SHEET STEEL AND TIN PLATE

BY

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TO

ALL THOSE ENGAGED IN THE UTILIZATION OF SHEET STEEL PRODUCTS

FOR THE FABRICATION OF ARTICLES

WHICH INCREASE THE COMFORT AND CONVENIENCE OF MANKIND

THIS WORK IS DEDICATED.

Foreword

The Author has honored me by asking me to write a brief preface to his book, and this I am very happy to do, because I am very much gratified that some well-qualified person has written a book on the production of sheet steel and tin plate from the standpoint of its utilization as well as its manufacture. So far as I know, no adequate treatment of this subject is available in print in any language, and especially none which covers the practical phase as well as the fundamentals, which this book does. Unfortunately, there are only a few men able and willing to write a book on manufacturing processes relating to steel, because they are either practical men who are unable or unwilling to put their knowledge into print for the benefit of everyone, or else they are so theoretical that they overlook some of the details of the subject which are important for the practical man. The present Author has sufficient knowledge of actual manufacture not to overlook the important details relating to operations as well as utilization, and to speak with assurance on them, combined with a grasp of the fundamental principles and the ability to clothe his ideas in clear and easily comprehensible language. I predict for this book an important place in the literature of the industry which it serves.

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Bethlehem, Pa.
May 15, 1930.

Preface

All industry is engaged in producing something to satisfy human wants. Consumption is the end and aim of all commodities. Therefore, the efficient and economical utilization of commodities must be a worthy goal.

It is necessary, for the greatest common good, that commodities be produced efficiently and economically and to this end there exists copious literature on the subject of steel products, written from the standpoint of the producer for the most part.

However, it is equally important, once commodities have been produced, or even before their production has been planned when they are to be made to order, that they be directed into those consuming fields for which they are best suited.

This book is intended to assist the layman toward the best and most economical utilization of sheet steel products.

The author is indebted to many in various capacities, from executives to workmen, in offices, in the mills and in consumers shops, who have supplied him, from time to time over many years, with practical and theoretical information on both the making and the utilization of sheet steel products; as well as to all those authors whose names appear in the bibliography. Direct quotations have been so noted in the text, but much which has been absorbed from study of these books and restated in the writer's words cannot be acknowledged specifically.

Particular thanks are expressed to Mr. William C. Tamplin for much valuable information on the manufacture and fabrication of sheet steel and for reviewing sections on these subjects; to Professor Bradley Stoughton, whose "Metallurgy of Iron and Steel" provides such an admirable introduction to this study, for reviewing, with helpful suggestions, sections involving metallurgical problems; to Mr. Stephen Badlam for his generous permission to use much of the data he collected on continuous sheet rolling; and to Mr. L. H. Pyle for his review of the section on tinning.

Photographs and photomicrographs reproduced as illustrations have been courteously supplied by: Wheeling Steel Corporation, Youngstown Sheet and Tube Company, American Sheet and Tin Plate Company, Jones and Laughlin Steel Corporation, United Engineering and Foundry Company, E. W. Bliss Company, and New York Testing Laboratories. Numerous diagrams and sketches have been prepared by the author in the hope of presenting clearly the essentials of certain operations and equipment without any confusing details; also, the photographs of sheet steel surfaces have been prepared under his supervision by the New York Testing Laboratories.

Quotations from reports and publications of the American Iron and Steel Institute, the Association of American Steel Manufacturers and the American Society for Testing Materials, also from several publications of the McGraw-Hill Book Company and other publishers are gratefully acknowledged.

R. W. SHANNON.

New York City,
June 1, 1930.

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PART I.

Industrial Iron Products in General.

Courtesy of United Engineering & Foundry Co.

Fig. 1.—Modern sheet mill: General view, showing sheet furnaces to rear of hot mills and two cold mills in the foreground; also piles of packs of sheets which have been rolled out and are ready for shearing and opening.

CHAPTER 1.

INTRODUCTION.

THE AGE OF IRON.

Without our present plentiful supply of iron and its products, civilization, as we know it today, could not exist. This fact is so commonplace that most people regard iron metal as one of the vital substances which Nature provides Man, almost for the asking, such as stone, wood, coal, salt, etc. But this is not the case, for while stone, wood and coal may be acquired from Nature merely by gathering, digging or cutting, metallic iron on the other hand, does not exist in Nature except in the rare and peculiar case of meteorites. The iron in the earth's crust occurs, not as the metal with which everyone is familiar, but as a chemical compound of iron and other elements, much on the order of iron rust, intermingled with numerous earthy substances. Iron ore, then, is rock or earth containing, in varying proportions, compounds of iron which are not metallic. The iron part of the ores most employed at the present time consists of what the chemist calls "iron oxides," that is, substances composed of iron and oxygen chemically combined.

The metallic iron must be obtained from the iron ore by chemical methods, involving heating; all under human direction.

When the metallic iron has been produced, however, it is merely a raw material, such as logs of wood or slabs of stone, and must be worked or shaped into useful form. Unlike wood or stone, though, iron is capable of having its natural properties modified so as to suit the multitude of different uses to which iron products are now put. This is accomplished by combining other elements with the iron; by mechanical manipulations during manufacture, or by treatments after the product is shaped. By these means, the natural characteristics of the iron may be altered, either slightly or greatly, as desired.

As the art of making iron products progressed, our material civilization, or methods of living, developed. It is the strength, adaptability, magnetic properties and abundance of iron and its products which make possible the profusion of tools, machines, engines, motors, vehicles and other devices upon which our present mode of life depends. It is not impossible that some day another substance, say aluminum, may become more useful than iron, but iron and the art of iron-making comprise the bulwark of our present civilization.

THE OBJECT OF THIS BOOK.

If we may correctly assume that existing institutions and future material progress depend greatly upon iron and the iron-making and iron-fabricating arts, it would seem proper that iron-making be better understood by the layman, particularly by the man whose occupation or interest is connected with some iron product, even though indirectly. To acquire a thorough, technical knowledge of only one phase of the complex subject of iron and its products requires a vast amount of study and work. Nevertheless, the rudiments of the subject in general and the principal details of a particular product are not so complicated or abstruse as would appear to the layman upon reading a more or less technical description by a skilled engineer.

If the essential facts concerning sheet steel and tin plate could be clearly expressed in everyday language, the layman should be able to gain therefrom an insight into the possibilities and limitations of these important kinds of iron products which would permit him to understand present uses better and possibly to visualize new uses for these materials which would represent economic advances of value to society at large.

The foregoing reasoning has impelled the writer to endeavor to describe, as simply as possible, using technical terms only where these are unavoidable or necessary for the sake of clarity:

1. The underlying principles of iron- and steel-making as these relate to the forms of steel called sheet steel and tin plate.
2. The operations and materials involved in the rolling and treating of these products.
3. The nature and purpose of the numerous grades and finishes in which sheet steel and tin plate are produced.

The aim has been to arrange the topics in the order in which questions concerning them would probably arise in the mind of the reader who has had no previous understanding of the subject.

Should this non-technical "First Reader" convey to the layman reader a real, though necessarily incomplete, knowledge of sheet steel and tin plate, thus permitting a better understanding of the utility, as well as the limitations, of the numerous grades and finishes of these flat steel products, the writer's hopes will have been realized in great part. If, in addition, it should stimulate the layman reader to study standard technical books, to observe his work with sheet steel more carefully, or otherwise to pursue the subject, then this book will have fulfilled its entire purpose.

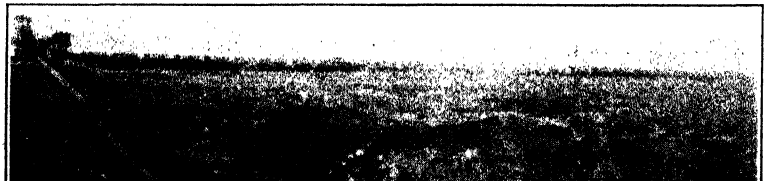
CHAPTER 2.

THE DIFFERENT KINDS OF IRON PRODUCTS.

GENERAL DISCUSSION.

No better introduction to the study of iron products in general could be given than the following quotations from Bradley Stoughton:[1]

> "*Iron*—Iron as such—by which I mean pure iron—does not exist as an article of commerce, but appears in service and in the market only in the form of cast iron, steel or wrought iron—that is, when contaminated with carbon and other impurities. Some of these impurities are present because they cannot



Courtesy of Wheeling Steel Corpn.

FIG. 2.—Open pit ore mining (Mesabi District).

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[1] Bradley Stoughton, "The Metallurgy of Iron and Steel," McGraw-Hill Book Co., New York, 1913, pp. 3-6.

cheaply be gotten rid of, and others, because, like carbon for example, they benefit the metal by giving it strength or some other desirable property. Pure iron is a white metal and one of the chemical elements. It is with one exception the commonest and most abundant metal in the earth, and almost all rocks contain it in greater or less degree, from which we extract it if it is large enough in amount to pay for working. It is almost never found in nature in the form of a metal, but is always united with oxygen to form either a blackish, brownish, reddish or yellowish substance. Indeed, if it should occur in metallic form it would very soon become oxidized by the action of air and moisture. . . ."

"*Carbon*—Carbon is also a chemical element and familiar to everyone; graphite, lamp-black, charcoal, and diamond are the various allotropic forms in which it appears. It is a common substance and present in every form of organic matter, while its oxides—carbon monoxide, CO; and carbon dioxide, CO_2—are well known gases. Its chemical affinity for iron is very great; iron practically always contains some amount, but if it is desired to remove it entirely, the last traces are eliminated only with extreme difficulty."

"*Iron and Carbon*—Carbon has the peculiarity of conferring on iron great strength, which, strange to say, it does not itself possess, and also hardness, which it possesses only in its diamond allotropic form. At the same time it takes away from the iron a part of its ductility, malleability, magnetism and electric conductivity. So important is the influence of carbon in regulating and controlling the characteristics of the ferrous metals, that they are individually and collectively classified according to the amount and condition of the carbon in them. . . ."

"*The Ferrous Metals*—***These three products—cast iron, steel and wrought iron—together comprise the whole of the so-called 'ferrous group of metals'—that is, the group which we classify together under the name of 'iron and steel.' . . ."

The principal groups of iron products may be classified and briefly described as outlined in the following table:

TABLE I. PRINCIPAL GROUPS OF IRON PRODUCTS.

Pig Iron and Cast Iron.

Definitions: (1) The metallic iron product of the blast furnace.

or, (2) Iron containing so much carbon (from about 2% up to 5% or more) that it is not malleable as cast, although it may be made relatively malleable by subsequent annealing.

"Pig Iron" is the term used to describe the iron product of the blast furnace. Formerly, upon being tapped from the blast furnace it was generally cast into uniform, oblong castings called "pigs"; but now, most of it never exists as "pigs," but while molten is run into ladles which are transferred to near-by open hearth furnaces or Bessemer converters, into which the molten pig iron is poured or charged for further refinement. Also, it is frequently cast into a desired shape direct from the blast furnace, thus becoming cast iron. There are numerous varieties of cast iron, viz., "gray," "white," "malleable," etc.

Hot (or molten) pig iron is used for:

(1) Making Bessemer steel.
(2) Making open hearth steel, together with steel scrap.
(3) Casting direct into cast iron parts.
(4) Casting into cold pig iron.

Cold (or solidified) pig iron is used for:

(1) Making open hearth steel, together with steel scrap.
(2) Remelting for casting into cast iron parts.
(3) Making puddled iron.

Stoughton writes: "Cast iron is impure, weak, and must be brought to its desired size and form by melting and casting in a mold. A typical example would contain about 94 per cent iron, 4 per cent carbon, and 2 per cent of other ingredients or impurities." Pig iron is a raw form of cast iron, and malleable cast iron is a semi-purified form."

Steel.

Definitions: (1) Product of open hearth furnace, Bessemer converter, electric furnace, crucible process and cementation process. (Cement steel is unimportant at the present time.)

or, (2) Iron which is "malleable as cast," *i.e.*, congenitally malleable and of molten origin. (This definition excepts "cement steel," which is not cast, being of plastic origin.)

TYPICAL REDUCTION OF ELEMENTS IN REFINING PIG IRON INTO VERY LOW-CARBON NORMAL STEEL IN BASIC OPEN HEARTH FURNACE

	Carbon	*Manganese*	*Sulfur*	*Phosphorus*	*Silicon*	*Iron Content (by difference)*
				Per Cent		
Pig Iron	3.80	1.50	.05	.45	.85	93.35
Steel	.08	.40 *	.04	.04	.01	99.43
Difference	3.72	1.10	.01	.41	.84	

* Manganese reduced lower than this but added again.

Finished forms of steel are: Rolled steel;
Drawn steel;
Forged steel;
Steel castings.

Stoughton writes: "Steel is purer than cast iron, much stronger, and may be produced in the desired size and form either by melting and casting in a mold or by forging at a red heat. It usually contains about 98 per cent or more of iron, and, in different samples, from 1.50 per cent down to almost no carbon, together with small amounts of other ingredients or impurities."

Wrought Iron.

Definitions: (1) Product of puddling furnace, charcoal hearth. etc.

or (2) Slag-bearing, malleable iron; congenitally malleable and of plastic origin.

Wrought iron, formerly, was an important iron product, but now has been largely replaced by very low-carbon steel made by the open hearth and Bessemer processes.

Stoughton writes: "Wrought iron is almost the same as the very low-carbon steels, except that it is never produced by melting and casting in a mold, but is always forged to the desired size and form. It usually contains less than 0.12 per cent of carbon. Its chief distinction from the low-carbon steels is that it is made by a process which finishes it in a pasty, instead of in a liquid form, and leaves about 1 or 2 per cent of slag mechanically disseminated through it."

STEEL.

Steel is by far the most important finished iron product at the present time. The annual production of finished steel greatly exceeds that of finished cast iron or wrought iron products.[2] Of course, much pig iron is used as a raw material in making steel.

Rolled steel comprises the bulk of finished steel. The annual production of all kinds of finished rolled steel products in the United States during 1929 was approximately forty and one-half million gross tons. In that year the tonnage of steel castings amounted to less than 4 per cent and that of forged steel to less than 2 per cent of the rolled steel tonnage. These figures are for steel mill production.

THE STEEL-MAKING PROCESS.

Steel is not made directly from iron ore at present in appreciable quantities. It has been found economical first to convert iron ore into a metallic iron product in the form of pig iron, by the use of the blast furnace, then to purify the pig iron, which seldom has over 95 per cent iron content, in the open hearth furnace or Bessemer converter, the products of which are called "steel." A large part of the steel used today has over 99 per cent iron content. This gives an idea of the purification effected in the open hearth furnace and Bessemer converter. Further purification and treatment are sometimes accomplished in the electric furnace, particularly in the case of special alloy steels.

A "direct process" produces steel from the iron ore in one operation. Before the days of the modern blast furnace this method was employed. Numerous direct processes, intended to produce steel as efficiently as it can be produced with the aid of the blast furnace, have been and are being tried, but none is commercially successful at present.

The diagram on the following page (Fig. 3) indicates the steps in the process of converting iron ore, first into pig iron and cast iron; then the further refinement into steel.

ELEMENTS OTHER THAN IRON COMMONLY PRESENT IN IRON PRODUCTS.

There exist in practically all iron products varying amounts of certain solid elements other than iron which are sometimes termed "metalloids." These are either carried over from the ore in small

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[2] **Finished rolled (wrought) iron production in United States during 1929 was 475,049 gross tons according to the 1929 Annual Statistical Report of the American Iron and Steel Institute.**

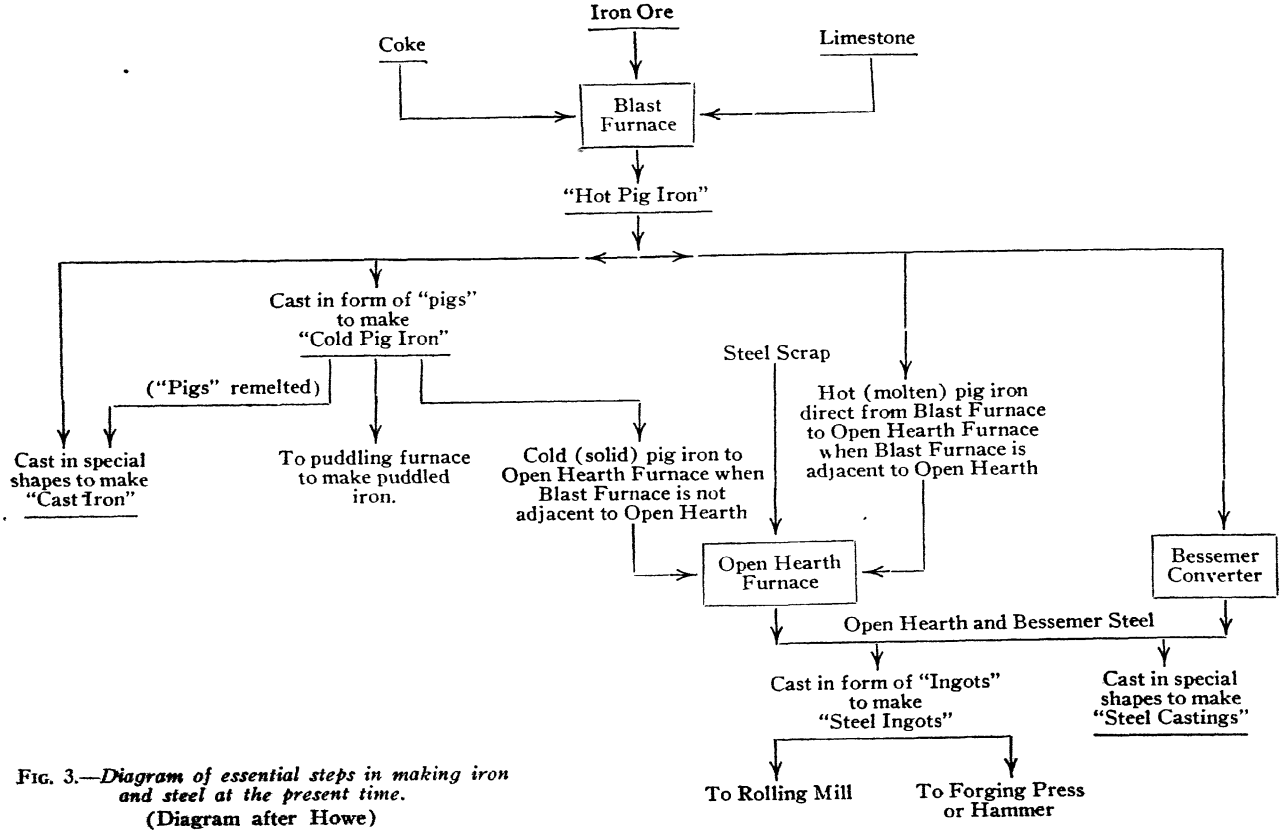


FIG. 3.—*Diagram of essential steps in making iron and steel at the present time.*
(Diagram after Howe)

amounts, or are introduced during the process from the fuel or in other ways.

The word "metalloid" correctly means "something resembling metal," but it has acquired a meaning of its own in the iron trade, in which it has become customary to speak of the following non-iron, solid elements, commonly present in iron products, as "metalloids": carbon, manganese, sulfur, phosphorus and silicon. (See note p. 270.)

A brief discussion of some of the better known effects of the so-called "metalloids" upon iron products will permit a clearer understanding of commercial steels, particularly those used for sheets.

Element. *Effect in Iron Products.*

Carbon.—Up to about 0.12 per cent carbon has little effect on steel, so far as commercial usage is concerned. Higher than this, its effect of adding strength, hardness and brittleness, gradually increases. Until fairly recent times, carbon was the main alloying element used for altering the properties of steel through the chemical composition.

Manganese.—Approximately 0.40 per cent manganese is considered beneficial to steel for most purposes. Although the Bessemer and open hearth processes both reduce the manganese lower than this percentage, in normal steel more manganese is purposely added after the steel is made to bring its content of this element up to about 0.40 per cent. This is believed to assist in overcoming the ill effects of the sulfur content and in deoxidizing the metal.

In manganese alloy steel, much larger percentages, even higher than 10 per cent manganese, are used. This is called Manganese Steel and is tough and non-magnetic.

Sulfur.—Sulfur is seldom of any benefit in steel. In very small amounts, however, it is not thought to be harmful for average use, particularly when the proper amount of manganese is also present.

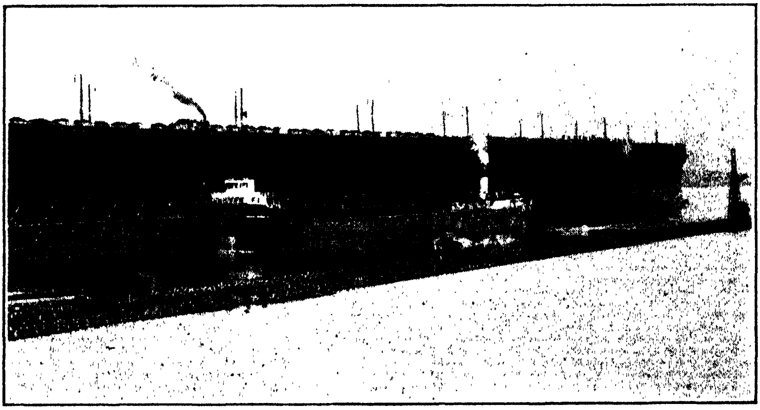
Too much sulfur causes steel to be "red short," that is, brittle while hot, which interferes with rolling. In steel for sheets the sulfur is generally kept under 0.06 per cent. Such small percentages, together with the counteracting effect of the manganese added to normal steel, do not have appreciable effects on the strength or ductility of the finished piece of steel. Sulfur is reduced to a commercial minimum for some special grades of sheet steel, as for difficult drawing and welding.

Sulfur in high percentages is said to hasten the corrosion of steel under certain conditions, but one of the effects of the addition of copper appears to be that of counteracting this tendency.

Phosphorus.—Over 0.10 per cent phosphorus may cause steel to be brittle when cold, or "cold short." However, it is usually much lower than this in normal steel. For deep drawing and other special sheet steel, it is kept very low at extra expense.

For very thin gage steel sheets, it is allowed to run about 0.04 per cent to 0.06 per cent, sometimes about 0.075 per cent, as this slightly higher phosphorus content helps to prevent sheets from

Element.	*Effect in Iron Products.*
	sticking together when hot rolled in packs of several sheets, as these thin sheets must be.
Silicon.	—Most normal steel for sheets contains from a trace to 0.05 per cent silicon. Such amounts have practically no effect on the physical properties for practical purposes. Larger amounts, from about 0.10 per cent up to about 5.00 per cent are added to make silicon alloy steel sheets, which have valuable electrical properties for motors, generators and transformers.



Courtesy of Youngstown Sheet & Tube Co.

Fig. 4.—Loading an ore vessel at one of the upper lake ports. The ore having been hauled from the mines to the Lakes in long trains is carried out on these huge docks and allowed to flow by gravity into bins. From the bins it flows through the iron spouts, which are lowered so as to conduct it into the hold of the vessel. A steamer which carries 13,000 tons of ore can be loaded at one of these docks in about three hours.

Table 2. CLASSIFICATION OF STEELS.

Any product of the open hearth furnace, Bessemer converter, electric furnace, crucible process or cementation process, is termed "steel" in the technical sense. Needless to say, there are many varieties. It is customary at the present time, however, to divide them into two main groups, based on chemical composition, as follows:

I. Plain Steels.

This group embraces those types of steel in which the relative absence or presence of carbon determines how the steel is classified with respect to analysis.

The carbon inherited from the pig iron is either reduced to a commercial minimum, as in very low-carbon steel; or it may not be fully reduced or more carbon may be added, depending upon what pecentage is desired for effective carbon-content steels. (See pp. 25, 26.)

The other metalloids beside carbon, that is manganese, sulfur, phosphorus and silicon, as a general rule are kept normally low and remain about the same regardless of the carbon content, subject to the usual unavoidable variations. Of course, the content of these other metalloids may be varied as desired. Manganese is frequently increased in the higher carbon range.

Sometimes the term "Carbon Steel" is applied to this entire group, but this seems misleading because the group contains types of steel in which the carbon is so low that it exerts practically no effect. It does not seem reasonable to classify a steel in which the carbon content is incidental and practically ineffective as "Carbon Steel." (See p. 35.)

Plain steels make up the majority of the steel output today, although special alloy steels are on the increase and their use will doubtless continue to expand.

II. Special Alloy Steels.

This group includes those special steels which contain, in addition to the desired amounts of carbon and the usual content of other metalloids, one or more effective alloy contents of elements such as nickel, chromium, copper, manganese, silicon, tungsten, molybdenum and others.

These additional alloy contents are usually in relatively large amounts which materially change the natural iron properties.

The list of alloy steels is very large and grows constantly. Many remarkable results have been accomplished with special alloy steels employing new alloys and various combinations of alloys.

The foregoing two main groups may be subdivided further. The following is an outline of the principal types of plain steels, according to chemical composition:

PLAIN STEELS.

A. Those in which the carbon content is practically ineffective. (See note, p. 270.)

1. **Very Low-Carbon Steel** or **Normal Low-Metalloid Steel** } Carbon content ranges from 0.05 per cent to 0.12 per cent

Also called: "Very Low-Carbon Normal Steel," "Very Mild Steel" and "Dead Soft Steel."

This type of steel is used for the great bulk of sheet steel and tin plate, for which purposes the chemical composition is generally kept within the following range,* varying somewhat according to the purpose for which the finished product is intended and owing to unavoidable variations in the steel making processes. The following figures * are for ladle analysis (sample taken from hot metal leaving ladle) which represents the average for the particular heat of steel but will not agree exactly with analyses taken from different parts of the finished product in a check analysis. (See note, p. 270.)

2. **Extra Low-Metalloid Open Hearth Steel.** (See p. 35.) Carbon content ranges from 0.01% to 0.05%.

Sold under various trade names, which usually include the words "iron" or "metal."

This type of steel is always made by the open hearth process and the metalloids are reduced, at extra expense, lower than the average for

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* See analysis range at top of page 26.

USUAL LADLE ANALYSIS RANGE FOR SHEETS AND TIN PLATE.

(Maximum and minimum content of the metalloids usually found in average commercial practice.)

		Basic Open Hearth			Bessemer		
Carbon	These reduced as low as is commercially necessary or desirable for particular use	0.05%	to	0.12%	0.05%	to	0.12%
Sulfur		0.02%	to	0.05%	0.03%	to	0.06%
Phosphorus		0.01%	to	0.06%	0.07%	to	0.10%
Silicon		0.005%	to	0.05%	0.005%	to	0.05%
Manganese	Purposely added ...	0.30%	to	0.50%	0.30%	to	0.50%
Total Metalloids		0.385%	to	0.78%	0.455%	to	0.83%
Iron Content (by difference)		99.6%	to	99.2%	99.5%	to	99.1%

normal low-metalloid steel; also, little or no manganese is added, which circumstance largely contributes to the difference in total metalloids between these two types. In other words, if its manganese content were raised, say to 0.30 per cent, then a heat of this extra low-metalloid steel would at once become normal low-metalloid steel, according to the accepted technical terminology.

Some makers do not permit total metalloids to be higher than about 0.15 per cent; others allow up to about 0.25 per cent total metalloids for this type of steel. This leaves approximately 99.85 per cent to 99.75 per cent iron for this type as compared with about 99.6 per cent to 99.1 per cent iron in normal low-metalloid steel.

B. Those in which the carbon content is effective. (See note below.)

(This group might be called "True Carbon Steels," see p. 35.)

1. **Low-Carbon Steel.** Carbon content ranges from 0.15 per cent to 0.30 per cent.

   This type is used for sheets to some extent, when ordered. For sheet purposes, such carbon contents are appreciable.

2. **Medium-Carbon Steel.** Carbon content ranges from 0.30 per cent to 0.60 per cent.

   Occasionally used for sheets, when ordered. The sheet maker considers this range a high-carbon content.

3. **High-Carbon Steel.** Carbon content ranges from 0.60 per cent to 0.90 per cent.

   Used for sheets, when ordered, but rarely. Such carbon percentages are considered very high for sheets.

4. **Very High-Carbon Steel.** Carbon content over 0.90 per cent, but seldom over 1.5 per cent.

   Also called "Hyper-eutectoid Steel" in differentiation from all those steels containing less than 0.89 per cent which are called "Hypo-eutectoid."

   These hyper-eutectoid steels are practically never used for sheets.

Note: The subdividing of this group under names as here given is a synthesis of the names and corresponding carbon ranges used by Howe,[3] Sauveur[4] and Tiemann.[5] These subdivisions are arbitrary, of

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[3] Howe, "The Metallography of Steel and Cast Iron," New York, McGraw-Hill Book Co., 1916.

[4] Sauveur, "Metallography and Hearth Treatment of Iron and Steel," New York, McGraw-Hill Book Co., 1926.

[5] Tiemann, "Iron and Steel" (a pocket encyclopedia), New York, McGraw-Hill Book Co., 1919.

course, but may provide the reader with an idea of the general opinion on this subject. However, when effective carbon content is desired, it should not be specified by name (as "Low," "Medium," etc.) but should always be specified by a definite carbon range, as "0.30 to 0.40 per cent" carbon. In this connection, Tiemann writes (*loc. cit.*, p. 455.):

> "Furthermore, the terms "low carbon," "medium carbon," and "high carbon" . . . must be considered in connection with the context; thus a hard structural steel of, say, 0.35 per cent carbon, is much lower in this element than a soft spring steel with 0.70 per cent. The safest and best method to follow is to furnish specic details and not trust to indefinite and ambiguous generalities."

SPECIAL ALLOY STEELS.

The subject of special alloy steels is very broad and complicated. An almost endless variety are made, utilizing different percentages of one or more elements, other than carbon, either with or without effective amounts of carbon. There are nickel steels, chrome steels, vanadium steels, manganese steels, chrome-nickel steels, chrome-tungsten-vanadium steels and a host of others, all designed for particular uses. It will suffice here to discuss briefly only those which are commonly used in the manufacture of sheet steel and tin plate, which are:

1. **Copper Steel (or Copper-bearing Steel).**[6] Usually containing from 0.20 per cent to 0.30 per cent copper, aiming at 0.25 per cent.

   This copper alloy greatly retards rusting or corrosion of certain kinds, particularly atmospheric corrosion. (See reports of Committee A-5 on Corrosion of Iron and Steel, American Society for Testing Materials, Vol. XXIII, 1923, et seq.) The effectiveness of the copper in this respect appears to be increased by the manganese and phosphorus content of normal steel.

   Rust appears upon the surface of copper steel as quickly as on non-copper-bearing steel, but where the copper content is effective, as in the weather, the rust penetrates much less rapidly.

2. **Silicon Steels for Eectrical Sheets.**[7] Contain varying percentages of silicon, from 0.10 per cent up to 5 per cent, according to the purpose for which intended. Always low in other metalloids.

   The silicon content, together with proper working and annealing, produces high magnetic permeability together with high electrical resistance, the former

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[6] The commercial manufacture of this type of steel was largely brought about through the efforts of the late Daniel M. Buck. While metallurgical engineer of the American Sheet and Tin Plate Co. he recognized the value of the copper-alloy effect as shown by the earlier work of others in this direction, notably Stead and Wigham in England. By exhaustive practical and laboratory tests, he proved the efficacy of the copper alloy and later results have corroborated his findings. The world is indebted to him for annual savings of millions of dollars through the lessening of corrosion loss in steel and iron products due to the present widespread use of copper-bearing steel. A most fitting tribute to the work of Daniel M. Buck is paid by Dr. William H. Walker, formerly professor of chemical engineering, Massachusetts Institute of Technology, in these words:

"If he who makes two blades of grass grow where there was but one before is a benefactor to the race, what shall we say of him who makes one pound of steel serve its owner double the years of two." (Year Book, American Iron & Steel Institute, N. Y., 1920, pp. 387-388.)

[7] Robert A. Hadfield, the eminent metallurgist of Sheffield, England, discovered the characteristics of silicon alloy steels for electrical purposes and secured patents on silicon content from 1 per cent up to 5 per cent.

contributing to low hysteresis and the latter to low eddy currents, both of which are desirable in the laminated structures of transformers, motors and generators. Hysteresis and eddy currents go to make up what is called "iron loss" in electrical work.

3. **Chromium Steels.** Contain varying high percentages of chromium and frequently nickel, silicon and other elements. Sold under various trade names; commonly referred to as: "Stainless" or "Rustless" steel or iron.

Some say that in the low-carbon type, the chromium content should be not less than 14 + (18 × carbon content) = 15.8% for 0.10% carbon.

A large user of the low-carbon variety calls it "Rustless Steel" which seems an excellent term, since it avoids the ambiguity, if not inaccuracy, of the word "iron" in connection with this alloy steel and also describes its inherent resistance to rusting without attributing to it absolute stainlessness which it only possesses when specially finished and under certain conditions.

Originally employed mainly in the higher carbon contents for cutlery, chromium steels are being applied to a great variety of purposes today. Their field of usefulness has been materially widened by the availability of low-carbon types which are malleable and ductile while cold.

These steels are quite expensive but their use is constantly growing and will, no doubt, increase greatly as time goes on. They offer remarkable resistance to atmospheric corrosion as well as to the direct attack of many chemicals. However, sulfuric and hydrochloric acids attack them readily. They also resist destructive scaling (oxidation) at high temperatures.

Possibly the most unique property of chromium steels is that whereby they may be finished with a white, lustrous surface which will not stain, tarnish or discolor in the atmosphere. To accomplish this desirable result, the surface must be polished smooth and free from any film or foreign matter such as dirt, scale, or particles of other metals. This bright, stainless surface, it must be remembered, is only imparted by mechanical cleaning and smoothing of the surface, as by grinding and polishing properly, for up to the present no method of pickling alone appears to render the surface entirely bright and stainless. When chromium steel carrying surface scale, either from hot-rolling or annealing, is exposed to the weather, the scale will undergo a chemical change and turn yellow but this does not indicate that the underlying metal itself is rusting.

NOMENCLATURE OF IRON AND STEEL.[8]

The nomenclature of iron and steel is ambiguous and confusing. As the reader may already have concluded from the preceding pages, the word "steel" does not describe the nature of any particular iron product. In one sense it merely indicates in what sort of furnace or process the refining of the iron product in question has been carried on. In another sense, the word "steel" defines any product which is "malleable as cast," that is, (1) naturally or congenitally malleable (able to have its shape changed by hammering, rolling, etc.) and (2) delivered from the refining furnace in molten condition, necessitating casting into molds either in the form of ingots for rolling and forging,

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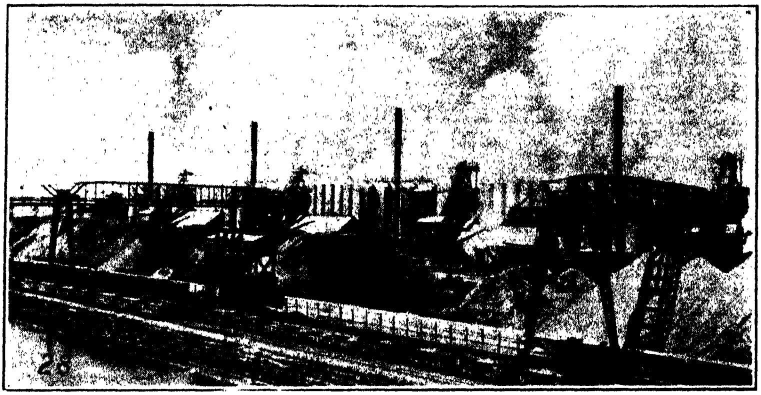
[8] The reader desiring to pursue further this very complicated subject of nomenclature may well refer to the learned and clear discussion in H. M. Howe's "The Metallography of Steel and Cast Iron," New York. McGraw-Hill Book Co., 1916.

or in the form of a steel casting. The first characteristic differentiates steel from cast iron (pig iron) which is never malleable and from malleable cast iron which is not malleable as cast but is rendered relatively so by subsequent annealing. The second characteristic mentioned differentiates steel from wrought iron, which is taken from the refining furnace in a semi-liquid, pasty mass and cannot be cast, although it is congenitally malleable.

In neither of the above senses does the word "steel" have much more descriptive value than the words "wood" or "stone." It merely describes a genus or class of substance, the individual kinds of which may, and do, have very different characteristics and properties. Thus, when the words "wood" or "stone" are mentioned, we have a general idea of the substance referred to, but since there are many different kinds of wood and stone, we cannot know definitely what is meant unless some particular kind of wood or stone is named, as "pine," "oak," "sandstone," "marble," etc. Likewise, unless a particular kind of steel is named, we have no way of knowing to what degree the metal referred to is soft or hard, brittle or tough, magnetic or non-magnetic, or what its other properties and characteristics are.



Courtesy of Youngstown Sheet & Tube Co.

FIG. 5.—Blast furnaces.

At this point it may be well to emphasize that some confusion exists in the minds of many persons not intimately connected with the steel business as to the meaning of the word "steel." This is not surprising, since the nomenclature employed is so imperfect and ambiguous that even the authorities themselves are not in agreement.

Before the introduction of the Bessemer converter and the open hearth furnace, there were three classes of iron products, each differing from the others in a marked degree:

1. **Wrought Iron.**—Deriving its name from the fact that it was capable of being "wrought" or hammered into shape, *i.e.*, malleable, even when cold; but it was not capable of being cast, nor could it be materially hardened, as by sudden cooling from a high heat.
2. **Cast Iron.**—Deriving its name from its ability to be cast into shape; but not capable of being wrought into shape, *i.e.*, not malleable.
3. **Steel.**—At that time meaning an iron product which was malleable at some temperature, permitting it to be hammered or forged into shape, usually while hot; but differing from wrought iron in that it could be materially hardened by rapid cooling, this hardening property of steel being due to the carbon added in either the crucible or cementation process.

Swords, knives and shears were common steel articles, and the names of places where such steels were made became famous for them — Damascus, Toledo, Sheffield, etc. From long tradition, the name "steel" has associated itself with a metal which is strong and hard but generally brittle. The word "steel," by itself, has no such general meaning today, but the traditions of centuries are not easily broken and a remnant of the old idea about steel lingers in many minds still, if only subconsciously, as the psychologists say.

On the other hand, before what is called the Bessemer method of refining pig iron was introduced in about 1850 and the Siemens, or open hearth, method a few years later, "wrought iron" or simply "iron" was the name used for all soft iron products, the low carbon content and relative purity of which made them malleable under the hammer of the blacksmith at all temperatures and capable of being wrought and bent into many intricate and useful shapes even while cold. Several types of wrought iron were made, but their properties were the same in general. It was by adding carbon to wrought iron that the original steel was produced, in the form of blister steel and crucible steel.

There are two general classes of wrought iron,—charcoal iron and puddled iron. Charcoal wrought iron was originally produced direct from the iron ore and was made by the earliest known method of securing metallic iron. The principle of this was to mix iron ore in burning charcoal, bringing about the following results: When the iron ore (containing iron combined with oxygen) reached certain temperatures, its oxygen was attracted away and went into chemical combination with some of the carbon in the surrounding charcoal, thus becoming either the gas "carbon monoxide" or the gas "carbon dioxide" which escaped. This left the iron part of the iron ore in its metallic state, and being semi-liquid, or "pasty," on account of the heat, it collected, finally, in the bottom of the hearth, together with a certain amount of "slag" or dirt, in the shape of a pasty mass. This pasty, semi-liquid iron metal mass was then gathered into a ball, lifted out of the furnace and hammered or pressed to eject as much of the slag from the mass as possible before the metal cooled and solidified.

Courtesy of Wheeling Steel Corpn.

FIG. 6.—Blast furnace: Tapping. Observe stream of molten pig iron running from the furnace.

This charcoal wrought iron, made directly from the iron ore, provided the only source of metallic iron from prehistoric times down to about the Fourteenth Century. Then the ancestor of the present day blast furnace came into being and its pig iron was further refined into "wrought iron," first by the charcoal refinery hearth and later by the puddling furnace. Each step provided a cheaper product. Then in the Nineteenth Century, the Bessemer and open hearth methods for refining pig iron were introduced and their product became known as "steel" for various reasons, among which was in order to distinguish it from cast iron which is not malleable and from wrought iron which is not cast molten, although the low-carbon Bessemer and open hearth steels did not resemble the high-carbon crucible and blister steels in their physical properties.

As has already been stated, in the pre-Bessemer days the principal iron products were distinguished from each other by their physical properties, which differed materially in the then-existing three classes of products. Cast iron and wrought iron have the same general characteristics as they always had and therefore are as readily distinguishable nowadays as they were originally. With steel, however, the case is different. In the pre-Bessemer period, steel (then only crucible and blister or cement steel) was malleable when hot but relatively hard and brittle when cold; it was designed to be hard and strong notwithstanding a certain degree of brittleness which accompanied the hardness. The word "steel" in these days embraces a much wider field. In the open hearth furnace and Bessemer converter there are made not only products which live up to the ancient conception of "steel," but also the very low-carbon normal steels, the properties of which resemble wrought iron in many ways, although they do not have the internal structure produced by the slag in wrought iron. At the present time, a large proportion of the finished iron production is made from

Courtesy of Youngstown Sheet & Tube Co.

FIG. 7.—"Molten pig iron from blast furnace running into ladles mounted on trucks. In these ladles, the molten pig iron is then hauled to a large vessel known as a 'Mixer' in which its heat is conserved until desired for charging into the Bessemer converter or the open hearth furnace."

open hearth and Bessemer low-metalloid normal steel containing one-tenth of 1 per cent (or less) carbon and over 99 per cent iron. Wrought iron, on the other hand, seldom has such a high percentage of iron since it frequently contains from 1 per cent to 2 per cent of slag alone which is mechanically mixed in the metal.

It would seem, at first glance, much more logical to call this very low-carbon normal steel some sort of an "iron" since it contains 99 per cent or more iron. It is certainly more of an "iron" than pig iron (or cast iron) which usually contains less than 95 per cent iron. Nickel of 99 per cent purity is still called "nickel," and so with many other metals.

The technical authorities recognize the ambiguity of the term "steel" as used today and many attempts have been made to devise a nomenclature which would be more descriptive than that now employed in this country. The Germans, years ago, applied the term "ingot iron" to the mild, very low-carbon steel produced by the Bessemer or open hearth processes. But this term, as well as the term "open hearth iron," are used in this country at present as trade names for certain brands of extra low-metalloid open hearth steel and consequently cannot well be appropriated back into technical terminology for describing the normal low-metalloid steel. The scientific objections to the use of the word "iron" in this connection are well set forth by the noted metallurgist H. M. Howe in his "Metallography of Steel and Cast Iron," New York, McGraw-Hill Book Co., 1916, p. 624, here quoted:

> "To calling carbonless and very low-carbon steel either 'ingot iron' or 'iron' there is the objection that each of these names is ambiguous, because it is capable of being used either specifically or collectively. 'Iron' has, besides its collective sense, two other specific senses already in wide use, 'wrought iron' and 'cast iron.' Indeed the attempt to call the very low-carbon A.R.M. steel 'iron' seems to have led to confusing it with wrought iron, or at least to inferring wrongly that it has some of the specific qualities which have given wrought iron its special fields of usefulness. All classes of iron and steel are 'iron' in the collective sense. In such a work as this each word should be used as far as possible in a single sense, which in the case of 'iron' must needs be the collective one. This requires us to call the various products by their specific names, the unambiguous one for this low-carbon molten-origin product being 'steel.'"

The extract from Table 2 of this same book by Howe will give the reader an idea of the struggles of the metallurgists with the problem of iron and steel nomenclature. (See p. 34.)

The writer is not fitted and does not desire to suggest alterations in the existing technical nomenclature, but from his own experience in endeavoring to understand and differentiate between the various types

TABLE 3. EXTRACT FROM: TABLE 2. VARIOUS NOMENCLATURES OF THE INDUSTRIAL IRON PRODUCTS.
H. M. Howe, "The Metallography of Steel and Cast Iron."

	Iron										
	Carbon Series								Special Series		
	Congenitally Malleable						Post-genitally malleable	Not malleable	Used only as vehicle for introducing element, etc.	Used directly otherwise than as an introducing vehicle	
	Molten Origin				Plastic origin						
(A) Pre-Bessemer	Non-hardening	Hardening			Non-hardening	Hardening	Malleable castings	Cast iron	Ferro-alloys	Non-hardening	Hardening
	Non-existent	Steel			Wrought iron	Steel				Non-existent	Non-existent
(C) Presumptive Industrial	Steel				Wrought iron	Non-existent	Malleable castings	Cast iron	Ferro-alloys	Special steels	
	Low-carbon	Medium carbon	High-carbon	Hyper-eutectoid							
(F) 1914 Proposal Presumptive State	Low-carbon (Ingot iron)	Medium carbon	High-carbon	Hyper-eutectoid	Wrought iron	Non-existent	Malleable castings	Cast iron	Ferro-alloys	Special steels	
		Ingot steel									
(G) Philadelphian Presumptive	Ingot iron Tensile strength				Weld iron Tensile strength		Malleable castings	Cast iron	Ferro-alloys	Special ingot irons Tensile strength	
	<71,000 lb.	>71,000 lb.			<71,000 lb.	>71,000 lb.				<71,000 lb.	>71,000 lb.
	Ingot iron	Ingot steel									
	Low-carbon ingot iron	Medium carbon ingot iron	High-carbon ingot iron	Hyper-eutectoid ingot iron	Wrought iron	Wrought steel				Special ingot iron	Special ingot steel

of present-day iron products he has found that the following classification is clearer to the lay mind than the more involved and technical official classification; therefore this is shown for whatever benefit it may be to the general reader in assisting him to visualize the iron group. It should be remembered that there is nothing official about this arrangement; it is merely the writer's idea of a classification scheme which is more logical and less complex to the person who has no technical knowledge of iron and steel than the fine distinctions and traditions of the scientists will permit.

TABLE 4. SIMPLIFIED CLASSIFICATION OF INDUSTRIAL METALLIC IRON PRODUCTS *

I. Molten Origin (those delivered molten from the refining process).

- (A) **Pig Iron.**—Product of the blast furnace. Not malleable as cast. Carbon content from about 2 per cent to 5 per cent or more. (Might be termed "blast iron" rather than "pig iron" because most of it goes molten into the open hearth furnace and Bessemer converter, never existing as pigs.)

  The finished and semi-finished forms are:
    - (1) Cast iron (special shapes).
        - (a) Malleable cast iron (annealed).
    - (2) Pig iron (rough shape for later melting).
- (B) **Steel.**—Product of open hearth, Bessemer, crucible or electric process. Various rolled, forged and cast forms; finished and semi-finished.
    - (1) *Normal Steel.*—Low-metalloid; ineffective carbon content. (See pp. 270-271.) Commercial soft iron. Carbon content (under 0.13 per cent) practically ineffective. Other metalloids less than 0.75 per cent total, usually including from 0.30 to 0.50 per cent manganese purposely added.

      (Extra-low-metalloid steel is included under this general head since its analysis varies and it merges at no definitely decided point into normal-low-metalloid steel, especially when manganese is low in the latter. In a more detailed classification, an arbitrary distinction might be made as in "A-2," p. 25.)
    - (2) *Special Steel.*—Natural iron properties materially altered, in numerous ways, by effective content of other elements.
        - (a) *True Carbon Steel (or simply Carbon Steel).* Relying upon carbon alone, in effective quantities (0.15 per cent to 1.5 per cent), to alter materially the natural iron properties. May be designated as low-carbon, medium-carbon, high-carbon, very-high-carbon; or, more accurately, by carbon content, as 0.20 to 0.30 per cent carbon, etc.
        - (b) *Special Alloy Steel.* Relying upon effective quantities of one or more elements other than carbon, in conjunction with carbon or not, to alter materially the natural iron

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* The above contemplates only truly metallic iron products and does not include, therefore, the ferro-alloy group (ferro-manganese, ferro-silicon, etc.) which are used as materials in steel making but are not used as metals. Those outside the steel industry have no interest in the ferro-alloys and might confuse them with the alloy steels. Hardening power has been rejected as a means of identifying "steel" because normal, low-metalloid steel containing under 0.13 per cent carbon cannot be hardened any more than wrought iron of similar carbon content.

properties; such as manganese steel, chromium steel, silicon steel, etc.

II. Plastic Origin (those delivered plastic from the refining process).

(A) **Wrought Iron.**—Product of the puddling furnace, charcoal hearth, etc. (Blister or cement steel is disregarded and omitted because it is of no commercial importance in this country today, otherwise it would have to be included here.)

Courtesy of Youngstown Sheet & Tube Co.

FIG. 8.—Bessemer converter: Blowing.

In conclusion of this chapter, the following extracts from Howe, "Metallography of Steel and Cast Iron," are given because they contain a brief and simple summary of the processes whereby iron is extracted from iron ore and transformed into the useful iron products of commerce:

"CONVERSION OR PURIFICATION PROCESSES FOR MAKING STEEL AND WROUGHT IRON.

"If path 2 is followed, the metal (*pig iron*) has to undergo a very great purification, and it is of this purification that its conversion into wrought iron or steel really consists.

"To explain, the blast-furnace process by which the cast iron (*pig iron*) is made is necessarily a strongly carburizing one, so that the cast iron necessarily contains much carbon. Further, the iron ore usually contains much silica (SiO_2), and some phosphoric acid in the form of apatite ($3CaO, P_2O_5$), together with more or less manganese in the form of manganese dioxide (MnO_2)and sulfur in the form of pyrites (FeS_2). The blast-furnace process is so very strongly deoxidizing that most of this phosphoric acid is deoxidized, as is much of the manganese dioxide and some of the silica; and the unoxidized phosphorus, manganese, and silicon which result unite with the molten cast iron, because they are unoxidized. At the same time some of the sulfur initially present as pyrites passes into the cast iron, which thus consist of metallic iron contaminated with these other elements, or impurities.

"The following reactions may serve as types of those by which the deoxidation takes place in the blast furnace:

$$
\begin{gathered}
SiO_2 + 2C = Si + 2CO \\
P_2O_5 + 5C = 2P + 5CO \\
MnO_2 + 2C = Mn + 2CO \\
Fe_2O_3 + 3CO = 2Fe + 3CO_2 \\
FeO + C = Fe + CO
\end{gathered}
$$

"The essential difference between cast iron (*pig iron*) on one hand and wrought iron and steel on the other, is that the former always contains much more carbon, usually more silicon, and often more manganese, phosphorus, and sulfur than are permissible in the latter; and the essence of all the processes by which cast iron (*pig iron*) is converted into wrought iron or steel is the elimination of these foreign elements. The difference between the two classes may be illustrated by the following cases:

	Cast iron (*pig iron*) for the basic Bessemer process	Basic Bessemer steel, made from this cast iron (*pig iron*)	Difference removed in conversion
		Per Cent	
Carbon	3.50	0.10	3.40
Silicon	1.00	0.01	0.99
Manganese	1.80	0.50	1.30
Phosphorus	1.80	0.07	1.73
Sulfur	0.10	0.07	0.03

"**Chemistry of Purification.**—The removal of carbon, silicon, phosphorus, and manganese is brought about by oxidation, and so is part of the removal of sulfur. The ultimate source of the oxygen may be either the atmospheric air as in the Bessemer process, or iron oxide such as native magnetite as in the puddling process, or both these jointly as in the open-hearth process. But even when atmospheric oxygen is used it appears to act indirectly rather than directly. That is to say, the atmospheric oxygen appears to act by oxidizing some of the iron itself to ferrous oxide, FeO, or by oxidizing ferrous oxide to magnetic oxide (FeO to Fe_3O_4) ; and the actual oxidation of the carbon and other foreign elements seems to be effected chiefly by the means of the iron oxides thus formed instead of by the means of the atmospheric oxygen directly.

"The reactions by which the oxidation takes place are of the following types:

$$2P + 5Fe_3O_4 = P_2O_5 + 15FeO$$
$$Si + 2FeO = SiO_2 + 2Fe$$
$$C + FeO = CO + Fe$$
$$Mn + Fe_3O_4 = MnO + 3FeO$$
$$S + 2FeO = SO_2 + 2Fe$$

* * * * * * * * * *

"**Classification of Processes.**—We may roughly classify the more important processes as follows:

"(1) *The Extraction Processes*, the blast furnace, and the 'direct processes' of making steel or wrought iron direct from the ore; these latter are unimportant today.

"(2) *The Conversion or Purifying Processes*, the Bessemer, open-hearth, electro-thermal, and puddling processes. The Bell-Krupp process is one of arrested or incomplete purification. The purification in all these processes consists chiefly in removing by oxidation the excess of carbon, silicon, phosphorus, and manganese introduced in the blast-furnace process, over that desired in the steel or wrought iron.

"(3) *The Adjusting Processes*, adjusting the composition. These include the carburizing processes, cementation, case-hardening, and the Harvey and Krupp processes; and the process of making malleable castings.

"(4) *The Shaping Processes.*—These include the 'mechanical processes,' rolling, hammering, wire-drawing, etc., and the 're-melting processes,' those of the iron foundry and the crucible process. The pig and scrap variety of the open-hearth process may, from one point of view, be put here.

"Such classifications can rarely be complete or consistent. For instance, while the crucible process as carried out in Great Britain is essentially a re-melting process, as carried out in this country it is at once a re-melting and an adjusting (carburizing) process. Nevertheless these classifications have their use."

PART II.

Sheet Steel and Tin Plate.

CHAPTER 3.

DEFINITIONS, ANNUAL PRODUCTION IN UNITED STATES AND TYPES OF STEEL USED.

For the benefit of the reader who is not at all familiar with the subject, it may be well at the outset to describe the broad, general meaning of the terms "sheet steel" and "tin plate."

SHEET STEEL.

As the name implies, "sheet steel" consists of steel in the form of flat pieces which are both relatively thin and relatively wide.

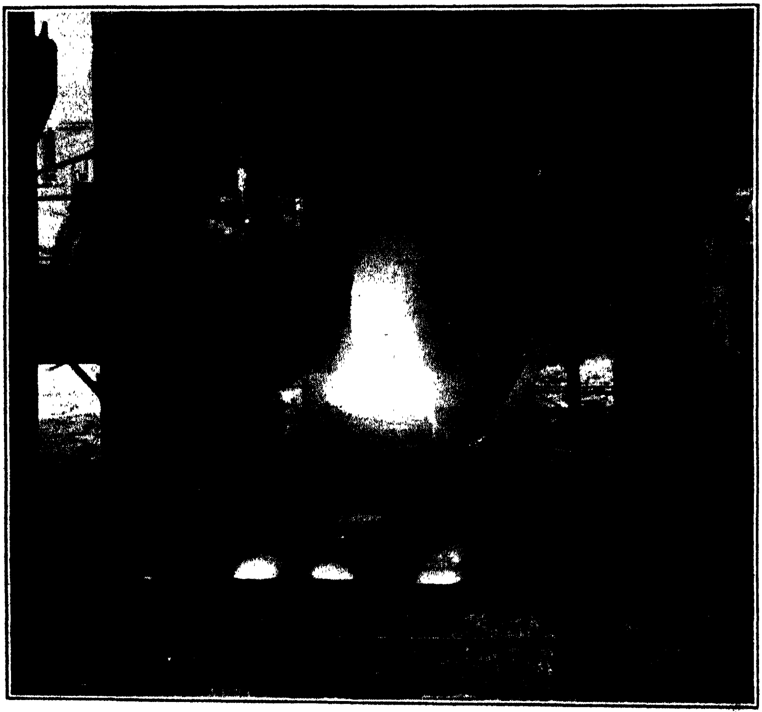
The "gage" of a sheet signifies either its weight per square foot or its thickness in parts of an inch, depending upon the gage system employed. Thicker sheets, being heavier per square foot, are called "heavy gage"; thinner sheets are referred to as "light gage."

