etc., is transferred to the press for moulding or shaping it is in an ideal condition for fabrication and enables very considerable reductions to be made in the actual time of moulding and the pressure needed to produce sound commercial shapes.

When moulding powder is heated in the ordinary way in a steel mould there is a tendency for the heat to be distributed somewhat unevenly owing to the uneven thermal conductivity or heat transfer of the resin. In the case of very thick mouldings this low heat conductivity proves a serious handicap owing to the risk of the interior of the piece being undercured and lacking the strength of the resin on the outside. Unfortunately, if the temperature of mould is increased so as to reach the interior of the section there is a danger of the outer layer becoming burned and blistered. Exactly the same argument holds good where very thick laminated sheets are being pressed.

Radio frequency heating overcomes with great ease and economy the difficulties inseparable from ordinary surface heating. The principle is quite simple and depends on the fact that when a high frequency voltage is set up across two metal plates or electrodes separated by air or some other insulating material a current will flow between them, and if the material has a high power electrical factor, its temperature will rise. This power factor may be regarded as a measure of the internal electrical friction, to overcome which energy is absorbed from the set and converted into heat. (Average frequency employed is 100 megacycles.)

In standard works practice the powder (which needs to be contained in a shallow tray of low loss insulating material) or pre-formed sections, is placed between the electrodes of the set and heated up to 130 deg. C. to 150 deg. C., and then quickly transferred to the hot mould in the

press, which is at once closed. The time taken for heating by means of the radio frequency current is only a matter of seconds.

This new method of pre-heating thermo-setting resins renders practical the economical fabrication of very large and thick shapes and brings nearer the day when plastics will compete with the largest pressed metal work. The plastic coffins which, before the war, took hours to mould, can now be moulded in a matter of minutes. It is generally recognised that radio frequency heating is of the greatest importance to the plastics industry in the development of new markets.

#### *Transfer moulding*

Many mouldings, particularly those intended for the electrical industry, are moulded complete with metal, ceramic and glass inserts. A new method has, within the last few years, been specially developed to produce the best results where delicate inserts are required. Transfer moulding differs fundamentally from ordinary compression moulding as with the former the moulding material flows into the mould cavity, and is not, as is the case with ordinary compression moulding, simply placed there to fuse and flow. The obvious advantage of the transfer process is that there is evenly controlled flow and a reduction in the stresses liable to be set up if the moulding powder is allowed to flow unevenly, which is unavoidable where large inserts are present.

#### *Extrusion*

Phenolic and urea resins may be extruded in the form of continuous rods, tubes, sections, etc. Here the fused resin is forced through a heated die by means of a screw feed. Special types of resin are usually developed for extrusion which is primarily employed for the fabrication of thermoplastic resins. Very large quantities of P.V.C. (polyvinyl chloride) and polythene cable covering were extruded during the war, using modified rubber extruders.

#### *How strong are the thermo-setting resins?*

When compared with steel, which may have a tensile strength of 80 tons per sq. in. (stainless steel), or aluminium alloy at 30 tons per sq. in., the strength of even the most robust plastic at 10 tons per sq. in. does not appear very impressive. In considering strength it is, however, necessary to bear in mind the relationship of strength to weight—called the specific strength. The specific gravity of steel is 7.6–7.8; pure aluminium is 2.7, and the plastic, say a paper base laminated sheet, is approximately 1.3–1.4, or more than five times as light as steel and twice as light as aluminium. For the same weights of materials the strength of the plastic appears much more favourable, although still below that of aluminium.

There are special experimental plastics, such as the material known as Gordon 'Aerolite' developed by Dr. N. A. de Bruyne of Aero Research Ltd., which consists of phenol formaldehyde resin with unwoven linen filler. This has a tensile strength of 30 tons per sq. in. and a specific

gravity of approximately 1.47. On a basis of equal weights this material is stronger than steel. There are other high tensile strength laminated materials with figures of 20-25 tons per sq. in., but most of them are still in the experimental stage.

When considering strength it is necessary to bear in mind that the engineer is generally more concerned with all-round toughness than a freakish tensile strength. He requires a plastic to stand up to all the workaday stresses and to show low fatigue when subject to steady loading. So far plastics lag a long way behind steel and even plywood for structural engineering.

Mouldings made from standard moulding powder are brittle and do not possess great strength, usually in the region of 3-4 tons per sq. in. for good quality material (tensile strength). They are, however, eminently suitable for many thousands of applications where strength is not the chief requirement. In the case of mouldings generally, tensile strength is not so important as impact strength or resistance to shock (generally referred to as toughness) and where this is required to a high degree special powders containing long textile fibres or chopped-up fabric are employed. These high impact moulding powders are difficult to mould and expensive to produce.

The laminated sheets, which generally possess the highest strength of the thermo-setting resins, were originally employed almost exclusively in the electrical industry for switch-boards, fish-plates for electrical tracks, terminal boards and numerous electrical parts, but an increasing number of mechanical uses are now being found, such as bearings, gears, etc. Tests have shown that where metal bearings have been replaced by laminated ones, a saving in power of 50% or more has resulted. The use of plastic gears in camshaft timing of internal combustion engines is now fairly well known, and it has the advantage of being silent. (There is still a very wide discrepancy between the stress-bearing properties of the laminated gear and metal such as phosphor bronze and the special case-hardened steels.)

### *Thermo-plastic materials*

These constitute the most extensive plastic materials and every year witnesses new additions to the range, which includes the cellulose esters (celluloid and non-flam celluloid or cellulose acetate); cellulose ethers; acrylic resin (Perspex); polyvinyl resins; polystyrene; polyethylene; protein plastics and such new comers as Mycalex.

### *Cellulose esters*

The best known of this very important family is, of course, celluloid, which, in spite of its high inflammability, is still of great importance for cinema films, toilet articles, knife handles and such things as protractors and various navigation instruments. Celluloid is the oldest commercial plastic and the claim for its invention is shared by an Englishman, Alexander Parkes, in 1864, and two Americans, the Hyatt brothers, in 1869.

The origina of celluloid is cellulose in the form of the short fibres, known

as cotton linters, which lie next to the seed in the cotton boll. The cellulose is purified and treated with mixed nitric and sulphuric acids. The celluloid, sometimes called pyroxylin, is then mixed with camphor, alcohol and various colouring matters, and the dough-like mass rolled out into slabs, which are then baked, seasoned and polished. The plastic is then sliced up into sheets, cut into rods or extruded into tubes. Like all thermo-plastics, celluloid is very amenable to fabrication and may be moulded in dies by compression or injection moulding processes; extruded; blown into dies with hot air; formed on wooden or brass formers; cut, drilled, planed and sawn or shrunk on to metal as in the case of knife handles.

### *Cellulose acetate*

This material is often called non-flam celluloid, which is really quite incorrect, as it will burn when a naked flame is applied but will not burst into flame or explode in the same way as celluloid. This thermo-plastic is made in a somewhat similar way to celluloid, except that the cotton linters are treated with acetic acid and acetic anhydride. It was first developed on a large commercial scale for aeroplane dope during the 1914 World War. Its use as a plastic followed its employment on a rapidly extensive scale as a textile fibre or Celanese artificial silk.

Cellulose acetate is easier to fabricate than celluloid as it is available in flake form for injection and compression moulding and may be extruded in many strip shapes. It is available in a number of different grades, which vary from soft and yet durable compositions to very hard and rigid materials. This plastic offers an almost unlimited range of beautiful transparent, translucent, mottled, opaque and pearl effects. The fact that it is slow-burning renders it more serviceable than celluloid for many applications.

Improvements have, during the last ten years, been made in the properties of cellulose acetate so as to increase its resistance to water, ability to retain its shape without crazing (formation of tiny cracks or blisters just below the surface) or cracking, and resistance to creep and cold flow. (Cold flow may be defined as the inherent tendency of a material to change its shape, or 'flow,' even when there is no increase in temperature. Bitumen is a good example. Creep is the dimensional change which takes place when a material is subject to stress or load.) A new and improved form of cellulose acetate has been developed which represents a considerable improvement over the old type. This new material, cellulose acetate butyrate, is made in a similar manner to ordinary acetate, except that butyric acid is used as well as acetic acid and acetic anhydride. Both types of cellulose ester find their chief use in the aircraft industry for transparent cockpit coverings, windows, gun turrets, fillets and fairings, and in normal times in the fancy goods industry.

### *Cellulose ethers*

Of recent industrial importance is ethyl cellulose which now makes many claims for consideration by the electrical and other rubber-using

industries. The origin of this material is the same cellulose that is employed for making celluloid and cellulose acetate. In the case of the ether, however, the bleached and purified cellulose from the cotton plant is first treated with caustic soda to form alkali cellulose, and then reacted with a simple organic chemical, ethyl sulphate.

Ethyl cellulose is a white, flock-like substance readily amenable to moulding and extrusion. It is mixed with various plasticisers or chemicals able to modify its physical properties so as to give soft rubber-like materials for tubing, transparent sheeting for aircraft and hard compositions like vulcanised rubber.

The electrical insulating properties of ethyl cellulose are excellent, and this plastic is now extensively employed instead of rubber for wire covering. Unlike rubber it is not injuriously affected by exposure to oils and a number of solvents, it also withstands heat well and retains its flexibility at temperatures down to  $-59.4$  deg. C.

Methyl cellulose is worthy of mention, although it is not of any interest from the fabrication angle owing to its solubility in water. It is available as a white, fibrous mass which is soluble in water but insoluble in most organic solvents. It is colourless, odourless, tasteless and non-toxic and is unaffected by acids and alkalis. The chief use for methyl cellulose so far is as a substitute for size, and it is recommended for making various types of water paints, cosmetics, pharmaceuticals and foods.

#### *Methyl methacrylate resin*

This is an all-British invention, and Rowland Hill of Imperial Chemical Industries, Ltd., was the first to study methyl methacrylate monomer and polymer in detail and to appreciate the possibilities of the polymer as a commercial resin, later to be known as "Perspex."

Methyl methacrylate resin was introduced to industry only a few years before the 1939 World War, and immediately created the widest interest on account of its amazing transparency. Its light transmission properties are comparable with those of the best quality optical glass, and this property is retained in sunlight and under conditions of high ultra-violet light intensity. Moreover, methyl methacrylate resin has the lightest weight of any of the ordinary transparent materials used, the specific gravity being 1.19 for Perspex compared with 1.35 for safety celluloids and 2.5 upwards for glass.

The manufacture of this resin starts with acetone, a familiar solvent, which is treated with prussic acid to form acetone cyanohydrin which, by a complex series of chemical reactions is converted into the monomeric ester of methacrylic acid. The monomer is a clear, water-white liquid, but when made to combine with itself or polymerise it is converted into a crystal-clear, practically unbreakable solid.

This plastic, polymethyl methacrylate (usually referred to as methyl methacrylate or acrylic resin), is cast into sheets of various sizes and thicknesses. These sheets can then be softened by heat and bent or formed to make all manner of shapes. Sheets can, when rendered plastic by heat, be blown to shape using compressed air. A powdered

form of the polymer is also available for compression and injection moulding.

During the war "Perspex" fulfilled a major role as a transparent glazing for all types of aircraft, and it met practical Service requirements in every theatre of war. Unlike cellulose acetate, "Perspex" does not turn yellow with age or become brittle when exposed to high humidity and heat.

Now that the war is over this glass-clear resin is in the greatest demand for a hundred and one purposes. Corrugated "Perspex" sheets are being used in industry for roof lighting, and plain sheets for making up into all kinds of domestic and commercial lighting fittings. Transparent and coloured sheets are utilised for the manufacture of a wide range of fancy goods such as cigarette boxes, dressing table requisites, trinkets, jewellery, etc. "Perspex" is also finding important uses in the building trade for bathroom and kitchen fittings.

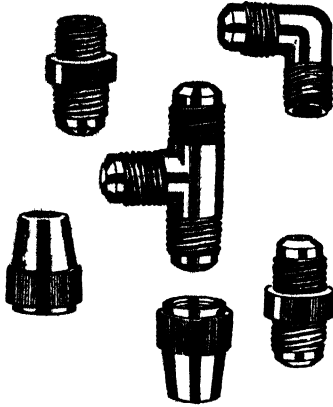
A special form of unplasticised Perspex known as Transpex I possesses optical properties similar to those of normal optical crown glass. This plastic has now been employed for some time for the construction of lenses, prisms and mirrors for all types of optical equipment, such as cameras, binoculars and projector systems. Transpex I, and also Transpex II, which is unplasticised polystyrene, possess certain advantages as optical materials, namely, ease of fabrication; high light transmission, constancy of refractive index from batch to batch; resistance to mechanical and thermal shock; low specific gravity. Acrylic resin also finds many uses of a miscellaneous nature which vary from dentures to materials used for modern plastic surgery. The ability of the resin to carry light rays round curves due to total internal reflection renders it of great interest and service for self-illuminating surgical and dental instruments, glowing advertisements, shop fittings and even show furniture. One form of Perspex can withstand boiling water, and surgical instruments fabricated of this material may be sterilised in the ordinary way.

### *Vinyl resins*

These plastics constitute a modern family which is yearly assuming more importance owing to its wide range of useful properties. Vinyl resins are made largely from acetylene, which, if passed into acetic acid, will form vinyl acetate, and, if reacted with dry hydrogen chloride gas (used to form hydrochloric acid), will form vinyl chloride. The vinyl acetate and the chloride are simple monomers and the process of polymerisation needs to be completed before they are converted into useful plastics or polyvinyl acetate and polyvinyl chloride. If vinyl chloride and vinyl acetate are mixed together and then polymerised, a so-called mixed polymer is formed. The physical properties of these various polymers is greatly influenced by the presence of plasticisers which are able to modify their flexibility, elasticity and general toughness.

The polyvinyl resins are the most versatile of the entire range of plastics. Some elastic types are utilised as belts, leather substitutes and similar fancy goods, whilst other soft and semi-soft grades are extruded into tubes to carry water, chemicals and gases and for electrical insula-

tion. There are liquid polyvinyl resins for the impregnation of fabrics to be used as waterproofs and solid, extremely hard materials used as light bearings in the engineering industry, and hard-working parts of pumps.

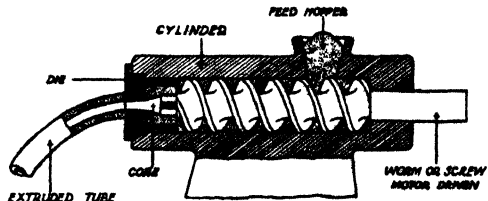


Various types of threaded fittings fabricated of saran, the new thermo-plastic extruded tubing. These fittings are now used in the chemical industry and may one day replace metal in the household plumbing system.

One of the most interesting of the vinyl type of resins is saran or vinylidene chloride which is produced from two basic raw materials, petroleum and brine. From the first material, the gas ethylene is produced which is made to react with the chlorine derived from common salt. The chemical trichloroethane is then treated with lime to form vinylidene chloride monomer. This, on polymerisation, forms the plastic of commerce. Extruded saran is used for rods for making gaskets, valve seats, ball checks, medicinal probes; chemically resistant flexible tubing and pipe is extruded for use in the chemical and food industries; conveyor belts and industrial tapes. The vinylidene monofilament is used instead of hemp, reed, rattan, linen, horsehair, etc., where high chemical and fungi resistance are specified.

One of the most interesting properties of saran is its behaviour when stretched or orientated. The orientation process provides a method of effecting a plastic deformation and partial recrystallisation of the shaped, super-cooled material. It results in a very considerable increase in the tensile strength of the resin, from 8-10,000 lb. per sq. in. to 30-60,000 lb. per sq. in., and also an increase in the impact value or resistance to shock.

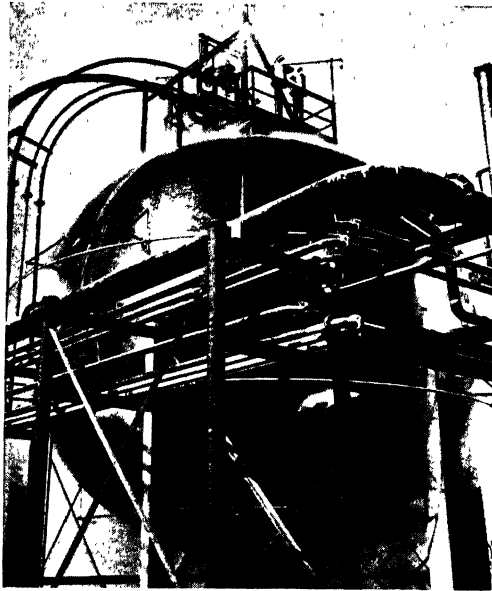
Vinylidene chloride resin is likely to prove of great value for upholstery intended to withstand heavy wear, for instance in use in trains, commercial vehicles, industry, etc., and also for making all kinds of bags and travelling cases.



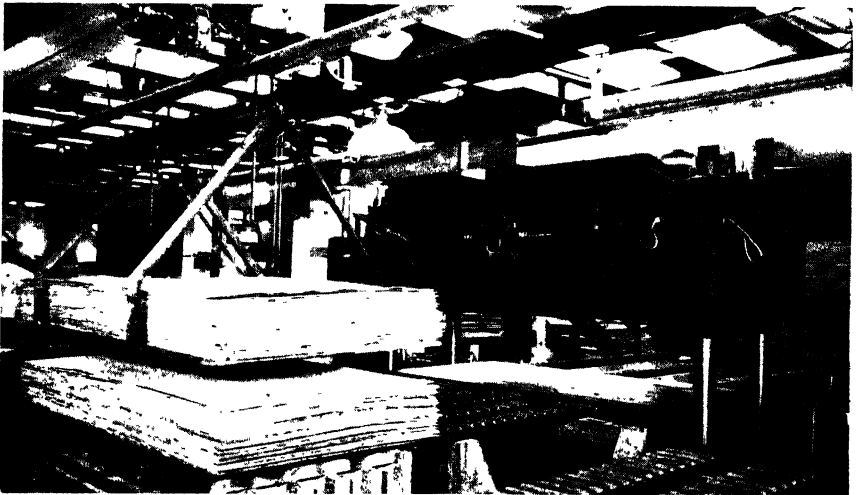
The new P.V.C. tubing is produced by this type of simple extrusion machine.

### *Polyvinyl aldehyde resins*

Combinations of polyvinyl acetate and polyvinyl chloride with various aldehydes, such as formaldehyde, butraldehyde, etc., are now being extensively employed as special adhesives. The best known of these are Formvar and Butvar, which are used for making safety laminated glass and for general industrial adhesive jobs.

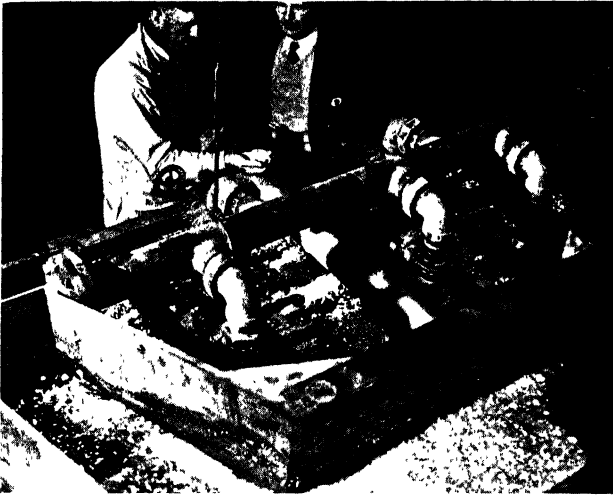


Owing to the instability of butadiene great care has to be taken to prevent premature polymerisation. This storage tank in the works of the United States Rubber Co. is completely enveloped in water spray. The cooling system, which operates both automatically and by hand, prevents undesirable polymerisation with its attendant development of pressure and heat and protects against external fire.

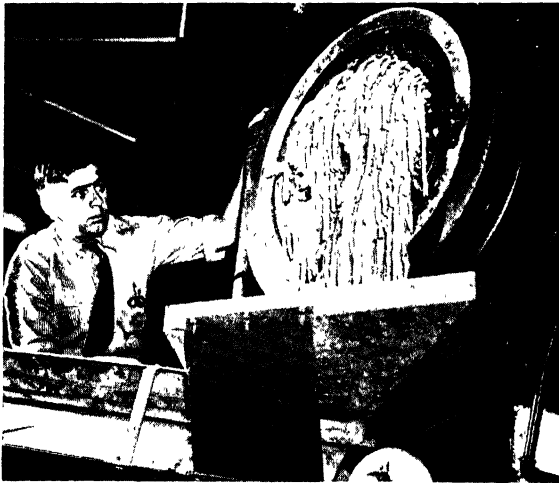


Modern plywood manufacture employs radio-frequency heat applied in large hydraulic press. Synthetic resin glues are used, and the heat supplied by R F Sets enables a quick cure to be effected. Production is speeded up and a superior grade of plywood produced.





This operation shows particles of synthetic rubber being separated from water. In the left-hand corner water containing rubber particles flows down a trough on to a vibrating screen which is seen beneath the pipes. The white material which looks like popcorn is synthetic rubber.



This is how synthetic rubber looks as it goes through a tuber. The tuber is a machine like a meat mincer that squeezes large chunks into smaller pieces, and in so doing removes water from the rubber. From here the material goes into a drying oven and then into a mill where it is finished in sheet form.

### *Polystyrene*

This is a plastic possessing amazing clarity and optical properties. Strangely enough, its origin dates back 105 years ago, although it was not produced as a commercial resin until a year or so before the 1939 World War. The manufacture of polystyrene depends first on the production of styrene from the gas ethylene and benzene from coal or petroleum. Ethyl benzene is cracked at high temperature yielding styrene. The monomer styrene is readily converted into the polymer by merely heating, exposing to light or chemical means. The resin may be cast into sheets, rods and tubes, etc., or it is available in powdered form for injection and compression moulding.

Polystyrene is unique for its extremely high resistance to moisture and its excellent electrical insulating properties, particularly where high radio frequencies are encountered. Apart from the rigid and rather brittle polystyrene resin there is now available a flexible polystyrene which promises to be more useful as an electrical insulating medium.

### *Polythene*

This is a new and all British thermo-plastic discovered and subsequently developed by Imperial Chemical Industries Ltd. It is interesting to note that strong claims have been made in the U.S.A. that polythene is really the result of American research, but this is contrary to the facts, as it was only after this tough and flexible hydrocarbon was produced on a fairly large scale in Great Britain during the beginning of the war that full-scale manufacture in the U.S.A. was undertaken. Polythene or polyethylene is manufactured by subjecting the gas ethylene to very high pressures in the region of 20,000 atmospheres. Its chemical structure is undoubtedly the simplest of all plastics.

The outstanding properties of polythene include very low density (0.92), chemical inertness of a high order, outstanding electrical insulating properties and ability to retain flexibility at low temperatures (-60 deg. C.).

During the war this thermo-plastic has been extensively utilised for high frequency cables in radar equipment and here its extremely low power losses have enabled great magnification of signals to be carried out with remarkable efficiency. It is no exaggeration to say that the use of polythene has rendered possible the development of radar on a really large scale. Another important application of polythene is found in the manufacture of insulated sleeving for instrument wiring, and during the war one firm alone (Telegraph Construction and Maintenance Co.) has supplied over 75,000,000 feet. There is no doubt that polythene has a great future in the electrical and chemical fields, and there is a possibility that fibres made of this thermo-plastic may eventually be developed for important textile uses.

### *Protein plastics*

The best known is, of course, casein, which was produced as a plastic in 1890, when Dr. Adolph Spitteler of Hamburg set out to make a white 'blackboard' for school use. He mixed sour milk with formaldehyde and obtained a shiny, hornlike substance which was later used so exten-

sively for buttons and buckles. This casein plastic, although dimensionally unstable, is still important as a source of easily fabricated and readily coloured buttons. Other natural protein plastics are made from such raw materials as soya beans, coffee beans, lignin from wood, and various other types of agricultural products.

The best known synthetic protein plastic is nylon, which promises to become one of the most useful monofilaments or fibres produced. The term 'nylon' is really the generic term for all materials defined scientifically as synthetic fibre-forming polymeric amides having a protein-like chemical structure, derivable from coal, air, water, or other substances and characterised by extreme toughness and strength. This plastic owes its origin to the brilliant research work carried out in America by Dr. William Carothers, a Du Pont chemist, who was attempting to find a new type of synthetic rubber of the protein type. He continued the experiments of the famous German chemist, Emil Fischer, who much earlier in this century had attempted to make synthetic animal proteins but only succeeded in producing various semi-protein bodies known as polypeptides. Dr. Carothers and his very able co-workers carried Fischer's work to a more advanced stage by the production of an entirely new range of compounds, the polyamides, of which nylon is the generic name.

Nylon melts at 237·8 deg. C., and is usually extruded to form continuous filaments to be spun into yarn, or monofilaments for brushes, sutures and fishing casts. The tensile strength of the monofilament (diameter 7·20 mils—a mil is ·001 millimetre) is 50,000 lb. per sq. in. Although nylon is primarily of interest as a textile fibre, it may, of course, be moulded and extruded in a similar manner to ordinary thermo-plastic materials. A new and most interesting application of one of the nylons is its use as a wire covering to meet certain exacting electrical requirements. There seems little doubt that when the price of moulding grades of nylon is reduced to an economic level it will find many more important new uses.

### *Silicones*

The term silicone is a generic one and applies to a number of semi-organic compounds which link the organic and inorganic materials. The molecule of the silicone resins has an inorganic structure, a silicon-oxygen chain, and in consequence the resins possess very much greater thermal endurance than the best of the conventional organic resins. Silicones have so far found their greatest use, and almost exclusively in the U.S.A., in association with glass fibres for the insulation of industrial motors, making possible a reduction in weight up to as much as 50%. These silicon plastics have also been suggested for many other purposes, such as lubricating greases, filling compounds and water-repellant fluids for treatment of paper and fabric.

It is significant that many of America's largest industrial concerns, such as Westinghouse Electric, General Motors, Dow Chemical Company, etc., are collaborating with the chief glass manufacturing concerns to develop silicon plastics. The raw materials are very much cheaper and more plentiful than those needed for the ordinary organic resins, and the finished silicon plastics possess many unusual properties.

### *Mycalex*

This is a pure inorganic plastic, that is made from mineral as distinct from natural materials, and is formed when a mixture of ground mica and lead borate is heated to the melting-point of glass. The mixed powder may be moulded to shape by compression or injection moulding technique and rod and plate sections can be fabricated by machining on the lathe. The outstanding properties of this interesting new plastic are very high dielectric strength, good mechanical strength, good resistance to moisture, nil absorption in 48 hours, immersion and ability to withstand considerable heat without disintegration. At present Mycalex finds its chief use for radio transmitter insulators on account of its excellent insulation at radio frequencies.

### *Common methods of fabricating thermo-plastic resins*

These may be classed as compression and injection moulding, and extrusion. The first-named has been fairly fully described for the thermo-setting resins, but the method differs slightly for thermo-plastics. Here the moulded piece needs to be hardened by cooling the steel mould before it can be ejected. In other words, the piece is ejected from the mould as a cold piece, whereas in the case of thermo-setting resins it is extracted as a hot piece from a hot mould. Injection moulding consists of feeding flake or powdered moulding material into a hopper, from which it is forced into a heated chamber, where it melts or fuses. The liquid resin is then forced into the die, which is immediately cooled and the formed piece ejected as a finished piece. The complete cycle takes only a few seconds. Modern injection moulding presses can turn out articles varying in weight from half an ounce to 16 ounces or even more. Compression moulding can produce articles weighing many pounds in weight and of considerable dimensions. Extrusion of thermo-plastic material follows standard metal extrusion practice to a large extent. The thermo-plastic is melted and forced through a steel die, which is kept cooled, and the strip supported until it has cooled sufficiently to be cut into lengths and handled.

Sheets of cellulose acetate, Perspex and vinyl polymers can be softened in hot-air ovens and shaped to form over wood or brass formers. The material quickly sets and takes on the shape of the former.

### *Trend of modern research in plastics*

In the laboratory the chemist and physicist are both working on new types of plastics. The chemist is engaged primarily on the synthesis of compounds from simple and inexpensive derivatives, while the physicist is concerned with structure and methods of changing it so as to improve the physical properties of the material. The tempo of research during the war was greatly accelerated, due to the need for special types of plastics and improved methods of moulding and fabrication. Alongside short term research there has been undertaken fundamental investigation concerned with the structure of polymers and the mechanism of polymerisation, and this must inevitably yield rich dividends in the form of new and greatly improved plastics. The process of making plastics is

somewhat akin to the building up of patterns in a Victorian kaleidoscope, a slight twist to the box, the merest alteration in the position of the component parts being capable of major changes in the pattern. Molecules can be made to measure and the mechanism of polymerisation may be so accurately controlled as to obtain a wide range of products varying from varnish-like resins to hard and ebonite-like solids.

Not only is the chemist interested in the synthesis of plastics with improved physical and chemical properties, but also the conversion of coal and lignite into plastics by direct chemical action without involving combustion which must inevitably entail a serious loss of volatile constituents. It should be noted here that both coal and lignite possess marked plastic properties themselves.

It is noticeable that work carried out on the development of new types of synthetic rubber and their intermediates has resulted in the discovery of several rubber-like thermo-plastics which are likely to find important uses in the cable and allied industries. Particularly important is the present large-scale availability of styrene, so necessary in the manufacture of Buna S. type rubber, and this has encouraged the production of several new styrene polymers.

Of the greatest significance is the development of silicon plastics from cheap and abundant raw materials and these will eventually play a vital part in the electrical industry, to mention only one outstanding group of silicones. It is rather unfortunate that the development of these new resins is due in the main to the initiative of American manufacturers.

Glass fibre resin combinations have attracted a good deal of attention for applications in industry requiring a hard, strong material possessing a high resistance to moisture and heat. In addition, glass plastics can be moulded or shaped by low-pressure methods, and in some cases by the use of contact pressure only. The function of the plastic is to protect and support the reinforcing glass fibres and to enable the great compressive strength of glass to be utilised. The method of manufacture appears to be fairly simple and quite briefly it consists of mixing glass flock with a suitable resin, such as the new thermo-setting allyl resin, and then applying this to a stack of glass fabric layers to form laminated sheets by the application of light pressure. In the case of moulded shapes, the flock-resin mixture is applied to pieces of glass fabric which are carefully tailored to fit moulds and formers. It is reported from America that glass fibre laminates prepared in this way by the use of light pressure have a tensile strength varying from 34,000 lb. per sq. in. to 105,000 lb. per sq. in., and an ultimate compressive strength of 17,000 to 29,000 lb. per sq. in.

The mechanical or fabrication side of plastics is now receiving close attention by engineers who are concerned with the development of methods of increasing production rates, the lowering of the cost of preparing moulds and the initiation of economical methods of producing thick section and large moulding of uniform strength.

For quantity repetition work there is no doubt that compression and injection moulding techniques are the most suitable. Tool costs are, however, very heavy and the size of the finished article is strictly limited. Where it is necessary to produce very large shapes, such as pieces of furniture, building fittings, car bodies and similar types of goods, there is no doubt that the low pressure or contact moulding processes offer consider-

able promise. As mentioned above, by the use of special quick-setting resins, e.g. allyl resin or new phenolic types, it is now possible to turn out several different types of laminates.

The radio frequency method of pre-heating preforms and so reducing the curing time necessary in the press has enabled moulders to speed up production of both small and large mouldings. According to published figures, radio frequency pre-heating enables the curing time of a propeller block to be reduced from 12 to 2 minutes, a telephone handset from 8 to 3 minutes and an ignition part from 6 minutes to 1 minute. The fact that it is now a practical proposition to mould very thick sound section by the use of radio frequency pre-heating is a great step forward and increases the scope of trade moulding.

Tests carried out on moulded 'woods' used for bowling have shown that whereas previously these required some hours in the press and even then cure was not uniform throughout the section, to-day by means of radio-frequency pre-heating of the powder it is practical to ensure uniform cure throughout the moulding and to reduce the curing time by more than 50%.

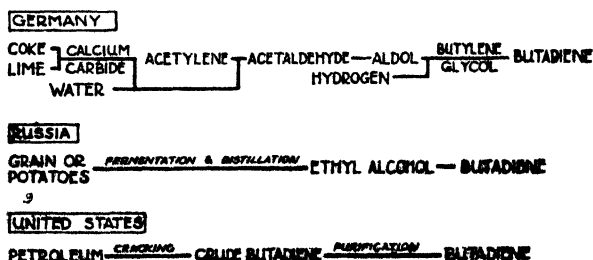
## CHAPTER IV

## SYNTHETIC RUBBER

THE TERM 'SYNTHETIC RUBBER' IS SOMEWHAT MISLEADING, AS IT NATURALLY implies that it is a substance produced by chemical means with the same composition and structure as plantation rubber. Such, however, is not the case. While some of the factory-made products resemble natural rubber in a general kind of way, there are many new additions to the range of synthetics which bear no chemical resemblance to natural rubber but do possess well-defined rubber-like properties.

The generally accepted meaning or definition of synthetic rubber is that it is a material possessing rubber-like properties, particularly an ability to stretch to a considerable degree, and, after release, to retract or draw back forcefully and quickly.

Dr. W. J. S. Naunton, the famous rubber expert of the Imperial Chemical Industries Ltd., says that "a rubber is any substance which shows an elasticity of 800% or more with a quick return (snap) at temperatures at which natural rubber shows the same effect, and which does



Butadiene forms the basis of most types of synthetic rubber and it can be produced from coal, agricultural products, such as grain or potatoes and from petroleum. Diagram due to W. G. Goggin, Dow Chemical Co., U.S.A.

temperatures at which natural rubber shows the same effect, and which does

not lose this property upon storage any sooner than does natural rubber."

### *Development of synthetic rubber*

The European discovery of natural rubber goes back to the time of Christopher Columbus who, in 1492, is popularly supposed to have come across some Haitians playing with rubber balls. It was approximately 350 years later that Charles Goodyear by his famous discovery of vulcanisation turned soft and 'eraser' rubber into one of the most important strategic materials of our age.

Since the days of Michael Faraday, who as early as 1826 gave rubber an empirical chemical formula,  $C_5H_8$  (five parts of carbon and eight of hydrogen), chemists throughout the world had attempted to solve the riddle of its composition and, later, its synthesis. The riddle was solved in three easy stages. The first in 1860 when Williams isolated the parent hydrocarbon, isoprene, from rubber. Fifteen years later, the French chemist Bouchardat converted isoprene, a white, low boiling-point liquid, into an elastic rubber-like mass by allowing it to stand a long time or treating it with weak acids. Under the influence of light, heat or chemicals, the comparatively simple isoprene molecule links up with others to form a complex and heavy rubber-like molecule. (As stated in Chapter III, this process is known as polymerisation and the substances formed are called polymers) The third and final stage in solving the first of the many rubber riddles was completed by the British chemist William Tilden, who prepared isoprene from turpentine by a simple chemical process.

The sensational discovery by Tilden that a hydrocarbon, such as common turpentine, could be changed by chemical means into a synthetic rubber opened up tremendous possibilities and naturally created great interest throughout the scientific world. Intensive research was initiated in Great Britain, Germany and Russia. Turpentine, as such, could not be used in any industrial rubber-making process owing to its relatively high cost and short supply and some other hydrocarbon had to be found which, on polymerisation, would yield rubber. The first scientist to make any real headway was the Russian chemist Kondakoff, who produced a low grade synthetic rubber, so-called methyl rubber, from a little-known organic chemical, dimethylbutadiene, a derivative of acetylene.

The main difficulty encountered by early investigators was to discover a quick and yet controllable means of converting the hydrocarbon into rubber by polymerisation. Whilst heat alone would achieve this, the method was lengthy and tedious. Incidentally synthetic rubber was produced in Germany during the last war by heating the hydrocarbon dimethylbutadiene in drums at 60-70 deg. C. for several days. It was left to a small but progressive English firm, Strange and Graham Ltd., of London, to patent the first practical method of achieving polymerisation by the use of metallic sodium. This was in 1910, and two years later a patent was granted to Matthews, Strange and Bliss, working in association with Strange and Graham Ltd., to cover the manufacture of

butadiene, the gas now used to produce Buna S. and several other rubbers, from butylene glycol, a product of the fermentation industry. That process developed 32 years ago now forms the basis of one of the most successful methods of making synthetic rubber.

It is to the everlasting credit of British scientists that the early work of William Tilden was developed into a practical process, but no credit can be given successive British Governments for their complete indifference to the progress made. As a result of Ministerial apathy and the sullen opposition of the various rubber firms who were securely held within the planters' ring, the synthesis of rubber by British scientists was never exploited.