There is no hard and fast rule as to what thicknesses and sizes comprise what is called "sheet" steel, as compared with the kindred flat steel products termed "plates" and "stripe." However, trade custom has quite generally established a rough classification for sheet steel, namely: flat steel thinner than ¼ inch (or, as some consider, thinner than $^3/_{16}$ inch) and about 24 inches wide and wider. Widths narrower than 24 inches can be obtained, of course, by shearing down wider sheets, but it is not economical to roll much narrower than 24 inches wide on sheet mill equipment.

Sheet steel under 24 inches in width, however, is efficiently produced and widely sold under the name of "tin mill black," always in fairly short lengths and usually in the lighter gages. Although tin mill black is actually "sheet steel," it is customary in the trade to refer to it separately because it is produced with a type of mill equipment which is particularly suited for the manufacture of steel sheets for tinning to make tin plate. These tin mill hot rolls are the same in principle as the sheet mill hot-rolling units, but vary slightly in design and method of operation, as will be referred to later. While these tin mills, so-called, are generally located in tin plate plants, they may be, and sometimes are, included in the equipment of the regulation sheet steel plants for the production of the very light gages and small sizes. The regular sheet mill equipment is not fitted to produce sizes smaller than about 24 inches x 60 inches except by shearing down after the sheets are finished, but tin mill equipment treats and finishes much smaller sizes, although tin mill hot-rolling is usually done in multiples of the final size.

PLATE STEEL.

Flat steel about 1/4 inch thick and thicker is called "plate steel" or "plate" if it is relatively wide. Where surface finish and working quality are not important, plates are sometimes rolled down to 3/16 inch thick or even thinner. Heavy sheets approaching 1/4 inch in thickness are sometimes called "light plates." Plates are wider (except universal plates) and longer, as a rule, than the average sheets in addition to being thicker.



Courtesy of Youngstown Sheet & Tube Co.

FIG. 9.—Bessemer converter: Pouring steel from converter into ladle from which it is cast into ingots.

STRIP STEEL.

Until quite recently, the term "strip steel" has designated a class of flat steel products, narrower than sheets and produced by a different rolling process, related to bar-rolling, which permits the production of very long lengths. The term "strips," naturally, was intended to describe something narrow, flat and usually long; but the strip mills have increased their width limits in recent years until strip steel is now made not only 24 inches wide, but considerably wider in the heavier range of gages. Obviously the word "strip" is a misnomer for a piece of flat steel of such considerable width as 24 inches or more; a person does not think of a piece of such width as a "strip" but as a "sheet." Nevertheless, the tendency is to use the terms "wide strips," "broad strips" or "strip sheets" for these sheet steel widths produced by the strip-steel process. "Continuous sheets" might be a better name.

TIN PLATE.

Tin plate is sheet steel, generally quite thin, on which has been placed a coating of pure tin. It must not be confused with sheets of pure tin. Terne plate (sometimes called "roofing tin") is sheet steel coated with "terne mixture" which is an alloy of lead and tin. Wrought iron was formerly used as the base sheet for tin plate and terne plate, but very mild steel is now employed. The sheet steel used for tinning is the tin mill black plate above referred to.

GROWING USE OF SHEET STEEL AND TIN PLATE.

The consumption of sheet steel and tin plate has grown enormously in recent times. This has been due to numerous causes, among which are:

1. The growth of the automobile industry, which requires large quantities of flat steel for drawing and forming into parts for body and chassis.
2. Development of drawing, stamping and forming machinery and methods which resulted in cheaper and lighter stampings to replace castings.
3. Greater scarcity and cost of wood has caused substitution of steel parts for wooden parts for many purposes.
4. Development of welding methods, electric-spot, electric-arc, oxygen-acetylene, etc., has lowered cost of fabricating articles from sheet steel, and has made new results possible.
5. Trend of public demand toward safety and permanence resulted in utilization of the fireproof qualities and strength of steel for: railroad cars, furniture and filing equipment, automobile bodies, window and door frames, doors, partitions, shelving, lath, lumber, etc.
6. Improvement of painting methods widened use of steel parts.
7. Increased use of gas substituted gas ranges, in which much sheet steel is used, for coal ranges made largely of cast iron.

8. Development of lithographing methods permitted tin plate to be formed and stamped into cans, boxes, toys, signs, etc., after being decorated, increasing use of these products by lowering cost.
9. Development of automatic can machinery lowered the cost of tin cans and enlarged the market for these.
10. Improved canning methods increased the use of tin cans for preserving food products.
11. Growth of electrical industry enlarged the demand for sheet steel for electrical purposes.
12. Last, but not least, the sheet steel and tin plate makers have constantly improved the forming qualities and surface finish of their products and in other ways adapted them to new and more exacting uses.

Sheet steel products today are subjected to drawing, welding, painting and other operations which would have been impossible even 10 years ago, and which would have been considered fantastic 50 years ago. Much smoother, cleaner and denser surface has been provided to permit glossy paint finishes without the preliminary filler coats and rubbing employed in former years. Along with this, the drawing and forming qualities have constantly been improved.

To illustrate the growth of the production of sheet steel and tin plate, and the important position they occupy in the steel industry today, the following figures are shown; these are taken from the statistics published by the American Iron and Steel Institute:

TABLE 5. PRODUCTION IN THE UNITED STATES—GROSS TONS.

Sheet Mill Products.	1916*	1929
Sheared plates, under ¼ inch thick **	?	?
Black sheets, rolled on sheet or jobbing mills	2,249,597	5,254,998
Tin Mill Products.		
Black plates (*i.e.*, Sheets) rolled on tin mills (The great majority for tinning)	1,526,999	2,159,173
Total Sheet Steel and Tin Plate, rolled on sheet, jobbing and tin mills, but not including any sheets which may have been reported under "Sheared plates, under ¼ inch thick"	3,776,596	7,414,171
Total Finished Rolled Iron and Steel (all forms)	32,380,389	41,069,416
Percentage of total finished rolled iron and steel represented by sheet steel and tin plate	12%	18%

* 1916 was the first year in which total finished rolled iron and steel was over 30,000,000 gross tons.

** Although reported under "Sheared plates, under ¼-inch thick," some of this tonnage may have been made in gages No. 3 to No. 12 on light plate mills operated by sheet steel manufacturers and marketed as sheets. However, the definite tonnage of sheets so made is not known and therefore the correct tonnage of sheets produced on this type of mill cannot be given.

From the foregoing tabulation it will be seen that the kindred products, sheet steel and tin plate, occupy a very important position in the steel industry today, together comprising about 18 per cent of the total of all finished rolled products in 1929.

Very few people realize that "sheet steel" (which, of course, includes that made into tin plate) now vies with "merchant bars" for the honor of representing more tonnage than any other form or class of rolled steel produced in this country. In former years "merchant bars" usually had the largest tonnage of any rolled form, but since the war the production of "sheet steel" has been expanding at such a rapid rate that it finally passed "merchant bars" in tonnage in 1926 and maintained its lead in 1927, but fell slightly behind in 1928 and 1929, as shown by the following figures from the 1929 Annual Statistical Report, American Iron and Steel Institute:

TABLE 6. PRODUCTION IN THE UNITED STATES—GROSS TONS.

	1926	1927	1928	1929
Sheets, rolled on sheet, jobbing and tin mills	6,327,874	5,906,924	7,092,422	7,414,171
Merchant bars, including concrete reinforcing bars	6,289,665	5,686,260	7,229,723	7,423,496

The above figures for "sheets," as previously mentioned, only include the production which is clearly reported as sheets and do not include any of the some 600,000 to 700,000 gross tons reported during these years as "Sheared plates, under ¼ inch thick," since there is no exact way to determine how much of this was made in gages Nos. 3 to 12 on light plate mills operated by sheet-steel manufacturers and marketed in sheet-steel grades, although a considerable part of this tonnage probably was so made and marketed. If the correct tonnage of sheet-steel products rolled on light-plate mills were known and added to the above figures for "sheet steel," these would be increased materially.

Another reason why the above figures for "sheets" do not truly represent the total production of flat steel which is formatively sheet steel regardless of the method of rolling, is that very large amounts of what are customarily considered "sheet" gages and widths are now produced on wide strip mills. The production of hot-rolled steel strips (including flats for cold rolling) has increased from 586,524 gross tons in 1920 to 2,502,793 gross tons in 1929. (1929 Annual Statistical Report, American Iron and Steel Institute.) The figure for 1929 includes an indeterminate tonnage of flat steel which would have been produced on regular sheet mills and jobbing mills had there been no modern, wide strip mills. The latter are destined to encroach, gradually, upon the field of the conventional sheet mill and jobbing mill.

A comparison of the tonnage produced in 1928 and 1929 in the eight principal forms which combined constitute practically 90 per cent of all finished rolled iron and steel may prove interesting:

TABLE 7. PRODUCTION IN THE UNITED STATES DURING 1928 AND 1929* OF THE EIGHT PRINCIPAL FORMS OF FINISHED ROLLED IRON AND STEEL.

(Figures from 1929 Annual Statistical Report, American Iron and Steel Institute.)

	Production Gross Tons		Per Cent of Total Finished Rolled Iron and Steel	
	1928	1929	1928	1929
Sheet steel *Including product of sheet, jobbing and tin mills. (See note ** p. 44)*	7,092,422	7,414,171	18.8	18.0
Merchant bars Including concrete reinforcing bars.	7,229,723	7,423,496	19.2	18.1
Plates Including "Universal plates," "Sheared plates, ¼ inch and over in thickness," and all "Sheared plates, under ¼ inch thick." (See note ** p. 44.)	3,913,628	5,022,141	10.4	12.2
Structural shapes	4,096,143	4,778,020	10.9	11.7
Skelp, flue and pipe iron and steel Does not include billets or blanks for seamless tubes.	3,368,973	3,517,238	9.0	8.6
Wire rods	3,080,816	3,134,409	8.2	7.6
Rails	2,647,493	2,722,138	7.0	6.6
Hot-rolled strips and flats for cold-rolling	2,161,988	2,502,793	5.7	6.1
Total of the above eight forms	33,591,186	36,514,406	89.2	88.9

THE STEEL USED FOR SHEET PRODUCTS.

The great bulk of sheet steel (including tin-mill black-plate and tin plate) at the present time is rolled from very low-carbon normal steel, *i.e.*, normal low-metalloid steel. (See A-1, p. 25.)

This very mild steel is made either by the open hearth or Bessemer process. No attempt will be made here to describe these processes, other than the brief extract from Howe quoted on pp. 37-38. For information concerning them the reader should refer to standard technical works on steel. For the purposes of this non-technical outline, it will suffice to discuss briefly the general differences between these two types of steel as made for rolling into sheets, their general characteristics and where and why they are commonly used in the sheet steel and tin plate industry.

WROUGHT IRON *vs.* STEEL FOR SHEETS.

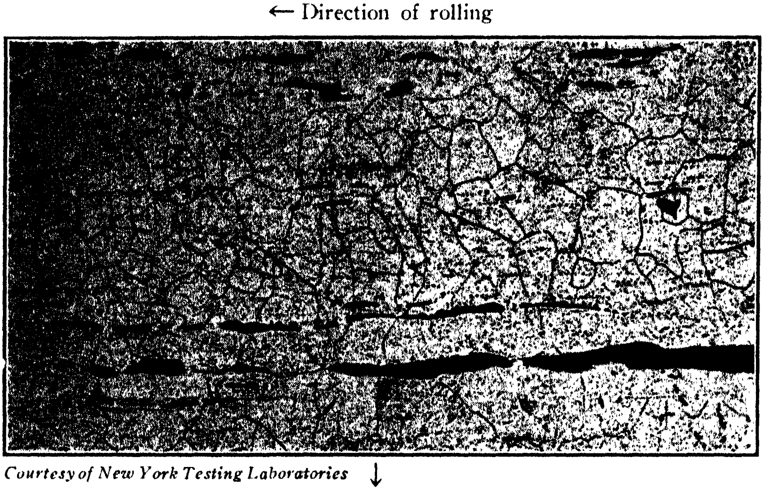
Originally, wrought iron was used for making sheets, as for all other soft, malleable products. Some of the older members of the sheet metal working industry, possibly recalling their early experiences in comparing wrought iron sheets with those made from the rather inferior steel at first produced by the Bessemer process before this process and the open hearth process reached their present state of perfection, and possibly overlooking other industrial changes since the days when wrought iron sheets were common, hold the opinion that the old-fashioned puddled iron sheets were superior to modern steel sheets. A careful examination of the facts, however, does not support this supposition. In fact, there is little doubt that modern steel sheets are, in many ways, more useful and satisfactory than wrought iron sheets would be for present-day needs.

Courtesy of Wheeling Steel Corpn.

FIG. 10.—Open hearth furnace: Charging. The charging machine is putting a charging box full of steel scrap into the open door of the furnace. When the charging box is entirely inside the furnace, its contents are dumped out by revolving the box, which is then withdrawn.

Wrought iron contains a relatively large amount of slag which extends out in thin lines parallel to the direction of rolling during the rolling operations. This network of slag actually benefits in one way, that is by seeming to reduce the tendency toward brittleness under repeated stresses or shocks, which is an advantage for chain links and such purposes. However, this same network of slag, by breaking up the homogeneity of the iron, reduces both the ductility and the strength of the finished piece of wrought iron when the stress or pull comes perpendicular to the direction of rolling. (Note: The "grain" of a rolled product is said to lie in the direction of rolling. "Grain" in this sense is a steel mill term for the "fiber" of the mass of metal, and is not to be confused with "grain" in the metallurgical sense referred to on p. 64.)

This explains the marked difference between longitudinal and transverse strength and ductility in wrought iron.



Courtesy of New York Testing Laboratories

The slag lines diminish strength and ductility materially when pull is in this direction, *i.e.*, across the grain.

FIG. 11.—Magnified longitudinal section of a piece of wrought iron, showing the manner in which slag lines extend in the direction of rolling (Photomicrograph—longitudinal section × 100).

Although steel contains small amounts of slag, these are inconsiderable as compared with the amount of slag in wrought iron, particularly the puddled iron of commerce. Yet, even without the handicap, in this sense, of so much slag as wrought iron contains, rolled steel is generally less ductile, although the tensile strength may be, and frequently is, greater when pulled transversely (across the grain) than when pulled longitudinally (with the grain). This is because the grains of iron are flattened out and elongated in the direction of rolling and strain lines are introduced. Perfect annealing corrects this condition, causing the grains to return more nearly to their normal shape and arrangement. But perfect annealing cannot always be expected in practice, consequently, even well-made steel is inclined to be somewhat less ductile when the pull comes across the grain than when the stress is with the grain, *i.e.*, in the direction of rolling. Nevertheless, the average steel is more uniformly ductile and strong in all directions than the average wrought iron. Sheets of steel usually have slightly greater tensile strength, although less ductility, transversely than longitudinally.

The deep-drawing operations in which the strain is not confined to one direction, and severe bending parallel[1] to the grain, to which sheet steel is frequently subjected these days, would not be possible with puddled iron sheets.

With respect to softness for bending modern very low-carbon normal steel is made just as soft and workable as wrought iron.

CORROSION RESISTANCE.

There is a prevalent idea among laymen that wrought iron resists corrosion better than modern mild steel. It is true that there are instances of ancient wrought iron articles having withstood corrosion remarkably well, but investigation usually reveals that one or more of the following factors have contributed to the long life of the wrought iron articles subjected to atmospheric corrosion:

1. A heavy, protective layer of oxide was built up and hammered down on the surface of the wrought iron piece which was forged or hammered in the old-fashioned way; several reheatings, followed by hammering, were frequently necessary, adding to the thickness of the oxide coating, which thus became an excellent protective coating for the underlying iron.

Modern rolling methods create a much thinner and less protective oxide coating, or none at all. Famous old forged wrought iron articles have been taken, heated and rolled into sheets, then exposed to the weather and have corroded as rapidly as modern rolled non-copper-bearing steel.

2. The surface of wrought iron, on the average, is rougher than steel and consequently holds paint somewhat better. Also, painting probably was more thoroughly done and better paint materials were used on the average sheet metal job in the old days.

The more porous surface of wrought iron naturally took heavier metallic coatings in hot-dipping methods such as galvanizing and tinning, but equally heavy coatings can be applied to modern steel sheets, through special means, when the trade will pay for heavier coatings.

3. Enough copper was accidentally present in some old wrought iron to retard corrosion in the same manner as an effective copper content in modern steel. Some of the ores used years ago for making wrought iron contained enough copper to produce the copper-bearing effect in the finished article.

An example of this is described in an article by J. J. Tatum, Superintendent Car Department, B. & O. R. R., "Railway Age," June 16, 1923, telling how 0.54 per cent copper was found to exist in wrought iron plates of railroad cars built in Civil War days and still in good condition.

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[1] A bend parallel to the grain is comparable to a pull perpendicular to the grain, so far as strain in the piece is concerned.

4. Conditions under which a given ancient wrought iron article was exposed may not have been especially conducive to corrosion. For example, the atmosphere may have been very dry. There is no way of knowing how a modern rolled steel article would have lasted under similar conditions.

A comparative test, under exactly similar conditions, is the only reliable method for determining the relative resistance to corrosion of various iron and steel products. Conclusions drawn from other sources are likely to be erroneous.

There are numerous claims, but no preponderance of impartial evidence indicating that, as a general rule, wrought iron corrodes much, if any, slower than normal low-metalloid steel of good quality, provided the conditions of exposure are exactly the same and no factor such as copper content or protective oxide is involved; on the other hand there is good evidence that copper-bearing normal steels are more rust-resistant in the atmosphere than commercial wrought iron, even when the latter contains an effective copper content.

Copper-bearing Steel (Copper Alloy Steel).

There is a preponderance of impartial evidence, drawn from numerous authentic, comparative tests, indicating that in the atmosphere steel or iron sheets containing approximately ¼ of 1 per cent (0.25%) copper greatly outlast non-copper-bearing sheets of an otherwise similar character. There are some few elements in the steel industry, however, which continue to dispute, although in diminishing numbers, the beneficial effects of a copper alloy in retarding corrosion.

The weather tests of uncoated iron and steel sheets conducted by the American Society for Testing Materials are, without doubt, the most comprehensive, exact and unbiased tests of their kind which have ever been made; consequently these tests furnish the best available measure of the resistance to atmospheric corrosion offered by the various metals involved. Therefore, they are quoted here in order to give the reader what seems to be the most reliable information on the very interesting and important subject of corrosion. A summary of the Pittsburgh tests[2] is quoted on page 51.

The atmosphere in the neighborhood of Pittsburgh is extremely conducive to corrosion and for this reason some have stated that the Pittsburgh tests should not be taken as an index of what would happen in a milder atmosphere. Therefore, the following references[3] to the

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[2] Extract from "Report of Committee A-5 on Corrosion of Iron and Steel, Proceedings of the American Society for Testing Materials, 1923." (Vol. XXIII, 1923, pp. 151-152.)

[3] Extract from "Report of Committee A-5 on Corrosion of Iron and Steel, Proceedings of the American Society for Testing Materials" (Vol. XXVIII, 1928).

Society's similar tests at Fort Sheridan, Ill., where the atmosphere is much less corrosive than at Pittsburgh, are interesting. (See p. 52.)

"The following summary is presented as indicating the order of resistance of uncoated sheets to corrosion under atmospheric exposure as recorded for the various types of metals, together with average compositions, for the No. 22 gage sheets at the Pittsburgh location, the most resistant being given first.

		Average Analysis					
Rating	Type Designation	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper
		Per Cent					
First	Copper-bearing Bessemer Steel	0.041	0.365	0.097	0.068	0.008	0.252
Second	Copper-bearing Acid Open-hearth Steel	0.107	0.447	0.091	0.046	0.004	0.237
Third	Copper-bearing Basic Open-hearth Steel	0.069	0.387	0.016	0.027	0.004	0.244
Fourth	Copper-bearing Pure Iron	0.016	0.051	0.007	0.031	0.004	0.251
Fifth	Copper - bearing Wrought Iron....	0.033	0.034	0.114	0.021	0.134	0.283
Sixth	Low-copper Wrought Iron	0.03	0.055	0.139	0.021	0.218	0.020
Seventh	Low - copper Pure Iron	0.02	0.035	0.006	0.025	0.003	0.024
Eighth	Low - copper Basic Open-hearth Steel	0.10	0.32	0.069	0.044	0.002	0.018
Ninth	Low-copper Bessemer Steel	0.038	0.386	0.089	0.040	0.007	0.014

"In the No. 16-gage sheets the following order of resistance was recorded, the most resistant being given first. None of the copper-bearing materials has failed.

		Average Analysis					
Rating	Type Designation	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper
		Per Cent					
First	All Copper - bearing Materials	....	....	....	....	....	....
Second	Low - copper Basic Open-hearth Steel	0.108	0.371	0.009	0.029	0.007	0.029
Third	Low - copper Pure Iron	0.021	0.062	0.008	0.030	0.005	0.028
Fourth	Low - copper Bessemer Steel	0.043	0.419	0.083	0.042	0.004	0.012

"At the close of approximately six years' observations of these tests, the sub-committee would again direct attention to the fact that the failures recorded at the Pittsburgh and Fort Sheridan locations point definitely to the conclusion that copper-bearing metal shows marked superiority in rust-resisting properties as compared to non-copper-bearing metal of substantially the same general composition under atmospheric exposure."

"Table III is presented as indicating the order of resistance of uncoated sheets to corrosion under atmospheric exposure as recorded for the various types of metals, together with average compositions, for the No. 22 gage sheets at the Fort Sheridan location. Groups rated as 'first' have shown no failures in the 132 months of the tests. Groups rated as 'second' have shown failures mainly within the past year after 119 months exposure. The group rated as 'third' has shown an increasing number of failures over the preceding groups during the past year, and so on in the rating in the order of earlier and increasing number of failures to the end of the table.

TABLE III.—Summary * Indicating Order of Resistance to Corrosion Under Atmospheric Exposure, Fort Sheridan Tests.

		Average Analysis					
Rating	Type Description **	Carbon	Manganese	Phosphorus	Sulfur	Silicon	Copper
		Per Cent					
First	Copper-bearing Basic Open-hearth Steel	0.069	0.387	0.016	0.027	0.004	0.244
	Copper-bearing Bessemer Steel	0.041	0.365	0.097	0.068	0.008	0.252
	Copper-bearing Acid Open-hearth Steel	0.107	0.447	0.091	0.046	0.004	0.237
	Non-copper Bessemer Steel	0.06	0.38	0.077	0.035	0.009	0.130
	Copper-bearing Bessemer Steel	0.06	0.37	0.094	0.038	0.007	0.263
	Copper-bearing Bessemer Steel	0.05	0.37	0.114	0.048	....	0.533
	Copper-bearing Open-hearth Steel	0.06	0.35	0.049	0.059	....	0.212
	Copper-bearing Open-hearth Steel	0.06	0.39	0.047	0.047	....	0.286
	Copper-bearing Open-hearth Steel	0.07	0.41	0.042	0.042	....	0.532
Second	Copper-bearing Wrought Iron ...	0.033	0.034	0.114	0.021	0.134	0.283
	Copper-bearing Open-hearth Steel	0.079	0.334	0.012	0.038	0.007	0.189
Third	Copper-bearing Pure Iron	0.016	0.051	0.006	0.030	0.004	0.245
Fourth	Non-copper Pure Iron	0.021	0.035	0.006	0.025	0.003	0.024
Fifth	Non-copper Wrought Iron	0.03	0.055	0.139	0.201	0.218	0.020
Sixth	Non-copper Bessemer Steel	0.054	0.413	0.098	0.043	0.005	0.012
Seventh	Non-copper Open-hearth Steel	0.06	0.32	0.065	0.044	0.002	0.018
Eighth	Non-copper Open-hearth Steel	0.121	0.536	0.008	0.030	0.249	0.020

"The discontinuation of the Pittsburgh tests on March 9, 1923, and of the Fort Sheridan tests on April 16, 1928, leaves the Annapolis test remaining for further study. The rate of corrosion continues slow at Annapolis with very few additional failures during the past year.

"At the close of eleven years' observations of these tests the sub-committee would direct attention to the fact that the failures at the Fort Sheridan location confirm the findings at the Pittsburgh location that copper-bearing metal shows marked superiority in rust-resisting properties as compared to non-copper-bearing metal of substantially the same general composition under atmospheric exposure."

* Column headed Group is not shown here.

** Copper-bearing indicates copper content 0.15 per cent or over. Non-copper indicates copper content less than 0.15 per cent.

Unfortunately, our space will not permit giving much more of the interesting information to be found in these reports of the American Society for Testing Materials. The most significant feature of their findings under atmospheric exposure is, of course, that copper-bearing steels, whether Bessemer, acid open-hearth or basic open-hearth, are rated ahead of all other irons or steels. Apparently under atmospheric exposure the copper content is more effective in normal low-metalloid steel than in either wrought iron or in the so-called "pure iron" (extra-low-metalloid open hearth steel), judging by these tests.

The difference between the copper-bearing and non-copper-bearing groups in these tests was very pronounced. At Pittsburgh, in No. 22 gage very-low-copper sheets (excluding some sheets containing 0.082%, 0.133% and 0.139% copper since these contents would give some copper-bearing effect) failures commenced at 16 months and all these sheets had failed by 28 months. The Pittsburgh atmosphere, of course, is extremely destructive to iron or steel. However, at that location, the No. 22-gage copper-bearing steel did not commence to fail until 35 months and some sheets were still sound at 75 months when all other sheets had failed. All sheets lasted much longer at Fort Sheridan, but the general order of failure was the same.

Because of their better average showing, the low-copper wrought iron and low-copper pure iron were rated ahead of low copper steel in the No. 22 gage tests at both Pittsburgh and Fort Sheridan. The results in the low-copper division, however, at both locations were quite erratic from group to group; but the difference is not very pronounced between the worst sheets and the best sheets of the three different types in the very-low-copper class (excluding sheets containing over 0.05% copper because more than this will produce some copper-bearing effect) as will be seen from the tabulation on page 54, prepared by the author from the American Society for Testing Materials reports, in which a comparison with the copper-bearing sheets is made:

The foregoing can only give the reader a rough idea of the results of these most comprehensive atmospheric tests conducted by the American Society for Testing Materials, and the reports themselves should be studied by all those concerned with atmospheric or similar corrosion.

The American Society for Testing Materials has also conducted tests in which the test pieces were totally and continually immersed in various kinds of water. The results of these total-immersion tests as completed show no apparent difference in corrosion resistance between copper-bearing and non-copper-bearing metals under the conditions of

Location of Test; Gage; Type of Sheets.	First Failure Occurred At	Final Failure Occurred At	Sound at End of Test. (Months Exposure When Test Stopped.)
No. 22 gage—Pittsburgh			
All low-copper steel..........	16 months	22 months	None
All low-copper pure iron.....	16 months	28 months	None
All low-copper wrought iron..	28 months	28 months	None
All copper-bearing steel......	35 months	(81 months)*	23 sheets (75 months)
All copper-bearing pure iron..	35 months	52 months	None
All copper-bearing puddled iron	22 months	41 months	None
No. 16 gage—Pittsburgh			
All low-copper steel..........	28 months	(81 months)*	1 sheet (75 months)
All low-copper pure iron.....	41 months	(81 months)*	1 sheet (75 months)
All low-copper wrought iron.	52 months	58 months	None
All copper-bearing steel......	No failures		All (75 months)
All copper-bearing pure iron.	No failures		All (75 months)
All copper-bearing puddled iron	No failures		All (75 months)
No. 22 gage—Fort Sheridan			
All low-copper steel..........	32 months	132 months	None
All low-copper pure iron.....	48 months	132 months	None
All low-copper wrought iron.	42 months	101 months	None
All copper-bearing steel......	132 months	....	76 sheets (132 months)
All copper-bearing pure iron..	101 months	132 months	None
All copper-bearing puddled iron	101 months	....	10 sheets (132 months)

* Sheets sound at termination of tests could not have been reported as failures until the next examination, if there had been any, 6 months later.

the test. The 1927 American Society for Testing Materials Committee A-5 Report states:

> "* * * where the metals are submerged the presence of copper does not give increased resistance to corrosion." (American Society for Testing Materials, Vol. XXVII, p. 175.)

Articles made from sheet-steel products are seldom continually immersed in water or other liquid, consequently the atmospheric tests are what chiefly concern users of sheet steel. The alternate wetting and drying which takes place in the weather is comparable to the conditions under which most sheet steel is placed in service. For water pipe, boiler tubes and other products which may be continually immersed, another set of conditions apply and the problem of corrosion must be undertaken all over again, but this need not concern the average sheet steel user.

OPEN-HEARTH *vs.* BESSEMER STEEL FOR SHEETS.

Open Hearth. The term "open hearth" is used here to refer only to basic open-hearth steel, since little acid open-hearth steel is now employed for sheets.

Open-hearth steel can be, and usually is, lower in metalloids, especially sulfur and phosphorus, than Bessemer steel; consequently open hearth is, on the average, somewhat softer and more ductile, hence better suited for severe drawing or forming than Bessemer.

Open-hearth steel is preferable for welding operations, such as oxy-acetylene and electric arc, where the steel is actually melted and flows together to make the joint. (In electric-spot-welding the principal requirement is that there be a minimum of oxide on the surface of the steel sheets.)

Courtesy of Wheeling Steel Corpn.

Fig. 12.—Open hearth furnace: Tapping the molten steel into the ladle.

Open-hearth steel, made with extra care, is used for all deep drawing and extra-deep-drawing quality sheets.

Bessemer. Owing chiefly to a slightly higher phosphorus content, on the average, Bessemer steel sheets tend to be somewhat stiffer than open-hearth sheets. However, well-made Bessemer sheets will perform ordinary bending and forming operations satisfactorily.

A certain degree of stiffness is desirable for some purposes, such as for rolling into cylinders, where a dead soft sheet will bend or "flute" at intervals instead of maintaining a curved shape. In such cases, Bessemer or purposely stiffened open-hearth is desirable.

OPEN-HEARTH PURE IRON, *i.e.*, EXTRA LOW-METALLOID OPEN-HEARTH STEEL.

It has been previously mentioned that the great majority of sheet steel today is made from low-metalloid normal steel. There is, however, a slightly different type which is considerably used at present for sheets, this is what has been described under A-2 on page 25, as "extra low-metalloid open-hearth steel.

This type of metal was originally introduced under the theory that it would offer great resistance to atmospheric corrosion. However, in many impartial, comparative weather tests, such as those of the American Society for Testing Materials just referred to, it has proved inferior to copper-bearing low-metalloid steel with normal manganese content.

For vitreous enameling, however, this type of steel appears to have a very real field of usefulness. Thousands of tons are used annually for this work, especially for large vitreous-enameled parts where flatness of the finished part is important. It is said to retain its flatness under the heating in enameling better than normal steel and to give better enameling results in other ways.

It is more expensive to make than normal steel, owing to the difficulty of reducing the metalloids as low as required, and for other reasons.

Another advantage claimed for this type of steel is superior softness and "workability." It is probable, however, that extra careful annealing of sheets made from good quality, normal low-metalloid steel will produce sufficient softness for all practical purposes and be much less costly than this extra-low-metalloid steel. However, this is a matter of opinion.

SPECIAL STEELS USED FOR SHEETS.

Copper Steel (Copper-bearing Steel).—This has already been referred to on pp. 27 and 50-54. Used where it is desired to retard corrosion, such as atmospheric, at small extra cost. Slow rusting in air, but not "rust-proof."

Silicon Steel.—Widely used for electrical apparatus (see pp. 27, 28).

Carbon Steel (True Carbon Steel).—Used in carbon contents from over 0.15 per cent up to 0.90 per cent, but seldom over 0.50 per cent, for work requiring greater strength or hardness than is afforded by the usual very-low-carbon sheets. (See pp. 26, 35.)

Chromium Steel.—Extremely resistant to atmospheric corrosion and to the direct attack of many chemicals; also heat resistant; stainless in the atmosphere when the surface is polished clean and bright. (See p. 28.)

Quite expensive, costing in sheet form upwards of ten times as much as normal steel. The present high cost of chromium-steel sheets limits their uses, but these are increasing rapidly notwithstanding.

Employed for sheets principally in very-low-carbon content (about 0.10%) with chromium content of 15 per cent or more, and frequently with the addition of about 8 per cent nickel. Types commonly used for sheets today are straight 18 per cent chromium, and 18 per cent chromium—8 per cent nickel, the latter being exceptionally ductile; both are considerably stronger than normal steel with similar carbon content.

CHAPTER 4.

THE PRINCIPLES OF ROLLING SHEET STEEL PRODUCTS.

HISTORICAL DEVELOPMENT.

The first sheet iron was made by hammering a crude chunk or slab while hot so that it spread out into the general shape of a sheet. Originally this was laboriously done by hand, then less laboriously by various types of power-driven hammers. Finally, sheet iron was produced by the more accurate and easier method of passing a heated bar repeatedly through the same pair of rolls until the desired length and thickness were obtained.

The art of rolling sheet iron is over two hundred years old. It is said that John Payne first conceived the idea, although Major Hanbury was responsible for the first practical application of the method in his tin-plate works. The following extract from Thomas Turner's "The Metallurgy of Iron," London, Charles Griffin & Co., 1920, is of historical interest:

> "But in 1720 the tin plate manufacture was started at Pontypool (Wales) by Major Hanbury, who in 1728 introduced the process of sheet iron rolling, or, as it was then described, 'the art of expanding bars by compressing cylinders.' This mill was driven by water power and had plain rolls. Hand rolls for the production of lead sheets are known to have been in use as early as 1615."

According to Turner, it was not until many years later, or in 1783, that Cort invented the use of grooved rolls, which invention was destined to play such an important part in the development of the production of numerous iron products such as bars, rods, rails, etc. Cort also invented the puddling process in 1784. A sad commentary is that Cort died in poverty in 1800, his patents having been seized to satisfy the liabilities of a partner.

Thus, we see that sheets were the first iron product known to have been produced by rolling and, as pointed out on p. 45, sheets now vie with merchant bars for the honor of constituting the largest single item of all the different forms of rolled iron and steel produced in this country today.

In the early hammering method it was found necessary, in order to produce the thinner sheets, to place two or more of the partially hammered-out sheets on top of each other, forming a pile or pack, and this was then hammered out further, finally producing the relatively thin sheets desired. These piled sheets did not weld or stick tightly together because of the presence on their surfaces of oxide which formed when the red-hot metal was being worked in contact with the air. This multiple-layer-pack principle was found to be advantageous in making sheets by hot-rolling also, since the greater thickness retains heat longer and assists in securing the necessary uniform pressure. Thus, ply-rolling (rolling a pack made up of several sheets) was introduced to the sheet industry at its very beginning and is still used for most sheets, since only the heaviest gages are hot-rolled in a single thickness.

Courtesy of Wheeling Steel Corpn.

FIG. 13.—Pouring ingots: The molten steel is tapped from the bottom of the ladle into the ingot mold.

In the following, when speaking of sheet hot-rolling, reference is made to the conventional sheet hot-rolling unit (tin mills being the same in principle) consisting of a single stand of two rolls, one above the other, through which the piece is passed, then returned to be passed through again, and so on until the work is completed, only the one set of rolls being utilized during each stage of the rolling of a particular piece. The operating principle of this type of hot-mill consists, briefly, of the following steps: heat the piece, pass the piece through the rolls, push the piece back over the top roll with hand tongs, pass the piece through the rolls again (see Figs. 35, 36 and 37, pp. 107-108), and so on until the piece being rolled either is of the required thickness or else has cooled down to the point where it must be reheated before the rolling can continue. This is only a bare outline of the elements of the operation, which is very much further complicated by matching (putting two or more sheets together), doubling the pack, adjustments of the rolls, and various other factors, according to the nature of the sheets being rolled. Owing to the fact that the piece is fed to the rolls by the roller, passes through the rolls, is caught on the other side and handed back over the rolls to the roller for passing through the rolls again, and since there are only two rolls, one above the other, in the set, this conventional sheet hot-mill or sheet mill is described as a "two-high, pull-over mill." More than one of these mills may be employed in the rolling unit, each performing a separate stage of the work, but the principle of each remains the same.

Courtesy of E. W. Bliss Co.

FIG. 14.—Cold-rolling strip steel 18 in. wide. Four stand, 2-high, tandem cold strip mill.

The operating principle of the conventional sheet mill, therefore, differs considerably from that of the mills employing the "tandem" principle, used for rolling some steel products, such as bars, strips, etc. In the latter type of rolling unit, the piece passes only once through each stand of rolls, which are arranged in tandem; the piece goes consecutively through one set of rolls after another, receiving as many passes as there are sets of rolls in the tandem train. This tandem principle is employed in the production of wide-strip steel which has recently come to be made in what have hitherto been considered as sheet sizes and gages. However, these wide-strip mills, thus far, are more or less in the development stage and only produce the heavier range of sheet gages and these not nearly so wide as can be produced with wide sheet, jobbing or plate mills. (See Chapter 5.)

Up to the present, these wide-strip mills are not a predominating factor in the production of what are considered sheet gages and sizes, although they will probably become a much larger factor as time goes on. Meanwhile, the two-high, pull-over hot-mill may be considered the main unit for final shaping in the sheet steel industry (see p. 105), supplemented by the slightly different tin mill hot-mill and sheet jobbing hot-mill for lighter and heavier gages, respectively, both employing the same intermittent rolling principle, and further supplemented by the light-plate mill which involves the same rolling principle slightly modified. Therefore, while the product of the wide-strip mill may be finished into any desired sheet-steel grade, the term "sheet steel" as used in these pages will refer to a product which has been hot-rolled into its final shape by the intermittent principle employed by the above described conventional sheet hot-rolling equipment, and not by the continuous rolling principle involved in the wide-strip hot-rolling equipment now being developed, although the latter may have been employed in the preliminary or "roughing" stage of the hot-rolling, as will be referred to later. (See Chapter 5.)

It should be remembered that ordinarily sheet steel receives its shaping entirely in the hot-rolling, the cold-rolling of sheets being merely a surfacing, flattening and stiffening operation. Therefore, where the word "rolling" is used here in connection with sheets it is to be assumed that "hot-rolling" is meant; cold-rolling will be referred to as such.

In this connection, another recent development requires mention. Within the past few years cold-rolls have been designed which will actually thin down and draw out steel sheets of considerable width while cold; in other words, these powerful rolls will effect cold reduction and consequently are capable of shaping cold steel into sheets of predetermined thickness and length, which cannot be done by the ordinary sheet cold-rolls. These newly developed mills are not widely used yet, however, so the statement that sheets receive their shaping from hot-rolling still holds good for the sheet industry as a whole. Nevertheless, before many years the cold-rolling of sheets may undergo radical changes and developments.

With the retention in use of the two-high, pull-over mill, the art of sheet rolling as practiced today differs little in its fundamentals from the earliest method. Of course, numerous refinements have been made, but the principle is the same. The great progress in the sheet industry has been in means and methods of treating the sheet after hot-rolling.

Courtesy of Youngstown Sheet & Tube Co.

FIG. 15.—Stripping ingots: The mold is raised from the solidified, but red hot, ingot.

Rolling sheet steel remains largely a matter of individual skill and judgment. There is little that is automatic about the rolling operation. It is doubtful whether the human element enters so largely into the rolling of any other basic steel product as it does into that of sheets.

Each pass through the rolls requires a setting or adjustment of the rolls and this is made by the roller on his own judgment. This, together with factors introduced by the relatively great width and thin section of the piece being rolled, accounts for the fact that the same precision and accuracy is not found in sheets as in some other steel products where the production is more automatic and subject to more exact mechanical control, as, for example, wire products, cold-drawn bars, cold-rolled strip, etc.

ROLLING, IN GENERAL.

Rolling may be defined as "the passing of a piece of metal, either heated or not, through compressing rolls for the purpose of changing its shape or properties."

Rolling, of course, is one method for applying mechanical pressure; consequently rolled metal is subject to the effects of mechanical work, of which there are two basic types, *viz.*: hot work and cold work.

The external, or surfacing, effects of mechanical work, being readily visible, are the more easily understood. These will be discussed later when rolling, both hot and cold, and other operations, are considered.

On the other hand, the effects of work upon the interior of metal, being complex and not discernible except to the trained metallurgist, constitute a vast study in themselves, concerning which there is very little definite knowledge, in spite of numerous acceptable theories, as to the exact causes of the observed effects. Only those features of this subject which pertain particularly to sheet steel will be touched upon here.

A fundamental concept of what takes place inside a metal during mechanical working is provided by the following brief but illuminating paragraphs from Bradley Stoughton: ("Metallurgy of Iron and Steel," New York, McGraw-Hill Book Co., **1913**, pp. 173-174.

> "Crystallization of steel.—Metals are crystalline substances, the individual components arranging themselves in regular forms unless opposed by the rigidity of the mass in which they form. Indeed, the metallic crystals grow with astonishing rapidity when the metal crystallizes from the molten state (*i.e.*, solidifies), or even when it is in a mobile condition (*i.e.*, at temperatures near or above a red heat). Once crystals have formed they cannot be reduced in size except by annealing, or by breaking them up by mechanical crushing. These facts are important, because large crystals do not adhere to each other firmly, and thus they cause a weak and brittle mass. Iron and steel follow the same laws as other metals in these respects."

> "Rationale of the effect of work.—Mechanical pressure upon a metal crushes the crystals, mixes them intimately together, and breaks up the cleavage planes along which they would yield. If the work is finished above

> a red heat where the mass is still mobile, the crystals reform to a certain extent, decreasing the strength. * * * If the work continues while the metal is cold, there is no opportunity for the reformation of the crystals, and the strength, hardness, and brittleness are much increased."

Lest confusion arise in the reader's mind, it may be well to point out here that both very large crystals and very small crystals cause brittleness, though for different reasons, in the low-carbon type of steel used for sheets.

In the following pages, as is now customary, the term "grain" will be used to refer to those metallic crystalline units, which appear in rather definite outline under the microscope and of which steel is mainly composed. It must be remembered that each "grain" consists of a great number of smaller crystals which group themselves together around a center or "nucleus" when the structure of the metal forms. (See microphotographs, pp. 125-126).

In deciding upon rolling methods, the main considerations are:

1. The characteristics of the metal itself.
2. The gage and size desired.
3. The physical properties desired in the finished product:
    a. Internal properties, such as strength; hardness; ductility; stiffness; etc.
    b. External properties, such as presence or absence of oxide; freedom from surface irregularities; porous or polished surface; accuracy of shape and size; suitability for taking coatings, etc.
4. Cost.

After considering the multitude of factors involved in the above, the cheapest method or combination of methods of rolling which will give the desired results will, of course, be selected. The methods will vary considerably with the different metals and with the different products of the same metal.

HOT-ROLLING AND COLD-ROLLING.

If the steel to be rolled is heated very perceptibly and then rolled, this is called "hot-rolling," practically speaking. If the steel is rolled without being previously heated, this is called "cold-rolling." [1]

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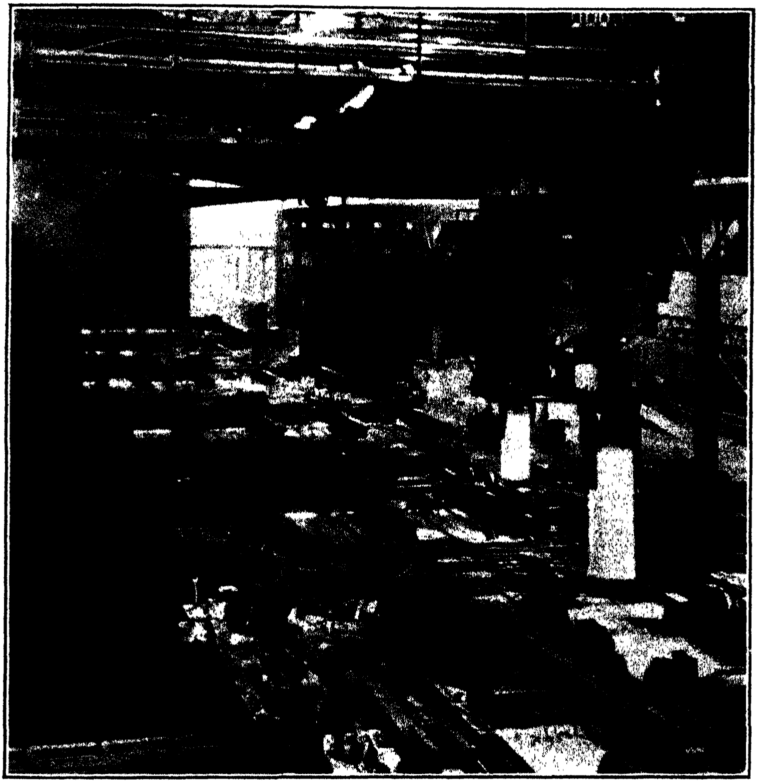
[1] The technical distinction between "hot-working" and "cold-working" is based upon the critical range of the metal. (See Appendix "A.") For low-carbon steel, from the viewpoint of the metallurgist, *true* hot-rolling is that carried on at temperatures within or above the critical range, *i.e.* above about 1,300° F., and cold-rolling is any rolling performed at temperatures below the critical range. However, high temperatures at the finish of the hot-rolling of sheets are not practicable in most cases, so that most of the hot-rolling of sheet steel, in the latter stages of the operation, is performed at temperatures below the critical range. This is especially the case with the lighter gages where the hot-rolling sometimes continues after the pack of sheets turns almost, if not entirely, black in color, although still decidedly hot. While this is not true hot-rolling in the metallurgical sense, nevertheless it is hot-rolling in the practical sense inasmuch as metal must be considered as being "hot" even though its temperature be considerably below 1,300° F. Therefore, the writer uses the term "not-hot-enough" in referring to hot-rolling at temperatures below the critical range, which is regular practice in sheet steel hot-rolling, to distinguish it from sheet steel cold-rolling which is performed on sheets which have not been heated. This "not-hot-enough" hot-rolling produces some of the effects of "cold-working."

In order that the reader who is not at all familiar with the working of steel may gain an insight into the basic differences between these two types of rolling and may understand why each is sometimes advantageous and sometimes not, the following well known facts are cited:



Courtesy of Wheeling Steel Corpn.

FIG. 16.—Soaking pits: General view. The cranes are raising white hot ingots from the heating furnaces called "soaking pits," in which the ingots are heated for rolling on the blooming mill.

Steel is generally more plastic, consequently more easily shaped and worked, when heated;

At temperatures near or above a red heat, the grains of iron become less stable and tend to grow and otherwise change, depending upon the nature of the product and the temperature involved;

But the hotter the steel is, while in the presence of air, the more it tends to form an oxide or scale on its surface. This is frequently a disadvantage in the case of sheets, as when a fine, smooth surface is desired.

Rolling crushes and distorts the grains of the steel piece. If the rolling finishes above a certain temperature (about the temperature of red heat, approximately 1300° F.), and especially if the piece cools relatively slowly after such rolling is completed, then the grains grow larger again and the internal strains set up by the rolling are released, thereby producing a fairly soft product, unless high in carbon or other hardening alloy.

On the contrary, if rolling is carried on and finishes while the piece is materially below a red heat, the grains, which have been crushed and distorted by the rolling, do not have an opportunity to grow or adjust themselves, with the result that, for complicated metallurgical reasons, these small, distorted grains produce greater stiffness, hardness, strength and brittleness. This is the case with cold-rolled steel and, in varying degrees, when hot-rolling is finished at lowered temperatures, either through accident or design.

Thus, the effects on very low-carbon normal steel of the different types of rolling and finishing may be roughly visualized as follows:

Type of Rolling.	*Effect on Sheets.*
1. Hot-rolling finished well above red heat and piece cools relatively slowly, because it is thick or for other cause.	Steel has about normal properties after rolling. Grains grow and adjust themselves.
2. Hot-rolling finished above red heat but piece cools very rapidly because it is thin, etc.	Finished piece has added stiffness, hardness, strength and brittleness, about in the order of (2), (3) and (4). Grains remain relatively small and distorted with internal strains, until annealed.
3. Hot-rolling finished materially below red heat.	
4. Cold-rolling; piece not heated (Refers to true cold reduction).	

The use of the words "red heat" is inexact but will give an idea of the approximate range of temperatures involved. For more precise information and data, any standard work on metallography or heat treatment should be consulted. Steel begins to appear red in the dark around 750° F. but does not appear distinctly red in sunlight until over 1,000° F.; obviously, therefore, "red heat" means little scientifically, but will probably serve to create an approximate idea for the layman.

Because they are relatively thin, thus losing their heat fairly rapidly and further because of the rather intermittent nature of hot-rolling on the two-high pull-over mill, sheets are usually finished in hot-rolling under conditions (2) or (3) described above; consequently all sheets are annealed after hot-rolling to soften them except those few grades which are desired somewhat stiff or hard. In rare, special instances, particularly heavy gage thick sheets are finished hot enough and cool slowly enough so as not to require annealing to make them fairly workable. However, since there are few purposes requiring stiff, hard sheets and few sheets can be made soft without an annealing operation, in general it may be assumed that all sheets are annealed after hot-rolling. They usually receive further treatment as well.

Cold-rolling is performed without heating the piece and on the average is more costly than hot-rolling, but has advantages for certain results.

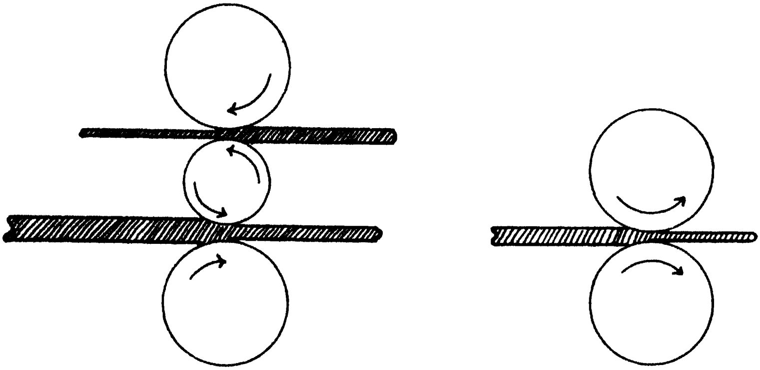
Since no oxide is formed on the piece during cold-rolling, this operation has the advantage of smoothing and polishing the surface of the piece, more or less, according to the pressure the particular rolls are able to exert. Sheet steel cannot be cold-rolled, with the equipment generally existing, under as heavy pressure as strip steel, on account of its greater width, therefore more passes through the cold rolls are necessary to produce the same degree of smoothness, polish and density of surface on sheets than on narrow strips. From the standpoint of commercial practice, the best grades of the narrower cold-rolled strips may always be considered as having smoother, closer grained surface than the best grades of the wider cold-rolled sheets.

Cold-rolling, like all cold-working, also has the effect of imparting a degree of stiffness and strength to the piece, depending upon the intensity of the cold-rolling. This is used to good effect in making the better grades of sheets in producing the fine shadings of temper required for certain purposes by varying the number and intensity of the cold-roll passes given the sheets. When sheets are cold-rolled merely to smooth and polish the surface and dead soft temper is desired in the finished product, it is necessary to anneal after cold-rolling to remove this stiffness.

HOT-ROLLING IN GENERAL.

Practically all rolled steel products receive their preliminary shaping from hot-rolling, that is, rolling while the piece is heated. The obvious reason for this, as previously stated, is because steel is more plastic while hot and therefore is more readily and cheaply worked. Some products, such as cold-rolled strip and cold-drawn bars, receive a final shaping by cold-working operations which very materially change the size as well as the properties of the piece, but both these products are made from a semi-finished piece of steel which has been roughly shaped by hot-rolling so that no more cold work will have to be done than is necessary to produce the desired shape and qualities.

In the case of sheet steel it may be assumed that the final size is approximately that resulting from hot-rolling, except where the final size has been sheared from a multiple size, of course. Although sheets are cold-rolled and otherwise treated after being hot-rolled, such treatment is not at present designed to alter the shape of the sheets, but, depending upon what is desired, is for the purpose of making them smoother, softer or stiffer, flatter, cleaner, etc., than they would otherwise be. While it is true that the various treatments which are given sheet steel after hot-rolling sometimes do alter the size, this effect may be looked upon as a necessary evil, as will be discussed later.



Three-high rolls.

Single stand: for heavy (thick) sheets and plates.

(For purpose of illustration the sketch shows two pieces engaged in the mill at the same time, passing in opposite directions. In the case of plates, however, only one piece is engaged in the rolls at one time.)

In rolling plates or heavy sheets, the piece passes through the bottom pass in one direction onto a table which elevates it up to the upper pass, through which it returns in the opposite direction, is caught on a table and lowered to go through the bottom pass again, etc.

Two-high rolls.

Single stand: for sheets, during the rolling of which the piece passes through, is handed back over top roll, then is passed through again, etc.

Several stands in tandem line: for sheet bar, strips, etc.

Reversing single stand: for extremely heavy pieces, as rolling ingots into blooms, slabs, etc., during the rolling of which the piece passes through in one direction, then the rotation of the rolls is reversed and the piece is passed through in the opposite direction.

Fig. 17—Types of rolls commonly used for hot-rolling.

The ideal hot-rolling process is one that is continuous, permitting the ingot which is received from the steel works to be heated and then rolled out into its final form through a series of sets of rolls without having to be reheated or the process interrupted in any way. This has been accomplished with some forms of steel. It is performed on the bar, termed "sheet bar," from which sheets are made. Up to the present, however, hot-rolling methods which are nearly or entirely continuous have been employed with universal success only in making those products where the thickness of the piece being rolled is relatively great or the width relatively narrow.

SOME DIFFICULTIES ENCOUNTERED IN HOT-ROLLING WIDE, THIN SHEETS.

The heat absorbed by the rolls from the hot steel piece being rolled causes expansion and contraction of the rolls which interferes with good results and accuracy unless prevented or counteracted. The surest way to maintain the rolls at uniform temperature and thereby prevent distortion is to play water over or through them constantly, but this keeps the temperature of the rolls much lower than that of the steel being rolled and hence cannot be resorted to where the rolled piece is thin, since this would result in cooling the piece down below the proper rolling temperature before rolling is completed. Water cannot, as a general rule, be used on the rolls which give the final or finishing passes on such thin sections as light sheets because this would cause too rapid cooling for ordinary purposes. (Water is used on the rolls, however, in finishing sheets that are desired to be very stiff, with a hard surface, as for oil-well casings, but this is very exceptional and is accomplished only in the heavier gages with resultant disadvantages in many other respects.)

The surface of the sheet finishing rolls absorb much heat from the rolled piece and are subjected to only slight artificial cooling by means of a steam jet applied where it is desired to cool somewhat a particular portion of the rolls which has become too hot and therefore too much expanded. This steam is applied against the middle portion of the rolls. Also, a small stream of water is directed over the necks or ends of the rolls which rest in the bearings in the housings to prevent the heat from friction and that absorbed from the roll surfaces from becoming too great, but this does not mean that these necks are cool, by any means.

This heated condition of the sheet-finishing rolls, together with the intermittent passing of the piece being rolled (causing cooling of the rolls between passes) and variations in the temperature of the piece in different places, produces a constant change in the shape of the rolls.

The wider the piece that is being rolled, the more difficult it becomes to control this variation in the shape of the rolls, since more surface is affected. The thinner the section of the piece being rolled, the more noticeable are the effects of this variation of the roll shape, especially with regard to flatness, since the thinner the piece, the more easily it is distorted by irregularities in its thickness.

This shape variation of the hot rolls, due to unavoidable expansion and contraction of the wide roll surfaces involved, is the main cause of the sheet maker's difficulties in controlling gage variation and flatness in the finished sheets.