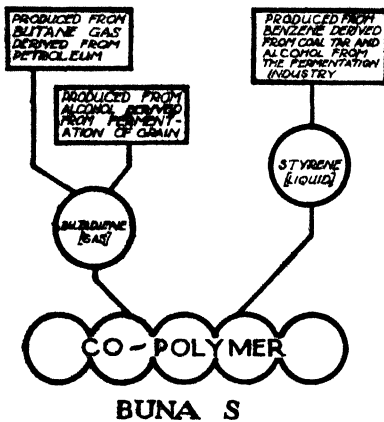
In Germany, however, the experiments of British chemists had been followed with the greatest interest, and as soon as it was realised that synthetic rubber was a practical proposition, every effort was made to translate the laboratory experiment into a factory process. The I.G. Farbenindustrie was heavily subsidised by the Kaiser's Government and given every encouragement to produce a useful form of synthetic rubber and to draw up blue prints for its large-scale manufacture in an emergency. Much of this work was entrusted to Dr. Fritz Hoffman of the famous Bayer Company, and Professor Harries, a well-known rubber scientist.

During the 1914 World War, Germany was cut off from all sources of natural rubber by the British blockade, and the High Command then commissioned the I.G. to produce a substitute. This was the methyl rubber originally made by the Russian scientist Kondakoff, and it was chosen, not because it was the best type, but because it offered fewer technical difficulties in manufacture than others. Well over a thousand tons of synthetic rubber were produced in Germany during the war years, and, although it was of poor quality, it served as an emergency substitute to eke out the rapidly dwindling stock of natural rubber. There was nothing radically wrong with this first ersatz rubber, it merely required compounding with carbon black to improve its strength and render it more generally serviceable. Fortunately German technologists did not discover the tonic effect of carbon black until some years afterwards.

During the Versailles years, whilst Allied statesmen were holding a wearisome and futile succession of conferences, the chemists in the laboratories of the I.G. were analysing their failure to produce a sound commercial rubber during the war. The old scheme was scrapped and new methods tried out. At no time did the Directors of the I.G. lose their faith in synthetic rubber, and credit must be given them for their pertinacity and refusal to accept a technological defeat. It took nearly five years of patient research by several teams of chemists to perfect a practical and economical method of producing synthetic rubber from the country's natural resources—coal, lime and water. Buna was Germany's antidote for rubber starvation imposed by the British Empire which owned the bulk of the Eastern plantations. Buna fitted into the vital economic pattern already outlined for World War No. 2.



The world announcement of the large-scale synthesis of Buna rubber (the word 'Buna' is derived from a combination of the first syllables of the two words, butadiene and natrium, the Latin for sodium), and the authenticated publication of its promising behaviour as a material for making tyres caused some concern to the planters' cartel and stimulated research by a few of the large American and British oil and chemical companies. There was, however, very little encouragement from the respective Governments, and independent manufacturers found progress difficult owing to the obstacles so cunningly placed, in the form of most exhaustive patents taken out in every country, by the ubiquitous I.G.



Buna S, the most important type of Buna, is produced from butadiene and styrene. Buna N, another type of Buna rubber showing exceptional resistance to oil and petrol, is produced from butadiene and acrylonitrile.

In 1935 Du Pont chemists of America developed a very successful method of converting acetylene, made from coke and lime, into a simple organic chemical (gas) known as monovinylacetylene.

This was then treated with hydrochloric acid gas to form chloroprene, which, on polymerisation, became a synthetic rubber, originally called Duprene, but later known as neoprene.

About the same time, the Standard Oil Company (New Jersey) which had a working arrangement with I.G. for the exchange of technical information, began work on the utilisation of petroleum refinery gases, and their research chemists produced several interesting polymers, of which butyl rubber was the most important. This colourless, odourless and easily vulcanisable synthetic rubber was made from the union of two simple hydrocarbons (gases), isobutylene and a diolefin, both present in refinery and natural gases.

Other American chemical concerns also carried out experiments, particularly Goodrich, Goodyear and the Thiokol Corporation. The last-named produced a most interesting and important form of substitute rubber made from sulphur, caustic soda, chlorine and the gas ethylene derived from natural gas. Incidentally this was the first of the American rubber-like materials to be manufactured. The discovery of Thiokol goes back to 1920, when an American chemist, Dr. C. J. Patrick, in his search for a new anti-freeze liquid, mixed ethylene dichloride (well-known organic solvent) with sodium polysulphide. Instead of an anti-freeze he obtained an evil-smelling rubber-like substance that proved insoluble in most solvents, such as petrol, and was not softened by oils or adversely affected by sunlight or heat. This was the first of a range of Thiokols and was later known as Thiokol A.

Up to the outbreak of war, Britain depended almost entirely on the output of her rubber plantations in the Malay Peninsula, and America

had only a shadow synthetic rubber industry in being and relied upon imports. (In 1939 the world production of synthetic rubber was only 7.5% of the world production of natural rubber.) Moreover, the United States was severely penalised by cartelisation initiated by the German I.G., which withheld from its American associates the vital technological details concerning the manufacture of Buna, the most important of all the synthetics since it could be used for tyre manufacture. After Pearl Harbour, America had to pay heavily for this bad debt !

### *Types of synthetic rubber*

It is convenient to consider synthetic rubber as falling into three fairly general groups. The first consists of the true synthetic rubbers, known as 'elastomers,' which are derived from butadiene and similar hydrocarbons. The second group embraces the so-called 'neo-synthetics,' that is, those produced from vegetable oils and sulphur compounds, and the third group includes the non-vulcanisable plastics, such as polyvinyl chloride (Koroseal), polyvinyl alcohol (Compars) and similar plastics. So far, the true 'elastomers' have proved the most valuable to industry, primarily because they possess properties more akin to natural rubber and may be employed for tyre manufacture.

### *Large-scale production of synthetic rubbers*

The present large tonnage of synthetic rubber made in America is made up largely of Buna S, (known in America as G R-S which stands for Government rubber-styrene), butyl rubber and neoprene, in order of quantity precedence, with Thiokol, Koroseal, Vistanex, and others as subsidiary and highly specialised lines. German and Russian production is concerned mainly with Buna grades.

### *Buna S from petroleum*

In the United States two types of raw materials are used in the manufacture of butadiene required for Buna S, alcohol from the fermentation of grain, and natural gas or petroleum refinery gases. About one-third of the total production of Buna is obtained from alcohol and two-thirds from petroleum.

There are several processes for the production of butadiene from petroleum or natural gas sources, but a typical one makes use of the gas butane. This is heated to a very high temperature, 565.6 deg. C., and passed over a catalyst. The process, known as cracking, yields a mixture of gases. The butadiene is withdrawn and the unchanged butane and a conversion product, butylene, are again cracked, yielding a much higher percentage of butadiene. This gas is separated from the other hydrocarbons by various means, notably by passing the mixture through solvent solutions possessing the property of dissolving it out and leaving the other gases unaffected.

For the manufacture of Buna S, which is made by combining butadiene with styrene, large quantities of this latter chemical are required. It may be formed from coal tar benzene by treating it with ethyl alcohol in the presence of solid phosphoric acid at a high temperature and pressure, or by passing benzol and ethylene over a catalyst to form ethyl benzene,

which is converted into styrene (a colourless and pleasant smelling liquid). The styrene links up with the butadiene molecule to form a co-polymer or the rubber-like material Buna S. This is then mixed with various chemicals, including carbon black, and milled to form sheets ready for the fabricating industries. (Butadiene may itself be polymerised to form a synthetic rubber, but this is much inferior to compounds made by uniting butadiene with other chemicals.)

#### *Buna S from grain*

The Russian chemical industry makes great use of grain and potatoes as a source of starch from which to produce alcohol by fermentation, the alcohol being later converted into butadiene. One bushel of corn (61% starch and 12% moisture) yields 5.60 lb. of butadiene. The process is relatively simple and consists of passing the very hot vapour of alcohol over certain catalysts. The butadiene is recovered from the mixture of gases by fractional distillation.

Instead of producing alcohol from grain by fermentation, it is now considered more economical to convert the starch into butylene glycol as the yield of butadiene is considerably greater, namely, 6.25-6.5 lb. per bushel of corn. The American synthetic rubber industry is now gradually switching over from the alcohol process to butylene glycol, which is stated to be nearly 30% more efficient.

#### *Buna S from coal and lime*

In Germany, the bulk of the synthetic rubber is made from the country's rich mineral resources, coal and lime. Coke produced from coal is heated with lime in electric furnaces to produce calcium carbide. This is then treated with water which generates acetylene, the starting point for a series of organic conversions. The first is acetaldehyde (similar in many ways to formaldehyde), which, on being heated with a dilute solution of potassium carbonate, becomes aldol. This chemical is changed by a process of hydrogenation into butylene glycol and finally by dehydration into butadiene.

The actual production of Buna S is carried out in glass-lined reaction vessels where the styrene, liquefied butadiene gas and a soap solution, are thoroughly mixed and emulsified and heated in the presence of a catalyst able to promote fairly rapid polymerisation. The solution in the processing chamber gradually becomes more viscous and then changes into a creamy kind of fluid or latex. This is coagulated by treatment with sulphuric acid and salt and the rubber floc or crumb separated by filtration, washed, dried and pressed into bales or flocs.

#### *Properties of Buna S*

This synthetic rubber has a specific gravity of 0.94. It possesses a very slight and not unpleasant odour and varies in colour from tan to black. In several important respects it resembles natural rubber, particularly as regards ageing properties, toughness and resistance to heat. Its elasticity and resilience are somewhat inferior to plantation rubber, but it can be made quite serviceable for tyre manufacture, provided running speed is not excessive and the tyre is run for the prescribed mileage only.

*Perbunan (Buna N)*

Perbunan is produced by polymerising an emulsion of butadiene and a chemical known as acrylonitrile. The creamy latex formed by this association is coagulated with acids and salt and the rubber crumb washed, dried and milled into sheets in a similar manner to Buna S or ordinary plantation rubber. Various chemicals, such as carbon black, are added to the Buna N and a number of different grades are manufactured according to market requirements. The outstanding and most important property of this rubber is its resistance to oils and solvents, coupled with its excellent ageing properties and resistance to heat and abrasion. The chief applications of Buna N are hose, cable sheathing, belting, gaskets, seals, printers' rollers, etc. It is not suitable for tyre manufacture.

*Butyl rubber*

This is essentially a petroleum synthetic rubber and is a co-polymer or union of two refinery gases, isobutylene and a small amount of a diolefin. The polymerisation product is somewhat similar in appearance to natural rubber, although it is colourless and odourless. It possesses excellent ageing properties, good physical properties, low gas permeability and chemical resistance, but somewhat inferior elasticity when compared with natural rubber. Butyl rubber tyres are claimed to have an average life of 20,000 miles at speeds below 40 m.p.h. Most of the present-day applications appear to exploit the electrical insulating and chemical resistance properties of butyl rubber.

*Neoprene*

This type of synthetic rubber, which is now well known in Great Britain, is formed from acetylene. This gas is carefully purified and passed into a solution of copper chloride (cuprous chloride) and ammonium chloride. A chemical reaction occurs which results in the formation of two derivatives of acetylene, vinylacetylene and divinylacetylene. These are carefully separated by fractional distillation and the vinylacetylene treated with hydrochloric acid to form chloroprene, a colourless and pleasant-smelling liquid. Chloroprene is readily polymerised under the action of heat and light to form a rubber-like mass which can be processed on ordinary rubber machinery. The commercial grades of neoprene are invariably compounded or mixed with various chemicals, such as magnesia, zinc oxide, wood rosin (natural product as distinct from resin, which is a synthetic material), etc., and vulcanised to the required degree of hardness. Neoprene latex is also available for the impregnation of cloth and paper and for several uses formerly satisfied by natural rubber latex.

A number of different grades of neoprene are manufactured to meet specific industrial requirements, such as high resistance to oils, chemicals, light, heat, impermeability to gases, electrical insulation and as an impregnant for balloon cloths, etc.

**NEOPRENE**  
IS MADE FROM



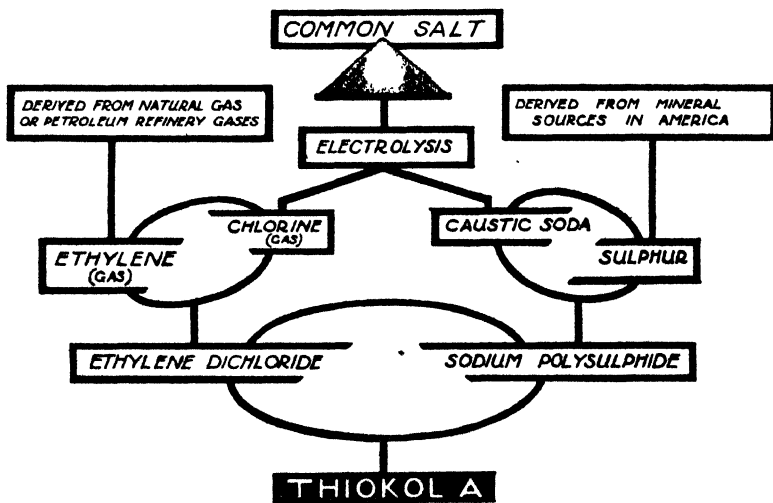
### *Vulcaprene A*

The constitution of Vulcaprene A, manufactured by Imperial Chemical Industries Ltd., Dyestuffs Division, has not been disclosed, but it is known to have a different structure from butadiene copolymers since sulphur is not used in its vulcanisation. It is characterised by its outstanding resistance to petrol, oil and many solvents, low permeability to gases and high resistance to ozone. It has excellent tack and adhesive properties, particularly to wood, leather and fibrous materials generally and is therefore used alone or in admixture with other materials as an adhesive.

A leather cloth of outstanding resistance to abrasion, flexing and scuffing can be obtained by mixing Vulcaprene with hydrolised leather dust and spreading this composition upon cloth.

### *Thiokol*

As mentioned previously, this product was the first rubber-like material, being produced in 1920. Thiokol A, made by mixing ethylene dichloride and sodium polysulphide, is still extensively used where extreme impermeability and resistance to solvents and gases are specified, such as for oil-resistant sheaths on cables and hose on tankers.



Thiokol is the earliest artificial rubber-like material and possesses great resistance to oils, petrol and various solvents.

Another type of Thiokol, the F Grade, also possesses very high resistance to oils, but is somewhat easier to fabricate. It is employed for various kinds of hose and tubes and coated fabrics for balloons, flexible tanks, rafts, buoys. Several other types of Thiokol are being produced, also Thiokol latex, which is used for coating purposes. By wringing the changes on the type of organic polysulphide used and the compounding ingredients chosen, as well as the vulcanising agent employed, it is

possible to secure a most comprehensive range of materials, varying from soft cements to ebonite-like mouldings. They all possess great resistance to solvents, chemicals, water, heat, and the penetration of gases. The major use for Thiokol to-day is for re-treading motor tyres.

### *Hycar*

This is an important new synthetic rubber which is available in several grades designed to meet market requirements for an oil and solvent resistant rubber and a high insulating rubber. The range of rubbers are made by co-polymerising butadiene from the petroleum industry with various other chemicals, including styrene, acrylonitrile, etc., in an emulsion form. The latex form is coagulated and the crumb washed and pressed into slabs, which are later processed in a similar manner to natural rubber. Apart from the use of Hycar grades for applications calling for oil and solvent resistance and electrical insulation, such as wire and cable covering, it is also recommended for mechanical goods. Various cements for bonding metal to metal or metal to wood are made with a Hycar base.

### *Koroseal*

Although generally included in any list of synthetic rubbers, this product is really a rubber-like plastic and is essentially a specially processed or plasticised form of polyvinyl chloride. Owing to the excellent flex resistance of this material it finds its principal application for tubing. Tests have shown that whereas ordinary rubber tube fails after 300,000 flexures, the Koroseal type is quite serviceable after being subjected to 3,000,000.

### *Compars*

This is the name given to compounded polyvinyl alcohol now so extensively employed for hydraulic hose, aircraft fuel tanks, protective aprons, etc. The various grades of this elastoplastic are capable of withstanding extremes of temperature without harmful effects, e.g., polyvinyl alcohol hose is able to maintain its flexibility at  $-56.7$  deg. C. and up to  $148.9$  deg. C.

### *Synthetic rubbers produced from vegetable oils*

Most vegetable oils can be processed to form rubber-like compounds which are useful for miscellaneous purposes, such as coatings, impregnating agents, gaskets, seals, hose, etc. When large surpluses of vegetable oils exist and prices have fallen to an optimum figure for industrial use, then considerable amounts of neo-synthetics may be thrown on to the market.

### *Silicone rubber*

Some very interesting and potentially important research and development work has been carried out on silicone rubbers by the General Electric Company of America. These new synthetic elastic substances are produced by combining organic chemicals with silicon oxide and the actual structure of the silicone rubber molecule consists of alternate

silicon and oxygen atoms with two methyl groups ( $\text{CH}_3$ ) attached to each silicon atom. Although a special technique of vulcanising has to be developed to modify the properties of the silicone rubber, when vulcanised, the compound retains elasticity for a long time at 200 deg. C. and will stand a temperature as high as 300 deg. C. for days.

#### *Natural rubber versus synthetic rubber*

In any comparison of natural and synthetic rubbers it is necessary to remember that in America and, to a much lesser extent, in Great Britain, the synthetic rubbers were originally developed to satisfy specific industrial requirements not satisfactorily fulfilled by plantation rubber, particularly resistance to petrol, oil, chemicals, heat and light. In Germany, however, synthetic rubber was developed as a strategic material necessary for the new mechanised war she was already planning. The avowed aim of the I.G. Farben was to produce a rubber from native resources that would render Germany independent of imports of natural plantation rubber. The intensive research carried out in Germany during the early 1930's was designed to increase all those properties necessary for a tyre rubber, and there is every reason to suppose that considerable progress was made, although the resiliency, elasticity and tensile strength of natural rubber were not equalled.

The specific gravity of Buna S and butyl rubber types is about the same as natural rubber, but Perbunan is slightly heavier, the figures being 0.91 to 0.93 for natural rubber against 0.97. Neoprene is considerably heavier, its specific gravity being 1.25, and Thiokol is 1.34-1.60. These figures are what might be expected, as neoprene contains chlorine, which is a much heavier element than carbon or hydrogen, and, of course, Thiokol contains sulphur, another moderately heavy element.

As regards tensile strength, the synthetic rubbers are somewhat inferior to plantation rubber, the figures being 350 kg. per sq. cm. for natural rubber, and approximately 300 kg. per sq. cm. for Buna S. The elongation of synthetic rubber is about the same, or even slightly better than that of natural rubber.

The factory-made rubber shows up rather disappointingly when it comes to resilience, or the ability to return quickly to its original form after stretching or compression, the latter being most important for tyre manufacture. In this respect natural rubber is definitely superior. As regards resistance to abrasion, there is not a great difference between the natural and the synthetic products.

For tyre manufacture synthetic rubber requires admixture with natural rubber to give the best results, otherwise there is a danger of 'flats.' Until the plantations of the Far East are in working order again it will always be something of a problem to meet the requirements of the motor trade.

#### *The future of synthetic rubber*

There seems little doubt that synthetic rubber has come to stay. It owes its genesis and growth to scientific research and its future to-morrow depends entirely on the progress made in our laboratory to-day. The great advantage of synthetic rubber is that, broadly speaking, it can be made to measure. Thus, if a manufacturer wishes to produce a material

suitable for a particular type of electrical insulation involving exposure to chemical fumes and water, he can, by suitable modification of the conditions of polymerisation and subsequent compounding, obtain a product able to meet those requirements. This is an important asset and ensures a much wider field for specialised products. It should be stressed here that synthetic rubber is most admirably suited for the difficult conditions where oils, solvents, chemicals, heat, light and ozone are known to be present.

Research now being undertaken on the physical structure of synthetic rubber must undoubtedly be reflected in improved physical properties, such as greater elasticity and resilience. It may be possible to orientate the molecule in some way so as to secure more typically rubber properties.

It is claimed by American authorities that synthetic rubber (G.R.S.) will eventually be produced at a cost even less than natural rubber, which in 1941 was selling in the U.S.A. at 20 cents per lb. There is a strong feeling among industrialists in America that even if natural rubber does come on the market at a price equal to or perhaps slightly lower in price than natural rubber, there are good economic reasons why a synthetic rubber industry should be kept alive. Its presence would, it is claimed, be a valuable insurance against a sudden world shortage of rubber or price manipulation by cartels. Against this argument is the fact that the supply of petroleum necessary for making synthetic rubber is threatened with a short life, and until atomic power can be harnessed to industry, it may not be possible to use petrol for making the tyres of automobiles, thereby denied of their fuel!

## CHAPTER V

### THE NEW WOODS

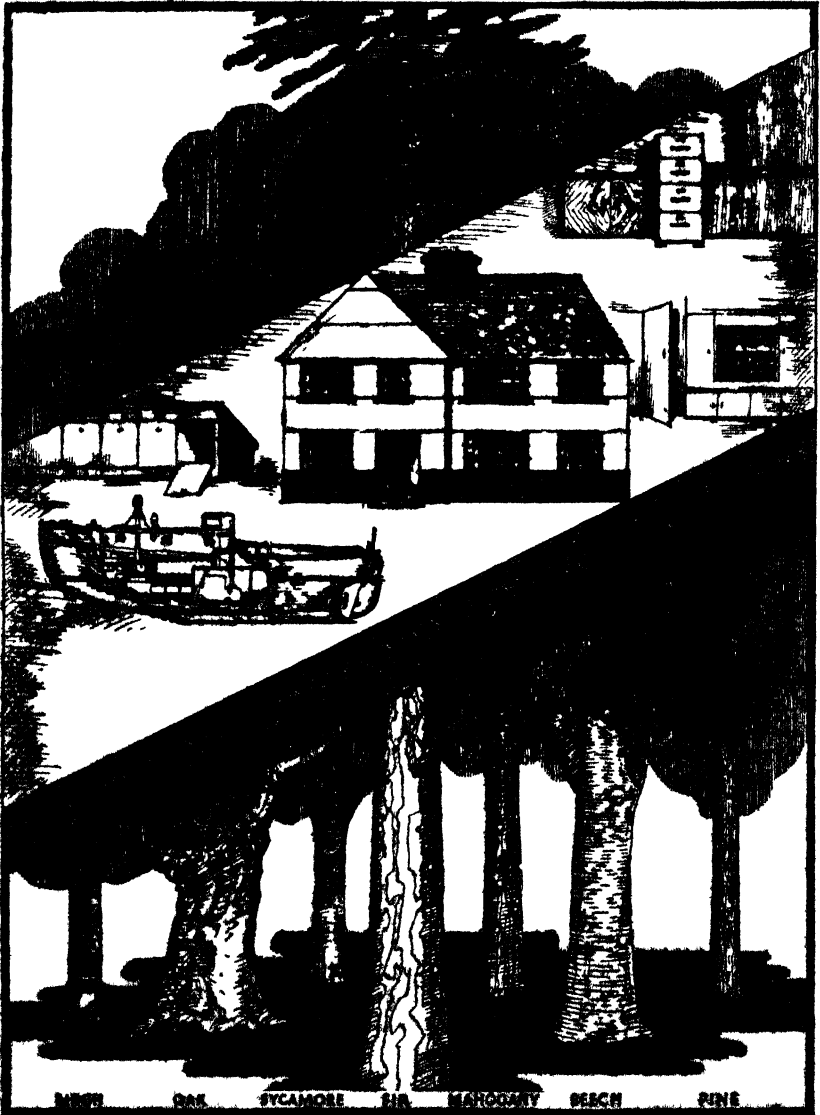
WOOD, THE OLDEST AND AT ONE TIME THE MOST PLENTIFUL BUILDING material in the world, is now taking on a new lease of life as a basic constructional material in conjunction with synthetic resins. When properly tailored, the new forms of wood prove amenable to revolutionary methods of fabrication which render them very acceptable to industry because of their favourable strength to weight ratio, and, what is even more important, particularly for aircraft and motor body plywood, their excellent stiffness to weight factor.

Although solid wood has a tensile strength equivalent to that of duralumin, when compared on a basis of equal weight, it possesses a number of serious disadvantages as a structural material. It is, for instance, variable in strength throughout its thickness and length owing to the presence of knots, cracks and other natural defects. Moreover, it absorbs moisture fairly rapidly and swells or shrinks according to gain or loss of water. This is a serious defect as it renders unprotected wooden structures at the mercy of the elements and dimensional changes are liable to take place which adversely affect serviceability. Add to this the facts that solid planks of wood require many months or even years of seasoning before they are suitable for working, and it is awkward and expensive to fabricate heavy sections of timber.



*The marriage of wood and plastics*

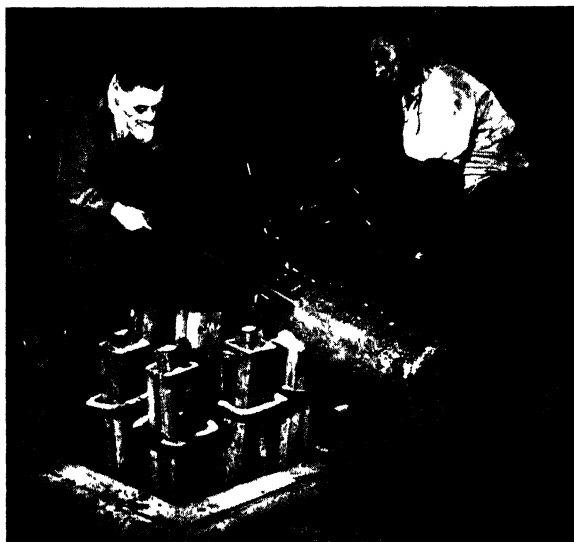
The use of synthetic adhesives in association with wood veneers not only renders possible the production of a robust plywood with a glue line impervious to moisture, fungus and insects, but the bond itself is even stronger than the solid timber. The new resin-bonded plywood



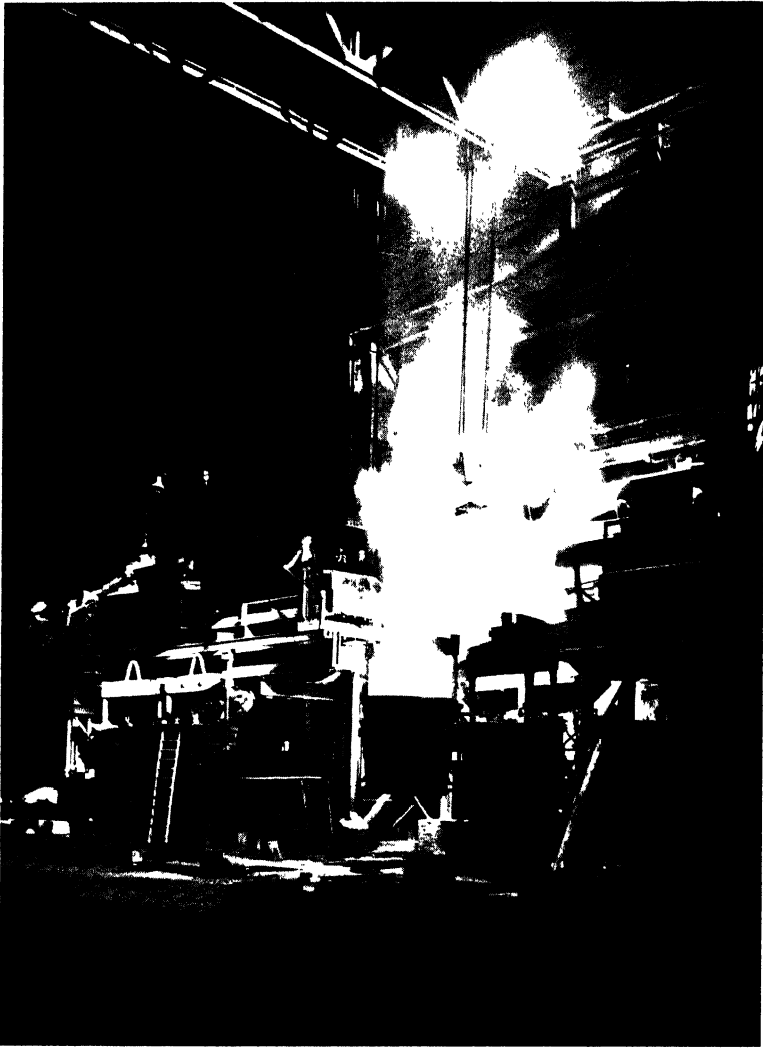
Plywood bonded with synthetic resin has a great future owing to its great strength, resistance to water (even boiling), fungi and vermin. Resin bonded plywood is to-day being used for building houses, furniture, boats, and many other things.



Siemens open hearth process, simultaneous tapping of three huge furnaces at the works of Thos. Firth and John Brown Ltd.



Crucible process of steel manufacture in the works of Thos. Firth and John Brown Ltd.



Tapping of an electric arc furnace in the works of Thos Firth and John  
Brown Ltd

structures have a mechanical strength that compares very favourably with metals when considered on a basis of equal weight. (A useful definition of veneers is that they are the thin sheets of wood produced by slicing, sawing or rotary cutting the solid timber.) It would be no exaggeration to say that this marriage of plastics and wood has produced a most versatile and talented family with inherited gifts from both parents. The natural fibrous structure of the wood gives great mechanical strength and the synthetic resin reinforces this strength, improves the stiffness and provides a bond that is impervious to all those agencies most prone to injure wood, moisture, fungi, bacteria, insects. The plastic bond is so tenacious that in tests to destruction the wood itself is sheared before the glue line.

### *Development of resin-bonded plywood*

Contrary to popular conception, plywood is by no means a new material, and veneered panels can, indeed, be traced back to the days of the Pharaohs about 1500 B.C., when Egyptian craftsmen piled sandbags on the veneers to provide sufficient pressure to ensure that the hide glue made a perfect bond.

Plywood received its first important chance as an engineering material during the 1914 World War, when it was employed for the stressed skin covering combat aircraft. It was found, however, that it suffered from one most serious defect, namely, its liability to delaminate when exposed to moisture or to conditions where mould or bacteria would grow and destroy the glue. This meant that plywood could not be relied upon for general use, and even the protection afforded by heavy dopes was not really adequate.

The adhesive employed in the manufacture of the early hot-pressed plywood was either casein or dried blood, both of which are animal proteins and therefore highly susceptible to moisture and the natural agencies of decay. Attempts made to improve the durability and general serviceability of casein glue by mixing it with lime were only partially successful as, although increased resistance to moisture was effected, the glue line became stone-hard and had an abrasive action on the tools used for working the wood.

The introduction of synthetic adhesives in plywood mills in 1929 to 1930 took the form of a phenolic resin-impregnated tissue paper, known as Tego Film, a German product, which was exclusively used for making aeronautical and shipping plywood. The original German Tego was later manufactured under licence in Europe and America and found extensive applications. Alongside with the development of Tego, liquid phenolic resins, either solvent solutions or emulsions, and urea formaldehyde and vinyl resins (Formvar) were introduced and adopted by the wood fabricating industries.

There is no doubt that the use of these synthetic adhesives completely revolutionised the plywood industry, as it enabled composite woods to be produced with great resistance to moisture, even unaffected by boiling in water or oil for many hours, and immune to attacks by moulds and insects. In addition, the glue line, which gradually increased in strength with use, was stronger than the solid wood itself. From the fabrication angle, the use of the new adhesives enabled plywood to be

moulded to shape and also greatly facilitated the rapid assembly of wooden structures by means of cold setting cements. The evidence is certainly very convincing that this marriage of convenience has proved a singularly happy one and produced a long issue of remarkable fabrications, including the Mosquito fighter bomber, which has played such a vital part in aerial warfare, and a long list of stress-bearing units for the ship-building, aeronautical and building trades.

### *Tego Film*

As mentioned previously, this is a phenolic resin-impregnated or resin-coated tissue paper. The paper not only acts as a carrier for the actual glue but reinforces the glue line, thus increasing the tensile strength of the properly assembled wood. This adhesive is very economical in use, as every scrap can be employed and there is no waste. In the manufacture of plywood by the hot press method, the resin film, which is supplied in large rolls, is cut to size and placed between the two veneers. The assembly is then transferred to a hydraulic press where it is subjected to heat and pressure for 3 to 15 minutes (135–162.8 deg. C. and 150–300 lb. per sq. in. pressure). The combined application of heat and pressure causes the phenolic resin to soften and flow so as to bond the two wood surfaces together, and this is rapidly followed by a hardening or polymerisation action which renders the glue line impervious to moisture, insects and fungi. Success in the manufacture of hot pressed plywood depends on several factors, but particularly the moisture content of the veneers and the conditions of pressing. The moisture content needs to be kept at the optimum figure, which varies from 4–10%, for the particular kind of veneer handled and the type of resin adhesive employed. Tego is most suitable for high-grade thin veneers.

### *Liquid phenolic glues*

There are now several of these excellent adhesives on the market and they fulfil the growing requirements of those plywood mills unable to employ the resin film. The liquid glue, which usually embodies a chemical hardener able to promote fairly rapid setting, is applied to the wrong side of the veneer by means of a spreader or machine equipped with two or three rollers, one of which spreads the glue on to the surface, and the other removes the excess. These liquid glues are more economical to purchase than the resin film and find a wider application.

### *Urea formaldehyde glue*

This is available in powder or syrup form. It needs to be mixed with a small volume of water in the former case, and in both cases is used in conjunction with chemical hardening agents which may be present in the glue itself, or more generally applied separately to the wood surfaces prior to gluing. Urea glues are suitable for the manufacture of plywood by the hot pressing method, and also for the assembly of wooden structures when the adhesives are known as cold cements, although a little heat is generally applied. For plywood the urea glue is generally mixed with rye flour, known as an extender. This reduces penetration of the syrup and reduces manufacturing costs. It should be pointed out that

although undoubtedly urea formaldehyde glue is most useful for assembly work, it is liable to craze, and for plywood manufacture it is not so reliable as the phenolic type.

### *Vinyl glues*

These are thermo-plastic as distinct from the thermo-setting or heat-hardening cements mentioned above. The well-known Formvar type of adhesive requires less heat during the actual bonding process and gives a more elastic bond than phenolic or urea glues.

### *Fabricating plywood veneers*

The modern method of rotary cutting, which consists of revolving the selected log against a knife running the whole length of the log, enables great economies to be effected in the use of solid timber and the production of veneers. The veneer as it comes from the log is taken away on a conveyor belt to the automatic cutters, where all knots and unsound portions of wood are removed. The veneer at this stage is cut into convenient widths and conveyed to the kiln driers, where the moisture content is reduced to the correct figure for satisfactory gluing. The veneers are next examined, graded and then joined together by means of a most ingenious machine called an edge splicer, which glues the edges of the plies and converts narrow widths into the desired size of sheet. The speed of joining up these pieces of veneer into sheets is at the rate of 100 ft. per minute, and the resulting edge joint, which is effected by means of urea formaldehyde glue, is just as strong as the veneer itself.

The next stage is gluing. Thin panels are made up of three sheets of veneer; face, core and back. Panels  $\frac{3}{16}$  in. and thicker are made with five or more veneers. These veneers are interleaved with Tego Film or other type of glue film, or they may be coated with liquid resin. If the latter course is adopted, it is necessary to dry the coated veneers in a low temperature drying kiln to facilitate subsequent handling and loading of the press. Very large hydraulic presses equipped with steam or electrically-heated platens or leaves are used, and the assembly or stack of veneers is placed between two sheets or cauls of polished steel or aluminium and loaded into the press, where the correct pressure and heat are applied.

### *Uses of high frequency methods of heating*

It is not practicable to use radio frequency heating for curing plywood boards of large area and thin section for the following reasons:

- (a) The plywood board forming the load forms a dielectric which is too large in capacity to resonate with the frequencies generally used.
- (b) The stress voltage necessary for heating would have to be too low due to flash over between the electrodes.

It is, however, possible to overcome the difficulties outlined above by placing the plywood sheets together in the press in a block, thus effectively decreasing the capacity of the condenser forming the load. Rapid heating of the plywood board is thus ensured. It is anticipated that this method will be very useful in the production of commercial plywood where the

limits placed on the difference in section across the board are not too close. Radio or high frequency heating is particularly suitable for bonding together a large number of plies or veneers in the manufacture of very thick sections, multi-plywood (improved wood) which is already finding uses for bulkheads, spars, booms, pulleys, masts, deck houses, floor boards in vehicles, etc.

#### *Infra-red heating*

The American aircraft industry has made good use of infra-red radiation for the curing of joints of wooden assemblies. The wood itself is not over-dried or in any way injuriously affected, whilst the glue line quickly reaches a setting temperature and excellent bonding is ensured. The infra-red method of heating is only suitable for joints that are not too deep seated, as wood is, of course, opaque to the red rays.

#### *Strip heating*

For the production of shaped plywood units, use is now being made of strip heating by means of low voltage electricity. The heated metal strips are laid along the glue joint and pressure applied in the normal way by means of the pressing jig. The great advantage of this method is that heat can be locally applied exactly where it is most required and the temperature carefully controlled so as to give the strongest joint without over-drying the wood. In the manufacture of furniture, building units and possibly motor-car bodies, strip heating will undoubtedly prove of the greatest value.