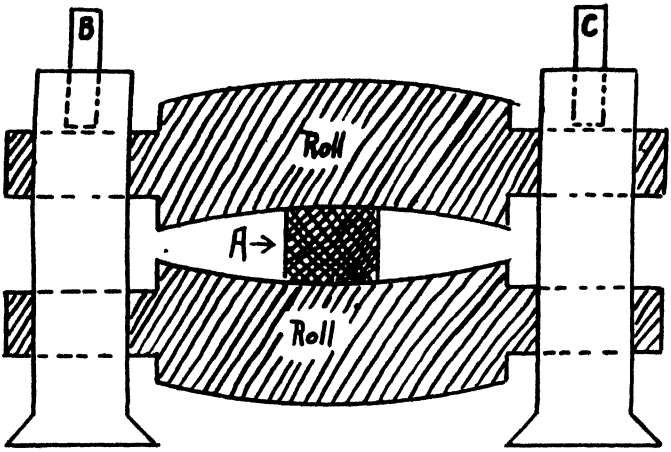


Fig. 18.—Skeleton diagram illustrating "spring" in two-high rolls. (Greatly exaggerated.)

A—Piece being rolled: This presses upwards and downwards against rolls, causing them to spring. (Effect greatly exaggerated for purpose of illustration.)
B and *C*—Screws in top of housing which bear against ends of rolls and press top roll toward bottom roll.

Another factor contributing to the difficulties of hot-rolling (or even cold-rolling) thin, wide sheets is the tendency of the rolls to spring or give slightly in the middle due to the pressure caused by the resistance to deformation of the piece being rolled.

Naturally, this "spring" of the rolls is greater, other things being equal, the wider [2] the rolls are. To the uninitiated it would appear that this could be remedied by increasing the diameter of the rolls, thereby making them stronger, but the problem is not so easily solved. For

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[2] The term "width" is here used in the sense of length along the axis of the roll. This has become common practice in the sheet industry, probably because the roller habitually faces his rolls and comes to think of them as being "wide" instead of "long." Also it is natural to think of wide sheets being made in wide rolls.

certain technical reasons in the mechanics of rolling, there is a maximum roll diameter which may be used efficiently for a given purpose. The diameter, then, being limited, other means must be adopted, and at present progress is being made, in overcoming or reducing the spring in wide rolls through the use of one or more "backing-up" or "reinforcing" rolls, placed above and below the working rolls which receive the piece, thus assisting the latter to bear the pressure produced when the piece passes through and minimizing the spring in the middle. Such reinforced rolls, called "four-high" and "cluster" rolls, according to the particular type, are roughly illustrated by the above diagram.

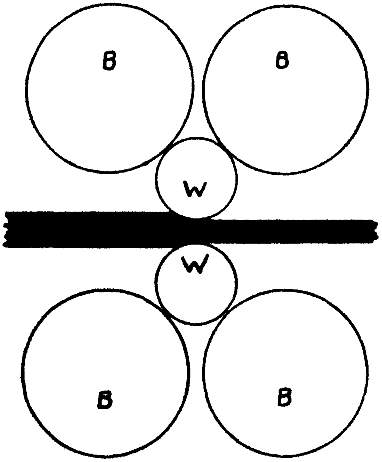


Fig. 19.—Cluster type rolls.

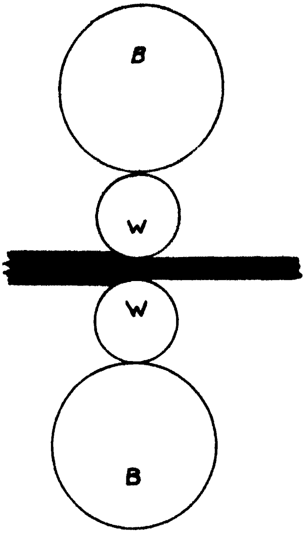


Fig. 20.—Four-high type rolls.

Skeleton diagrams showing roll arrangements.

W—working rolls.
B—backing-up rolls.

This "spring" produced in the ordinary two-high rolls is relatively slight compared with the length and size of the rolls, but it is sufficient to cause a very noticeable effect in a wide sheet. Theoretically, it is possible for very wide, ordinary two-high rolls with the screws clear down to exert practically no effective rolling pressure in the center on the piece being rolled if this is not thick enough to more than take up the spring and the "slack" of the screw-down mechanism. While the rolls may be almost pressing against each other at the ends, they would exert no more pressure at the middle than the elastic force of the rolls themselves, which might be counteracted by the strength of the rolled piece at that point. This is not permitted to take place, of course, as it would produce a sheet which would be wafer thin and wavy on the edges and much thicker in the center. The foregoing partly explains the necessity for ply-rolling of thin sheets, that is, rolling several thicknesses at a time, accomplished by matching and sometimes doubling the pack over on itself, all in order to provide sufficient thickness for efficient hot-rolling.

GENERAL COMPARISON OF SHEETS WITH PLATES AND STRIPS.

As discussed on pp. 41-43, sheet steel is usually assumed to be relatively thin and wide as compared to other flat forms and the following further discussion may clarify the distinctions between these forms of steel products.

Courtesy of Youngstown Sheet & Tube Co.

FIG. 21.—Plate mill.

Formatively, sheets are distinguished from plates by being thinner and smaller, but they overlap each other to some extent. Ordinarily, ¼ inch thick and thicker classifies material as plate (if in wide widths) although many plate mills roll lighter than ¼ inch, sometimes down to $\frac{3}{16}$ inch thick, but seldom thinner.

Sheets are always annealed unless specially required not annealed.

Plates, on the contrary, are not annealed unless so ordered or required. This is one of the reasons why in the same gages, sheets are generally more expensive than plates. It should be pointed out, however, that although plates are not ordinarily expected to stand much cold-forming, even if not annealed they are quite workable if made of low-carbon normal steel, especially in the heavier gages, because these thick plates finish the hot-rolling at high enough temperatures and their heavy body permits slow enough cooling to overcome much of any stiffening effect of the rolling. (See pp. 65-67.)

Formatively, sheets are differentiated from hot-rolled and cold-rolled strips by being wider in proportion to their thickness. Strips are made much longer than sheets and frequently are coiled, whereas sheets cannot be made long enough to justify coiling. Sheets are seldom rolled narrower than 24 inches, except at tin mills, but of course can be sheared down to narrower widths.

There is no fixed dividing line between sheets and strips in the matter of gage and size. They overlap each other considerably, so that within the range of this overlapping, certain gages and sizes can be obtained either in sheets or strips. In this case, price and physical properties must determine which is desirable. Owing to the marked difference in the manufacturing processes of sheets and strips, in some instances certain physical properties, such as surface, gage accuracy or other qualities can be produced better in strips than in sheets. Nevertheless, it is true that some desirable results are obtainable in the sheet process which are not regularly provided by the strip process. Therefore, when the gage, size and other considerations permit the use of either, the decision as to whether a sheet or strip product is preferable for a given purpose should be based on a determination as to which will do the work involved at the lowest cost. For example, cold-rolled strip might have a better surface than is actually required for a certain article, whereas the surface of hot-rolled strip might not be good enough. In this case, one of the cold-rolled finishes in sheets would likely be found to possess a surface sufficiently good for the purpose and be less expensive than cold-rolled strip.

This brief and very general comparison of sheet, plate and strip steel has been given so that the reader who is not familiar with these products may better visualize the proper fields of each.

CHAPTER 5.

CONTINUOUS HOT-ROLLING OF SHEETS.

So far as the actual hot-rolling operation is concerned, the method employed in making strip steel approaches theoretical perfection in that it is practically continuous. On the other hand, the hot-rolling of sheets on the conventional two-high, pull-over type mill is not at all continuous in so far as the individual piece is concerned, and becomes increasingly intermittent as the gage becomes lighter, requiring reheating, matching and doubling. It is entirely logical, therefore, to inquire why all flat steel products are not hot-rolled by a continuous method such as is employed in making strip. The answer is that the continuous process, at present, is limited to certain widths and thicknesses. As the width becomes greater and the thickness less, rolling operations meet increased difficulties and problems which are only slowly being solved by mechanical improvements.

Numerous attempts have been made for many years to devise methods of rolling sheet widths and gages continuously. Efforts in this direction are now being rewarded with considerable success, but, thus far, only in the heavier sheet gages (generally 16 gage and heavier) and in what are relatively narrow widths for sheets in these gages.

In a paper presented before the October, 1927, meeting of the American Iron and Steel Institute ("The Evolution of the Wide Strip Mill," Proceedings American Iron and Steel Institute, 1927) Mr. Stephen Badlam, Consulting Engineer, Pittsburgh, Pa., gives a most interesting and illuminating outline of the progress made during the last twenty or thirty years in methods for the continuous hot-rolling of thin, wide, flat sections. Beginning with the time when strip steel was merely a special product of the merchant bar mill, he points out how increasing demand brought forth mills specially designed, first for the production of "the narrower sizes, from 3 inches down to ⅝ inch wide, and from 16 gage (0.065 inch) to 22 gage (0.028 inch) in thickness, which were known as 'hoop' "; next for the production of "pipe skelp, 4 inches wide and over"; and later for the production of "thinner gages in the wider widths, which became known as band."

Then this writer goes on to describe typical mills, which were successively put in operation from about 1890 until about 1925 to take care of the steadily growing demand for widths still wider than the original concept of "hoops" and "bands" (but in lengths exceeding those obtainable in standard plates and sheets), which products became known generally as "universal plates" in the heavier gages, and as "hot-rolled strip" in the lighter gages. The trend of the design of these hot-strip mills was away from the "looping" type, inherited from the merchant mill origin of the product, and in the direction of arranging the rolls in tandem line, at first involving lateral transfers and reversal of the direction of rolling, but more recently tending toward the single straight line, tandem, arrangement of rolls which permits maximum continuity and speed of rolling. As a summary up to that point, Badlam states:

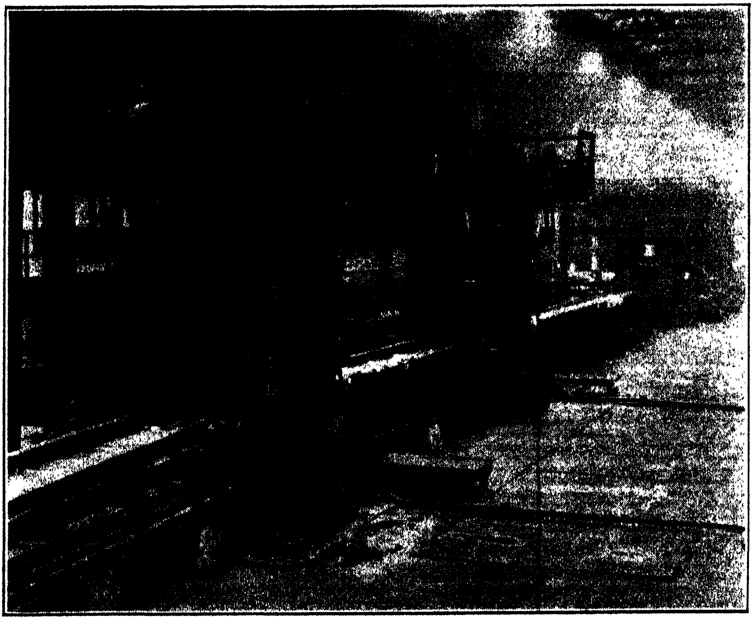
> "In the foregoing pages we have endeavored to picture the development of strip rolling from a maximum width of seven inches in 1890 to a maximum width of twenty-four inches in 1925, and from a length of 100 feet in the former year to a length of 500 to 1,000 feet in 1925.
>
> "You will note that the development progressed in more or less gradual stages; the maximum width being: 1890 about 7 inches; 1899 about 10 inches; 1902 about 12 inches; 1905 about 16 inches; 1918 about 21 inches; 1922 about 24 inches. There was also a fairly definite limit to the ratio between width and gage; in 1924, for example, the widest 16-gage strip that would be furnished on regular order was about 16 inches."

After thus describing the history of rolling what he refers to as "wide strip," having a maximum width in the heavier gages of about 24 inches and produced primarily (except for a few instances where a variety of three-high rolls formed a part of the roll train) by two-high rolls, Badlam then goes on to review the developments in the continuous hot-rolling of sheet widths or what he terms "broad strips" over 24 inches wide.

The continuous hot-rolling of these wide widths has been made a commercial success only in recent years, largely owing to the employment of "backed-up" rolls of the three-high and four-high type. Modern improvements in bearings and drive for the rolls and in heating furnaces have also contributed a great deal to the success of these wide continuous-sheet or broad-strip mills.

Then, quoting from Prof. S. B. Ely, he describes the continuous sheet mill operated at Teplitz, Bohemia, in 1902, "which is reported to have rolled sheets up to 50 inches in width, in gages from 0.080 inch to 0.120 inch, and in lengths up to 60 feet" but the finished sheets from which "showed a variation in thickness of about 0.5 mm. (0.020 inch) from one end to the other, due to the cooling of the sheet in its passage through the mill. The works at Teplitz were abandoned in 1907 so it may be assumed that the mill was not a commercial success."

Next, Badlam reviews the "most ambitious early attempt to roll sheet width material by methods other than those of the ordinary sheet mill" made by Charles W. Bray, first in 1902 at the Monongahela Works of the American Sheet and Tin Plate Company and later at their Mercer Works in 1905. Both of these mills embodied the same general principle, *viz.*, the tandem arrangement of stands of two-high rolls of the conventional sheet-mill type. The regular sheet bar was used and the piece, after passing through one stand of rolls, was conveyed mechanically to the next. Since the piece cleared one set of rolls before engaging in the next, these mills were of the simple tandem type, rather than the strictly continuous type in which the piece may engage in more than one set of rolls simultaneously. Both the Monongahela and Mercer mills had as their object the production of partly rolled-out sheets, *i.e.*, "breakdowns," already matched together in a pack of two or three layers and doubled, ready for further reduction and



Courtesy of United Engineering & Foundry Co.

FIG. 22.—Continuous hot-rolling of sheets. 4-high roller bearing continuous sheet hot strip mill. With capacity for rolling up to 30 inches wide.

finishing into sheets on regular hand-operated hot mills. Therefore, both mills provided for matching after the sixth tandem pass; at Monongahela two pieces were matched and then passed through two more tandem stands, receiving eight passes in all, while at the Mercer mill three pieces were matched and the pack of threes went on through three more sets of rolls in the tandem train, receiving nine passes in all. The packs were doubled mechanically after leaving the last pass. Both of these mills were failures from the commercial standpoint, owing to mechanical difficulties. Although they effected savings in labor costs, much difficulty was experienced with the drive of the rolls, with roll breakage, with the sticking together of sheets in the finished pack and in securing proper heating of the bars. The losses resulting from these causes were found to overbalance the saving in labor costs effected by the tandem mills. The Monongahela mill was shut down in 1905 and the Mercer mill was dismantled in 1910. Neither went much beyond the experimental stage, although some 43,000 tons of sheets were produced on the two mills.

Badlam's paper next describes in considerable detail the continuous sheet mill at the Ashland Plant of the American Rolling Mill Company, which has been operating since 1923-1924. So far as known, it is the first mill to apply the continuous, or rather, tandem, hot-rolling method to the production of sheet gages and widths with commercial success. While it does not produce, in a given gage, widths as wide as are produced in that gage by the conventional rolling equipment, nevertheless it produces widths greatly exceeding anything previously accomplished by continuous rolling methods. The mill is somewhat complicated and our space will not permit more than a brief résumé of Badlam's complete description, the significant features of which may be condensed as follows:

There are four stages of rolling from the ingot to the thinnest sheets produced, *viz.*: (1) Blooming Mill, (2) Bar-plate Mill, (3) Rough-sheet Mill and (4) Sheet Mill.

In the first three stages the piece being rolled is never allowed to become cold.

Backed-up rolls, of the three-high type with small middle roll, are used in the latter stages of the rolling.

ESSENTIALS OF MILL AND OPERATION.	NATURE AND PURPOSE OF PRODUCT.
Blooming Mill: Reduces ingot into long slab. Long slabs, still hot, are conveyed into holding furnace of bar plate mill.	Slabs for bar plate mill. 36-inch slab, from 3 inches to 4 inches thick, according to the weight of the bar plate desired.

ESSENTIALS OF MILL AND OPERATION.	NATURE AND PURPOSE OF PRODUCT.
Bar-plate Mill: Reduces slabs into bar plate. Consists of seven stands of two-high rolls in tandem; two * vertical edgers; preceded by slab-holding furnace; slab shear. From the long slab, a piece is sheared to a length which represents the width of the bar plate to be rolled, this is turned 90° and enters the mill with the sheared ends of the slab becoming the edges of the bar plate. The piece passes through the seven sets of rolls consecutively and emerges as a bar plate of the desired width, from 5/16 inch to 7/16 inch thick and approximately 30 feet long.	Bar plate, of desired width, from 5/16 inch to 7/16 inch thick and approximately 30 feet long, either for further reduction in rough-sheet mill, or for shipment to other sheet mills of the company to replace sheet bar, or for use as pipe skelp in the manufacture of lap-welded pipe.
Rough-sheet Mill (or Jobbing Mill): Reduces bar-plate into "rough sheet." Consists of seven stands of rolls in tandem, the first three stands are two-high and the last four stands are three-high; preceded by holding furnace for bar plate and shear. The bar plate passes through the holding furnace, a piece of the proper length is sheared off and immediately enters the first stand of rolls, passing successively through each stand, emerging as a sheet from 0.0625 inch to 0.203 inch thick. The "rough sheets" are allowed to cool.	Rough sheets from 0.065 inch to 0.095 inch thick, intended for further reduction to lighter gages in the sheet mill or black sheets for shipment, also blue annealed sheets, in widths up to 48 inches and in gages from 6 to 16 inclusive.
Sheet Mill (separate unit from above): Reduces rough sheets of 16 gage or heavier into lighter gages. Consists of five stands of three-high rolls in tandem, with continuous furnaces before the first, third, fourth and fifth stands. A pack of two rough sheets (which previously have been pickled, matched and cropped) is heated in the first continuous furnace, then passes immediately through the first and second set of rolls, second furnace, third set of rolls, third furnace, fourth set of rolls, fourth furnace, and fifth set of rolls, successively and without stopping.	Sheets from about 18 to 22 gage in thickness. These may subsequently be cold-rolled.

The finished sheets leave the last stand of the sheet mill at about 18 to 22 gage, or a little heavier if they are to be cold-rolled; they are edge-sheared on a rotary slitter, then cut to length on a cross-cut shear.

The production of the Ashland Plant was over 24,000 tons in both May and June of 1927 and this was limited, not by the capacity of the mill, but by the open-hearth production. Much of the product was in sheets of 16 gage and lighter that went into the highest grade of automobile body and crown fender stock.

The following quotations are extracts from Badlam's description of the broad-strip mill at Butler, Pa., built by the Columbia Steel Com-

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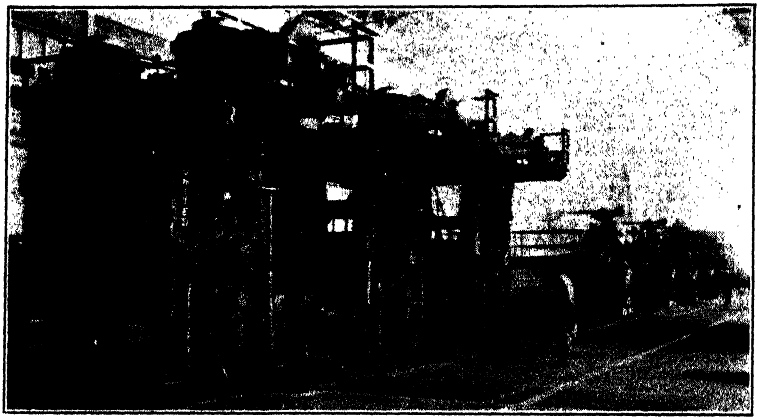
* Badlam, in private communication, states there are now 4 vertical edgers.

pany, first operated in 1926, and now owned by the American Rolling Mill Company:

> "Slabs were produced on the (existing) universal slabbing mill . . . and ranged in size from 12 inches to 36 inches in width, by 2 1/2 inches to 5 inches in thickness, and from 6 feet to 12 feet 6 inches in length.
>
> "The strip-roughing mill consists of a two-high, reversing, universal stand with vertical rolls on both sides. The horizontal rolls are 27 inches by 48 inches and the vertical rolls are so arranged as to go back into the housings and give a maximum opening of 37 inches thus utilizing nearly the full length of the body of the horizontal rolls.
>
> "The finishing mill, located 165 feet away from the universal mill, consists of four stands of 16 1/2-inch and 40-inch by 42-inch four-high rolls, equipped with roller bearings, and spaced on 22-foot centers, with loopers between.
>
> . . .
>
> "The heated slab, after leaving the furnace, passes through a scale breaker consisting of five staggered corrugated rolls which serves to break up the furnace scale. It passes to a manipulator which turns it over and knocks off the loosened scale, and then passes to the mill.
>
> "The slab receives from 5 to 7 passes in the universal stand (strip roughing mill) where it is reduced to a thickness of from 1/4 inch up to 1/2 inch, according to the required thickness of the finished strip. On leaving the universal mill it passes direct to the finishing mill, receiving one pass in each stand.
>
> "From the last stand of the finishing mill, the piece travels down a roller table to a coiler where it is coiled up for further operation. Heavy-gage material may also be cut to length by a shear in the line of the roller table without passing through the coiler.
>
> "This mill represented the first application of the four-high mill to the hot rolling of strip, and this, together with the high finishing speed, was the means relied upon to secure the thin gage and wide width desired.
>
> "The mill started operation in November, 1926, and has produced strips from 12 inches to 36 inches in width and from 3/16 inch down to 0.058 inch in gage. The mill has rolled as much as 1,000 tons in 24 hours and in March, 1927, produced over 14,000 tons, and in June, 1927, over 16,000 tons of hot-rolled material.
>
> "The hot-strip sheet mill was designed to produce gages as light as No. 16 only. When lighter gages are required they are produced by cold-rolling.
>
> "For this purpose there are six four-high cold mills located in a parallel bay of the building, the intermediate bay being occupied by the continuous pickling and annealing equipment. The coils of hot finished material are transferred to this latter bay where they are passed through a continuous pickler, being uncoiled just before entering the pickling bath, the front end of each coil being welded to the back end of the preceding coil in such manner as to make the process continuous. After pickling, the strip is coiled up again and the coils divided by shearing out the welded portion. The pickled coils are then transferred to the cold-mill building where they receive the required number of passes to reduce them to the gage desired. The coils are then transferred back to the central bay where they are annealed in a continuous furnace to remove the effects of the cold-rolling. After annealing it may or may not receive a further reduction as determined by the physical properties desired."

After a discussion of the development of the four-high mill, cluster mill and other types of backed-up rolls, and descriptions of the broad strip mill of the Trumbull Steel Company designed to produce widths up to 36 inches, of the mill of the Weirton Steel Company designed to produce broad strip from 16 inches to 48 inches in width, 16 gage and heavier, and of the broad-strip mill at the Gary Plant of the American Sheet and Tin Plate Company designed to rough-down sheets to from 16 to 18 gage for finishing on the tin mill, Badlam then gives the following interesting summary of the entire subject:



Courtesy of United Engineering & Foundry Co.

FIG. 23.—Continuous hot-rolling of sheets: Modern 4-high roller bearing continuous sheet hot strip mill. (With capacity for rolling up to about 54 inches wide.)

> "The character and extent of the advance in rolling mill practice, represented by the new broad strip mills and by the continuous sheet mill can perhaps best be appreciated by a study of the maximum widths rolled in the various gages. In tabulated form data are shown below, in which the letters A to E represent the following classes or types of mills:
>
> A—Hand-operated strip mill, 1900-5.
> B—Tandem rougher, strand finisher, strip mill, 1905-20.
> C—Tandem rougher, continuous finisher, strip mill, 1920-5.
> D—Four-high tandem finisher, broad-strip mill, 1926-7.
> E—Continuous sheet mill, 1924.

Thickness		Maximum Width				
Inches	BWG*	A	B	C	D	E
.049	18	8″	6″	9¼″	..	..
.065	16	10″	10″	15″	25″	42″
.083	14	12″	13½″	18″	..	..
.109	12	..	16″	21″	..	..
.134	10	..	17″	23″	..	..

* **Birmingham wire gage.**

. . . .

> "The figures in the table . . . should not be taken to represent accurately any particular mill, but are intended only to represent a general relation. They do, however, show that the field of the new mills is radically distinct from that of the standard type of wide-strip mill which preceded it.
>
> "It is too early in the day to predict the future of this new type of mill in which, after half a century of separate development, the strip mill and the sheet mill have come together, but the best minds in the steel industry agree that it represents a tremendous advance in the art of rolling. That the operation will be a success, and that the broad-strip, or continuous sheet mill, has come to stay is generally conceded, but that it will entirely supersede the hand sheet mill is questioned.
>
> "There is a considerable tonnage of certain classes of sheets that, in all probability, will for years to come be made on the hand sheet mill. There is also a large aggregate tonnage, made up of small lots of special sizes, which will have no place on the schedule of the new mills. The economical limit of gage that can be produced on the continuous mills is today not lighter than 16 gage. This will mean that, for the present at least, a great part of the sheet tonnage produced will be open to other methods. Some will be produced by rerolling hot as in the Ashland system, some will be produced by cold-rolling, and the remainder will be produced on the existing hand mills.
>
> "The old style sheet mill represented but a small investment whereas the new type of mill represents a tremendous investment, say anywhere from five to fifteen million dollars, and only those companies best situated financially will be in a position to enter the field, and reap the benefits of anticipated economies in operation.
>
> "Undoubtedly as the older mills become economically unprofitable, which they will do eventually in any case, they will not be replaced and will gradually fade out of the picture but, as has been the case with almost every other innovation, the new method will create its own demand for its product, over and above the existing demand, and the old will continue to maintain its existence alongside the new. Any disturbance of the existing order of things will be gradual rather than abrupt."

For the sake of brevity, Badlam's paper has, of necessity, been inadequately represented here and those interested in the subject will be repaid to read it in its entirety, since it gives a complete and clear account of what he correctly considers, to use his own words: "The outstanding achievement of the present decade, in the history of the rolling mill. . . ."

A discussion of Badlam's paper by C. W. Bennett, Vice-President, American Sheet and Tin Plate Company (also Proceedings American Iron and Steel Institute, 1927) contained some interesting comments on the subject, which he summarized as follows:

> "Giving due credit to the importance of recent developments in the rolling of wide strip or sheets, which mark distinct economic and humanitarian advances in steel mill operation, the new mills have certain inherent limitations, which should not be overlooked in a study of their relations to old style mills. In some cases a group of hand mills may well complement a continuous mill installation to secure a desired increase in plant capacity. For the gages at

> present within the range of the new type mill, it will be found that cost of installation of such a mill is practically that of the equivalent tonnage group of old style mills, without, however, the flexibility of operation of the single mills. Until the new type mill is developed to the stage of satisfactorily and economically handling practically the entire range of sheet mill gages and widths, the old style mills have their field and may well supplement the new type for some time to come."

In concluding, the writer believes that the following general remarks on the present scope of the continuous mill in the sheet steel industry, its future possibilities and its relation to the conventional single hot mills of the sheet family may be of interest to the reader of these pages.

In its present stage of development, the continuous method of hot-rolling a single thickness from a single heating, in sheet widths, will not economically produce much lighter than 16 gage nor much wider than 48 inches. Furthermore, economical operation of the continuous mill requires the rolling of a large quantity of one gage and width.

However, in addition to producing a finished product, so far as shaping is concerned, in the form of hot-rolled sheets (within its range of gage and width) ready for annealing, pickling, cold-rolling, galvanizing or any of the refining operations given sheets following their shaping, a mill of the type above mentioned also has an important field in the production of semi-finished pieces for further reduction in gage on different types of mills.

Where the continuous hot-rolling of a single thickness from a single heating leaves off, at about 16 gage at present, the further reduction may be taken up and lighter gages produced:

(1) By the conventional two-high, pull-over sheet mill, which then starts with breakdowns produced on the continuous mill and reduces these to as light gages as desired in the usual way, thus eliminating the operation of roughing-down sheet bars on the hand-operated single mill.[3]

(2) By cold reduction [4] in backed-up cold rolls of the four-high or cluster type.

(3) By continuous hot-rolling involving two or more thicknesses in the rolled piece, or frequent reheating between passes, or both, as in the continuous sheet mill at Ashland (p. 78) which is designed to produce 18 to 22 gage.

When very considerable cold reduction is effected, as by cold-drawing or by cold-rolling, one of the problems is that of annealing to

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[3] The above practice is already being followed, to some extent, both at sheet mills and tin mills.

[4] Such cold reduction is being practiced today, producing average sheet widths as light as 24 gage successfully, but only in the more expensive cold-rolled finishes, of course.

overcome the stiffening and hardening effect of the severe cold-working and make the steel soft and ductile enough, either to stand the forming required of the finished product, or to stand further cold reduction when this is necessary.

The continuous hot-rolling of light gages encounters the familiar obstacle of too rapid cooling of the thin piece if a single thickness is rolled; and if recourse is had to building up a pack of several layers in order to secure a piece thick enough to prevent too rapid cooling, then the difficulty of sticking is met and must be overcome. On the pull-over hot-mill, the pack can be opened between passes to combat the tendency of the sheets to stick together in the pack, but obviously this cannot be done on the continuous hot-mill, so that other and possibly more expensive means must be taken to combat sticking in continuous, hot, ply-rolling.

Courtesy of United Engineering & Foundry Co.

Fig. 24.—Continuous cold-rolling of sheets: 5-stand tandem 4-high roller bearing cold strip mill. (Arranged for rolling sheets and wide strips.)

Without doubt, the next few years will witness very considerable progress and improvement in continuous mills, both hot and cold, and the limits of such mills will be extended to include both lighter gages and wider widths in these gages than are now produced profitably. With the present improved design of backed-up rolls and bearings for these rolls, it may be that the major development in the roll stand itself, for the time being at least, has already taken place—with room for refinement, of course. However, there is still a great field for development and improvement in heating furnaces to be used for reheating between passes in hot-rolling light gages either by the continuous or "tandem" method; therefore, it is not unlikely that the next major development may be in this direction.

One of the greatest problems of the sheet maker these days is that of preventing flaws in the surface of sheets of the finer finishes, and excessive oxidation is an almost certain source of imperfections in a steel surface. Furthermore, heavy oxidation causes a loss of metal which is proportionately higher as the gage becomes lighter. It will be readily seen that heating for continuous rolling of light gages must be accomplished very rapidly, uniformly, with a minimum of oxidation, with exact temperature control and without depositing dirt or foreign substance on the surface of the steel being rolled.

Great impetus may some day be given to the development of the continuous rolling of sheet widths in light gages by improved furnaces of the oil- or gas-fired variety, or by some such innovation as electrical furnaces designed and perfected for such work, of the resistance type or of the high frequency induction type. The latter acts on the principle of casting a high frequency magnetic field about the metal to be heated and the heating of the metal is effected very rapidly and uniformly by the eddy currents and hysteresis induced in it by the magnetic field.

While further developments are taking place, the conventional type hot-mills of the sheet family (see p. 100) will do the shaping (1) of sheets about 16 gage and heavier in widths exceeding about 48 inches; (2) of most sheets from about 17 to 24 gage which are not desired with an expensive, highly finished surface, and all sheets in these gages where the width exceeds the limit of continuous rolling; (3) of practically all sheets lighter than 24 gage; and (4) of all items of sheets where the quantity of one gage and width is not so large as necessary for economical rolling on continuous mills.

Therefore, at present the field of the existing single hot mills of the sheet family is still very large and the predominating factor in the hot-shaping of the sheet steel industry.

The following pages, except where otherwise stated, will be devoted to the conventional methods employed today for the production of sheet steel and tin plate products, and will not deal further with the product of continuous rolling methods, except where this may find its way into the standard sheet-refining operations which follow the hot-rolling.

CHAPTER 6.

THE SHEET STEEL MAKERS' CONTRIBUTION TO INDUSTRY.

The sheet steel maker supplies the very important present-day need of wide sheets of relatively thin steel. Without sheet steel in its various forms as made today our present method of living would be different. It is to the credit of the sheet steel makers that they have done as well as they have with the existing rolling equipment.

Courtesy of Wheeling Steel Corpn.

Fig. 25.—Hot-rolling sheets. Jobbing Mill: Catcher's side.

It should again be observed, however, that while the hot-rolling forms the basis of the sheet steel industry, since it provides the shaping of the product, it is only the initial step in the sheet-making process. Only a very small fraction of the sheet steel produced is marketed without further treatment after hot-rolling.

The great improvement in and development of methods for treating the individual sheets after hot-rolling is responsible for the ever-increasing usefulness of sheet steel products. Since the day when the first sheet steel rolling mill produced its crude, rough, rather brittle sheets, there have grown a multitude of qualities and finishes, the result of various treatments and refinements after hot-rolling, each developed for certain purposes, until now the words "sheet steel" no longer describe a particular kind of article, but merely denote a class of articles. Today, it is necessary to say what kind of sheet steel, not only what gage and size, is contemplated in order to describe it.

The experience and practice of the sheet maker in treating and inspecting relatively small units and the opportunity for craftsmanship on the part of the roller permits the sheet industry to make some important contributions to present civilization. For example, practically all flat steel of any considerable width which is produced with a protective metallic coating, *i.e.*, galvanized sheets, terne plate and tin plate, comes from the sheet mill, or its brother, the tin mill. The reason for this is that all coatings are subject to imperfections and in order to secure commercial prime quality it is necessary to inspect the product after coating, sorting out the commercially perfect from the more imperfect. It is obvious that the smaller the unit assorted, the greater proportion of prime quality will be secured. A piece sixty feet long would be classified as imperfect if it had a single defect although the rest of the piece might be of prime quality, but if the sixty-foot piece is cut into ten pieces, the defect would only cause the rejection of one six-foot piece. Also, smaller units of flat steel are more advantageously prepared for coating and coated than larger ones.

This same principle of individual treatment of small units also applies to numerous other finishes which are advantageously made by sheet and tin mills.

The individual craftsmanship of the sheet roller is called into play for the production of silicon-alloy thin steel sheets for motors, generators and transformers, on which the present development of the electrical industry depends.[1] Such material can only be made today by the sheet method of hot-rolling.

[1] Extract from article by T. S. Fuller in "Mining & Metallurgy," Oct., 1928:

"In the form of its ferro-alloy many thousand tons of silicon are used annually in this country for additions to steel for electrical sheets, which go to make the core material for our transformers, motors, generators and other devices. Silicon in amount up to and including 4.5 per cent, depending on the use to which the steel is to be put, is added.

"Ruder has pointed out that the improvement brought about in magnetic properties by the addition of this element may be regarded as being due to three effects, namely, (a) increase in electrical resistivity, such increase being 11.4 microhms for each per cent of added silicon; (b) decrease in solubility of iron for carbon, and (c) the ability of silicon to produce grain growth in iron.

"From the economic standpoint, the addition of silicon to iron is tremendously important. It would have been impossible for the electrical industry to have progressed to its present position with steel having the magnetic losses of those of twenty-five years ago. Considering

Since wide sheets of relatively thin steel cannot be hot-rolled by the more mechanically exact and continuous processes used in making some other basic steel products, the sheet maker must substitute the skill and dexterity of the individual workman for more mechanical methods. A person seeing sheets hot-rolled for the first time will generally wonder how such good results are obtained in the finished product as form the present standards in sheets. Only very attentive management and highly skilled workmen make these results possible. The crew of a sheet steel hot mill must have skill, strength and endurance. The heat, smoke and arduous physical labor combine to make the work hard, but apparently it is healthful for those who are fitted for and trained in it. Like all craftsmanship, however, it is interesting and fascinating. The steel mill has a lure for men who enjoy seeing their handiwork take shape before their eyes. These hot-mill men must be capable of exercising judgment at their work under trying circumstances and considerable training and practice is required before a man can properly do even the simpler jobs on the hot-mill crew. The more responsible jobs on the crew, such as rollers and heaters, are only given to men with many years of experience and proven ability. The roller has charge of the crew and is responsible for the product of the mill. Some men work all their lives on the hot mills and never qualify for a roller's job, or else will not accept its responsibilities.

CONCLUSION OF THE GENERAL DISCUSSION.

Every effect has a cause; all consequents have antecedents. No result can be analyzed or its true meaning grasped without knowing something of what has gone before. Therefore, at the risk of trying the reader's patience, it has been the aim, up to this point, to outline as briefly and in as plain language as possible, certain phases of the making of iron products in general which underlie even a partial understanding of sheet products in particular.

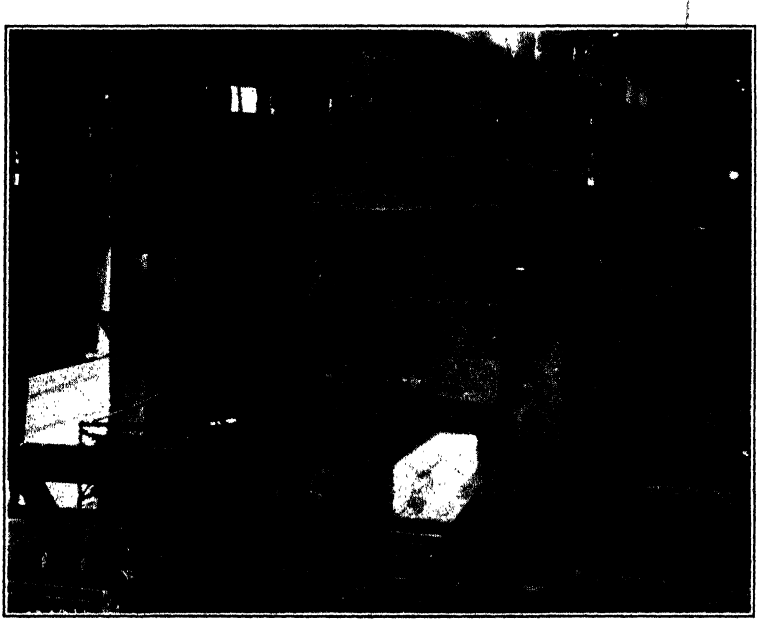
No easy rule-of-thumb can be cited as to nomenclature, chemical composition, effect of hot- and cold-rolling, corrosion resistance, and other factors, but, based on known practice and established facts, enough has been said about these various subjects to provide the lay reader with a background for the more definite discussion of the manufacture and utilization of sheet steel and tin plate products which follows. Such a background would be different, of course, for another type of iron product.

only the transformers made in the United States, and assuming only those made during the last ten years to be still in service the yearly saving in watt loss alone in 1925 has been conservatively estimated to be $15,000,000. At the present rate of transformer production, the yearly saving is being increased at the annual rate of about $3,000,000."

CHAPTER 7.

TABLES PERTAINING TO SHEET STEEL PRODUCTS, GAGES, SIZES, FINISHES AND OPERATIONS INVOLVED.

The reader, upon commencing to consider definitely the various operations involved in the manufacture of sheet steel products, will most naturally inquire: "What are the gages and sizes of sheet steel products, both sheet mill and tin mill; what is the nature of each of the numerous grades and finishes; and what are the operations required to produce them?"



Courtesy of Wheeling Steel Corpn.

FIG. 26.—Blooming mill: Ingot being rolled down into a "bloom."

It is impossible to answer these questions fully in concise form, but the following tables have been prepared with the object of consolidating, as definitely as circumstances permit, certain fundamental information which will provide the reader with a basis for comprehending the whole field of sheet steel products, collectively. If this is accomplished at the start, then the relative scope and particular purpose of the individual operations will be better understood, as these are discussed later.

The term "gage," when used in connection with sheet steel products, refers either to the weight per square foot or to the thickness. Most uncoated sheet steel and practically all coated grades are made on the basis of weight per square foot, expressed by gage number or by square foot weight, or, in the case of tin plate, by base weight or symbol. Of course, a certain weight per square foot will give a certain theoretical thickness, but thickness is not the governing factor, technically, unless material is ordered by thickness. In special instances, where exacting drawing operations will be involved or where for any other reason gage accuracy is very important, uncoated sheets are ordered and made on the basis of thickness in decimal parts of an inch, whereupon thickness alone and not weight becomes the determining factor as to gage.

Considerable gage variation, in either weight or thickness, must be expected in all sheet steel products. The customary tolerances for gage variation are given on pp. 264-265.

REMARKS ON GAGE TABLES.

United States Standard Gage (p. 91).

This gage is standard for all uncoated sheets and is employed for long terne sheets. Also, it is used for tin plate, regularly for the heavier tin plate, and occasionally in the very light gages.

It was established in 1893 by an act of Congress. The basis of each gage number is the weight per square foot in ounces. The square foot weights in pounds are derived from the basic ounces. Likewise, the approximate thicknesses are derived from the weights per square foot, which accounts for their irregularity and for the ridiculous number of decimal places in some of the approximate thicknesses.

The approximate thicknesses of this gage are calculated from the weight of wrought iron, which is slightly lighter than steel, therefore they are not correct for the latter. For the nominal thicknesses of rolled steel to give the weights per square foot of the United States Standard Gage, see the table headed "Equivalent Thicknesses in Rolled Steel, etc."

Weight is the determining factor of the United States Standard Gage. For example: sheet steel ordered in No. 9 United States Standard Gage is made to weigh 6.25 pounds per square foot, which would have a nominal thickness of 0.153 inches, not the 0.156 inches given in the United States Standard Gage table of approximate thicknesses which are for wrought iron.

Gages heavier than No. 1 have been omitted from this table of the United States Standard Gage; also the columns have been rearranged to bring the column "Weight per Square Foot in Pounds" adjacent to the gage numbers, for convenience, since these weights comprise the heart of the table today. Further, the column "Weight per Square Foot in Ounces" has been placed at the extreme right so as to afford ready comparison with the weights of the same gage numbers in the "Galvanized Sheet Gage" which is opposite.

Equivalent Thickness in Rolled Steel (p. 91).

When the United States Standard Gage was established in 1893, the density of wrought iron of 0.2778 pounds per cubic inch, or 480 pounds per cubic foot, was used in calculating the approximate thicknesses which would give the square foot weights of the individual gage numbers.

Now that steel is used for practically all sheets produced in this country, the approximate thickness columns in the United States Standard Gage are obsolete, but they are shown in order not to confuse the reader who is accustomed to seeing them included in a table of the United States Standard Gage. To supply the deficiency created by the obsoleteness of these columns and to provide data from which the nominal thickness in rolled steel of the standard gage weights can be secured, there has been placed at the left of the United States Standard Gage table, a separate table of "Equivalent Thicknesses in Rolled Steel." These have been calculated from the density of rolled steel adopted as standard by the American Society for Testing Materials and the Association of American Steel Manufacturers, also approved by the Bureau of Standards, *viz.:* 0.2833 pound per cubic inch, or 489.6 pounds per cubic foot.

The following is a very useful formula for deriving the decimal thickness from the pounds per square foot, or *vice versa:* [1]

Pounds per square foot ÷ 40.8 = decimal thickness.
Example: 2.04 lb. per sq. ft. ÷ 40.8 = 0.05 inch
40.8 lb. x decimal thickness = pounds per square foot
Example: 40.8 lb. 0.05 inch = 2.04 lb. per sq. ft.

Galvanized Sheet Gage (p. 91).

This gage, which draws its authority from long use in the trade, is used for zinc-coated iron or steel sheets, *i.e.*, galvanized sheets. It is a weight gage. Each Galvanized Sheet Gage number weighs 2½ ounces per square foot more than the same United States Standard Gage number.

Tin Plate Gage (p. 92).

This gage is used for tin plate and short ternes. It was inherited from the English tin plate industry. It is a weight gage, but instead of employing gage numbers or weights per square foot, the gage is indicated by the weight of a base box in pounds, called the "base weight." A base box consists of the area equivalent to that contained in 112 sheets of 14 inches x 20 inches, *i.e.*, 31,360 square inches or 217.78 square feet.

By "107 pound base weight" is meant: tin plate of such weight per square foot that 217.78 square feet of it will weigh 107 pounds. Certain base weights have symbols to indicate them. For example: IC means "107 pounds per base box."

The equivalent weights per square foot of these base weights are given in this table, and the near-by United States Standard Gage weights are interpolated for comparison.

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[1] But see p. 267 for precise methods of calculating the weight of steel sheets in the different classes.

TABLE 8.—SHEET STEEL WEIGHT GAGES.*

Equivalent Thicknesses in Rolled Steel for the Square Foot Weights of the U.S. Standard Gages in Decimal Parts of an Inch	United States Standard Gage For Sheet and Plate Iron and Steel					Galvanized Sheet Gage		
	Number of Gage	Weight per Square Foot in Pounds Avoirdupois	Approximate Thickness in Decimal Parts of an Inch	Approximate Thickness in Fractions of an Inch	Weight per Square Foot in Ounces Avoirdupois	Number of Gage	Weight per Square Foot in Ounces	Weight per Square Foot in Pounds
0.2757	1	11.25	0.28125	9–32	180	..	....	...
0.2604	2	10.625	0.265625	17–64	170	..	....	....
0.2451	3	10.	0.25	1–4	160	..	....	....
0.2298	4	9.375	0.234375	15–64	150	..	....	....
0.2145	5	8.75	0.21875	7–32	140	..	....	....
0.1991	6	8.125	0.203125	13–64	130	..	....	....
0.1838	7	7.5	0.1875	3–16	120	..	....	....
0.1685	8	6.875	0.171875	11–64	110	8	112.5	7.031
0.1532	9	6.25	0.15625	5–32	100	9	102.5	6.406
0.1379	10	5.625	0.140625	9–64	90	10	92.5	5.781
0.1225	11	5.	0.125	1–8	80	11	82.5	5.156
0.1072	12	4.375	0.109375	7–64	70	12	72.5	4.531
0.0919	13	3.75	0.09375	3–32	60	13	62.5	3.906
0.0766	14	3.125	0.078125	5–64	50	14	52.5	3.281
0.0689	15	2.8125	0.0703125	9–128	45	15	47.5	2.969
0.0613	16	2.5	0.0625	1–16	40	16	42.5	2.656
0.0551	17	2.25	0.05625	9–160	36	17	38.5	2.406
0.0490	18	2.	0.05	1–20	32	18	34.5	2.156
0.0429	19	1.75	0.04375	7–160	28	19	30.5	1.906
0.0368	20	1.5	0.0375	3–80	24	20	26.5	1.656
0.0337	21	1.375	0.034375	11–320	22	21	24.5	1.531
0.0306	22	1.25	0.03125	1–32	20	22	22.5	1.406
0.0276	23	1.125	0.028125	9–320	18	23	20.5	1.281
0.0245	24	1.	0.025	1–40	16	24	18.5	1.156
0.0214	25	0.875	0.021875	7–320	14	25	16.5	1.031
0.0184	26	0.75	0.01875	3–160	12	26	14.5	0.906
0.0169	27	0.6875	0.0171875	11–640	11	27	13.5	0.844
0.0153	28	0.625	0.015625	1–64	10	28	12.5	0.781
0.0138	29	0.5625	0.0140625	9–640	9	29	11.5	0.719
0.0123	30	0.5	0.0125	1–80	8	30	10.5	0.656
0.0107	31	0.4375	0.0109375	7–640	7	31	9.5	0.594
0.0100	32	0.40625	0.01015625	13–1280	6½	32	9.0	0.563
0.0092	33	0.375	0.009375	3–320	6	33	8.5	0.531
0.0084	34	0.34375	0.00859375	11–1280	5½	34	8.0	0.500
0.0077	35	0.3125	0.0078125	5–640	5	..	....	....
0.0069	36	0.28125	0.00703125	9–1280	4½	..	....	....
0.0065	37	0.265625	0.006640625	17–2560	4¼	..	....	....
0.0061	38	0.25	0.00625	1–160	4	..	....	....

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* See remarks on pp. 89-90.

TABLE 9.—TIN PLATE GAGE.

Symbol	Base Weight Pounds per Base Box	Equivalent in Pound per Square Foot	*United States Standard Gage Weights Interpolated for Comparison*
8 X	275	1.263	
		1.250	No. 22
D 4 X	270	1.240	
8 X L	268	1.231	
7 X	255	1.171	
7 X L	248	1.139	
		1.125	No. 23
D 3 X	240	1.102	
6 X	235	1.079	
6 X L	228	1.047	
		1.000	No. 24
5 X	215	0.987	
D 2 X	210	0.964	
5 X L	208	0.955	
4 X	195	0.895	
		0.875	No. 25
4 X L	188	0.863	
D X	180	0.827	
3 X	175	0.804	
3 X L	168	0.771	
		0.750	No. 26
	163	0.748	
2 X	155	0.712	
		0.688	No. 27
2 X L	148	0.680	
	143	0.657	
D C	139	0.638	
		0.625	No. 28
I X	135	0.620	
I X L	128	0.588	
	125	0.574	
	123	0.565	
		0.563	No. 29
	118	0.542	
	112	0.514	
	110	0.505	
		0.500	No. 30
I C	107	0.491	
I C L	100	0.459	
		0.438	No. 31
	95	0.436	
	90	0.413	
		0.406	No. 32
	85	0.390	
		0.375	No. 33
	80	0.367	
	75	0.344	
		0.344	No. 34
	70	0.321	
		0.313	No. 35
	65	0.298	
		0.281	No. 36
	60	0.276	
		0.266	No. 37
	55	0.253	
		0.250	No. 38

The following table showing approximately the gages rolled on the different types of hot mills used to produce sheet steel products; subdivided into sheet mill and tin mill. It will be noted that the gages overlap considerably.

TABLE 10. SHEET MILL AND TIN MILL GAGES AND SIZES.

Minimum base sizes *—all gages:
Sheet Mill .... 24″ x 60″
Tin Mill .... 14″ x 14″

Average maximum widths and lengths for hot-rolling: §

Gage	*Sheet Mill Products*	*Tin Mill Products*	*Sheet Mill*		*Tin Mill*		*Gage*
			Width	*Length*	*Width*	*Length*	
3	Light plate mill (No. 3 to No. 12 gage)		66″ ‡	240″			3
4			66″ ‡	240″			4
5			66″ ‡	240″			5
6			66″ ‡	240″			6
7			66″ ‡	240″			7
8			66″ ‡	240″			8
9			66″ ‡	240″			9
10	Sheet jobbing mill (No. 10 to No. 16 gage) Sheet mill (No. 10 to No. 30 gage)		66″ ‡	240″			10
11			66″ ‡	240″			11
12			66″ ‡	240″			12
13			60″	180″			13
14			60″	180″			14
15		Tin mill (No. 15 to No. 38 gage)	60″	168″	32″	54″	15
16			60″	168″	32″	60″	16
17			54″	144″	32″	68″	17
18			54″	144″	32″	78″	18
19			50″	144″	32″	84″	19
20			50″	144″	32″	84″	20
21			48″	144″	32″	84″	21
22			48″	144″	32″	84″	22
23			48″	144″	32″	84″	23
24			48″	144″	32″	84″	24
25			44″	144″	32″	84″	25
26			44″	144″	32″	84″	26
27			40″	144″	32″	84″	27
28			40″	144″	32″	84″	28
29			36″	144″	32″	84″	29
30			36″	144″	32″	84″	30
31					32″	84″	31
32					32″	72″	32
33					32″	72″	33
34					32″	72″	34
35					30″	42″	35
36					30″	42″	36
37					30″	42″	37
38					30″	42″	38

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* Minimum base size is the smallest size sold without extra charge for shearing down; smaller sizes, of course, are sold.

§ Average maximum widths and lengths for hot-rolling: These figures are arbitrary, necessarily; some mills can hot-roll greater widths or lengths than those shown here and some mills cannot make so great, but these figures represent average, advanced, commercial practice. A requirement for extra wide or extra long sheets should be submitted to manufacturers with full details. In special cases, the usual limits may be exceeded.
Frequently the maximum width cannot be made in the maximum length.
These are representative of hot-rolling limitations, only. Refining operations, such as annealing, cold-rolling, pickling, coating, etc., have their own size limitations, depending upon the particular equipment available.

‡ Gages Nos. 3 to 12 are rolled as wide as 72 inches or even 84 inches by some mills.

TABLE 11. GENERAL CLASSIFICATION OF SHEET STEEL PRODUCTS ACCORDING TO GRADE AND FINISH.*

- I. Uncoated sheets.
  - A. **Not pickled.**
    - 1. Not cold-rolled for surface.
      - a. Un-annealed.
      - b. Open annealed. (Commonly called "Blue Annealed.")
      - c. Box annealed. (Commonly called "One pass cold-rolled and box annealed," but its cold-rolling is mainly for flattening purposes and is not intended to smooth the surface materially.)
    - 2. Cold-rolled for surface. (Treatment includes box annealing, as a rule.)
  - B. **Pickled.** (Treatment includes either open or box annealing or both, depending upon the finish and physical properties desired, gage being a factor.)
    - 1. Single pickled.
      - a. Not cold-rolled for surface.
      - b. Cold-rolled for surface.
    - 2. Double pickled (*i.e.*, Full pickled).
      - a. Not cold-rolled for surface.
      - b. Cold-rolled for surface.
        - i. Regular.
        - ii. Automobile finishes.

Note: "De-oxidizing" is sometimes possible on finishes involving box annealing.

With numerous variations and combinations within each group and class, according to the purpose for which the particular sheets are intended, the above are marketed under various trade names and designations, principally from sheet mills, but are also made at tin mills which market tin mill black plate. Tin mills make the smaller sizes, and lighter gages usually. Tin mills do not produce open annealed and automobile finishes.

- II. Coated sheets.
  - A. **Tin plate.** (Pure tin coating; made at tin mills only.)
    - 1. Cokes.
      - a. Standard cokes.
      - b. Best cokes.
      - c. Special cokes.
    - 2. Charcoals. (Several grades of coating.)
  - B. **Terne plate.** (Lead-tin alloy coating.)
    - 1. Short Ternes. (Made at tin mills only.) Numerous different weights of coating and finishes.
    - 2. Long Ternes. (Made at sheet mills only.) Several different weights of coating.
      - a. Regular grade.
      - b. Auto body grade.
  - C. **Galvanized sheets.** (Zinc coating; made at sheet mills.)
    - 1. Regular spangled galvanized. (Various weights of coating.)
    - 2. Non-spangled galvanized. (For special purposes.)
- III. Blued sheets.
  - A. **Not pickled.**
    - 1. Steam blued.
      - a. Not polished.
      - b. Polished.
    - 2. Air blued—polished.

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* See pp. 230-243.

TABLE 11. GENERAL CLASSIFICATION OF SHEET STEEL PRODUCTS ACCORDING TO GRADE AND FINISH (Continued).

III. Blued sheets (Continued).
  B. **Pickled (before bluing).**
    1. Steam blued.
      a. Not polished.
      b. Polished.
    2. Air blued—polishing.

Note: Blued sheets, in slightly differing finishes within these classes, are made either at sheet mills or at tin mills, depending upon the gage, size and particular finish.

IV. Special grades and finishes.
  A. **Special analysis and quality.**
    1. Copper-bearing steel.
    2. Deep drawing and extra deep drawing quality.
    3. High-carbon steel.
    4. Electrical sheets.
    5. Special vitreous enameling sheets.
    6. Rustless steel (chromium alloy).
    7. Tack plate.
  B. **Special finishes.**

These involve a rearrangement of the regular treatment of the preceding standard grades; or extra cold-rolling, annealing or pickling; or extra finishing operations such as "white finish," "roller leveling," "stretcher leveling," etc.; or extra careful inspection of the finished sheets. The treatment and inspection of these special finishes are designed to produce sheets suitable for special and exacting purposes. Such sheets are usually designated by an individual title indicating the intended use, both for the purpose of identifying the finish and treatment on repeat orders, and, in some cases, for concealing the treatment which the mill has worked out for the particular purpose involved.

There are hundreds of such grades and finishes, of which the following are a few examples: Common enameling stock, milk can stock, show card stock, metallic furniture stock, auto hood top stock, auto running board shield stock, galvanized sign board stock, galvanized refrigerator lining stock.