#### *Moulding plywood by the rubber bag method*

In principle, the rubber bag method of moulding or shaping plywood is relatively simple. It consists of using an inflated or deflated rubber bag as one of the halves of a pair of moulding dies. The veneers coated with synthetic adhesive, or interleaved with Tego Film held in position with adhesive tape, are placed over a wood or metal mould. The veneers are prevented from moving by means of tacks in the case of wooden moulds, or tape where metal dies are employed. The whole assembly is then placed in a rubber bag provided with a vent to atmosphere by way of a flexible metal hose. The air is removed from the bag by a compressor and the complete outfit then placed in a large autoclave. A pressure of 50-100 lb. per sq. in. of steam is applied, and there is an increase of temperature amounting to about 190-300 deg. C.

As soon as the baking process is completed, which may take only a few minutes, or an hour or more, depending on the size of the mould and thickness of the plies, the assembly is removed. Where vinyl or other thermo-plastic glues are employed it is, however, necessary to cool the bag with a spray of cold water so as to set the glue before taking the bag out of the autoclave.

So-called rubber bag machines are now in use for small components. The machine in this case consists of an electrically heated platform on which the metal mould is placed. The veneers are laid over the die or mould and pressure applied by a rubber bag which is heated with hot air to the required temperature.

Instead of placing veneers over a die, shapes can be made by wrapping very thin resin-coated veneer tape round a mandrel. This method is particularly useful in the case of unusual curves and difficult shapes generally. Staples are often employed to keep the veneer in position. The mandrel, when properly covered, is placed in a rubber bag and subjected to sufficient pressure to convert the veneer tape into a solid and extremely strong plywood.

#### *The strength and serviceability of resin-bonded plywood*

The strength varies according to the conditions of bonding, that is, actual time in the press, temperature of the press platens, pressure and, what is most important, the moisture content of the veneers. By the use of very thin veneers and by arranging these in different ways so that the grain is criss-crossed, or in the same direction, and by increasing the resin content, the strength of the finished plywood may be varied. To ensure absolute uniformity of strength, which is a most important consideration for plywood intended for constructional work, there must be standardisation of a number of different conditions. In modern plywood manufacture this is done almost automatically.

High-grade plywood intended for aircraft work and made up of three plies of the same thickness may have a tensile strength of 18,700 lb. per sq. in. along the grain and 2,200 across the grain; spruce can be 7,950 lb. per sq. in. along the grain and 900 lb. per sq. in. across the grain.

The most important property of resin-bond plywood is its great resistance to water. Whereas solid timber warps, shrinks and cups after exposure to long hours of moisture, and ordinary plywood delaminates, resin-bonded plywood is quite unaffected. Specimens of resin-bonded birch plywood have been immersed for two weeks in water, exposed two and a half months to open air, again immersed two weeks in water, and so on for a period of two years, yet at the end of this gruelling test shown no decrease in strength of the glue line. Resin-bonded plywood can be boiled in water for 48 hours without delamination, and even boiled in oil for 15 days at a temperature of 140 deg. C. without suffering any noticeable deterioration. The writer has examined a specimen of phenolic resin-bonded plywood that has been boiled in 15% caustic soda solution for several hours, followed by heating on a blacksmith's anvil to dry out, all without separating the plies. Recent tests carried out at the Forest Products Research Laboratory have shown that resin-bonded plywood when soaked in cold water for twenty-four hours, and subsequently frozen for a day at -50 deg. C. (-23 deg. F.) and then thawed, showed no signs of deterioration or loss of strength. Even when holes were made in thick plywood sections and then filled with water, frozen and allowed to thaw, and finally dried rapidly, there was no loss of strength in the adjacent glue line.

Resin-bonded plywood has been soaked in water for over a year and exposed to mould, bacterial growth and insects throughout that time, yet the wood has, at the end of the test period, shown no ill-effects.

#### *• Future uses of resin-bonded plywood*

There is obviously a great future for a material that is stronger per pound than steel and more mobile per yard than timber, waterproof,



vermin-proof and heat-resistant, will not split, crack or bulge and is very light in weight, as well as being available in large smooth, leak-proof surfaces.

The plywood pre-fabricated house is a practical commercial proposition and forms one solution for the re-housing problem. True it is likely to cost a little more than one made of brick or concrete, but it offers many important advantages and is, in addition, very much easier and quicker to construct. Naturally the brick and concrete interests are firmly entrenched and will not lightly accept the challenge from plywood manufacturers. It is quite possible that there may be a campaign to belittle its value as a serious engineering material.

During the war, plywood was used for the decks of boats, platforms of searchlights, small bridges, and, of course, in the construction of aircraft. Now that the war is over plywood will be employed instead of solid wood or metal for building railway coaches and the flooring and sides of lorries. It has been suggested in America that the plywood car body might well be used in combination with a 150-lb. aircraft-type motor and aircraft running gear to produce a sensationally light-weight car, possibly about 1,000 lb. Ray Russell, Detroit plastics engineer, built the first plywood motor-car body in 1942. It weighed only 2,500 lb., a saving in weight of 600 lb. on the body alone. This designer claimed that in mass production such a body could be formed and bonded in one operation, using a phenolic type of resin.

One of the most interesting applications of plywood in building practice is for shuttering. The large, light-weight resin-bonded panels are so easy to handle that one man can cover an entire floor which would normally require a gang of five. The new plywood shuttering can be used at least five or six times as often as solid wood planks, and recently the same shuttering was used sixty times in the construction of a conduit. It was then still serviceable for the roofs and walls of contractors' huts. The large size of these shuttering panels greatly reduces the footage of joints and, because they shrink and expand to such a very small degree, the joints stay tight, with the result that there is a great saving in concrete and an amazingly smooth finish.

For large sewer projects it is customary to use trench supports consisting of timber sheeting, wales and braces which are cumbersome to fix in position and require extra width of trench to allow for the thickness of the timber. A replacement now advocated by engineers is plywood panels held by trench jacks. Work actually carried out in the U.S.A. under the W.P.A. showed that 12,500 sq. ft. of plywood was sufficient for  $1\frac{1}{2}$  miles of 21 in. to 36 in. sewer, 14 to 21 ft. deep. After exposure for four months and repeated re-use, 65% of the plywood was salvaged, and with 13,400 sq. ft. of new material was used on another two-mile project.

Resin-bonded plywood will most certainly be widely used for furniture manufacture, including garden furniture, packing cases, especially for valuable merchandise going to the tropics, poultry houses, laundry boxes, motor trunks, laboratory bench tops, shop fitting purposes, outdoor signs, domestic flooring and panelling, caravans, etc. There is no possible doubt that resin-bonded plywood is one of the most important constructional materials of the age and has a great future. For practically every application where solid wood was normally employed, plywood can give better results. Experiments carried out on canal lock gates, which are

always made of solid timber and by reason of dimensional movement due to shrinkage or expansion cause considerable trouble, and incidentally, allow a lot of water to escape, have shown that when these gates are built of multi-plywood they give much better service. It is possible, therefore, that the lock gates of the future may be built of plywood.

The use of resin-bonded plywood for 'blown' or sandwich constructions is of considerable importance and it is likely to find many uses in building. The material Jicwood X consists of thin plywood (plastic or light metal) skins permanently resin bonded to a low density expanded plastic or synthetic rubber core. The purpose of the core is to stabilise the skins and to prevent them from buckling; in addition, the cores used have a thermal insulation (B.Th.U. 0.23) some 33 per cent better than high-grade cork. The material combines with these insulating properties a remarkable rigidity/weight ratio and freedom from subsequent distortion. It is non-water absorbent, vermin and bacteria proof and can be made resistant to fire. During the war Jicwood X was used principally in the manufacture of aircraft fuselages and stressed parts (such as bomb doors, undercarriage doors, flooring, etc.) and in the construction of deck-houses for motor gunboats, R.A.F. rescue craft and human torpedoes. More recently, it has been used for the pre-fabrication of houses. It is suitable for pre-fabricated structures of all types, bus and railway coaches, caravans, boats, etc., in fact, all stressed applications.

#### *High duty woods*

Ordinary plywood is manufactured by hot-pressing softwood plies coated with natural or synthetic adhesives at moderate temperatures and pressures. The compression does not usually exceed 10% and is often much less. If very thin veneers, say 1/36 in. thick, of hardwood are coated with synthetic resin, packed together in a large hydraulic press and subjected to a temperature sufficient to fuse and flow the glue and a pressure of many hundred tons, then the degree of compression will greatly exceed 10%, and may be as much as 50% or more. The character of this new manufactured wood, which has a density of about 82 lb. per cu. ft. compared with 47 lb. per cu. ft. for solid beech (hardwood), is dictated largely by the following factors :

1. Type of wood.
2. Thickness of wood.
3. Percentage of moisture present.
4. Arrangement of veneers in the pack.
5. Type of synthetic adhesive employed.
6. Percentage of resin present in the finished wood.
7. Temperature of bonding.
8. Pressure exerted in the press.

It is possible to ring the changes on production to a considerable extent; thus, by using very thin veneers, say 20/1000 in. thick, and increasing the resin content by vacuum impregnation, it is possible to obtain a commercially useful dielectric suitable for switchgear construction. High duty woods are to-day used mainly for variable pitch airscrew blades mainly of the high-performance type of fighter aircraft, and consists of Canadian or American birch veneers bonded together

under high pressure. Whilst thermo-setting resins are used to the greatest extent for bonding the veneers, one important new high duty wood makes use of a thermo-plastic cement (Formvar), the material, Hydulignum, is a well-known British high duty wood utilising this type of bonding agent. It is unique in the fact that the use of a thermo-plastic adhesive enables the wood to be pressed in one plane, then cooled and re-pressed in another, thus producing a variable density. The majority of the airscrew propellers made of Hydulignum have a density at the outer part towards the tip of 60 lb. per cu. ft., and at the root, to which the metal ferrule or "adapter" is fitted, of 82 lb. per cu. ft. In addition, the thermo-plastic cement being itself an elastic type of plastic, endows the wood with unique resilience and thus renders it particularly suited for applications where a high resistance to flexing or shock is required. The tensile strength of Hydulignum is 45,700 lb. per sq. in.

#### *Chemically Treated Wood*

A good deal of work has been carried out in America on the chemical treatment of wood, and prominent among the modified woods is Uralloy. This is ordinary wood, hard or soft, impregnated with a hot saturated solution of urea. Uralloy can, in its first stage, that is, immediately after impregnation, be bent or twisted almost any desired shape, and when the urea solution sets or polymerises inside the pores of the wood, then the wood takes on the required shape. Treatment of wood with urea results in the formation of certain resinous bodies actually inside the wood structure and so converts wood into an entirely new type of constructional material. This is exceptionally hard and strong and suitable for a large number of industrial purposes. By the use of urea and the simple technique outlined above it is now practical to convert cheap softwood into hardwood, and moreover a hardwood that is resistant to moisture and abrasion and does not require long seasoning to render it fit for use.

## CHAPTER VI

### THE NEW STEELS

**WAR IS A GLUTTON FOR STEEL AND MAKES INCREASING DEMANDS ON THE industry for ships, tanks, guns, shells and all the other engines of destruction. Every new alloy that is harder, stronger, and more resistant to corrosion than its accepted counterpart represents a technological victory, often of the greatest tactical importance. Every improvement in plant which enables a higher quality of steel to be produced or which renders possible economies in time and labour is an advantage which may be realised in a practical way as superior armour for tanks and ships and more deadly artillery and small arms.**

Whilst the soldier thinks of war in terms of territory, prisoners and booty, the industrialist views it in terms of material development, either quality or quantity, made possible by the joint efforts of the metallurgist, the engineer and the technician.

**It comes as something of a shock to many people not actually engaged**

in the steel industry to learn how much Great Britain depends on imports of raw material to produce high-grade steels. In schools they still teach children that coal and iron ore are two of Britain's most important natural raw materials. There is still plenty of coal and fairly plentiful deposits of ore, but this, unfortunately, is mostly low-grade and, before the war, had to be supplemented by imported high-grade ore from the Scandinavian countries, India, Spain and French Africa. In 1939 nearly four-fifths of the raw materials of the steel industry (excluding coal) were imported from overseas.

It will be appreciated that with the fall of France in 1940 the British steel industry was faced with an emergency unprecedented in any industry. The rich ores from Narvik, billets from Sweden and high-grade ores from French North Africa became only records on bills of lading. In addition we were cut off from many of the normal sources of supply of the alloying elements, e.g., ferro-alloys from Scandinavia; 20% of our chrome ore from Greece; 20% of our tungsten from China, and nearly two-thirds of our titanium from Norway, as well as 10% of our nickel. Nevertheless, our Empire had normally supplied 94% of our manganese, 65% of our chrome ore, 87% of our nickel, and 63% of our tungsten.

The crisis was met with great energy and resourcefulness, and the industry quickly re-orientated itself so as to use large quantities of low-grade ores. This entailed important alterations to plant and development of new processing schedules. It speaks well for the adaptability of an industry run by private enterprise that it never failed the nation in its darkest hour.

If steel is indispensable to war, it is also vital to the needs of peace when the fabric of civilisation has to be repaired. Metallurgical victories gained in war, when research laboratories are working at high pressure to discover new alloys and to establish technological supremacy over the enemy, are able to make substantial contributions to the reconstruction period which now follows.

Although it might at first appear that the war-inflated steel industry can face the future with confidence owing to the enormous demands of the building trade, motor industry and civil engineering concerns, etc., it remains to be seen if British steel will be able to compete with American steel for the export trade. The manufacturing cost of American steels is less than that of British steels and there is no possibility that the figures can be improved as home manufacturers will have to import the raw materials as they did in pre-war days. The use of low grade ores is generally uneconomical in peace time. The latter fact is a disturbing thought when viewed against a background of demobilisation. That the British steel industry is fully alive to the dangers of intense foreign competition is evidenced by the impetus given by the Iron and Steel Federation to co-operative research. A new permanent organisation, the British Iron and Steel Association, will have authority to spend up to £250,000 a year on research. This amount is, of course, independent of the sums spent by individual firms and by the Department of Scientific and Industrial Research.

#### *Types of steel*

Carbon steels are generally regarded as steels containing up to about 1.7 or even 2% carbon with not more than 1.5% manganese and 0.5%

silicon. The tensile strength of an unalloyed steel (*i.e.* a steel not containing other elements) is largely a reflection of its carbon content. For example, a 0.10 to 0.20% carbon steel has a tensile strength of 24 to 30 tons per sq. in., whilst a 0.55% carbon steel with normal heat treatment will possess a tensile strength of about 45 tons per sq. in., but it can also be treated to give higher tensile strengths. By varying the composition of the steel and modifying the physical treatment, an infinite variety of steels can be obtained, each one possessing clearly defined characteristics. For all types of light pressed machine fittings, stampings and pressings employed in aircraft and motor-car manufacture a carbon steel (0.20–0.30%), which has been afforded heat treatment up to 900 deg. C., is suitable. A carbon content of 0.50% and heat treatment about 840 deg. C. gives a steel suitable for cylinder barrels of aircraft engines required to resist wear.

The plain carbon steels, which might well be termed the bread and butter lines of the industry, are strong and excellent for a large number of general engineering uses, but alloy steels are recommended for the construction of the very highly stressed parts employed, for example, in aircraft or motor-car manufacture and in the chemical processing industries, where resistance to heat and corrosion is demanded. To produce these it is necessary to use a selection of alloying metals. Manganese, in an amount of the order of 0.3 to 0.7%, is an essential constituent of practically all steels, its function being the production of soundness and the prevention of blow holes. It is often added to structural steels in amounts up to 1.5% to improve the tensile strength without seriously affecting the ductility. Chromium improves the wear resistance and markedly raises the tensile strength without decreasing the ductility to any appreciable extent. Tungsten is widely used in tool manufacture; it increases the toughness for the same hardness and renders the carbides much more stable, so that the steel is not softened by the heat generated in use. A typical high tensile alloy steel with a strength of about 100 tons per sq. in. may contain about 0.30% carbon; 0.25% silicon; 0.50% manganese; 4.25% nickel; 1.25% chromium. This steel is an air hardening steel, *i.e.* it can be hardened by merely cooling in air from a temperature of about 870 deg. C. Modern alloy steels, containing as they do various combinations of elements, are exceedingly complex, and their production demands the closest chemical and physical control in order to meet the exacting requirements of the engineering industry. The composition must be standardised within very close limits and subsequent chemical and physical treatment so regularised as to produce absolutely uniform results. The metallurgist has to secure hardness without incurring internal stress or distortion and high strength without losing the requisite degree of elasticity, always it is a question of balancing various kinds of treatments and compositions to ensure absolute uniformity of mechanical strength throughout the mass of metal.

### *The manufacture of steel*

Before the invention of the open-hearth or Bessemer processes steel was made by carbonising wrought iron. This was effected by heating bars of wrought iron in specially constructed cementation furnaces, at a

temperature below the melting-point of iron, until the bars became impregnated with carbon. These bars were then forged down into 'shear' steel or melted down in fireclay crucibles by the Huntsman process.

About fifty years ago nearly half the steel produced in this country was made in the Bessemer furnace, but this was gradually superseded by the open hearth until, in the years immediately preceding the war, only about 5% of our total production was Bessemer steel. In modern German practice, however, owing to the high phosphorus content of their native ores, basic Bessemer steel still represents nearly half the total production.

The Bessemer converter consists of a pear-shaped mild steel vessel lined with a refractory material of either basic or acid nature according to the quality of the raw material charged. Molten pig iron is poured into the converter, and air, which is blown through the metal, raises the temperature sufficiently to cause the oxidation of the silicon, carbon, sulphur and manganese, and in the basic process the phosphorus passes into the slag, which thus enriched with phosphates becomes of considerable commercial value as a fertiliser. The acid Bessemer process is devised to deal with relatively high silicon irons and the basic Bessemer deals with the low-grade high phosphorus irons.

Over 90% of the steel produced in this country is made by the open hearth process. The open hearth consists of a shallow trough lined, in the acid process, with ganister or silica sand fritted together with iron oxide, and in the basic process, with magnesite or dolomite. In either process the roof and walls of the furnace are constructed of silica brick. In the back of the furnace is a tap hole stopped with a refractory material. The charge, pig iron and scrap, is charged on to the hearth and the heat is turned on. To obtain the required high temperature the gas and air used in the combustion are pre-heated before entering the furnace by means of heat absorbed from the hot waste gases. Combustion takes place above the hearth and across the furnace. At the melting stage, the temperature is about 1550 deg. C. Fluorspar is added to give fluidity to the slag and feeds of iron ore and limestone are given until the 'boil' is attained at a temperature of about 1630 deg. C. The 'boil' is caused by bubbles of carbon monoxide liberated by the reaction of the carbon in the charge and the iron oxide in the ore, which burst through the slag and burn on the surface with a blue flame. The molten metal is tapped when the carbon content is reduced to the required degree and the slag floats on the surface of the molten steel and flows away at the end of the tapping operation. In both acid and basic processes silicon is oxidised and passes into the slag, carbon being removed by reaction with the iron oxide when the silica content of the slag attains a certain value, silicon and manganese begin to be reduced from the slag and pass into the molten metal where they complete the deoxidation of the steel. This stage of the reaction is maintained for some time before tapping. In the acid process there is no decrease in the sulphur and phosphorus contents of the charge and therefore only high-grade irons can be used, but in the basic process lower grades of the ore with high phosphorus contents can be used, as the phosphorus reacts with the basic lining and passes into the slag, whilst the manganese acts as a de-sulphurising agent. The

basic open hearth process does not, however, give such complete facilities for deoxidation as exist in the acid process, and 'acid' steels are regarded as of higher quality than basic steels.

High alloy steels are generally produced in the electric furnace, as in this process the composition of the steel is under close control; impurities such as sulphur and phosphorus can be limited to less than 0.01%, and the steel is particularly free from non-metallic inclusions. These furnaces may range in size up to about 30 tons. The hearths are basic, *i.e.* they consist of either dolomite or magnesite bonded with tar, crushed basic slag being frequently mixed with the dolomite to assist in bonding the hearth at the high temperature used in this process. The charge consists of scrap which is first melted under a basic slag for the removal of silicon and phosphorus. This slag is then removed and a refining slag added. The average time from charging to tapping the steel in this process is about six hours.

The most recent development is the high frequency induction furnace in which the capacity ranges up to about one ton. The refractory vessel in which the steel is melted is wound by a water-cooled copper coil through which the current is passed. When the charge, consisting of steel scrap, is melted the electro-magnetic forces developed give to the metal a swirling motion which ensures homogeneity, and is of considerable advantage in the production of steels containing heavy elements such as tungsten. The average time for the completion of a heat by this process is about one hour.

A point that has emerged in the foregoing description of steel manufacturing processes, but which may be emphasised as it is often overlooked by the layman, is that steel contains less carbon than cast iron. A carbon content of 2% is very high for steel, but cast iron may contain as much as up to 10%.

### *Heat and mechanical treatment of steel*

Steel has a form of crystallisation depending upon the method and rate of solidification which, in the untreated casting, endows the metal with certain inherent weaknesses. The primary coarse crystallisation is only completely broken up when distortion by forging or hot working operations takes place, as well as re-crystallisation brought about by heatings and coolings above and below the recalcence temperature of the steel. If a steel containing approximately 1% carbon is heated to a high temperature and then suddenly cooled it becomes hardened steel, and is so hard that it will scratch glass, but so brittle that it soon snaps when bent. Annealing is a method of controlling physical properties of steel, particularly its hardness and ductility, by re-heating hardened steel and cooling it under certain controlled conditions. Tempering is the re-heating of hardened steel at fairly low temperatures.

Steels differ a great deal in their reaction to forging, thus whilst very mild carbon steels are relatively easy materials to handle, the higher carbon steels require more care, and some of the alloy steels containing relatively large proportions of chromium, tungsten, etc., are more difficult to work owing to the risk of cracking or tearing of the metal.

Unless the metal is uniformly heated during forging, non-uniform

thermal expansion effects, take place which set up substantial thermal stresses and so constitute a serious weakness liable to cause a fracture. To ensure freedom from fractures it is essential that the greatest care is exercised not only during heating, but also during the cooling of the steel forgings, particularly if their dimensions are exceptionally large. The determining factors are the shape and size of the piece and the speed of cooling, as well as the analysis and previous thermal history of the steel.

Hot deformation or working of the heated steel which is necessary to break down the crystalline structure of the metal takes several forms, such as hammering, pressing, rolling, etc. In the steam hammer deformation, a tup of substantial weight is lifted and then dropped or forced downwards so that it acquires a substantial velocity, and with the momentum corresponding to that velocity, the face of the tup or tool strikes a blow on the waiting hot mass. The press, instead of exerting a blow, exerts a direct squeeze generated from the pressure of the hot working cylinders and more effectively kneads the centre material than the hammer, although the latter is sometimes preferred owing to its rapid breaking-down effect on the crystalline structure in the material being forged, particularly in the zones near the surface. The principle of the rolling mill is really that of the press except that the point at which the squeeze is applied is continuously transferred as the metal passes through the rolls.

After deformation and change in the crystalline structure of the metal it is usually necessary to give it some kind of heat treatment, which may be annealing or normalising. The latter is similar to annealing and consists of heating the metal to about 50 degrees above the recalescence temperature and allowing it to cool in the air. Other methods of heating entail water, oil or air hardening and tempering, or oil toughening, which comprises an oil quenching operation in which the cooling is interrupted after a period and the heat remaining in the forging allowed to distribute itself throughout the mass, which produces a self-tempering action.

Castings as well as forgings are usually submitted to an annealing or normalising treatment; that is to say, the mass is slowly heated up to a temperature which will permit of recrystallisation of the steel and consequent removal of the original cast structure. Close pyrometric control is necessary as well as periodic microscopical examination of structure to ensure uniform results.

### *Special steels*

Of the various types of steel the following may be mentioned: carbon steels, medium tensile alloy steels, high tensile alloy steels, case-hardened steels, nitrided steels, spring steels, ball-race steels, non-expansible steels, high expansion non-magnetic steels and magnet steels. It is not proposed to describe all of these, but to discuss briefly some of the more special steels likely to assume great importance in industry.

Stainless steels are chromium alloys with varying carbon content. The range includes stainless iron and stainless steels containing 12-15% chromium and carbon up to 0.35%; 18% chromium, 2% nickel and 0.15% carbon, and 18% chromium, 8% nickel and other alloy elements in small proportions. (Famous Staybrite steels.)



During the last few years increasing use has been made of corrosion-resistant steels in the chemical and processing industries. In the manufacture of nitric acid the special chromium nickel steels, containing approximately 18% chromium and 8% nickel, are very suitable and extensively used for plant. They are also widely used for the plant required for the production of fertilisers. The 18-8 chromium nickel steels with 3% addition of molybdenum is resistant to glacial acetic acid and other chemicals normally very severe on steel. For the cracking of oil at relatively high temperatures, the hydrogenation of coal, low temperature carbonisation and tar distillation these special steels, particularly the 18-8 group of steels, are recommended. In the processing industries where contact is made with corrosive chemicals and solutions this group of steels finds many uses, which vary from filter presses and pipe lines used in paper mills to soap-making kettles and vats for dyeing textiles. There is undoubtedly a great future for the stainless steels in industry.

Modern high-speed tool steels usually contain fairly high proportions of tungsten or molybdenum and cobalt with small quantities of vanadium.

The range of tool steels manufactured by Thos. Firth and John Brown, Ltd., include one containing 18% tungsten, 4% chromium, and 1% vanadium, which may be employed for machining forgings, castings, alloy steels, cast steel and steel railway tyres. A still higher grade steel contains 22% tungsten and some vanadium, whilst super-high-speed steels possess 10% cobalt tungsten or tungsten-free molybdenum cobalt. Non-shrinking steels for tools and dies contain 1½% to 2% manganese and saw steels are tungsten steels with or without small proportions of chromium.

Heat-resistant steels for engine parts may contain 13% chromium; up to 30% each of chromium and nickel, and up to 4% tungsten, and also up to 60% nickel and 20% chromium. There are a so special valve steels containing 8% chromium and 3½% silicon (S.L.V. silicon chromium valve steel made by Firth Vickers). The presence of chromium and nickel enables steel to retain mechanical strength up to higher temperatures than when those elements are absent. During the present war great progress has been made in the development of new heat-resisting steels for internal combustion engines, which is reflected in the greatly improved performance of British aircraft engines. Alloys containing 15-25% chromium, with 60-80% nickel, exhibit good resistance to oxidation up to about 1,150 deg. C., combined with good mechanical properties at high temperature.

Special hardened steels are now in the greatest demand for aero engines, where the parts are required to stand up to very heavy bearing loads as well as increased bearing speeds. It is not always realised that every increase in the efficiency of the engine due to the use of high octane fuel, now over 100, and changes in design, throws a heavy strain on the wearing parts. The metallurgical contribution is a vital one to the success of every new type of engine. Nitrided steels are the latest addition to the range of steels of extreme hardness. They are special steels which are surface-hardened in an atmosphere of ammonia gas by a low temperature treatment and produced for items of engineering equipment requiring maximum resistance to abrasion. The hardness

secured by nitriding these special alloy steels is much greater than is obtainable with steels hardened by any other method, the diamond hardness numbers ranging from 1,050 to 1,100 or even higher. Although nitrided steels cannot be included in the stainless steel category, they are, nevertheless, in the nitrided condition, extremely resistant to the corrosive action of fresh water, sea water, steam or moist atmosphere. The full nitrided hardness is retained up to a temperature of 500 deg. C., particularly when the nitrided surface is not in contact with the heat for prolonged periods, which is a great advantage over other surface-hardened steels which begin to soften at about 200 deg. C. For engine parts such as bearings, liable to become overheated due to faulty lubrication, etc., there is much less risk of seizing when nitrided steels are used than with ordinary case-hardened metal. One example of these nitrided steels, Nitralloy LK.I., made by Thos. Firth and John Brown, Ltd., contains 0.50% carbon, 0.35% silicon, 0.65% manganese, 1.60% chromium, 1.10% aluminium, and 0.20% molybdenum. This has a maximum tensile strength approaching 100 tons per sq. in. (98.4).

In many different industries these specially hardened steels are likely to prove of the greatest practical value. Thus in motor-car manufacture, where it is necessary to reduce cylinder wear to a minimum, nitrided steels will undoubtedly prove invaluable, also for water pump spindles, brake drums, steering gear parts, etc. In the brick, concrete and cement industries, nitrided steels are likely to be employed for brick-press liners, air-ring liners, kerb and slabbing press plates and scores of other wearing parts subjected to the abrasive action of these difficult materials. For modern machine construction where increased speed and high precision limits make extra demands on materials of construction nitrided steels are likely to be specified. A modern application of considerable interest is the use of nitrided steel for the dies required for the manufacture of plastic articles where an exceptionally hard and fine surface finish is required. In modern railway, electrical and tramway engineering, mining, quarrying and the ceramic industries nitrided steels will undoubtedly play an increasingly important role.

During the war alloying material has been reserved for essential purposes. Nevertheless, intensive research on alloy steels was continued throughout the war years. Knowledge gained cannot yet be made known, but reference may be made to the investigations carried out, in connection with machine tools, on high speed cutting steels and the sintering alloys such as the hard metal carbides. The development of scale and heat resistant steels for the aircraft industry has obviously been of first importance and in the field of high tensile steels it can be safely stated that during the next few years alloy steels possessing considerably higher tensile stress will be available.

## CHAPTER VII

### LIGHT METALS

SOME YEARS AGO THE FAMOUS SCIENTIST ARRHENIUS WROTE A BOOK called *Chemistry in Modern Life*, in which he predicted that the time would come when the workable deposits of iron ore would become

exhausted and civilisation forced to rely on light metals. As aluminium is present in the earth's crust to the extent of 8% as against 5% for iron, this might appear somewhat likely. Unfortunately, however, science has not yet discovered an economical method of extracting the so-called 'silver in clay' from the clay itself. It is, however, interesting to note that aluminium can be extracted from clay, and plants have been built during the war for doing this. The processes are more expensive than those using bauxite and are not competitive in normal times.

If an 'Age of Light Metals' does arrive it will not be due to any lack of iron, there are still many billions of tons awaiting exploitation, but rather to several co-related and co-ordinated factors, such as the existence of war-swollen electro-metallurgical and fabricating industries which possess the equipment and organisation necessary to supply world markets. Add to this the fact that technological improvements, mainly due to war stimulus, have increased the peace-time usefulness of aluminium and magnesium alloys and rendered them more attractive and acceptable to industry. War-time alloys originally developed for aircraft engine crank-cases and air-screw blades can be fabricated into essential components for new light-weight motor-cars, modern furniture, radiators, bridges and railway coaches. It is not a question of turning swords into ploughshares, but aircraft parts into useful commodities of peace.

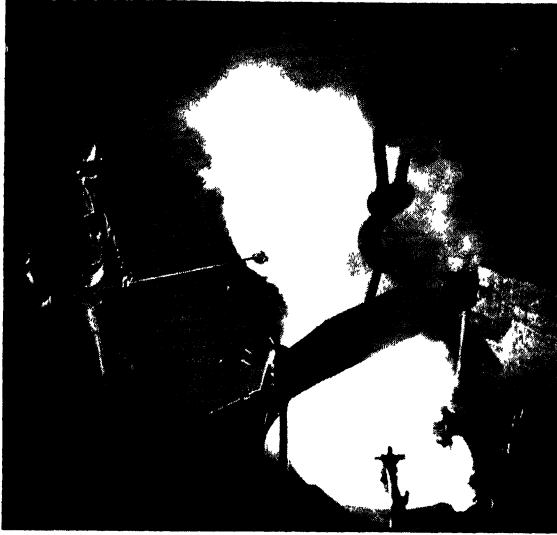
During the second World War the light metal industry was presented with its first great opportunity to make good, and this it succeeded in doing to the satisfaction of the industry. The industry, during the critical years of war, grew in size and importance so that it promises soon to become a veritable giant, towering like Steel amongst the materials of to-day and to-morrow. (During the first World War full use was made of aluminium alloys by the Germans for building Zeppelins.)

It is to this country's interest that the light metal industry should never be allowed to adopt, either voluntarily or compulsorily, a policy of retrenchment. It would be a gross betrayal of security to allow the aluminium and magnesium industries to become less important in peace than in war, as on these depend our future air supremacy. The United Nations must ensure that never again is Germany permitted to build up a large light metal industry or to hamstring by cartelisation—that insidious but deadly weapon of a cunning enemy—the light metal industries of the free democracies. There must be no 'understandings' or 'gentlemen's agreements,' no 'division of spheres of interest' or 'ceilings of production,' all of which can be manipulated and engineered by unscrupulous negotiators to imperil international security.

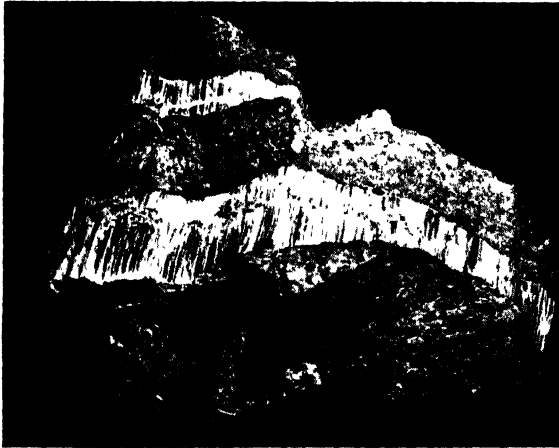
By State encouragement and even subsidy, by research and development, the Empire light metal industry will have to be maintained on a footing commensurate with international obligations. In Great Britain, which is poor in light metal raw materials, there should be accumulated an enormous stockpile of bauxite for aluminium manufacture and magnesite for magnesium, at least 5,000,000 metric tons of each, that is, about 40 months' supply at war rate of consumption.

#### *History and development of aluminium.*

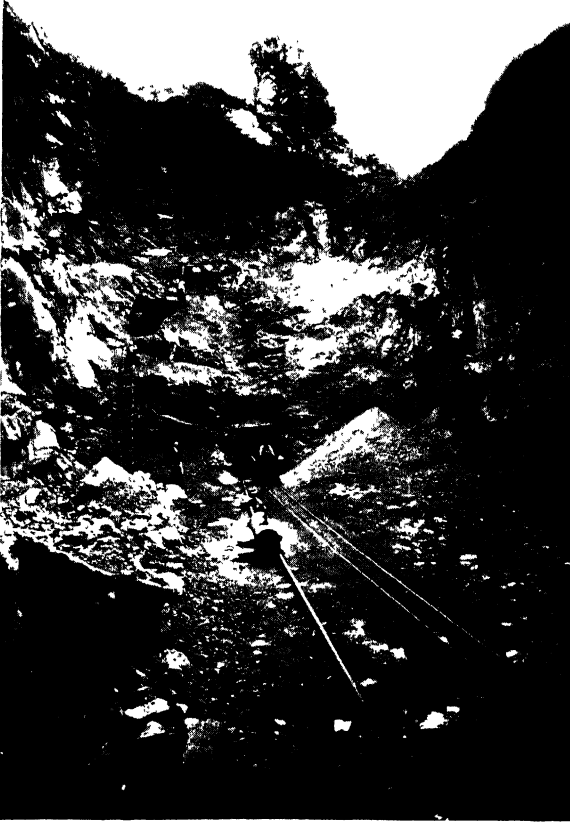
Aluminium, the 'silver in clay,' is the most widely distributed light metal on the surface of the earth, being present, in the form of silicates,



Electrolytic process of steel manufacture.



Crude asbestos formation in serpentine rocks. The fibrous mineral needs to be separated from the stone.



Bauxite mining showing view of opencast and entrance  
to the Combecave Mine, near Brignoles, Var Union des  
Bauxite.

to the extent of 8% of the earth's crust. The most important source of aluminium is bauxite, which is a common form of the hydrated oxide, whilst other sources, such as china clay (double silicate), are also being utilised, and cryolite, or sodium aluminium fluoride, which is found in very large masses in Greenland, is a most important raw material. Cryolite is a natural double fluoride of aluminium and sodium, which functions as a solvent for alumina, producing a bath capable of electrolysis. In 1938 the world output of bauxite was 4,130,000 metric tons, of which the British Empire produced 16%.