V. Extra finishing operations. (Added to treatment of certain grades when desired.)
  A. **White finish (pickling last or de-oxidizing).**
  B. **Roller leveling.**
  C. **Stretcher leveling (i.e., patent leveling).**
  D. **Resquaring.**
  E. **Oiling.**
  F. **Liming.**

VI. Formed products.

Sheet mills produce, in black (uncoated and unpainted), painted or galvanized, numerous types of formed products, chiefly for roofing, siding and culverts, the most important of which are:

  A. **Corrugated sheets.** (Various sizes of corruptions, flat for roofing and siding, or curved for culverts, awnings, arches, etc.)
  B. **V-crimped sheets.** (Various types.)
  C. **Ridge roll, ridge angle, flashing, etc.** (plain or corrugated).
  D. **Roll roofing.**
  E. **Weatherboard siding, plain brick siding, rock face siding, etc.**

TABLE 12. MANUFACTURE OF SHEET STEEL AND TIN PLATE.

Outline of the Operations Employed in Shaping and Refining Sheet Steel Products.

Sheet Mill Products.

Operation (*In Ordinary Sequence*)	*Function*	*Grade or Finish for Which Employed*
	I. The Shaping Process.	
Hot roll.*	To shape into sheets.	All grades.
Shear to size, roughly.** (Called "Mill Shearing" because done at hot mill.)	To produce rectangular shape of commercial accuracy, removing ragged and irregular edges.	
Open pack (if ply-rolled).	To separate sheets after ply-rolling.	
	II. The Refining Process.	
	A. Ordinary Refining.	
Anneal: *** 1. Open anneal, heavy gages. 2. Box anneal, light gages.	To soften by removing the stiffening and embrittling effect of hot-rolling.	These operations, following the shaping, comprise the total treatment given to the two grades of common "black" sheets, *viz.*: "Blue Annealed" (Open Annealed), in No. 16 gage and heavier; and "Box Annealed," in No. 17 gage and lighter.
(Heavy gage sheets are box annealed when this is desirable. In this first annealing, box annealing is usually preceded by one pass in unpolished cold rolls to flatten and open annealing is usually followed by roller leveling to flatten.)		
	B. Extra Refining.	
Pickle sheets.	To remove oxide (scale) which forms on sheet during hot-rolling and annealing, thereby producing clean iron surfaces, for cold-rolling, coating, etc.	Single pickled finishes and Double (full) pickled finishes, the latter having been pickled previously in the bar or breakdown.* Also for galvanized sheets and long ternes.
Dry sheets } if sheets are not to be coated.	To remove moisture.	All pickled finishes except those limed.
Lime sheets	To neutralize any remaining acid; used in lieu of drying.	Heavy gage single pickled finishes which are not dried.

TABLE 12 (Continued).

Operation	*Function*	*Grade or Finish for Which Employed*
Coat sheets—galvanizing.	To coat with zinc.	Galvanized sheets.
Cold-roll sheets.	To improve the surface of the sheet or, sometimes, to stiffen the sheet.	All cold-rolled finishes, either unpickled, single pickled, or double pickled. On unpickled grades, of course, there is no pickling of the sheet and cold-rolling follows box annealing.
Re-anneal sheets *** (by box annealing).	To thoroughly soften and especially to remove strains or stiffness from cold-rolling.	Re-annealed grades.
Re-pickle sheets after re-annealing.	To prepare sheets for coating by providing clean iron surface.	Long ternes.
	To secure a clean "white" finish on uncoated sheets followed by drying.	White finish uncoated sheets, except where white finish is secured by deoxidizing.
Coat sheets—terne coating.	To coat with lead-tin alloy.	Long ternes.
Roller level sheets.	To flatten somewhat.	Roller-leveled finishes.
Stretcher (patent) level sheets.	To flatten all possible.	Higher standard of flatness than roller-leveled sheets.
Resquare sheets.	To make the final size exact.	Resquared finishes.
Oil sheets.	To coat lightly with oil for protection against quick rusting.	Oiled finishes.

III. **Inspection.**

Final inspection of coated sheets takes place immediately after the coating operation.

Final inspection of highly finished uncoated sheets takes place after all other operations have been completed but precedes resquaring and oiling when the latter are involved.

Preliminary inspections are made whenever desirable and effective.

Table 12 (Continued).

Sheet Mill Products (Continued).

IV. Forming and Painting.

The forming of formed products, such as corrugated sheets, etc., is a final operation. In the case of galvanized sheets, forming takes place after the inspection which follows coating. Formed products, other than galvanized, are ordinarily made from common box-annealed sheets which are generally painted before forming.

V. Preparation for Shipment.

Preparation for shipment follows all manufacturing operations and involves: weighing, bundling, crating, boxing, marking, bracing in the car, etc., depending upon the nature of the order.

Tin Mill Products.

Tin Mill Uncoated Sheets (Tin Mill Black Plate).—These grades involve practically the same operations as sheet mill products of the same general character, except that there is no open annealing, breakdown pickling, or stretcher leveling at tin mills.

Tin Plate.—The regular refining process for tin plate, following hot-rolling, shearing and opening, consists of: pickle; box anneal; full cold roll (3 pass) to close pores and polish surface of sheet; re-anneal (box annealing); pickle; coat with tin; clean; inspect and assort; reckon (count sheets and weigh); box or otherwise prepare for shipment.

Terne Plate (Short Ternes).—Treatment similar to that for tin plate, except that the black plate usually receives less cold-rolling than tin plate and is coated with terne mixture instead of tin, of course.

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* Before hot-rolling can commence, sheet bars of the proper length and thickness must be sheared from the long sheet bars in the case of sheet mills, jobbing mills and tin mills; while, in the case of light plate mills, slabs of the proper size must be provided. Bar and breakdown pickling for double pickled sheets takes place previous to or between hot-rolling operations, respectively. Such pickling removes all scale present up to that stage and prevents this from being rolled into the steel as the rolling proceeds further.

** Mill shearing follows open annealing and hot-roller-leveling in light plate mill and jobbing mill practice.

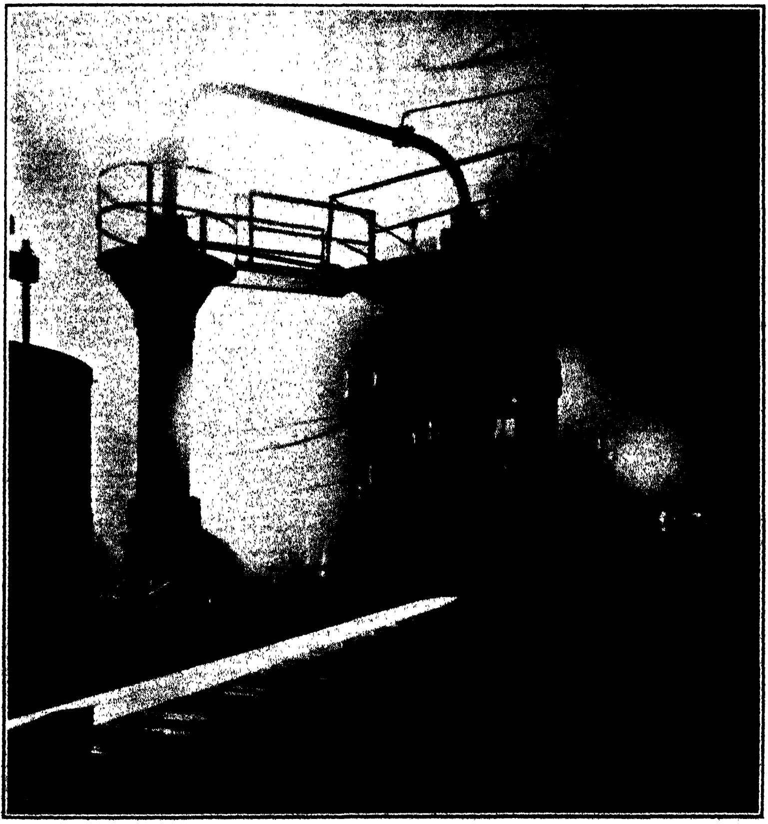
*** Deoxidizing and steam bluing are accomplished during box annealing; air bluing is done immediately after box annealing.

CHAPTER 8

THE SHAPING PROCESS.

HOT-ROLLING.

As the preceding outline indicates, hot-rolling is the first operation in the actual manufacture of all kinds of sheet steel. The steel is shaped into the form of sheets by the hot-rolling, but since the sheets leave the hot mills more or less stiff and brittle, not always flat and with their



Courtesy of Wheeling Steel Corpn.

FIG. 27.—Hydraulic shear for shearing blooms.

surfaces oxidized and none too smooth, various refining operations (such as annealing, cold-rolling, pickling, galvanizing, tinning, etc.) must follow in order to produce the numerous grades and finishes necessary for the many purposes for which sheet steel products are used.

An exceedingly small proportion of the sheet steel produced is sold just as it comes from the hot mills. Such sheets are usually designated as "un-annealed" although they might be called "hot-rolled only." Sometimes people speak of "hot-rolled" sheets in referring to the common and cheapest grades when what they mean is either "blue (open) annealed" or "box annealed" grade. It is customary and most accurate to describe the grade of a sheet by naming the treatment it receives after hot-rolling (hot-rolling being taken for granted) as, for example: "Blue Annealed, Pickled, Dried and Oiled," or, to take another finish, "Full Pickled, Full Cold-rolled and Re-annealed—Oiled".

THE FAMILY OF HOT MILLS FOR HOT-ROLLING SHEET STEEL.

Light plate mill.—Usually one two-high reversing stand for roughing and one three-high stand for finishing.

Sheet jobbing mill.—Practically the same as single sheet mill except larger.

Sheet mill.—Single mill. Two stands of two-high pull-over mills, one for roughing and one for finishing.

Double mill: Three stands of two-high pull-over mills, one roughing, one intermediate and one finishing.

Tin mill.—Single mill: One stand of two-high pull-over type which does both roughing and finishing.

Double mill: Two stands of two-high pull-over mills, one for roughing and one for finishing.

The rolls used in the above mills are all plain cylinders, that is, they have no grooves in them.

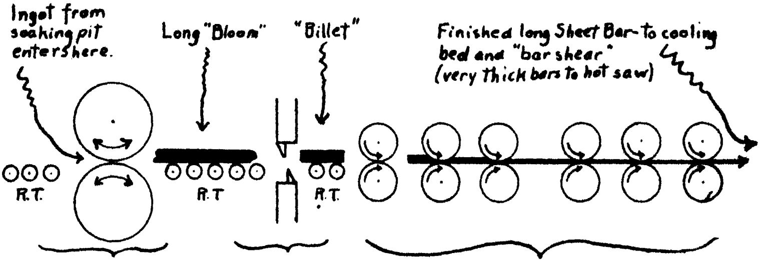
These slightly different types of mills are designed and operated to suit best the production of certain gages and sizes (see p. 93). However, there is a broad latitude in the field of each and they may roll outside their usual gage range in special cases.

All sheets are rolled from bars, called "sheet bars," except those heavy sheets produced on light plate mills, the latter rolling from slabs instead of from sheet bars.

Sheet bars are uniformly about 8 inches wide. They are made direct from the ingot, usually, from a single heating of the ingot in a bar mill.

The practice in rolling sheet bars varies, of course, but one method is, fundamentally, as follows:

The ingot, just stripped from its mold and still very hot, is placed in a heating furnace called a "soaking pit" and brought up to a uniform high temperature for rolling.



Blooming Mill (Reversing) 6-grooved, open passes. Reduces ingot into bloom.

Billet Shear Crops end off bloom and cuts it into billets.

Bar Mill Proper (tandem line). All but last stand: grooved, closed passes. Last stand of rolls: straight, finishing pass. Reduces billet into long sheet bar. Long sheet bar cut up for rolling into sheets.

FIG. 28.—Skeleton diagram of a sheet bar mill.
(Section-length of mill condensed.)

The ingot is then passed back and forth in a stand of reversing rolls in which are grooves of different sizes, called a "blooming mill," until it has assumed the shape of a "bloom," in this case about 8 inches wide and from 3 to 4 inches thick, the length depending upon the size of the ingot used.

This long bloom, while still white hot, is cut into shorter lengths called "billets" after the front end of the bloom has been cut off and discarded—called "cropping" the bloom. This bloom cropping is done because the front end of the bloom has

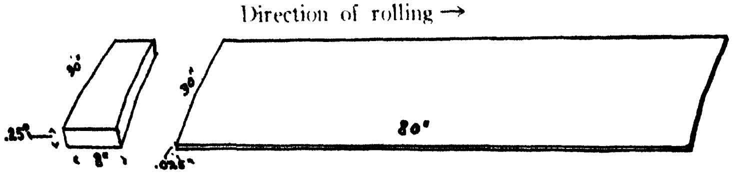
Courtesy of Wheeling Steel Corpn.

FIG. 29.—Sheet bar mill.

become "fish-tailed" in rolling and also contains the "pipe" of the ingot. The pipe is a cavity which forms near the top of the ingot during cooling. Sometimes the pipe occurs low in the ingot and this cropping does not remove it all, so that sheets rolled from the steel containing the pipe are what is called "laminated," that is, composed of two layers which will pull apart. The inside surface of the pipe is generally oxidized and therefore will not weld together in subsequent rolling. The pipe existing in a billet is spread out and extended as further rolling progresses. Laminated sheets also come from large blowholes, another type of cavity found in ingots, for substantially the same reasons. The last billet also is discarded because its end is irregular and fish-tailed.

This shearing is quickly done and the billets, still retaining rolling heat, are promptly fed to the bar mill itself, which is a tandem series of rolls in which, by means of closed "tongue and groove" passes, the width of the piece is constantly maintained the same—about 8 inches—but the thickness is progressively diminished by each stand of rolls.

The finished long sheet bar is about 60 feet long, about 8 inches wide and as thick as the length and thickness of the sheet to be made from the bar requires, plus allowance for scrap and other contingencies.



Sheet bar 0.25" thick Sheet 0.025" thick rolled from this bar

FIG. 30.—Sketch illustrating sheet sizes resulting from sheet bar.

To provide a bar of the proper size for the hot mills to roll into sheets, these long sheet bars are then sheared to shorter lengths as long as the width of the sheet to be rolled, plus scrap allowance. Since the long side of the bar is fed to the rolls in sheet rolling, the 8 inch dimension of the bar becomes its length, so far as sheet rolling is concerned.

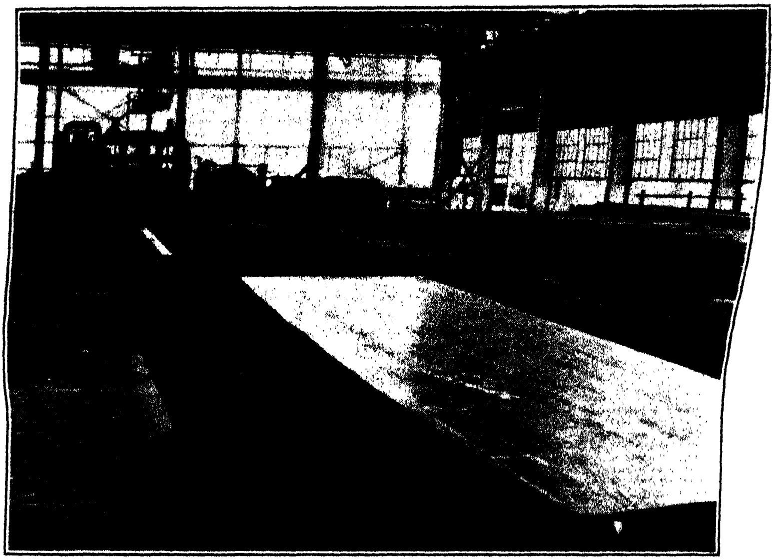
For example, disregarding the allowance for side and end trimming, etc., a sheet bar ¼ inch (0.25") thick x 30 inches long x the usual 8 inches wide could be used to make a sheet .05 inch thick x 30 inches wide x 40 inches long, or .025 inch thick x 30 inches wide x 80 inches long and so on. (See Fig. 30.) Since the 8-inch dimension of the sheet bars is fixed, the length of a sheet to be rolled from a given bar thickness may be computed as follows:

	Bar thickness	sheet thickness	sheet length	bar width
Assume	0.25"	0.025"	X	8"
then	0.25" ÷ 0.025"		equals	X ÷ 8
and			X equals 10 times 8	
therefore		Sheet length is 80" in this case		

LIGHT PLATE MILL.

Light plate mills roll from slabs, not sheet bars. Slabs are rectangular chunks of steel of which the width is considerably more than twice the thickness; they are wider, thicker and shorter than sheet bars and are made in slabbing mills.

The slab is heated very hot and the rolling into the plate or sheet is finished without reheating. The slab is removed from the slab-heating furnace and deposited at the roughing mill with the aid of mechanical devices, since it is very heavy. The scale on the surface of the slab (from heating) is partly removed either by brushing with a wire brush or by directing a stream of water against it, causing steam explosions which blow off the scale. It is then roughed out and finished as indicated in the sketch shown in Fig. 32. A dial indicates the spacing between the rolls and thus shows the gage of the piece being rolled—not very precisely, however.



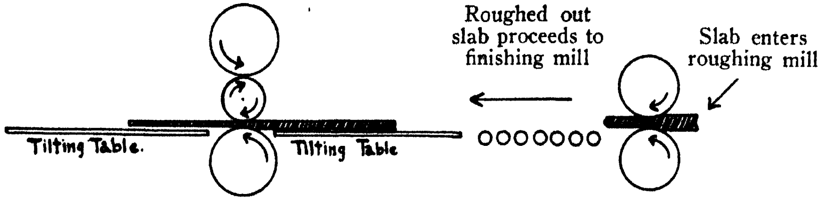
Courtesy of Youngstown Sheet & Tube Co.

Fig. 31.—Plate mill: Rolled plate or sheet travelling over cooling table toward shears.

Sheet Mill. (See footnote p. 106.)

The sheet mill process of hot-rolling is much more complicated than that of the plate mill because of the thinner gages worked. The tonnage output per mill is relatively small and the man power expended is relatively great. As previously stated, sheet mills roll from sheet bar.

The stands or sets of rolls are not arranged in tandem, but are placed side by side in trains, several being driven by the continuation of the drive shaft of one engine. Formerly steam engines were used entirely, but electric motors are rapidly replacing these, driving fewer mills each.



Three-high finishing mill.

Top and bottom rolls driven. Top and middle rolls movable. Middle roll rests alternately against top and bottom rolls, which thus alternately "back-up" or reinforce it.

The piece passes in one direction between bottom and middle roll, then it is raised by means of tilting table and passes back between top and middle rolls, then is lowered to repeat the operation until finished.

Rollers to return piece to roughing mill and to convey it to finishing mill.

Two-high roughing stand, reversing. Slab is first rolled out as long as sheet is to be wide, then the piece is turned at right angles and roughed out in length.

FIG. 32.—Diagram of a type of light plate mill.

(One two-high reversing roughing stand. One three-high finishing stand)
(Single sheet rolled, never multiple layers. All rolls cooled with water spray)

The sheet mill hot-rolling unit (single mill) and crew may consist of (see Fig. 33, opposite):

Equipment.

One pair furnace (for heating bars or "pairs")

One sheet furnace with 2 or 3 compartments (for reheating breakdowns and packs)

One soft mill (for roughing or "breaking-down" bars)

One hot mill (for finishing sheet rolling)

One doubling stamp (for doubling packs)

One shear (for mill shearing)

Crew.

Roller
Roller's helper
Pair heater
Heater (sheet)
Heater's helper
Rougher
Second rougher
Doubler
Matcher
Catcher
Shearman
Shearman's helper
Openers

Soft mill, or roughing mill—Characteristics:

Rolls can be spaced more than one inch apart and chalk marks on spanner wheel, or sometimes a dial, indicate the spacing of the rolls.

Usually both rolls are driven, in which case the top roll is coupled to drive shaft with a universal joint and this is called a "balanced" mill, because the top roll can be raised and lowered at will by the screw mechanism.

Sometimes the top roll is not driven and in this case the mill is called a "jump" mill because the top roll jumps up and strikes the screw bearing when the piece enters the mill.

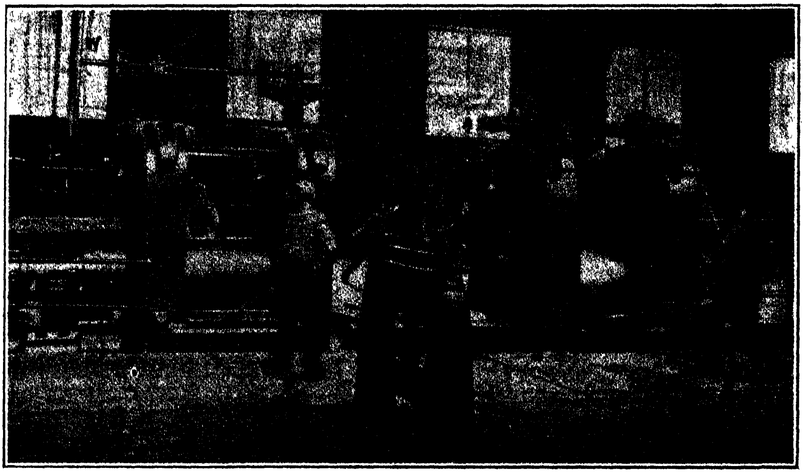
Rolls used are old finishing rolls the chill of which is worn off, or low-chill cast iron rolls. Water flows over them constantly, keeping them at about uniform temperature, consequently these rolls are turned straight, *i.e.*, with no curvature in their surfaces. The water loosens bar scale by seeping into the scale and exploding as steam.

Function: To reduce the bar from the thickness it had upon leaving the bar mill down to above ¼ inch thick or less so that it may be worked on the hot mill. Also to remove bar scale by action of water.

"Soft Mill"
or
Roughing Mill.

Stamp for
doubling

"Hot Mill"
or
Finishing Mill



"Rougher" breaking down bars, *i.e.,* "pairs," on soft mill.

"Roller" finishing pack of sheets on finishing mill, *i.e.,* hot mill.

FIG. 33.[1]—Illustration of sheet mill (single mill).

A—Spanner wheels attached to screws. *B*—Screw levers notched in spanner wheels. *C*—Spanner bar connecting screw levers, makes spanner wheels turn screws the same on both sides. *D*—Water pipe, from perforations of which water drops on rolls of soft mill. *W*—Wheel to operate screws of soft mill.

Hot mill, or finishing mill—Characteristics:

Rolls cannot be spaced much more than ¼ inch apart. One complete revolution of the screw would change the distance between rolls by one inch, but the screw lever is not made to be moved much more than ¼ of a revolution.

Position of screw lever indicates approximate spacing between rolls.

Only the bottom roll is driven. The top roll rotates by friction. The "drag" of this top roll on pack passing through helps to keep sheets from sticking together.

No water is used on the surface of the hot mill rolls (because the piece being rolled is too thin and because of the ply rolling being done) and consequently the rolls become very hot—around 700° to 775° F.

Rolls used are surface-chilled cast iron. They are turned on a lathe so that the roll surface is very slightly concave or "hollow" in the middle. This is because the heating and cooling of the rolls causes them to expand and contract which prevents the surfaces from being maintained uniformly straight across. Since they cannot be kept straight, the only alternative is to keep them slightly "hollow" or concave. If they become convex or bulged out in the center, the sheets would not be flat or rolled properly.

[1] Courtesy of American Sheet and Tin Plate Co.

Function: To reduce bars or breakdowns from a thickness of about ¼ inch and finish the rolling to the final thickness and length desired. At the finish, the sheets are usually in packs consisting of two or more layers.

SHEET JOBBING MILL.

The jobbing mill rolls from sheets bars. (See Fig. 25, p. 85.) It is practically the same as a sheet mill, only larger and equipped with special labor-saving devices to assist the crew in handling the heavier and larger bars and sheets it works. Its product being only heavy gages, no doubling is done, consequently it has no doubling stamp.

It consists of two stands, a soft mill for roughing and a hot mill for finishing.

TIN MILL.[1]

The tin mill is the little brother of the sheet mill and is similar except that it has only a single stand of rolls, a hot mill quite like that of the sheet mill. Having no soft mill, all rolling, both roughing and finishing, is done on the hot mill. (See Fig. 59.)

It rolls from sheet bars, of course. Since its finished sheets (called tin mill black plate) are all in relatively small sizes and generally in light gages, thin bars are always used, seldom exceeding about 5/16 inch in thickness. This explains why roughing down of the bars can be done on the hot mill. The bars are heated in a furnace of the same general type as the sheet furnace.

Courtesy of Wheeling Steel Corpn.

FIG. 34.—Hot-rolling sheets. Sheet mill: Close view of hot mill. Roller (at right) rolling pack on finishing mill. Rougher (at left) ready to "break-down" bars on roughing mill.

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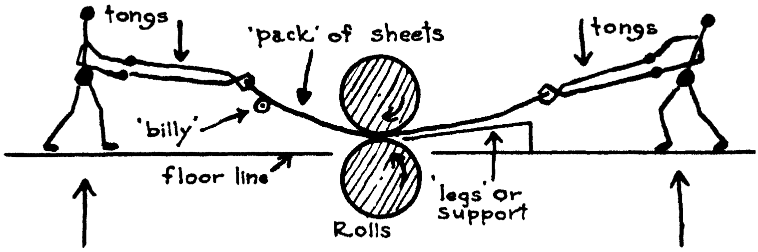
[1] The above references to sheet mills and tin mills contemplate the standard "single mill" type. There are numerous "double mills" in operation which have an extra mill in the rolling unit. This arrangement increases the output of the finishing mill but does not alter the principles of operation.

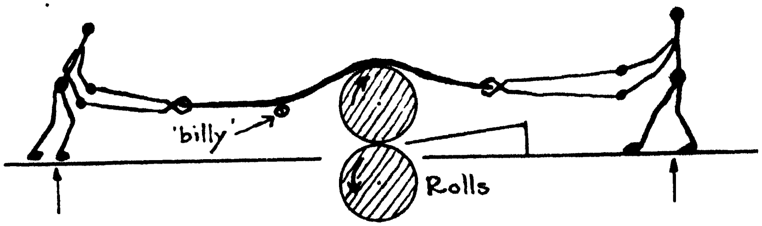
(1) Passing "pack" of sheets through finishing hot rolls.



"Catcher," receiving pack which is passing through the rolls.

"Roller" starts pack through the rolls, resting it on the "legs," and continues to guide it as it pulls away from him.

(2) Returning the "pack" of sheets for another pass.



"Catcher" pushes pack back to the *"Roller"* over the top roll, the rotation of which helps to carry the pack along. To start the pack over the top of the roll, he obtains leverage on a small idle roll or "billy."

"Roller" receiving pack from the *"Catcher,"* and helping to pull it back so that he can again pass it through the rolls.

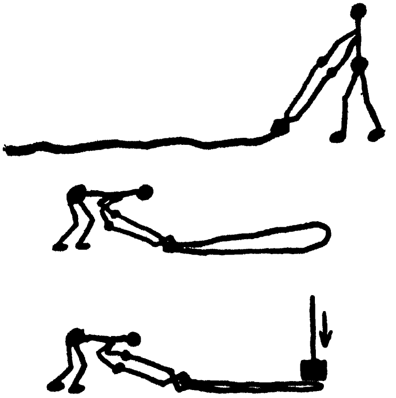
FIG. 35.—Sketches of hot mill operations (two-high, pull-over sheet mill).

After either single sheets or packs have been rolled so thin that they lose their heat rapidly and will not properly roll out longer, then the proper number of sheets, two, three or four, are placed on top of each other. This is called "matching" and the pack so formed is then reheated and rolled again. When very thin sheets are rolled (as at tin mills), packs themselves may be matched.

"Matcher," placing either sheets of packs on top of each other, or "matching."

FIG. 36.—Matching (to form a pack of sheets, or to rematch packs).

After a "pack" consisting of two or more layers of sheets has been rolled out so thin that it loses its heat rapidly and will not "pull" or roll out longer properly, then it may be "doubled."



"Doubler" grips pack with his tongs, after first pulling each sheet apart to see that it is not sticking or welding together, and then—

doubles pack over on itself, then he takes a fresh grip on both loose ends of pack and—

places folded end under broad steam hammer which is wider than pack and stamps fold down flat. The pack is then ready for reheating and rolling.

(Machines to do this work, called "mechanical doublers" are today largely used at tin mills where the packs are short, but the hand doubling method is still used at sheet mills where the packs run longer.)

FIG. 37.—Doubling. (See also Fig. 60.)

The rolling practice varies slightly from sheet mill practice, being suited to the light gages and small sizes habitually rolled at tin mills. The preponderance of tin mill output is "double iron" and "double-double iron."

THE HOT-ROLLING PROCESS AT SHEET AND TIN MILLS.

The practice in rolling heavy, large sheets on light plate mills has been discussed briefly on page 103 and is relatively simple compared with the practice of hot-rolling as employed on sheet and tin mills.

No further mention will be made of jobbing mills, for the sake of brevity. The reader may regard the jobbing mill as a large sheet mill rolling only heavy gages, requiring no doubling and never rolling more than two thicknesses at a time.

The art of hot-rolling on sheet mills and tin mills is very complicated and would require many years of experience and study for a thorough understanding and much space to describe it fully. However, an attempt will be made in the following pages to present its rudiments and significant phases of interest to those who work with sheet steel after it is made.

During hot-rolling, the sheet bars are generally called "pairs" because two bars are always roughed down simultaneously. At first, one

Courtesy of Youngstown Sheet & Tube Co.

FIG. 38.—Hot-rolling sheets. Sheet mill: General view of hot mill floor, showing (left to right) sheet furnaces; doubling stamp to rear; and hot rolls.

bar is passed through the rolls while the other is being handed back over the top roll to be passed through the rolls again, and so on; later on, when thinner, they are matched (placed one on top of the other) and rolled in double layer.

After pairs have been put through the roughing or "breaking-down" operation, which consists of all the rolling possible from the pair heating, usually, they are called "break downs."

The sequence of operations in hot-rolling sheets is in general as follows: more operations being required, the thinner and longer the sheets are to be finished:

Heat bars (called "pairs")	avoid excessive scaling, especially for sheets to have a fine finish.
Rough out, *i.e.*, break-down, pairs.	
Match breakdowns and roll	if final gage and size will not permit finishing in single thickness.
Re-match, or double	if cannot finish in 2-ply thickness from first heating and matching.
Re-heat pack	care is used to secure uniform heating and to avoid excessive scaling.
Roll pack	this rolling called "re-run" or "run-over."
* Re-double (double-double) or double re-matched pack	if pack still too thin to finish in very light gages.
Re-heat pack a second time.	
Roll out pack	this rolling called second run-over.
Measure pack	to see if it has been rolled out long enough. This is done whenever rolling nears completion.

---

* Re-doubling, also called "double doubling," is tin mill practice, developed for very light gages and is seldom employed in sheet mill rolling. Also, at tin mills, in rolling the gages approaching the thinnest rolled (around No. 38 gage) it is necessary to match two packs which have already been "double-doubled," in order to get sufficient thickness for finishing the rolling of such light gages.

There are numerous combinations of matching, doubling and reheating for building up the thickness of the pack as the gage becomes lighter, but the foregoing will give a general idea of the sequence of these operations.

All except the thickest sheets are ply-rolled, that is, more than one layer is being rolled at the finish.

The term "single iron," in mill parlance, describes sheets which are finished without doubling. It does not mean a single thickness. "Single iron" may have as many as three or four sheets in the final pack.

"Double iron," likewise, does not mean that only two layers are involved, but refers to packs which are folded over or "doubled" once. Double iron always has four layers or more in the final pack, sometimes eight layers.

"Double-double iron" is that which has been doubled twice and therefore always has eight or more layers at the finish, sometimes twelve and sixteen.

The number of sheets in the pack at the finish of rolling, other things being equal, increases as the gage becomes thinner. The following table will give a rough idea of this feature and may help the layman to visualize and appreciate the difficulties and complexities of ply-rolling. It should be remembered that this tabulation is only an approximate index, that there are no fixed rules and that the hot mill foreman or roller must use his own judgment as to the method to be employed after taking into consideration numerous factors, such as: the nature of the sheets being rolled, condition of the mill, gage and length to be rolled, etc.

TABLE 13.—POSSIBLE COMPOSITION OF PACK AT FINISH OF HOT-ROLLING.

Gages	Number of Sheets at Finish	How Pack Is Built Up for Finishing	Pack Called
		Sheet Mill Practice	
3–12	1	Single sheet finished if made on plate mill,	....
	or 2	Lighter gages of this range are sometimes matched in pairs if made on sheet mill.	Single iron
13–18	2	Matched in pairs.	Single iron
19–22	3	Matched in threes.	Single iron
	or 4	Matched in pairs, then doubled.	Double iron
23–24	4	Matched in pairs, then doubled.	Double iron
	or 4	Matched in fours, not doubled.	Single iron
25–28	6	Matched in threes, then doubled.	Double iron
29	6	Matched in threes, then doubled.	Double iron
	or 8	Matched in fours, then doubled.	Double iron
30	8	Matched in fours, then doubled.	Double iron
		Tin Mill Practice	
15–20	2	Matched in pairs.	Single iron
	or 3	Matched in threes.	Single iron
21–24	3	Matched in threes.	Single iron
	or 4	Matched in pairs, then doubled.	Double iron
25–26	4	Matched in pairs, then doubled.	Double iron
27–30	6	Matched in threes, then doubled.	Double iron
	or 8	Matched in pairs, doubled and re-doubled.	Double-double iron
31–34	8	Matched in pairs, doubled and re-doubled.	Double-double iron
35–40	16	Matched in pairs, doubled and re-doubled, then two such double-double packs are matched (*i.e.*, "tagged").	Double-double iron, matched or "tagged".

The following tabulation of examples of the manner in which different gages and sizes might be rolled will permit the reader to grasp the general scheme of hot-rolling. It will also serve to illustrate how variable the exact method may be, depending upon the gage, size, condition of the mill, properties desired in the finished sheets, and various other factors:

TABLE 14. EXAMPLES OF HOT MILL WORKING.

	Number of Passes Given Piece on:	
	Soft Mill	*Hot Mill*
Sheet mill—tight rolling.		
Finished pack to shear to No. 19 gage—33 inches x 120 inches.		
Heat bars (pairs).		
Roughing passes (single thickness)	3	4 or 5
Matching passes (two-ply)		1 to 3
Re-heat pack.		
Finishing passes (two-ply)		3 or 4
Sheet mill—loose rolling.		
(Full-pickled finish—auto body stock.)		
Finished pack to shear to No. 22 gage—28 inches x 90 inches.		
Heat bars (pairs).		
Roughing passes (single thickness)	1	4 or 5
Matching passes (two-ply)		2
Pickle breakdowns.		
(The pickled breakdowns are then matched in threes, the one inside breakdown having been coated with a film of charcoal by dipping in hot water containing powdered charcoal.)		
Re-heat pack.		
Finishing passes (three-ply)		4 or 5
Tin mill—tight rolling.	(A tin mill has no soft mill.)	
(Tin mills do not loose roll.)		
Finished pack to shear to No. 30 gage—24 inches x 72 inches. or smaller fractions of this size.		
Heat bars (pairs).		
Roughing passes (single thickness)		4 or 5
Matching passes (two-ply)		3
Double pack.		
Re-heat pack.		
Run-over passes (four-ply)		3
Re-double (double-double) pack.		
Re-heat pack.		
Finishing (or second run-over) passes (eight-ply)		3 to 5

Having provided a broad conception of the entire process of hot-rolling sheets, making use of tabulations and illustrations instead of literal descriptions for the sake of brevity and clearness, it will next be in order to discuss, as briefly as possible, some of the individual operations in the process which are significant from the standpoint of the user, rather than the maker, of sheet steel products.

Probably the most unique feature of sheet steel hot-rolling is that the finished piece ordinarily consists of two or more layers. As previously stated, rolling commences by passing the bars repeatedly through the rolls, one at a time. However, after the two single pieces (breakdowns) have been reduced to a certain thickness, they are not thick enough in single thickness to hold their heat sufficiently or to roll down effectively or properly—as the mill men say they will not "pull out." (See pp. 69-72.) At this stage ply-rolling must be resorted to, if the sheets are to be longer than can be secured in single thickness, which generally is the case, and the following operations are performed so as to produce a piece (called a "pack") of sufficient thickness both to retain enough heat and to provide enough body for efficient elongation and reduction of thickness during subsequent rolling.

Matching. (See Fig. 35, p. 106.) Matching consists of placing two or more breakdowns or packs on top of each other. It is always performed, except with the very heaviest gages. The layers must not overlap extensively along the sides and at the front or back. In the case of matching in pairs, the longest sheet is placed on the bottom because the friction of the undriven top roll pulls the top sheet more. When matching in threes or fours, the shorter sheets are placed inside because the middle sheets stay hotter and consequently pull out more than the cooler outside sheets.

Doubling. (See Fig. 36, p. 107.) Doubling consists of folding a pack over on itself and stamping the fold down flat. The folded end is fed to the mill so that the free, *i.e.* open, end will be at the back of the pack and permit the metal to flow back with the least possible hindrance. The sheets of the pack are always pulled apart and loosened before the pack is doubled.

Double-doubling (Re-doubling). When a doubled pack has been rolled so thin that it will no longer pull out properly, but still is not down to the gage required, it is then either matched with another pack, or, more often, doubled again; it is then spoken of as "double-double iron." In this case, the fold from the first doubling comes to the back of the pack and is always sheared off where equipment permits as at tin mills where double-doubling is largely practiced; this is done so that the back of the pack may be opened, and the sheets free to move past each other as rolling progresses. After this shearing of the end of the pack, the sheets are always pulled apart or opened before being heated for rolling again.

Other operations and features of hot-rolling which deserve mention even in a brief description of this kind are:

Measuring the Pack. A measuring stick or rod, on which the required length of the finished pack has been indicated by a mark, is provided. When the roller judges the pack to be nearly long enough, he lays the measuring stick on it; if the pack is found to be too short, it is passed through the rolls again and the measuring repeated. Care must be taken in measuring to see that the pack is full length all along the end, otherwise sheets with round corners or hollow ends are produced. After the pack has been determined to be full length, it receives no more rolling and is ready for shearing after cooling.

Polishing the Rolls. Small pieces of steel are detached from the piece being rolled and stick to the rolls. These mark the surfaces of the next pieces rolled unless removed. This "rough roll" condition must be corrected by polishing the rolls with an abrasive stone attached to a long bar, by means of which the polishing stone is pressed against the rotating roll. Polishing is done at intervals depending upon the surface finish desired in the final sheet and the "roughness" of the particular rolls.

Controlling the Shape of the Rolls. The roll surfaces of the hot mill are made slightly concave or "hollow," as it is called. When a mill starts up, it is necessary to heat the rolls gradually, starting in the center where they are the most hollow. This is accomplished either by rolling narrow scrap ends of bars or else by applying a gas flame against the rotating rolls for some time previous to the commencement of rolling. Heating the center causes the roll to expand there, and reduces the "hollowness" to a point where rolling can commence, starting with narrow widths.

The roller judges the shape of the rolls by the shape the pack assumes during rolling. If the pack has long "ears" (See p. 118), this indicates that the mill is too hollow. The pack should be almost straight across the back end, slightly concave and with only fairly small ears. The roller controls the shape of the rolls by applying steam through a jet against the center of the rolls to cool them there, making them more hollow, or *vice versa;* also he regulates a stream of water which flows over the necks of the rolls, more water cools the necks, causing the ends of the rolls to become smaller, and *vice versa.* In these and other ways, he is able to keep the rolls about the shape and temperature he wants them to be, if he is skillful, but constant attention must be given since the roll shape is always changing due to variation in the temperature of parts of the pack and of different packs, the cooling between passes and while getting a new pack from the furnace, etc.

Too much friction in the bearing around the neck of a roll will heat up that end excessively so that the necks must be kept carefully greased with a heavy grease.

Order of Rolling. When a mill starts up, after the week-end shutdown, the narrowest widths are rolled first. The widths rolled are gradually increased as the mill becomes more "full," that is, as the roll surfaces become more nearly parallel.

After sizes as wide as the mill will accommodate have been rolled for some time, the rolls become marked slightly where the edges of the pack have been continually biting into the roll surfaces and the mill is then allowed to "come down," that is, to become more hollow, and narrower widths are progressively rolled until at the end of the week comparatively narrow widths are again being rolled as at the first of the week.

Continuity of Rolling. From the above it will be seen that it is difficult and expensive to start up a hot mill after a shut down. For this reason, the operation of hot mills is always continuous during the twenty four hours of the day and night, and throughout the working week. They are only shut down over the end of the week.

Adherence of Sheets in the Pack. During all the stages of hot-rolling where two or more layers are being rolled simultaneously, which is the case during the latter part of the hot-rolling of all sheets except the very heaviest gages, constant care must be taken to prevent sheets from becoming *firmly welded together,* even in spots.

TIGHT ROLLING.

However, it is frequently desirable, especially in the lighter gages, for a pack of sheets to become what mill men call "set," that is, to adhere lightly together temporarily. At the same time, the sheets must not be tightly welded or "stuck."

Iron surfaces will not weld firmly if a foreign substance be between them. Therefore, the common and cheapest method of preventing the welding together of sheets in a pack is to cause the surfaces of the sheets to be covered with a thin film of oxide. This is done by separating, or "opening," the sheets in the pack, allowing the air momentarily to strike and oxidize the hot surfaces. This "opening" is performed whenever in the opinion of the crew it is necessary, but specifically previous to matching and doubling, and is performed by bending up a corner of the pack with tongs to loosen the edges of the sheets, then gripping the corner of a sheet with the tongs and raising this free end, holding the rest of the pack down with the foot, and so on with the other sheets of the pack. Another important function of this separating operation during hot-rolling is to loosen any "sticking" up to that time.

The foregoing applies mainly to rolling performed with a "set" pack, called "tight rolling," which is employed for all sheets except those made to take a very fine finish, such as auto body stock, etc.

The loosening or "opening" referred to here, accomplished during hot-rolling, must not be confused with the final or "cold opening" of the pack after hot-rolling is completed, which will be discussed later.

Loose Rolling.

Another and more positive means of preventing sheets from sticking tightly during hot-rolling is to place a layer of finely ground charcoal on the inside surfaces. The breakdowns, in this case, have already been pickled clean. Before rolling commences again, the breakdown (or breakdowns) to be in the middle of the pack is dipped in a bath of hot water containing this powdered charcoal; the water evaporates quickly, leaving a film of charcoal on the surfaces of the breakdown which is then matched in the middle between other breakdowns. The pack thus formed is then carefully re-heated and rolling proceeds, the charcoal layer preventing the sheets from welding together. This is called "loose rolling" and can only be performed effectively on the heavier gages, not lighter than No. 22 gage, as a rule.

This pickling and dipping of the breakdown interrupts the hot-rolling and requires extra care in other ways, so that it is more expensive than the usual "tight rolling" method. Consequently, it is only used where extra fine surface finishes are required, justifying the extra cost, as for automobile finishes, etc. This practice is confined to sheet mills; although tin mills pickle the bars for some of their highly finished grades, they do not pickle breakdowns nor loose roll, as a general thing.

Gage Control.

This is one of the greatest problems confronting the sheet steel manufacturer.

The United States Standard Gage for sheets is a "weight gage," that is, it is based upon weights per square foot, not upon measured thickness.

Sheets ordered by gage number are made to conform as closely as possible to the square foot weight of the gage in question and are checked for gage, after rolling and shearing, by comparing the actual weight of a group of sheets with the theoretical weight of that many sheets of that gage and size. The variation of actual from theoretical weight is kept within 5 percent on heavy gages, 3½ percent on medium gages, and 2½ percent on light gages, either plus or minus, based upon the weight of a group of sheets. The allowable variation for a single sheet is usually 10 percent, however. (See "Tolerances," pp. 264-265.)

If sheets are ordered to decimal thickness and it is known that gage accuracy is important, the greatest possible care is exercised in rolling, but results cannot be very exact.

In the case of sheets ordered to decimal thickness, the weight tolerances do not apply, but a different set of tolerances for thickness, based upon individual sheets and parts thereof. The proportional variation in thickness, as in the case of a single sheet on a weight basis, is greater than the variation from theoretical of the weight of a group of sheets, because the compensating factors, whereby thicker sheets offset thinner sheets, do not operate when only one sheet or a part thereof is involved.

That present commercial practice is very close work will be realized upon considering the following factors which affect the gage of the finished sheets:

Sheet bars. The bar used is of a weight per lineal foot (bar width being constant) which will produce a sheet of the desired weight per square foot in the desired length. The difficulties with the gage of sheets begin with the sheet bar, because it is not always possible to secure bars of the exact weight required for the innumerable combinations of length and gage which are ordered in sheets. Also, some variation in the bars themselves cannot be avoided and this is necessarily reflected in the sheet.

Scrap allowance. Allowance must be made for shearing off the ragged edges and irregular ends of the rolled pack. If the pack is pulled out too long, there is excessive scrap and the sheets are proportionately light in gage.

Cold-rolling and pickling allowances. Cold-rolling and pickling both reduce the gage slightly, depending upon their degree, and where these operations are to follow, this must be allowed for in hot-rolling.

Irregularity of hot-roll-surfaces. The necessary concavity of the hot-roll surfaces, together with the constant change of shape of the rolls due to heating and cooling, prevents uniformity in gage of the finished sheets.

Gaging the pack. In plate mill practice, where only a single thickness is being rolled, it is possible to know approximately the thickness being rolled by means of a dial indicating the spacing between the rolls and also to micrometer the plates or sheets during rolling. Although the latter is not very practicable and would be expensive, it can be done if necessary. However, with sheets which are finished two or more in a pack, the thicknesses of the individual sheets cannot be accurately determined from the thickness of the pack, because each sheet is sure to vary somewhat; the outside sheets (when there are three or more in a pack) being cooler, do not pull out at exactly the same rate as the hotter inside sheets, and the top sheet elongates at a greater rate than the bottom sheet owing to the "drag" of the undriven top roll.

In the ply-rolling employed in making sheets, with two or more layers in the finished pack, the only steps the roller can take to keep the gage as accurate as possible are:

1. By observing the shape of the back end of the pack—
    - A. Keep the gage as uniform as possible.
    - B. Avoid rolling the sides excessively thin, this condition being indicated by long "ears."

      (Note: The opposite condition, where the middle would be much thinner and pulled out much longer than the sides, is not likely to happen, since this would be caused by a very "full" mill, the roll surfaces being decidedly convex. Passable sheets could not be rolled on a mill in this condition and the roller would be forced to correct the extreme "fullness" of the mill.)
2. Finally, by measuring the pack, insure that it is at least the required length and not much too long.

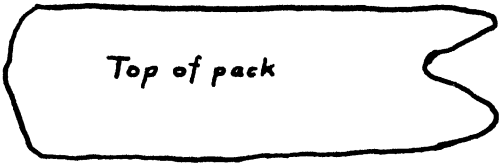


FIG. 39.—Very long "ears" on back end of pack, caused by mill being too hollow.

MILL SHEARING.

This is done immediately after hot-rolling, when packs have cooled sufficiently to be picked up by hand, and consists merely of cutting off the ragged and irregular sides and ends of the pack.

A guillotine knife shear is used. The operation is performed slightly differently at sheet mills than on the smaller shears at tin mills, but the result is the same.

The size sheared to is either approximately that of the ordered size or multiples thereof. Great accuracy is impracticable, because subsequent operations alter the shape and size of the sheet more or less. Even if desirable, great accuracy would be impossible on the larger sheets, particularly, because the packs are not always flat as they leave the hot mill. When the finished sheets must be extremely accurate to size, sheets have to be "resquared" after manufacture is complete, or practically so.

All shearing, as a rule, contemplates that the variation be over, not under, the specified size, so that finished sheets will not be smaller than ordered.

Burred Edge. What is called a "burr" on the edge of a sheet consists of a small fin of metal which is pulled down at a right angle to the sheet surface by the shear knife in the shearing operation. The burr should be slight on resquared sheets, since the knives of resquaring shears are kept very sharp and true. More or less burr is to be expected from regular mill shearing, however, since the ordinary shears cannot receive the attention warranted by the resquaring shears. When sheets are cold-rolled after shearing, any burr on the edges is flattened out, of course.

OPENING THE PACK.

After mill shearing, the sheets in the pack are separated from each other by simply loosening the edges at a corner, grasping the corner of one sheet and pulling it free, using long tongs on the big sheets at sheet mills and with the hand on the smaller sizes at tin mills.

When sheets stick badly, they must be "sworded" apart, that is, separated by striking between them with a long, heavy blade resembling a sword.

STANDARDS.

By this time, the reader has probably concluded that a great number of things can happen during the shaping process to prevent absolute perfection in the finished product. This is the unfortunate truth. Absolute perfection and uniformity cannot be expected from the sheet steel hot-rolling method. That results are as good as they are is remarkable and is due to the care and ingenuity exercised by the management and crew. In spite of the closest attention, human and mechanical errors occur, leading to deviations from an ideal standard of excellence.

Since practically all sheets contain hot mill imperfections in varying degrees, and their relative absence or presence influences the grading of the sheets, these imperfections are of interest to the user of sheet steel and the commoner and more important ones will be listed with brief comments on their cause and effect.

Hot Mill Imperfections.

Gage Variation: All sheets vary in gage more or less in the individual sheet and from sheet to sheet. (See pp. 116-118. Variation due to wrong weight bar is not a fault of the hot mill work, of course.)

Rough Rolls: Pieces of metal from pack adhere to rolls and unless polished off mark outside surfaces of pack.

Grease Pits: Grease from necks of rolls accidentally gets on pack and is rolled into outside sheet.

Round Corners: Pack not drawn out long enough and the sheared sheets are not full size, leaving corners round. Generally occurs on inside sheets which cannot be seen when roller measures pack.

Crescent or Hollow End: Same cause as above but occurs when long "ears" are drawn on pack, making end considerably curved. Sheet is scant at hollow end.

Thick End: Occurs where end of a sheet protrudes beyond a sheet which is too short, causing greater thickness in former.

Thick Edges: Pack not matched properly along the sides. Edges of sheets protruding beyond rest of pack are thicker than they should be.

Ragged Edge: Sheet slipped sideways during rolling and its rough edge is not removed when rest of pack is sheared.

Patching or Sticking: Occurs in tight rolling. Caused by welding together of sheets in spots. When sheets are forced apart in the opening of the pack, sometimes pieces of metal pull away from the opposite sheet, resulting in roughness and depressions of the surface or even holes in thin sheets. This tight welding of the sheets is caused by various things, such as: uneven heating; pack not evenly set (adhering lightly) throughout and sticks at edges of open spots; pack not opened properly during hot-rolling; too heavy draught in rolling, *i.e.*, too much pressure from rolls; etc.

Jump Seams: If sheets in a pack are free in front and tight in back during rolling, the metal is forced back from the rolls and will lap or "jump" over and crease down where pack is stuck together.

Pinching: Pinches are caused, generally, by rolls being too hollow, *i.e.*, too concave. The effect of this is to force the center of the sheets forward and to press the sides of the sheets both backward and inward, producing a creasing or pinching at the crowded point, the creasing assuming a V-shaped seam, point of the V toward front of pack.

Open Surface: Where this occurs, the surface of the sheet has small breaks in it where the metal has been torn apart. The "breaks" or pits in the surface are numerous and are closely packed together and are more or less deep, according to whether it is "light" or "heavy" open surface. Generally caused by too severe strain on the metal during hot-rolling, owing to excessive draft or to metal being too hot, causing it to pull apart instead of being compressed and elongated solidly.

Finishing Scale, or Tail Scale: Small pieces of oxide fall off outside surfaces and lodge between sheets of pack, generally near the end, there being rolled into the surface of the metal.

Furnace Dirt: Pieces of brick or furnace lining material get on packs in heating furnaces and are rolled into surface of sheets.

Pair Furnace Scale: Bars are scaled or oxidized excessively in the pair furnace and this scale, not being properly brushed off during breakdown, is rolled into the sheet.

Not Flat: *Wavy Edges.*—Pack rolled too thin on sides owing to mill being too hollow, causing extra length on the sides which assume wavy shape.

Wavy center or "corrugations."—Pack rolled too thin in center owing to mill being too full, causing extra length in the center which assumes wavy shape, being confined by the sides of the sheet which may be fairly flat.

The above are classed as imperfections in that they prevent the finished sheet from being considered absolutely perfect, but since "perfection" is a relative term and its meaning depends upon the standard by which we judge, it is necessary to caution the reader as to the interpretation of the word "imperfection" as here employed.

Since absolute perfection is impossible in the making of sheet steel and tin plate, as in every field of endeavor and particularly in bulk industries, it is necessary to refrain from even thinking in such terms. In place of this, there are certain established "standards" of excellence by which the various grades and finishes of sheets are judged. These standards are somewhat arbitrary, but nevertheless, have fairly definite boundaries. They are based upon a reasonable expectation of quality for the grade in question considering the price paid for the grade, the purpose for which it is to be used and the limitations of the sheet-making art. The standard of quality for common box-annealed sheets is different, of course, than the standard for full pickled, full cold-rolled and re-annealed sheets, the latter being considerably more expensive than the former. If buyers of sheet steel products did not permit a lower standard for less exacting purposes, the sheet maker would have to work to the highest standard in making all sheets, with the result that the average cost of sheet steel products to the consuming public would be much increased.

With the foregoing in mind, it will readily be understood that the hot mill imperfections mentioned and numerous others, as well as what will be called imperfections produced in other operations, such as cold-rolling, coating, etc., when present in a sheet do not cause this sheet to be classified as defective for the grade involved, unless the degree or nature of the particular imperfection is not customarily permissible in the standard for the particular grade.

In other words, whether or not an imperfection is a positive defect depends entirely upon the degree or extent of the imperfection and the standard of the grade for which the sheet was made. For example, open surface would have to be extremely pronounced and uniformly found throughout a lot of common box-annealed sheets before it would be classified as a defect for that grade; however, only a slight degree and moderate amount would be permissible in a highly finished grade such as prime quality in full pickled, full cold-rolled and re-annealed grade. A small round corner would pass in a Galvanized Second, but not in a Galvanized Prime sheet.

It is well for all connected with the sheet steel industry, whether as buyers, sellers or consumers, to bear in mind constantly that the excellence of the product is judged by reference to standards for the grade in question and not by comparison with absolute perfection.

CHAPTER 9.

THE REFINING PROCESS[1]

ANNEALING.

As outlined in the table on pp. 96-97, the process of refining sheet steel may be divided into two classes, viz.: "Ordinary" and "Extra."

Ordinary Refining Embraces:

Ordinary annealing: Open annealing — 16 gage and heavier.
Box annealing — 17 gage and lighter.
Ordinary flattening: Roller leveling after open annealing.
One pass in unpolished cold rolls before box annealing, usually.

Extra Refining Embraces:

Extra annealing operations.
Extra flattening operations: Extra roller leveling.
Stretcher (patent) leveling.
Pickling operations: In bar, breakdown and sheet.
Drying and liming: After pickling for uncoated sheets.
Cold-rolling: To improve the surface or to stiffen.
Coating: Galvanizing, terne coating and tinning.
Resquaring: Final, accurate shearing.
Oiling.
De-oxidizing.
Bluing.

After having gone through the shaping process of hot-rolling, mill shearing and opening, the steel exists in the form of sheets. However, in this state the sheets are more or less stiff, not always very flat and in general are not suited for the great majority of purposes for which sheet steel products are used. (See pp. 66-67.)