Although aluminium, as a source of various clays, was suspected and suggested by some of the ancient philosophers, it was not until 1722 that it was actually identified by Hoffman. Nearly a century later, 1809, Sir Humphry Davy, the man who discovered Michael Faraday, produced the first iron aluminium alloy or amalgam and named the new element aluminium. The Danish chemist, Hans Christian Oersted, carried Davy's work a step further by obtaining a purer form of the metal in 1824. The final step was taken by the German chemist, Friedrich Wohler, the father of organic synthesis, who, in 1827, evolved a successful method of making the pure metal by heating potassium with aluminium chloride. Aluminium remained an interesting laboratory curiosity, costing about £30 a pound, for some years. The first article to be fabricated of the metal was a baby's rattle, which was presented to the infant Prince Imperial of France in 1855. This metal was produced by the French scientist, Henry St. Claire Deville, who spent many patient years trying to improve on Wohler's expensive method of production. Deville had great faith in aluminium and at one time spoke of a forthcoming aluminium age.

The birth of the aluminium industry took place when the electrolytic method was discovered. The credit for the discovery is really shared by three men, all working independently. Charles S. Bradley, U.S.A., who applied for a patent in 1883 to cover a process of manufacture by passing an electric current through an aluminous ore; Charles M. Hall, also U.S.A., who isolated the metal from its oxide by electrolytic means in 1886, and Paul Heroult, France, who worked on practically identical lines at about the same time.

Twenty-two-year-old Charles Hall, a freshly graduated science lecturer and experimenter, is usually given the chief credit for the electrolytic method. Handicapped by lack of funds and without the encouragement or interest of others, this enthusiastic young scientist built the first electrolytic unit for the manufacture of aluminium. His first silvery beads of the new commercial metal are to-day carefully preserved in a richly ornamented casket by the Aluminium Company of America.

Hall's patent expired in 1906 and Bradley's in 1909, so that the twentieth century opened with a 'free for all' in so far as the production of the metal was concerned. Manufacture on a large scale developed fairly rapidly. In 1886 the world production of aluminium reached 16 tons, in 1929 the figure climbed to 281,615 metric tons, in 1938 it was 579,900 tons, and the estimated figure for the Allied Nations alone in 1943 was: U.S.A., 1,000,000 tons; Canada, 500,000 tons. Germany, although possessing no domestic deposits of bauxite, had near at hand a plentiful supply (Hungary, Yugoslavia and formerly France), and paid the greatest attention to the new light metal industry. In 1937 one company alone, the Vereinigte Aluminiumwerke of Lautawerk, produced upwards

of 90,000 metric tons, which was 72% of the country's alleged total of 130,000 tons. In 1938 the above figure had swollen to 163,600 metric tons, a little less than a third of the world's total. According to *The Metal Industry's Handbook*, 1943, Germany's aluminium production for that year reached 300,000 metric tons.

It was Napoleon III who first realised the commercial and military potentialities of aluminium. He encouraged Deville, the brilliant French chemist, to continue his research, although he did not translate such encouragement in terms of French currency. The qualities which appealed to Napoleon were lightness and strength, corrosion resistance and ease of fabrication. These are the same properties which appeal to industrialists to-day.

### *Production of aluminium*

This may roughly be divided into two main stages, the preparation of pure alumina from the mineral ore, which is carried out by the wet chemical process, and subsequently the electrolytic reduction of the oxide. The bauxite mined from important deposits in British Guiana, France, Dutch E. Indies, Hungary, Yugoslavia, Dutch Guiana, etc., is crushed, ground to a fine powder, and then digested with strong caustic soda solution in autoclaves under a pressure of 60 to 70 lb. per sq. in. The alumina goes into solution as sodium aluminate and the iron oxide and silica are thrown down as an insoluble precipitate or mud. Sodium aluminate is unstable in solution and is slowly converted into aluminium hydroxide, such decomposition being accelerated by the addition of a little aluminium hydroxide and mechanical agitation.

The aluminium hydroxide is separated by filtration and calcined or dried at a high temperature to remove the combined water and to produce the anhydrous aluminium oxide or alumina.

The electrolytic reduction of the pure alumina is carried out in a large rectangular open bath, lined on sides and bottom with carbon, this carbon constituting the cathode of the cell. Until a comparatively short time ago, carbon electrodes were used and these dipped into the open top and were adjusted from time to time as the carbon was consumed. The latest practice employs a single large Sodaberg electrode. The bath or furnace is packed with a mixture of alumina and cryolite, the latter being a natural double fluoride of aluminium and sodium, which is found in great abundance in Greenland, but is now also produced synthetically. The mixture is readily fused and kept molten by the heat of the current passing through the anode and the cathode, which at the same time dissociates the alumina into oxygen and aluminium. The metal is deposited in a molten condition on the floor of the furnace, from which it is tapped off at intervals and cast into ingots. The cryolite itself is unattacked at the voltage applied and serves merely as a flux or solvent for the alumina.

The process of reduction is a continuous one, fresh alumina is added as the bath becomes impoverished.

The furnaces operate for considerable periods without ceasing, until, due to the continuous action of the heat, and the gradual absorption of aluminium and impurities, the carbon lining cracks or erodes and re-lining becomes necessary.

The purity of the metal produced depends essentially upon the purity of the materials employed. Aluminium may be refined electrolytically after production, but the process is by no means simple and cannot be looked upon as suitable for mass production. For all practical purposes, however, this is unnecessary, and by eliminating impurities, first in the alumina, and, secondly, in the carbon employed for the furnace lining it is possible to ensure a good quality of metal.

### *Aluminium and its alloys*

The metal has a specific gravity of 2.71 and a high specific strength. It is unique, not only in ease of fabrication, but also in the number of different forms in which it is available to the fabricating industries. Aluminium may, for instance, be obtained in sand, die castings, sheet, plate and foil, bar, rod and wire, structural shapes, tubing and mouldings, forgings, rivets, powder for paint manufacture, etc. Of the greatest importance is the valuable alloying property of aluminium, or ability to form high strength metals with manganese, copper, silicon, iron, magnesium, titanium, etc.

The earliest engineering alloy was, of course, Duralumin, which has a specific gravity of 2.8 and consists of 3.5-4.7% copper, 0.7-1.5% silicon, 0.4-1.0% magnesium, and 0.4-1.5% manganese. This alloy has a tensile strength of 25 tons per sq. in. and finds extensive applications in aircraft and automobile engineering. Another fairly common alloy is the familiar silicon casting alloy, which contains about 12% silicon. The silicon range of alloys are particularly interesting as they attain their maximum strength by virtue of a preliminary treatment in the molten stage prior to casting. A mixture of silicon and aluminium when cast in the ordinary way exhibits no outstanding mechanical properties, but if, before casting, a quantity of sodium or of sodium fluoride or hydroxide, or other suitable salt, is stirred into the melt, this has the effect of refining the grain size. No alteration in the composition of the alloy occurs, but the changes in the internal structure of the alloy due to this modification are sufficient to produce a very marked improvement in the physical properties. For example, a chill cast specimen of an unmodified 11% silicon alloy may have a tensile strength of 10 tons per sq. in. with 3% elongation, whereas after modification the strength may rise to 15 tons per sq. in. and elongation increase to 17%.

Y alloy, developed originally at the National Physical Laboratory and being one of the first commercial high-strength alloys, is interesting, as it contains 2.0% nickel and no manganese. This alloy is now used only for pistons and has been largely replaced by Hiduminium RR59. It has a minimum tensile strength of 23-27 tons per sq. in. as compared with 5-9 tons per sq. in. of pure aluminium; on a strength to weight basis, *i.e.* specific strength, it is stronger than high tensile steel, which has an ultimate stress of 65 tons per sq. in. The R.R. series of alloys were originated after years of experiment by Messrs. Hall and Bradbury of Rolls-Royce, Ltd., in 1927, and subsequently produced commercially by High Duty Alloys, Ltd. The Hiduminium R.R. (Rolls Royce) range contain copper, nickel, magnesium, iron, titanium and silicon. The high strength wrought alloy, R.R. 59, has approxi-



mately the following composition: 1.5-3.0% copper, 1.0-1.5% iron, 1.2-1.8% magnesium, 0.5-1.5% nickel, 0.2% titanium, and 1.3% silicon, the remainder being aluminium. This alloy, which is employed for aircraft engine pistons, has a tensile strength of 26-28 tons per sq. in. and is specially developed to stand up to high temperatures. In 1937 High Duty Alloys, Ltd., produced Hiduminium R.R. 77 with an ultimate tensile strength of 38-40 tons per sq. in.

The presence of small quantities of non-ferrous metals in aluminium is not in itself sufficient to produce great improvements in mechanical strength. Such improvements are brought about by a combination of alloying and heat treatment. The latter produces a reformation of the internal structure of the alloy and depends on the increase in solubility of certain metallic compounds in the alloy at the high temperature, followed by re-precipitation. It is obvious that these changes in the solid solution will take place more readily in a solid compact mass than in a loose porous structure, and it is natural, therefore, that the effects of heat treatment should be more apparent in chill cast metal or in forged or rolled metal.

The production of these high duty alloys has only been rendered possible by ensuring that the laboratories of the plant, which are given over to chemistry, physics, metallurgy, pyrometry, mechanical testing at ordinary and high temperatures, X-ray analysis, etc., are closely geared to the metallurgical processes, thus guaranteeing that every treatment is checked and counter-checked by the eyes of science. The success of modern alloying depends on several co-related factors, and to secure absolute uniformity of properties for the engineer, there must be uniformity of chemical composition and structure, both atomic and microscopical. Just as a needlewoman works closely to a pattern, choosing the right type of linen, suitable needles and silks, so the modern metallurgist, out to produce a high duty alloy, chooses his basic materials and plant with most meticulous care and works to a pattern, the pattern of a crystalline structure proved by exhaustive mechanical testing and experience to give the best results.

### *Improving the corrosion resistance of aluminium and its alloys*

Although pure aluminium is resistant to corrosion, and is, therefore, used for many applications in industry involving exposure to chemicals and for lamp reflectors (99.99% purity), it cannot, because of its relatively low strength and softness, find important uses as an engineering material. Unfortunately, aluminium alloys, unless specifically developed to resist corrosion, such as those containing 1.25% manganese and alloys with 2.5% magnesium and 0.25% manganese and the magnesium silicide type, require some form of protective treatment to render them fully serviceable. The most important form of protection is that involving the use of anodic oxidation, a method discovered by Dr. Bengough and J. M. Stuart in 1921-24, which consists of covering the exposed metal with a closely textured film of anodic aluminium oxide formed by making the aluminium object the anode in an electrolytic bath. The full anodic film is opaque and its colour varies from white to leaden grey, according to the aluminium alloy used. The anodic film can be dyed, giving a

coloured finish which differs entirely from ordinary paints and enamels in that it is extremely adherent and cannot be chipped off or removed by any means short of such drastic methods as grinding.

Although anodic treatment of aluminium normally results in a decrease in reflectivity as compared with polished aluminium, recent metallurgical discoveries now render practical the production of an anodised metal with an actual increase in reflectivity. The process, known as the 'Brytal' process, and due to the research work carried out by the British Aluminium Co., Ltd., is carried out in two stages, the first designed to brighten the surface of the aluminium, and the second to put on a protective film without affecting the brightness of the surface from the first stage. The reflectivity of the new type of aluminium is given below, the tests being carried out at the National Physical Laboratory.

<i>Specimen.</i>	<i>Total Reflectivity %.</i>	<i>Specular Parts in 100.</i>	<i>Diffuse Parts in 100.</i>
Polished commercial aluminium ..	73.1	93.1	6.9
Brytal on commercial aluminium ..	76.8	86.2	13.8
Brytal on 'A' reflector aluminium ..	82.4	96.25	3.75
Brytal on super purity aluminium ..	84.1	99.4	0.6
Stainless steel .. .. .	59.5	97.0	3.0
Chromium plate .. .. .	63.0	99.7	0.3
Rhodium on nickel plate .. ..	69.1	99.55	0.45
Lacquered silver plate .. .. .	89.8	96.5	3.5

Exposure tests have been carried out in an industrial atmosphere, and expressing reflectivity values relative to silvered glass as 100, Brytal reflectors have been found to have the same order of durability as stainless steel, while being at least 20% more efficient as reflectors. Heat resistance is good and reflectors made of the newly treated metal retain their efficiency up to 500 deg. C. (polished copper falls off rapidly after 100 deg. C.).

Chromium can be deposited on to aluminium surfaces. The standard method consists of first removing the oxide film by means of a chemical solution, usually an acid ferrous chloride pickle, and then plating with pure chromium at a low temperature and a minimum current density of 40 amps per sq. dm. The chromium plated metal is very hard (Vickers hardness of 550-560), and it is suitable for pistons and cylinders as it ensures a greatly reduced wearing rate, which means longer mileages at high efficiency and less maintenance. There is undoubtedly a great future for chromium-plated cylinder materials, and considerable interest is being shown in their development by motor-car manufacturers.

Another method of protecting aluminium alloys is to spray on them a thin coating of 99.99% aluminium, which is highly resistant to corrosion. Plastic coatings, particularly phenol formaldehyde resin varnishes which can be cured by low heat treatment, melamine resins, etc., may also be employed to improve the resistance to chemicals and gases.

*Decorative finishes for aluminium*

Dyed aluminium is now fairly well known, but 'Imprest' aluminium is a new development whereby the metal may be given a wide variety of decorative finishes. The designs, being actually formed in the metal, are permanent, and the panels can, if desired, be coated with clear or coloured lacquers, or alternatively can be anodised. A great variety of repetition patterns may be supplied at only a moderate increase in price over plain sheet aluminium of similar gauge. A feature of the process of interest to architects is that individual designs can be reproduced quite easily, provided they are of a type suitable for cutting in stencil form. Apart from its value as a decorative medium for walls, panels, plaques, etc., 'Imprest' aluminium enhances the charm of many articles such as trays, waste-paper baskets, note-pads, etc.

*Applications of aluminium*

Before the outbreak of the 1939 war it was claimed that aluminium found applications in thirty different industries, and this figure is likely to be increased as a result of war-time technological improvements. Prior to 1939 the metal was solving problems of economic goods transport, providing the electrical industry with its standard overhead line conductor (steel-cored aluminium), and fast becoming the outstanding packaging material for damageable products. In chemical manufacture and the food and beverage processing industries, high purity aluminium was a standard medium for tanks, pans, piping and miscellaneous vessels.

With the outbreak of war the normal application of aluminium to aircraft was, as is well known, multiplied beyond measure. The comparatively recent introduction of free-cutting aluminium alloy was diverted to the production of fuse bodies. The 'Brytal' process gave a non-shattering reflector to searchlights.

There seems little doubt that light-weight and immensely strong aluminium alloys will be extensively employed in peace-time car manufacture, where there will be an urgent need to conserve weight without loss of reliability and so obtain the maximum efficiency for each taxed h.p. Not only will aluminium find more uses in the production of the popular type of motor-car, but also in the manufacture of commercial vehicles, including luxury buses and trucks. By the employment of light metals and plywood for freight trucks there will be an appreciable saving in weight of vehicle with consequent increase in load. Apart from the use of aluminium alloys for mere weight-saving applications in the automobile industry, the war experience has shown that the high thermal conductivity of aluminium and its alloys is of great importance as influencing the thermo-dynamic performance in the internal combustion engine and enabling a greatly improved performance to be assured. Aluminium alloy bearing metals have proved eminently suitable for heavy duty bearings in engines of the Diesel type.

Aluminium piping is very suitable for conveying water and is likely to be installed in new hotels and flats where the waters have a suitably low chlorine and carbon dioxide content. Whilst the initial outlay is

greater than is the case with heavy non-ferrous or ferrous metals, the maintenance is lower and there is less risk of bursts during winter.

In post-war houses, flats and commercial and industrial structures aluminium alloys should find many important uses. New corrosion resistant alloys, such as the Anti-corodal alloys made by High Duty Alloys, Ltd., possess high strength and yet are roughly one-third, or less than one-third, the weight of all other architectural metals. By using these alloys for roofing, lifts, staircases, railings, panelling, all domestic and utility equipment, exterior and interior metal trim, considerable saving of weight on structure may be achieved. These new alloys are light to handle and transport, easily worked on site and fixed without difficulty. Extruded sections for windows and doors of standardised design may be pre-fabricated in quantity at relatively low price. Anti-corodal sinks with drainer and splashback fabricated as one unit, baths and lavatory basins are ready examples of what may be expected. Brytal metal will certainly receive attention for fittings and furniture and even built-in mirror decorations. Imprest aluminium, either alone or used in conjunction with plywood, offers considerable scope for domestic and hotel decoration of a permanent nature.

The aluminium house was originally sponsored by the Aircraft Industries Research Organisation on Housing and the design was due to Hiduminium Applications, Ltd., which was formed in 1944 by High Duty Alloys and Reynolds Tube Co. for development of aluminium alloy applications. The principle of construction is similar to that adopted for the emergency houses erected under the American T.V.A. project, and the design confirms approximately to the Ministry of Works Temporary House needs. Aluminium alloys used during the war for aircraft construction are employed in the construction of the house and insulation of walls is effected by means of foam concrete. Each unit comprises five structural sub-assemblies—floor, wall panels, spinal partition and roof.

To increase corrosion resistance the sheets of aluminium alloy are coated with pure aluminium and therefore require no additional protection.

Crumpled aluminium foil is certain to assume a very much greater importance for heat insulation. The effectiveness of aluminium for this purpose depends on the bright surface of the foil, which is so excellent a reflector of heat that a number of layers of the foil provide an almost impenetrable barrier to the passage of radiation. The insulating value of this type of insulation, which is known as 'Alfol,' is, in fact, about equal to that of an equal thickness of cork, but its weight is very considerably less. Cork weighs more the seventy times as much as 'Alfol' for insulating power. In the case of a 2,000-gallon milk tank the use of aluminium foil instead of cork will provide a total weight reduction of 750 lb. Other important properties of 'Alfol' are resistance to fire, vermin, dust and vibration. There is a great need for the heat insulation of both domestic and commercial buildings, and aluminium foil seems in many ways ideal. Its installation in pre-fabricated plywood houses would ensure greater comfort throughout the seasons and also render possible worthwhile economies in the use of fuel for domestic and general heating. (It is worth while noting that aluminium sheets are now being recommended for use with gas-expanded plastics for thermal insulation). Aluminium

is likely to become of increasing interest to civil engineers on account of the high specific strength of many of its alloys. Before the outbreak of war some of these were being used for floor systems on bridges, and also for dredge and dragline booms, emergency bulkheads for roller gate dams, and wherever there was urgent need for a strong and light-weight metal.

The railway engineer will most certainly make more liberal use of aluminium alloys, and they can be applied to practically every part of rolling stock from grab handles to such highly stressed parts as the frame. In America the Pullman and Manufacturing Corporation built all aluminium combined saloon and sleeper cars, showing a weight reduction of nearly 50% over steel. The Italian State Railways in 1932 were able by the use of aluminium alloys to keep the weight of the 1921 type of car at 42 tons, and yet increase the bogey wheel base sufficiently to permit of the addition of one compartment per vehicle. In steam railways the use of light alloys is applied chiefly to coachwork, since in the locomotives weight is desirable to obtain the necessary rail adhesion, nevertheless certain parts of the locomotive could with advantage be made of aluminium alloys, particularly where reduced inertia stresses of certain heavily loaded parts, such as connecting rods, are obtained.

For tankers and freight cars aluminium has obvious advantages. For the former, the use of strong aluminium alloys renders possible substantial reductions in weight and a greater pay load. It follows that weight saving effected by the use of these light alloys, although involving an increased initial cost, must eventually result in a greater profit. For the transport of liquids, aluminium has a number of very definite advantages. For the handling of foodstuffs, such as milk, and various chemical liquids, corrosion and hygienic qualities of the metal are advantageous, in addition to the weight reduction. It should be stressed that aluminium is non-toxic and has no effect on the most sensitive substances. The metal used for the tank construction is either pure aluminium or an aluminium manganese alloy. In Great Britain pure metal is chiefly used, but the alloy has a large following in the U.S.A. and France, permitting a small decrease in metal thickness on account of its higher strength.

Tin foil, at one time exclusively used for wrapping chocolates and cigarettes, was before the war almost entirely superseded by aluminium foil. One pound of aluminium produces more than two and a half times as much foil of any given thickness, and as a pound of tin costs twice as much as a pound of aluminium, the economy of aluminium foil will be appreciated. This use of aluminium, particularly in association with plastics, such as cellulose transparent material and vinyl foils, will surely increase.

#### *Magnesium, development and manufacture*

Although many attempts had been made to isolate magnesium from its salts, of which, of course, Epsom are the best known, and Sir Humphry Davy has described his own failure in 1808, it was not until 1829 that the French chemist Bussy succeeded in producing the metal magnesium. Bunsen laid the foundation of the twentieth-century magnesium industry by his electrolytic method, which consisted of the electrolysis of fused

magnesium chloride in a porcelain crucible, but the first commercial method was developed by Sainte Claire Deville in 1857. The Frenchman fused magnesium chloride with metallic sodium, taking care to prevent the oxidation of the magnesium by atmospheric oxygen, as this metal has a very great affinity for the gas.

The development of magnesium on any large commercial scale was first undertaken in Germany during the first World War, when there arose a great demand for a light-weight structural metal for dirigibles and, later, aircraft parts, also magnesium for flares, tracer bullets and bombs, etc. There are plentiful supplies of magnesium salts within Germany's own borders, and therefore great efforts were made by the home chemical industry to develop these natural resources to the full. The first important range of alloys of magnesium was produced by the Chemische Fabrik Griesheim Elektron, and later by I.G., after the war at a time when Great Britain was only academically interested in magnesium and appeared to attach no undue significance to the claims of the then 'German metal,' as it was called. In 1921 the alloy Elektron was introduced to industrialists in this country, being imported from Germany, and it immediately created some interest in aircraft circles, but not sufficient to encourage its production in Great Britain. The Magnesium Elektron Company was eventually formed in 1935 and the first British magnesium produced in 1936. In Great Britain to-day the two main magnesium alloy manufacturers are: (1) Magnesium Castings and Products, Ltd., in association with High Duty Alloys group of companies who produce the metal under British patents, and (2) Magnesium Elektron, Ltd., producing under patents of German origin. The alloy products of these two companies are available commercially under the names of 'Magnuminium' and 'Elektron.'

The German I.G. relied upon magnesium alloys to make good aluminium deficiencies for the aircraft industry which, in the early thirties, was being given a new war orientation. Magnesium was also required in large quantities for the manufacture of the incendiary bombs which were later to spread the Kultur of the Herrenvolk. Realising the enormous strategic value of magnesium as a good strength to weight constructional material, it is no wonder that Germany, through the I.G., did everything possible to restrict production in other countries. Magnesium, the German metal, was to be reserved for the Third Reich alone.

In 1940 out of an estimated world production of 45,880 metric tons, Germany produced more than half, 25,000 tons, with the U.K. 6,500 and U.S.A. only 5,680. An estimated figure for German production in 1943 is about 250,000 tons, which is eclipsed by the U.S. total of 300,000.

About 80-90% of present-day commercial magnesium is produced by electrolysis, but thermal reduction has been making great progress in recent years, and there is every reason to believe that it is the process of the future. The raw materials used in the production of magnesium are natural chloride obtained from brine wells and sea water, or in the form of Carnalite from the Stassfurt deposits, and the minerals, brucite, dolomite and magnesite. These last three minerals are very plentiful in Canada, where there is one of the largest magnesium-producing plants in the world.

One of the most interesting processes of manufacture depends on the simple reaction between the magnesium oxide, produced by burning dolomite or magnesite in kilns, and the silicon in ferro-silicon, a product of the electro-chemical industry. The burned or dead dolomite is briquetted with the ferro-silicon and quicklime. The briquettes are heated in a special steel alloy retort at a temperature of 1,150 deg. C. and under vacuum. The magnesium metal distils off and is collected as a crystalline liner in a condenser tube. As the metal recovered in this way is of great purity and the process is efficient and economical, great importance is attached to its development in America and Canada, where there are substantial deposits of dolomite and magnesite. The above method, which is known as the Pidgeon method, since it owes its inception to Dr. L. M. Pidgeon, of the Canadian National Research Council, is an improvement on the theoretically ideal, but practically dangerous Hansgirg process used at H. J. Kiser's extensive plant in California. This consists of heating briquettes of calcined magnesite and petroleum coke in an arc furnace in the presence of hydrogen. The gaseous mixture containing magnesium and magnesium oxide dust is shock-cooled by injecting a large volume of natural gas or hydrogen, and the dust, which usually contains 60-67% pure metal, is collected and distilled under vacuum at 750 deg. C.

Mention has already been made of the Dow method of recovering magnesium from salt water brines which was calculated to recover 50,000 tons of magnesium in 1943. The process depends on treating the brine with lime and precipitating the magnesium as the hydroxide. This is filtered off and treated with hydrochloric acid to form the soluble magnesium chloride, which is heated to remove all trace of moisture and electrolysed in an electric furnace at about 700 deg. C. Chlorine is liberated at the anode and the metal at the cathode. In 1942 about 27% of American magnesium production was extracted from sea-water brines, 40% magnesite, 23% dolomite, and 10% miscellaneous brines and potash.

### *Properties of magnesium and its alloys*

Pure magnesium is of little use as an engineering material owing to its lack of strength, although, generally speaking, it is stronger (except for modulus of elasticity) than pure aluminium. The tensile strength of aluminium is about 6.0 tons average against 11.0 tons per sq. in. for (rolled) magnesium. The value of magnesium to the engineer depends on its low specific gravity, which is 1.74 against 2.71 for aluminium and 7.8 for steel, plus its increased hardness and tensile strength and greater ease of fabrication. The disadvantages include low resistance to corrosion, inflammability and difficulty of working the metal or its alloys at low temperature or high temperature and low degree of stiffness under stress. Modern magnesium alloys overcome many of these disadvantages and find ready use where rigidity with lower weight of metal is a first requirement. It should be pointed out that the high resistance to shock offered by magnesium alloys is due to the low modulus of elasticity of the metal.

The majority of commercial alloys are made up of magnesium as the bulk constituent with aluminium, zinc, copper, manganese and silicon as

modifying metals. Magnesium alloys made up of magnesium, aluminium, zinc, copper and manganese, the usual proportions being, approximately, up to 11% aluminium, 3.5% zinc, and about 0.5% manganese, and the remainder magnesium (sand cast alloy), other types contain small quantities of copper and also silicon. New nickel copper magnesium alloys have recently been developed which possess good strength and reasonably good ductility, the latter being particularly valuable as magnesium alloys have a tendency to be on the brittle side.

One of the great defects of magnesium alloys is poor resistance to corrosion, and some kind of surface treatment is necessary to render the metal really serviceable. Apart from the use of surface coatings, there are chemical protection methods involving the use of various chemical solutions, such as chromates, fluorides, selenious acid, etc. Some progress has been made in the nickel plating of magnesium alloys which renders the metal resistant to indoor corrosion, but provides too porous a film for outdoor work.

The modifying effects of the various metals at the disposal of the metallurgist are quite remarkable. Aluminium, for instance, increases tensile strength, whilst zinc improves ductility and zinc and aluminium render the metal readily adaptable to extruding. Magnesium, aluminium, cadmium alloys are also of importance for extrusion, and possess a higher tensile strength than the zinc alloy, 23 tons per sq. in. maximum against 21.0 tons per sq. in. Manganese is a most valuable metal additive for improving the corrosion resistance, and copper affords improved heat transfer and electrical conductivity. The metallurgist has to balance the effects of these various alloying materials so as to secure optimum results.

### *Applications*

As magnesium alloys were originally developed for the aircraft industry it is only natural that they should find their greatest use in that industry. Applications include small brackets and levers, fuel and oil tanks, cowlings, flaps, rudders and the under-carriages, tailwheel fork and airscrew blades of some of the largest bombers. Prior to the war these alloys were employed in the automobile and railway industries for many moderately stressed components; in the textile industries for spindles and other moving parts, and in the machine tool industry for all kinds of portable tools and for components on precision lathes. In the motor trade magnesium alloys have already supplanted aluminium alloys for many uses, such as crank cases, and as there is a 40% reduction in weight, it is reasonable to suppose that they will eventually be employed for body building. Magnesium furniture, refrigerators, domestic appliances, radiators, and fittings of all kinds are likely to be seen in the course of the next few years. Magnesium camera cases, binoculars, bicycle frames and toys are all possibilities.

### *Beryllium*

The first investigations into the metallurgical potentialities of beryllium were undertaken by the Siemens & Haske Company in Germany shortly after the first World War. Exhaustive and costly experiments



revealed to German metallurgists some astonishing facts about this rare metal. Although one of the lightest of metals, density 1.84, it was of little use on its own owing to its extremely brittle nature, but it was able to impart great strength and hardness with ductility to copper and nickel. Beryllium nickel alloys containing 1.9% beryllium, 0.5% manganese, and the remainder nickel, could, for instance, be produced with a tensile strength exceeding 85 tons per sq. in., and wrought beryllium nickel copper containing 2.25% beryllium, had a Brinell hardness of 400. (Nickel has a Brinell hardness up to 150.) Particularly important was the fact that beryllium alloys could be used at high temperatures without loss of strength and also under conditions of service involving exposure to chemicals, corrosive gases and salt spray. In many cases, beryllium could be used as an alternative to tin, vital for the manufacture of phosphor bronze, which has always been a war metal of the first importance.

The strategic importance of beryllium for helping to forge the weapons of World War No. 2 was early appreciated by Germany, and Siemens & Haske A.G. were encouraged to develop the metal so that it might be available to the armament industry. Beryllium was manufactured in Germany towards the middle of the twenties, the raw material being beryl, a mineral containing 4% of the metal, imported from South America. At the same time every effort was made to exploit home deposits in the Bavarian forests and Austria. An international entanglement of master patents was spread over America and other likely producing countries so as to warn off inquisitive foreigners. When the manufacture of beryllium was undertaken in America in 1934 it became necessary for the producing company to reach an agreement with Siemens & Haske A.G., an agreement which, needless to say, placed restrictions on the sale of beryllium in Europe. It was hoped in Germany that the net thus closely drawn round beryllium would ensure its virtual monopoly by the Third Reich. Fortunately, British perspicacity and American resourcefulness and drive overcame the formidable obstacles, and a beryllium industry was developed able to supply all requirements for the metal. But a leeway had to be made up.

Beryllium, which was discovered in 1798 and isolated in 1828, is an extremely difficult and expensive metal to extract from its ore, beryl, as the latter is not attacked by any known chemical, except hydrofluoric acid. The method generally used in America to extract the metal consists of heating beryl to its sintering point, about 1,450 deg. C., which renders it susceptible to the action of sulphuric acid at high temperature and under pressure. Thus at 250 deg. C. the acid opens up the ore and about 91% of the metal is converted into beryllium sulphate. This is then separated from other soluble metal sulphates and converted into the oxide in a rotary kiln. A temperature of 1,450 deg. C. is required to effect the oxidation. One ton of beryl is required to produce 240 lb. of beryllium oxide or beryllia, which yields 80 lb. of beryllium metal. The latter is produced from its oxide by reduction with carbon in an open hearth furnace. The estimated world annual output of beryllium is about 500 tons, which is enough to produce something like 20-40,000 tons of copper and nickel alloys for specialist uses.

Probably the most important use of beryllium, in the form of copper or nickel alloy, is for springs required to resist extremely high fatigue without loss of efficiency. Thus springs made of these metals will stand

over 20 billion vibrations without suffering any ill-effects. This compares very favourably with steel at 2-3 million, and about half a million for heavy non-ferrous metal. Beryllium springs are practically everlasting under normal conditions, and even when subjected to salt spray, heat, corrosive gases, etc., they give a far better performance than those of other metals. There is an optimum figure for the beryllium content, above or below which produces an inferior strength. The copper alloy containing 1.0% beryllium has, when quenched, work hardened and heat treated, a tensile strength of approximately 45 tons per sq. in., against 66 tons per sq. in. for the 2.0% beryllium, and approximately 85 tons per sq. in. for the 2.4% content.

Beryllium copper and nickel alloys are likely to find many important uses in a number of industries, for the hardest wearing springs, high tensile wire, bearings, gears and for a wide variety of electrical components requiring great resistance to wear and mechanical shock. An interesting application of beryllium alloy is for making the dies required for the moulding of plastics where absolute fidelity of impression is essential.

Beryllium has now assumed a new importance by its use in the building of atomic bombs and the harnessing of atomic energy to the wheels of industry.

#### CHAPTER VIII

### CEMENTS FOR POST-WAR RECONSTRUCTION

CEMENT IS THE WILLING SERVANT OF WAR AND PEACE. IT TURNS THE sapper's plans into blockhouses and fortifications, barracks and aerodromes, and the architect's blue prints into workers' houses, factories, farm buildings, hospitals, cinemas and libraries. Cement can make either a Maginot line or a garden city. It has, in fact, become an essential commodity of modern civilisation, and as the raw materials for the production of concrete are indigenous to most countries, concrete is the obvious choice at a time of emergency when metal and timber are not readily available.

There is no doubt that the Mulberry harbour, an all-cement construction, did contribute immensely to the success of the invasion of German-occupied France in 1945, and so hastened the end of the war. It will be remembered that two prefabricated ports, each as big as Gibraltar, were manufactured in Britain in sections, towed across the channel and set down off the coast of Normandy.

Before the outbreak of war the British cement industry produced some 7,000,000 tons of cement, but in spite of the very considerable amount used for building Britain's chain of airfields, the Mulberry project, new roads, gun emplacements, etc., not to mention air raid shelters and conventional building, this figure was not reached during the war.

War greatly intensified the use of concrete in its pre-cast or factory-produced form, and very generous use was made of pre-fabricated sec-

tions in the construction of all kinds of buildings from ports to large factory buildings of spans up to 120 ft. clear.

Several hundreds of reports, findings, recommendations, etc., have been published during the last twelve months dealing with housing; methods of meeting public requirements; town planning; suitable methods of constructions and so on. There is certainly no lack of information; indeed, the Ministry of Reconstruction looks like suffering from data indigestion, but there is as yet no evidence that a really comprehensive plan has emerged or that the various trade interests are prepared to pool their resources. As it is the intention of the Government to encourage the building of temporary houses to meet immediate requirements and to replace these by really sound permanent structures over a period of ten years or so, then it will be necessary to ensure that expediency is not accepted as an excuse for poor quality and shoddiness. Far too much prominence is given to so-called utility patterns, the word utility being used merely to cloak inferior workmanship, low grade materials and bad designs.

Asbestos cement, concrete and steel appear to be the most suitable materials for temporary homes as they can be pre-fabricated and quickly assembled on the spot. The Coventry housing plan might well be taken as a pattern as this follows to some extent the Swiss pattern of terrace grouping to provide not only pleasant individual houses but a street architecture. The Coventry type of house could easily be made to last twenty years or so, thus allowing a really adequate period for permanent reconstruction. Incidentally, concrete can be used for both traditional and modern types of construction.

During the next fifteen years there will undoubtedly be a boom in cement, not only for the home rebuilding programme, but for export, and the figure of 10%, which was a fair average export tonnage prior to 1939, will be largely exceeded. U.N.R.R.A. is likely to prove one of the industry's best export customers as it will take several years before the Continental plants are fully operating and able to supply home requirements.

#### *Development of Portland cement*

Portland cement was produced as an answer to the acute shortage of cementing material experienced at the beginning of the 19th century, when vast building and engineering projects were started. It was the most opportune moment in history for Joseph Aspid's discovery that by mixing in specified portions finely pulverised chalk and clay, burning them at a high temperature and grinding the resulting clinker, it was possible to obtain a hydraulic binding material far superior to any product known up to that time. Joseph Aspid of Leeds named this new material Portland cement, because when set it looked so much like the then popular Portland stone used for so much of London's fashionable landscape. His sensational discovery in 1824 was really the culmination of research and development carried out by several previous workers over many centuries. The ancient Egyptians used a cement of sorts as long ago as 3600 B.C., and the Greeks and Romans were well acquainted with a number of excellent structural binding agents of the lime mortar type. The dome of the Pantheon at Rome was constructed entirely of lime concrete over

2,000 years ago, surely a magnificent testimonial to the strength and durability of cement. From the fall of the Roman Empire to the early part of the 18th century knowledge of cement seems to have largely vanished. It was first revived by John Smeaton, an engineer, who in 1750 devoted much thought to the setting of lime under water. After many disappointments he eventually discovered a formula for a cement, which in many ways is similar to one used by the Ancient Egyptians at the dawn of civilisation. John Smeaton's cement was formed by mixing lime and puzzolano which, on the addition of water, set to a hard and solid mass. This first British hydraulic cement was used for the construction of Smeaton's lighthouse, which the inventor built with his own product. It braved the elements on Eddystone rock for 120 years, a fitting memorial to British inventiveness and craftsmanship.

Smeaton's hydraulic cement was dismissed at the time as a building novelty with very limited applications, and even Trinity House's interest in the use of cement for lighthouses was only ephemeral.

The next great step forward in the development of Portland cement was a discovery by the French chemist, Vicat, fifty years later, that an improved type of cement could be produced by burning together finely pulverised chalk and clay in the form of a cement. Vicat's hydraulic cement was, however, a decade too early and received very little serious attention.

Tremendous strides have been made in the production of Portland cement since Aspid's pioneer days, and to-day the cement industry ranks as one of the most progressive in the country, utilising many different kinds of technicians from quarrymen to blacksmiths and fuel engineers to analytical chemists. For well over seventy-five years the industry was organised on a purely empirical basis, but nowadays science has afforded a working explanation of the complex changes which take place during the various operations of slurry making, calcinating and grinding and thus made possible the rapid control of key stages.

### *Manufacture of Portland cement*

If the geological map of Great Britain is closely studied it will be seen that there are rich deposits of chalk and clay along the banks of the Thames, and these are the areas of the country where the cement industry flourishes. Suitable limestone for cement manufacture is also found in the Midlands and North. The industry, being a very heavy user of coal and dealing in heavy and bulky products, requires adequate transport facilities, such as are afforded by rivers and canals.

The first stage in the manufacture of Portland cement is the excavation of the limestone or chalk. This is removed by mechanical excavation and the modern steam or electric navvies employed have a capacity up to as much as 100 cu. ft. In the present-day cement plant the trucks are loaded up with chalk and then run into the shunting yard of the wash-mills where they are hoisted up by means of a lift and the contents of the trucks tipped out on to a conveyor belt which takes the chalk direct into the washmills. The washmill is a circular pit usually about 8 ft. deep and 20 ft. or more in diameter, in the centre of which is the pivot round which four ponderous harrows revolve, suspended by heavy

chains from beams connected to the driving mechanism at the top of the central column. Into this pit carefully regulated quantities of chalk, clay and water are introduced and are churned together and disintegrated until the particles are sufficiently small to pass through a screen which covers the outlet. The clay, in the form of a thick sludge, is usually pumped direct to the washmills from the clay pits.

The above mixture, which contains all the ingredients of cement, is called the 'slurry,' and after passing through a further series of screens it is finally pumped into slurry tanks, whilst all rejected material that is caught on the screens is returned to the washmills for further pulverisation.

The slurry tanks are large concrete containers, about 10 ft. to 12 ft. deep and varying in diameter from 60 ft. to 120 ft., and provided with means of agitating the liquid during storage. The slurry is analysed by the works chemist, and any adjustments necessary are effected by altering the proportions of the chalk and clay in the washmills to give a different mix, and then adding that mix to the slurry already in the storage tanks until the chemical proportions are balanced to the correct percentage.

The next stage in cement production, which is calcination, takes place in a kiln or huge steel cylinder 12 or 14 ft. in diameter, varying in length from 200 to 500 ft., and weighing hundreds of tons. This kiln revolves slowly at the rate of roughly one revolution per minute. The interior is lined with a special type of heat-resisting brick, and the length of tubing is set above the ground so that it slopes gradually down from the feeding end to the firing zone, where a temperature of 2,500 deg. F. is maintained by means of pulverised coal blown in under pressure through a feed pipe. Incidentally, 120 tons of coal a day is an average figure for a standard kiln.

There are two methods of feeding the kiln, the first is the direct one, which means that the slurry is pumped up to a feed controller regulated to give the correct amount of feed, and the second, the calcinator method which entails pre-heating the slurry in a revolving steel drum filled with calcinator bodies. The heating is done by means of hot gases from the kiln which would otherwise go up the chimney. This pre-heating ensures that the slurry loses a large percentage of moisture before passing into the kiln.

Slurry, in its passage down the kiln, not only loses moisture but undergoes a number of important chemical changes. It leaves the kiln in the form of a white-hot clinker. This is partially cooled by cold air before it is passed through automatic weighing machines and then to the clinker store, where it is thoroughly cooled before being ground.

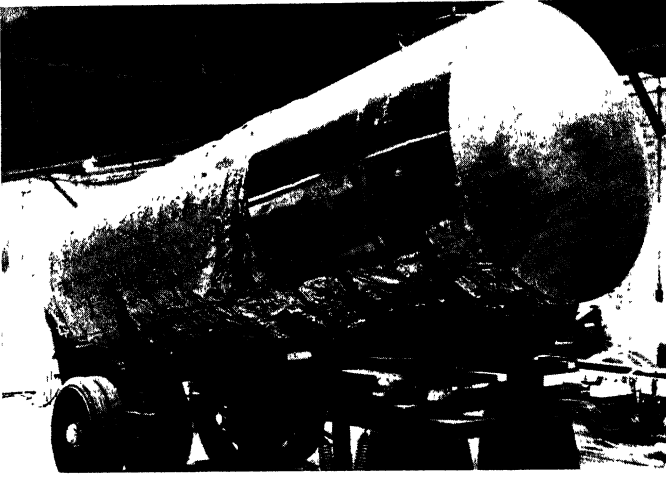
During the grinding, which is the last manufacturing process, a small percentage of calcium sulphate (gypsum) is added to retard setting time, otherwise cement would set rock-hard almost instantaneously and thus prove unworkable. Each grinding mill is fed by two rotary feed tables at the mouth of which are sliding shutters to control the amount of feed. One of these tables is for clinker and the other for gypsum, and they are both supplied through separate hoppers, which are refilled when necessary from an overhead crane. The grinding mills are steel tubes, 6 ft. in diameter and about 40 ft. long, and are usually divided into three compartments containing in all about 26 tons of steel balls and pellets. Driven



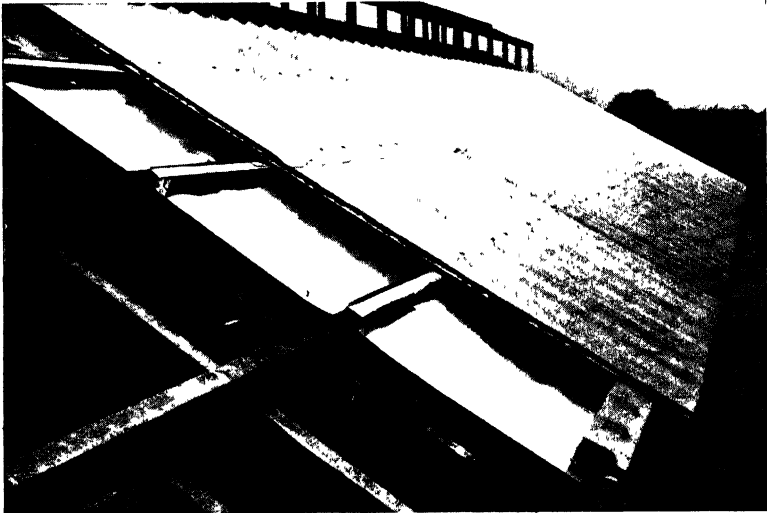
The decorative value of glass is likely to be stressed to an increasing extent after the war. This lovely panel was designed by Maurice Adams.



Imprest aluminum panels, such as the one illustrated, are now being produced for decorative as well as structural applications.



Aluminum foil insulation (Alfol) is one of the most efficient means of providing thermal insulation, particularly for large containers, such as this 2,000 gallon capacity milk transport tank



Asbestos reinforced aluminum foil is now being produced by Turners Asbestos Cement Co Ltd., for insulating asbestos cement and other types of roofs, etc.

by 400 h.p. motors, these mills revolve at high speeds, and the steel balls in rolling over each other crush the clinker and gypsum into fine powder, which is so fine that from 96 to 99% of it will pass through a sieve having 28,900 holes per sq. in.

After grinding, the cement is forced by compressed air to silos to await package. In a modern cement works these silos, built of reinforced concrete, are usually over 30 ft. diameter and about 80 ft. high, with a capacity of as much as 2,500 tons.

The packing of cement in the familiar paper containers is performed automatically by special machines able to pack 30 tons each an hour. These machines fill, weigh and dump the hundredweight bags of cement on to conveyors which take them to the road trucks, railway trucks or ships.

### *Applications of Portland cement*

Cement is virtually useless by itself and is only really serviceable to man when used in combination with other materials, such as sand, stones, asbestos fibres and other aggregate to form concrete or asbestos cement. Concrete is strong, durable and fireproof, and in addition to these three great qualities, its size and form can be varied indefinitely. Before concrete has set it is a plastic material and can be cast into any shape either on the site or in the factory. Over the past fifty years the design of *in situ* concrete work has been extensively developed and applied to many forms of buildings. There are, however, a great many possibilities which remain unexplored.

The technique of reinforced concrete design is based largely on post and beam construction. As the monolithic character of the concrete frame has been more fully realised, cantilever and 'mushroom' column or 'flat slab' construction has been developed. It is, however, only in recent years that the inherent plasticity and strength of reinforced concrete has been freely exploited, and it is in functional forms such as thin reinforced concrete vaults covering vast spans that the future may be glimpsed.

Now that the war is over concrete will be extensively employed for road building as it is the only material which combines both the strength and the adaptability necessary to provide economically complicated intersections. For years the road has been regarded only as a method of obtaining access to buildings, but to-day the through road is no more concerned with delivering you to your front door than is the railway. The through road introduces new elements into road building—speed and freedom from interruption by cross traffic. Implicit in this conception of the road is the abolition of ribbon development, the protection of these great highways by broad belts of countryside and the division of the road itself into dual carriage ways separated by a wide planted reservation.

From roads to bridges is a natural thought, and here, again, concrete will undoubtedly come into its own. Apart from ease of handling and rapidity of erection, the advantage of *in situ* concrete construction is that the whole structure has that freedom of movement essential to provide for changes in temperature. In the future increasing use is likely to be made of pre-cast units for bridge building. An interesting experiment



was carried out by the Canadian National Railways during the winter of 1937, when a pre-cast concrete bridge spanning a 32-ft. square opening on a 45 degrees skew was built. The overall length of the bridge slab along the centre line was  $60\frac{1}{2}$  ft., the depth was  $3\frac{1}{2}$  ft., and the width 13 ft. The slab, in two 108-ton sections with a longitudinal centre joint, was constructed on a special platform alongside the track at a point about 200 ft. away from the site of the bridge. Moving operations started on November 14th at 6.30 a.m., and the bridge was ready for traffic at about 8.0 p.m., in spite of an interval between 1.30 p.m. and 3.30 p.m. for the passage of two trains.

Concrete as a structural medium for railway stations, factories, farm buildings, etc., is now fully accepted and welcomed. The light colour of the concrete adds to the brightness of the building and gives the lie to the generally accepted opinion that such structures must necessarily be gloomy-looking. Considerable improvements may be expected in the colour and finish of concrete buildings. Cement manufacturers now market cements blended in the process of manufacture with colouring agents which give a uniformity far surpassing that which can be achieved by the more haphazard hand methods which necessitate passing the cement and colouring agent simultaneously through a fine sieve. Various methods are available for giving concrete an attractive finish, for instance a lining of hessian to the shuttering gives a pleasing effect and prevents pock marks due to air or moisture, crepe rubber sheets give a ripple finish, and proprietary building boards a smooth finish. Bush hammering removes the film of laitance (surplus surface film) and exposes the beauty of a carefully chosen aggregate. Another method of exposing the aggregate is by the application of a retarding agent to the shuttering before the concrete is poured.

The uses of concrete products are endless, from the simple paving flag or road kerb to the more elaborate roof truss or flooring unit, and for every shape there is an equivalent moulding process. Concrete products are made under factory conditions where it is possible to control, with great accuracy, the mixing, consolidation, setting and curing processes, thus developing the inherent qualities of the material to the maximum. In recent years, many advances have been made, both in manufacturing technique and in the control of the chemical processes involved. The realisation of the importance of consolidating the concrete in the mould has led to the development of spun concrete, where consolidation is obtained by centrifugal force. This type of concrete is now extensively used all over the world for water supply systems, sewers, culverts, drainage, irrigation, etc. Originally this process was introduced into this country by Mr. Hume, an Australian, about twenty odd years ago. He is said to have hit upon the idea while applying paint to some articles in a revolving barrel, on the inside of which was formed a rough pipe in paint.

The modern pipe-spinning machine consists of a set of live rollers, on which the pipe moulds are placed horizontally. When these external moulds have attained a suitable speed the ready mixed cement concrete is inserted from both ends of the mould, thus forming an even and compact layer of concrete up to the level of the end rings of the mould. The concrete is automatically consolidated by centrifugal force; all surplus cement, water and any foreign matter, as well as air, is squeezed

out to the inside and run off. The inside is finely gauged and polished by means of a steel bar. The whole process takes from two to three minutes.

Centrifugal concrete, properly spun, is very hard and dense, and therefore extremely resistant to attrition, free from voids and practically non-porous even under high hydraulic pressure.

Centrifugal spinning and concussion has been evolved by the originator of the former process and combines all the advantages of centrifugal spinning with that of low frequency vibration. It is claimed that the method gives an even distribution of the aggregate throughout the pipe wall, allows the use of semi-dry and lean mixtures, and thus produces a dense and nearly impervious pipe, giving a high strength, resistance to attrition and chemical attack.

Mention might also be made of a Japanese method of making crude small-bore monolithic concrete pipelines *in situ* by depositing concrete in the trench round an inflated rubber core, the latter being deflated and withdrawn as soon as the concrete has hardened sufficiently to be self-supporting.

Other methods involve the well-known rotary compression and vibration concrete making and the more recent centrifugal packing which has been in use in the U.S.A. for some years. The use of pre-stressed steel in conjunction with pre-cast concrete products opens up a further field. Naturally the type of aggregate used for the concrete determines the appearance of the pre-cast products, and by using stone aggregates the exact colour and texture of the natural stone can be reconstructed.

Gunite, a system whereby a mixture of cement and sand is blown on to the surface to be treated and the ingredients pass through a fine mist of water at the nozzle of the gun by way of hydration, is likely to find important new applications. In the U.S.A. buildings have been constructed by pumping the gunite mixture over a large inflated rubber bag covered with reinforcing wire mesh. When a layer of concrete sufficient to bear a reasonable weight is injected the bag is deflated and removed. The injection of further sand and cement is carried out until a thickness of the required extent is obtained. Gunite can also be applied to damaged walls of houses and factories and enable property to be renovated in a very short time.

Cement and wood wool mixtures are now being used as filling materials for hollow constructions in pre-fabricated housing units.

#### *Asbestos cement*

A very wide range of asbestos-cement products is now being manufactured in Great Britain and the United States, especially the latter country, where the industry has assumed enormous proportions owing to an increasing demand for an economical and permanent building material. The bulk of the trade in America is in shingles or tiles, also sidings, but in this country the various flat building sheets and corrugated roofing sheets constitute the bulk of the trade.

In the manufacture of asbestos cement asbestos fibres act very much like the steel reinforcements in ferro-concrete and endow the cement mixture with greatly improved resistance to transverse mechanical and tensile stresses. The inclusion of asbestos in the cement also renders

the building sheet or other asbestos cement material more resistant to fire and better able to stand up to severe service conditions than ordinary cement or concrete, in fact in the case of the latter material the aggregate tends to lower the strength of the mass.

A special shingle grade of asbestos is used by asbestos cement manufacturers and is evenly graded so as to ensure that the length of fibre is uniform. What is desired for high grade asbestos cement goods is a short, strong and rather bulky fibre. The presence of long stapled fibre in the mixture inevitably leads to trouble in the form of 'blobs' and weak spots in the finished sheets.

There are two general methods of manufacturing asbestos cement products. The first and most important is the 'wet' or 'Eternit' process first used in Austria, the second is the 'dry' method.

In the wet process the raw asbestos fibre, after being further separated and cleansed, is mixed in huge beater tanks with exact proportions of cement and water. If the shingles or sidings are to be of a particular colour, the necessary pigments are added.

The liquid mixture next passes into vats containing revolving screen cylinders which are a part of the so-called 'wet machine.' Continuously moving over these vats is an endless woollen felt belt, making contact with the screen cylinders and picking up from them a web of wet fibres and cement which passes on and builds up to the desired thickness on an accumulation drum or cylinder. The resulting large wet sheets are then automatically conveyed to a machine which cuts them into units of the desired size.

The 'wet shingles' are next piled in stacks, with thin sheets of steel, textured on one side, between them. It is from these textured sheets that the shingles and sidings receive the impress of wood grain or stone texture that adds so much to their attractiveness.

The next step is that of compressing and squeezing out part of the water. This is accomplished by subjecting a stack of wet shingles and press plates, in a huge hydraulic press, to a pressure of several thousand pounds per square inch, or as much as 600 tons per shingle.

The shingles are stored in piles for days and even weeks to complete the chemical reaction and setting known as 'curing.' The final process after the shingles are hard and dry is that of trimming the edges, punching the nail holes, and bundling for shipment.

Asbestos lumber and corrugated sheets are made by the same general methods as asbestos cement shingles, and are used in the construction of modern industrial plants.

The general composition of asbestos cement shingles and other building products is 75% Portland cement and 15% asbestos fibre. Colouring matters, in the form of pigments, fillers and various special additives, some of which reduce efflorescence, are added. Porous asbestos cement products can be made by adding powdered aluminium or zinc which reacts with caustic soda, also added, to form hydrogen which creates the desired porosity.

Apart from shingles, or tiles and building sheets of all kinds, pipes, cisterns, etc., are also manufactured in considerable quantities. A very large number of pressure pipes and rain-water goods are now being used by the building industries. The most favoured method of production is that invented by Comm. Mazza in Italy in 1913. In principle it consists

of building up on an endless belt a film of asbestos cement which is conveyed to a polished steel mandrel and rolled up to the requisite thickness. When the pipe is removed from the mandrel a split wooden mandrel is immediately inserted until the pipe has set hard. This wooden core ensures perfect accuracy in the bore of the pipe. All pipes are left to mature in water tanks for a week or more, when they are trimmed and made ready for use. Before use is possible, however, all pipes have to be matured in air for five or six weeks to ensure the curing and strengthening of the asbestos cement.

The so-called dry process of manufacturing asbestos cement is briefly summarised by Oliver Bowles in his book on 'Asbestos': 'Cement, asbestos and colouring agent are mixed dry in a cylindrical mixer provided with paddles. The mixture is spread evenly on an 18-in. conveyor belt and sprayed with water at 180 deg. F. Rollers compress it to the required thickness and a rotary cutter separates it into individual shingles. The shingles are piled in stacks separated by steel pallets and squeezed in a hydraulic press at a pressure of 20,000 pounds per square inch, after which they are cured, trimmed and punched for nailing.'

Asbestos cement products are all pre-cast and merely require assembling on the site. A very wide range of pre-fabricated building units are now available, and their number has increased due to the shortage of timber and steel. Asbestos cement tubular purlins, beams and stanchions have been extensively used and specified in hutting and hostels, and the lighter types of construction for the principal Government Departments. These units are non-inflammable, non-corrosive and require no painting or other treatment for preservation. The tubular section lends itself to continuity of fixing by the use of dowel connectors, hence full advantage may be taken of the developed strength. Asbestos cement pressure pipes are designed and normally used for the conveyance of water under pressure, but as described above they can be used under emergency conditions to replace timber or steel as purlins, beams and stanchions.

Asbestos cement rain-water goods were in extensive use before the war and will undoubtedly be widely employed afterwards. Cisterns and tanks are now being made of the same material and as they contain no metal they are entirely free from rust or corrosion and do not cause any electrolytic action in the presence of copper pipes. The normal thickness is  $\frac{1}{2}$  in., with all internal corners coved. For additional strength, tanks of 250 gallons capacity and over are specially designed to afford extra strength. Asbestos cement cubicles for shower baths and lavatories, sheets for cupboards, shelves, conduits for electric cables, these are but a few of the modern uses of asbestos cement in building practice.

## CHAPTER IX

### STRUCTURAL GLASS

**THE PROSPERITY OF THE GLASS INDUSTRY IS IN DIRECT RATIO TO THE development of the building trade, and every house that is erected or blitzed building repaired means more sheet glass for general glazing.**

Add to this the urgent need for plate glass for shops and commercial establishments of various kinds; glass bricks for hotels, houses, hospitals, schools and municipal buildings, new forms of glass heat, sound and electrical insulating materials and glass units for chemical, food processing and pharmaceutical industries, and some idea can be obtained of the magnitude of the initial orders which the glass industry will be required to fulfil. It is, perhaps, seldom realised that whilst deploring the wicked extravagance of war, the devastation which is condemned in one breath as insane waste of material can be assessed in the next in terms of orders for bricks, cement, steel, glass, etc.

Glass is a most fascinating material with literally thousands of applications which range from the ubiquitous window pane to the Pyrex glass pipes and vessels in the modern chemical works. Glass, in the form of high precision instruments, such as bomb aimers, sights, range-finders, altimeters, etc., is a prime necessity in war, and in peace it serves many masters, the scientist with his spectroscope and microscope, and the builder with his structural glass bricks. Glass foam may be blown one-sixth the weight of water, glass gauges harder than steel, and glass textile as soft as silk. If there are industrial miracles performed anywhere they surely take place in the modern glass factory.

### *Definition of glass*

Glass is really a solid solution, and if its cooling curve is studied it will be seen that the change from the molten state to the solid state is shown on paper as a smooth curve. Glass has no definite melting point, but the raw materials under heat become softer and softer until it merges from the thick syrupy form to a watery liquid.

Modern glass is stronger than its counterpart of fifty years ago. This is due to more perfect processes in manufacture and greater precision in annealing. Unlike various organic materials, glass does not materially weaken as it grows older. It is, of course, true that the very slow attack of the atmosphere by etching the fire-finished surfaces of the glass does produce a slight weakening, but this is so slow a process, and even in the ultimate state the effect is so relatively slight that it can be disregarded.

The reason for the over-assessment of the likely stresses due to wind pressure, etc., when considering glass for structural purposes is, firstly, the inevitably variable nature of a material like glass, and secondly, an allowance, based on statistical figures, to reduce the chance of failure to an agreed percentage risk (usually taken as 1%) under the maximum loading conditions.

### *The composition of glass*

Having decided that glass is a solid solution, it is useful to devote a little attention to its composition. Glass is essentially the product of heating together various oxides, particularly silica (silicon

dioxide) in the form of pure sand, with varying proportions of soda, potash, lime, magnesia, boron oxide, lead oxide, alumina, etc. Thus if sand and soda are heated together at a very high temperature exceeding 1,000 deg. C., a vitreous or glassy compound is formed. It is possible to produce a great variety of glasses by merely altering the composition of the mix and the conditions of melting. Each particular formula produces a glass with special and distinct characteristics. Thus the product formed by heating together sand and glass is sodium silicate or water glass, a soluble form of glass much used as an adhesive and preservative. By adding lime (calcium oxide) to the sand and soda mix an insoluble glass is produced, and modifying this formula still more by the introduction of other oxides, such as alumina, magnesia or boron oxide. If boron oxide in the form of borax is used instead of lime, and a mix made up of about :

80% sand,  
12% boron oxide,  
4% soda,  
2% alumina,  
0.4% potash,

a type of glass, known as borosilicate, is formed of which the world-famous Pyrex is the best known example. Due to the very low coefficient of expansion this type of glass has an excellent thermal resistance. It is interesting to note that Pyrex pipe lines and apparatus are now being used extensively in the chemical and food industries as they permit and invite visual inspection of flow, quality and cleanliness. A glance tells of sediment, condensation, or colour. These pipe lines possess mechanical strength ample for a wide range of conditions in modern chemical manufacture and will operate satisfactorily at pressures up to 50 lb. per square inch.

Whilst all the suggested combinations of oxides produce colourless or near colourless glasses, depending, of course, on the purity of the ingredients, if a coloured glass is desired it is necessary to introduce traces of certain metallic oxides, such as copper, cobalt, chromium, etc. When impure sand is used for glass-making the resultant glass has a greenish tint due to the presence of iron oxide in the sand. Incidentally, window glass still possesses the characteristic greenish tint due to the presence of iron oxide. Copper oxide gives glass a greenish-blue tint, whilst cobalt, one part in 10,000, colours the glass an intense purple, chromium affords a range of tints from green to orange, depending on the proportion of chromic oxide added and the composition of the glass. A great deal depends on the latter factor, and whilst nickel will colour a potash lime glass a reddish violet hue, it converts a borosilicate glass into a decided brown.

### *The manufacture of glass*

Both the ancient Egyptians and the Romans were well acquainted with the manufacture of glass, and the oldest pure glass, of Egyptian origin, dates back as far as 9000 B.C. These early glass vessels, used

mostly as containers for unguents and cremation ashes, were made by winding softened strands of glass round a core made of sand or other suitable materials, and then smoothing over and ornamenting the built-up article, a tedious and lengthy task. The great impetus was given to the glass trade by the invention of the blowpipe, a childishly simple and yet truly sensational discovery which enabled a blob of molten glass to be converted as if by magic into a perfectly symmetrical flask, bottle or jug of exquisite proportions. It can be said without exaggeration that with the blowpipe the glass industry, as distinct from the craft of glass manipulation, was born overnight.

The empirical methods of glass manufacture as formulated by the Egyptians were generally in vogue, although, of course, with considerable development, right up to the beginning of the 20th century. It was about that period that competition forced manufacturers to devote more thought and money to research and development. As a result there was a general mechanisation of the industry and mass production methods were adopted for many types of goods.

To-day the modern glass factory is a strange mixture of the very latest and largest automatic machines and hand operations, such as the drawing by hand of tubing of odd size and the blowing of specialised items not possible to produce by machine. The skilled worker in the plant is first a craftsman and second an engineer.

The first stage in the manufacture of glass is the selection of raw materials, and naturally the choice of these is governed by the type and quality of glass to be produced. For high grade optical work it is necessary to specify very pure materials and the sand used must not contain more than 0.009% iron oxide. Even in ordinary clear polished plate glass the presence of 0.075% iron oxide is objectionable, as for shop fronts it distorts the colour value of goods displayed behind it. Some of the latest shop window glass is produced in two types, one possessing a delicate shade which cuts out any suggestion of green and another transmitting light with rather more warmth in it than the former. These clever devices overcome to a large degree the objection due to the presence of iron oxide in the glass, which is exceedingly difficult to remove.

The various ingredients necessary to produce the glass, such as selected and properly graded sand, soda or potash, lime, borax, lead oxide, etc., are weighed out on automatic batch weighing machines. The batch or 'frit' is properly mixed and then automatically fed into the tank or furnace, where it is melted. The waste glass or cullet is fed in separately.

The melting of the sand mixture or 'frit' and cullet to produce a good commercial glass is dependent upon the strength and durability of the refractory or lining of the furnace or tank. The refractory materials, such as silica bricks and fireclays, are required to stand up to temperatures exceeding 1,000 deg. C. A good deal of research has been carried out by the ceramic industry to discover new and better refractories, and so-called synthetic materials have been developed which appear to offer some promise. X-ray analysis has contributed largely to the solving of some of the problems connected with the study of refractories.

A furnace is used for each separate batch of glass-making composition. One furnace may, for instance, produce glass for tableware, another for

glass bricks, and tank furnaces for drawn sheet glass. The conditions of melting naturally vary with each type of glass. The melting of the sand and other oxides is a somewhat anxious process, as not only must these ingredients be properly melted and mixed, but there must be no bubbles present to weaken the glass when it is drawn, moulded, etc.

Melted glass can be processed in many ways, such as manual blowing, which still cannot be dispensed with for highly specialised work, moulding and casting, automatic blowing machines for bottles and continuous sheet drawing for window glass. Plate glass is usually made by the now fully continuous process (glass made by this process being known as Twin Ground Plate). The rough rolled product is used for factory windows, and the finest ground and polished plate for shop fronts.

Various finishing operations are sometimes necessary after actually forming the glass shape, thus moulded or blown articles may require their rough edges removed and certain cutting, engraving, etching and polishing operations completed to give the glass the requisite decoration and finish.

Of the greatest necessity is the process of annealing which prevents the formation of stresses in glass. It is possible to determine the degree of strain remaining by examination of the annealed glass object by polarised light, when strain shows as a double refraction.

The toughening of glass can take place direct from the 'make' or after it has been thoroughly annealed. The sheet is heated well above its annealing point and the surfaces cooled by cold oil or cold air, etc. This drastic action produces an equilibrium of stresses, those due to internal tension being balanced by compressive stresses near the surfaces. The great resistance of toughened glass to mechanical loads and sudden changes in temperature is due to its compressed surface and internal tension.

### *Laminated glass*

Laminated glass is a sandwich made up of two sheets of glass with an interlayer of synthetic resin, usually a vinyl product. The plastic layer prevents splintering of the glass on heavy impact. The conditions under which modern safety or laminated glass are made are such as to ensure that the interlayer of resin, besides adhering tenaciously to the two glass surfaces, does not interfere with vision or the light-transmitting property of the glass and is not adversely affected by U.V. light. The air in the plant is conditioned and filtered so as to ensure that there will be stabilisation of temperature and relative humidity and complete absence of all dust. At the Ford Company's safety glass plant at River Rouge, United States, claimed to be the largest in the world, a vinyl sheet is used 0.015 in. thick. The moisture content of the scrupulously clean resin is reduced by passing the sheet through a 40-ft. oven regulated at 130 deg. F. and relative humidity of 1 to 3%. After a few hours' baking in the oven, the sheet is passed over cooling rollers, cut and allowed to condition for 24 hours at 60 deg. F. It is then washed by means of a high velocity spray, dried and inspected under polarised light to detect impurities. The vinyl resin interlayer next meets the glass and the sandwich or laminate is effected. The completed sheets



emerge from the air conditioning rooms and are taken through a series of infra-red ovens and pressure rollers. Finally the sheets are placed in an autoclave and subjected to steam pressure to complete the bonding. The finished product is immensely strong and it is impossible to separate the sandwich.

### *Foam glass*

This newly developed product consists of glass blown into innumerable bubbles forming a kind of solidified froth or foam. It is made from finely powdered glass, with which is mixed a small amount of material capable of giving off gas at a temperature which is somewhat higher than the softening point of the glass. This mixture is heated and the glass particles become softened and joined together, thus trapping the gasifying material. The temperature is then raised a little higher, which results in this material generating gas which causes a bubble to be blown in the glass around each particle. The heating is done in moulds of any desired shape. The glass foam swells until it fills a mould and on cooling a formed glass is made of great lightness and buoyancy. Foam glass can be manufactured one-sixth the density of water, but if a reasonably strong product is required it is better to increase the density to between one-fifth and one-quarter that of water. In comparison with cork, foam glass is somewhat heavier (bulk for bulk), but it floats high in water, as cork does, and has the advantage that it does not soak up water and so tend to settle down in the water as time goes on.

Foam glass would be rather fragile for use as a replacement of cork in such things as life-belts, unless well protected by a stout casing of waterproof canvas, but it can replace cork in another important way—namely, as a heat insulator. There is little doubt that foam glass will find many important applications for the thermal insulation of steam pipes, hot-water cylinders, fire boxes, and it is also likely to be employed for lining refrigerators and cold storage rooms. A layer of foam glass  $2\frac{1}{2}$  in. to 3 in. thick is as effective in opposing the passage of heat as a 2-in. thickness of cork, and it has the great advantage that as it is available in block form of regular shape the filling in of the required space is a simple matter, whereas with cork it is necessary to enclose it in hollow partition walls. Foam glass is, in addition, damp-proof and vermin-proof, so that there is no risk of rot or mould developing in a foam glass wall, and vermin cannot eat their way through it.

### *Forms of structural glass*

Modern glass blocks provide a rigid wall face with the maximum amount of light transmission. They combine decorative properties with utility and are translucent but not transparent, thus ensuring privacy. Glass blocks are eminently suitable for external and internal walls, for stair-cases, panels, bays, partitions and for flat or curved surfaces where a diffused uniform light is required. These new blocks blend harmoniously with standard building materials.

The fire-resisting properties of modern glass blocks are good, and

tests carried out at the Building Research Station indicate that they may be classed as a fire-resisting building material.

Glass blocks are hollow, translucent units made in two halves and sealed together, forming non-load-bearing blocks which will carry their own weight with a wide safety factor up to any practical height, but because of wind pressure and other stresses it is necessary to afford an intermediate support in panels over 20 ft. high or 120 ft. super. Very wide panels require an expansion joint every 20 ft.

There is little doubt that glass blocks will find great use in the building of many different types of structures, from municipal libraries and hospitals to commercial premises and housing estates. They are particularly suitable for small domestic houses, allowing the maximum amount of light in halls, stairways and living-rooms, and yet ensuring privacy and affording good thermal and sound insulation.

Glass blocks are particularly suitable for offices and showrooms, as they afford the maximum daylight and reduce street noises. They also provide an ideal background for display.

#### *Prismatic glass and glass domes for modern factories*

The use of prismatic glass in factories has been shown to aid considerably in output owing to the increased light of the workshops. A recent report of the Industrial Fatigue Research Board stated that the bottom floor of a factory gave 11% less production per worker than the top floor, due primarily to poor light. The introduction of daylight via prismatic glass is one means of introducing more light and speeding up production. There are three types of prismatic glass for use in industrial buildings: the first is for situations where the angle of the light's incidence taken from the horizontal is up to 30 deg.; the second, angles between 30 deg. and 40 deg., and the third angles over 40 deg. The glass is glazed with the prisms running across the glass on the inside with the smooth surface of the glass outside. These prismatic glasses are made in dimensions up to 100" wide and 60" high and  $\frac{1}{4}$ " thick.

Domes are manufactured in one piece, usually  $\frac{3}{8}$ " rough-cast glass, 18" diameter to 72" diameter, and they may be quickly fitted to wood or concrete curbs. They afford excellent light to the interior of factory workshops, offices and showrooms and save artificial light and reduce eye strain.

#### *Specially toughened glass*

The process of toughening glass consists of heating it so as to release existing strains and then rapidly cooling it, usually by blowing air on all its surfaces.

So-called 'Armourplate' will bend, twist and resist hard knocks and high temperatures, but it cannot be worked or cut, as complete fracture will result owing to the release of certain of the balanced stresses and consequent disruption of the equilibrium. If the glass is broken as the result of impact or stress beyond its capacity it disintegrates into innumerable small pieces not sharp enough to cause serious injury. When bedded evenly on a layer of sand the resistance of this specially toughened

glass to impact loading is about twice that of ordinary plate, but when simply supported at the ends this figure is stepped up to about seven times that of ordinary plate glass. Transverse tests on sheets simply supported show the specially toughened glass to be about four times as strong as ordinary plate, e.g. when the load is applied without shock to the centre of the surface, the breaking load for  $\frac{1}{4}$  in. 'Armourplate' size 45 in.  $\times$  10 in. is about 230 to 250 lb., whereas for ordinary plate glass of the same size and thickness the breaking load is about 50 lb. per sq. ft. Of particular interest is the resistance of this new toughened glass to sudden changes in temperature. Ordinary plate glass breaks if unevenly heated, but specially toughened glass will withstand temperatures up to 300 deg. C. on one surface, with the other surface exposed to ordinary atmospheric temperature. When at 300 deg. C. the glass can actually be sprayed with cold water. Intense cold will not crack this exceedingly robust glass, and the type known as 'Armourplate' has been tested to -70 deg. C. without its quality being affected, and it is equally satisfactory under any climatic conditions from Asia to Iceland.

This toughening process can be applied to flat glasses other than clear polished glass, *i.e.* tinted polished plate, black glass, rough cast glass, sheet glass, cathedral and figured rolled glasses, selenium coloured sheet and flashed opal glasses. These toughened glasses are only twice as strong as standard window glazing materials of the same kind and thickness and, provided that the heat is uniformly distributed, will withstand temperatures up to 150 deg. C., and even stand up to those conditions when sprayed with water.

The exceptional strength of the specially toughened glass renders it suitable for use in industrial and domestic spheres where exceptional strength and durability are called for and wide differences in temperature are likely to be encountered. Present constructional applications of toughened glass include doors, screens, shelves, surrounds of balconies, machinery guards, table tops, display signs, fire screens, shop and restaurant fronts. War experience has shown that  $\frac{1}{4}$ -in. toughened clear polished plate glass, solid or hollow building lenses, or glass bricks set in concrete frames are highly resistant to blast (from 500 to 1,000-lb. H.E. bombs bursting at a distance of 50 feet or more). Moreover, toughened lenses have shown themselves to be highly resistant to incendiary bombs, both Thermite and Kilo-Electron, and whilst the top surface of glass melted and cracked, in no single case did the glass lens allow any incendiary material to pass through, and it still remained gas-proof.

Toughened glass insulators are now being used for carrying cables of transmission lines operating at 132,000 volts.

### *Architectural glass*

Several new forms of glass have, during the last ten years, been introduced to the building trade for both exterior and interior applications. These include opaque coloured rolled glasses with smooth or fluted surface and available in a useful range of permanent colours, although black is the most popular choice. These glass materials, which are mainly utilised for the fronts of shops, cinemas and hotels and hospitals, are non-load-bearing, and generally used in association with

steel and concrete structures. They should prove increasingly acceptable to the modern builder for the interiors of cafés, public buildings, and also for the kitchens and domestic offices of the better-class suburban house.