Since practically all sheets are used for purposes requiring them to be more workable and flatter than they generally come from the hot-rolling, most sheets must go through ordinary annealing and flattening operations after the shaping process. These operations are here called "ordinary refining" because they are included in the price of the common, basic sheet steel grades, *viz.*, ordinary blue annealed (meaning open annealed) in 16 gage and heavier, and ordinary box annealed in

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[1] Here, the reader's attention is directed to Appendix "B," "Definitions of the Terms Used Herein for Describing the Texture of Sheet Steel Surfaces," pp. 251-253; and to Appendix "C," "Definitions of Terms Relating to the Physical Properties of Sheet Steel," pp. 254-256. Before reading the following chapters, if he is not already so, it is suggested that the reader become familiar with these terms since they are employed frequently in the ensuing pages.

17 gage and lighter. When it is desired to produce something better than these common, basic grades of sheets, with regard to forming or drawing quality, surface finish, protective coating or other properties, then further refining operations must follow the "ordinary refining." These later treatments, which are in addition to the "ordinary refining" and usually at extra cost over the basic grades, are here classified as "extra refining."

The different classes of refining operations employed for sheets, *viz.*, annealing, pickling, cold-rolling, coating and supplementary operations (see pp. 96-97), will be discussed in the following chapters. Such discussion here must necessarily be incomplete, but it will be the aim to describe briefly why, where and how each is used and what the results are, in the hope that the layman may be given a general understanding of the functions of the various refining operations, their advantageous uses, as well as their limitations.

ANNEALING. (See pp. 63-68, on "Rolling.")

"Annealing" is one type of heat treatment. Other types of heat treatment are "hardening" and "tempering," and although these are practically never performed in the making of sheet steel, the following quotation from Stoughton is given to show their general distinction from annealing:

> "Hardening, Tempering and Annealing.—Only quenching in water, or in some other medium which takes the heat away as fast or faster, goes under the name of hardening. Quenching in heavy oil, melted lead, etc., cools the steel less rapidly, and makes it less hard and less brittle than quenching in water, so to this operation the name of 'tempering' is given. Cooling in the air, in sand, in the furnace, or by any other slow method, is called 'annealing.'" (Bradley Stoughton—"The Metallurgy of Iron and Steel," New York, McGraw-Hill Book Co., 1916.)

The heat treatment of metals consists of producing various changes in the physical properties of the metals by heating and cooling them in different ways. Metals are composed of small crystals which are usually grouped into larger, interrupted crystalline forms called "grains."[2] Depending upon its chemical analysis and the treatment the metal receives during and after shaping, these crystals and grains assume different sizes, forms and arrangements, whereby the physical properties of the metal are altered.

Metallography is the science dealing with the study of the crystalline structure of metals. It is carried on by microscopic examinations and by the study of magnified photographs (photomicrographs) of sections of

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[2] See note on p. 272.

the metal, the surface of which is first polished and then, frequently, etched with acid to make the structure stand out more prominently.

By means of metallography, modern metallurgists are able to observe the grain formation and crystalline structure of a particular piece of steel and from this they can fairly accurately judge certain characteristics of the steel. There are various known relationships between grain structure and physical properties. Metallography permits an accurate study of the effects of heat treatment and has contributed greatly to the enormous advance in metallurgical science which has taken place in recent years.

A thorough understanding of the heat treatment of metals is a life's work. Only the superficial aspects of the annealing of sheet steel will be touched upon here. The reader desiring a somewhat more detailed discussion will find this in Appendix "A," pp. 245-250. Those interested in complete details should consult any standard technical book on heat treatment.

The purpose of annealing steel sheets is to make them soft and ductile so that they will be "workable," that is, perform bending and forming operations easily and without breaking.

Annealing is accomplished by heating the metal to certain temperatures and cooling at certain relatively slow rates, previously decided upon, the particular method used depending upon the results desired and the character of the metal itself.

When steel is heated beyond certain temperatures, the grains change their shape, arrangement and character; when held at high temperatures for some time, the grains tend to grow larger.

The type of steel we are dealing with here is very low in carbon and is made up of 99 percent or more pure iron. The pure iron content is called "ferrite" by metallographists and the ferrite grains appear white in the photomicrographs (Fig. 40). The dark-appearing parts of the pictures shown here are principally what is called "pearlite." Pearlite is composed of alternate layers of the pure iron, *i.e.* ferrite, and a substance called "cementite." Cementite is a compound of iron and carbon. In photomicrographs of annealed, low-carbon sheet steel, such as Pictures "B" to "E," the white-appearing ferrite grains, which form the main constituent of the metal, are bounded by thin dark lines as if in a thin envelope. The pearlite appears in small, dark spots at the junctions of the ferrite grains. Slag, oxide and other foreign included matter appear very dark in the pictures, frequently within the ferrite grains, and usually in round spots or well defined streaks. (Note streak or pocket of slag near one edge of the sheet in Picture "A.")

At this point, the following quotation from Howe[8] is appropriate:

> "The lowest-carbon rivet, tube, and sheet steel, consist essentially of ferrite, for they contain, we may almost say, are contaminated by, only the small quantity of carbon, and hence of cementite, which it is difficult to remove industrially. Their cementite is tolerated rather than sought. Starting from these practically carbonless products, there is a continuous increase of carbon content, and hence cementite content, up to the white cast irons richest in carbon, consisting of about one third ferrite and two thirds cementite."

A

Thin sheet strained from hot-rolling.
(See pp. 66-67.)

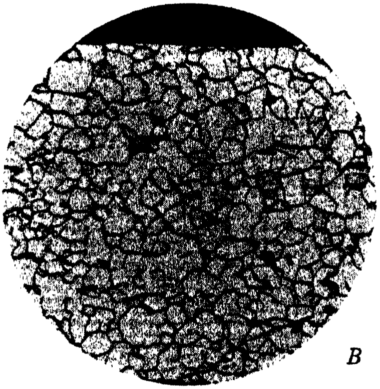
Carbon — 0.12 Percent.

Showing the strained and banded structure produced in a thin sheet by the hot-rolling and not removed by annealing. (See note p. 64.)

The ferrite is lying in long, thin plates in the direction of rolling.

The pearlite is between these plates in much the same condition.

A large slag pocket is noted near one surface, while a somewhat similar one is shown near the other surface.



B

"Normalized" Structure.

Carbon — 0.05 Percent.

Produced by open annealing above the critical range with retarded cooling in the continuation of the heating chamber of the "normalizing" furnace, resulting in an entirely new structure with medium-size, uniform, ferrite grains; all the effects of rolling having been eliminated. (See Appendix "A," p. 248, "I.")

Fig. 40.—Photomicrographs of steel sheets (longitudinal sections).

All are at magnification x-100 (100 times actual size) and are "edge views with the direction of rolling," that is, views looking into the thin section of the sheet at the side, which brings the rolling direction horizontally across the picture.

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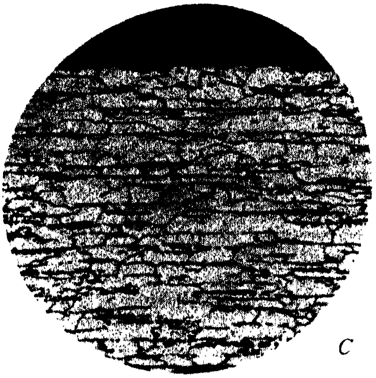
[8] Howe, "The Metallography of Steel and Cast Iron," New York, McGraw-Hill Book Co., 1916.

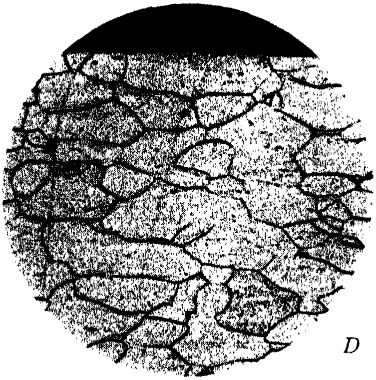


C

Open-annealed Structure.

Carbon — 0.10 Percent.

Produced by open annealing within the critical range, which does not bring about an entirely new grain structure, such as in "B." The rolling strains have been removed, but while the ferrite grains have reformed and grown to a considerable extent, they still are in a somewhat banded condition and elongated in the direction of rolling. (See Appendix "A," p. 248, II-A.)



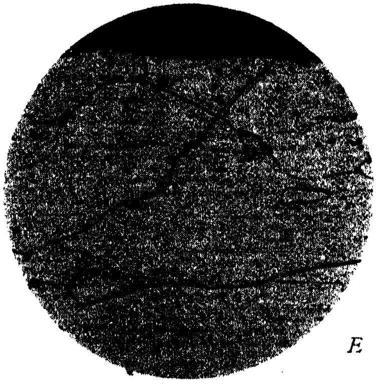
D

Good Box-annealed Structure.

Carbon — 0.06 Percent.

The grains are large, but quite regular.

This has the appearance of a dead-soft sheet.



E

Very Large-grained Box-annealed Structure.

Carbon — 0.05 Percent.

The grains are entirely too large.

Fig. 40.—Photomicrographs of steel sheets (longitudinal sections).

All are at magnification x-100 (100 times actual size) and are "edge views with the direction of rolling," that is, views looking into the thin section of the sheet at the side, which brings the rolling direction horizontally across the picture.

EFFECT OF ANNEALING ON GRAIN SIZE AND STRUCTURE. (See Appendix "A.")

As mentioned previously (pp. 65-67), in the hot-rolling of sheet steel, the grains are crushed to small size and also are flattened out and elongated in lines in the direction of rolling, called "strain lines" or "rolling lines," as illustrated by Picture "A." This condition produces stiffness and brittleness and must be corrected to make a soft, pliable and workable sheet with sufficient ductility for sheet steel purposes. Upon heating such a sheet up to annealing temperature and allowing it to cool relatively slowly, the grains of ferrite will grow and readjust themselves in the mass, so that after thorough annealing the grains will have assumed fairly uniform shapes and will have nested together in a more or less natural way, varying somewhat with the annealing method, as shown in the other pictures, instead of being pulled out in tightly meshed lines, all crushed together, as in Picture "A."

There are complicated scientific explanations for the rearrangement and growth of the grains of iron during annealing. A layman's conception of this phenomenon might be as follows: as the metal is heated, it grows more plastic or mobile and its parts become more energized and active from the absorption of heat, whereupon the grains, in effect, pull themselves together and start assuming their natural, balanced crystalline shape around a center or nucleus. Thus the "strained condition" of the metal, produced by cold working (not only true cold-rolling but also the "not-hot-enough" hot-rolling customary with sheet steel) is said to be relieved. (See note p. 64.) Under certain conditions, as the annealing process is prolonged, one grain merges with another, and if the temperature is high enough and is maintained long enough or if the rate of cooling is very slow, the grains grow larger and larger until finally they may become so big that the metal is spoken of as being "coarse crystalline" or "coarse granular." In the latter condition, a sheet of steel is useless for most practical purposes, being soft enough to bend, but having little strength or toughness. A coarse granular sheet will pull apart or break off easily, especially under sudden strain or shock.

INFLUENCE OF GRAIN STRUCTURE ON PHYSICAL PROPERTIES.

Thus, we see that there is a happy medium in the grain size of sheet steel for practical use. Skill in annealing is a large factor in suiting the sheet of steel for its particular purpose. The very small and deformed grains, as after cold-rolling or "not-hot-enough" hot-rolling, create strength accompanied by relative stiffness and brittleness. On the other hand, too large grains (from long overheating, too slow cooling, or other causes) produce a relatively weak sheet, although soft enough in simple bending. Metallurgists do not all agree as to why large grains soften and either weaken or, if very large, embrittle low-carbon steel, whereas very small grains harden and strengthen it, apparently.

RÉSUMÉ OF THEORIES ON BEHAVIOR OF IRON DURING COLD-WORKING.

Many theories have been advanced regarding the behavior of iron under stress and the following is a résumé of certain of these, expressed in a non-scientific way. This may give the non-technical reader some conception of what is supposed to take place inside the metal when it is "cold worked," that is, pulled, drawn, bent, hammered, rolled, or treated in any way which tends to distort it or change its shape while it is relatively cold.

1. When iron solidifies, it forms crystals.
2. These crystals group themselves into larger interrupted crystalline forms called "grains." (See pp. 123 and 272.)
3. The shape and properties of the grains, and hence the physical properties of the metal, may be varied by re-heating and cooling in certain ways, and by mechanical treatment.
4. The following is what some say takes place during the cold, plastic deformation of low-carbon mild steel: (See Fig. 41.)

Let "I" represent a piece of such metal, greatly magnified, composed of three grains (large squares), *1, 2* and *3;* each grain, in turn, being made up of smaller crystal units, indicated by the small squares, *a, b, c, d,* etc.

Imagine *"P"* to be a punch pressing downward over crystal unit *"h."* (Actually, such a condition could not exist because punch *"P"* would have to be so small, but this serves for illustration.)

Also, imagine the piece of metal to be supported at the points *"X"* and *"Y,"* but not elsewhere.

Further, assume that the downward pressure of punch *"P"* is so great that it distorts the metal past its "elastic limit," in other words, so great that the metal must yield to the pressure and change its shape permanently and not hold together, ready to spring back into its original shape as soon as the pressure is released, which it would do if the distortion had not exceeded the elastic limit of the metal.

Let *II, III* and *IV* represent the same piece of metal in different stages of deformation caused by pressure from punch *"P."*

Now, according to Howe, ". . .[4] in its first stages, deformation may occur close to, if not truly in the grain boundaries," so that the entire grain *2* may slip down slightly between its neighboring grains *1* and *3* as it commences to yield to the downward pressure tending to deform it. This stage is illustrated by *II.*

But, according to Beilby's amorphous cement theory,[5] as grains or crystals slip past each other, the friction causes the formation of an amorphous (*i.e.,* non-crystalline) cement along the slipping surfaces or "slip planes." This cement hardens instantly and acts as a glue, preventing further slipping along this plane.

[4] Howe, "The Metallography of Steel and Cast Iron," New York, McGraw-Hill Book Co., 1916, p. 366.

[5] *Ibid.,* pp. 373-386.

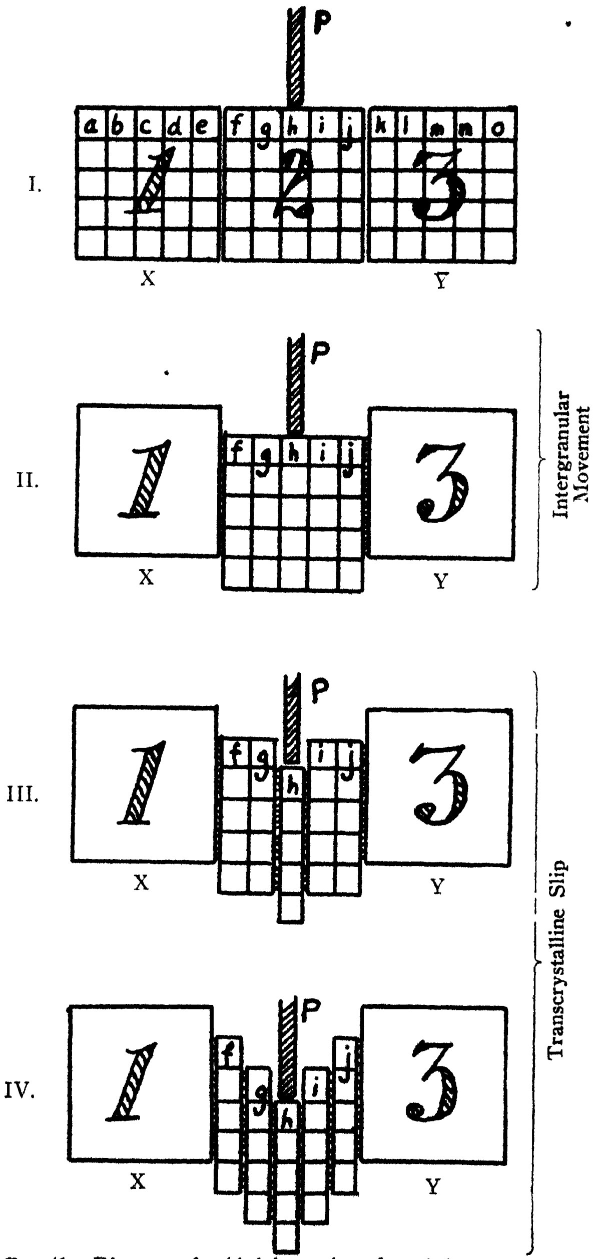


Fig. 41.—Diagram of cold deformation of steel (presumptive).

Therefore, ". . .[4] the final stages (of deformation) not only avoid those (grain) boundaries, but actually seek the grain centers." Also, it is said that the grains interlock to an extent which hinders slipping at the grain boundaries. Since the grains are retarded from slipping at their boundaries, slipping must occur elsewhere, say along the block of crystal units topped by "*h*," and this block now slides down as in *III*.

However, amorphous cement is also formed along the surfaces of the block of crystal units topped by "*h*" as it slips between its neighbors. The cement so formed fixes it tightly to the adjoining blocks topped by "*g*" and "*i*," and the pressure from punch "P" continuing and increasing, these adjoining blocks are pulled down as shown in *IV*, and so on.

5. The formation of much amorphous cement, which is assumed to be harder and stronger than the crystalline metal, is said to account for the hardening and strengthening effect of cold working. Also, the small grains caused by cold working are said to resist deformation, due to their interlocking effect being greater than is the case with larger grains.

In explanation of the strengthening effect of small grain size, it is further said that with small grains, the slips within the metal have to cross more grain boundaries filled with strong amorphous cement than with larger grains.

6. Annealing is said to restore the ductility and softness of the metal after it has been cold worked, by permitting the return of the amorphous metal, which is not plastic, to the crystalline state, which is plastic.

7. Coarse crystallization (very large grain size) causes brittleness, according to Howe, because:[5] "Assuming, to fix our ideas, that slip occurs simultaneously along the whole of any one plane, and thus creates the weak mobile state along the whole of that plane simultaneously, coarseness of grain, and consequent great breadth and length of each plane, may increase the proportion of the total potential path of rupture which is simultaneously weak. This sufficiently explains the brittleness which accompanies coarseness of grain."

8. The tendency of the metal to yield in blocks during deformation partly accounts for the roughening effect on the surface of the metal which is generally noticeable, to a greater or less extent, after deep drawing and severe bending of sheets of steel. The larger the grains, the greater such roughening effect will be, as a rule.

The amorphous cement theory, cited above, is still a theory, even though a successful one, as will be noted from the following remarks of Howe:

> "This brilliant theory[5] is extremely useful in explaining a great mass of extraordinary and hitherto unexplained phenomena. The doubts which remain today, so soon after its enunciation, as to its competence to explain the intricate phenomena discussed in the last three sections are indeed such as might be expected. They may lead us to class it rather among the precious working theories than among those firmly established."

GRAIN STRUCTURE OF VERY-LOW-CARBON SHEET STEEL. (See Appendix "A.")

With the foregoing in mind, it will be seen that in making sheet steel for very severe forming and deep drawing, a medium size, uniform grain is the aim, thus producing a sheet which is tough rather than dead soft, yet with sufficient softness to permit the steel to "flow" in the dies; with sufficient ductility to permit it to be drawn out and literally "stretched"; and with sufficient strength and toughness to resist tearing apart under the strain put on the sheet when it is severely deformed while cold. (See Picture "B," Fig. 40.) All this must be accomplished, in sheets for highly finished articles such as automobile parts, without increasing the tendency of the surface of the sheet to "pull coarse," as by the creation of a large-grained, and therefore weak, structure. Grain structures which are best suited for severe deep-drawing operations are generally produced by special methods of open annealing, frequently followed by box annealing.

For all-around purposes, where costly special annealing methods are not justified because the sheets are only expected to withstand bending or moderate forming, the annealing is designed to produce as much freedom from rolling strains and as much uniformity of grain structure as cost and other conditions permit. Ordinary open annealing, for the heavier gages, and box anealing, for the lighter gages of sheets, produce varying degrees of ductility, toughness and pliability, as will be discussed later.

The photomicrographs of Fig. 40 will give the reader an idea of the varying results effected by different annealing methods in the same general type of steel, *viz.*: very-low-carbon (0.05% to 0.12%) normal steel. While the structures shown are representative of the different annealing methods mentioned, they must not be considered typical or standard because the variations in structure from one part of the sheet to another, from sheet to sheet, and from lot to lot, are too great to permit any standardization as to grain structure.

The following comments on these pictures will differentiate briefly, and in a very general way, the nature and usefulness of the sheets represented:

Picture "A."—This sheet would not be very useful. While it would be strong in the direction of rolling, it would be weak and brittle across the grain. Also, it would be quite stiff.

Picture "B."—A sheet with a structure of this kind would be very good for drawing and severe forming. It would be strong, tough and ductile, and quite uniformly so in all directions, both with and across the grain, owing to the complete elimination of all rolling effects. It would be less soft and pliable than "D," but sufficiently so to "flow" and follow the dies reasonably well in drawing operations.

Picture "C."—An ordinary open-annealed structure of this kind would be quite strong, tough and ductile, although less so than "B." It would probably be somewhat less soft and pliable than "B" and considerably less so than "D." It would be less uniform in all directions than "B," owing to the slightly banded condition and elongated grains.

Picture "D."—The box-annealed structure shown in this picture is indicative of a sheet which would be a good soft, pliable sheet for bending and shallow stamping, with marked ductility under easily applied stresses, although it would probably "pull coarse" in a deep draw. It would not be so tough and strong as "B" and "C" but would be softer and more pliable than these. Such a structure as "D" represents what is sought in the thinner gages of sheets, which must be box annealed necessarily, and in which much toughness and strength are not generally required, since thin sheets are not expected to elongate to the same extent as thick sheets in forming operations and must "flow" rather than "stretch" in forming, as a rule.

Picture "E."—The very coarse-grained box-annealed structure shown here, while soft and pliable for easy bending, would be weak and brittle. Such a sheet would be of little value, for although it might be bent and formed to a moderate degree if this were done slowly, it would be likely to fracture under any sudden shock, or in any quick-forming operation.

In general, the annealing of sheet steel products must be adjusted to give the grain size and structure which will result in the desired physical properties in the finished sheet after considering the following factors:

1. Chemical analysis of the steel.
2. Rolling methods employed.
3. Gage of sheets.
4. Work for which sheet is intended:
   a. Nature and degree of bending, forming or drawing.
   b. Surface finish desired on completed article made from it.
5. Price the buyer considers warranted for the purpose involved.

A sheet may be properly annealed for one class of work and at the same time be improperly annealed for another purpose.

The only way to determine the suitability of a given treatment for a given purpose is actually to try a representative quantity of such sheets in a practical test. Sheets treated in one way may work all right in one shop under its particular dies and methods, but may not give satisfactory results at all for the same kind of work in another shop, due to the variations in shop methods and die construction.

Patient experimentation is the only sure road to success in sheet steel forming and drawing operations. Variations in materials and practice are bound to occur even with the best workmanship and the fabricating shop generally serves its interests best by first "giving the steel a chance" and then being frank with the steel maker about any difficulties encountered.

OXIDATION OF IRON.

Iron oxidizes readily when heated in the presence of air. All steels, except certain special alloy types, are subject to this action. This tendency of iron to oxidize when hot is an important factor in the manufacture of sheet steel, especially in rolling, annealing and pickling.

When air strikes the surface of hot steel, the oxygen in the air unites chemically with the iron surface and produces a film of iron oxide. The hotter the steel and the more air present, the more pronounced the oxidation will be. When this oxide on the steel surfaces is quite thick (as is the case with most common steel products) it is referred to as "scale" in shop language. The heavier the oxide or scale, the more it tends to loosen and drop away from the steel, especially when the piece is bent.

Hot-mill Oxide. The outside surfaces of the pack of sheets immediately after hot-rolling are covered with a fairly heavy and uniform layer of oxide which is very dark blue, almost black, in color. This hot-mill oxide is altered later during annealing and is removed, of course, if the sheets are pickled.

The inside surfaces of the pack carry much less hot-mill oxide because the air is largely excluded, and what oxide there is consists of mottled patches because when the sheets are pulled apart some of the oxide sticks on one sheet and some on the other sheet. This mottled appearance of the inside surfaces of the pack is termed "hot-mill flashing." (See Fig. 44, p. 140.)

Annealing Oxide. Annealing oxide differs from hot-mill oxide and will be described during the following discussion of annealing.

METHODS OF ANNEALING SHEET STEEL.

There are two methods employed for annealing sheet steel, *viz.:* "open annealing" and "box annealing."

OPEN ANNEALING.

This type of annealing is only employed for relatively heavy gages because it does not produce the dead softness required for most light gage sheets, because of its tendency to produce heavy oxidation, because it would distort light gages excessively and because it would not be economical for extremely light gages.

Although practical manufacturing conditions may neither permit nor warrant its perfect accomplishment, the general object of open annealing is to remove, or at least minimize, the rolling strain lines and cause the grains, which were crushed and elongated by the hot-rolling, to reform into uniform, medium-sized grains, preferably in an entirely new arrangement or structure. This would restore ductility to the sheet and tend to make it equally strong in all directions.

The essential steps in open annealing are:

1. *Place sheets in an open furnace, one or two at a time.*
2. *Allow sheets to become uniformly heated to the desired temperature. (Ordinary open annealing temperatures range around 1,400° to 1,600° F.*
3. Remove sheets from furnace.
4. Allow sheets to cool in the air.

The ordinary equipment for open annealing consists either of a simple furnace into which the sheets are pushed and from which they are removed by hand tongs; or else an open furnace with some type of conveyor running through it, on which the sheets are placed to be carried through the furnace and out into the air at the other end to cool.

During open annealing the sheets do not lie on a uniformly flat support, nor are they under any pressure, consequently at the high temperatures involved, they tend to sag and warp, which would result in their not being at all flat unless special means are taken to flatten them. Therefore, immediately after being removed from the open annealing furnace and while still hot, the sheets are passed through a machine called a "roller leveler," which flattens them out to ordinary commercial flatness.

Common open annealing creates a rather thick layer of oxide, dark blue in color, all over the outside surfaces of the sheets. For this reason, sheets marketed without further treatment after open annealing have come to be called "Blue Annealed" sheets. Standard blue annealed sheets may carry scale so thick that it tends to loosen in patches. It is possible, however, to make common blue annealed sheets with a relatively light, and therefore relatively tight, scale, but such sheets, generally, are not so thoroughly annealed as blue annealed sheets which carry heavier scale.

Blue annealed sheets, that is, sheets open-annealed last, are marketed only in No. 16 gage and heavier, as a rule. However, open annealing is used in the treatment of lighter gages when other operations follow, whenever it is desired to secure the physical properties resulting from the open annealing method of heat treatment.

There are special kinds of open annealing for sheets, designated by various names, such as "heat treating," "normalizing," etc. These embody the principles of open annealing, but usually employ higher temperatures than ordinary open annealing, going well above the critical range, that is, above about 1,600° F. Special furnaces are used; these are designed to provide more accurate control of temperature, of rates of heating and cooling, and generally, to minimize scaling. Furnaces of this type, nowadays, are frequently designed with a long cooling chamber which is a continuation of the heating chamber proper, and the relatively slow cooling effected in the diminishingly heated air of this cooling chamber, as compared with the relatively rapid cooling which takes place when sheets are immediately cooled in the open air after heating in the ordinary open annealing furnace, produces a somewhat larger grain size. This medium-large grain size promotes more pliability so that sheets annealed in this manner will "flow" in the dies when drawn while still retaining the greater part of the properties imparted by the heating above the critical range, *viz.*, the toughness and ductility required for deep drawing and a small enough grain size to avoid "pulling coarse." Such special and modified open annealing or "normalizing" treatments are used for the better grades of sheets intended for difficult drawing and forming work.

Open annealing, properly done, produces sheets which are quite uniformly strong, tough and ductile, but not so soft for bending (*i.e.*, pliable) as properly box-annealed sheets.

BOX ANNEALING.

This type of annealing is employed for all gages, but its principal use is for sheets lighter than No. 16 gage.

The function of box annealing (sometimes called "close annealing") is to soften and improve the ductility of the sheets after hot-rolling or cold-rolling, and leave them with only a relatively light oxide on their surfaces, not heavily scaled as they ordinarily would be after open annealing

Box-annealing temperatures for unpickled sheets are seldom above 1,400° F. Considerably lower temperatures must be employed in box annealing pickled sheets, frequently not much over 1,000° F.

Thorough box annealing produces a relatively large grain size and creates softness, pliability and ductility as well as a tendency toward weakness. Box-annealed sheets are inclined to "pull coarse" in drawing. By this is meant that the strain from deep drawing causes a roughening effect on the sheet surface, possibly because of the distortion of the large-grained, weak structure brought about by the localization of the stretch at those points of weakness where "coarseness" appears.

The Box-annealing Operation. The elements of the box-annealing operation are:

1. **Loading on bottom.**—A pile of sheets, several feet in height (the height varying according to the character of the sheets and other conditions), is placed on a comparatively flat, cast-steel tray called an "annealing-box bottom."

The old-fashioned annealer judged the temperature of the furnace by eye through a peep-hole, and with surprising accuracy. However, in modern practice, for most particular work, thermo-couples are inserted between the sheets at different places, usually at the top, middle and bottom of the pile, so that by means of an electrical pyrometer, the temperature of the sheets at these points may be known during annealing.

2. **Covering with lid.**—A bottomless steel box, of cast or riveted type, called an "annealing-box lid or cover" is picked up by the crane and lowered down over the pile of sheets, its edges resting all around on the extension of the "annealing-box bottom."

Courtesy of Wheeling Steel Corpn.

FIG. 42.—Box annealing: Lowering lid over pile of sheets.

3. **Sealing with sand.**—The foregoing gives a pile of sheets in a closed steel box; then sand is heaped around the juncture of the cover and lid so as to hinder air from getting under the lid into the box.

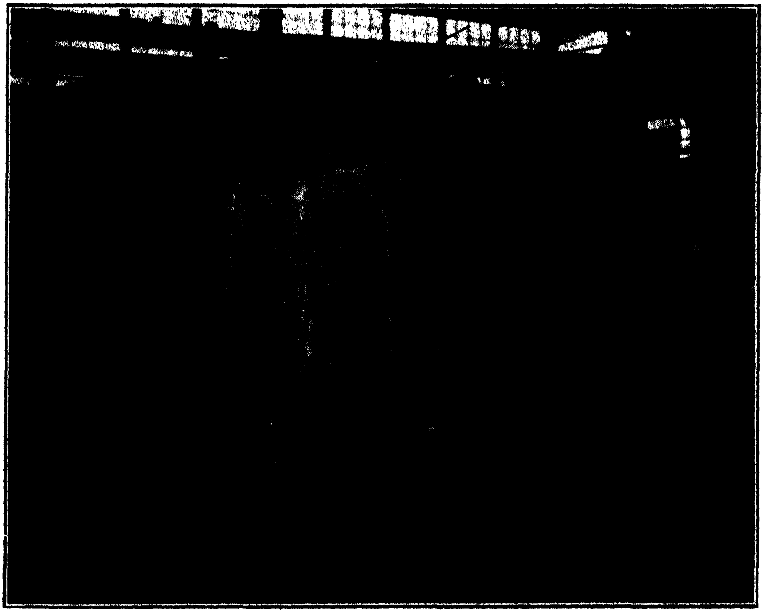
4. **Charging box into furnace.**—The full box is then mechanically pushed into an oven-type furnace and the doors of the furnace are closed.

5. **Firing.**—The furnace is then brought up to the required temperature, determined beforehand. Box annealing temperatures range from about 1,000° F. to 1,400° F., depending upon the type of sheets involved and the results desired.

6. **Soaking.**—After the furnace itself is brought up to the annealing temperature desired, which requires several hours, the stack is damped so as to distribute the heat as uniformly as possible and to maintain the furnace at the annealing temperature as nearly as can be done. In this way, the furnace is kept at the desired temperature, fairly uniformly, for a number of hours and then it is allowed to cool down, quite slowly, for several hours more. This is called "soaking" and its object is to permit the heat of the furnace to penetrate to the center and bottom

of the pile of sheets in the box so that the whole pile will be heated to the annealing temperature as uniformly as practicable; also, to allow time for the rearrangement and growth of the grains of the steel sheets, which, of course, is the function of the whole operation.

7. **Withdrawing box from furnace.**—The above-described firing and soaking requires about 24 hours, sometimes less and sometimes longer, depending upon the nature of the sheets and the annealing result desired. After this the doors of the furnace are opened and the box containing the sheets is withdrawn from the furnace mechanically.



Courtesy of Wheeling Steel Corpn.

FIG. 43.—Box annealing: Charging closed box full of sheets into furnace.

8. **Cooling and removing lid.**—After being withdrawn from the furnace, the box is allowed to cool off in the air with the lid still on. Leaving the lid over the sheets in this way prevents rapid cooling of the sheets, because the heat from the pile of sheets is dissipated only by radiation from the surface of the lid, between which and the pile of sheets is a space which acts as an insulator. Slow cooling is one of the requisites in the box annealing of light gage sheets, to produce the desired softening effect.

The presence of the lid during cooling from the higher temperatures also hinders the entry of air into the box, and thus protects the sheets from heavy oxidation, which would occur if the pile of sheets were fully exposed to the air while near the annealing temperature.

After the box has cooled in the air for several hours, the temperature of the sheets will decline to a point where it is practicable or desirable to permit the cooling to take place more rapidly. The lid of the box is then lifted off by the crane and several more hours are consumed while the sheets, fully exposed to the air, cool down near enough to atmospheric temperature to permit men to handle them with gloves. The lid may be left on as long as 40 hours after the box is drawn from the furnace, although usually a shorter time is employed, all according to various factors.

The foregoing explains why it is that box annealing requires much time. As many as 96 hours may elapse from the time the box is charged into the furnace until the annealed sheets are cool enough to be handled for further treatment, where this is not the final operation, or for shipment where box annealing is the last work to be done on the sheets. This feature is here emphasized for the benefit of those buyers of sheet steel products who, because of unfamiliarity with the facts, cannot comprehend the delays incident to sheet steel manufacture. Many treatments call for two box annealings, and in such cases, the double box annealing alone, allowing time for assembly of material, loading and unloading boxes, charging and drawing, may consume ten days or more.

Sticking During Box Annealing. Great skill must be exercised in the box annealing of sheets because numerous obstacles prevent following annealing theory exactly in practice.

"Sticking" is one of the principal difficulties in box annealing. The weight of the sheets above presses down on the sheets below and tends to cause welding together or "sticking" at high temperatures. The less oxide present on the sheets' surfaces, the more easily they weld together; consequently, pickled sheets, and especially those pickled sheets which have been polished by cold-rolling, cannot be annealed at so high temperatures without sticking as unpickled sheets. Therefore, when sheets are required to be very soft after pickling and cold-rolling, they are usually open annealed or thoroughly box annealed before pickling, so that a subsequent box annealing at fairly low temperature, after the cold-rolling, is sufficient to relieve the cold-roll strains.

At tin mills, where the only annealing method employed is box annealing, it is customary to give the first annealing, which requires high temperature and thorough soaking, after the sheets have been pickled. The result is that sticking is a regular occurrence and the sheets in the piles which are stuck must be pulled apart forcibly. First, the top of the pile is struck repeatedly with a hammer, the head of which is a round steel ball; this indents a number of sheets and tends to loosen them. The sheets are then separated by hand. The resultant indentations, when not too deep, are smoothed out in the later cold-rolling.

Coarse Granulation. (See Picture E, Fig. 40, p. 126.) Another difficulty encountered in box annealing is coarse granulation. Coarse granulation consists of the growth of excessively large grains, especially in heavy gage sheets, producing weakness and brittleness. It is caused, generally, by box annealing such heavy gage sheets at too high temperatures or for too long a time, or by cooling too slowly, or a combination of these, especially when the steel is strained.

Oxidation of Box-annealed Sheets. Although box annealing is designed to prevent the oxidation of the steel surfaces during annealing, it is only partly successful.

Naturally, there is air in the box when heating begins. This expands as the heating progresses and is largely expelled through the sand seal. The oxygen in the air remaining under the lid forms iron oxide on the sheet steel surfaces. Then, no more free oxygen remains under the lid. After this, the theory is that if the temperature reaches the neighborhood of 1,400° F., the carbon in the steel reacts with the oxygen in the oxide on the sheet surfaces, forming carbon monoxide gas which escapes through the sand seal, the iron part of the oxide being left as metallic dust. When conditions are such as to permit the foregoing to take place, theoretically, any *light* (that is, thin) oxide on the sheet surfaces is removed. This is called "clearing" the sheets. Thick oxide, however, is not readily cleared in box annealing.

It must be remembered, however, that this cleared or clean condition exists, if at all, while the sheets are at a high temperature. Later on, as the box cools, the atmosphere within it contracts and air is drawn in unless special preventive measures are taken. (See De-oxidizing, p. 141.) This new air contains oxygen which immediately forms a new oxide where it strikes the hot sheets. The result is that oxide forms progressively inward from the edge of the sheet as the air finds its way between the sheets during cooling. More oxide is formed where the air more readily enters the pile, as at the edges, also nearest the top of the pile where less weight above causes the sheets there to be less firmly pressed together than near the bottom, and at points where the pile gapes open, due to the sheets not nesting together evenly because they are not quite flat. This latter feature is one reason for giving sheets, especially large, sheet mill sizes, one pass in the cold rolls to flatten them out and permit neat, even piling before box annealing.

After regular box annealing, therefore, a sheet has a dark blue color around the edge, where the oxide is heaviest, fading into lighter blue and finally into a red or yellow tinge as it nears the center of the sheet where the oxide is thinnest, particularly if the sheet has been well "cleared." This coloring of the sheet is called the "box annealing border." If the sheet has been well cleared, the center will be a light yellow color.

The border will be deeper, that is, will extend further inward on sheets which have been toward the top of the pile, where the air enters more freely than near the bottom of the pile. Thus, different sheets from the same box will have different borders. Therefore, the size of the border need not necessarily indicate anything more about the annealing of the sheet than that for some reason more or less air reached it while it was hot.

FIG. 44.—Surface of common box-annealed sheet (not cold-rolled for surface and not pickled; hot-rolled "tight"). Surface on inside of pack, illustrating "hot-mill flashing." Dark areas are oxide (mill scale) and light areas are clean steel where the oxide has been removed because it adhered to the opposite surface when sheets were pulled apart or "opened" after being lightly stuck together in the pack during "tight" hot-rolling.

The oxide produced by box annealing is not nearly so heavy as the oxide which covers the surface of a blue-annealed (open-annealed) sheet, and frequently is not objectionable, even for some work which requires the surface to be painted. On an unpickled sheet, however, where it is combined with what remains of the hot mill oxide which is seldom completely removed or "cleared" in ordinary box annealing (see Fig. 44), the surface oxide after box annealing is sufficiently heavy to be a factor in causing wear of dies in drawing work. During drawing or stamping, any oxide on the surface of the sheet breaks up into an abrasive powder which wears the dies. On sheets which have been pickled and then box annealed, the annealing "border" is ordinarily so thin a film that it may be disregarded for most practical work.

Even on pickled sheets, however, box-annealing oxide is a factor where die wear is to be avoided as much as possible and some very particular users prefer complete elimination of box-annealing oxide, or what is called a "White Finish" sheet. This is accomplished either by picking and drying the sheets after box annealing, or by what is termed "De-oxidizing."

De-oxidizing. As previously stated, if only a relatively thin oxide is present on the sheet surfaces previously, this may be decomposed during box annealing and the sheet "cleared" of oxide while it is very hot. The purpose of de-oxidizing is to prevent oxide from forming on the sheet again during cooling. This de-oxidizing, therefore, is accomplished, where natural gas is available, by first clearing the sheet of oxide by careful box annealing and then introducing a pipe under the lid and keeping the box filled with natural gas while it cools down to slightly above 212° F., when the gas is turned off, lest moisture condense on the sheets and form rust. The presence of gas in the box prevents air from entering the box as the temperature declines, thereby preventing the formation of a new oxide. In the case of pickled sheets, which cannot ordinarily be heated up to the de-oxidizing temperature (about 1,400° F.) without causing sticking, it is necessary to prevent air from entering the box during heating as well as during cooling; consequently the gas is fed into the box as soon as firing commences and continues to flow into the box throughout the annealing.

Thick oxide cannot be removed satisfactorily by this de-oxidizing operation. Pickling is required to remove heavy scale, after which the reformation of oxide during box annealing may be prevented by de-oxidizing as above described for pickled sheets. De-oxidizing is not very effective on unpickled sheets heavier than 22 gage.

Carbon Reduction. The union of the carbon in the steel with the oxygen in the oxide on the surface (p. 139) during high-temperature box annealing removes carbon from the steel. The carbon content in the sheet of steel is thus reduced more or less during such box annealing. The reduction is more pronounced with the thinner gages of sheets. Sometimes several hundredths of one percent (or "points") of carbon are thus removed.

ALL ANNEALING REQUIRES MUCH SKILL.

The present utility of sheet steel is due in no small measure to the progress in the art of annealing it. Originally consisting merely of thrusting the rolled sheets into a furnace and pulling them out later to cool, annealing has now developed into a complicated system, calling for results unheard of years ago. Nowadays, the annealer must deliver varying degrees of temper to suit the multiplicity of forming and drawing uses to which sheets are put. Often this must be accomplished without spoiling a fine, smooth surface.

Many are the handicaps of the sheet steel annealer. Electric pyrometers, permitting exact knowledge of the temperature of the sheets during annealing, have helped him materially, also improved heating methods have aided, but absolute precision and perfection in annealing are still far distant. The operator's skill remains an important factor in determining annealing results, especially in box annealing. Without the hard-won craft of the modern annealer, sheet steel would not occupy its present wide field of usefulness.

BLUING.

Frequently it is desired to have the surface of the steel sheet coated with a layer of oxide to protect it from further oxidation and rusting when the sheet is put in use, especially where the sheet is likely to become heated in its final application, as in stoves, ranges, stove pipes, etc.

This intentional covering of sheets with the most uniform possible layer of oxide is called "bluing." There are two main classes of blued sheets: "steam blued," which are cheaper and comprise the bulk of blued sheet production, and "air blued," which are more expensive, consequently less used, but have certain advantages.

Steam Bluing. This is accomplished during box annealing by inserting a steam pipe under the lid and turning on the steam (which supplies extra oxygen) when the box is cooling down, thus forming a film of oxide all over the sheets. The steam is turned off before the temperature descends to 212° F. This oxide has a rather light blue color. Of course, the aim is to have the oxide uniform, both in color and thickness, but as previously pointed out when discussing box-annealing borders, the steam cannot penetrate exactly evenly throughout the pile, with the result that the centers of the sheets generally are not as blue as the borders. Steam bluing may be done both on unpickled and pickled sheets.

Air Bluing. After a pile of sheets has been heated up in an annealing box, and while still almost red hot, the cover is removed from the box and the sheets are picked up, one by one. Their hot surfaces, thus exposed to the air, oxidize lightly all over, the color being darker than that of the steam-blue oxide. Air bluing usually is only performed on sheets having a smooth, cold-rolled surface, on which the thin, uniform layer of oxide from the air bluing forms, creating a pleasing appearance. The sheets may be pickled or not before the cold-rolling and air bluing.

Characteristics of Blued Sheets. The oxide on blued sheets is a very poor protection against severe corroding agencies. If exposed to the weather or to much moisture of any kind, it will not long prevent the rusting of the steel beneath. Some blued sheets are better than others for protection against rusting, particularly those on which a very heavy oxide is built up on the sheet through successive steps in the manufacture. However, a blued sheet is principally useful indoors, not outdoors, for the best blued sheet will rust quickly in the weather. In general, the bluing applied to a sheet which has not been pickled is more protective than that applied over a pickled surface.

It is sometimes desirable, however, to apply the bluing over a pickled surface because the resultant blue oxide in this case is both thinner and more uniform in color than that applied to an unpickled sheet. The advantage lies in the better appearance as well as in the greater tenacity of the thin blue oxide. The thinner the "blue," the better it stays on the sheet during forming. The thicker the "blue," the more it flakes off in forming, other things being equal.

The oxide coating formed on sheets by air bluing, other things being equal, is more uniform in thickness and color all over the sheet surface than that formed by steam bluing. This is because air bluing affects the whole sheet surface equally, so that there is not the tendency, found in steam-blued sheets, for the color to vary somewhat from the edges to the center.

After they have been blued, the sheets either may be polished by passing them through cold rolls, or not, according to the grade being made. Blued sheets should be oiled to darken and to bring out the color, as well as to protect them from rusting in transit and in storage. However, whether or not they are oiled is optional with the buyer.

GENERAL REMARKS ON ANNEALING.

ANNEALING DEFECTS.

Improper and insufficient annealing are the principal annealing defects. The causes of these are various.

Stickers, i.e., sheets stuck together in box annealing, cause trouble at the mill. However, stuck sheets can only be shipped in common grades where box annealing is the final operation and even in these grades they are usually detected before shipment and therefore are seldom encountered in the trade.

Burnt edges is the term used to describe the edges of sheets on which an excessive amount of oxide has been formed during box annealing, caused by a leak in the lid of the annealing box; an imperfect sand seal; removing the lid too soon; edges of some sheets protruding from the pile owing to uneven piling, or other causes.

The term "burnt" also is applied to sheets which have been improperly heated or annealed in such a way as to make them brittle, but this is a different matter.

General Comparison of Box Annealing *versus* Open Annealing for Sheets.

Open Annealing.	**Box Annealing.**
Produces more uniform results than box annealing because each sheet is heated to practically the same temperature, owing to being heated one or two at a time.	Results vary from top to bottom of pile, because even with most careful work the temperature is higher at the top than at the bottom and with average practice there is considerable variation.
Produces strong, tough structure because temperatures are high enough either to cause an entirely new grain structure and remove hot-rolling strains, or at least to go a long way in this direction. Does not produce so much softness or pliability as box annealing because of quicker cooling, but restores ductility after hot-rolling.	Cannot go to high enough temperatures to remove hot-rolling strains entirely but permits some rearrangement of grain structure and marked growth of grains, which promotes softness, pliability and ductility, but not toughness. Removes cold-rolling strains.
Ideal for most heavy gages because it produces properties generally desired in these, also is cheap so long as sheets are heavy gage.	Dangerous for heavy gage sheets because it may produce grains in these so large as to cause coarse granulation with resultant weakness and brittleness.
Impracticable for very light gages because the scale formed would be disproportionately heavy; because it would tend to warp and buckle thin sheets too much; also, it would be expensive to feed very light gage sheets a few at a time.	Desirable for light gages because it produces the degree of softness, pliability and ductility generally desired in these and does not scale sheets heavily. Also, does not warp or buckle the sheets and is more economical for thin sheets. The thinness of a light gage sheet retards formation of too large grains, thus minimizing the danger of coarse granulation in these.

Effects Summarized.

Toughness, strength and ductility, with moderate pliability.	Dead softness, pliability and ductility with tendency toward weakness.
Uniformity of temper.	Some variation of temper in the same sheet and from one sheet to another.
Heavy scale all over sheet.	Light scale with blue "borders."
Tends to remove "rolling lines," thereby minimizing weakness across the grain of the sheet after hot-rolling.	Does not remove "rolling lines" as effectively as open annealing, but will remove strains from sheet cold-rolling.
	Permits de-oxidizing, bluing and carbon reduction.

CHAPTER 10.

THE REFINING PROCESS—Continued.

PICKLING.

The function of pickling is to remove oxide or scale from the surface of the steel sheet.

Surface oxide must be removed before the coating operation can commence in the manufacture of galvanized sheets, tin plate and terne plate. Oxide is undesirable on sheets for drawing and for some kinds of welding and painting. It must be removed to permit cold-rolling to be most effective in smoothing, polishing and closing the "pores" of sheets where a smooth, clean and dense surface is required, as for fine paint enamel finishes, tinning, electro-plating, etc. It must be removed from sheets for vitreous enameling. Therefore, pickling is a part of the treatment of galvanized sheets, tin plate, terne plate and, of course, all pickled sheet finishes.

The operation of "pickling" consists, essentially, of immersing the sheets for a period of time in hot water containing a small amount of acid, usually sulfuric acid. This weak acid solution, or "pickle bath," does not dissolve the type of oxide called "scale," but loosens this quite rapidly by quickly dissolving a little of the iron under the scale. Some believe that the scale is further loosened by the hydrogen gas generated by the chemical reaction of the acid and the iron. The type of oxide called "rust," however, is readily dissolved by the pickling solution. The result is that surface oxide, both scale and rust, may be removed and the sheets taken out of the pickle bath, washed and the acid remaining on the sheets neutralized, before the steel is materially attacked. Of course, some metal is dissolved during pickling, but only a slight amount, called the "pickle loss."

The equipment for pickling consists of racks, made of acid-resisting metal, to hold the sheets, and of wooden tanks to contain the acid solution (pickle bath) and the fresh water in which the sheets are washed after pickling to remove the acid which adheres to the sheets. There must also be mechanical means for agitating either the sheets or the bath during pickling so as to force off any particles of loosened scale which do not drop off of their own accord. Sometimes, particularly where sheets are not annealed immediately after pickling and where traces of acid might permanently stain the sheets or otherwise be objectionable, as at sheet mills, another wash tank is provided to contain an alkaline solution, such as soda ash in water.

The sheets are loaded vertically into the racks, that is, on edge. The men must see that the sheets are not stuck together. Also, the sheets must be so loaded that they will not press firmly together, otherwise the pickle cannot get between them to attack the surface and remove the oxide. To keep the sheets fairly upright and to prevent them from leaning and sagging together, large metal pins or rods are stuck at intervals into holes in the bottom of the rack. These pins extend up vertically above the sheets and break up the load into sections. Sometimes, as a further precaution with heavy sheets, metal clips, on the order of clothes-pins, are slipped over the top edge of each sheet, thus preventing the top edges from pressing together. The rack, pins, hooks and chains for lifting the rack, etc., are all made of special bronze or other acid-resisting metal.

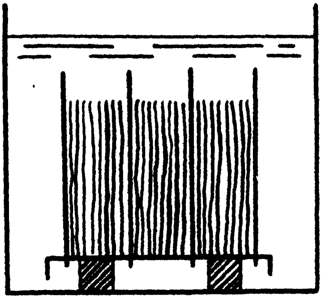


FIG. 45.—Loaded rack in pickle tank. Skeleton diagram, cross section.

(Showing sheets on edge between the pins of the rack.)

After the rack is loaded with sheets, it is lowered into the pickle tank. Then it is either moved up and down in the pickle solution (plunger type), or else the pickle solution is caused to move up and down around the sheets (surging type). The motion of the sheets, or of the bath, assists in circulating the solution over the sheet surfaces and tends to remove loosened scale.

The pickle solution generally consists of from 4 percent to 8 percent sulfuric acid in water, heated with steam so as to be quite hot but not boiling. The pickler usually pries the sheets apart with a wooden stick from time to time while they are in the pickle. From 10 to 30 minutes in the pickle is required to remove the oxide from the sheets, except where they have been pickled previously and only a light annealing oxide is to be taken off, in which case a shorter time is required. The length of time the sheets are left in the pickle depends on the extent and nature of the oxide on the sheets, the acid strength of the pickle bath, and other factors.

At tin mills (and at sheet mills where the plunger type pickler is used) it is customary to employ a second pickle tank, containing a weaker acid solution, between the first pickle tank and the wash water.

After the sheets have been pickled clean of oxide, the rack containing them is removed from the pickle tank and lowered into a tank containing cold, fresh water, where the acid is washed off.

At sheet mills, as already mentioned, a wash in an alkaline solution may follow the fresh water washing to insure the neutralization of all acid traces.

After pickling and washing, the sheets have a clean, white, iron surface and are ready for coating in the case of galvanized sheets, tin plate or terne plate, and for drying in the case of sheet mill pickled finishes, or for box annealing in most cases at tin mills.

During pickling, the steel absorbs varying amounts of the gas, hydrogen. Therefore, after being washed to remove the acid, and when not to be annealed immediately, the sheets are left for some time in a tank of clean, cold water, which tends to liberate the hydrogen imprisoned in the steel.

The absorption of hydrogen during pickling is one of the causes for the development of what are called "blisters" in sheets. Where there are small, or more rarely large, pockets in the steel, resulting from blowholes, slag inclusions and other causes, the hydrogen seeps into these pockets, which have been flattened out and elongated during rolling. If gas gets into them and expands sufficiently, they are expanded outward, causing the raised appearance on the surface of the sheet indicating a blister. As the sheet passes through a bath of molten metal, as in galvanizing and tinning, the heat causes any imprisoned gas to expand, consequently blisters often are produced in these hot-coating processes. Blistered sheets are never considered of "prime" quality.

DRYING.

Moist steel sheets, allowed to dry slowly in the air, will rust, especially clean, pickled sheets.

Therefore, at sheet mills where large sizes are made, sheets of the various "pickled finishes," which have been pickled solely in order to provide a clean steel surface for the user and not for the purpose of receiving a metallic coating, must be put through a special drying operation immediately after the pickling operation so as to prevent rusting.

A "dryer" consists of a machine in which the sheet of steel is conducted, by means of rolls and guides, through the following steps in the drying operation: (See Fig. 46.)

1. Wash in weak acid solution, to remove stain which forms immediately on pickled sheets as soon as they are exposed to the air after removal from wash water. This weak acid wash will also remove light rust stains.
2. Hot water spray, which removes acid traces.
3. Rolls, covered with absorbent cloth, which remove a large part of the water.
4. Warm, blown air jet, which evaporates more of the water.
5. Gas flame or heated oven, the heat driving off any remaining moisture.

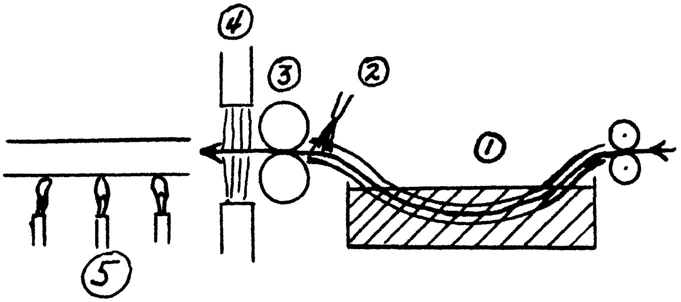


FIG. 46.—Skeleton diagram of a "Dryer." (Sheet passing through in direction of arrows.)

At tin mills, dryers are not ordinarily used, because after the first pickling, the sheets are box annealed at high enough temperatures to "clear" them of pickle stain and light rust, regardless of the fact that they may stick together during such box annealing. (See p. 138.) But in making double box-annealed, pickled, full cold-rolled, at sheet mills, the first box annealing, which is at high temperature, is performed before pickling so that the oxide on the sheet surfaces will hinder sticking. As previously pointed out, clean pickled sheets, when annealed at the high temperatures necessary to soften them sufficiently after hot-rolling, will stick badly and it is not practicable to permit this to take place with the big sizes and heavier gages made at sheet mills. As will be noticed when treatments are discussed later, the first box annealing of reannealed sheets at sheet mills precedes the first sheet pickling, the latter being followed by drying in the case of "pickled finishes." Sheets which are to receive a metallic coating are not dried after the pickling which immediately precedes coating. However, at tin mills it is customary for the first sheet pickling to precede the first box annealing, thus eliminating the necessity for drying but frequently causing extensive sticking. The foregoing describes an important distinction between sheet mill and tin mill practice and therefore is emphasized.

LIMING.

Heavy gage sheets are sometimes "limed," instead of "dried" after pickling. Liming is accomplished by lowering the rack of sheets, after pickling and washing, into a tank containing powdered lime in water kept hot by steam jets. Upon removal from this tank, the sheets, being thick, contain enough heat to dry themselves fairly rapidly and a film of lime is left on their surfaces. This lime film is moderately effective in preventing rusting of the clean, pickled metal.

DEFECTS FROM PICKLING AND DRYING.

The principal defects from pickling and drying are:

Black Patches.—Areas where pickling has not removed oxide. They are irregular in shape and black in color. Caused by sheets pressing together at those points during pickling, preventing the pickle from reaching them to do its work.