### *Wired glass*

This type of glass, which is reinforced by a wire mesh embedded in the centre, is most valuable as a safeguard against accident, burglary and as an efficient fire retardant. It is likely to be specified to an increasing extent by architect and used by the builder of new industrial premises, where it can be used for rooflights, lantern lights and vertical glazing. A very serviceable type is the rough cast double rolled glass reinforced with fine  $\frac{1}{4}$ -in. square mesh wire electrically welded at intersection. In its resistance to dislodgment by blast, wired glass is superior to any other type except toughened glass, glass bricks and lenses. During the Second World War, wired glass was tested and shown to offer considerable resistance to the blast from 500-1,000 lb. bombs bursting on the ground at a distance of 50 to 100 ft. or more.

### *Fibre glass for insulation*

The general principles of fibre glass by the continuous process are described in the chapter dealing with textiles, but as a kind of preface to this it can be said that fibre glass is ordinary glass that is melted and drawn out into threads which can later be woven into tapes and cloth. (Alternatively, while still molten, the threads can be split up by steam into material which is all glass but looks like silk.)

The common use of fibre glass by the engineer is for the lagging of hot water and steam pipes in the form of jacketing (fibre glass will withstand temperatures of more than 1,200 deg. F.) As an insulation for cables and electric motors in the form of insulating tapes and cloths, and as a wool packing for the insulation of refrigerators and ships, this material is extremely suitable. Incidentally, the use of glass fibre insulating material for battleships reduces the weight by 25 tons. It is lighter and more efficient than cork for these applications. Quilts of fibrous glass are now being used for the heat and sound insulation of cinemas, audition halls in film, radio and gramophone studios. The material also finds uses as a filtering medium in the form of oil-impregnated fibre glass to which particles of dust adhere as the air current flows through the filtering wool. Other interesting uses include fireproof curtains for cinemas and theatres.

In modern building practice fibre glass is likely to assume importance not only for insulation, thermal and electrical, but as a decorative fireproof material for use by the designer as a wall covering.

### *Welding metal to glass*

Whilst wires have been welded in glass bulbs for years, for the first time in history a method has been perfected in Britain for welding metal to flat glass. The glass used is a specially toughened type and metals

such as aluminium and its alloys containing a high percentage of aluminium. It has recently been reported that metals other than aluminium and its alloys can be sprayed on to annealed glass. This process is at present mainly used for making electric heaters which are made by spraying aluminium, which is in the form of wire, by means of a 'Schoop' gun, in a zig-zag pattern on the specially heated glass. An electric current is then passed through the long conducting path so formed. This heats the aluminium pattern and so, by conduction, the glass. A heater is normally formed of two such plates mounted back to back in a framework, so that the live metallised strips are inside. This arrangement protects the user from shock. These 'glass heaters' have been tested over a long period and have emerged satisfactorily. This process is now also being used for soldering metal discs or bolts on to glass. Tests have shown that very great strength is obtained in such a joint. The metal sticks so firmly that any attempt to dislodge it breaks the glass before the joint between the metal and the glass.

By combining the use of toughened glass and aluminium and having overcome the technical difficulties of spraying, the process is now a practical one. The soldering of metals to glass can be used for furnishing and fittings and has been used instead of complicated mouldings for radio frequency condensers. It is also possible to stick glass to glass by the same process. This enables glass parts to be made of sizes and shapes otherwise impracticable.

It is not difficult to visualise the enormous field opened up by this new process. For all kinds of shop fittings, interior fittings in houses, hospitals and commercial buildings, as well as furniture, the combination of glass and metal offers many advantages.

### *Reviewing the use of glass in modern building*

Glass is likely to be used extensively in building practice, either alone in the form of glass blocks or bricks for non-load-bearing applications, but where light transmission is required to be at a maximum consistent with privacy and coupled with thermal and sound insulation; rolled opaque for the fronts of buildings and interior facings and also in association with concrete blocks as a facing. In the latter case the glass facing renders concrete, which is basically a somewhat dull building material, suitable for the most attractive and modernistic designs.

Glass is a medium of rich, permanent colour, and in this respect alone, apart altogether from its excellent weathering properties, it commends itself to the architect and builder. For the exterior of public buildings, commercial premises and flats, architectural glass will undoubtedly find many more uses and it is ideal for the walls of libraries, hospitals, day nurseries and public institutions.

For the interior fittings of the modern house glass will undoubtedly make generous contributions, although it would appear unlikely that glass furniture has more than a novelty appeal owing to its coldness to the touch, and the fact that it is difficult to calculate with any degree of accuracy the impact load liable to be exercised during service. It is likely, however, that the union of light metal and glass offers considerable promise, the design being developed so that the metal parts take the load.

Apart, however, from heavily stressed items, glass is, of course, ideal for table tops, desk tops, book shelves, door knobs, cupboards and built-in fittings, also doors of electric and gas cookers. It is, perhaps, in the kitchen and on the dining table that the housewife expects to find glass. Glass frying-pans, and saucepans for use on open flames as well as electric hot plates, new forms of coloured ovenware, and tableware in all its crystalline clarity and beauty of form.

Peering into the future, what new forms of glass are likely to take shape? The author is of the opinion that some interesting developments may be expected in the association of glass and plastics. Fabric woven of glass fibres could be made up into laminated sheets with thermo-setting or thermo-plastic resins and moulded or otherwise fabricated into various shapes for use in building, motor body work, and in the aircraft industry. There is surely a great future for glass wool and synthetic resin which, in the form of some intimate and uniform mixture, could be sprayed on to walls and other surfaces, and also used as a flooring material.

#### *Glass in the chemical industry*

Borosilicate glass, such as Pyrex, is widely used in plants for the manufacture of chemicals and fine drugs where highly corrosive acids or alkalis (except hydrofluoric or glacial phosphoric acids) have to be handled. It also finds ready employment where there is a specification that no traces of metal must be introduced into the product, or where visual inspection of any particular process is essential. Glass fractionating columns, condensers, retorts, storage tanks, pumps and piping are in regular use and they may be flushed with boiling water or steam without fear of breakage. Piping is particularly useful as the flow of liquid can be closely watched and undesirable turbidity, etc., seen at a glance.

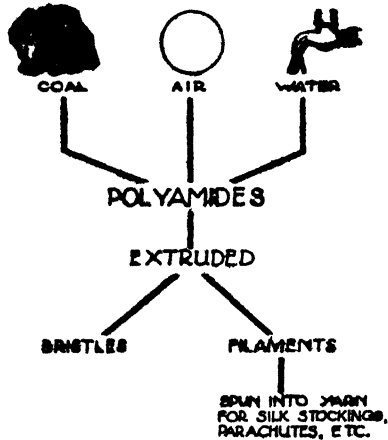
The most interesting use of glass manufacturing apparatus is in the production of fine drugs, such as Penicillin, where metal containers cannot be used and special chemical resistant glass has to be specified. As the range of anti-biotics and other drugs is rapidly increasing and their synthesis becoming more likely, the use of glass manufacturing plant will most certainly expand very considerably. The fine drug factory of the future may be made almost entirely of glass processing vessels.

## CHAPTER X

### THE NEW TEXTILES

THE TEXTILE MANUFACTURER'S WEB OF TOUGH GOSSAMERY FIBRES HAS for its centre the basic raw materials of the chemical industry, cellulose, coal, lime, sand and petroleum or natural gas. The conversion of these unpromising materials into soft and beautiful yarn for weaving into delicate fabrics, or robust monofilaments for hard-wearing brushes, is one of the most fascinating romances of modern industrial chemistry.

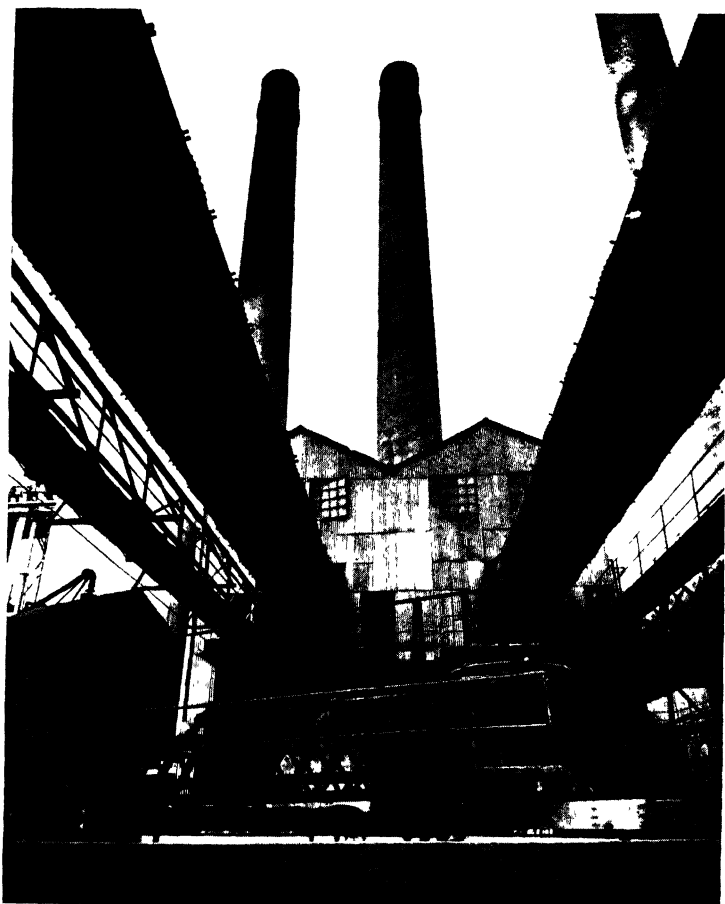
During the last few years a number of entirely new synthetic fibres, such as nylon, Vinyon, saran, Fibreglas, protein fibres, have been developed with excellent physical properties and often with an attractiveness unequalled by the natural fibres. In addition, the semi-synthetic fibres, such as viscose rayon and acetate rayon, which are made from wood or cotton cellulose, have been greatly improved both in strength and appearance. Viscose thread can now be produced with an



The chief components of nylon are said to be sebacic, adipic and methyl adipic acids, on the one hand, and hexamethylene diamine and decamethylene diamine on the other. These materials are, or can be, indirectly produced from coal, air and water.

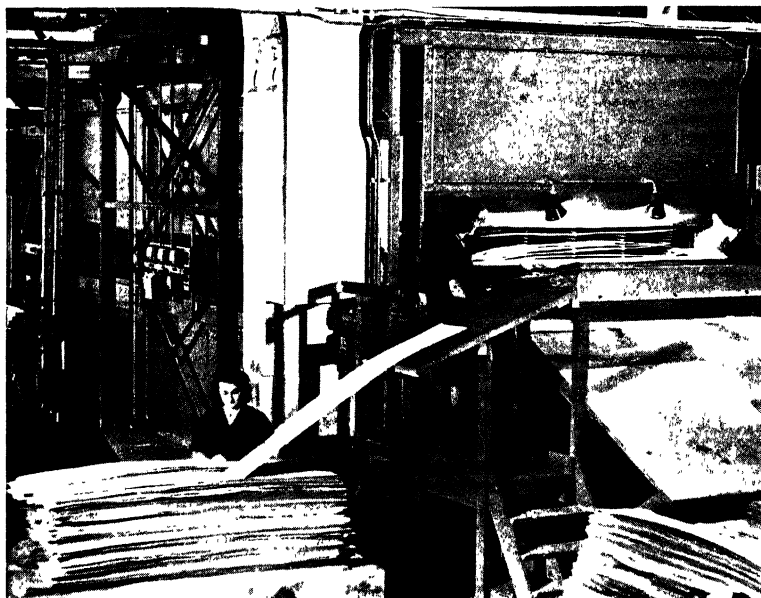
extension and strength greater than that of Egyptian Sak cotton, and it may also be given a water-repellent finish by suitable compounding of the viscose liquor before extrusion and spinning. Permanently crimped acetate rayon with an appearance and feel very similar to wool can also be made.

So phenomenal has been the progress made in textile technology by the very new and not so new materials, that it appears likely that some of the natural fibres may become casualties of the peace. King Cotton with its 151 million spindles (world production figure) is likely to find it increasingly difficult to exercise full sovereignty in the face of so many puissant rivals, but for three or four years at least Lancashire will be kept busy making good war-time deficiencies. Incidentally, there are two and a half million people in Lancashire who depend directly or indirectly on cotton in normal times. Silk in particular will find it difficult to meet the challenge of nylon, the first in the promised range of true 'artificial silks.' Nylon, which like silk is a protein-type, has all the desirable silk-like properties, both in the dry and wet state, and yet is considerably stronger than the product of the lowly silkworm. (It should, however, be noted that nylon yarn is rather troublesome

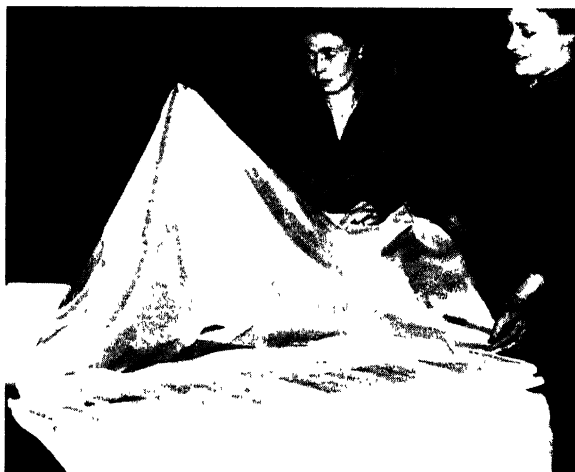


The modern rotary cement kiln is one of the giants of industry. This view gives some idea of the enormous proportions





Pre-conditioning kiln for the treatment of birch veneers used in the manufacture of "Hydulignum" high duty woods



Fibreglass cloth is now being made in this country by Fibreglass Ltd, and although it finds its principal applications in the electrical industries it will soon be in the shops for use as an upholstery, curtain and even dress material.

to handle, especially in cold weather, and in mills without air conditioning it has proved difficult to machine nylon when the temperature falls below 65 deg. F. Nylon yarn, like glass fibre, is difficult to knot.)

It is now appreciated in the textile industry that the price to be paid for new markets is research. The real assets on the balance sheet of any firm are the queer hieroglyphics in the chemist's notebook; the X-ray photographs of fibre structure in the physicist's library and the blue prints on the engineer's drawing-board. The hieroglyphics may be a formula of a new synthetic fibre or compounds able to improve the quality of staple fibres, such as viscose or cotton; the X-ray diagrams may reveal the beneficial changes in the fibre structure due to cold drawing or stretching the fibre, and the blue prints show the ingenious machines capable of translating the latest scientific discoveries into works practice.

Polymerisation, that magic metamorphosis from simple molecules, as represented by gases and some liquids, into long chains or clusters of molecules (polymers) forming queer, elastic bodies capable of being extruded and spun into yarn, this is the key to many of the new synthetic fibres. Almost as important is the tempering of these fibres by purely physical means, such as high velocity winding or stretching under special conditions, which improves the tensile strength. Intensive research on the structure of fibres, natural and synthetic, is of the greatest importance as it helps to improve and thus commercialise fibres which might otherwise prove of little practical value. On the physical side of fibre production, mention might be made of glass, which can, when molten, be extruded into very fine filaments and drawn or wound so as to change the crystalline structure. Such a change converts a brittle and hard glass into a silky and immensely strong fibre, stronger even than steel.

During the war years there was a considerable amount of research undertaken in the preservation of fabrics, as experience with cellulose fibres in the tropics showed that under conditions of high humidity and high temperature decay is generally very rapid. In some of the Pacific theatres of war the relative humidity never falls below 85% throughout the year and materials built up of cellulose fibres disintegrate after a few days.

By treating cellulose fibres with a solution of a metallic soap in a suitable solvent it is possible to ensure reasonable immunity to deterioration due to fungi and insects. Copper naphthenate or oleate are now generally recommended, and the former is particularly useful. To ensure immunity to decay it is necessary to give the fabric a copper content of 0.8-1.0%. Other forms of treatment include the employment of the cuprammonium process and the use of various preservative, such as chlorinated phenols and salicylanide.

### *The future of natural fibres*

The future of cotton, wool and silk depends on the improvements which can be effected in their processing and fabrication, and in the economics of manufacture. The various research organisations supported by the respective branches of the trade are striving hard to render their materials

more acceptable to a public constantly tempted by so many new and attractive fabrics.

Great progress has been made in the production of non-shrinking fabrics, and it is no exaggeration to say that the problem of shrinkage control has, in the case of all styles of cotton, linen and rayon fabrics, been finally and efficiently solved by the development of a purely mechanical method of controlled compressive shrinking. If the amount of shrinkage is zero (within the tolerance of  $\frac{1}{4}$  in. per yard) the fabric may be branded 'Sanforised-shrunk.'

The modern process of controlled compressive shrinking eliminates both length and width shrinkage and the machine can be adjusted to give any shrinkage required to the highest degree of precision.

The fabric enters the machine between feed control rollers. It is carried through the water sprays and steam dampener to the clip expander. The latter regulates the width of the material and conducts it to the modified palmer or drying cylinder. As it passes through this machine, the action of the machine itself, combined with its control of the fabric, shrinks the cloth to the desired degree. An auxiliary palmer then gives the same smooth finish to both sides of the fabric. It is now completely shrunk and finished.

On a less spectacular scale has been the progress made in the production of non-shrinking wool fabrics by the well-known Drisol and other methods, which depend upon the treatment of the wool with certain chemicals involving some kind of chlorination. There is still plenty of room for improvement, however, to ensure that the wearing properties and feel of the knitted wear are not adversely affected, and also that other fibres which may be present, such as rayon, are not injured. Many interesting developments have taken place in the production of chemically treated crease-resisting and shrink-resisting cotton goods. Apart from the well-known Tootal Broadhurst Lee Company's process, a number of other methods using resins of various kinds have been perfected, for instance a mixture of cyanamide and formaldehyde is used for rendering textiles crease-resistant. Urea formaldehyde resins are utilised for the anti-shrink treatment of cotton goods. A most extensive range of chemicals is employed for water-proofing cellulose fabrics and also for making them resistant to mildew, moths and other insects.

The textile chemist and technologist spare no effort to improve the natural fibres, and there is no doubt that they will fight hard to retain their markets. It should, however, be realised that synthetic fibres possess certain inherent advantages, particularly versatility. The rayon manufacturer can alter the formula of the viscose solution so as to obtain dozens of novelty effects, and the producer of nylon can turn out scores of distinct and characteristic fibres.

This competition for markets which wool, silk and cotton must expect from rayon and the pure synthetics is calculated to stimulate technical research. (Production of rayon in 1938 was about 950,000 tons.) There is a constant struggle going on. The natural fibre interests are straining every effort to make their products more appealing to the public, both as regards appearance and serviceability, and the manufacturers of the rayons and synthetics are organising their side of textile industry so as to meet natural fibres on a more equal economic footing and to cater specifically for the higher quality and luxury lines.

The association of natural and synthetic fibres offers great promise owing to the novel effects which may be obtained. The advantages of combining the thermal quality of wool with the smartness of rayon, or the felting property of protein wool with natural wool, these are becoming obvious, and there are many such combinations which offer even greater promise.

### *Viscose rayon*

Rayon consisting of re-generated cellulose is still the most important artificial textile, primarily because manufacturers of viscose have, by assiduous attention to research, ensured that their product is able at all times to meet competition from whatever quarter. Viscose rayon is being produced to-day with a tensile strength varying from 1.5 to 3.6 grms. per denier, and a range of elongation 9–30%. The higher limits are the super-grades developed for specialised uses, but the super grades of to-day are the bread and butter lines of to-morrow. There are viscose yarns to meet practically all textile requirements, from the high tenacity yarns for the tyre cords of giant trucks, which retain their strength under high temperatures caused by over-driving, to the daintiest and most intimate of women's garments.

The manufacture of viscose yarn is really a cyclic process which commences with solid cellulose, in the form of wood pulp or cotton, and then by a somewhat complicated chemical action converts this cellulose into complex viscous bodies and finally back into pure and solid cellulose. (The name 'viscose' is derived from the word 'viscous'.)

First of all the cellulose is purified, that is, all the lignin and natural resin removed by boiling with dilute alkaline solutions. The broken-down cellulose fibres, during the cleaning process the cellulose is finely shredded, are then compressed into sheets ready for treatment with strong caustic alkali.

The sheets of pure cellulose are cut up into small rectangular pieces and soaked in a strong solution of caustic soda for two or more hours. This converts the pure cellulose sheets into alkali cellulose, which is then disintegrated by mechanical means to form fine shreds or crumb. Before this crumb can be treated with carbon disulphide to form cellulose xanthate it needs to be aged for 48 hours or more. After adequate ageing, the crumb is churned with carbon disulphide in large steel vessels and changed into the thick, adhesive and amber-coloured viscose. This is also aged, then filtered and allowed to settle in large tanks so as to get rid of all bubbles. The viscose is next forced through spinnerets with holes 2–5 thousandths of an inch in diameter and the extruded fibres passed into an acid solution for hardening and drawing off on to spools. Later the spun yarn is thoroughly washed to remove all traces of chemicals and finally dried.

The strength of viscose in grammes per denier (denier being the weight in grammes of a length of 9,000 metres) varies from 2 to 3.4, the latter being the strong viscose manufactured for tyre cords. The above figures should be considered alongside with natural silk at  $2\frac{1}{2}$ –3 and nylon at 5 grammes per denier. Special strong viscose yarns made by a new process are produced with a strength exceeding 5 grammes per denier.

It is possible to secure many novelty effects by adding various chemi-

cals to the viscose before spinning. Water-repellant finishes may be obtained by adding carbon black or certain resinous bodies to the spinning solution. The addition of derivatives of cellulose, particularly methylenecellulose, improves the strength of the yarn and renders it more amenable to dyeing and finishing operations.

An expanded form of viscose monofilament has an interesting future as a thermal insulating material in place of Kapok. The fibre is inflated with air and consists of countless bubbles of gas surrounded with transparent cellulose. The American firm of Du Pont has made large quantities of this inflated fibrous material for use in filling life jackets.

Some of the most interesting developments in viscose yarn manufacture have been in the physical treatment of the fibres by variations of the spinning conditions, that is, development of wet spinning or high reeling velocity. A number of different methods have been adopted which result in increased tensile strength and improved stretch, as well as crimped cellulose structures.

It would appear likely that the future of viscose lies in the successful marriage of technological chemistry and applied physics. The chemist can ring the changes on the composition of the viscose solution to produce novel and sales-stimulating effects. The physicist working in conjunction with the textile engineer can temper or anneal these viscose compounds by subjecting the fibres to carefully calculated stresses or toughening operations.

The cellulose molecule is a most complex one, and scientists have by no means elucidated all its mysteries, but as they are being solved vital new information is made available to the technical chemists for exploitation or translation into improved fibres.

#### *Acetate rayon*

Whereas viscose rayon is really a pure cellulose, the acetate artificial silk is, as the name indicates, a chemically altered form of cellulose. There is quite an extensive range of cellulose acetates, dependent on the percentage of combined acetic acid present in the molecule, and no two manufacturers work to exactly the same formula. In some cases there is about 62% combined acetic acid present and in others about 54, the figure being dictated by the type and character of fibre required.

The cellulose is converted into the acetate by means of acetic acid and acetic anhydride and the dry flake material is dissolved in acetone. The viscous solution thus produced is scientifically blended or plasticised and then forced through the tiny holes of the spinneret. The fine strands are wound on to bobbins and subsequently twisted, etc.

There are scores of possible variations in the composition of the acetate extrusion liquid. It can be modified by adding small quantities of titanium oxide pigments so as to produce a dull fibre, or pure acetate used for a lustrous fibre. Various solvents may be added to the acetone, for instance a new one is polymethylene oxide, which lowers the viscosity of the acetate solution and enables a stronger fibre to be extruded and spun. Recently interest has been focused on the improved cellulose esters, such as the acetate butyrate and acetate propionate. These are

more water-resistant and stronger than acetate. Acetate rayon may now be produced with twice the normal tensile strength. These high tenacity yarns were originally developed to replace silk for parachute fabrics, and some of the best are finer and stronger than the natural product. Hosiery manufacturers are particularly interested in these new rayons and also in new processes of throwing, twisting and dyeing which render ordinary grades of acetate more suitable for hosiery. It is claimed that the new acetate stockings show no bagginess at the knees, which was an old complaint, and the yarn has an improved resistance to moisture absorption and elasticity.

On the mechanical side of acetate production there has, during the last few years, been considerable improvement so as to render possible the manufacture of a much wider range of materials, from permanent moire fabrics to rugs and blankets containing rayon in the pile. So-called laminated fabrics produced by forming a kind of three-ply with two fabrics, one of which is usually cotton, adhering to a third, which is a mixed acetate and cotton fabric. The acetate yarn is softened by means of acetone and rendered adhesive and in a suitable condition to stick to the two layers of material.

Mixed yarns are likely to assume greater importance in the future as they can be blended so as to exploit the special advantages of each type. It is claimed, for instance, that mixtures of crease-resisting acetate rayon and wool are of great usefulness for blanket manufacture and for weaving into new and attractive types of dress material.

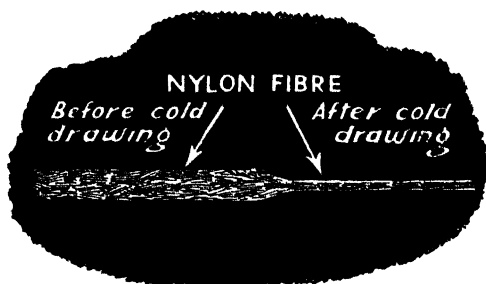
#### *Cellulose ether rayon*

Although still in the experimental stage, this type of rayon offers great promise for the future. It is considerably stronger than ordinary acetate and the fibres are more flexible and possess improved elasticity. The increased moisture resistance of ether fibres is undoubtedly one of their great practical advantages. Various mixed cellulose ethers have been used to produce a fairly extensive range of new yarns.

#### *Nylon*

Nylon has captured the public imagination because of its claims, many of which have been substantiated, that it has all the desirable properties of natural silk without its disadvantages. As explained previously, nylon is a generic term for a range of complex fibre-forming synthetic organic compounds, known as polyamides. There is, therefore, not just one nylon, but a dozen or so types in actual large scale or pilot plant production with several hundred possibilities and even thousands of potentials. This is easy to understand if it is remembered that nylon is a polymer or super-polymer formed by the linking up of various intermediates, including dibasic acids and diamines. If nylon can be made by reacting A with A<sup>1</sup> or A with A<sup>2</sup> or A with A<sup>3</sup>, and so on, also A<sup>2</sup> with A<sup>1</sup>, or A<sup>1</sup> with A<sup>3</sup>, etc., it becomes obvious at once that the possible combinations and permutations are very large. These various types of nylon all possess distinct and characteristic properties, thus

the polymer formed by linking A molecules with A<sup>1</sup> molecules might have a melting point of 400 deg. F., whereas another polymer, produced, say, by linking A<sup>2</sup> with A<sup>3</sup> molecules, might melt at 600 deg. F.



When nylon fibre is cold drawn or stretched there is a certain orientation of the molecules accompanied by a marked increase in mechanical strength, particularly tensile strength.

The most important nylon at the moment is '66' polymer, the original nylon made by Dr. Carothers on February 28, 1935.

A definition of nylon has been agreed upon by British Nylon Spinners, Ltd., Imperial Chemical Industries, Ltd., Courtaulds, Ltd., and the Comptroller of H.M. Patent Office. This is as follows :

'Nylon is a generic term for all synthetic fibre-forming polyamides, *i.e.* organic condensation products which contain a multiplicity of structural units linked in series by amide or thioamide groupings produced by a process of manufacture in which non-fibre-forming organic substances of lower molecular weight are converted into products of such high molecular weight as to be capable of being formed into filaments, which upon cold drawing acquire a true fibre structure recognised by X-ray examination.'

The original nylon was, as stated above, the result of research initiated by the brilliant American chemist, Dr. W. H. Carothers, of Du Pont. During an examination of several hundred complex polymers, Dr. Carothers found that some of them possessed interesting fibre-making properties. Thus by reacting adipic acid with hexamethylene diamine or similar organic chemicals, long chain compounds possessing a protein-like structure not dissimilar to that of silk, wool, and hair, were obtained. Moreover, Carothers found that the fibres extruded from these queer polymers could, by a process of cold drawing, be given an oriented or true fibre structure. During the commercial cold drawing process the nylon fibre is reduced to one-tenth the diameter of a natural silk fibre. Carothers' pioneer work did not stop with the invention of fibre-forming polymers; methods had to be discovered of producing the main constituents, which were comparatively rare chemicals, in large quantities.

The outstanding features of nylon fibre are its good resistance to moisture (nylon stockings dry very much quicker than either silk or rayon), high strength (50 kg. per sq. mm.) and breaking extension of 22%, which means that hosiery does not run or ladder like silk or rayon.

Nylon hosiery and fabric have a good resistance to kinking and are able to withstand high temperatures. Thus yarn can be held at 200 deg. C. for three hours without loss of strength or appearance. It may also be steamed six days at 100 deg. C. and yet not be spoiled. Nylon is 100% moth-proof, and is also unaffected by mildew. Dry-cleaning solvents and many chemicals are without effect on this synthetic fibre, and it is, therefore, very suitable for applications involving contact with agents known to exercise a corrosive action. Nylon brushes are being used for painting, and bristles find such varied applications as sutures, toothbrushes, etc.



Nylon finds many uses in war, the best known being the canopy and lines of parachutes. In peace it is likely that this new synthetic fibre will be employed for silk stockings, dainty lingerie and a wide range of feminine garments formerly made of natural silk.



Nylon yarn can now be crimped similar to wool, de-lustred and processed and dyed to produce results comparable with the rayons. It also lends itself to use with rayons and natural fibres. An interesting and potentially important development is the addition of nylon polymer to acetate spinning dope before spinning. A great future is predicted for these new combinations as unusual novelty effects are possible.

Prior to the entry of the U.S.A. into World War No. 2, about 16-20 million pounds in weight of nylon were used for hosiery. The fibre is eminently suitable for making up into stockings as it is stronger than any other textile fibre, either natural or synthetic. Of particular importance is the high extensibility at breaking point and good tenacity, which is claimed to be 95% of that of the dry fibre, and knot tenacity corresponding to 85-97% of the dry tenacity.

Of some interest is the German material known as Perlan, which is a polyamide similar to nylon. The Perlan fibre has a low specific gravity of 1.1, which compares very favourably with silk, 1.37, and viscose 1.5. The tensile strength is 50% higher than silk, three times greater than cotton, and about nine times that of wool. The elasticity of Perlan exceeds that of wool and silk, and the resistance to flexure greatly improves on the figure for the finest silk. The textile fibre grade of this polyamide melts at 260 deg. C., and therefore stands up well to ordinary laundering.

Special nylons are being manufactured for brush bristles, sutures, fishing lines, and even strings for tennis racquets. On test, these filaments have shown themselves to possess far greater wearing properties than the natural fibres, particularly important is their ability to retain their usefulness equally well when wet or dry. After finding nylon superior for inside bottle washing-brushes, one manufacturer replaced Tampico fibre with nylon in an outside bottle washing machine and found that it withstood the hot caustic solution used for removing labels and accumulation of dirt without loss of stiffness, and outlasted the natural fibre by four times.

As an alternative to natural gut for tennis racquets, nylon is of some interest. American sources have claimed that nylon-strung racquets are unaffected by moisture, and that damp-weather play does not entail worry about string breakage. In this country, however, nylon for tennis racquets has not been proven, and there is considerable doubt as to its usefulness for this purpose.

### *Vinyon*

This is a co-polymer formed by linking up two relatively simple compounds, vinyl chloride and vinyl acetate. Each of these link up with each other to form polymers and these polymers then link up to form the co-polymer. As is the case with nylon, various forms of Vinyon may be obtained by altering the proportions of the combining compounds, and each co-polymer possesses distinct and characteristic properties. Commercial grades of Vinyon fibre are noticeable for their high tensile strength and elongation. The strength may vary from 10-40

grms. per denier, and the elongation from 11-400%. Incidentally, viscose has a tensile strength 1.5-3.6 grms. per denier.

The German Pe Ce fibre made by the I.G. Farbenindustrie has a softening point 85-90 deg. C., whereas Vinyon is not recommended for use at higher temperatures than 65 deg. C., above which it shrinks.

Vinyon yarn is fully water-resistant, although it can be wetted by use of special wetting agents, and shows remarkable resistance to chemicals and solvents. It is, therefore, most used in the manufacture of filter cloths. The German Pe Ce fibres are claimed to resist aqua regia and 50% caustic soda for periods in excess of 24 hours without injury, and filter cloths made of this material have a life five to six times greater than cotton or wool. The cloths do not swell or show any signs of mildew after months of use.

The manufacture of Vinyon yarns is relatively simple in practice. The co-polymer powder is dispersed in acetone to form a highly viscous solution. This is filtered and de-aerated so as to avoid all risks of bubbles forming, which weaken the fibres, and then after 48 hours the liquor is extruded through the tiny holes of the spinneret. The dry spinning of the fine strands is carried out and a twist is given by wet twisting after a lapse of twelve hours or so. Stretching is the next process, and this is very important, as it changes the molecular structure and greatly increases the fibre strength. Generally speaking, Vinyon is stretched to about 140% of its original length and, of course, the diameter of the fibre is only a fraction of that originally extruded through the spinneret. De-lustreing can be carried out by adding various pigments to the Vinyon dope before spinning, and a satisfactory dyeing process has been developed.

Although Vinyon fabric is of major interest for specialised industrial use, it is likely to assume importance in the future for all kinds of knitted wear, gloves, shoes, belts and soft furnishings. (It should be pointed out that Vinyon is the registered trade name of Carbide and Chemical Corp., U.S.A., but, like Saran, there is every reason to suppose that it will eventually become de-restricted and adopted as a generic name for this type of material.)

### *Saran*

This is a generic name covering polymers produced from vinylidene chloride, which is made from ethylene derived from petroleum cracking gases or natural gas and chlorine from common salt. The solid resin is heated to softening point and extruded to form monofilaments, strips and ribbons for specialised purposes, particularly upholstery for commercial vehicles, curtains and wall decorations for cinemas and theatres, also high tensile cords.

The fibres of saran have a definite crystalline structure which may be oriented by stretching so as to modify the tensile strength and elastic elongation. Full orientation, which results in a very considerable increase in tensile strength up to 60,000 lb. per sq. in., or even more, needs to be carried out under special conditions, which usually involve preliminary heating below the softening point followed by controlled cooling and stretching.

Saran fibres possess a high resistance to moisture and solvents, also a

wide range of corrosive chemicals. Fabrics made up of this synthetic material may be laundered and ironed without risk of damage if the temperature of 140 deg. C. is not exceeded. De-lustreing and dyeing permit the production of many novel and attractive fabrics suitable for a growing list of domestic textile requirements, especially where toughness of fibre is a prime necessity.

#### *Peanut protein fibre (Ardil)*

This is an interesting material produced from ground nuts, otherwise peanuts or earth-nuts. Fibres are prepared from the natural proteins present in the residue left after the ground nuts have been subject to solvent extraction for the removal of the oil. The natural proteins are dissolved in alkali and spinnable solutions thus prepared. The extrusion or spinning is carried out in a manner somewhat similar to that employed in the manufacture of viscose rayon. 'Ardil,' the peanut fibre, developed by Imperial Chemical Industries, Ltd., is a cream-coloured, crimped fibre with a soft wool-like handle. Crimp is developed in 'Ardil' during the shrinkage in the manufacture. Tensile strength is 10 kg./mm.<sup>2</sup> and elongation 50%–100%.

#### *Lanital*

The most publicised of the protein fibres is the so-called casein wool, known as lanital, developed by Ferretti in 1936. Contrary to public belief, it can only be used successfully in association with wool and other natural fibres able to impart the required working strength to the fabric. Lanital is essentially a weak fibre, particularly when wet, but it is useful as a diluent owing to its excellent felting properties, which have already interested the felt hat manufacturers. There is every reason to believe that casein wool may be improved in strength by modifying the properties of the casein by treatment with resinous compounds, or subjecting the spun fibres to special chemical action.

The standard method of lanital production consists of preparing a viscous solution or dispersion of casein in caustic alkali, and extruding it in the form of fine monofilaments into an acid bath which immediately coagulates the protein. The soft strands of casein are then treated with formaldehyde solution to harden them. It is of interest to note that casein is used to modify the viscose spinning solution so as to obtain a rayon with wool-like properties. Examples of modified cellulose fibres are Rayolanda X.S. and W.D.

#### *Soya bean wool*

A good deal of research and development work has been carried out by the Ford Motor Company on soya bean wool, but experiments were largely discontinued during the World War No. 2. The wool produced by Ford and other independent organisations offered considerable promise owing to its noticeable softness, ease of crimping and excellent elasticity, plus good resistance to acids and alkalies, boiling water and steam. The

tensile strength of the Ford Soya Wool was given as about 80% that of natural wool, elongation dry 40% and wet 60%. When worked up with cotton and rayon some attractive materials can be produced which are suitable for suitings and soft furnishings.

The usual method of producing soya bean wool consists of dissolving the oil-free protein in alkaline solution, extruding and then treating the fibres chemically, washing, drying and cutting up into staple fibres.

### *Cornmeal wool*

Cornmeal wool has received a good deal of attention during the last few years, as it appears to offer a profitable and useful outlet for crops not wanted for food purposes. Zein from corn meal is the starting-point for this textile fibre. The heavy viscous zein solution is extruded through a spinneret, passed through a coagulating bath, and hardened with formaldehyde. The fibre possesses good elasticity and strength, particularly wet strength, and it is suggested for use with rayon, cotton and wool, as it improves the resilience and handle of finished fabrics.

### *Seaweed textiles*

Alginate fibres have been developed from seaweeds, particularly *Gigartina stellata* and *Chondrus crispus* known collectively as carrageen or Irish Moss. Although the jelly produced from this agar has not the same high strength as Japanese agar it can be used for most of the purposes formerly found for the latter material. Experiments carried out on the manufacture of textile fibres from common seaweed have been successful. The usual method consists of washing the seaweed and converting it into sodium or metallic alginate. This is then extruded through spinnerets into various chemical solutions, such as a solution of beryllium sulphate, which renders the monofilaments resistant to alkalis. The future of seaweed textiles depends on several factors, especially on the continuance of adequate supplies. At present there seems to be little known about the life history and ecology of native seaweed, and until more progress has been made in this direction it will be difficult to arrive at any definite conclusion regarding the rapidity of regeneration.

### *Polythene*

This comparatively new plastic is extensively used in the electrical field and in connection with submarine cables, but so far no important uses have been found for it in the textile industry. Polythene can, however, be spun as a yarn or used as a bonding and finishing agent.

### *Glass fibres*

Considerable technical improvement has been effected in the manufacture of glass fibres, and whilst the bulk of the output during the last few years has been mainly for electrical insulation, there is little doubt

that fibres suitable for draperies, upholstery and dress lengths will be produced in large quantities. In America, prior to the 1939 World War, glass fabrics were sold for household use, soft furnishings, table linen and clothing.

There are two principal methods of manufacture, the continuous filament and staple fibre processes. The first, which produces a particularly smooth and fine fibre, is very suitable for electrical insulation, whilst the staple fibre is the general utility grade for curtains and general domestic purposes.

High-grade glass is the first essential, and the type and quality are reflected in the properties of the finished fibre. Thus for electrical uses a specialised alkali-free glass, that is, free from alkali metal oxides, is necessary so as to ensure high dielectric strength, high insulation resistance and good weathering properties. The presence of these alkalis in glass is generally undesirable as, under humid conditions, particularly when exposed to the weather, free soda or potash leaches out and forms on the fibre surface; it then absorbs more moisture and sodium or potassium hydroxide (caustic soda) is formed. This in turn attacks the silicates in the glass. More soda is liberated and the process continues, breaking down the glass continuously.

Dealing first with the continuous filament process, the glass, usually in the form of marbles, is melted in small electric furnaces, each of which has many small holes in the base of the melting chamber through which molten glass flows by gravity. These fine streams of cooling glass are caught up by a high-speed winder which draws them into a thread, and, at the same time, reduces their diameter to a fraction of the diameter of the holes through which they originally flowed. The stretched strands are usually about 0.0002 in. diameter, and the thread produced to a standard yardage of 90,000 yards per pound. This purely physical action of subjecting the cooling glass to controlled stress brings about an amazing change in the properties, converting a vitreous substance into a soft and silky fibre suitable for weaving into a fine fabric comparable with 3-4 Momme Jap silk in handle and appearance and yet with a strength greatly superior to silk.

An approximate comparison between glass yarn counts and other systems is as follows:

Glass Fibres	Nominal Yarns per lb.	Silk Denier	Cotton (840 yd. hank)	Linen (500 yd. hank)
1/900	90,000	50	106	298
2/1/900	45,000	100	53	149
4/1/900	22,500	200	27	74
2/2/900	22,500	200	27	74
3/3/900	10,000	450	12	33
4/3/900	7,500	600	9	25
5/5/900	3,600	1,250	4	12

In the staple process, the fine streams of glass as they descend from the base of the electric furnace are struck by jets of high-pressure air or

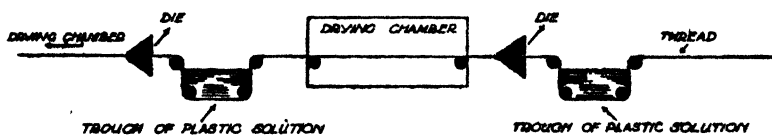
steam which, by its cyclonic action, causes the filaments to be broken up into fibres about 8-15 in. in length. These fibres are forced by the current on to a large revolving drum where it forms a delicate gossamer-like web. This is removed from the drum and wound on to highly polished steel tubes in the form of slivers which later on are twisted and worked up into yarn suitable for working in textile mills.

As mentioned previously, the most important application of fibrous glass at the present time is for electrical insulation. Its chief claim is that the continuous fibre, yarn, tape and sheet offer a Class B insulation with a space factor comparable with that of commonly used Class A materials. Laminated glass fabrics not only possess high dielectric strength but extremely good mechanical strength.

For general textile applications glass fibres are likely to be reserved more for curtains, table cloths, upholstery and fabrics where low extensibility does not constitute a disadvantage. The extensibility of glass yarn is about 1-2% compared with 5% for cotton. Incidentally this lack of extensibility or elasticity necessitates more accurate adjustment during weaving, but the finished fabric does possess an exceptionally neat and smooth surface, which is an asset for table linen and draperies. Glass fabric is not, as many people might think, a cold material owing to its good thermal insulating properties. It retains body heat to a greater degree than some other textile fibres.

### *Plastic coated yarns*

Many fibres, but particularly those possessing an extremely smooth, fine surface, such as glass, nylon, silk, etc., may be given a waterproof, lustrous or dull and extremely tough and flexible coating of plastic. Modern methods of coating enable fibres as fine as 0.0008 to over 0.030 in. to be covered successfully. The plastics used for coating vary with the requirements of the manufacturer, but a good deal of attention is now being given to ethyl cellulose, the new cellulose esters, such as cellulose acetate butyrate and propionate, cellulose nitrate and the various polyvinyl resins. The point the manufacturer has to consider when choosing a plastic is percentage of elongation and elasticity. It is obviously no



Plastic-coated yarn has a big future in the textile industry. This simple little sketch gives a rough idea of its manufacture.

use coating an elastic fibre with a firm resin. The plastic has, therefore, to be selected so that there is no great discrepancy between the physical properties of the coating and the actual fibre itself.

In principle, the method of coating is simple, although the plant and space required represent quite a considerable capital outlay. Dry and

clean yarn is drawn through a solution of the selected plastic and then through a die which removes excess of the coating compound and ensures that exactly the correct thickness is present. The thread then passes through a drying chamber where the solvent is drawn off and later recovered for future use. On leaving the chamber, the yarn is again passed through another plastic solution, usually of a slightly higher viscosity, and drawn through another die, which this time allows a slightly larger diameter of coated fibre to pass through. This process may be repeated several times if necessary, although it is usually found that two applications are sufficient. It is far better to build up the plastic coating in two or more very thin layers than by using a more concentrated solution and a larger die. The former method ensures a tougher and more serviceable covering.

These coated yarns are likely to assume great importance in the future as they are available in many beautiful colours and enable windproof, waterproof and moth-proof garments to be made up. In some cases the coating is so cunningly applied that it takes an expert to detect its presence.

### *Coated fabrics*

At one time in disgrace because of their linoleum and artificial appearance and unpleasant handle, coated fabrics have staged a very successful come-back. Vinyl resins have been chosen as the most generally suitable for coating purposes, producing the heaviest paulins for covering aircraft and also the lightest and softest rainproofs. The range of coated fabrics is growing longer each day and now includes filter cloths, hospital sheeting, upholstery, pontoon cloth, truck covers, sports wear and raincoats, shoe uppers and even dress fabrics. It is possible to coat the individual fibres of the fabric so as to allow an adequate passage of air to penetrate and yet to ensure good waterproofing qualities. Modern plastic coatings add little to the weight or stiffness of the finished fabric, but the strength is greatly increased.

Plastics manufacturers have collaborated closely with textile technologists in the development of a new range of coating compounds and the popularity of coated fabrics is likely to increase as more varied materials become available. There is obviously a great future for coated fabrics for children's clothing where resistance to water, foods, soil, etc., plus good strength are urgent day-to-day requirements. Nylon can now be used in a form suitable for coating fabrics, and materials similar to calf and kid may be obtained which are suitable for making up into shoes and bags. Another new plastic of interest for coating purposes is polythene, which is also recommended as a bonding and finishing material.

## CHAPTER XI

### MODERN TRENDS IN CERAMICS

RATIONALISATION AND MECHANISATION APPEAR TO BE GRADUALLY OUSTING the familiar hand operations, such as the traditional throwing, from the modern pottery in favour of semi-automatic and automatic processes.

Whilst this change may be regretted by all who regard true craftsmanship as something individual, innately beautiful, and the antithesis of the dull standardisation of mass production, it is a change dictated by the efforts to survive in the face of intense and sometimes unscrupulous world competition, and also to meet the growing threat of plastics.

The pottery industry must organise itself for mass production on a large scale if it is to stand up to new economic blizzards, and it is obvious from the lessons learned during the pre-war years when there was an orgy of price-cutting to supply home markets, that some kind of central selling organisation is badly needed. In the past too many small potters have been ruined through the machinations of unscrupulous financiers anxious to under-cut the market. The year 1937 was indeed a bleak year for the Potteries, a year when the contents of warehouses were sold far below cost to pay the wage bill, and later sold in shops in the six towns at two or three times that figure.

It is, perhaps, not always realised that labour charges in the pottery amount to 50% of the manufacturer's price of a particular line of goods, so that to sell cheap in world markets indifferent to quality must inevitably entail the widespread substitution of mechanical for hand processes.

Until recent years it was the boast of the industry that craftsmanship not only existed but was actually fostered, and that the art of the potters was kept alive as a kind of jealous possession or trust. While the credulous might still believe this William Morris tinted story it bears little relation to the facts, which are simply these. The so-called craftsman in the Six Towns has, for a number of years, been a kind of robot who could, as the result of long and arduous practice, turn out an incredible number of pieces a day for an astonishingly low wage. A man who turns out about 3,600 cups in 47 working hours is no more a craftsman than a modern milling machine or capstan lathe! Incidentally he earns less than one quarter of a farthing per cup. The real craftsmanship of the pottery is reserved for the exclusive millionaire lines, a few of which are still exported to South America.

The pottery industry with its unenviable reputation of being one of the sweated trades has a peculiar patriarchal structure, and it would appear from a fairly close acquaintance with this depressing area of industrial England that, with one or two notable exceptions, such as the Wedgwood Institute, the industry has not made any considerable contribution to the social amenities of the Six Towns. There is, however, reason to think that this is changing.

The industry has a poor record of research, and it is estimated that it spends only a fraction of 1% of its revenue on research, and although it has recently embarked on co-operative research the average amount spent on this activity in recent years is distressingly low, being less than the amount put aside for E.P.D. by many of the individual manufacturers as indicated by the published company reports. Although it might appear obvious to all that research is a form of industrial insurance which must be taken out to maintain technological progress, and even trade survival, British potters have in the past shown a great reluctance to invest more than token sums in any scientific enterprise the benefits of which are likely to be shared by all. This lack of interest in research augurs ill for the British ceramic industry which has the highest loss factor in manu-



facture of any industry. It is estimated that about 5% of the output of any pottery is cracked or otherwise spoilt in the kilns.

Not only is there an urgent necessity to embark on co-operative as well as individual research, but the artistic side of the industry needs overhauling. Dr. H. Webb, in his address to a meeting of the Pottery Managers and Officials Association, April 27, 1943, stated that ideas in design appear to have been limited either to blatant copying, or the futile imaginings of the owner or manager, or more frequently to the mechanical efforts of a decorating shop foreman. "We seemed," said Dr. Webb, "at one time to think it logical to offer a trained designer the wages of a dustman and simultaneously to proclaim that there were no designers in the industry who could justify their work in term of sales." This lack of real artistic application to the wares of the trade has penalised manufacturers facing foreign competition, and bad designs and crude colouring will continue to act as effective brakes on the wheels of commerce.

When considering export trade the fact which potters will have to bear carefully in mind is that this country is no longer in the vanguard of industrial progress, but on a level with other nations, both large and small, several of them with much lower standards of living than exist over here. In the case of the American ceramic industry this is highly mechanised and in a most favourable position to develop overseas markets.

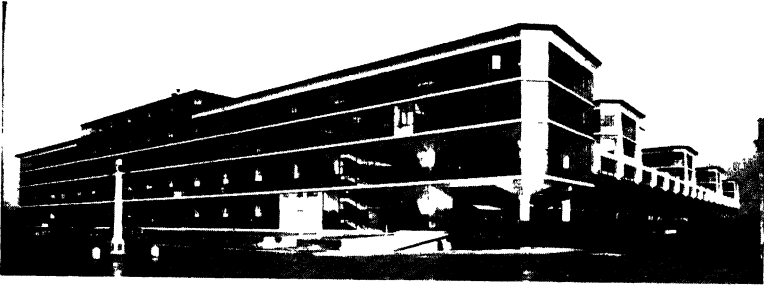
#### *Raw materials*

The raw materials of the ceramic industry are the most plentiful in the world, and one cannot possibly conceive a time when the clays, which have a basis of hydrated aluminous silicate mineral and are due to the decomposition of igneous rocks, will become exhausted. The principal raw materials are: ball clays (purer deposits of secondary clay); china clay or kaolin; fireclays, red clays (colour due to the presence of iron oxide); flint; bone (preferably South American and British); Cornish stone; feldspars; talcs or steatite; bentonite; water and fuels, etc., most of which are indigenous to this island. (Bentonite, a product of the U.S.A., has presented some difficulty during the war, but it is understood that satisfactory substitutes have been developed.)

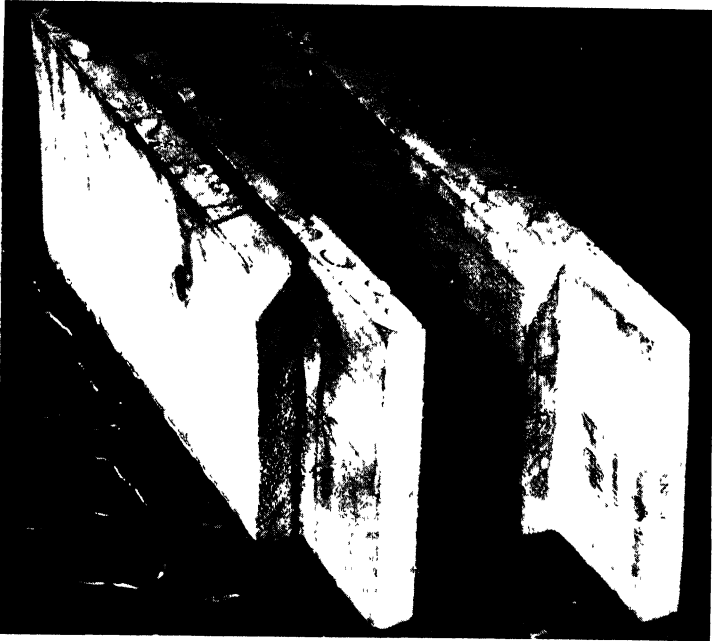
The range of clays, etc., mentioned above, is sufficient to feed the six main branches of the industry: earthenware and china; jet and Rockingham (brown glazed cheap pottery much used for teapots and ovenware); glazed and floor tile; sanitary earthenware; sanitary fireclay and electrical porcelain fittings. The refractories are rather in a class to themselves, making use of high-grade silicon, zircon, zirconia, carborundum, sillimanite (aluminium silicate), certain bauxitic fireclays, beryllia (beryllium oxide), etc. The manufacture of sparking plugs has always been a highly specialised line and distinct from the real pottery industry; minerals of the sillimanite group are used.

#### *Development of the potter's art*

The art of the potter can be traced to the dawn of civilisation. There are pieces of pottery in some of our national museums which date back more than 10,000 years and which, superficially at least, appear to be



Glass is destined to play an increasingly important part in post-war architecture. This view of Boots factory at Beeston, Notts, shows the glass cantilever-hung roof protecting the arrival dock.



Modern synthetic cements are absolutely resistant to water. The planks on the left were stuck together with casein glue and those on the right with Beetle urea formaldehyde cement. Both specimens were soaked in water for some days with the results shown.



Barges can be made of concrete and prove just as serviceable as those made of wood or steel, moreover, they can be produced in large numbers with a comparatively small amount of labour



Asbestos cement is now recognised as one of the most important building materials, and, in the form of glazed sheets it is very suitable for panelling kitchens. This modern kitchen has been panelled throughout with asbestos cement.

little different from the ceramics in common usage to-day. When the world was young so far as man was concerned, the first potter baked his clay in the sun, then followed the craftsman who deliberately fired his hand-modelled clay cups and vessels. Slowly and by a process of trial and error, the art of the potter was developed to produce not only strong and permanent earthenware, but also beautifully decorated and exquisitely coloured pieces, opaque and translucent. The ceramic industry in Staffordshire owes its origin to the clays and coal found in Burslem, but it is indebted for its prosperity and growth to the discovery of pure china clays near St. Austell, Cornwall, which occurred during the lifetime of Josiah Wedgwood. This great potter who, according to Flaxman's Monument, "converted a rude and inconsiderable manufactory into an elegant and an important part of national commerce," was quick to realise the importance of this new clay and was foremost in the development of the china industry. The ceramic industry has since its inception been based on empiricism and trade secrets. It is only during the last fifty years (generous estimate) that science has been applied to pottery. It is interesting to note here that Josiah Wedgwood was a member of the 'Lunar Society' in the 18th century and invented a thermoscope by means of which the extent of the firing could be judged. On the basis of this work he was elected a Fellow of the Royal Society. The number of fully qualified scientists directly engaged in the pottery industry is, to-day, somewhat disquieting, and it is probable that less than a couple of dozen chemists and only a few physicists are employed.

The foundation of ordinary white earthenware, which constitutes something like 60% of the total output of the industry, is clay, the purity and physical condition of which largely determine the strength, durability and appearance of the properly fired cup or saucer. Clays constitute a large proportion of the earth's crust. They are exceedingly complex mixtures of mineral fragments due to the decomposition and disintegration of rocks, but the most important mineral constituent is a hydrated aluminosilicate, such as kaolinite. When clay is intimately mixed with water it forms a plastic colloidal mass (a colloid is a substance which, although in apparent solution, does not pass through a membrane. The particles,  $10^{-6}$  to  $10^{-7}$  cm. diameter, are actually in suspension.) Such a plastic mass may be readily shaped by being thrown on the potter's wheel or moulded in plaster casts. The formed pieces when baked or fired in special ovens or kilns become vitreous in character and possess a rock-like hardness and durability. The addition of readily fusible ingredients, such as feldspar (form of aluminium silicate, e.g. albite is sodium aluminium silicate, and orthoclase is potassium aluminium silicate), lowers the temperature of vitrification and acts as a kind of flux. A mixture of calcined bone, clay and Cornish stone is used for making china which is a translucent vitrified glazed ware.

Whereas the old potter was content to work with a very limited range of raw materials, the manufacturer to-day has available something like two or three hundred different ceramic materials. Very great care is taken to ensure that the selected clays and minerals are properly ground, mixed and purified to give absolutely uniform results.

The preliminary treatment of the various clays which entails weathering, or storing in the open for several months, blunging, stirring, sieving, magnetizing, filtering, grinding, pugging, ageing, etc., is all designed to

produce material of the required purity, plasticity, strength, texture, fusibility, porosity and known shrinkage properties. (Ageing is a process whereby clay is stored under special conditions to increase plasticity. Blunging is a simple method of preparing clay slips or suspensions of clay in water, and pugging a means of mixing clay and water to obtain a suitable plastic mass. Magnetizing removes particles of free iron from the clay.)

Research carried out during the last ten years, as judged by the technical and scientific reports of the various publishing bodies, has been largely concerned with the study of the fundamental properties of the raw materials, viz. the effect of organic matter present in clays on their physical properties, the action of the salt content and the influence of purely mechanical treatment on the plasticity and firing properties of the clays. One of the outstanding discoveries of the 20th century, in fact the only really outstanding improvement in technique since the 18th century, was that the addition of certain hydrolysable salts, such as a mixture of small quantities of sodium silicate and sodium carbonate, rendered clay slips more fluid, thus enabling the potter to work with slips containing a greatly reduced water content.

#### *Manufacture of whiteware*

The first stage is the making of the slip. This consists of weighing out certain selected and weathered clays and stirring the mass in a blunger until a creamy fluid or slip is prepared. Various ground minerals, such as feldspars, flint, Cornish stone, etc., may be added to produce exactly the required composition. The slip is sieved to remove extraneous matter, such as bits of stone, wood or bone and passed over a magnetic separator which removes particles of iron liable to stain the whiteware during the firing. The slip may be heated up during this preliminary processing to facilitate blunging, filtering and its general purification. Filtration removes the water and leaves behind in the press a soft and plastic clay, which is then aged in bins to increase its plasticity and improve its texture. After a period of days, the clay is mixed with water and pugged, various hydrolysable salts being added, and run over a magnetic separator. The heavy cream which results from these operations is called a casting fluid and is run into plaster of Paris moulds, where a certain amount of water is removed by percolation through the body of the mould. At the end of 10-15 minutes the excess slip is poured off and after an hour or so the clay sets and shrinks, allowing the mould to be removed without disturbing the shape. The cast pieces are trimmed and dried in hot air ovens where the clay loses all of its mechanically held moisture.

The formed stage may be reached by other methods apart from casting, particularly jiggering and throwing on the potter's wheel. The first-named process consists essentially of shaping the clay, usually of a stiff mud consistency, in a revolving plaster of Paris mould. The jiggerman takes a lump of soft clay from a cylindrical-shaped piece, commonly called a wad, and places this in the revolving mould which gives the outer shape of the article. He then takes a metal tool and forces this down

into the mould so as to give it its inside dimensions and a properly shaped form. The thrower shapes a lump of clay by means of a few simple hand manipulations as the ball spins on the wheel or lathe made to revolve at a controlled speed by means of a foot treadle or separate motor.

The most rapid fabricating process is jiggering, and a skilled operator can turn out phenomenally large quantities of simply shaped articles, such as cups and saucers, jugs, etc., at a rate greater than one every ten seconds.

The dried pottery, packed in clay boxes or saggars to protect it from soot and dust, is next fired in kilns or ovens. The modern ovens are of the continuous type where the saggars are passed by means of trucks into a constant zone of high temperature, approaching 1,200 deg. C. These ovens are designed in the form of tunnels, 100 to 400 ft. long, and the pottery travels through at a speed of from 3 to 12 ft. per hour. The advantage of this type of oven over the ordinary beehive-shaped kiln is that considerable economies are rendered possible in the use of fuel and labour and a more uniform ware is produced. Incidentally, these ovens are very expensive, the smallest costing about £8,000, but they quickly pay for themselves. Only about 15% of the potteries have so far installed tunnel ovens for biscuit ware, and about 50% for glost. After the war, however, most of the large potteries will go over to this type of firing. In the case of very large items, such as porcelain insulators of unusual shape, individual firing in kilns may be necessary, but it pays the potter to organise his work on the assembly line principle as far as possible.

The success of firing is largely determined by close pyrometric control, but little is now left to the individual judgment of the fireman, who is expected to work to a predetermined firing schedule. Cones are widely used to determine the finishing point of ceramic kilns of the intermittent type. These cones are pyramid-shaped, fusible bodies of progressive softening order. The changes which take place in the clay mixture during firing are exceedingly complex and still little understood. At about 800 deg. C. the alumina and silica constituents of the clay unite to form the compound mullite, and as the temperature approaches 1,200 deg. C., the crystals of mullite grow and there is separation of the silica which forms complex compounds with other minerals present. The fired piece may be a mixture of mullite crystals and glass, and the degree of vitrification is, of course, determined by the temperature maintained during firing.

The pottery when it emerges from the kiln is in the biscuit stage and suitable for under-glaze decoration. This generally consists of coating the ware with a special form of varnish and then applying transfers. Hand painting is also carried out for the more expensive and exclusive lines.

The decorated pieces are next passed into a suspension of the finely ground glaze, which is merely a mixture of glass-forming substances, such as lead silicates, boro-silicates, tin, titanium and zirconium oxides, etc., forming colourless glazes. Coloured glazes are made by introducing other metallic oxides, e.g. copper, manganese, cobalt, nickel, etc.

The glaze-coated pieces are fired (without touching) in ovens at a

somewhat lower temperature than is necessary in the case of biscuit ware.

Instead of decorating pottery in the biscuit stage pieces may be coloured and ornamented over the glaze, the decoration being rendered permanent by a brief firing. It is likely that under-glaze decoration will become more prevalent after the war as it has certain advantages from the point of view of user as well as producer.

### *Electrical insulating materials*

The greatest advances during the war have been in the development of high-grade porcelain for electrical insulation. (Porcelain is a vitreous, often translucent, ware made by one firing only.) The common raw materials are kaolin or china clay, quartz and feldspars, small quantities of gypsum, steatite or talc (a form of hydrated magnesium silicate), and particularly the sillimanite group of minerals, also beryl, zircon, etc.

The choice of raw materials influences the electrical properties of the fired piece and the greatest care has to be taken to secure a mix suitable for the particular type of application. Whereas whiteware is generally a mixture of crystalline mullite and glass and is not completely vitrified, porcelain is fired at a higher temperature to ensure complete vitrification. It is harder and more brittle than pottery.

The four main types of electrical porcelain are those produced by the dry process, wet process, refractory and steatite. The first-named, which is suitable for insulation up to 600 volts, consists of grinding and mixing the chosen ingredients, such as kaolin, quartz and feldspars with gypsum and soda, etc., with just sufficient water to render it moist and workable by pressing into the desired shapes. Small electrical components are pressed out in pelleting machines. The wet process is closely allied to the standard technique for pottery manufacture and is suitable for the production of insulators which have to stand more than 600 volts. The ingredients are ground in mills, mixed with water, sieved through lawns, passed over magnetic separators and filtered. The moist cakes from the press are cast or extruded to shape, dried off, spun to the final dimensions, glazed and fired in continuous kilns or ovens.

Refractory ware consists of fireclay mixtures and is used for items of equipment where thermal insulation must be the first consideration. Steatite porcelain, which is really an improvement on the ordinary kaolin porcelain, possesses excellent mechanical strength and low contraction or shrinkage figure. It is made by the wet or dry process.

Owing to the highly secret nature of low loss ceramics little can be said about them, but it is obvious to the industry that the advances made in their development during the war must be reflected in an improvement in radio and television sets now that the war is over. The midget radio receiving set has, to a large extent, been made possible by the use of special high frequency ceramics. Bodies composed of clinoenstatite, rutile, cordierite, etc., are now being used for condensers and coil formers and are claimed by the experts to be improvements over the steatite type. New titania ceramics find their chief use in condensers and they

possess high mechanical stability as well as greatly improved electrical properties.

Mention might also be made of interesting new porous ceramic for high-frequency insulators. These consist of grains sintered together only at three points of contact so as to produce a body with at least 10% fine pores. (Sintering consists of heating to a temperature below liquefaction and thus coalescing the mass.)

In the manufacture of ceramic insulators, increasing use is being made of pure oxides, such as aluminium oxide (alumina). This inorganic substance melts at 2,050 deg. C. and sparking plugs and other electrical accessories made of alumina possess good thermal conductivity, good electrical resistance and good mechanical properties and resistance to chemical attack. Unfortunately, pure alumina has no plastic properties and cannot easily be shaped. Various methods of overcoming the difficulty of shaping have been tried out, and one of the most interesting consists of mixing the finely ground oxide with a phenol formaldehyde moulding powder and then moulding this mixture under conditions of heat and pressure in the ordinary way. When the alumina plus phenolic resin moulding is subsequently fired in a tunnel kiln the polymerised resin bond is burned away and there is no trace of it on the finished article. The resin acts merely as a means of forming the shape, and during the high temperature of firing the organic content is burned away and the particles of alumina are sintered and made to form a solid and firm shape.

#### *General summary*

As mentioned previously, the most important advances made in the pottery industry during the last century have been mechanical rather than chemical or physico-chemical, and the tendency is towards still greater mechanisation and rationalisation of the industry. Even the production of low loss porcelains for radio work has been due not so much to actual research but to the application of empirical knowledge to the solution of certain topical problems.

The fact has to be realised that the craftsman, as distinct from the mere hand operative, is likely to become redundant (apart from his value as a show piece), and this must entail a lowering of the artistic quality of the more personal items of pottery. There is certainly not likely to be any shortage of pottery, but this will tend to become more standardised in shape, colour and decoration. The multiple tailors have reduced human sartorial foibles to a comparatively few standard sizes, why should not potters do the same with man's ceramic requirements?

In the field of glazed, coloured and decorated tiles there would appear to be a promising market, and one which has not received the attention it richly deserves. By the use of coloured tiles our public and commercial buildings could be made far more attractive and the interiors of our houses more colourful and hygienic.

In passing, mention might be made of the coming use of pre-fabricated brickwork. Two experimental houses have already been built in America using pre-fabricated sections of brickwork, of one brick thickness and weighing up to 15 cwt. per section.



## CHAPTER XII

## SYNTHETIC ADHESIVES

IT IS CLAIMED THAT HIDE GLUES WERE USED IN THE TIME OF TUTANKAMEN, and probably before, but the science of gluing is of recent origin. The first real and co-ordinated study of glues was made during the 1st World War, when the Adhesive Research Committee set out to determine the true nature of adhesion and how to improve the production and quality of natural glues then in great demand. The conclusion reached by the Committee, which, incidentally, has since been confirmed many times, was that adhesion was due to a specific attraction between the adhesive and the surfaces to be joined together, and not to mere mechanical interlocking. It was demonstrated by Prof. J. W. McBain that many pure substances can act as adhesives, thus naphthalene and paraffin wax will give reasonably good joints between metals, and water, on freezing, makes excellent joints between wood surfaces. It is now claimed that water is probably the ideal adhesive and will stick together two wood surfaces to provide a bond of very great strength, provided there is contact between the surfaces within a few wave-lengths of light! Naturally this cannot be proved, but the theory is interesting as revealing the trend of modern scientific thought on the subject.

The forces which are exerted by mutually attractive bodies, that is glue and the surfaces to be stuck together, are of two kinds, polar and non-polar. They are commonly called secondary or cohesive forces, being responsible for the holding together of molecules. In the case of water, for instance, the elemental molecules of  $H_2O$  must be held together by some force, otherwise they would spread out and form gas instead of liquid water.

Both adhesives and adherents can be divided into these polar and non-polar groups, and a study of practical adhesion confirms that polar glues are needed to bond together polar materials, and vice versa. Thus wood, which is strongly polar, requires polar glues, such as phenol-formaldehyde resin, urea formaldehyde resin, etc., and metal, being non-polar, needs non-polar glues or cements, such as rubber mixtures or special vinyl resins.

Modern gluing practice has become highly specialised as, with the introduction of new synthetic adhesives, it affects so many industries and offers competition to a number of established methods of fabrication. The great advantage of the synthetics, as opposed to natural glues, such as fish and hide glues, blood, soya bean and casein, is that they are absolutely uniform in composition and quality and enable a standardised gluing technique to be developed. In addition, and this is of vital importance for aircraft and constructional work generally, the bond produced by use of synthetic glues is impervious to moisture, fungi and insects, and possesses a strength often greater than that of the material to be bonded.

*Phenol formaldehyde resin glues*

Probably the best known is Tego Film, which is a phenolic resin-impregnated tissue paper with a resin content of about 37-40% and a

thickness which varies between 0.003 to 0.01 in. The thinner type of gluefilm is used for delicate veneers, and the heavier type for thicker sheets. Tego, which, incidentally, is a German development specially designed for use in the manufacture of aeronautical plywoods, is suitable only for hot bonding, that is, use of hot platens in the hydraulic press. The film, which arrives at the factory in the form of a roll, is first cut to size and then slipped between the veneers and packed into a hydraulic press capable of exerting a pressure of 200-300 lb. per sq. in. The temperature is round about 135-149 deg. C. After being in the press a matter of minutes, 5-20, depending on the thickness, the board is removed. It is not only extremely strong, but may be boiled without separating the plies and is absolutely impervious to fungi and insects, even the most voracious termites leave this wood alone. To ensure complete success in bonding with Tego Film it is necessary to control the moisture content of the veneers, this is done by drying them in special kilns and storing in air-conditioned workrooms, and to work strictly to a set schedule of time, temperature and pressure. It can thus be readily appreciated that by the introduction of this amazing new adhesive much of the work of making high grade plywood is standardised and uniformity of quality assured.

Apart from the use of Tego or dry gluefilm, there are several other forms of phenol formaldehyde resin. One type is supplied as an amber-coloured solid of low softening point which can be moulded in the fingers. It is too plastic to be powdered except at low temperatures. The resin melts between 40 deg. C. and 75 deg. C., and commences to harden rapidly at 130 deg. C. This phenol formaldehyde adhesive is used in the form of an alcohol (methylated spirits) solution for the manufacture of laminated sheet, tube or rod, for impregnating coil windings, for bonding and waterproofing fibre board, and as a stoving varnish for waterproofing porous substances. In the production of laminated sheet, for instance, the paper or fabric is impregnated by passing it through a bath containing 50-60% by weight of resin in methylated spirits, the excess resin solution being removed by roller or other suitable squeegees. The impregnated material is then dried to remove solvent and layers of the dried fabric or paper are pressed together in a daylight press with heated platens. (A daylight press is so called because daylight can be seen between the platens when the press is open.)

Fibre boards, which are of great importance in the building trade, are bonded and waterproofed by the addition of an alkaline solution of the phenolic resin to the fibres at the beater stage followed by precipitation of the resin on to the fibres with subsequent felting and hot pressing at temperatures up to 135 deg. F.

Alcoholic and water soluble phenolic glues are now extensively employed in the plywood industry and give a bond that is highly resistant to water, even boiling water, insects and fungi. Practical tests carried out on various kinds of plywood bonded with liquid phenolic glues have shown them to be just as good as dry gluefilms for general use; in fact, for some types of work they are preferable.

Other forms of phenol formaldehyde resin (syrups) are used for the bonding of graphite brushes and impregnating brake linings. Here the resin is mixed with the materials to be bonded and the mixture cold moulded to the required shape. Hardening is then carried out by slow

baking. One kind of phenolic resin is used with a special acid hardener as a setting cement for pointing brickwork for acid-resisting tanks, for coating metals to prevent attack by acids, for cementing bristles into brushes, for cementing corks to moulded caps, and for plugging holes in mouldings. Phenol formaldehyde resin is also used for capping lamps or valves.

It will be appreciated from the above description that phenolic resins find many varied and important applications as adhesives and their usefulness in industry is being fully appreciated. There is no doubt that their unusual properties have proved of the greatest value in the aircraft industry where aeronautical plywood is used to such a large extent.

#### *Urea formaldehyde resins*

These are available in the form of powders, but more often as syrups. The latter are highly concentrated and have to be used in conjunction with certain hardening chemicals, whilst the former, which contain both resin and hardener, only require dissolving in a fixed amount of water to become immediately available for use. The great advantage of the powder form of glue is that it is easier to handle and does not deteriorate on storage. The breaking load of a joint effected with a good urea formaldehyde glue is about 25% to 30% higher than with a good casein glue, and the former will stand up to a three-hour boiling test without break-down. Although urea formaldehyde resin glue is used in plywood manufacture, generally with an extender such as rye flour which makes it go further, its chief use is for assembly work as a cold adhesive. In general practice, however, bonding is always carried out under a certain amount of heat as this quickens up the process and ensures uniform hardening and strength. Urea glues are almost colourless and can be used without fear of staining; they are, therefore, very suitable for employment in furniture and decorative plywood manufacture. A low pressure, in the region of 30 lb. per sq. in., is quite sufficient, provided it is uniformly distributed over the wood, and this can be applied by clamping devices or press. The temperature can vary a good deal, but 75–100 deg. C. is generally considered workable for most types of joints.