Pickle Stain.—Irregular brown and black stains, where black foam from the pickle and sometimes the acid itself has not been properly washed off in washing or drying.

Rust.—Caused by sheets being allowed to stay in air too long after pickling; or else not properly dried.

Blisters.—These can be produced by over-pickling, but there is always the question as to whether the pickling or the steel itself is responsible for blisters.

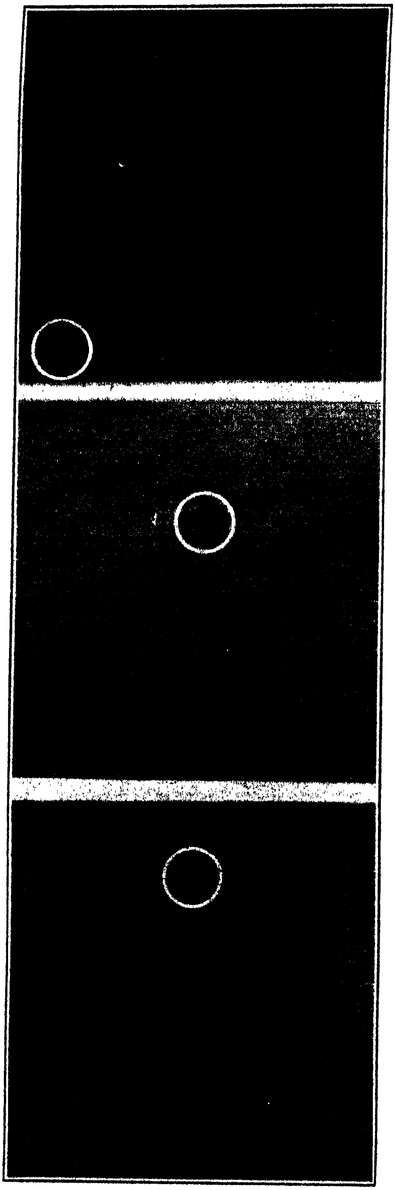
PICKLED SHEET FINISHES.

Numerous different pickled sheet finishes are produced, varying in cost and surface finish, each suited for certain classes of work. (See Group "I-B," pp. 94 and 231-234.)

Pickling affects the surface finish of sheets in three important ways: (1) it removes any oxide which lies on the surface of the sheet; (2) it removes any heavy patches or lumps of oxide (called "scale" when it is heavy) which may have been rolled into the surface and the removal, by pickling, of such embedded scale leaves more or less deep pits in the surface of the pickled sheet, depending upon the amount of embedded scale present at the time of the sheet-pickling; (3) it tends to roughen the steel surface itself, more or less according to the strength of the pickle and the duration of the pickling, by eating into the metal itself, this effect being called "etching."

When it is desired to minimize the embedded scale and consequently the pitting caused by its removal during the pickling of the sheet, the mill resorts to what are called "bar-pickling" and "breakdown-pickling" which differ from sheet-pickling in their effects. The sheet bar naturally carries fairly heavy scale and unless steps are taken to remove this, it will be rolled into the surface of the sheet during the hot-rolling of the sheet. The scale may be removed from the bar by pickling. Of course, care must be exercised against scaling the pickled bars all over again during heating for sheet rolling, or else the benefits of the bar-pickling will be nullified. For sheets of light gage, which are rolled from thin bars, bar-pickling is quite effective in minimizing embedded scale in the sheet; however, for sheets of heavy gage, rolled from thick bars, effective elimination of embedded scale is only accomplished by pickling the breakdown, which is the partly rolled-out bar (p. 110). After being pickled, the breakdowns are returned to the hot mill, where they are matched, reheated and the hot-rolling into sheets completed. Breakdown-pickling has the advantage over bar-pickling of occurring nearer the end of the hot-rolling operation, so that there is less likelihood of heavy scale being built up and rolled into the surface during the subsequent hot-rolling. As a rule, the breakdowns for light gage sheets are too thin to permit their being pickled and the hot-rolling resumed. The automobile grades of pickled sheets are always made from pickled breakdowns, which are inspected for defects which would mar the sheet surface; also these grades, being of relatively heavy gages always, are loose rolled (see p. 116). Pickled breakdowns for regular double-pickled (*i.e.*, full-pickled) finishes, not automobile grades, are not necessarily inspected nor loose-rolled.

It will readily be understood that although the heating for hot-rolling after bar or breakdown pickling must be carefully done to avoid excessive scaling, nevertheless, after the hot-rolling is completed the surfaces of the sheets carry a fairly heavy, though uniform, oxide. To remove this, the sheets themselves must be pickled, hence the term "double-pickled" for this treatment. (The term "full-pickled" is more commonly used in this sense, but "double pickled" seems to be more descriptive.) Bar-pickling and breakdown-pickling, therefore, are used for reducing the amount of scale which would otherwise be embedded in the sheet as it leaves the hot mill and thereby reduce the amount of pitting which would be caused by the removal of such embedded scale during a subsequent sheet-pickling. Thus, these preliminary pickling operations are very necessary in the production of dense, close surfaces in pickled sheet finishes. (See pp. 164-168.)



Surface (A)—Natural size.
Open Annealed (not pickled).
No. 14 gage.

Showing heavy, loose scale from excessive oxidation during open annealing. Dark areas are heavy scale adhering to sheet and light areas are where scale has fallen away, exposing steel surface.

Surface (B)—Natural size.
Double Pickled, Not Cold-rolled.
No. 13 gage.

Pickled in the breakdown as well as in the sheet.

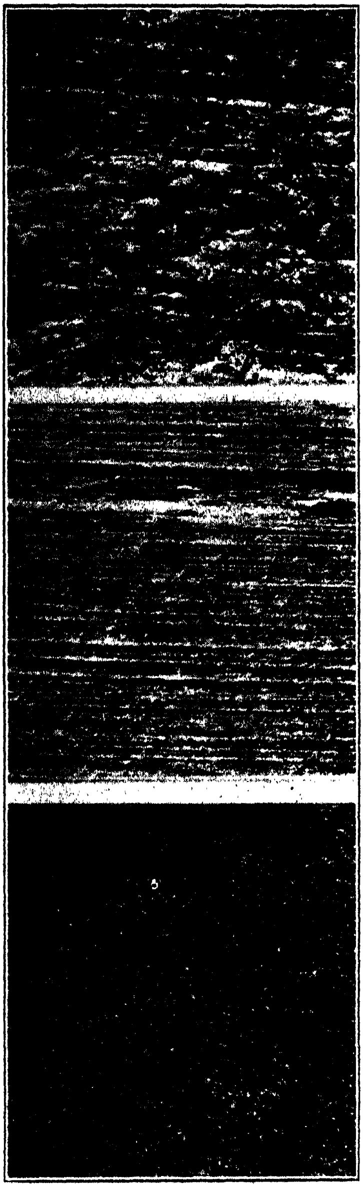
Marks from very rough hot rolls (possibly due to rough polishing of the roll surfaces) are plainly visible even in this unmagnified picture.

Surface (C)—Natural size.
Single Pickled, Not Cold-rolled for surface.
No. 18 gage.

Pickled in the sheet only, after box annealing.

Observe dark and light areas indicating remnant of hot-mill flashing marks. (See picture of "Box Annealed," Fig. 44, p. 140. Also see Surface D, "Single Pickled and Cold-rolled," Fig. 52, p. 166.)

FIG. 47.—Sheet steel surfaces—natural size. Not Cold-rolled for surface. See Fig. 52, p. 166, "Sheet steel surfaces: Single Pickled and Cold-rolled; Double Pickled and Cold-rolled."



Surface (A)—Magnified 12 times.

(After pickling to remove scale.)

Illustrating effects of removal of embedded (rolled-in) scale, and the deep scars caused by excessive oxidation ("rash open annealing mottle"); also pits where surface has opened up during hot-rolling and marks from rough hot rolls.

This surface would be classified as: very rough; very pitted and open; very porous.

Surface (B)—Magnified 12 times.

Showing that the breakdown pickling, even in this heavy gage, has prevented rolled-in scale, but illustrating marks from very rough hot rolls.

This surface would be classified as: dense, but porous and rough, with roll marks. It would be made smooth, the shallow pits and marks would be closed, but the deeper marks would be only partially closed by subsequent cold-rolling.

Surface (C)—Magnified 12 times.

Showing deep pits where embedded scale has been removed by sheet pickling and smaller pits where surface has opened up in hot-rolling. However, having been box annealed, the surface contains no pitting from excessive oxidation as in (A) above.

This surface is rough; pitted and open; porous. It would be made smooth and the shallower pits closed by subsequent cold-rolling, but the deeper pits would not be completely closed.

FIG. 47.—Sheet steel surface—magnified. Pickled but not Cold-rolled for surface.

The above photographs are magnifications (approximately 12 times) taken from within the small circle on each natural size picture directly opposite on the left page.

Single-pickled finishes.—Those pickled finishes which receive pickling in the sheet only are classified under the general head of "Single-pickled Finishes"; however, there are a number of varieties of these. (See I-B-1-a, b, pp. 94 and 231. If they are not cold-rolled for surface, they will be quite porous, owing to the removal of the oxide and the "etching" effect of the pickling, consequently dull and not polished; in addition they will contain relatively deep pits where the embedded scale has been pickled out, this condition varying considerably from sheet to sheet and from lot to lot, as a rule increasing as the gage becomes heavier.

If single-pickled sheets are cold-rolled for surface, they will be smooth and polished, but will contain considerable pitting where embedded scale has been pickled out, for the relatively deep pits thus formed will not be closed up entirely in the cold-rolling, but pitting of this character will be less pronounced, on the average, than in single-pickled sheets which have not been cold-rolled for surface.

Double-pickled finishes (i.e., full-pickled finishes).—When sheets are given either a bar-pickling (in the case of light gages) or a breakdown-pickling (in the case of heavy gages and long lengths) as well as a sheet-pickling, they are generally classified as "full-pickled," or more accurately as "double-pickled." A great number of variations of surface finish are produced in the "double pickled" group (see I-B-2-a, b-i & ii, pp. 94 and 232-234).

If not cold-rolled, the surface will be relatively dense and free from deep pits, but at the same time quite porous. If given surfacing cold-rolling, the surface will be dense, close, free from deep pits and smooth; also, the "top surface" of the sheet will either be "dull" or "polished" depending upon the nature of the cold-rolling (see pp. 168-169).

As is true of many other phases of sheet steel manufacture, the mere specification and routine performance of pickling treatment does not guarantee the production of any fixed quality of sheet. It is frequently possible for a single pickled grade to turn out to be a full-pickled standard of quality; for a bar-pickled treatment to produce in the same gage (although, perhaps, in a shorter length) a surface equal to that produced by breakdown pickling; and so on. Much depends on other factors during manufacture, such as the character of the bars used, the manner in which the hot-rolling or the cold-rolling is performed, and, of much importance, the standard to which the sheets are finally inspected. Of course, the pickling of the sheet controls the feature of surface oxide on the finished sheet, but while pickling operations greatly influence, they do not entirely control the texture of the sheet's final surface, that is whether this be dense or pitted, relatively speaking. The bar or breakdown pickling removes embedded scale and the pits and crevices thus formed have the opportunity of closing up or welding, since they are clean, while the heated, plastic metal is being hot-rolled; however, the bar may contain very deep seams which will not close even during hot-rolling, or the heating may be improperly done and build up heavy scale which will be rolled into the once clean metal, or the hot-rolling may be performed so as to tear and open up the surface of the sheets, or numerous other things may happen to offset the benefits of the bar or breakdown pickling. The sheet pickling removes the scale from the sheet and permits hard cold-rolling to close up small pits and crevices in the clean metal, but these may be too deep for the cold-rolling to close, so that the final sheet, although free from heavy oxide, and polished, may be more open and pitted than if the sheet-pickling had not been performed.

But in spite of the ever present exceptions and variations, on the average the surface texture will be determined by the treatment undergone, including the nature of the pickling, that is whether "single" or "double" pickled, and therefore the foregoing general differentiation between single-pickled and double-pickled finishes has been attempted for the purpose of giving the reader some conception of these terms.

It should be remembered, however, that the surface quality of pickled sheets, particularly those of high grade, is judged entirely by established standards for the different grades, as with other fine sheet steel products. The fact that a lot of double-pickled sheets has received the full treatment specified for the grade will not automatically cause the sheets to be considered of the standard required for that grade. They must be found by inspection to be fully up to the standard for the particular grade before they will be passed by the inspector at the mill. Numerous sheets in each lot of highly finished pickled sheets are either classified as "seconds" or sent back to the various departments to receive additional treatment or else classified as a lower grade.

Although inconsistent and somewhat confusing, it should be mentioned that bar-pickling is sometimes included in the treatment of heavy gages in single-pickled cold-rolled grades. Strictly, this should classify such a treatment as "double-pickled," but it is only done to produce in those heavy gages the same surface standard as is obtained by sheet-pickling alone, together with the rest of the treatment, in the lighter gages of that particular single-pickled finish. In heavy gages, the production of a double-pickled standard of surface requires pickling of the breakdown, as a rule.

CHAPTER 11.

THE REFINING PROCESS—Continued.

COLD-ROLLING.

As has already been indicated (pp. 67, 96-97), cold-rolling is performed on sheet steel for the following purposes, mainly:

I. To flatten the sheet by removing dents, creases and some types of "waves."

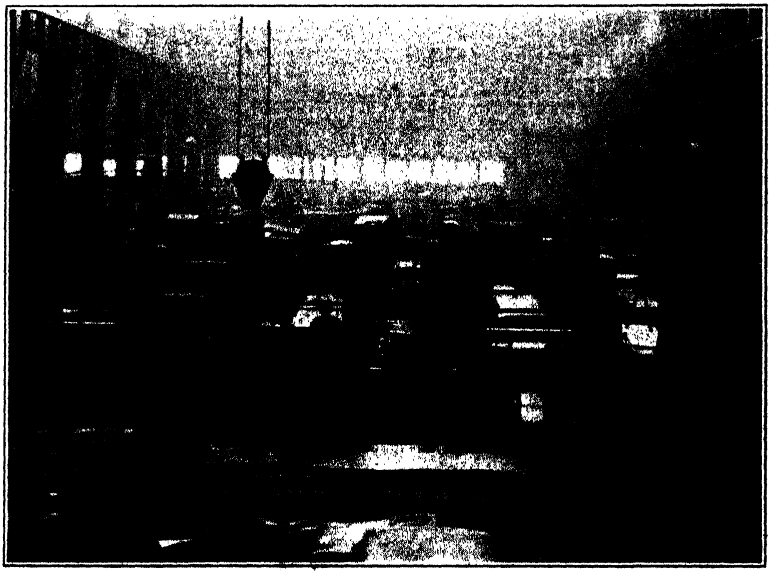
II. To improve the surface of the sheet and produce:
  A. A close and smooth surface (but not, necessarily, a glossy, polished surface) by closing the "pores" and small crevices in the surface, and by smoothing down small "high spots" or lumps.
  B. A glossy, polished surface by imparting a gloss to the sheet surface by means of highly polished rolls.

III. To stiffen the sheet through the stiffening effect of cold working.

THE COLD-ROLLING OPERATION.

Cold-rolling, as regularly performed on sheet steel today, is not for the purpose of shaping; the latter is done entirely by the hot-rolling. Actually, however, the sheets stretch appreciably during cold-rolling, more or less depending upon the amount and intensity of the cold-rolling and other factors. Nevertheless, this stretching or "pulling out" of the sheets is only a handicap to the mill, since it is not sufficient to be useful and only enough to be troublesome. The stretch caused by cold-rolling, in addition to elongating the sheet slightly, has the natural companion effect of reducing the thickness, and both these results must be allowed for in arranging the hot-rolling of sheets which are to receive much cold-rolling. For example, if a sheet is ordered 0.05 inch thick, 30 inches wide and 96 inches long in a finish which calls for two or three cold-roll passes, it must be hot-rolled slightly thicker than 0.05 inch and sheared, after hot-rolling, somewhat over 30 inches wide and considerably less than 96 inches long if it is to approach, as nearly as practicable, the size and thickness ordered after completion of the cold-rolling. There are always some variations in the dimensions of full cold-rolled sheets which have not been resquared; the length, especially, tends to run materially over that specified. The "stretch," and consequently the length variation, is inclined to be greater if the treatment calls for cold-rolling after the sheet has been softened by annealing.

The conventional cold rolls for sheet steel are of the two-high type, the two rolls being contained in housings somewhat similar to those used for the hot rolls. Screws in the top of the housings provide means of regulating the roll pressure. These screws, unlike the screws on the hot mills, are designed to be moved only by the use of considerable force, as by striking the screw bar with a wooden mallet. This is because it is desired to have the screws, and consequently the rolls, permanently set in the interval between times when they are being purposely adjusted. Cold rolls do not require adjustments so frequently as hot rolls. The rolls themselves have hard, chilled surfaces and are turned straight, not hollow. A new roll is first turned on a lathe and then is ground smooth with an abrasive stone. If a highly polished surface is desired on the rolls, a finer stone and other polishing means are utilized until the roll surfaces are mirror-like.



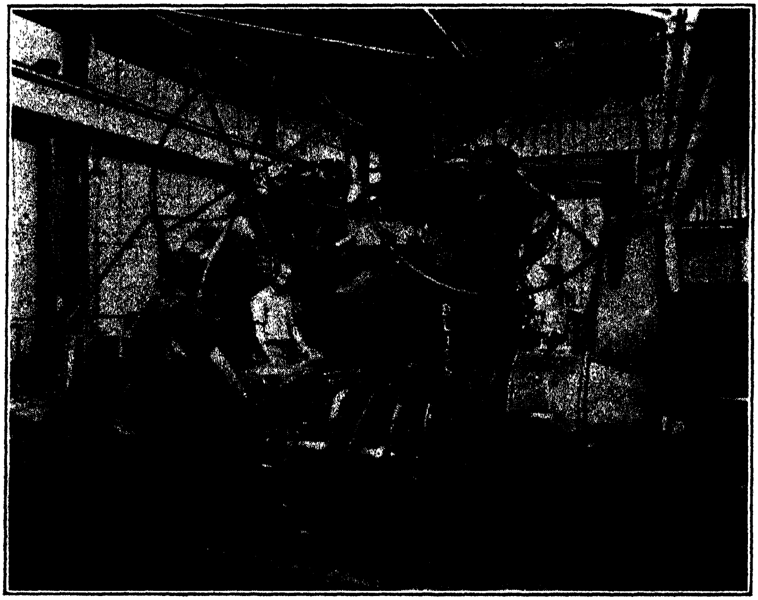
Courtesy of Wheeling Steel Corpn.

FIG. 48.—Cold-rolling (sheet mill): General view of cold rolls. Regular 2-high mills.

Four-high and cluster mills are being used now to a limited extent, particularly in the continuous cold-rolling of sheets, but here we are only dealing with conventional sheet mill and tin mill practice.

The operation of cold-rolling sheet steel appears quite simple, but actually is very complicated and requires much skill and close attention by the crew if good results are to be obtained.

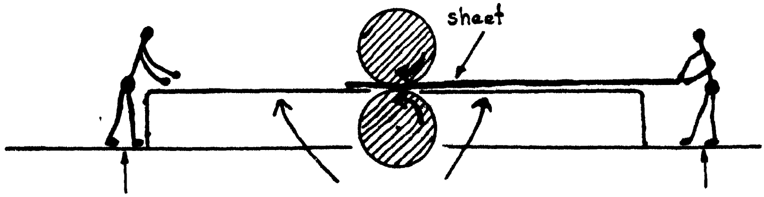
The essentials of the operation consist of adjusting the rolls properly for the particular lot of sheets to be cold-rolled and then passing the sheets, one at a time, through the rolls. A pile of sheets is placed convenient to the cold roller, who picks up a sheet, engages one end in the rolls which pull the sheet through. The catcher, standing on the other side of the mill, grasps the sheet which has passed through the rolls and places it on a pile by his side. (See Fig. 50.)



Courtesy of E. W. Bliss Co.

FIG. 49.—Cluster cold mill—for cold-rolling sheets.

The details of the operation are not the same at sheet mills and tin mills. At tin mills, the principal cold-rolling equipment consists of three stands of rolls, arranged in tandem, with belts to convey the sheets automatically from the first to the second stand, and from the second stand to the third stand, so that no one ordinarily has to touch the sheet from the time the cold roller feeds it into the first stand of rolls until it emerges from the third stand to be piled up by the catcher. In the meantime, the sheet has received the three passes called for in the treatment of full-finish tin-mill black plate, for which purpose the rolls are kept highly polished because a glossy finish is desired on the steel sheet for tinning. A few single stands (not the tandem arrangement), both polished and unpolished, are operated at tin mills to provide means for giving sheets one pass at a time. The unpolished (but smooth) rolls are to give ordinary flattening passes and for non-glossy cold-rolled finishes.



Cold-roll *"Catcher,"* ready to grasp each sheet as it slides to him. Either alone, or aided by a helper, he piles the sheets up neatly alongside of him, generally on an annealing box "bottom" because annealing frequently follows cold-rolling and in any event this heavy, flat steel "bottom" serves for lifting up the pile with the crane.

Wood-faced bench to support sheets entering and leaving the cold rolls.

"Cold Roller" pushes sheets into the rolls, one sheet at a time.

Fig. 50.—Cold-rolling (with regular, two-high cold rolls) (sheet mill practice, tin mill practice is slightly different).

In cold-rolling sheets, the sheets are not handed back over the rolls as in hot-rolling. If another pass through the rolls is desired, the whole pile of partially cold-rolled sheets is picked up (by attaching crane to "bottom" on which pile rests) and is set down on the *Cold Roller's* side. The operation is then repeated for the next pass.

The reason the tandem cold rolls are practicable at tin mills is because the bulk of tin mill production consists of light gages and short lengths, which lend themselves to such manipulation. The sheets worked at sheet mills average much thicker and longer, which circumstances, combined with other factors, interfere with the practicability of the tandem cold-rolling method for sheet mill use. A few tandem cold-roll trains are maintained at some sheet mills for special purposes. However, the great preponderance of cold-rolling at sheet mills is done on single stands of rolls, the sheets being handled separately for each pass. The catcher piles the sheets on an annealing box bottom or other support, and if the sheets are to receive another pass, the whole pile is transported by the crane around to the roller's side of the mill and the process is repeated.

Proper care and adjustment of the rolls is the essence of good cold-rolling. The necks (bearings) must be carefully lubricated, otherwise the friction from the enormous pressure generates too much heat in them, causing local expansion and uneven roll pressure. When necessary, a gas flame is burned against the center of the rolls to counteract and equalize the normal heat in the necks due to friction. Mention of all this heat may cause the reader to wonder at the name "cold rolls." It is true that the cold rolls, when working, are much too hot to touch, nevertheless they are "cold" in a metallurgical sense, inasmuch as the steel being rolled is far below red heat and is only heated by the work being done on it.

Although the surface of the rolls is extremely hard, any sharp projection, dirt or foreign substance on the sheet passing through is likely to mark the rolls, owing to the great pressure involved. It is surprising to know what innocent sounding things will mark the rolls, such as a heavy thread from canvas hand rags worn by the men; a drop of heavy grease, or any solid substance. A turned down corner on a sheet or what are called "lappers" (sheets fed into the rolls before the preceding sheet is through) will put bad marks in a polished set of rolls. Once the rolls carry marks, these are transferred to all sheets rolled thereafter. Consequently, since the rolls are constantly being marked more or less, even by the ends and sides of flat, clean sheets, it is necessary to stop rolling to grind out the marks with grinding and polishing stones at frequent intervals, depending on the severity of the marks and the character of the sheets being rolled. If the marks are too deep to be ground out with the rolls in place, the roll must be removed from the housing and turned down in a lathe, then smoothed down properly before it can be used again for first class work.

Setting the Rolls. When a new set of rolls is started up, or when a different gage or, in fact, any new lot of sheets is to be rolled, the cold roller proceeds carefully to "set" his rolls, that is, to adjust them. He sets the screws to what he thinks is about right and then passes a few sheets through the rolls. Then he observes the cold-rolled sheets closely. These may not be sufficiently flat, because it is easy to warp sheets by improper cold-rolling; or they may not have a proper, even polish; or they may be curved on the edge (sometimes this is called "camber"); or numerous other imperfections in the cold-rolling results may appear to his practiced eye. Then he will readjust his mill and try again, and so on until the results are satisfactory, after which he will proceed to roll as fast as the sheets can be fed to the mill, meanwhile making occasional adjustments to the mill when these seem necessary.

Camber. Of more than passing interest to the sheet steel or tin plate user is the feature of "camber." A sheet is said to be "cambered" when its side edges curve away from a straight line. Under this classification practically all sheets which have not been resquared as a final operation, even those which have not been cold-rolled, have more or less camber, because a condition resembling camber may be due to shearing, particularly in the case of long sheets, owing to the shear knife engaging unevenly along the side of the sheet. A slight degree of this "shearing camber" may be found in resquared sheets. However, true camber is a condition wherein the curvature is convex on one side of the sheet and concave along the other, and is an effect of cold-rolling. This is not objectionable for many purposes, but where close cutting, blanking and great accuracy are involved, allowance must be made for camber when ordering sheets, unless resquaring is specified.

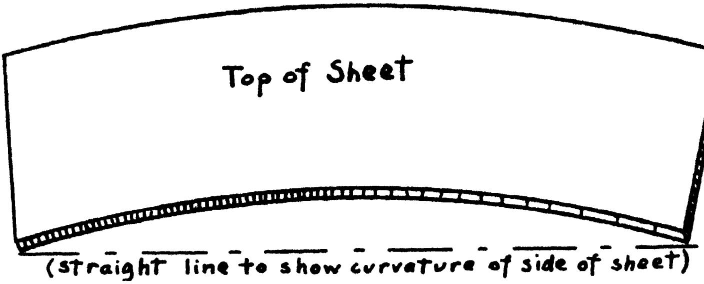


FIG. 51.—Diagram illustrating camber (exaggerated).

The effect mentioned above is produced during cold-rolling by heavier pressure on one side of the sheet than on the other, resulting in curvature of the sheet. This heavier pressure may be due, either to the rolls being set closer together on that side, or, when the cold rolls are set perfectly even, to the sheet being thicker on one side than the other when it reaches the cold rolls. In the latter case, the original fault lies in the hot-rolling, or it may be due to the fact that the sheets have been rolled in double width and slit in two before cold rolling, leaving the thicker middle, as hot-rolled, on one edge of each slit sheet. In any event, it is the duty of the cold roller to endeavor to adjust his rolls so as to keep the camber within a commercial allowable maximum. The usual commercial tolerances for camber vary according to the treatment and size, as shown in the table on p. 268. The mill must allow for camber in sheets to be resquared and the user must likewise allow for it in his cutting and piecing. For example, a sheet ordered 36 inches x 96 inches may measure exactly 36 inches in width across any section, but owing to camber, a 36 inch x 96 inch rectangle may not be secured therefrom. The camber and shearing allowance must be added to the width to insure a 36 inch wide strip with parallel sides being obtainable from the sheet. This is especially true of long sheets.

In order to give the non-technical reader a better insight into the nature and purpose of the several types of sheet steel cold-rolling mentioned at the beginning (p. 156), these will be enlarged upon below.

I. FLATTENING.

The pack of sheets, especially in the lighter gages and larger sizes, is frequently not very flat as it leaves the hot mill; furthermore, the opening of the pack after hot-rolling (and, at tin mills, the separating of sheets which have been stuck in box annealing) puts creases, wrinkles, kinks, dents, etc., into the sheets. For the removal of these and for flattening in general, cold rolling is employed.

When this flattening effect is the only object of the cold-rolling, no great amount of attention is given to the surface of the cold rolls. Since improvement of the surface of the sheet is not an object, this is not true cold-rolling according to a strict interpretation of the term.

The standard treatment, following hot-rolling, for sheet mill common box-annealed sheets is "one pass cold-rolled and box annealed" and this phrase has become a common trade designation for such sheets, frequently being abbreviated into "one pass cold-rolled," or even further into simply "one pass" sheets. Inasmuch as the one pass in the cold rolls in this case is given solely for the purpose of flattening and not with the intention of materially improving the sheet surface, such a designation, although technically exact, is practically a misnomer, and a very misleading one at that, in the writer's opinion. Many persons unfamiliar with sheet steel gain the impression that "one pass cold-rolled" sheets are a cold-rolled product in the sense of possessing a surface materially refined by cold-rolling. Ordinarily, this is not the case, the surface being typical of a sheet hot-rolled and box annealed only. Of course, even a flattening pass in the cold rolls will have some smoothing effect, however slight, but no sheet steel manufacturer will represent common "one-pass" sheets as having a true cold-rolled sheet surface. It would seem more logical, therefore, to disregard the flattening cold-roll pass entirely when referring to this grade in the trade, and call it "hot-rolled and box annealed"; or, conforming to the practice of describing sheet steel finishes by naming only the significant treatments following the hot-rolling, simply "box annealed." The term "box annealed" for such sheets would be entirely descriptive, would differentiate them from "blue annealed" sheets, and would not be misleading.

The flattening effect from cold-rolling, of course, need not be secured by a separate operation; in fact, it frequently is secured in combination with a surfacing effect where sheets are being cold-rolled for surface. The best example of this is in the case of "full finish tin mill black plate" (p. 199), the cold-rolling of which is designed for surfacing, but incidentally provides the flattening effect frequently necessary after the first annealing.

II. SURFACING.

Cold-rolling, in general, as applied to sheets as well as to other forms, has as its principal function the production of a cleaner, smoother and more close-grained surface than can be secured by hot-rolling alone.

The terms "smooth," "dense," "close" and "polished," and their opposites, which will be used to describe sheet steel surfaces, require some definition and explanation of their specific meaning as here employed. For the purpose of explaining the meaning of these terms when dealing with the surfacing effects of cold-rolling, the following brief definitions will probably suffice; but if not, the reader should refer to pp. 251 to 253 for more complete definitions and a full discussion of the use of these terms.

"Smooth" means simply—smooth to the touch, with no projections. The word is sometimes used inaccurately in the sense of "dense." "Smooth" is the opposite of "rough."

"Dense" refers to the physical structure of the steel at the surface of the sheet. It is difficult to define in few words. A sheet steel surface is said to be "dense" if it is free from crevices and marked depressions or "pits." A "dense" surface is the opposite of an "open" or "pitted" surface. However, a dense surface may also be somewhat "porous," that is, contain small, shallow depressions or "open pores," close together, uniformly distributed. A "dense" surface need not be a "polished" surface, since it may be "dull," that is, not glossy.

"Close" means a high degree of density. A "close" surface cannot be strictly "porous," although it may be "dull" (very slightly porous).

"Polished" means a high degree of smoothness, *i.e.,* glossy and lustrous. "Polished" is the opposite of "dull." A sheet may be glossy and polished over the majority of its surface and still not be a dense sheet if it contains pits or openness in some places. A "polished" surface, of course, is always "smooth." However, a "smooth" surface need not be "polished."

It will be recognized that all these adjectives are relative and cannot be defined in absolute terms, but the foregoing should permit some conception of their special meanings in relation to sheet steel surfaces. Even in the sheet steel trade there is no uniformity in the use of these terms and many other expressions are also used, but the opposite terms: "smooth" *vs.* "rough"; "dense" *vs.* "pitted" and "open"; "close" *vs.* "porous"; and "polished" *vs.* "dull," in the senses here defined, will permit adequate description of any sheet steel surface, so far as the steel itself is concerned, apart from such considerations as color, presence or absence of oxide, coating, etc.

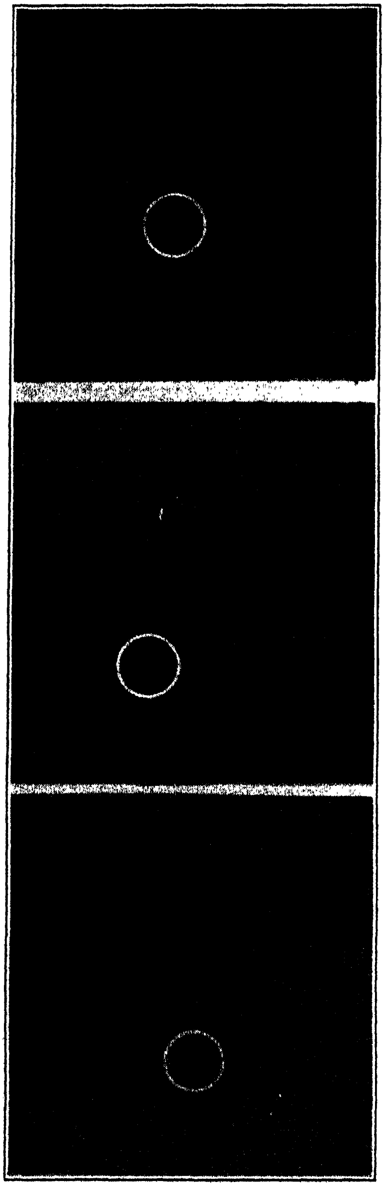
Having defined our terms relating to sheet steel surface condition, we may now proceed to discuss briefly the surfacing effects produced by cold-rolling sheets for surface improvement.

In this operation, one of the most desired effects is density (*i.e.*, absence of pits and openness) of surface. Unfortunately, however, ordinary sheet cold-rolling cannot control density. The kneading and pressing of the steel during hard cold-rolling tends to close up apertures existing in the surface. After hot-rolling, annealing and pickling, a sheet of steel is always porous, at least, and may be more or less "pitted" and "open"; in other words, it contains varying degrees and amounts of crevices and depressions. In the cold-rolling of strip steel, the great pressure which can be brought to bear on the relatively narrow widths involved is successful in eliminating these crevices and depressions. Likewise, the greater pressures on wider sheets made possible by the four-high, cluster and similar types of "backed-up" cold rolls will produce in sheets or strip-sheets the cold-rolling results formerly only obtainable in the narrower strip widths. On the other hand, the conventional two-high, sheet cold-rolling mill cannot exert enough pressure on the widths it rolls to close up deep pits in the steel surface, nor even to close up completely medium-sized crevices and pits, except with numerous passes through the cold rolls, which explains why surface density cannot be insured by such cold-rolling. From two to four "hard" passes through a good sheet cold roll, however, will very effectually close up shallow depressions and small crevices in a clean, pickled sheet, thereby providing closeness and smoothness of surface. From this it will be seen that with the existing equipment, the quality of the surface of sheet steel is not determined entirely by the number of cold-roll passes it receives. This is an important point for buyers to remember. For example, the same number of cold-roll passes, say two or three, will not produce the same surface on a single pickled sheet as on a full pickled sheet. The deeper pits in the single pickled sheet will not be entirely closed and some depressions are likely to remain; although the surface will be smooth, it will not be equally as dense and close as the full pickled sheet which receives equal cold-rolling. Thus, the condition of the surface when cold-rolling begins has much bearing on the character of the final surface. It is for this reason that clean, sound, steel, bar or breakdown pickling, loose rolling, careful hot mill work, and other factors must not be overlooked when considering finished sheet surfaces.

The Cold-rolling of Unpickled Sheets. Cold-rolling unpickled sheets for surface is a relatively simple matter, being almost entirely for the purpose of smoothing down and polishing, not only the steel surface where this is exposed, but also the oxide on the surface of the sheet. The main difficulty here is when the oxide is so thick that it breaks and loosens from the stretching produced by the cold-rolling, causing the surface to be roughened by the loose particles of oxide. Polished, glossy surfaced rolls are used for this work. (See Grade I-A-2, p. 94 and p. 230.)

The Cold-rolling of Pickled Sheets. The cold-rolling of pickled sheets for surface improvement is a rather complex subject. (See Grades I-B-1-b and I-B-2-b, p. 94 and 231-234.) In order to fix our ideas of the effects of cold-rolling pickled sheets, we may divide these effects into those which have to do with what we may call the "sub-surface" and those which control what we may call the "top-surface."

By the term "sub-surface" we refer to what lies immediately below the outermost surface and in which any considerable depressions, pits, and crevices would exist if present. Cold-rolling of the type here dealt with, as already stated, will affect this "sub-surface" by closing up shallow crevices and smoothing out shallow depressions, but will not eliminate the deeper varieties. Therefore, an important part of the control of the condition of this "sub-surface" rests in the treatment before cold-rolling. A dense surface is one in which this "sub-surface" is compact and free from relatively large depressions, or deep pits. Now, it has already been pointed out that bar-pickling and breakdown-pickling and other phases of the work prior to cold-rolling are instrumental in promoting "density" of surface through minimizing the extent and number of crevices and depressions, hence it will readily be seen that these operations in conjunction with cold-rolling, and not the latter alone, control the state of the "sub-surface," *i.e.*, the relative density of the sheet surface.



Surface (D)—Natural size.
Single Pickled and Cold-rolled.
No. 22 gage.

Some remnants of hot mill flashing marks are observable.

Surface (E)—Natural size.
Double Pickled and Cold-rolled.
No. 21 gage.

A dark line indicating the remnant of hot mill flashing is evidence of tight rolling on the hot mill.

Surface (F)—Natural size.
Double Pickled and Full Cold-rolled.
(Hot-rolled loose.)
No. 21 gage.

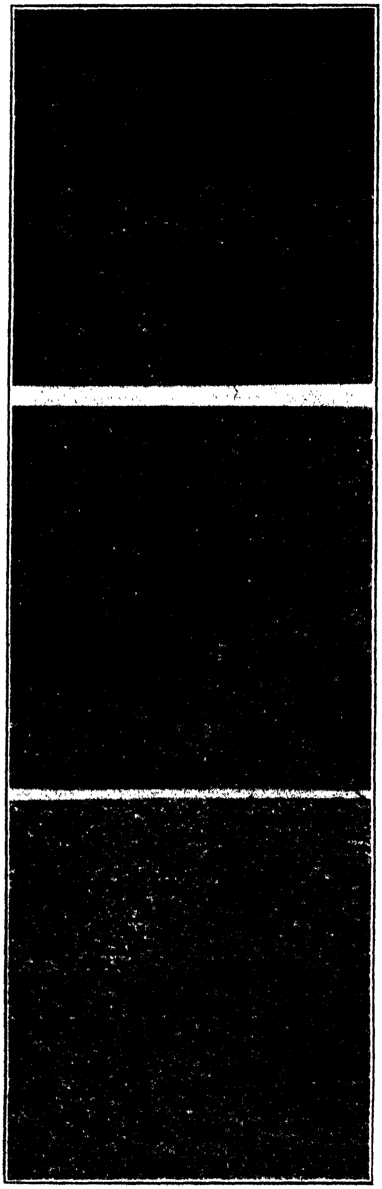
This is an Automobile Body Sheet, Dull Finish, White.

In a high-grade sheet of this kind, the loose hot-rolling prevents hot mill flashing marks or pits due to sticking, and the careful heating and hot-rolling avoid excessive oxidation and opening up of the surface during hot-rolling, all of which combined with breakdown pickling and four passes in the cold rolls, tends to produce the fine texture and uniform appearance of this surface.

Fig. 52.—Sheet steel surfaces—natural size. Single Pickled and Cold-rolled; Double Pickled and Cold-rolled.

All are "White Finish," *i.e.*, have been given a second sheet pickling after the box annealing which follows the cold-rolling, so as to remove all surface oxide.

See Fig. 47, p. 152, "Sheet steel surfaces: Pickled but not Cold-rolled for surface."



Surface (D)—Magnified 12 times.

Illustrating how the deeper pits and open surface of the sheet after single pickling (see "Surface C, Magnified," p. 153) have not been closed entirely by the cold-rolling, although made much less pronounced. The surface has been improved materially by the cold-rolling, but still is not dense owing to the presence of shallow pits and openness, although it has been smoothed down and polished by the polished cold rolls used.

This surface would be classified as: somewhat pitted and quite open; smooth and polished.

Surface (E)—Magnified 12 times.

The breakdown pickling of this sheet has prevented rolled-in scale with its consequent deep pits after sheet pickling, but there is evidence that the surface was opened up slightly during hot-rolling, although the cold-rolling following sheet pickling has closed this surface quite effectively.

This surface would be classified as: dense; smooth and polished.

Surface (F)—Magnified 12 times.

As in (E), owing to the breakdown pickling, there were no deep pits from embedded scale after sheet pickling, and the hot mill work having been very carefully done, there was very little opening up of the surface during hot-rolling, so that the thorough cold-rolling (on dull-surfaced cold rolls in this case) following sheet pickling has closed the surface most effectively.

This surface would be classified as: close (very dense); smooth but dull finish (very slightly porous), not polished.

Fig. 52.—Sheet steel surfaces—magnified. Single Pickled and Cold-rolled; Double Pickled and Cold-rolled.

The above photographs are magnifications (approximately 12 times) taken from within the small circle on each natural size picture directly opposite on the left page.

Differing from the above, the cold-rolling alone can control the "top-surface" of pickled sheets. The term "top-surface," as here employed, means the outermost surface of the sheet, the condition of which causes the surface to be "rough" or "smooth," "porous" or "close," "dull" or "polished." A surface already "dense" and yet "porous" may be made "close" by cold-rolling, and this "close" surface may be produced either in a "dull" or "polished" finish, according to the character of the surface of the cold rolls used. Therefore, the surface properties "rough" and "smooth," "porous" and "close," "dull" and "polished," may be determined by whether or not the sheets are cold-rolled and by the nature of the cold-rolling. The foregoing excepts roughness caused by loose oxide, since we are only concerned here with pickled sheets, and these should not have sufficient oxide to be loosened by cold-rolling.

Any pickled sheet which has been cold-rolled for surface will be smooth, and if double pickled will be dense as well as close, but, as has been mentioned in the preceding paragraph, the cold-rolling may be performed in such manner as to make the "top-surface" either "polished" or "dull," as desired. Since these two variations in the finish of cold-rolled pickled sheets are not generally understood, and each is better suited for certain uses than the other, the following brief discussion of them is given:

Dull finish (Also called soft or satin finish).

In this finish, the "top-surface" of the sheet, while smooth, is not polished or glossy. It is somewhat porous in the sense that the "top-surface" contains minute lumps and depressions which are not plainly visible to the naked eye, but which prevent a polished and lustrous appearance.

The rolls used to produce this finish, while free from pronounced irregularities, are dull and not polished. The sheets are either cold-rolled with water running over the rolls which prevents polishing, or else with dull surfaced (etched) rolls.

The "wet" or "dull" cold-roll pass permits higher temperatures to be used in the box annealing which may follow cold-rolling than in the case of the "polished" pass, because these dull-finish sheets do not stick so easily as highly polished, pickled surfaces during box annealing. Therefore, dull-finish cold-rolled pickled sheets can be made softer, as a rule, than those which are highly polished. Dull finish provides a better surface for some types of paint and lacquer finishing than polished finish.

Polished finish (Also called hard finish).

In this finish, the "top-surface" is extremely smooth, so that it appears glossy and lustrous. Highly polished rolls are used.

On the average, polished-finish cold-rolled pickled sheets cannot be made so soft as those in dull finish because they tend more toward sticking in box annealing after cold-rolling than do dull finish sheets, consequently cannot be annealed at as high temperatures.

Polished-finish sheets are preferred for high gloss paint, oil enamel and japan finishing; also for electro-plating, and tinning or for any purpose requiring a very glossy surface, but where the greatest softness is not needed.

Many variations are possible in the finish of cold-rolled pickled sheets and the mills are very skillful in providing the proper surface texture for the particular purpose involved. The cold-rolling of automobile sheets and furniture sheets is given especial care and the resultant surfaces are remarkably fine, particularly when it is considered that working qualities of the very highest order must accompany the fine surface. This is especially true in the case of automobile grades. Of course, the full pickling and other aids contribute greatly to the excellence of the surface of these highly refined grades, and the working qualities could not be obtained without expert annealing; still much of the credit for the final product must be given to the art and skill exercised in modern sheet steel cold-rolling.

While on the subject of sheet steel surfaces, it is appropriate to point out that, in general, the greatest degree of surface refinement from cold-rolling is incompatible with the greatest degree of ductility and softness. The reason for this is that, as previously explained, cold-rolling tends to stiffen and reduce the ductility of the sheets, and although subsequent annealing may counteract this effect of cold-rolling, nevertheless it always remains a factor of considerable influence on the final product. Therefore, there must always be a compromise between the degree of finish and the degree of workability of highly finished, cold-rolled sheets. Much of the skill and ingenuity of the mill-man in producing such sheets of the character required for exacting purposes is devoted to finding this compromise or intermediate point for the particular purpose or requirement being met.

III. STIFFENING.

Cold-rolling is frequently used as a means for adding stiffness to sheets. As already stated, practically all sheets must be annealed after hot-rolling to remove the hot-mill strains and banded structure. The annealing necessary in a particular treatment may make the sheets too pliable for certain uses, and in order to add the proper amount of stiffness to the finished sheet, one or more cold-roll passes are given after the last annealing.

A certain degree of stiffness, or, more accurately stated, the physical structure of the steel indicated by the stiffness resulting from cold-rolling after annealing, is desirable: to reduce the tendency of the surface to develop "stretcher strains" during stretcher leveling (see p. 174) and during certain types of drawing operations; and to reduce the tendency of the sheet to "flute," *i.e.*, form alternate flat sections and ridges, upon being rolled into cylinders. Also, it is sometimes preferable to have a sheet which is fairly workable, but stiffened somewhat so that it may not be dented easily. For various other purposes, considerable stiffness is added to sheets by cold-rolling.

Carefully planned combinations and variations of annealing and cold-rolling make possible the wide variety of nicely adjusted physical properties and surface qualities which are necessary for the multitude of drawing, forming, coating and painting operations for which sheet steel products are used today.

CHAPTER 12.

THE REFINING PROCESS—Continued.

RESQUARING, FLATTENING OPERATIONS, OILING.

RESQUARING.

As the name implies, resquaring consists of a very careful shearing to the exact size ordered after the completion of all operations in the treatment which tend to distort the shape of the sheet, such as cold-rolling, stretcher leveling, etc.

It is performed somewhat differently at sheet mills and tin mills, but the purpose is the same, namely, to deliver a sheet sheared as accurately to the specified size as practicable.

Sheets which are not resquared always are in excess of the widths and lengths ordered by an appreciable extent. Even resquared sheets must be allowed to run over size by a very small fraction of an inch, but not to anything approaching the extent allowable for sheets which are not resquared. (See "Tolerances," pp. 266-268.)

FLATTENING OPERATIONS.

The use of cold-rolling as a means of flattening has already been described. (See p. 162.) It has very decided limitations for such work, particularly for final flattening.

Unless special flattening operations are employed at or near the completion of the treatment of the sheets, considerable variation in flatness must be expected. Many of the sheets of an order which are not specially flattened will be exceedingly flat, but, on the average, a large proportion will contain "buckles" or waves of varying height and number. The normal flatness varies somewhat according to the grade and as a rule, the lighter the gage and the wider the sheet, the less flat the sheets will naturally run. Of course, even when sheets are not stretcher leveled they must still come within certain commercial standards for flatness. (See "Tolerances," pp. 268-269.)

The special operations employed for final flattening are "roller leveling" and "stretcher leveling." The latter is frequently called "patent leveling" also.

Roller Leveling. The roller-leveling machine consists of several sets of horizontal, small diameter rolls or "rollers," held in a housing and so arranged that the top and bottom layers are offset, permitting the rollers to mesh. The layers of rollers are movable with respect to each other, so that by means of screw pressure the rollers may be made to mesh more or less, as desired, thus controlling the pressure exerted on the piece during the operation. (See Fig. 53.)

The sheets are passed through the roller leveler one or more at a time, depending on the gage.

Roller leveling while the sheets are still hot from annealing is a regular part of the treatment of open annealed sheets, which, of course, are always heavy gages. This has the effect of removing much of the distortion caused by hot-rolling and open annealing. Such roller leveling will be done more carefully and more effectively if the open annealed sheets are specifically ordered "Roller Leveled" at a small extra charge.

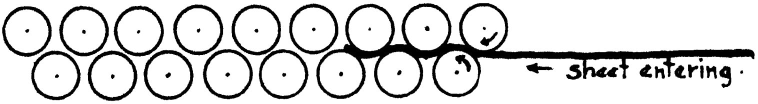


FIG. 53.—Skeleton diagram of roller leveler (cross section).

Roller leveling when the sheets are cold may be performed on any gage or grade of sheets where desired, except the very light tin mill gages. Such a roller leveling is an extra operation, subject to an extra charge unless already included in the charge for a special finish. This cold roller leveling removes minor flatness irregularities put in the sheet by handling, annealing, etc., and takes out small waves and other forms of non-flatness of a minor nature; however, it will not remedy deformation affecting the entire sheet, such as pronounced buckles.

The up and down course of the sheet as it passes through the successive rollers has a "kneading" action which not only tends to promote flatness, but also imparts some cold-working effect to the steel itself. This latter effect is utilized to good advantage in some kinds of drawing and forming operations. It has been found that the tendency of sheets to show "stretcher strains" is greatly reduced, if not altogether eliminated, by roller leveling the sheets or blanks immediately before forming them. This effect of roller leveling does not last indefinitely; sometimes it remains for weeks and sometimes it disappears in several hours. Therefore, the only way for the sheet steel fabricator to be sure of minimizing stretcher strains by roller leveling, is to have a roller leveler in his press room and put the sheets or blanks through it shortly before the actual forming is done.

Roller leveler corrugations, consisting of small waves across the sheet at frequent intervals, constitute the main defect caused by this operation. They are often encountered and are to be expected, more or less, in common sheets which have been roller leveled hot, such as ordinary blue-annealed sheets. They are not often produced by cold roller leveling, but occasionally appear when the roller leveling has not been properly done or when sheets are badly buckled before roller leveling takes place.

Roller leveling is only a semi-effectual means for flattening sheets. It is an inexpensive operation and therefore is widely and usefully employed, in spite of its limited effectiveness, for sheets which are desired somewhat flatter than the common standard, but which are not required to have the greater degree of flatness provided by the more expensive stretcher leveling operation. The fact remains, however, that the only way to be sure that the finished sheets will be as flat as they can be made is to have them stretcher leveled.

Stretcher Leveling (or Patent Leveling). Stretcher leveling is a positive means of producing flatness in finished sheets. In this operation, the sheets are gripped on each end by jaws attached to pistons which are forced apart slowly by hydraulic pressure. The number of sheets stretched at one time depends on the gage of the sheets.

The effect is actually to stretch the sheet, gradually taking up all slack which may exist in the form of waves or buckles, continuing until the sheet is stretched taut and its shape is practically a flat plane. The stretching proceeds, theoretically, past the elastic limit of the steel, so that the sheet will not spring back into its original shape. In this way, the sheet takes a permanent set in its flat condition which is not materially altered when the stretching is stopped and the sheet is removed from the jaws. It is claimed that when a stretcher-leveled sheet is later cut into pieces, strains are sometimes released which cause the pieces to be less flat, but this is not much to be feared in practice.

For stretcher leveling, sheets must be fairly soft and ductile, and have an elastic limit low enough to permit them to take a permanent set with a pull which is within the limit of the stretching machine. At the same time, the sheets must also have sufficient "body" or strength to cause the "pull" to be fairly evenly distributed throughout the sheet and not concentrated at weak spots. Very soft, coarse-grained steel is conducive to the formation of stretcher strains and coarseness of surface during stretcher leveling. Therefore, it is customary when sheets are to be stretcher leveled, to strengthen them by cold-rolling after annealing, particularly after box annealing, if stretcher strains are to be avoided. Stretcher strains appear as thin lines of depression where the metal has "necked down," the lines generally meeting at an angle.

Since cold-rolling frequently precedes it, and the operation itself is a form of cold work, stretcher-leveled sheets, although suitable for ordinary bending, are inclined to be somewhat stiffer than the same grade of sheets not stretcher leveled. Stretcher leveling is unnecessary and should not be specified for sheets which are to be subjected to any severe drawing work.

Stretcher leveling, ordinarily, is only performed on normal sheet mill sizes. It is most effective on the heavier range of gages, that is, No. 22 gage and heavier. On gages lighter than No. 22 gage, its effectiveness gradually diminishes and the operation becomes more difficult to perform.

When considering stretcher-leveled sheets, it must be remembered that after the operation is concluded, marks from the gripping action of the jaws (called "gripper marks") remain across each end of the sheet, at a distance of an inch or more from the end; also, that the sheet is stretched longer than its original length, the amount of stretch varying considerably since some sheets must be pulled out longer than others to get them flat.

Both of these factors, the gripper marks and the excess length, are taken care of when sheets are resquared, in which case the mill purposely makes the sheets large enough so that the gripper marks are sure to come outside the ordered length and, consequently, are removed when the sheet is resquared to the size ordered.

For some purposes, it is not objectionable to have the gripper marks remain on the sheet, especially since this saves the expense of the resquaring necessary to eliminate them.

Stretcher-leveled sheets are furnished under the three following plans:

(1) *Stretcher-leveled and resquared.*—The gripper marks are removed; the sheets are in the exact size ordered.

(2) *Stretcher-leveled but not resquared.*—The gripper marks remain on each end of the finished sheet. The length ordered exists between the gripper marks, consequently the total length of the sheet is considerably in excess of the ordered length.

(3) *Stretcher-leveled but not resquared—No allowance for gripper marks.*—The gripper marks remain on the sheet, but these marks may come within the ordered length. (If a sheet is ordered 96 inches long under this plan, the gripper marks may only be, say, 95 inches apart and thus occur inside the

ordered length.) The total sheet length is not permitted to be so much in excess of the ordered length as under plan (2) above.

OILING.

The purpose of oiling steel sheets is to protect them against rusting while in transit or in storage. This oil on the surface is advantageous where the sheets are to be drawn, but must be removed before painting may be properly done, except where linseed oil is used, as is sometimes the case with sheets for roofing purposes, or where special oils are employed, on which paint or lacquer may be directly applied.

As a general rule, "oiling" consists of coating the sheets with a film of light, clear, mineral oil by passing them through absorbent cloth rolls to which the oil is applied as needed.

"Oiling" is especially useful on pickled grades of sheets, which rust quickly unless they are oiled or otherwise protected. Blued sheets frequently are oiled to darken the blue color, as well as to protect them from rust caused by excessive moisture.

CHAPTER 13.

PROTECTIVE COATINGS.

CORROSION OF IRON AND STEEL.

Iron rusts readily, as everyone knows. "Corrosion" is the technical name for the rusting process. Iron rust, that all too familiar brown powder, is called by the chemist "ferric hydroxide," $Fe(OH)_3$, and is a combination of iron, hydrogen and oxygen. The joint action of both water and air causes rusting, the common type of corrosion which we see all about us. The water provides the hydrogen and the air provides the extra oxygen necessary to combine with the iron to form rust. Exposed to absolutely pure water alone, or to absolutely dry air alone, iron would not rust, it is said, but neither of these conditions could well exist because ordinary water always contains some dissolved oxygen (as well as ionic hydrogen), and air always contains varying amounts of water in the form of moisture.

It is believed that electrolysis plays a very large part in the corrosion of metal and that electrolytic action is set up when iron is exposed to water and air. Those desirous of studying the theory of corrosion should consult the more recent scientific works on this subject. In this brief discussion, it is possible to mention only a few salient features of the subject.

Electrolysis also takes place when iron and a substance of dissimilar electric potential, in contact or connected with each other, are immersed in an electrolyte, such as impure water, as will be discussed later when considering the different metallic coatings.

Conditions under which iron or steel is alternately wet and dry cause rapid corrosion. Such conditions are met when the metal is exposed to the atmosphere where rains are frequent, where very moist air prevails, and in industrial uses where steam or other vapor exists.

Certain acids in water and fumes in air, as from smoke, hasten corrosion.

RETARDING AND PREVENTING CORROSION.

Since rust is one of the greatest obstacles to the use of iron and steel, much study has been devoted in all ages to means of retarding and preventing corrosion.