Of considerable interest is the use of urea formaldehyde resin for decorative laminated sheet. The paper, fabric or other material is impregnated with a water solution of the resin and then carefully dried at about 70 deg. C. Pressing is carried out between polished stainless steel press plates in contact with heated platens of a laminating press. Usually a temperature of 150 deg. C. is the maximum, and a finished sheet  $\frac{1}{8}$  in. thick requires a minimum cure time of two minutes. The pressure for this type of laminated work is 0.3 to 1 ton per sq. in.

#### *Thermo-plastic resin adhesives*

Apart from the above-mentioned synthetic adhesives, which are all thermo-setting, there are various thermo-plastic glues in regular use. The most important of these is the series comprising Formvars, Gelvas

and Alvars, which are polyvinyl resins produced initially in Canada as by-products from the synthesis of acetic anhydride from acetic acid and acetylene, and only developed as commercial adhesives after several years of intensive research. The Gelvas are polyvinyl acetates, the Formvars are acetates produced by the partial hydrolysis of a Gelva and subsequent reaction with formaldehyde, and the Alvars are manufactured from Gelvas by reaction of the hydrolysis product with acetaldehyde.

In the plywood industry the greatest interest is now being taken in the Formvars, which are used not only for the production of moulded plywood shapes by the so-called Vidal process, involving use of a modified rubber bag procedure, but for the partial impregnation or heavy coating of veneers to make high duty wood of varying density. The material known as Hydulignum is a most interesting new wood compound (birch veneers coated with Formvar), and when shaped to blade size has a density towards the tip of 60 lb. per cu. ft., and at the root, to which the metal ferrule or adapter is fitted, of 82 lb. per cu. ft. This change of density is effected by means of a two-way consolidation. The boards are first pressed to 60 lb. per cu. ft. density throughout, and by a second pressing operation in special presses the end of the board which is to form the root is reduced in width to the higher density required. The tensile strength of the finished wood is 45,700 lb. per sq. in. and the shear strength 4,540 lb. per sq. in. By the use of Formvar coated veneers Hydulignum possesses unique properties and, unlike the high density woods made by impregnating veneers with phenol formaldehyde resin and pressing, thus converting the resin in the pores of the wood into a rock-like mass, the vinyl resin, being thermo-plastic, has a degree of elasticity or give which is of great practical value. The future of the high density woods would appear to lie in the use of these thermo-plastic resins which possess excellent adhesive properties and preserve to a great extent the valuable structural characteristics of the wood.

For bonding metal to glass and other non-polar materials the polyvinyl resins, particularly the Gelvas, are excellent. It has been shown that the strength of the bond on a straight pull where various polished metals and glass were bonded without pressure was in excess of 1 ton per sq. in., and under the test the bond is so strong that it is not uncommon for conchoidal pieces to be pulled out of plate glass without breaking the bond to a metal plug.

Various acrylic resin cements are now being used as adhesives for thermo-plastics, textiles, leather, 'Cellophane,' metal foils, wood, rubber, etc. These new compounds are colourless, transparent substances, and some are so elastic that they can be stretched 1,000% before a break occurs. Owing to the excellent electrical properties of these resins they are recommended for all kinds of assembly work in the electrical industries, and for all uses where the bonded assemblies are subject to flexure and elongation. Their advantages over competitive cements include water-white colour, colour stability, unusual adhesion, flexibility, electrical resistance, and resistance to ozone, mineral and animal oils and dilute acids and alkalis.

Chlorinated rubber cements are widely employed for bonding metals and rubber-metal joints. This special form of rubber, now very scarce,

is available as a white powder and is used in the form of a benzene or toluol solution, generally modified by the addition of certain chemicals known as plasticisers which increase the adhesive properties. Synthetic rubber, such as neoprene, can be bonded to metal by means of a chlorinated rubber cement. This is first applied to the metal surface, allowed to dry and re-applied, three or four coatings being given. The last coating is dried out until tacky and the neoprene is brought into firm contact with the surface. Metal chemical plant, such as hydro-extractors, is now protected from corrosion with a neoprene or other synthetic rubber coating in the above manner. Chlorinated rubber can also be employed to render impermeable textile fibres, leather, paper, wood, sheets of cellulose derivatives, etc.

There are various synthetic rubber cements of interest to manufacturers, one of the most important being Thiokol cement (Thiokol is a synthetic rubber manufactured by the Thiokol Corp., U.S.A.), which is used for bonding Thiokol and neoprene impregnated fabrics, and for many other applications, particularly in the aircraft industry. Two general groups of these cements, coatings and adhesives, are being supplied to the aircraft industry. The former have better low temperature flexibility, whereas the latter provide better adhesion to non-porous substances such as metals. Due to their better adhesion the adhesives are used as coatings for metal surfaces.

Thiokol coatings have been used successfully as primers in the linings of plywood and compressed fibre auxiliary jettison tanks. The coating or lining of these tanks is necessary to ensure suitable resistance to 100 octane petrol and aromatic fuels. A heavy-bodied Thiokol putty is also used as a sealant between sections of these tanks. Thiokol base compounds are also used to coat chip-board, fibre, and treated paper gaskets which are used on motor vehicles. This versatile cement is invaluable for a great number of applications where it is necessary to bond metal to wood, synthetic rubber to synthetic rubber, and rubber to metal. Thiokol cements are used extensively to cement diaphragms into place and they are, of course, completely unaffected by petrol and oils. Applications in which adhesives are used as coatings include the spraying of fin and elevator counterweights on blimps and dirigibles to prevent salt water corrosion. Metal gas tanks on United States navy flying boats are similarly coated for the same reason.

### *Conclusions*

It must seem apparent from the various descriptions given of standard synthetic adhesives that these new materials have a great future in British industry. The most obvious one, of course, is the use of resin-bonded plywood for pre-fabricated houses. The accommodation comprised a spacious 13 ft. 6 in. by 19 ft. 6 in. living-room, 10 ft. 6 in. by 14 ft. 6 in. and 11 ft. by 11 ft. bedrooms, modern bathroom, 10 ft. by 10 ft. kitchen, 8 ft. by 9 ft. service room, and single garage. The wood used for the construction was a partially impregnated as well as bonded plywood, and absolutely weather-proof and resistant to wood-boring insects, termites and dry rot fungi. It is claimed that the most pleasing characteristic of the attractive exterior of this simple pre-fabricated

house is the simple expression of the carefully integrated construction made possible by the large resin-impregnated and bonded plywood panels, lot size 72 in. by 126 in., capacity 7,800 cu. in.

Of considerable interest to the engineering industry is the development of metal to metal and metal to wood synthetic adhesives. The material, Redux, an English product produced by Aero Research, Ltd., has been the subject of much official testing in this country in connection with aircraft assembly, and has been in successful use for two or three years. The joints obtained by use of this new cement are more efficient and aerodynamically perfect than those normally produced by riveting. In metal-to-wood joints, this cement yields bonds of excellent strength characteristics, opening up a new field of uses wherein the combination of properties of metal and wood are of value. It is likely that these new adhesives will be extensively used in the motor car and building industries after the war. Another development is the introduction of a synthetic cement capable of mending broken plastic (Bakelite type) mouldings, etc., and here again industry will find many important uses for this material.

It seems evident that synthetic adhesives will be utilised in many more industries than those enumerated, as they are particularly applicable to mass production processes, eliminating awkward nails, screws, rivets, soldering, etc. There are new glues to solve the most troublesome adhesive problems. For food packaging a range of colourless, odourless, tasteless and tenacious cements are available for employment in conjunction with automatic packaging machines. In furniture manufacture the use of these glues has already been stressed, and it is not difficult to conceive a time when screws and nails will no longer be employed. In the aircraft and automobile industries synthetic glues find a great number of important but little known applications, and engineers are showing a keen interest in their potentialities.

## CHAPTER XIII

### THE NEW DRUGS

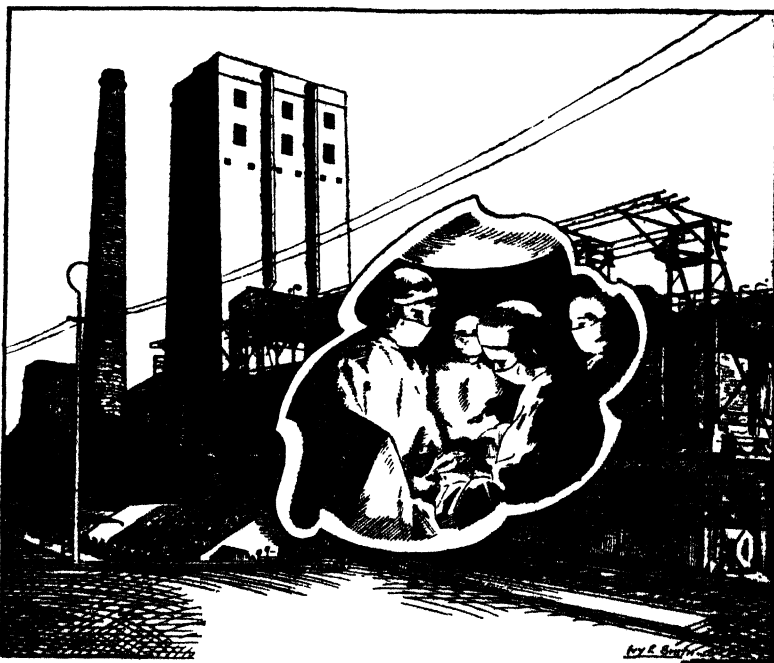
IT IS A SORRY REFLECTION ON THE SANITY OF HOMO SAPIENS THAT WHEREAS one branch of science is organised and developed to prolong life and relieve suffering, another branch seeks continually to devise more efficient and diabolical methods of destroying mankind. A new branch of medical science devoted to the treatment of disease with chemical bodies is chemotherapy. It is perhaps as well to point out that a chemotherapeutic agent differs from antiseptics in that it selectively attacks organisms causing the disease.

The search for Paul Ehrlich's 'therapia sterilans magna,' the drug of drugs, is pursued in every country in the world, but so far without complete success. Very great progress has, however, been made since the birth of chemotherapy in 1904, when the German scientist Ehrlich discovered 'Salvarsan,' the famous '606' cure for syphilis. It is stated

that this synthetic compound was termed '606' as it was the 606th arsenic compound prepared by Ehrlich in his attempts to obtain effective remedies for the protozoal diseases.

The success achieved by its use encouraged chemists and physiologists throughout the world to assess the curative properties of the many thousands of organic and inorganic chemicals made available largely through the newly developed coal tar by-product industries, particularly the dye industry. (There are more than 180,000 organic compounds, a large proportion of which have not been tested.) It will be remembered that Ehrlich owed a good deal of his success to the support given to his research by the German dye industry. The institution which he founded in 1906 was financed by one of the wealthiest dye manufacturers, who was shrewd enough to realise that closely allied to dyestuffs was the possible range of new drugs, some of which were, indeed, dyes themselves.

Great discoveries are rare in chemotherapy, and it takes many years of laborious research and clinical experience to produce new and important specifics, such as the sulphonamides and penicillin. The former group



From the byproducts of the coal industry many of our most valuable drugs and antiseptics are now being manufactured.

of important drugs is an offshoot of the parent sulphanilamide, a chemical of considerable interest to the dye industry. This was prepared synthetically by Gelmo, a German dye chemist who was studying the use and properties of azo dyes for textiles. Some of these dyes were later, 1932,

found by G. Domagk to be effective in streptococcus infections in mice, and opened up interesting possibilities for similar conditions in man. The German pharmaceutical house of Bayer followed up the work of Domagk by producing the drug, Prontosil, a special azo dye which developed sulphanilamide in the body.

The use of Prontosil was extended to clinics and its success in the treatment of acute infections caused by particular strains of bacteria, the so-called hæmolytic streptococci, aroused the greatest interest throughout the world. Incidentally, although sulphanilamide is the really active agent of Prontosil and Neo-Prontosil, these two dye products are more efficacious for the treatment of some phases of disease than the less complex sulphanilamide.

It was not until 1935 that it was finally proved that the active agent of Prontosil was sulphanilamide, a chemical found to be most successful for treating meningitis, gonorrhœa, childbirth infections, blood infections (septicæmia), erysipelas, etc. Sulphanilamide itself, which is a derivative of the coal tar industry, is a white crystalline powder with a bitter taste. It is only slightly soluble in very hot water and is suitable for oral administration in the form of 5 to 7½ grain tablets. The drug may also be administered by intramuscular and usually in the form of the sodium compound. The initial dose needs to be high enough to produce an effective concentration of the drug in the blood, at the same time the concentration must not exceed a certain maximum, which varies with individuals owing to the relatively high toxicity of the chemical. The doctor has always to balance effective concentration against toxicity and to appreciate that individual susceptibility to sulphanilamide poisoning varies quite considerably. Only a few years ago in America a number of deaths were caused from sulphanilamide poisoning due to the unrestricted use of this drug for the self-treatment of gonorrhœa (so-called three-day cure).

The discovery of sulphapyridine (M. and B. 693) shortly after the introduction of sulphanilamide greatly increased the scope of this range of new chemotherapeutic agents and placed into the skilled hands of science a new and powerful weapon for the treatment of pneumococcal infections and gonorrhœa.

It is usual to consider the sulphonamides under two broad headings, Group A and Group B drugs. The A type includes sulphanilamide and related compounds, such as Prontosil, and the B drugs, the famous M. and B. 693 or Dagenan, and the less well-known products, Uleron and Albucid. The A drugs are essentially specific for the treatment of the hæmolytic streptococci germs, whilst the B type are best known for fighting pneumococci.

How do these drugs act in the blood stream? They do not, as many people seem to imagine, actually kill all the germs present in the tissues or blood and so in this way overcome infection. Their action is really two-fold. When present in sufficient concentration the sulphonamides do destroy the disease-causing bacteria, but of greater importance is their ability to slow down the growth of the microbes so that the natural recuperative and disease-fighting properties of the body can get to work.

Clinical experience has shown that whilst some people respond well to treatment with the sulphonamides, others do not respond in such a



satisfactory manner. This difference in response to the curative properties of the drug is due largely to the fact that in some body systems a fairly large proportion of the compound is converted into an inert (acetylated) form which has no action on disease, whereas in other body systems the proportion of free and active drug remains fairly large.

The field of action of the sulphonamides has been largely extended and now includes interesting new compounds of lower solubility. The drugs, sulphaguanidine and succinyl sulphathiazole are finding new chemotherapeutic applications, for instance in the treatment of dysenteries and the diarrhoeas of infants and young children. Apart from the development of M & B 693 certain other related synthetic compounds are now proving of value as chemotherapeutic agents. The diamidines are now proving of great service to mankind in the treatment of Kala Azar, a dreaded Eastern disease, and Babesia in dogs. The latest diamidine compound, 4,4<sup>1</sup>-diamidino-stilbene—was developed by Dr. Ewin, chief chemist of May and Baker.

The story of penicillin is one of disappointing, and yet undaunted, patient research carried out over fourteen years by a team of British scientists. The discovery of this wonderful antibiotic, as it is called, was accidental, and occurred in this way. One day in 1928 Professor Fleming, a noted bacteriologist and research worker on the staff of St. Mary's Hospital, London, noticed that a freshly prepared culture of staphylococcus, a dangerous type of microbe present in infected wounds, was spoilt by a speck of air-borne green mould or fungus. This green fungus spoilt the culture in an unusual way, and Professor Fleming was intrigued to find that in the immediate vicinity of the mould the colonies of staphylococci were disappearing. This was a sensational discovery, and the Professor immediately set about to prepare some cultures of the particular fungus, *Penicillium notatum* Westling, a comparatively rare type of mould.

The highly bacteriostatic agent which the particular strain of the mould passes into the culture or medium is the drug known as penicillin. Its isolation, purification and concentration proved one of the most difficult problems yet solved by chemical science. First of all optimum cultural conditions had to be determined, and then methods of extracting the drug from the culture liquid. Three workers, P. W. Clutterbuck, R. Lovell and H. Raistrick, surmounted the first hurdles, but they found that although penicillin could be extracted with ether there was no way of removing the solvent without destroying the highly sensitive drug. At one time it looked as if penicillin was far too unstable to permit its production in sufficient quantities for clinical experiments. It is mainly owing to the work of Professor H. W. Florey and Dr. Chain, members of an enthusiastic group of scientists known as the Oxford Group because they worked at the Oxford School of Pathology, that a practical method of production was evolved which, although elaborate, could be adapted to manufacturing requirements.

The first step in the commercial production of penicillin is the preparation of the nutrient medium. This is a dark brown liquid which contains sugar and mineral salts, together with certain other materials which can be regarded as a kind of 'manure.' The nutrient medium is made up in large bulk and is then put into half-pint bottles which are filled mechanically like milk bottles in a large dairy. The bottles and their contents are then plugged with felt to exclude airborne organisms and sterilised by

being heated up in large ovens, and after they have cooled they are sown with the 'spores' of the mould *penicillium notatum*.

The inoculated bottles are then allowed to stand for nine or ten days at a steady temperature of 23 deg. C. while the mould gradually covers the surface of the liquid and excretes the penicillin into the liquid beneath it. The next problem is to extract the penicillin from the liquid, which is amber coloured, and to separate it from some of the many impurities which are also there.

The bottles are emptied and the mould itself, which has done its work and is no longer required, is thrown away, and the liquor is then allowed to come into contact with an organic solvent which has the property of extracting the penicillin and leaving behind some of the impurities. From the organic solvent the penicillin must be taken back into a watery solution, by which time it has been partially purified, and it is then dried so as to be ready for use. Penicillin is a very delicate material and if subjected to undue heat may be destroyed. It is therefore dried at the lowest possible temperature, actually by evaporation of ice from the frozen solution until the block of solid ice is gradually replaced by a dry, golden powder which is the penicillin known throughout the world as the most powerful chemotherapeutic agent yet discovered.

This material must then be ground and is subjected to rigorous testing before it is packed. First it is tested for potency, that is for the power it has of killing bacteria; then it must be ascertained that the powder is sterile and does not contain harmful substances. After these tests the powder is ready for issue to the medical services.

Clinical experience with penicillin has shown that at extreme dilution, even 1:50 million for the impure form, the compound prevents the growth of streptococci and has no harmful effect, even at relatively high concentration, on the white blood cells or body cells. Penicillin has to a large extent realised the dreams of Pasteur and Ehrlich, namely a most powerful and non-toxic antibiotic which can be used in shock doses for the treatment of infection due to streptococci, staphylococci, diphtheria germs, gas gangrene, spotted fever, pneumonia, etc. Unlike the sulphonamides, penicillin has no ill-effects on the delicate body system.

Burns which, in spite of treatment with 'sulpha' drugs, became infected and caused death can now be readily healed. Compound fractures and many other types of injury produced in war heal far more readily by the application of penicillin. The death rate from wounds and the number of amputations have been enormously reduced.

The experience of this war is conclusively proving that science has, with penicillin, prised open one of Nature's most valuable secrets, a secret which will undoubtedly be fully exploited for the benefit of suffering humanity in war and peace. It should be realised that this drug is only one of the hundred or so metabolic products of the lower fungi which have been isolated and found to possess powerful anti-biotic properties. The moulds *Aspergillus flavus* and unnamed species of *Aspergillus* have been found to produce powerful anti-bacterial agents, and a new species isolated from soil is likely to be developed as a new type of antiseptic. The substances, penicillic acid and citrinin, are of interest for the treatment of certain diseases not affected by penicillin.

With the development of penicillin it has been generally forecast that the sulphonamides will become largely redundant. This is considered

unlikely by scientists, as in many instances the naturally derived antibiotic can be used with advantage in conjunction with the synthetic product, or compounds such as propamidine and the amino acridine compounds, proflavine. Thus in treatment of war wounds use has been made of penicillin and sulphanilamide dressings with excellent results.

Vigorous research undertaken to determine the chemical constitution and formula of penicillin has been successful, and scientists now know the chemical structure and formula. The next step is the commercial synthesis of penicillin, and this may not be long delayed. The range of anti-bacterial substances from moulds is also being exploited, and it is highly probable that many new products will soon become available for use by the medical profession.

British scientists deserve the greatest credit for the production of anti-malarial drugs during the war when supplies of quinine were cut off due to the Japanese occupation of the Dutch East Indies. Malaria is one of the most terrible scourges known to man, and in peace alone more than 3,000,000 people in the world die annually of this disease; about half the deaths occurring in India. During war-time when vast expeditions are forced to fight in tropical and sub-tropical countries the need for anti-malarial drug becomes of the first importance.

Germany, prior to the last war (1939-1945), had a virtual world monopoly over the production of both pamaquin and mepacrine (synthetic substitutes for quinine). This was due chiefly to the fact that other countries were content to rely upon the natural sources of quinine—there were no strong medical reasons for gainsaying such a policy—and world interest in pamaquin and mepacrine was at most lukewarm.

The possibility of war with Germany, with consequent restrictions on shipping, changed British participation in this outlook, although not very markedly. Research was therefore undertaken to confirm the chemical constitution and method of preparation of these two drugs published in German patent specifications. The Germans had protected their discoveries well by patenting all conceivable ways of making the substances without any definite clue as to which were the most efficient methods of manufacture. A big research effort was necessary to explore all methods, to discover the most practicable ones and to find the best of the latter. However, when war broke out initial difficulties had been largely overcome and small amounts of both drugs were being produced. Quinine was then in good supply and the small demands for the synthetic drugs were met without much difficulty.

The entry of Japan into the war and the rapid conquest of the Dutch East Indies put a different complexion on matters. Quinine supplies had to be conserved and, with the war spreading more and more into the malarious regions of the world, the problem of supplying the armed forces of the United Nations with anti-malarials became acute and enormous civilian needs had also to be considered.

Mepacrine, as already stated, was the drug required to replace quinine, and literally hundreds of tons were needed to meet the total demands. When it is considered that 1 ton of the pure drug produces over 11,000,000 tablets each containing only 0.1 g. Mepacrine Hydrochloride and about four being required per week per man for prophylactic treatment, the magnitude of the requirements will be realised.

A complete pooling of information between the British firms concerned

helped and the resources of the dyestuff manufacturers were exploited to the full. The latter were particularly useful since plant and processes used for the manufacture of modern dyestuffs were essentially similar to those required for the synthetic medicinal products.

Since the announcement of mepacrine (atebrin) an entirely new and revolutionary compound for the treatment of malaria has been discovered by a team of British research workers. This compound, known as Paludrine, is not only considerably easier to manufacture than mepacrine or pamaguin, but does not produce the undesirable yellowing effect encountered in most cases treated with mepacrine. It is much more powerful in its action: one part of paludrine being equivalent to at least three parts of mepacrine or ten parts of quinine. Since its first clinical trials at the Liverpool School of Tropical Medicine in February 1945 this new anti-malarial drug has been subjected to more extensive clinical trials in Australia. The results of these trials have confirmed that this drug is not only more effective, but is also considerably less toxic than either mepacrine or quinine.

It is not only in the preparation of chemotherapeutic agents that science has triumphed during the last decade, but also in the synthesis of vitamins, hormones and other substances of natural origin. Synthetic thiamin chloride, or vitamin B, the anti-neuritic and anti-beriberi specific, is vital to health of all ages. Of considerable interest is the range of synthetic steroid hormones (oestrogens) of which stilboestrol is the best known. The development of this relatively simple compound as an alternative is the naturally occurring female sex hormone, oestrone or oestradiol, is due mainly to research carried out by Professor E. C. Dodds and his colleagues at the Middlesex Hospital, London, in 1938. Stilboestrol is three times more potent than the naturally occurring hormone. Another very important synthetic hormone is diethyestilboestrol used for the treatment of cancer of the prostate gland. Synthetic d-riboflavin, nicotinic acid and synthetic l-ascorbic acid are the vitamins made to-day in large quantities to fortify foods and to prevent various deficiency diseases. Ascorbic acid, vitamin C, prevents and cures scurvy, and the body-needs some 40-50 milligrams of this substance daily.

Of major importance is the development of two wonderful insecticides D.D.T. (American) and Gammexane (British). The discovery and production of these were largely due to the necessity of war which, in 1942, cut off all supplies of pyrethrum, a plant of the chrysanthemum family which contains small quantities of the highly toxic pyrethrins. D.D.T. the first of the synthetics, is known chemically as p. p<sup>1</sup> dichloro-diphenyl-trichloroethane and its insecticidal properties were first discovered a year or so before the war by a Swiss chemist; it was, in fact, successfully used in 1939 in Switzerland against the Colorado beetle. Extensive tests in America showed that D.D.T. possesses a powerful lethal action against many different forms of insects and it was used to stamp out a threatened typhus epidemic in Naples in December, 1943. Gammexane promises to be even more useful than D.D.T. This complex chemical is the result of long and patient research carried out at the I.C.I. Hawthorndale Laboratory at Jealott's Hill, and other centres of research. Early in 1942, scientists working in the I.C.I. entomological laboratories were looking for a substance to kill the turnip flea beetle and among the large number of chemicals tested was a sample of benzene hexachloride, known

as 666. This chemical was found to be most valuable and large quantities were used in place of derris in flea beetle powder for use in the spring and summer of 1943.

Meanwhile, chemists and entomologists were investigating the inconsistent action of different samples of 666 and K. C. Webster investigated both the possibility of an impurity being the active principle and also the toxicity of the various isomeric forms in which 666 was known to exist.

Late in 1942 pure specimens of the alpha and beta isomers of 666 were prepared and their toxicity tested. It was found that both isomers were relatively inactive to weevils and the beta-isomer was practically non-toxic. Early in 1943 the gamma isomer was isolated and found to be more toxic to weevils than any substance which the scientists had ever tested. It was thus established that the insecticidal action of 666 was due almost entirely to the presence of the gamma isomer, which was present to the extent of 10-12% in the crude material.

Gammexane, the name given to the gamma isomer of hexachlorocyclohexane, is highly toxic to many insects and certain other pests. It is, for instance, fatal to the African migratory locust; house cricket; body louse; bed bug; various leaf-eating larvæ; various flea beetles; various mosquitoes, housefly, etc., indeed, the list of easy victims is an exceedingly long one.

The public is always interested in a really sensational story about new drugs, but indifferent to the long drudgery of preliminary research necessary before the drug reaches the clinical stage. Government departments and public bodies, while anxious to bask in the reflected glory of new discoveries take little practical interest in long term research, and the pharmaceutical industry itself makes more money out of headache powders and patent cough cures than any of your genuine chemotherapeutic agents. Big business is not in the least interested in long term research and financiers at the head of our various combines realise that it is a costly, lengthy and disappointing business, moreover it pays but an uncertain dividend. This state of affairs cannot and will not be altered unless the pharmaceutical industry is compelled by the will of the people to set aside a reasonable proportion of its profits for long term research, preferably organised on a co-operative basis.

What is urgently needed as part of the new medical structure is a Therapeutic Substances Committee which should have statutory control over all therapeutic substances and appliances and over all advertisements of such commodities. In a recently published statement prepared by the Socialist Medical Association for submission to the Ministry of Health it was stated that 'it must have the duty to examine and report publicly on all the substances offered or advertised for the treatment of disease or protection of health. It should also have the duty to prepare and submit to every doctor reports on new remedies and to recommend their inclusion or exclusion from the National Formulary.'

## CONCLUSION

**ALTHOUGH THIS SURVEY OF BRITISH INDUSTRIES IS FAR FROM COMPLETE, at least sufficient information is given to indicate the trend of modern developments. Whilst British industry has greatly expanded to meet the war emergency, such expansion may in some cases give place to retraction now that the heat of the conflict grows less. It would be foolish to gauge future prosperity on the present condition of our war-swollen factories.**

The industrial legacy of the war is difficult to assess. First, there is the rich bequeathment of new technological knowledge and experience which may be exploited for the national good. Then there are the bad or doubtful debts such as the mortgage of so many of our assets to the United States ; the industrialisation of parts of the Dominions and countries which were formerly great exporters of raw materials ; the presence of large war surpluses not only of warlike stores, but machinery, textiles and goods of all kinds now scarce ; the seeds of industrial unrest which have been sown in the way of inflation wages.

It is impossible to strike a true balance, but on the credit side the technological assets are considerable, and Great Britain emerges from this war as second only to the United States as a fabricating country. We depend, however, more than ever on imports of raw materials, but our reduced financial strength makes it necessary to limit such imports. If there is open competition for markets Great Britain will find it difficult to compete without some lowering of the standards of life plus increased rationalisation and mechanisation. A great deal depends on the attitude of the U.S.A., and it is as yet impossible to appreciate the full trade implications of the recent Loan Agreement. The enormous industrial expansion which has taken place in the U.S.A. since Pearl Harbour is most certainly a potential menace to the industrial prosperity of this country, particularly as our bargaining power has decreased as our indebtedness to Uncle Sam increases. The great fear in this country is that Great Britain may become the dumping ground for surplus American goods.

In any consideration of our export trade it is essential that some attention should be given to China which offers an almost inexhaustible market for machinery and all types of manufactured goods. Unknown to most people is the fact that during the war the British Government has fostered a substantial export trade with China and carried out a good deal of unobtrusive but, nevertheless, powerful propaganda on behalf of British goods.

All this may prove somewhat of a shock to American business men who have been assured by their Government officials that the China market is secure for post-war exploitation. There has been and will

continue to be some bitterness between America and Britain over the China market, particularly as there is good reason to believe that during the war Uncle Sam attempted to secure economic preference in this sphere under the guise of military assistance to the Kuomintang regime.

The industrialisation of the self-governing Dominions, particularly Canada, whilst a source of pride during war, is regarded uneasily by manufacturers in this country. Canada has become the greatest base metal exporting nation in the world and in achieving the largest output in her history, was producing in 1943 the following percentages of the combined output of the United Nations: nickel 95%, asbestos 75%, aluminium 40%, mercury 20%, zinc 20%, lead 15%, and copper 12%. As long as Canada is content to export virgin metal, well and good, but the Canadian fabricating industry is expanding rapidly, and if it develops on true American lines it can only be to the detriment of the corresponding industry in this country. Canadian aluminium producers are turning out well over half a million tons of aluminium a year. If they would be content to export it in the virgin state for fabrication in this country the British light metal industry would remain prosperous, but as it is, the future is likely to be largely dictated by the policy of the Canadian manufacturers.

The industrialisation of India, so warmly advocated by many shrewd visitors to that country, may one day have a considerable influence on our economic future. Although India is not particularly rich in minerals she has important deposits of coal and iron ore, as well as manganese, mica and bauxite. The annual output of iron ore is about 2,750,000 tons and the production of steel more than 1,000,000 tons per year. Coal production is on the level of 25,000,000 tons a year, of which India exports about 2,000,000 tons.

Apart from minerals, it should be remembered that India is the largest sugar-producing country in the world, and is able to turn out 1,500,000 tons of white sugar annually. Jute is another non-mineral product of great value and the Indian jute mills alone consume 1,167,000 tons of jute per year. In addition to sugar and jute and other textile fibres there is the very considerable trade in hides and skins. India also produces very large quantities of lac and the export figure reaches a total of 800,000 cwt. per year.

It is suggested that from agricultural surpluses, particularly sugar, a new organic chemical industry could be built up in India and so supply fine chemicals, dyestuffs and plastics for which substantial domestic markets exist. Incidentally alcohol might also be employed as a fuel for internal combustion engines.

The glass industry might profitably be expanded as there are already some hundred or so glass factories in India and the demand is far greater than the supply. Here again, of course, cheap coal is essential as it requires about one ton of coal to make a ton of glass.

Industrialisation for India would mean a better economic condition for the people and tend more than any other factor to further the elimination of religious prejudices of which the caste system is an example. It is probable that industrialisation would smooth the way towards the complete co-operation of people of all creeds and political parties and further the creation of a unified India.

Would increased industrialisation of India result in a diminution of imports and adversely affect our home industries? Taking the long view, there is good reason to believe that a policy of Indian industrialisation would create new and more varied markets for British goods. Many millions of Indians previously deprived of goods through lack of purchasing power would enter the market as potential consumers.

Will the primary producing countries of the world be content to remain as such after a war-time experience of self-sufficiency and enforced expansion of manufacturing industries? The salvation is not likely to come from direct Government action, but from negotiations undertaken by private enterprise for mere self-preservation. This means the setting up of world monopolies or cartels which would require the closest supervision to prevent abuse of privilege. It is easy to point out the many obvious dangers of cartels, but on the other hand the dangers of cut-throat competition are just as real and likely to be felt more directly by the workers.

The presence in this country and America of huge stocks of plant, warlike stores and numerous commodities ranging from towels to mechanical excavators, is a threat to normal peace-time trading. Manufacturers are asking now about the release of these materials and how their release will affect peace-time production. It will be remembered that after the last war there was a wholesale dumping of war department goods on the open market and industry suffered a heavy blow from under-cutting. It seems not unlikely that U.N.R.R.A. will form a convenient outlet for war surpluses and thus remove a source of grave embarrassment to British and American industry.

The adjustment of labour to peace-time industry is proving difficult, and discontent must eventually be caused as a result of the inevitable lowering of standards of living in certain major trades, particularly engineering and general metal and wood fabricating industries. The inflation wages now being paid in some large plants bear no relation to peace-time economic rates. Cost in war means very little, but in peace-time every private enterprise has to be judged upon whether it can make a profit or loss, and a profit is only possible if the labour charge does not exceed a certain specified percentage of the manufacturing cost. The switch over from war to peace-time conditions of wages must necessarily be a gradual one, but, however long delayed, the problem remains an exceedingly difficult one to solve.

The present pseudo-peace is proving an uneasy and anxious time, but the real peace which must follow is likely to be an exciting period for all who view with interest the developments of science and industry. The discoveries and inventions made during the war will quickly be exploited. Chemistry is likely to play an even greater part in everyday life. Plastics, those amazing products of chemical synthesis, are likely to find many more important applications. Nylon, already known as a textile fibre and monofilament for brushes, will be available for fabricating in powder, tube and sheet form. New nylon impregnated or coated fabrics are earmarked for important developments as they wear extremely well and do not crack or scuff and can be made to resemble kid and calf for shoes and handbags. These nylon-coated textiles are also likely to be used for draperies and upholstery, as well as industrial components, such as



carburettor diaphragms, gaskets, etc., as they are impervious to oil and petrol, etc.

The future of synthetic rubber is governed to a large degree by the rate of recuperation of the natural rubber estates, but it is likely that synthetic rubber will be in general use for at least another five years, and possibly more. It should be remembered that the American Government has sunk many millions of dollars in plant for the production of synthetic rubber and it is very unlikely that Uncle Sam will readily agree to the dismantling of those plants before they have had an opportunity to pay for themselves. Synthetic rubber is "nearly" as good as natural rubber and during that interval necessary for re-working of the rubber plantations, it may be that it will be improved to such an extent as to make it as good as the natural product. The tendency in this country seems to be to undervalue the synthetic material, but it should be remembered that British rubber manufacturers have a heavy stake in the rubber plantations in the Far East and very little financial interest in synthetic rubber as only a tiny fraction of the British supply is produced in this country.

In the field of metals great developments have taken place during the war years, particularly in the case of light alloys, and they will find many more structural applications, especially in the building trade. Of growing interest is the use of the latest expanded plastics and rubbers in conjunction with light metals for thermal insulation in the food industry, domestic refrigerators and insulation of bulkheads on cars, buses and for ships' cabins, etc. In aircraft construction for struts, flooring, partition walls and for general construction applications these unique assemblies are certain to be widely used. (Expanded plastics are gas expanded and have a density between 7 and 30 lb. per cubic foot. The thermal conductivity is 0.28 British Thermal units per sq. ft. per 1 in. thickness of material and for 1 deg. difference in temperature.)

The use of wood as an engineering material has been one of the most interesting developments of the war, and this is an example of the successful marriage of wood and plastics, the latter being employed in the form of special adhesives which can also be used to impregnate veneers. Some very important work has recently been carried out in America on the use of resin-forming chemicals which are capable of reacting with the cellulose of the wood and forming plastics in situ. The wood treated in this way is an entirely new material. It is dimensionally stable under varying conditions of humidity, does not show grain raising, is hardened, has increased wearing qualities and has markedly increased compressive strength. Of considerable interest is the use of urea in the drying of wood. A surface treatment of urea applied to green lumber promotes drying from the inside out, that is in reverse, thus eliminating the stresses that are responsible for checking and cracking during the drying operation. This chemical process is applicable both to air drying and kiln drying, and opens up great possibilities for the timber trade.

The development of D.D.T. in America and Gammexane in Great Britain is likely to have far-reaching consequences. Malarial swamps can be sprayed with these highly toxic insecticides and cleaned of mosquitoes. Typhus-infected areas can be made perfectly safe in a few hours, houses may now be freed of all insect pests, including the common fly.

A book of this nature can never keep up with the pace of scientific discovery and invention, but at least sufficient has been said to indicate and suggest the trend of peace-time industry. There are great opportunities awaiting for those who have courage and initiative coupled with the requisite technological knowledge, but life in the new era will not be easy and international competition is certain to be intense, perhaps even unscrupulous.

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