Some expensive special alloy steels, containing large amounts of chromium, nickel and other metals, in various combinations, have been developed which very effectively prevent corrosion from ordinary causes, but their high cost limits their use at present.

An inexpensive alloy steel, containing about one-fourth of one percent copper, has been demonstrated to last at least twice as long as non-copper-bearing steel or iron in the atmosphere (see pp. 50-54). However, although an effective copper content greatly retards corrosion in the atmosphere or under other wet and dry conditions, copper-bearing steel does rust, even though less rapidly.

With the exception of some of the expensive special alloys above mentioned, iron and steel (including copper-bearing) must be protected in some way if rusting is to be entirely prevented.

Various coatings are applied to the surfaces of steel sheets to protect them against the formation of rust. All these vary in cost and effectiveness, being selected according to the needs of the particular purpose.

The protective coatings applied to sheet steel by the manufacturer may be divided into two classes: non-metallic and metallic.

NON-METALLIC PROTECTIVE COATINGS.

Oiling.—The thin film of oil provides protection against surface rust while sheets are in transit and while stored in a dry warehouse. Oiling will not protect for long against outdoor conditions.

Liming.—Like oiling, affords indoor protection for a while.

Bluing.—Different blued (oxide) coatings afford varying degrees of indoor protection. (See pp. 142-143.)

Painting.—Sheets of steel which are kept thoroughly painted with good paint will last indefinitely, even in severely corrosive atmosphere. However, paint is not very permanent and frequent repainting is necessary to secure protection to the steel.

Formed roofing and siding, made from black sheets, are sold already painted by the mills, when desired. The painting of these will be discussed later under "Formed Products."

In painting sheet steel for protection against rusting, after application to buildings or after fabrication into articles, the following are some of the rules to be observed:

1. Have surface perfectly dry.
2. Galvanized sheets should be roughened, either by exposure to weather for 6 to 12 months, or by brushing on a solution of 4 ounces copper sulfate in one gallon of water; after dry, brush lightly before applying paint.
3. Black (that is, uncoated) sheets should be carefully brushed if there is any dirt, loose rust, or loose scale on their surfaces.
4. Use good paint. Red lead ground in pure linseed oil is about the best paint for protection of steel. However, red iron oxide ground in pure linseed oil is good and less expensive. Graphite paint has its uses, particularly over other paint coats, to exclude moisture. Asphalt is frequently used for protection underground.

5. Tar should not be used as it generally contains acids which attack the steel.
6. When rust appears, paint again at once.

METALLIC PROTECTIVE COATINGS.[1]

The metallic protective coatings regularly applied to sheet steel at the mill are:

1. Zinc—on galvanized sheets.
2. Tin—on tin plate.
3. Terne mixture (an alloy of about 80% lead and 20% tin)—on terne plate.

All these must be applied to clean steel, therefore, sheet steel is pickled and otherwise prepared before galvanizing, tinning or terne coating.

Galvanized Sheets. "Galvanizing" is the term applied in years gone by to the method of coating iron products with zinc by means of dipping them into molten zinc. This is called "hot galvanizing" today and is the method employed at the mills for coating sheet steel with zinc.

FIG. 54.—Surface of regular galvanized sheet. Illustrating the characteristic "spangled" condition of the zinc coating. This is a very bright, clearly defined spangle.

"Cold galvanizing" (also called "wet galvanizing") is electro-plating with zinc. "Dry galvanizing" consists of coating the article with powdered zinc, including some zinc oxide, and then heating, thereby alloying the zinc with the iron. Both these processes are used on articles

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[1] For very complete information on this subject see H. S. Rawdon, "Protective Metallic Coatings," New York, Chemical Catalog Co., Inc., 1928.

fabricated from sheet steel, but are not employed at mills for the flat sheets. They are not practicable or economical for large sheets.

The coating metal on galvanized sheets is "spelter," *i.e.* commercially pure zinc. It exists on the surface of common galvanized sheets in the form of the familiar and characteristic "spangle" or "flower."

Zinc provides excellent protection to the underlying steel, because it is electro-positive to iron. This means that whenever electrolysis is set up between zinc and iron, the zinc will decompose and the iron will not. Consequently, where any break in the galvanizing exists and an electrolyte, such as moisture, is present, the zinc, in preference to the iron, will dissolve and partially plate out again on the iron, thus protecting the iron as long as the surrounding zinc lasts. In short, the iron is protected at the expense of the zinc. This explains why a raw edge (where the sheet is sheared or punched) or a scratch on a galvanized sheet does not rust for quite a long time. A raw edge or a scratch on tin plate or terne plate will rust very quickly because both tin and lead are electro-negative to iron.

The very reason why zinc is such a good protector of iron, however, militates against it in another way. Because it decomposes under electrolysis so readily, the zinc coating on galvanized sheets is always corroding away, more rapidly under some conditions than others, of course. Its corrosion, however, is retarded considerably as a consequence of the fact that when a galvanized sheet is exposed to the weather, as the zinc corrodes it forms a white film (a zinc compound) which protects the zinc beneath. If this film remained permanently, further destruction of the zinc coating would be prevented. However, this film is gradually worn away by wind and rain, and then the zinc, so to speak, corrodes further, forms a new film, and so on until it is all used up and the steel base sheet exposed. The heaviest zinc coatings will be consumed in time by atmospheric corrosion. Therefore, when galvanized sheets are exposed to the weather or other severely corrosive conditions, it is always good policy to paint them as soon as they appear dull gray in color.

So far as corrosion caused by moisture is concerned, the main advantage of a zinc coating over tin or terne coatings lies in the fact that it prevents localized corrosion in small breaks of the coating (such as pin-holes and scratches) from penetrating quickly at those spots, thereby ruining the sheet or article for most purposes. The healing effect of the zinc coating affords uniform protection all over the sheet until the zinc is about all used up.

Even distribution of the galvanizing is desired, as with all coatings.

In the old days, when sheets were dipped by hand, much zinc was applied, but not always effectively since it was much thicker in some spots than others. Any coating, of course, is no better than its thinnest portion. Modern machine coating methods permit a fairly even distribution of the galvanizing—immeasurably more so than the old hand dipping—but even with these the thickness of the coating will vary considerably from one part of the sheet to another. The modern galvanized coating, however, provides more protection with less total zinc per sheet than the old hand-dipped, lumpy coating.

Also, the modern uniformly and lightly coated galvanized sheet is capable of performing bending and forming operations without serious flaking which would be impossible with heavy, uneven coatings.

The amount of galvanizing on sheets is measured in ounces per square foot of sheet; that is, with a 2-ounce coating there will be, theoretically, 1 ounce on each side of one square foot of sheet, or 2 ounces total on both sides of one square foot. For example, there would be 20 ounces altogether on a sheet 2 feet wide by 5 feet long.

The weight of coating is determined, ordinarily, by the amount of zinc used to coat a known number of sheets of known size. Where special tests for coating are required, these are made by one of the three following methods:

Weight test.—In this testing method, the inspector occasionally takes several uncoated sheets from those being coated, has them dried, then weighed, thus obtaining what is called the "black" weight of the sheets. Then the sheets are coated in the regular manner, after which they are again weighed. The difference between the weight after and before coating gives the weight of the coating applied, which is then computed in ounces per square foot.

Spot test.—The inspector cuts a test piece from any part of the coated sheet, except immediately along the edge or end. This test piece is analyzed chemically for the amount of coating. An extra charge is generally made for coatings subject to this type of test because the coating is always lighter in some parts of a sheet than in others, and in order to make every portion of a sheet up to the full required coating weight, the mill has to apply a heavier average coating than when working to the weight test.

Triple spot test.—This consists of taking three test pieces from the sheet, one from the center and one each from near two diagonal corners. The average coating of the three pieces is the figure sought. This method is comparable to the weight test in the results obtained.

Ordinarily the buyer does not make tests for coating, except, in some cases, when galvanized coatings heavier than standard are ordered. Mills make tests regularly for their own information, of course.

For those who desire to order galvanized sheets by specification, an excellent and very practicable one is the "Standard Specifications for Zinc-coated (Galvanized) Sheets, Serial Designation A-93-27, American Society for Testing Materials, Standards, 1927, Part I, Metals, pp. 270-275."

When iron or steel is immersed for a time in molten zinc, the zinc, so to speak, penetrates into the surface of the iron, forming a layer of iron-zinc alloy. This action takes place in the galvanizing of sheet steel. The result is that the coating of a steel sheet after ordinary galvanizing consists of a layer of iron-zinc alloy, outside of which is a layer of relatively pure zinc in the large crystalline form indicated by the "spangles."

Although zinc is a soft metal, when properly made into zinc sheets, wire, etc., nevertheless, as it exists in a spangled galvanized coating it is rather brittle and tends to peel off the sheet in flakes when the sheet is bent down flat on itself or otherwise severely distorted. Pronounced heating also causes "peeling" of the galvanizing. This "flaking" or peeling of the galvanizing is attributed to various causes, one widely accepted explanation being that although the zinc outer layer is ductile enough, the iron-zinc alloy intermediate layer is brittle and when this breaks, as in bending, it causes the outer zinc layer to peel off. The writer has the theory that instead of this, the zinc outer layer exists in a brittle form, possibly because of its large-crystalline structure, indicated by the spangles themselves, and that where there is severe distortion the outer zinc layer itself breaks; further that this layer is not very adherent to the underlying iron-zinc alloy, consequently, the broken pieces of the zinc layer fall away in the characteristic flakes; whereas, the iron-zinc alloy frequently remains at the point of flaking. This theory, however, is based on practical observation only and cannot be substantiated by scientific data.

Spangled galvanizing, as has been stated, tends to peel and "flake" under distortion, and unfortunately, the thicker the coating, the greater is its tendency to break and peel when the sheet is severely distorted by bending or forming. This being the case, although it is always desirable to have the heaviest coating practicable, there is no advantage, rather there is a real disadvantage, in using a coating which is too heavy to perform a required forming operation without flaking at vulnerable points. Of course, if flaking occurs only at spots where it does no harm, for example, where it would be covered with solder when the article is completed, then flaking may be disregarded and heavy coatings used.

Because of the fact that heavy coatings tend to flake in severe bending and forming operations, sheet steel manufacturers have been called upon to develop galvanized sheets with especially tenacious coatings and these are called "tight-coated galvanized" sheets. Such coatings are intended for use where flaking is feared. The principal means of making the coating more tenacious is to make it thinner and therefore, although "tight coated" actually means "light coated," nevertheless, it is better, where forming is severe, to use a light coating and have it stay on, than to use a heavy coating and have it flake off the sheet.

A rough outline of the proper use of the various galvanized coatings is as follows:

Coating.	*Use.*
Heavier than standard (up to 2½ or 2¾ oz.).	Flat work, corrugating, curving or bending on a large radius—where severe corrosion will be encountered and long service is desired. The small extra cost of extra heavy coatings is generally economy in the long run.
Standard.	Ordinary bending. Most galvanized corrugated sheets are made in the standard coating because buyers are unwilling to pay for heavier coatings.
Tight.	Double seaming and fairly severe bending.
Extra tight (light gages only).	Very severe bending and seaming; also all work which involves an actual draw or stretch in the sheet.

As a matter of fact, all articles which involve even moderately deep drawing should be fabricated from uncoated sheets and galvanized afterwards. Even though galvanized sheets are available today which will perform drawing operations with remarkable freedom from flaking, it is not in the nature of any galvanized coating to withstand much distortion without fracture of the coating and the coating must be extremely thin to stand severe seaming or anything approaching a deep draw. Makers of galvanized ware, owing to the ignorance of the public concerning such things and low price competition, have turned to the use of galvanized sheets, more and more, so as to avoid the greater expense involved in forming the article from an uncoated steel sheet and then galvanizing after fabrication. However, this practice is a bad thing for the industry at large. The general public should be taught that it is economy to spend more for a heavy gage article, heavily galvanized after fabrication, and that it is no economy to buy a cheap, flimsy article, fabricated from a light gage galvanized sheet, the coating of which was quite thin to start with and has probably been fractured by severe forming operations during manufacture.

Non-spangled or Dull Galvanized Sheets. There have been introduced recently several brands of zinc-coated steel sheets, the coating of which does not have the "spangled" appearance which is characteristic of regular galvanized sheets. They are usually dull gray in appearance.

The advantages claimed for this dull, non-spangled coating over regular spangled galvanized sheets are, first, that it will withstand forming with less injury; second, that it will not flake off when heated; third, that it will hold paint better than spangled galvanizing.

The first and second claims appear to be substantiated by practical results. Under severe bending and moderate drawing, the non-spangled coating may "dust off" in very small particles, but does not peel off in relatively large pieces the way spangled galvanizing frequently does during severe forming. These dull coatings do not flake at all under heat, even up to 750° F. Owing to these two characteristics, this type of sheet is meeting considerable demand for use as linings of ovens in stoves and ranges; also for difficult forming.

There is some question as to whether this type of coating holds paint better than spangled galvanizing, however. It is a known fact that paint applied to a new, glossy galvanized sheet will not hold, but will peel off more or less. Yet, by preparing the surface properly and by carefully selecting proper paints and methods of applying, many manufacturers are able to make paint or enamel adhere very satisfactorily to spangled galvanized sheets.

There is considerable secrecy as to exactly how the various brands of non-spangled galvanized sheets are made. It is probable, however, that the application of extra heat, either during or after coating, is the principal factor differentiating their manufacture from that of spangled galvanized. The extra heat could produce the dull zinc coating by favoring the growth of iron-zinc alloy and possibly by causing a different crystallization of the free zinc in the coating. It is also probable that there is less zinc in the non-spangled galvanized coatings than in even the lightest spangled galvanized coatings.

Terne Plate. Terne plate consists of steel sheets coated with a metal called "terne mixture" (see p. 178), which is an alloy of lead and tin, principally lead. The word "terne" is a heritage from the ancient industry and means "dull" and was originally used to distinguish the dull, gray, lead-tin coatings from the bright, white, pure-tin coatings. It is made in big sheets at sheet mills called "long ternes," and in small sheets at tin mills called "short ternes."

The coating of terne plate is measured in terms of pounds per "double base box." A double base box contains approximately 436 square feet, or the area of 112 sheets in size 20 inches x 28 inches. This method of measurement is inherited from tin plate practice (see p. 90).

Long ternes, or large terne-coated sheets, are generally made only with relatively light coatings, *viz.*, 8, 12 and 15 pounds, and usually not heavier in gage than No. 16 or possibly No. 14 gage, nor lighter than No. 30 gage.

They are evenly coated with a thin layer of terne mixture metal, which protects the steel base sheet against mild corrosive influences. Such coatings are not sufficient, however, for protection against atmospheric or other severe corrosion. Long ternes are used where it is desired to have the strength and cheapness of steel together with one or more of the following properties:

1. Protection against mild corrosion.
2. Ability to be soldered readily. (The terne coating, being very similar to solder, unites well with this.)
3. A coating which will not fracture when the sheet is bent or drawn. (Terne mixture, being very soft, will not flake off like galvanizing under distortion. Of course, it will thin down where drawn.
4. Ease in drawing. (The soft coating acts as a lubricant in the dies.)
5. A coating which will hold paint or enamel readily.

Long ternes are sold either in "dry," *i.e.* "bright," finish, or "oil" finish; the latter for drawing work, usually.

Short ternes, or small terne-coated sheets, are made in the lighter coatings (8 pounds or lighter) for manufacturing purposes, where their light gages and small sizes make them preferable to long ternes; also, in the heavier coatings, from 15 pounds to 40 pounds, for roofing purposes, which is their principal use. The gage range of short ternes usually is from 215 pounds per base box to 100 pounds per base box.

What people commonly call "roofing tin" is not tin plate but terne plate. "Roofing ternes" is the correct name in the trade for these heavily coated terne plates. These are generally made with a base sheet of copper-bearing steel.

For permanent roofing work, not less than 20-pound coating should be used. It is economy in the long run to use the heavier coatings. The standard terne plate for the metal covering of fire doors is 20-pound coating.

Barring one feature, terne mixture makes an ideal coating to protect steel against corrosion. While cheaper than tin, it is a very stable metal, distributes more evenly than lead, and deteriorates more slowly than zinc. As a coating, it does not fracture or peel from the sheet under difficult forming. If it were possible to have the terne coating perfectly continuous, the steel base sheet would be fully protected against corrosion as long as the terne coating lasted, which would be a very long time, especially with the heavy coatings.

Unfortunately, a perfectly continuous terne coating on iron or steel sheets is a commercial impossibility. This also holds for tin coatings and lead coatings. In spite of the utmost care in manufacture, very small discontinuities or openings are present in the coating of both terne plate and tin plate. Any plates with coating imperfections which can readily be seen are not included in prime quality plates, but are thrown aside by the inspectors who examine both sides of every plate. However, some openings in the coating are so minute that they cannot be seen with the naked eye, and can only be detected by chemical and microscopical means; these are termed "pin-holes" in the coating. They are not to be confused with holes extending entirely through the steel base sheet, which are sometimes referred to as "pin-holes in the sheet," but which more properly should be called "perforations," or "holes in the sheet." The term "pin-hole," as here employed, will be used to refer to minute apertures or openings in the coating and will have no reference to the steel base sheet itself. The use of the term "uncoated spot" in this sense seems ambiguous for the reason that this term conveys the impression of a plainly visible uncoated spot, which is an entirely different thing than a minute opening in the coating, commercially speaking.

These minute pin-holes in the coating are not noticed until the plate has been exposed to corrosive conditions for some time, when they begin to show rust spots. The appearance of rust, of course, indicates that the steel base sheet is being attacked. Now, with galvanized sheets, the steel under a small opening in the coating would not be attacked until the zinc in the immediate neighborhood had been consumed by the corroding process. In the case of terne plate, however, the matter is different, for the following reasons:

1. Both tin and lead are electro-negative to iron, and in the presence of an electrolyte, the iron will dissolve in preference to the terne mixture, depositing out on the surface as brown rust.
2. Where there are small discontinuities in the coating or pin-holes, which are found to greater or less degree in all terne coatings, this dissolving of exposed iron in preference to the coating concentrates the action in the pin-hole (instead of tending to heal it, as a zinc coating would), thus hastening the corrosion of the exposed iron at that point.

Notwithstanding the inevitable pin-holes in the coating and the fact that lead and tin, being electro-negative to iron, have the effect of hastening corrosion of exposed spots in the steel base sheet, heavily coated terne plate has proved a satisfactory roofing material over a very long period because it is light, fireproof, easily applied in waterproof fashion owing to its ability to be soldered readily, and for other reasons. If kept well painted, a roof of 30-pound or 40-pound terne plate will last many years, 40-year-old terne roofs not being uncommon. The paint seems to fill up the pin-holes and prevents corrosion there. The under side should be painted before applying to the roof and the outer side should be painted when applied and again whenever it appears to need it.

Summed up, the advantages and disadvantages of terne plate for corrosion resistance and fabrication, as compared to galvanized sheets, are as follows:

Advantages of terne plate over galvanized sheets.

1. Freedom from flaking in bending and forming.
2. Solders somewhat easier and better than galvanized sheets.
3. Holds paint without preparation, whereas galvanized coatings must be carefully prepared for painting.
4. Terne mixture is not so actively attacked as zinc is by sulfuric acid caused by smoke and moisture.
5. Soft coating is easy on dies in stamping.

Disadvantages of terne plate compared with galvanized sheets.

1. Subject to pin-holes in the coating.
2. Coating is softer and more easily damaged by scratching than galvanizing.
3. Corrosion in pin-holes, scratches and raw edges is aggravated by the electro-negative nature of terne coating.
4. Costs more, as a rule.

Tin Plate.* Tin plate consists of sheet steel coated with pure tin. The lightest coatings applied to tin plate today, although evenly distributed, are very thin for the sake of low cost, but mills will gladly make heavier coatings whenever the buyer will pay the extra cost.

Tin is electro-negative to iron the same as terne mixture. Tin plate is subject to the same pin-holes in the coating described above in the discussion of terne plate; therefore, its behavior under corrosion is similar. Tin plate, however, is practically never used for outdoor work. Tin is more expensive than terne mixture, consequently the same amount of coating costs more in tin than in terne mixture.

The principal advantage of tin coating over zinc and terne coatings lies in the fact that tin, when in contact with most foods, does not generate substances which would be poisonous to human beings. Hence, tin plate is used for food containers in the shape of the familiar tin can.

When used for tin cans to contain moist food, tin plate is subjected to some corrosion from the inside, but this is lessened by the fact that

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* Very complete information on tin metal itself and its uses will be found in "Tin; Its Mining, Production, Technology and Applications," by C. L. Mantell, Chemical Catalog Co., New York, 1929. This includes a comprehensive discussion of the corrosion of tin and of the corrosion of tin plate by food products.

oxygen is largely excluded from the inside of the can. Full tin cans are practically never subjected to conditions which would cause corrosion of the exterior, so this is not a factor. Some foods attack the inside of the can more than others and at present it has become the practice, before packing these foods, to coat the inside of the can with a lacquer which protects the tin coating as well as any exposed steel due to scratches, pin-holes or other coating defects.

To state a complex subject briefly, although it is known that all tin plate contains pin-holes and other coating imperfections, the fact remains that perforations in tin cans containing food, caused by holes rusting through the tin plate, occur in such a small proportion of the enormous total number of cans packed as to be practically negligible. Tin plate has been amply demonstrated to be a successful material for food containers, owing to the great skill and care exercised by the tin plate manufacturers, the can makers and the canners.

Another advantage the tin coating has over zinc and terne coatings is its brighter and more pleasing appearance. As a result, tin plate is frequently used for the sake of appearance where galvanized sheets or terne plate could be used either at a saving in cost or with greater protection against rust at the same cost. Owing to the great scarcity of tin, it would be well to substitute these other coated sheets where appearance alone dictates the use of tin plate, but precedent and public fancy are slow to change.

A summary of the advantages and disadvantages of tin plate as compared to galvanized sheets and terne plate is as follows:

Advantages over Galvanized.

Not poisonous for food containers.
Freedom from flaking.
Brighter and more pleasing appearance.
Solders somewhat easier and better.
Soft coating is easy on dies in stamping.

Disadvantages compared to Galvanized.

Presence of pin-holes in the coating.
Tin promotes rusting in scratches and pin-holes, being electro-negative to iron.
Coating is softer and scratches more easily.
Costs more.

Advantages over Terne Plate.

Not poisonous for food containers.
Brighter and more pleasing appearance.

Disadvantages compared to Terne Plate.

Costs more for same weight of coating.

Tin plate is made in a number of different grades of coating. (See pp. 234-235.)

CHAPTER 14.

THE REFINING PROCESS—Continued.

METALLIC COATING PROCESSES.

Having given, in the preceding chapter, a general idea of the nature and use of galvanized sheets, tin plate and terne plate, we may now proceed with a brief description of the processes used in applying these metallic coatings as well as a more specific discussion of the character of these coated sheets.

The steel sheet must be clean and free from oxide before any of these coatings can be applied. Therefore, the steel sheets are thoroughly pickled and washed before coating. After pickling, they are kept submerged in tanks of clean water (containing a little hydrochloric acid in the case of black plate for tinning) until just before being fed into the coating pot, for if the sheets were allowed to remain long in the air after pickling, they would rust and be unsuitable for coating.

All treatment of the base sheets, such as annealing or cold-rolling, is done before the sheet is pickled for coating.

In each of these coating processes, the sheets pass through a suitable flux to prepare the steel surface for coating. Since they float on the molten metal bath, these fluxes are always very hot, so that as the steel sheet passes through, any remaining moisture is removed by being vaporized. The flux also gives a final cleansing to the steel surface, protects it from oxidation right up to the instant the sheet enters the coating bath, and may perform some other mysterious function in fitting the steel to take the coating.

Each of these coating processes involves the following basic steps, in the order given:

1. Cleansing the steel sheet by pickling.
2. Flux bath.
3. Coating bath.

After coating, tin plate must be cleansed, terne plate usually is, but galvanized sheets need not be.

The apparatus for coating is called the "pot." The galvanizing pot,

Courtesy of Wheeling Steel Corpn.

FIG. 55.—Galvanizing pot.

tin pot and terne pot are much the same in principle, although differing in details. The "pot" consists of the following two fundamental and separate parts:

1. *Pot, or kettle*, to hold the molten metal used for coating. Made of heavy steel plate for galvanizing and either of steel or cast iron for tinning.
   A brick furnace wall is built about the pot to contain the flame and heat for heating the coating metal. The top of the pot is left open, of course.
2. *Rigging* (for galvanizing)
   or
   Tinning Machine (for tin and terne plate)
   These consist of:
   - A. Conveying rolls:—spring pressure rolls to convey sheet through the pot.
   - B. Guides:—strips of steel curved to guide sheet through the pot.
   - C. Exit rolls (galvanizing) / Oil rolls (tinning) } spring pressure rolls at exit end of pot, specially designed to distribute and regulate the coating.

The rigging and the tinning machine are both movable in and out of the kettle or pot itself.

GALVANIZED SHEETS.

PREPARATION OF THE BASE SHEET.

The steel base sheets are desired to have a rather porous surface, which holds the galvanizing better than a polished, glossy surface. Therefore, the sheets are not cold-rolled for surface before coating. In gages lighter than No. 16 gage, which ordinarily are box annealed, the sheets are usually given one pass in unpolished cold rolls for flattening before being box annealed. In No. 16 gage and heavier, there is no cold-rolling at all and the sheets are open annealed as is customary for such gages of common sheets. Except in special cases, galvanized sheets are made as soft and workable as practicable.

After annealing, the sheets are pickled for coating.

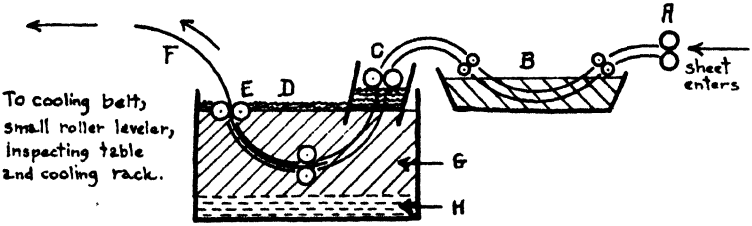

FIG. 56.—Galvanizing pot (skeleton diagram—section).
(Double curved lines represent guides to conduct sheet to next rolls.)

Legend:
A—Feed rolls.
B—Wash of muriatic acid solution.
C—Flux box, containing sal ammoniac which floats on the molten zinc; edges of flux box extend below the surface of the molten zinc.
D—Sal ammoniac "blanket" on zinc to protect it from oxidation.
E—Exit rolls.
F—Galvanized sheet leaving pot.
G—Molten zinc.
H—Layer of lead to protect bottom of pot and to collect "dross."

PROCESS AT THE POT.

The clean, pickled sheets, having been delivered to the galvanizing pot, are fed by hand, one at a time, into the feed rolls and then are mechanically carried through the pot, from which they emerge coated.

The process at the pot consists of the following steps, illustrated by Figure 56.

1. Wash in muriatic acid solution. To remove rust stains, film or dirt.
2. Wash in flux, composed of molten sal ammoniac. To remove moisture and prepare steel surface to receive the coating.

3. Immersion in molten zinc (spelter). (Zinc melts at 787° F. and the temperature is varied above this.) To coat steel with zinc.
4. Passage out of zinc through exit rolls, which distribute coating already adhering to sheet and apply a final, clean coating.
5. Cooling on chain conveyor belt, on which sheets are caused to fall after leaving pot. The "spangle" begins to form a few seconds after sheet leaves pot and is completely formed during journey on cooling belt.
6. Passage through a small roller leveler.* To flatten sheet after its bending voyage through the pot.
7. Inspection on both sides for coating or other defects. (Inspector uses small hand tongs because sheets are still too hot to touch with the hands.)
8. Cooling down further on a revolving (porcupine) rack. So can handle and mark sheets.
9. Marking with gage, size, brand, etc.

EXIT ROLLS.

Although the other rolls merely move the sheet along, the bottom and exit rolls serve to press the coating on and to remove excess lumps of zinc, thereby assisting in producing a smooth and uniform coating.

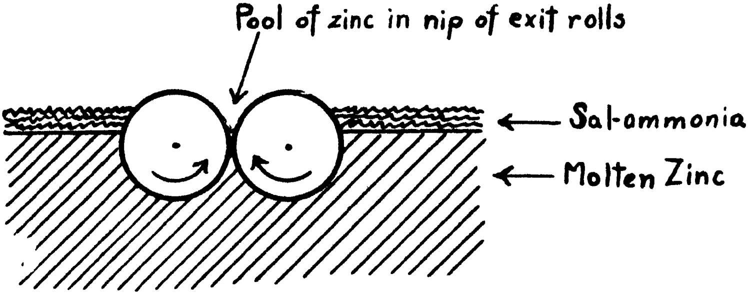

FIG. 57.—Exit rolls of galvanizing pot (section).

The exit rolls, particularly, must be turned true and adjusted so as to press together evenly.

The exit rolls perform very important functions in the galvanizing process. They operate approximately half immersed in the zinc bath; spiral grooves are cut in them, so that apertures exist between their surfaces and as they revolve, the rotation tends to pull up molten zinc, particularly since the level of the zinc usually is slightly above the juncture of the rolls, thus forming a pool of metal between the rolls above their point of contact. (See Fig. 57.) The sheet passes out of the zinc bath, through the exit rolls, which press off any lumpy, excess coating; then the sheet goes through the pool of zinc in the "nip" of the exit rolls and from this it takes up its final, smooth and clean coating, which ordinarily produces the bright appearance of regular

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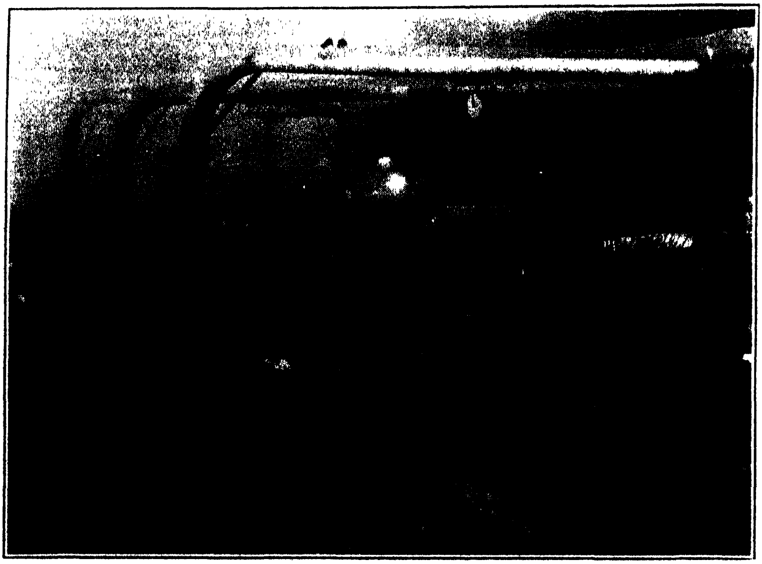
* A wash in water sometimes precedes this leveling.

spangled galvanized sheets. The higher the level of the bath comes on the exit rolls and the closer together the spiral grooves are, the deeper the pool of metal in the nip of the exit rolls will be and the heavier the final coating on the sheet. Therefore, it will be seen that the grooving of the rolls and the level of the metal are important factors in controlling the amount of coating. The speed of the rolls also tends to regulate the amount of coating.



Courtesy of Wheeling Steel Corpn.

FIG. 58.—Galvanizing: Showing cooling racks to which sheets travel by conveyor belt after leaving the pots.

Another very necessary function of the exit rolls is to keep the sal ammoniac foam (on top of the zinc bath) from coming in contact with the sheet as it emerges with its final coating. The foam must never be allowed to become so thick as to reach the top of the exit rolls. When dirty sal ammoniac foam accidentally gets on sheets leaving the pot, it causes dark spots.

The exit rolls must be kept smoothly coated with clean zinc, and to this end they are frequently sprinkled with clean sal ammoniac and allowed to revolve freely until they have taken a fresh zinc coating.

MILL CLASSIFICATION OF GALVANIZED SHEETS.

After coating, the galvanized sheets are inspected and classified into the following groups:

A. **Primes.**—Commercially perfect sheets:
   1. Properly coated on both sides.
   2. Full size.
   3. Reasonably flat for grade, gage and size.
   4. Clean and well spangled.

B. **Seconds.**—Less perfect than primes, but marketable as "galvanized seconds." (See pp. 193-194.)

C. **Gray Coated.**—(See pp. 194-195.)

D. **Strippers.**—Sheets which are imperfectly coated, but which might coat for primes if the coating is stripped off in "spent pickle" solution, then run through pot again.

E. **Re-runs.**—Sheets which are imperfectly coated, but which, it is believed, will coat properly if again run through pot without stripping off the coating.

F. **Scrap** or **Cobbles.**—Sheets too bad to come within any of the above groups. These are scrapped.

COMMERCIAL ASSORTMENT OF GALVANIZED SHEETS.

The only classifications of galvanized sheets which reach the market, of course, and in which a buyer would be interested, are primes, seconds and gray coated.

Primes.—When a buyer orders "Galvanized Sheets" he automatically receives all "Primes" unless he specifically orders "Seconds" or "Gray Coated."

Primes constitute the major part of the galvanized sheets sold and should, of course, be used where the whole sheet will be subjected to severe corrosion.

Seconds.—Mills produce varying percentages of seconds. These are laid aside for sale as such at reduced prices. They are always assorted to gage, but generally not to size; in the latter case they are sold as "so many tons of a certain gage" in random size with a minimum size agreed upon.

Although seconds are often used, by unscrupulous fabricators, where primes should be employed, there are many legitimate uses for seconds where they serve as well as primes. While some few second sheets may be uncoated over, say, 30 percent of their surface, the great majority of seconds are so classified because of small imperfections which may represent less than 10 percent of the sheet's area.

Under proper supervision, galvanized seconds may be correctly and economically used for the following classes of work:

1. Where the whole sheet will not be subjected to corrosive conditions severe enough to require a prime coating.

2. Where small parts are cut from the large sheet. These small parts can be reinspected and the percentage of rejection will probably be much lower than the percentage of cost saved through the use of seconds.
3. Where the coating is required mainly as an aid in soldering.

Most mills mark each sheet either with the full word "Second" or else with the letter "S." The mill brand is never placed on galvanized second sheets. These precautions are taken to protect the ultimate consumer against the misapplication of seconds.

The principal causes for classifying galvanized sheets as "Seconds" are:

Coating Imperfections.—Uncoated spots and porous, imperfect spots in the coating. The failure of a sheet to take galvanizing properly may be due to a great variety of causes, for example: where oxide and dirt is deep in the steel and is not pickled out, as in seams, streaks (from scabby bar), dirt and sand from hot mill furnaces which have been rolled into the steel; grease spots on the surface of the sheets, etc.

Size Imperfections (preventing sheet from being full size).—For example: Ragged edges, round corners, turned-down corners, hollow end, etc.

Lack of Prime Flatness.—For example: Very wavy edges, very pronounced buckles, etc.

Steel Imperfections (the coating itself may be all right).—For example: blisters, pinchers, holes, etc.

Extremely rough or pitted surface may cause rejection, depending upon the degree and extent; however, considerable roughness and pitting are allowable in primes, especially in heavy gages, provided the coating is perfect.

Gray Coated.—Sometimes gray-coated sheets are included in galvanized seconds. The better practice, however, is to segregate and sell gray-coated galvanized sheets as such. No great quantity reaches the market.

As the name implies, the coating on these sheets is a dull gray color, not glossy, and with small spangles or none at all. Coatings of this character are supposed to be due to irregularities, or peculiarities, in the composition and character of the steel sheet, because gray-coated sheets will show occasionally, here and there, in a run of bright-spangled sheets.

In spite of its poor appearance, the gray coating is said to be just as protective as the bright-spangled coating. However, gray-coated sheets are inclined to be brittle and should not be used for difficult forming.

Approximately 1,500,000 net tons of galvanized sheets were produced in the United States during 1929. (Annual Statistical Report, American Iron and Steel Institute, 1929.) This was slightly more than double the production during 1918. These figures illustrate the widespread and growing demand for this very useful type of sheet steel.

TIN PLATE.

Tin is a beautiful, white metal which corrodes very slowly. Owing to its scarcity, it is quite expensive and its usefulness, as pure tin is greatly impaired by its lack of strength. Tin plate combines the strength of steel with the good qualities of tin, at least so long as the coating of tin remains intact, and, of course, provides these combined qualities at relatively low cost.

The function of the tin coating is both to protect and to beautify the steel base sheet. Also, it facilitates soldering.

Tin plates are made with different amounts of tin coating. Those grades carrying the least tin coating are called "Cokes" and those carrying the most coating are called "Charcoals." In the early days of the industry, the better grades of tin plate (*i.e.*, those bearing the heavier tin coatings) were made with base sheets of charcoal iron, and the cheaper grades with base sheets of coke iron. Nowadays, however, all tin plates are made from mild, soft steel so that the words "Cokes" and "Charcoals" have lost their original significance, so far as the base sheet is concerned, but they still designate a difference in the amount of tin coating.

COKE TIN PLATE.

Coke tin plate constitutes, by far, the major portion of the tin plate produced. It is used for most of the tin cans, tin boxes, and the thousands of other uses to which tin plate is put.

The production of coke tin plate in this country during 1929 amounted to approximately 2,000,000 net tons. (Annual Statistical Report, American Iron and Steel Institute, 1929.)

Standard "Cokes" carry as little tin coating as will sufficiently protect and brighten the base sheets for the more or less temporary purposes for which such plates are used. This does not mean that no less tin could be successfully applied. On the contrary, tin coatings considerably lighter than those now put on standard "Cokes" could be applied; but although such lighter coatings might provide a passable appearance, they are not practicable from the standpoint of protection because the slightest abrasions would remove all the tin and expose the steel base sheet at the abraded points. Even standard "Cokes" are highly susceptible to damage from abrasions, but from experience, a practicable minimum amount of coating has been established, taking into account the uses for which they are intended.

Courtesy of Wheeling Steel Corpn.

FIG. 59.—Tin mill: General view of hot mill floor.

Although the amount of tin carried by standard coke tin plates actually is very small, modern tinning methods distribute it so evenly and thoroughly over the steel sheets that for most purposes it is ample protection and more would be superfluous. The limited amount of tin in the world, its high cost and mankind's dependence upon it for the manufacture of food-preserving containers, all these things dictate utmost conservation of tin in the interest of society at large. Of course, there are uses which require more tin coating than that on standard cokes, either for protection or appearance, and in such cases standard cokes should not be used, but one of the grades carrying more coating should be selected. It should be remembered, however, that beyond a certain point, the addition of more tin to the coating does not add either protection or brightness, but merely provides an extra amount of tin of benefit where abrasion is likely to rub off the coating, as in the case of kitchen utensils which will be scoured and like uses.

When the word "Cokes" appears alone in connection with tin plate, the mill understands this to mean "standard coke tin plate." Better grades of coke tin plate are made and these are designated by additional names, such as "Best Cokes," etc., and carry more coating than standard cokes, yet less coating than the "Charcoal" grades.

CHARCOAL TIN PLATE.

The "Charcoal" grades of tin plate have thicker tin coatings than the "Coke" grades.

Since charcoals are considerably more expensive than cokes, their use is small by comparison. Only about 36,000 net tons of charcoal tin plate were produced in the United States during 1929, or less than 2 percent of the coke tin plate output that year. (Annual Statistical Report, American Iron and Steel Institute, 1929.) Nevertheless, they are required for some important purposes.

The amount of coating on charcoal tin plate is indicated, in the trade, by special names or symbols in addition to the word "Charcoals"; frequently by the number of times the letter "A" appears in the title. For example, "A Charcoals" indicates plate carrying the least coating of the charcoal grades, "AA Charcoals" the next heavier coating, and so on up to "AAAAAA Charcoals" which have the heaviest coating. Sometimes these symbols indicating the amount of coating are written "1A," "2A," "3A," etc. Mills which do not employ the "A" symbols, use special names to designate their charcoal grades.

Charcoals (or at least the better coke grades) should be used where greater protection and fine appearance are sought.

Although, on the average, there probably are fewer pin-holes [*i.e.* minute openings in the coating (see pp. 185-187)] in the heavier coatings than in the lightest coatings, yet there are always some pinholes even in the heaviest charcoal coatings, so that freedom from pinholes is not secured in charcoals. Nevertheless, the heavier coatings provide greater protection against abrasion. Owing to the small amount of tin used on ordinary cokes, although this may uniformly coat the steel, it is so thin that it may be damaged easily by scratching, thereby impairing the protection afforded by the coating.

From the standpoint of appearance, there is a decided advantage in *favor of the heavier coatings. The tin coating on standard cokes may not be sufficient to fill up the small surface irregularities of the steel base sheet, with the result that the coating may not be very smooth and glossy. Charcoals, on the other hand, have enough tin coating to fill* and flow evenly over slight pits in the steel surface, producing a bright, smooth and glossy tinned surface.

Courtesy of Jones & Laughlin Steel Corpn.

FIG. 60.—Doubling pack during hot-rolling at tin mill.

WEIGHT OF COATING.

Although tin plates are never sold on the basis of the actual weight of coating, but always on the basis of recognized and established standards for the several coatings, yet the reader may be interested to know approximately what the coatings amount to. According to the grade and depending somewhat on the gage, the tin coating ranges from about 1.25 pounds to 2.75 pounds per base box in the coke grades and from about 3 pounds to 7 pounds per base box in the charcoal grades.

UNIT OF MEASURE.

The unit of measure of tin plate in the light gages is what is called the "base box," which is the area represented by 112 sheets of size 14 inches x 20 inches, or approximately 218 square feet. (See pp. 90 and 92.) However, the heavier gages, *i.e.* No. 24 gage and heavier, are sold by weight, the same as sheet steel, as a rule.

Method of Shipment.

Practically all tin plate was shipped in wooden boxes until quite recently, when fiber boxes and some other special methods of loading were introduced. (See p. 208.) The wooden box, however, is still the standard medium of shipment and its cost is included in the base prices of tin plate.

These boxes containing finished tin plate are called "packages" to differentiate from "base boxes." Packages contain, usually, either 56, 112 or 224 sheets, depending upon the size and gage; therefore, it will be seen that the package will contain all the way from a fraction of a base box up to two or more base boxes. Weight is the determining factor in the sheetage per package and it is customary not to have packages of tin plate weigh over 270 pounds each.

Preparation of the Base Sheet for Cokes or Charcoals.

For tinning, the steel base sheet is required to have a very smooth, polished surface for two reasons: first, to conserve tin, since a rough, porous steel surface would absorb more coating; and second, to permit the coating to adhere to the sheet evenly and smoothly, thereby producing the high gloss required in the tinned sheet.

To provide this smooth, polished steel surface for tinning, together with the requisite softness and workability, the base sheets, after hot-rolling, mill shearing and opening, are then subjected to pickling, annealing and cold-rolling operations. The sequence of these may be varied to produce special results, but ordinarily the treatment of the black, *i.e.* uncoated) plate consists of the operations below and in the order given. The black plate becomes what is called "Full Finish Black Plate" after the second annealing, and then must be pickled again before being coated to become tin plate.

Regular Treatment for Tin Plate.

(Following hot-rolling, mill shearing and opening.)

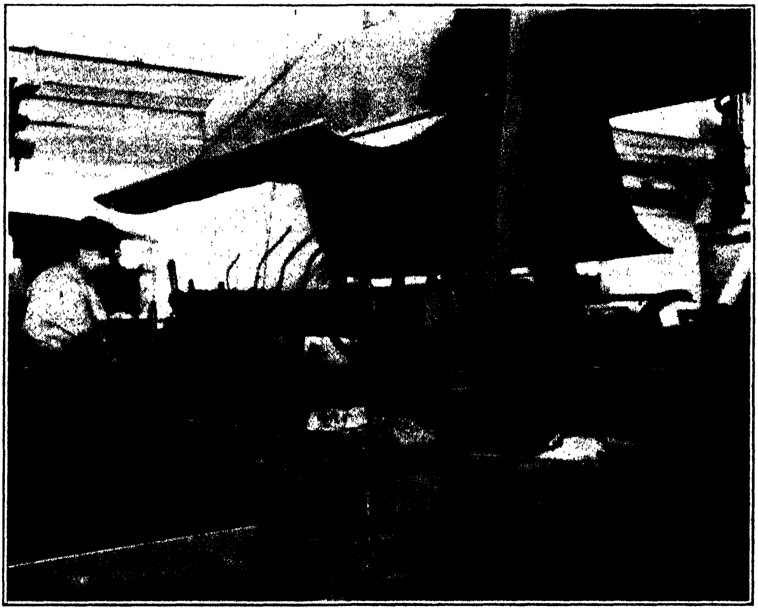
I. First (or black) pickling.........	Operations for "Full Finish Black Plate"
II. First (or black) annealing.......	
III. Cold-rolling (usually 3 passes)...	
IV. Second (or white) annealing.....	
V. Second (or white) pickling......	Further operations on "Full Finish Black Plate" to produce "Tin Plate"
VI. Coating in tin pot..............	
VII. Assorting	
VIII. Boxing, etc.	

The steel sheets as they come from the hot mills are covered with considerable oxide and are quite stiff and springy. They are then put through the first pickling to remove this oxide so that subsequent cold-rolling will operate on a clean steel surface and produce the desired smoothness and polish. Following this pickling, the sheets are box annealed very thoroughly to make them soft, after which they are separated by hand, because they frequently stick together in the high temperature first annealing. This first box annealing clears the sheets of stain from the first pickling and leaves only a small border of light oxide around the edges of the sheets, which are now clean and soft, fitted for effective cold-rolling. The sheets are now given three passes through polished cold rolls. The usual arrangement is to have three sets of cold rolls in tandem, the sheets being fed by hand to the first set of rolls and then carried by moving belts consecutively to the next two sets of rolls for the second and third passes. The sheets are now clean and smooth, but the cold-rolling has stiffened them slightly; therefore, to make them soft again, the cold-rolling strains must be removed by the second annealing which follows. This second annealing is carried on at lower temperatures and for shorter durations than the first annealing, because the clean, polished sheets would stick tightly together at very high temperatures and a fairly low temperature is sufficient to remove the stiffening effect of the cold-rolling.

Courtesy of Wheeling Steel Corpn.

Fig. 61.—Box annealing (tin mill): Small annealing boxes for tin mill sizes.

All these operations having been completed, the sheets now constitute what is called "Full Finish(ed) Black Plate," which means "black plate ready for tinning." However, the two annealings since the first pickling have produced a light film of oxide on the sheets, particularly around the edges, so that before the sheets are suitable for coating, they must be given the second pickling to remove this oxide and other foreign substances such as rust and dirt. The second (or white) pickling is quite brief, since there is much less oxide to remove than in the first pickling. After it has been performed, the sheets are immediately submerged in slightly acidulated water carried in small, movable tanks called "boshes," in which they remain until the bosh is moved to the tin pot and the sheets are not removed from the bosh until just prior to being fed into the pot.



Courtesy of Wheeling Steel Corpn.

FIG. 62.—Tinning: Hand-feed tin pot. The tinner is feeding the black plate into the tin pot.

TINNING COKE TIN PLATE.

Apparatus.—The tinning apparatus for cokes consists of a kettle or pot to hold the tin, flux and palm oil; also, a tinning machine which fits into the pot. The function of the tinning machine is to conduct the sheet through the molten tin in the pot, to distribute and to control the coating. In this respect it is comparable to the rigging of the galvanizing pot, but differs in construction and operation.

Process at the Pot.—The full-finish black plate, having been pickled clean in the second pickling, is taken from the water in the bosh and is fed into the tin pot, where it goes through the tinning process, the steps of which are briefly described below and illustrated by Fig. 61, emerging from the tin pot as tinned steel plates, or "tin plate."

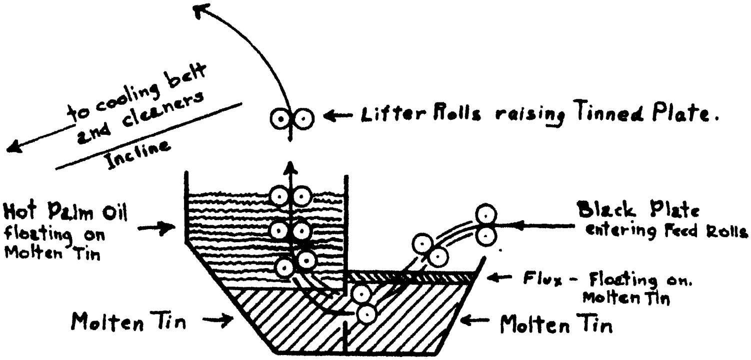


FIG. 63.—Tin pot—for cokes.

(Flux machine method—skeleton diagram—section)

Showing outline of pot, arrangement of tin, flux and palm oil; also rolls and guides in modern tin pot with roll-feeder.

To this installation may be added a machine which automatically picks the black plates out of the water bosh and introduces them into the feed rolls.

The old style tinning machine had no feed rolls and a skillful "tinner," by means of a long fork, pushed the black plate through the flux and tin until it engaged in the lower set of rolls on the exit (left) side.

The roll-feeder, and finally the automatic or mechanical feeder, have greatly increased the output per pot and lowered labor costs.

The process at the coke tin pot consists of the following steps in the order given:

1. Wash in flux composed of hot zinc chloride, or zinc-ammonium chloride.
   To remove moisture, clean surface further and to prepare the steel surfaces to take the tin coating.
2. Passage through molten tin.
   To coat the steel sheet with tin, as thoroughly as possible.
   First the steel must be heated up to the temperature at which the tin will adhere, therefore the tin is kept hotter at the entrance end of the pot—about 600° F.—to hasten this heating and to facilitate the operation of the tinning machine. The tin is kept about 100 degrees cooler at the exit end of the pot and this cooler tin assists in producing a lustrous coating.

3. Passage through hot palm oil and through the rolls which run in the hot palm oil.

   To remove excess coating, to distribute the remaining coating, and to produce a lustrous coating.

   The palm oil is heated, by the molten tin on which it floats, to a temperature around 475° F., which is just above the melting point of tin (450° F.). This keeps the tin coating barely molten, thereby permitting it to flow and be stripped off and distributed by the rolls.

   The palm oil having kept the tin coating just barely molten, the rolls tend to press off any excess coating and to press the remaining coating evenly against the steel sheet.

   The combined effect of the hot palm oil and the "oil rolls" is to produce a thin, evenly distributed, smooth tin coating.

   A little palm oil is kept in the "nip" of the top rolls. This coats the sheet with a thin oil film as it emerges into the air and prevents the hot tin from turning yellow, as it would in the absence of the protective oil film upon exposure to the air.

4. Conveyed by "lifter rolls," incline and moving belt to cleaners.

5. Passage through cleaners.

   To remove oil or other foreign substance and to polish the tinned surfaces.

   Cleaners for cokes and charcoals consist of two sets of buffing rolls, made of cloth, through which the plate is passed. Bran or cheap middling flour is circulated over the first set of rolls and this absorbs the oil from the plate passing through. Hence the name "branner," as the first set is called. Then the sheet passes through the second set of rolls which dust off and polish the tinned surfaces.

   The latest development is to pass the sheets through what is known as a "washer" containing a very weak solution of alkali, which cools the plate and removes most of the oil. This washing takes place just prior to the passage through the branner and buffing rolls.

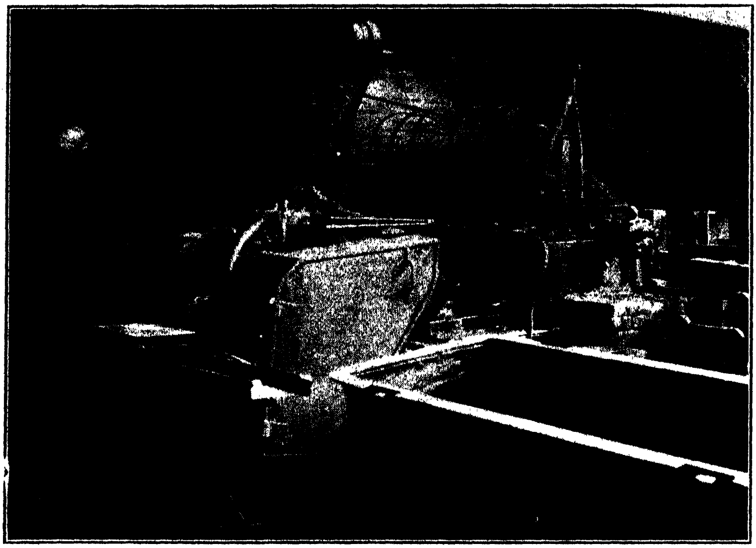
INSPECTION, ASSORTING, RECKONING, WEIGHING AND BOXING.

After tinning and cleaning, the tin plates are taken directly to the assorting tables, where they are carefully inspected on both sides and the commercial product is sorted out, ready for reckoning (counting the sheets), weighing and boxing.

ASSORTING COKE TIN PLATE.

It is often said that a man cannot draw a perfectly straight line. To all intents and purposes, the ruled line may be straight, but if one examines closely enough with precision instruments, some deviation from absolute straightness will be found. The same inadequacy of human ability applies to tin plate. It must always be borne in mind that it is physically impossible to produce a perfect tin plate, that is, with an absolutely continuous coating in which there are no breaks or apertures, however minute.

Minute pin-holes exist, to a greater or less extent, in the coating of all tin plate, but when these are so small as to be invisible to the naked eye, they do not interfere with the commercial utility of the tin plate and, therefore, may be disregarded. (See pp. 185-187.)



Courtesy of Jones & Laughlin Steel Corpn.

FIG. 64.—Tin pot with roll-feeder.

Courtesy of Jones & Laughlin Steel Corpn.

FIG. 65.—Inspecting and assorting tin plate.

A wide variety of visible imperfections, however, occur in the tin plate produced daily in each and every tin pot. These visibly imperfect plates are classified and graded by the inspection and assorting which all tin plate undergoes. In classifying tin plates, as with all other sheet steel products, certain standards are set, by which the different grades are judged. It will, therefore, be seen that in the final analysis, the standard used in assorting determines the relative excellence of the finished products. This is important for buyers to remember when considering competitive prices. Two different mills may be equally well equipped and operated, but if their assorting standard differs, their respective products will differ in quality.

After inspection on both sides, cokes are classified as follows:

MILL CLASSIFICATION OF COKES.

1. **Primes.**—First quality plates; free from visible coating defects and dirt; must be full size and commercially flat; also must be free from harmful defects in the steel base sheet such as blisters and heavy seams.
2. **Seconds.**—(Formerly called "Wasters") Second quality commercial plates with minor imperfections in the coating, in the base sheet, in the shape or size.

   Seconds can generally be used for the same purpose as the corresponding primes, provided a little extra care is exercised in utilizing them so that the small defects will not prove injurious.
3. **Waste-waste.**—Third quality commercial plates, with large imperfections in the coating, in the base sheet, in the shape or size.
4. **Menders.**—These are not sold, but are set aside during assorting as plates which may tin well enough for primes or seconds if run through the pot again. After being re-run through the pot, they are assorted again.
5. **Scrap or Cobbles.**—These are plates which are too bad to come within any of the above classifications and therefore are scrapped for de-tinning.

Coke Seconds.—There are numerous imperfections which cause coke tin plates to be classified as "Seconds," among which may be mentioned:

Coating Imperfections (lack of coating).
Dirt in steel or rolled into surface, preventing tinning.
Black patches—oxide not pickled off.
Grease.

Base Sheet Imperfections (impairing strength or appearance of plate).

Small blisters.
Scale pits—bar scale, open surface, annealing scale, etc.
Roll marks.
Pinchers.
Scratches.
Etched too deeply in pickling.
Lapped in cold-rolling.
Sledge marks.

Size or Shape Imperfections (rendering plate not full size or not flat).

Short sheets.
Round corners.
Crescent (hollow end).
Ragged edge.
Corner turned down in cold-rolling.
Crimped or bent in pot.
Not flat.

Many of the above must be moderate in degree or extent to pass for seconds, and if extremely pronounced or excessive they will frequently cause a sheet to be classified as waste-waste or even as scrap.

COMMERCIAL ASSORTMENT OF TIN PLATE.

Tin plate is sold under the following different plans and assortments:

1. **Primes Only.**—As the name indicates, only primes are shipped. An extra charge is made because primes cannot be produced without also producing seconds along with them, and since seconds may not be shipped under this plan, the mill will have to go the expense of holding and disposing of the seconds elsewhere.
2. **Primes, with Seconds Arising.**—This is the plan under which the great bulk of the tin plate production is sold. The primes and seconds are packed in separate boxes, but both grades are shipped. The packages of primes are marked with the letter "P," those of seconds with the letter "S." The seconds are billed at a reduced price.
3. **Unassorted.**—This plan contemplates shipping the seconds in the same package with the primes. The plates are inspected just the same as under the foregoing plans, and the menders and waste-waste are thrown out, but the primes and seconds are not separated from each other and are packed in the same box, which is marked "U/A," usually.

   In view of the inclusion of seconds, the unassorted packages are priced lower than the corresponding primes when seconds are taken separately.
4. **Seconds Only.**—This plan is only used in selling lots of seconds from excess stocks at mills. Some buyers can use seconds as well as primes and try to get seconds when possible, from excess mill accumulations, owing to the regularly lower cost of seconds and the further price concessions mills frequently make in disposing of excess stocks. Packages are marked "S."

In addition to the above, the following classifications of tin plate are sold:

Tin Waste-waste.—This consists of plates with more serious defects than seconds have, and is generally sold in packages containing random, mixed sizes in certain groups of gages. The buyers must assort it to gage as well as size, if necessary. Waste-waste is priced very materially lower than seconds.

Tin Strips.—These consist of narrow strips trimmed from various sheets. Tin strips differ from waste-waste in that they are, as a rule, of at least second quality on both sides. Like waste-waste, however, they are packed in random sizes in a range of gages, and sold at very low prices.

Courtesy of Jones & Laughlin Steel Corpn.

FIG. 66.—Reckoning and weighing tin plate.

BOXING, ETC.

As previously stated, it is standard practice for tin plates to be shipped in strong, hardwood boxes. The filled box is called a "package."

After having been assorted, the primes and seconds are "reckoned," that is, the proper number of plates to go into a box are counted out. This number of plates is then weighed, the weight is checked against theoretical weight, and the plates are placed in the box, which is then nailed up.

Sheetage.—Ordinarily, tin plates are packed 56, 112 or 224 sheets to the package, depending upon the base weight and size. The net weight of the tin plate should not exceed 270 pounds per package, since two men could not handle a heavier package very well. Most tin plate packages weigh considerably less than this 270-pound limit.

Marking.—The outside edges of the packages are marked with the grade, gage or base weight, size, mill name and with "P," "S," or "U/A," as the case may be.

Strapping.—The railroads require that packages for less-than-carload shipment have two or more steel straps or wires around the package as a reinforcement.

Special Packing and Loading of Tin Plate. Recently, fiber boxes, instead of wood, have been used to some extent. They are lighter, of course, but not nearly so strong as the wooden boxes.

Also, for large consumers and where carloads consist of but a few sizes, instead of the usual small boxes being used, the tin plate is loaded in the car in lots consisting of the equivalent of a number of ordinary packages. These larger lots are either contained in large wooden boxes, or sometimes where only a short haul is involved, the individual pile is not covered with a box but is securely bound with steel straps or wire. Such loading methods are sometimes called "ten-package containers" and "ten-package bundles," respectively. If desired, the individual pile, weighing perhaps 1,000 to 2,000 pounds, may be placed on blocks in the railroad car so that it may be raised and moved out of the car by a lift tractor.

Tin-lined Packages. Where it is necessary to provide complete protection against moisture while in transit, as sometimes is the case for export, the tin plates are enclosed in a tightly soldered tin case which is contained inside the usual wooden box.

SIZES OF COKES.

The only standard sizes of tin plate are 14 inches x 20 inches and 20 inches x 28 inches. All other sizes are odd.

Jobbers and dealers carry stocks of the two standard sizes and many manufacturing operations utilizing tin plate have been adapted to these sizes. However, the bulk of tin plate is produced in odd sizes specified by buyers according to their individual needs. Users should specify sizes calculated to do the work involved with the least scrap and at the same time come within the range of effective and economical production from the mill's standpoint. Extreme dimensions, either large or small, usually command an extra charge because they are more expensive to produce than the normal dimensions of a given product.

Although cokes can be made in some cases up to about 36 inches in width or in lengths up to 60 inches, there is generally an extra charge for widths exceeding 28 inches and for lengths much in excess of 30 inches. Extremely small sizes may take an extra for size. The maximum widths cannot be obtained in combination with the maximum lengths. Aside from the extra cost, extremely large dimensions should be avoided in tin plate, as in many other sheet steel products, because they militate against best results in manufacture.

GRAIN DIRECTION.

Where tin plate is to be seamed or bent more severely along one dimension than along the other, it is advisable to have the grain of the steel base plate run perpendicular to the line of severe bending. That is, if a 20-inch x 28-inch sheet is to be seamed parallel to the 28-inch dimension, the buyer should so state, or should specify: "Roll 28 inches wide," which will bring the grain direction parallel to the 20-inch and perpendicular to the 28-inch dimension.

"DRIP EDGE" OR "LIST EDGE."

As the tinned sheet comes up through the exit rolls, the tin tends to drain downward so that the bottom edge of the sheet as it leaves the pot carries a small bead of excess tin. This is called the "drip edge" or "list edge," and should be considered by the buyer in ordering when very particular work is contemplated. The buyer may specify, for example, on a 20-inch x 28-inch sheet that this is to be made with the "Drip Edge 20 inches." The bead is small on cokes and larger on the heavier coated charcoals.

TINNING CHARCOAL TIN PLATE.

Apparatus. The base plate for charcoals is prepared in exactly the same manner as for cokes. (See pp. 199-201.)

To apply the heavier coatings required on the better grades of charcoals, however, a different tinning method must be used. This includes a hand re-dripping in molten tin to increase the coating and is done in what is called a "combination pot," so called because it involves a combination of machine tinning and hand-dipping. (See Fig. 63.)

In this combination process, the sheets, after the white pickling, pass through a tinning machine very similar to that used for Cokes. (See p. 202.) After thus receiving a preliminary coating, they are grasped with small tongs and dipped by hand into a bath of molten tin, upon removal from which they are placed in a bath of hot palm oil. They are delivered out of this hot palm oil bath, by an arrangement of rolls, bearing the required coating for the grade of charcoals being made.

Precautions are taken to avoid scratching or damaging the bright coating of soft tin on the coated charcoal. As the plates emerge from the oil bath, they are seized with tongs and placed on edge in a traveling cooling rack, from which they are carefully fed to a cleaning machine, emerging clean and bright (or are cleaned by hand), whereupon they are carefully stacked by hand ready for assorting.

ASSORTING CHARCOAL TIN PLATE.

Charcoals are assorted into the same classifications as cokes (See p. 205), but the assorting standards are higher, of course, becoming more exacting progressively from 1A up to 6A grade. Both primes and seconds in 1A charcoal grade are higher quality than primes and seconds, respectively, in cokes, and 2A charcoals are higher quality than 1A, and so on up the list.

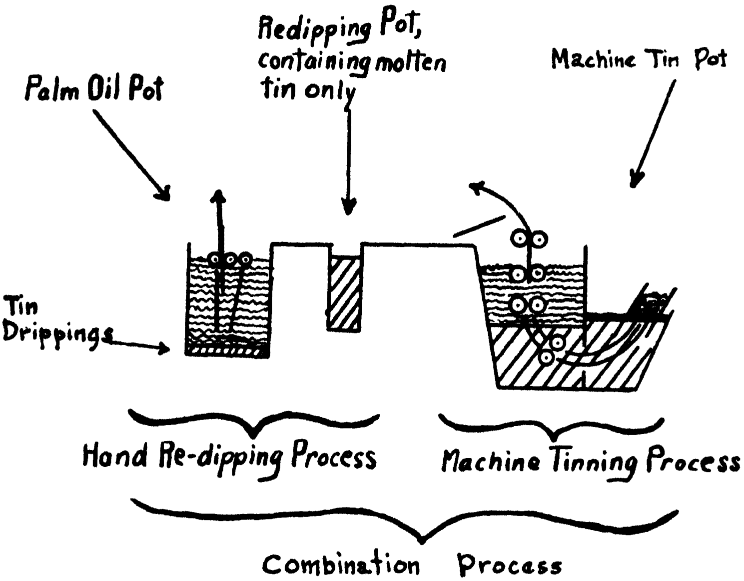


FIG. 67.—Combination tin pot (skeleton diagram—section). (For charcoals.)

The mill classification during the assorting of charcoals, however, includes an additional class which, naturally, is not included in the mill classification of cokes, namely, "Strippers." These are imperfect charcoal plates which are to be stripped down to a lighter coating, such as cokes. This is accomplished by running the plates through a pot adjusted to produce the lighter coating, thus stripping off any heavier coating present. After this they are reassorted and generally both primes and seconds of the lighter coating are obtained.

COMMERCIAL ASSORTMENTS OF CHARCOALS.

Charcoals are sold under the same plans and assortments as cokes, *i.e.*, "Primes Only," "Primes, with Seconds Arising," "Unassorted," and "Seconds Only—from Stock." (See p. 206.)

TERNE PLATE.

As already mentioned on p. 183, there are two types of terne plate, *viz.*: "short ternes" and "long ternes." The former are manufactured at tin mills, principally in heavy coatings for roofing purposes, and the latter in larger sizes at sheet mills.

According to the Annual Statistical Report of the American Iron and Steel Institute for 1929, the production in this country during that year of these two types of terne plate was: short ternes—approximately 43,000 net tons; long ternes—127,000 net tons, approximately.

SHORT TERNES.

The preparation of the steel base sheets for short ternes is almost exactly the same as for coke and charcoal tin plate. (See pp. 199-201.) As a rule, however, the black plate receives but one pass in the cold rolls. This is because, generally speaking, short ternes are not required to have an extra smooth surface and a highly polished steel surface would not satisfactorily take on the heavier terne coatings, such as 20 pounds and more.

Another difference in the regular black plate preparation is that "resquaring" is frequently performed, whereas cokes and charcoals are seldom required "resquared." The better grades of roofing ternes are always required "resquared" on three sides, at least, so that they may be easily and properly applied by the roofer. The sheets are not sheared exactly true and not always to the final size during the "mill shearing" which follows hot-rolling; furthermore, their shape and size are altered appreciably during the later cold-rolling, anyway. The resquaring, then, is done after the cold-rolling and the resquared black plate is piled ready for the second annealing. Resquaring after coating would produce raw, uncoated edges, which would rust quickly in the case of terne plate, and this would not be proper for roofing work.

There is one class of short ternes, however, to which the foregoing remarks on the treatment of the base sheet do not apply, namely, what are called "Manufacturing Ternes" (to differentiate them from "Roofing Ternes"). These "Manufacturing Ternes" are made with very light *coatings, 8 pounds or lighter, and are frequently given sufficient cold rolling to produce a smooth, rather glossy surface, the same as long ternes.*

COATING SHORT TERNES.

Three different methods are used in applying the coating to short ternes, depending on the weight of coating and other characteristics of the particular grade being made. These three coating methods are: the "flux" method, the "combination" method, and the "palm oil" method.

Flux method.—This is used for the lighter terne coatings, 8 pounds and lighter. The apparatus employed is similar to that used in coating coke tin plate (see Fig. 63, p. 202), with the exception, of course, that the pot is filled with molten terne mixture. The black plates enter the pot through a zinc chloride flux, then pass through the molten terne metal, from which the plates exit through hot palm oil.

Combination method.—This is used for producing the heavier terne coatings of the flux type, from 15-pound up to 40-pound coating. Zinc chloride flux is employed. It produces heavy coatings more cheaply than the "palm oil" method, and some say, of equal quality.

This method involves, first, machine coating as in the flux method, then hand re-dipping to increase the coating. The apparatus used is practically the same as the combination pot for charcoal tin plate (see Fig. 67, p. 210), substituting terne mixture for tin in the pot.

Palm oil method.—This method derives its name from the fact that palm oil is used for the flux as well as for the finishing bath, and consequently its product is called "Pure Palm Oil Process" terne plate.

It is entirely a hand process (being an ancient tinning method) and its products are more costly than similar coating weights made in a combination pot. Some believe that a "Pure Palm Oil" terne plate is better than a "Flux Method" plate of the same weight of coating. Only heavily coated roofing ternes are made by this method, generally from 30-pound to 40-pound coating.

The pot consists of: (See Fig. 68.)

1 tank containing warm palm oil.
2 pots of molten terne metal covered with palm oil.
1 pot of molten terne metal not covered with palm oil.
1 palm oil finishing bath tank.

The coating process consists of the following steps, during which the plates are handled with tongs by the tinners, no rolls or machines being employed in dipping to apply the coating:

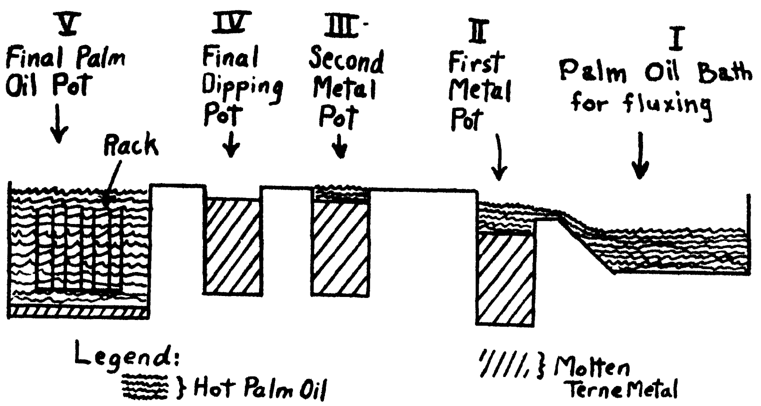


FIG. 68.—Hand dipping tin pot (skeleton diagram—section).
For "Pure Palm Oil Process" Terne Plate (short ternes).

1. Bath in warm palm oil—Tank I.
   A pack of pickled black plates is placed flat in tank.
   The warm palm oil cleans and fluxes the steel surface, preparing it for coating, also drives off moisture.
2. Bath in first metal pot (II).
   A pack of plates from tank (I) is placed, on edge, in pot (II); here the last of the moisture is removed by the heat, escaping as steam through the palm oil on top of the metal.
3. Bath in second metal pot (III).
   A pack of plates from pot (II) is place, on edge, in pot (III). From this, the plates are removed, about six to ten at a time and are placed flat on a ledge, ready for the final coating dip.
4. Dip in final dipping pot (IV).
   The plates are quickly dipped, one at a time, into clean, molten terne metal, where they take their last coating.
5. Bath in final palm oil tank (V).
   Upon removal from the final dipping pot, the plates are immediately placed in the rack in the final oil tank. The oil in this tank is at a temperature near the melting point of terne metal, so that the still molten coating on the plates can flow. This finishing bath in hot palm oil, therefore, tends to distribute the coating and to strip off excess terne metal. Upon removal from this final oil tank, the coating hardens and is in its final form. The length of time a plate remains in this final oil bath determines the final thickness of the coating—the longer the time it is in the oil bath, the thinner the coating.

CLEANING AND OILING.

Terne plate is made in two finishes, "oil finish" and "dry finish," the names indicating the presence or absence of excess oil.

Roofing ternes and those for deep-drawing operations usually are desired in "oil finish." Where terne plate is to be made into parts which are to be painted, "dry finish" is used, generally.

There is no uniformity in the method of finishing short terne plate after it leaves the pot. Everything depends on the grade and finish ordered. Some grades, made by the combination method, leave the pot so free of oil that in order to produce an "oil finish," the plates must be passed through cloth rolls saturated with oil. Other grades, including most of those made by the pure palm oil method, have so much excess oil on the surface as the plates leave the pot that even for "oil finish" they must have part of this excess removed in cleaning machines, similar to those used for cokes, except that sawdust is the absorbent medium, instead of bran.

For the sake of brevity, the foregoing must suffice on the rather involved and unimportant subject of cleaning and oiling short ternes.

Assorting Short Ternes.

Short ternes are assorted into the same mill classifications as charcoals, *viz.:* primes, seconds, menders, strippers, waste-waste and scrap. There is the difference, however, that all seconds (except odd sizes) in coatings heavier than 8 pounds are classified as "strippers" and are run through an 8-pound pot, the excess metal is recovered and the resultant 8-pound product is reassorted. This is because there is no demand for terne seconds in heavy coatings. Buyers must accept all seconds produced in odd sizes of heavy coated short ternes. Heavy coatings, ordinarily, are only produced in standard sizes (14″ x 20″ and 20″ x 28″) and are intended for application where severe corrosion is expected, as for roofing, for which only primes are suitable.

Stamping Short Ternes.

It is customary for mills to stamp (emboss) the weight of coating on each sheet of prime terne plate in coatings 20 pounds and heavier. This is for the protection of the ultimate consumer.

Commercial Assortments of Short Ternes.

Short ternes are sold in the following assortments:

Heavier coatings than 8-pound.	**"Primes Only"** (except odd sizes).
8-pound coating and lighter.	**"Primes Only."** **"Primes with Seconds Arising."** **"Unassorted."** **"Seconds Only"** (from stock).

"Terne Waste-Waste" and "Terne Strips" also are marketed; the assortment of these is the same as for "Tin Waste-Waste" and "Tin Strips" (p. 207), the coating alone being different.

The boxing of short ternes is carried out along the same lines as for cokes (pp. 207-208), except that packages are sometimes packed to weigh more than 270 pounds net.

MOTTLE.

One of the characteristic features of the heavier coatings of short ternes is the "mottle." This is a more or less regular patchwork of lines on the surface of the plate, creating a mottled appearance. The more lines there are, the smaller the individual mottle will be. Small, medium or large mottle may be specified by the buyer. The size of the mottle is controlled mainly by the speed with which the plate is allowed to cool. The mottle is not present in 8-pound coatings and is just barely visible, with very thin lines, in 15-pound coatings. As the coating becomes heavier, the lines become thicker, until in 30-pound and 40-pound ternes, the mottle is quite pronounced. An experienced workman can estimate the weight of coating quite accurately by observing the mottle.

LONG TERNES.

When the demand arose for terne plate in sizes larger than could be produced with tin mill equipment, means were developed for making this in sheet mill sizes and this product was called "Long Ternes." At present, long terne plate is usually manufactured at sheet mills which also make galvanized sheets, owing to the fact that the operations involved in the production of these two coated grades have much in common.

It is not customary to apply over 15-pound coatings to long terne sheets. They are made, for special requirements, in 12-pound and 15-pound coatings, but the bulk of this product is made in 8-pound coating or lighter. Long ternes are used, in the main, for automobile gas tanks, for covering wooden doors (kalamein doors) to make them fireproof, and for miscellaneous stamping and drawing operations. They are being increasingly used for metallic furniture, cabinets, etc. Extra smooth long ternes (sometimes called "Auto Body Long Ternes") are made, at extra cost, for purposes demanding an especially smooth surface.

The manufacture of the regular grade of long ternes borrows something from each of the processes used for coke tin plate, short terne plate and galvanized sheets. The black sheets from the hot mills are first annealed, then pickled to remove the scale, then cold-rolled to give them quite a smooth and polished surface, then box annealed to soften after the cold-rolling. At this stage, the sheets may be compared with full-finish tin-mill black plate. The next operation is a second pickling of the sheets to clean them for coating. After this they are passed through the long terne pot, in which, after first passing through a wash of weak acid solution as in the galvanizing process, they are subjected to the same series of steps as short ternes in the flux method, *i.e.*: zinc chloride flux, terne metal and palm oil, plus the action of the oil rolls. There is no hand re-dipping, as with combination short ternes, which explains why heavier than 15-pound coating cannot be made. To get 12-pound and 15-pound coatings, special pot adjustments are made, principally the installation of special oil rolls containing grooves. The machine which conveys and guides the sheets through the long terne pot is on the order of the rigging used in a galvanizing pot, but at the exit end there are rolls running in palm oil, and the pot itself is similar to that used for cokes and flux method short terns. (See Fig. 63, p. 202.)

CLEANING LONG TERNES.

Long ternes issue from the pot with more or less palm oil on their surfaces. Like short ternes, they are sold either with a "dry finish" or an "oil finish." However, the residual palm oil referred to above must be removed in either case, consequently the sheets are always passed through a cleaner, similar to the branner used for coke tin plate, but sawdust is circulated in this to absorb the excess palm oil, instead of bran or middling flour. After cleaning, the "dry finish" long ternes are ready for assorting, but to secure an "oil finish," the sheets then must be passed through cloth rolls saturated with a light oil. Even "dry finish" long ternes, however, carry a slight oil film on their surface, because the cleaning does not entirely remove all traces of the palm oil.

ASSORTING LONG TERNES.

Long ternes are assorted into the following mill classifications:

1. Primes—first quality.
2. Seconds—second quality.
3. Wasters—third quality.
4. Menders—to be run through pot again.
5. Scrap or Cobbles—no commercial value; scrapped.

In a general way, the remarks on these classifications in cokes on pp. 205-206 will apply to long ternes, but the assorting standards for primes and seconds are not so high as for coke tin plate, of course.

Long terne wasters may contain large uncoated spots, large blisters, seams, etc., the same as coke and short terne waste-waste, but long terne wasters are more valuable than these for cutting up into small parts because the percentage of good surface runs higher on account of the larger sheets.

COMMERCIAL ASSORTMENTS OF LONG TERNES.

Long ternes are sold in the following assortment:

1. Primes Only.
2. Primes with Seconds Arising (primes and seconds shipped separately).
3. Unassorted (primes and seconds mixed together).
4. Seconds Only (from stock).
5. Waster Only (from stock—assorted to gage but seldom to size).

CHAPTER 15.

INSPECTION, FORMING AND PAINTING, PREPARATION FOR SHIPMENT.

INSPECTION.

Much could be written concerning the final inspection of sheet steel and tin plate products, but only a brief, general outline of the subject can be given in a work of this scope.

The final inspection of coated sheets has already been described. (See galvanized—pp. 192-194; cokes—pp. 203-206; charcoals—pp. 210-211; short ternes—p. 214; long ternes—p. 216.)

The cheap, common grades of uncoated sheets, such as ordinary "blue annealed" and "box annealed" do not customarily receive a definite final inspection. They are, of course, observed by the workmen and foremen as they pass through the different stages of manufacture as well as while they are being prepared for shipment, and conspicuously bad sheets are discarded.

The more refined and highly finished the sheets are ordered, of course, the higher the standard becomes to which the mill must work, and the more carefully the sheets must be inspected, as a consequence.

FINAL INSPECTION OF SHEET MILL PICKLED GRADES.

Beginning with the single pickled grades, on which the inspection is cursory, more detailed inspection is given to the more refined grades until finally a careful examination is given each sheet of the double pickled, full cold-rolled grades, which include automobile finishes. The inspection of automobile sheet finishes is especially exacting.

In a sheet-for-sheet inspection, the inspector stands by the side of the pile and two men, one at each end of the pile, handle and turn over the sheets at his direction. The surface of each sheet is carefully examined by the inspector and if the first surface examined is up to the standard required for the grade, the sheet is stamped as a prime, otherwise, the sheet is turned over and if the other side passes it is stamped as a prime on that side. However, if neither side is up to the standard set for the grade in question, then the sheet is classified and stamped as a second, unless it is to be retreated, or is classified as a waster, or as scrap.

Speaking generally, such an inspection of each individual sheet is neither required by the standard, nor justified by the cost, of those grades cheaper than the full-pickled finishes and some other highly refined grades. However, there are times when special circumstances warrant a sheet for sheet inspection of the less refined finishes, but such cases are exceptional.

As previously stated, coated sheets are inspected for two good sides, that is, a Prime coated sheet should have prime coating on both sides.

In the case of uncoated, highly finished sheets, however, the inspection for surface is for one good side only. For example, an "Automobile Body Sheet" is a prime sheet if only one side is considered to be up to the prime surface standard for that grade.

Mill Classification of Double-pickled (Full-pickled) Grades. Double-pickled (*i.e.* full-pickled) grades are assorted at the mill into the following classifications:

Primes.—First quality sheets, with at least one side up to the surface standard of the grade in question, and up to standard in other respects, such as flatness, etc.

Usually each sheet is stamped with the mill name and the "heat number" (*i.e.*, the number of the heat of steel from which the sheet was made, for identification purposes), also the inspector's number; all this being included in the inspector's stamp, which is comparatively small.

Seconds.[1]—Second quality sheets for the grade in question. These sheets have some minor defects with respect to surface, flatness or other features which prevent them from being classified as prime sheets for the grade involved. They can usually be utilized for the same purpose as the primes with a little extra care in application.

Ordinarily, they carry an inspector's stamp similar to that used on primes, except that the heat number is omitted, or the stamp varies in some other way, so as to distinguish the seconds from the primes.

Wasters.—(Or some other suitable title indicating that these sheets are not of proper quality to be shipped against the grade in question, either as primes or seconds.) In most cases they are not purposely stamped. These sheets have more serious defects than seconds of the corresponding grade, nevertheless, they have commercial value and are set aside for sale.

Scrap.—Sheets with very pronounced defects making them of no commercial value. These are scrapped.

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[1] It is impossible to give in limited space any sort of an adequate description of the defects which cause sheets of the numerous full-pickled grades to be classified as "seconds," because these defects are not only difficult to describe, but also vary considerably according to the standard of the particular grade. What would constitute a defect for one grade would pass in a lower grade and the dividing line between grades is necessarily arbitrary and can only be established by a person experienced in pickled finish standards while actually examining the sheets.

This illustrates why it is practically impossible to write a specification covering the surface requirements of sheets. The buyer must accept the judgment of responsible persons who have examined the sheets as to whether or not they are up to the surface standard for the grade.

Commercial Assortments of Double-pickled (Full-pickled) Grades. The various grades of double-pickled (*i.e.* full-pickled) sheets are sold under the following plans and assortments:

Primes Only.—Usually at an extra charge because no seconds are shipped.

Primes, with Seconds Arising up to 15 Percent Included.—(Some grades and sizes require more than 15 percent seconds to be taken under this plan.) Seconds, within the percentage agreed upon, are shipped along with, but separate from, the primes. The seconds are billed at a reduction in price under the corresponding primes.

The great majority of users of highly finished pickled sheets purchase under this plan, arranging to utilize the seconds for the same work as the primes, possibly with a little extra care, or for less particular purposes.

Seconds Only.—From mill stock accumulations of excess seconds.

Other Commercial Classifications of Sheet Mill Uncoated Sheets. In addition to the foregoing commercial classifications of sheet mill full-pickled sheets, the assorting of sheet-mill uncoated grades gives rise to the following classifications which deserve brief mention:

Pickled Wasters (or equivalent title).—Included in this category are rejects below the standard of full-pickled and automobile sheet seconds, as well as rejects from single-pickled grades.

Sheets of this character can be put to very good use, where the fact that they are "pickled" is beneficial, particularly for small parts.

Frequently they are only assorted to gage and not to size, but are sold at greatly reduced rates to offset the feature of being in random sizes as well as their mixed character.

Black Wasters; or, Black Sheet Seconds (not pickled).—These are rejects from various unpickled grades and are of inferior quality, but can be well utilized for some purposes.

They are usually sold assorted to gage only, in random sizes, at prices even lower than pickled wasters.

INSPECTION OF TIN-MILL UNCOATED GRADES (TIN-MILL BLACK PLATE).

Tin-mill uncoated sheets, *i.e.* tin-mill black plates, are inspected, where this is called for, on much the same basis as sheet mill uncoated sheets. As a matter of fact, there are relatively few tin-mill black-plate finishes which warrant a final inspection of individual sheets, but there are some, of course. There is this difference between sheet-mill and tin-mill practice, namely, that such a final inspection is made of certain highly finished single-pickled grades, especially those which have been cold-rolled and are intended for very exacting uses. The reason for this is because tin mills, with their smaller sizes, can obtain somewhat better surface finishes, and consequently can set higher standards of surface, in single-pickled treatments than sheet mills can with their larger sizes and heavier gages.

Tin mills do not make any considerable quantity of what could be classified as "full-pickled finishes" and consequently do not ordinarily use this designation. They do not pickle breakdowns nor loose roll. The nearest approach to full pickling they do is when, for especially high finishes of uncoated sheets, the bar is pickled to remove embedded and surface scale, but in such cases the finished product is generally designated by a special name denoting the use for which it is intended. Their stock lists of excess material on hand at the mill generally list the material according to treatment under the general headings of "Primes" and "Seconds." If, on a tin-mill black-plate stock list, there is shown an item marked "PACR&A" under the heading of "Seconds," this identifies it as material which will not pass as prime stock for the grade indicated, but which has received the treatment "pickled, annealed, cold-rolled and annealed."

FORMING AND PAINTING.

PAINTING.

Sometimes buyers desire black (*i.e.* uncoated) sheets painted, for roofing and ceiling purposes. Roofing sheets are painted with red oxide of iron paint by mechanical means, ordinarily, and are oven dried. Ceiling sheets are painted gray in the same way. When so ordered, graphite and red lead paints are applied to roofing sheets; red lead usually being brushed on by hand. As a rule, painting is done before forming. Galvanized sheets are never painted at the mill. (See p. 177.)

FORMING.

Sheet mills perform certain forming operations in the manufacture of corrugated, V-crimped and other types of formed sheet products intended for roofing and siding purposes. These are usually made either of galvanized or painted black sheets, but may be formed from unpainted black sheets if desired. (The term "black" is here used in the sense in which it is employed in the trade, *viz.*: "uncoated.")

Corrugated Sheets.—Formed by passing sheets through corrugated rolls, except in the case of unusual corrugations or exceptionally heavy gages, when corrugating is done with a press.

V-Crimped Sheets.—Formed in a press.

Plain Brick Siding.—Formed in rolls.

Rock Face Brick and Stone Siding.—Formed in a drop-hammer die.

Weatherboard Siding and Beaded Ceiling.—Formed in a press.

Roll Roofing.—The sheets are seamed together, end to end, and then are rolled up into a roll.

Ridge Roll, Ridge Angle, Flashing, etc.—The plain varieties are formed by means of bending brakes. Where corrugated patterns are desired, these are formed in a press.

Courtesy of Youngstown Sheet & Tube Co.

FIG. 69.—Corrugating rolls.

PREPARATION FOR SHIPMENT.

TIN PLATE AND SHORT TERNES.

In former years, practically all tin plate, both cokes and charcoals, as well as short ternes, were shipped in hardwood boxes. (See pp. 207-208.) This is still the practice with charcoals and short ternes. These small wooden boxes, called "packages," are marked with the gage or base weight, size, grade, mill name and whether "primes," "seconds" or "unassorted." They must be employed for less-than-carload shipments of these products, in which case they must be reinforced with two or more steel straps or wires. For carload shipments, fiber packages are sometimes employed, nowadays.

In the last few years there have been some innovations in methods of loading coke tin plate. Large consumers have commenced to have their carloads of cokes shipped in large wooden or fiber boxes which contain the equivalent of ten ordinary packages, called "ten-package containers"; or in uncovered piles, each pile consisting of the equivalent of ten ordinary packages and being tightly bound into a unit by means of steel straps, called "ten-package bundles." These loading methods are cheaper than the small package method, involve less tare weight, avoid the time and labor consumed in opening numerous boxes and appear to give satisfactory results when shipments are over short distances. The "ten-package container" method is being used even for long hauls. When consumers are equipped with elevator tractors, the use of skids under the piles in the car, whatever the unit employed, permits one entire pile to be picked up with the tractor, thus facilitating the unloading of the car. Of course, arrangements must be made with the mill to have the piles no heavier than the tractor can lift.

ALL SHEET MILL PRODUCTS AND TIN MILL BLACK PLATE.

These may be shipped in the following ways:

1. **Boxed** (tight boxes; either "unlined," or "lined" with waterproof paper).—Recommended for less than carload shipments of highly finished sheets, or wherever there is the possibility of damage in transit or in handling at destination. Lined boxes should be ordered where rust from moisture is feared.
2. **Skeleton Crated** (either "unlined," or "lined" with waterproof paper).—These skeleton crates are cheaper than tight boxes, but serve the same general purposes, although in less effective manner. Unlined skeleton crates are principally useful in protecting the edges from damage and the entire sheets from being bent during shipment and handling.
3. **Bundled.**—Two or three steel bands are placed under a group of sheets and the ends of the bands are turned back over the edges of the sheets and hammered down, thus holding the sheets together and forming a "bundle." Sheet mill bundles weigh in the neighborhood of 150 lb. The weight of bundles of tin mill black plate varies. Lead-coated bands are used for bundling galvanized sheets to prevent discoloration of the coating on account of rust from the bands.

   Less-than-carload shipments which are not boxed or crated must be bundled, unless the sheets are very heavy and weigh about 100 lb. or more per sheet. Bundling is frequently preferable to loose shipment for carload lots of sheets which must be handled several times at destination, as for jobbers, or where consumers have no railroad siding adjacent to the plant.
4. **Loose.**—The sheets are placed in loose piles in the car and the piles are carefully braced with lumber which is nailed to the floor and walls of the car (box car) with heavy spikes. Piles of the better grades of sheets are sometimes covered with paper to provide some protection against moisture and dirt.

   A number of methods of unifying piles in "loose" shipments are being used. These consist of binding each separate pile of sheets into a solid unit by various means. A method employing several steel straps drawn tightly around the pile, then several piles being strapped into a still larger unit, called "strap bracing," appears to be the most practicable and successful. This method requires little or no wooden bracing.

   The great bulk of all sheet steel products, except tin plate and short ternes, is shipped "loose."

BRACING LOADED CARS.

Small, less-than-carload shipments, of course, cannot be braced in the car because the railroad must be able to transfer the material en route.

However, all carload shipments of sheet steel products shipped loose, bundled, boxed or crated must be braced with lumber or by other means, such as "strap bracing," in a manner approved by the railroad inspectors under the railroads' regulations. This bracing is intended to prevent the shifting of the lading when the car is jolted. The heavier the unit of the lading, the less extensive the bracing must be, of course, since the heavier the unit, the less easily it shifts.

The breaking down of bracing in carload shipments is usually the result of rough handling of cars while in transit. Although there undoubtedly are cases where the bracing could be improved upon, still the mills are very careful to install adequate bracing in accordance with the railroads' own rules, and shipments would almost invariably arrive with piles undamaged, were it not for the severe jolting sometimes given cars while en route.

MISCELLANEOUS ON LOADING CARS.

Box cars are used for loading sheets and tin plate unless open top cars are specifically requested. Open cars are only practicable or desirable for loading common sheets, usually in heavy gages, where rusting is not feared and where it is desired to unload the car at destination with an overhead crane, or where the sheets are too large to be loaded in box cars conveniently.

The minimum carload quantity of sheet steel products is usually 18 tons,[2] although for some destinations it is more, even up to 40 tons. The 18-ton minimum carload is a heritage of the days when railroad cars were smaller. Today, box cars have greater capacity and most carloads of sheet steel and tin plate contain from 25 to 50 tons. It is in the interest of national economy for cars to be loaded as near the capacity of the car as practicable, thus making the most efficient use of the railroads' equipment.

WEIGHING, MARKING, ETC.

The weighing and marking of packages of tin plate has been referred to on p. 208. Since all tin mill coated products lighter than No. 24 gage are sold by area, the weight of these is for mill record purposes mainly.

[2] Recently, a minimum of 20 tons has been required for many destinations.

Weighing Sheet Mill Products and Tin Mill Black Plate. These products are sold by weight, which is carefully determined for billing purposes as follows:

Boxed or Crated Sheets: Net weight of sheets to be placed in box or crate.

Bundled Sheets: Weight of sheets comprising each bundle, plus weight of the bands; this constitutes the weight of the bundle.

Loose Sheets: Net weight of each truck load of sheets as they are taken into the car; each item (*i.e.* each gage, size and grade) being compiled separately.

All weights are carefully checked against other mill records and a final check is made by comparing the net weight of the loaded car (loaded weight, less weight of empty car before loading, as determined by track scales) with the loader's record, which must check closely.

Marking. Sheet mill products are marked in numerous ways, according to the nature of the material and wishes of the buyer. In general, however, the sheet mill marking systems may be grouped and summarized as follows:

"Mark with Chalk": This consists of hand-markings in chalk, or stencilled markings in water color paint.

"Stencil with Paint": As the name implies, this consists of stencilled markings in oil paint, or stamp markings in ink.

"Omit Marks": This contemplates no marks on sheets except certain small identification marks, such as the heat number.

The features which, ordinarily, are included in the marking, according to the desires of the buyer or practice of the mills, are as follows:

Gage and size.—May be marked with paint or chalk on the top sheet of each bundle; or, in the case of loose sheets, on the top sheet of each pile or intermittently throughout the pile.

Brand (name of grade and mill name).—May be stencilled or stamped either on the top sheet of each bundle; or, in the case of loose sheets, intermittently throughout the pile. Some brands may appear on each sheet.

Heat number.—It is customary to stamp each sheet of pickled sheet-mill grades and of long ternes with a small inspector's stamp showing the heat number, inspector's number and mill name. This is for the purpose of identifying the sheets during and after the exacting operations for which such sheets are largely used.

Special markings are applied when necessary or desirable.

TESTING.

Chemical Analysis.—Each heat of steel is carefully analyzed from a sample taken when the ingots are being poured. This is called the "ladle analysis." Check analyses of the sheets themselves are made when necessary. Due to segregation, a check analysis almost always varies slightly from the ladle analysis of the same heat.

Physical Testing.—Bend tests and cupping tests are made regularly from pieces of sheets intended for difficult forming or when otherwise required.

Where the necessary laboratory equipment is available, pulling tests are made to determine the elastic limit, ultimate strength, and percentage elongation; also Brinell, Rockwell, and scleroscope tests for hardness.

All these laboratory tests are for the purpose of learning something about the strength, hardness, ductility and other physical properties of the sheets, but such tests can only be used as a guide since they can never be so comprehensive as to reveal the nature of any large number of sheets and, in fact, may not corrctly indicate the properties of even the whole of the single sheets from which the test pieces were taken. Therefore, without detracting in the least from the acknowledged usefulness of laboratory tests, it may properly be said that just as "the proof of the pudding is in the eating," likewise the proof of the sheet steel is in performing the actual work for which it is intended, and there is no practicable way to determine this absolutely by laboratory means.

Microscopic Examination.—Where the equipment exists, the structure of the steel is examined under the microscope and photomicrographs (microscopic photographs) are taken, whenever the occasion demands. Metallography is of great assistance to the manufacturer of sheet steel intended for difficult forming and drawing.

CHAPTER 16.

CLASSIFICATION, DESCRIPTION AND APPLICATION.

General Application of Sheet Steel Products.

The various grades and finishes of sheet steel and tin plate are used for such a multitude of purposes that anything approaching a detailed description of all these uses would require volumes. However, to give the reader an idea of the broad scope of the general application and utility of these materials, there are listed below some of the more important items contained in a compilation of 5,000 articles made from sheet steel, published by the Sheet Steel Trade Extension Committee:[1]

- Advertising Novelties
- Agricultural Implements
- Air-conditioning Systems
- Angles
- Arches, Corrugated
- Arresters, Dust
- Auto Accessories
- Automobiles
- Awnings, Corrugated
- Barrels
- Baskets
- Beads, Corner
- Beds
- Benches
- Bins
- Blower Systems
- Boats
- Bodies, Auto and Truck
- Boards, Running, Auto
- Boilers (Steam; Water; Range; etc.)
- Bowls
- Boxes
- Breechings
- Buckets
- Building Material
- Buildings, Steel
- Cabinets
- Cans
- Cars
- Cases
- Casings
- Caskets
- Ceilings, Metal
- Chairs
- Chutes
- Collectors, Dust, Systems
- Conveyors
- Coolers, Water
- Cornices
- Counters, Steel
- Covers
- Cribs, Corn
- Culverts
- Cups
- Desks
- Doors
- Dryers
- Eaves Troughs
- Elbows (Conductor, Stove, and Furnace Pipe)
- Elevators
- Enameled Articles
- Fans
- Feeders
- Fencing
- Fenders, Auto
- Flashing
- Flues
- Flumes
- Forms, Concrete
- Fountains, Poultry and Stock
- Frames, Auto
- Funnels
- Furnaces
- Furniture
- Gates
- Generators, Electric
- Guards
- Gutters
- Hampers
- Handles
- Hangers
- Hardware
- Heaters
- Hods, Coal
- Hoods, Auto
- Hoppers
- Incinerators
- Incubators
- Jackets
- Joists, Steel
- Kettles
- Kilns
- Laminations (for Motors, Generators and Transformers)
- Lamps
- Lanterns
- Lath, Metal
- License Plates, Auto
- Lockers
- Locomotives
- Machinery Parts
- Measures
- Meters, Gas
- Mixers
- Molding
- Molds
- Motors
- Nails
- Oilers
- Ovens
- Pails
- Panels
- Pans
- Partitions
- Perforated Metal
- Pipe (Various)
- Plates (Various)
- Plows
- Posts
- Pots
- Presses
- Pulleys
- Pumps
- Racks
- Radiators, Auto
- Ranges
- Reels
- Reflectors
- Refrigerators
- Registers, Heating
- Registers, Cash
- Ridge Roll
- Roasters
- Roofing
- Safes
- Scales
- Scoops
- Scrapers
- Screens
- Seats

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[1] "5000 Sheet Steel Products and Who Make Them."

Separators
Shelving
Shields
Shovels
Siding
Sifters
Signs
Sinks
Skylights
Spouting
Stacks
Stairs
Stampings
Stands
Stools
Stoves
Tables
Tacks
Tanks
Toasters
Tools
Tops, Table
Towers
Toys
Tractors
Transformers
Trays
Trim, Metal
Troughs
Trowels
Trucks
Tubing
Tubs
Urns
Utensils
Vats
Vaults
Ventilators
Ventilation Systems
Wagons
Warmers
Washers
Waterers, Stock & Poultry
Wheelbarrows
Wheels, Disc, Auto
Wheels, Pulley
Windows
Wringers, Mop

Where, and in what proportion, sheet steel products were consumed in 1929 is indicated by the following statistics prepared and published by "The Iron Age" (issue of Jan. 2, 1930) based upon reports to this publication covering a total of 1,903,000 gross tons of black plate for tinning and 5,564,100 gross tons of other sheet steel:

Table 15.—Estimated Distribution of Sheet Steel and Tin Plate in 1929 According to Shipment.*

	Sheet Steel (Sheets and black plate except for tinning) Percent	Tin Plate (Black plate for tinning) Percent
Automobile and parts manufacturers	28.6	1.9
Building and construction	8.2	...
(Hardware and trim companies 4.7%)		
(Fabricators and contractors 3.5%)		
Electrical manufacturers	7.1	...
Furniture and stove manufacturers	6.7	0.7
Metal containers	4.3	74.5
Agricultural equipment	3.6	...
Railroads (cars and locomotives, etc.)	3.2	...
Pressed and formed metal manufacturers	2.7	0.2
Oil, gas and water companies	1.7	1.3
Boiler and tank manufacturers	1.5	...
Machinery and hand tools	0.8	0.1
Mining and lumber companies	0.2	...
Shipbuilding	0.1	...
** Jobbers and warehouses	9.6	2.8
Miscellaneous	15.8	5.3
Exports	5.9	13.2
	100.0	100.0

* "The Iron Age," Jan. 2, 1930.
** Large part for roofing and other building purposes.

Classification, Description and Application of the Principal Grades and Finishes of Sheet Steel Products.

Although a complete description of the vast number of uses for sheet steel products might be too complex to have much practical value, and, at any rate, cannot be attempted here, nevertheless the reader may wish to have an approximate guide as to where and why the different varieties of these products are used.

The following tabulation has been prepared to summarize for the reader in brief and compact form, (1) a means of differentiating between the several main classes of sheets, based on the general classification given in Table 11 on pp. 94-95; (2) how the principal grades and finishes are referred to in the trade; (3) the characteristics of these grades and finishes and why they receive certain treatments; and (4) for what general type of work each grade is used, together with some typical, specific uses.

The author does not presume that this tabulated summary completely covers the whole field of sheet steel products and their uses; the essence of such a compilation is brevity which, naturally, precludes completeness.

However, if the reader has obtained, from the preceding chapters, some small knowledge of the various operations performed in the manufacture of sheet steel products, this tabulation, by definitely linking cause with effect, should enable him to differentiate between the main classes; help him to understand the reasons for the existence of the principal grades and finishes; and give him a general idea as to why these are treated as they are during manufacture, and for what purposes they are generally employed. Should this much be accomplished, the layman reader would then be provided with a basic comprehension of the manufacture and uses of the principal sheet steel products, as well as with the realization that considerable attention must be given to selecting the proper kind of sheets for any given work, particularly when the work is at all special or exacting, if best results and economy are to be secured; all of which would prepare and encourage the reader to study more carefully the particular classes, grades and finishes of sheet steel products which especially interest or concern him. This, at least, is the author's earnest hope.

(For definitions of terms and explanations of abbreviations which are used in the following tabulation, see Appendixes: "B," pp. 251 to 253; "C," pp. 254 to 256; and "D," pp. 257 to 258.)

TABLE 16.—CLASSIFICATION, DESCRIPTION AND APPLICATION OF THE PRINCIPAL GRADES AND FINISHES OF SHEET STEEL PRODUCTS.

(Giving the group and class of the grade according to the General Classification in Table 11 on pp. 94-95; the customary trade name or designation; remarks on the characteristics and the general application and typical uses of the grade or finish.)

GRADE			
Group and Class from Table 11, pp. 94-95	Trade Name or Designation.	Remarks on Characteristics.	General Application and Typical Uses.
I-A-1-a	(1) **"Tank Steel"** (No. 3 to No. 12 gage). (2) **"Trunk Sheets-Unannealed"** (light gages).	Sheets of this class, not being annealed, are harder and stiffer than annealed sheets; they carry the original hot-mill oxide.	Where little bending or forming is involved and stiffness is desired, as: (1) heavy tank and structural work; (2) cheap trunk covering.
I-A-1-b	**"Blue Annealed"** — or — **"Open Annealed."**	Made in No. 16 gage and heavier. Carries heavy oxide from open annealing. This is a crude, but tough and ductile sheet.	Heavy gage galvanizing; railroad cars; range boilers; heavy steel barrels; all work requiring crude, heavy, black sheets with good forming properties.
I-A-1-c	**"Box Annealed"** — or — **"One Pass Cold-rolled and Box Annealed."**	Made in gages No. 10 and lighter, principally lighter than No. 16. Carries box annealing oxide and some hot-mill oxide, but has a much cleaner surface than blue annealed. Not so tough and ductile, but generally softer for bending than blue annealed.	Light gage galvanizing; light steel barrels and drums; shelving; black metal lath; stove parts; and all work requiring soft, but crude sheets, and for which blue annealed is too heavy or not otherwise suitable.
I-A-2	**"Box Annealed, Full Cold-rolled and Reannealed."**	Principally made in gages lighter than No. 16. Carries about the same oxide as common box annealed, but this is smoothed down and the surface polished by the full cold-rolling. In gages heavier than No. 24, however, the oxide tends to loosen. The re-annealing after the cold-rolling makes the sheet soft and workable.	Japanned parts for stoves, etc., articles to be paint enameled requiring a fairly smooth, polished surface, but not a pickled and cold-rolled surface.

I-B-1-a	*Heavy gages (No. 16 and heavier).* **"Single Pickled"** (not cold-rolled) — or — **"Open Annealed, Pickled and Dried** (or limed)." *Light gages (No. 17 and lighter).* **"Single Pickled"** (not CR) — or — **"Pickled and Box Annealed"** — or — **"Box Annealed, Pickled and Dried"** — also — **"(Common) Enameling Stock"** (but see IV-A-5).	This open annealed, single pickled, is made in No. 16 gage and heavier. Same sheet as "I-A-1-b" except pickled so that surface is free of scale, but carries relatively deep pits from removal of embedded scale and of open-annealing oxide, therefore surface is pitted, open and porous. The box-annealed, single-pickled not cold-rolled grade is made, principally, in gages lighter than No. 16. Same as "I-A-1-c" except that sheet is pickled so that surface is free from heavy oxide and the rolled-in scale has been pickled out, leaving some pits. It will carry the light oxide from box annealing if this follows the sheet-pickling. Surface less open than "open annealed and pickled" grade, but still quite porous, not dense and not polished. If pickled after box annealing the surface will not carry any oxide.	Used for formed and drawn parts where oxide must be avoided to save die wear and for parts to be painted, enameled, spot or lap-seam welded, etc., where oxide is objectionable but, in all cases, where a dense or polished surface is not required. Examples: Open-annealed and pickled:—auto-frame parts, brake drums; heavy-gage articles to be drawn, spot welded or galvanized. Pickled and box-annealed:—inconspicuous auto-body parts; light-gage articles to be drawn, spot welded or galvanized. Common enameling stock is used, mainly in light gages, for small, drawn, vitreous-enameled articles, the relatively small size and drawn shape of which minimize the likelihood of objectionable warping under the heat of enameling.
I-B-1-b	**"(Single) Pickled, Cold-rolled and Reannealed."** Sheet mill: "A, Pk, Dry, CR, A." Tin mill: "Pk, A, CR, A."	Principally made in gages lighter than No. 14. This finish is a refinement of "I-A-2," the sheet being pickled before the cold-rolling and reannealing. It carries the light border from box annealing after pickling, unless "white finish" is ordered. The surface is smooth and polished, but subject to some pits and therefore not so dense as double-pickled grades.	Used for parts requiring a smooth, polished surface, but not requiring a surface so dense (free from pits) as double-pickled grades, and where, at the same time, heavy, loose oxide is objectionable on account of die forming, painting, spot welding, etc. Examples: Tinning; less particular filing cabinets and metal furniture; various formed, drawn, painted or japanned parts.

TABLE 16.—CLASSIFICATION, DESCRIPTION AND APPLICATION OF THE PRINCIPAL GRADES AND FINISHES OF SHEET STEEL PRODUCTS—*Continued.*

GRADE			
Group and Class.	Trade Name or Designation.	Remarks on Characteristics.	General Application and Typical Uses.
I-B-2-a	**"Double (*i.e.,* 'Full') Pickled** —not cold-rolled."	Made in heavy gages, mainly. This is a refinement of "I-B-1-a." In addition to the pickling of the sheet, a preliminary bar or breakdown pickling is given which minimizes embedded scale and consequently the pitting which would result from its removal in the sheet-pickling. Surface is dense and free from scale, but is etched from pickling and not being cold-rolled, is quite porous and not polished.	This is not very widely used, but is useful for some purposes requiring a heavy gage pickled sheet of dense surface, free from such deep pits as would be found in heavy gage "single pickled—not cold-rolled," but where a close, polished surface is not necessary. Examples: Electrical boxes, pressed stove legs, and various articles requiring a pickled sheet with a fairly good surface for painting and japanning.
I-B-2-b-i	**"Double Pickled, Cold-rolled and Reannealed."** commonly called: **"Full Pickled, Cold-rolled and Reannealed."** The best variety in this class is designated as: **"Metallic Furniture Stock—(First Grade)"** and is generally stretcher leveled; usually resquared after stretcher leveling but need not be unless desired.	Made principally in gages No. 16 and lighter. This is a refinement of "I-B-1-b" in that (like "I-B-2-a") the bar or breakdown is pickled to avoid the pitting which would result during sheet-pickling from the removal of much embedded scale. The cold-rolling closes up shallow pits, crevices and porous surface left by the sheet-pickling. Final surface is dense, close, polished and free from heavy scale but carries the light oxide from box annealing after sheet-pickling, unless ordered in "White Finish." The latter involves de-oxidizing or wash-pickling and drying after the final box annealing and costs extra, as a rule.	This class of sheet is widely used for work requiring a dense, close, polished, clean surface, in short, where a polished, pickled sheet, with a denser and closer surface than that of "Single Pickled, Cold-rolled and Reannealed," is needed, but where the finer surfaces of the more expensive Automobile Finishes are not necessary. Examples: First quality metal furniture and filing cabinets, steel doors, smooth welded tubing, etc.

I-B-2-b-i (*cont.*)		Given individual sheet inspection for one good side; assorted into primes and seconds.	
I-B-2-b-ii	**"Automobile Finishes."**	This class comprises the finest steel surfaces obtainable in sheets. Not usually made lighter than No. 22 or No. 23 gage. This class is a refinement of "I-B-2-b-i" because of loose rolling, more care throughout and closer final inspection.	In general, these finishes are used for sheet steel parts for automobiles which are conspicuous and on which a very fine enameled (paint or pyroxilin) finish is desired, or wherever the best possible sheet steel surfaces are required.

(There are several standard grades, listed below, which combine, in varying degree, both surface perfection and drawing quality. In addition to these, numerous special grades and treatments of Automobile Finishes are devised, from time to time, for specific purposes.)

Standard Automobile Finishes	(All sheets of this class are assorted into primes and seconds.)	*Typical Automobile Uses*
1. **"Auto Body Stock—(Full Finish)."**	The basic grade of this class. Surface very dense and close; polished.	Fender splash guards; hood sides; relatively flat body panels.
2. **"Auto Body Stock—(Dull Finish)."** also called: **"Auto Panel Stock."**	Surface is dull, not quite so polished as No. 1, but practically as close. A softer sheet than No. 1, better suited for severe drawing and stamping; generally ordered in "Deep Drawing" or "Extra Deep Drawing" quality.	Stamped and deep drawn body panels, and other parts requiring a surface similar to No. 1 but of a softer temper.
3. **"Auto Hood and Fender Stock."**	Surface of a higher standard, somewhat closer and more highly polished than No. 1. Temper usually slightly stiffer than No. 1.	Where a still better surface than No. 1 is needed. Hood tops and sides; running board shields. (Formerly used for shallow-drawn fender bodies, but not suitable for the modern full crown fender bodies.)

TABLE 16.—CLASSIFICATION, DESCRIPTION AND APPLICATION OF THE PRINCIPAL GRADES AND FINISHES OF SHEET STEEL PRODUCTS—*Continued.*

GRADE			
Group and Class.	Trade Name or Designation.	Remarks on Characteristics.	General Application and Typical Uses.
I-B-2-b-ii (*cont.*)	*Standard Automobile Finishes* (*cont.*)		*Typical Automobile Uses* (*cont.*)
	4. **"Deep Drawing Auto Crown Fender Stock."**	Surface is practically the equivalent of No. 3, but the sheet is better suited for deep drawing operations.	Deep drawn crown fender bodies and other parts where a "Hood and Fender" finish is required to stand severe forming.
	5. **"Extra Deep Drawing Auto Crown Fender Stock."**	Surface similar to No. 4; sheet still better adapted for severe drawing operations.	Same as for No. 4, but where the drawing or forming involved is even more exacting.
	6. **"Extra Deep Drawing Auto Radiator Casing Stock."**	Surface is dense and close but not so highly developed as Nos. 1, 3. 4 and 5, more comparable to No. 2 in this respect; but drawing properties very highly developed. Of all the automobile grades, this is the most capable of withstanding very severe drawing operations without breakage or injury to the surface finish, but the surface is not so good to start with as that of the other grades.	Radiator casings. (Generally plated with nickel or chromium after forming, although sometimes paint enameled.)
II-A-1-a	**"Cokes."** (Standard coke tin plate.)	Cheapest tin plate made; carries the lightest tin coating consistent with thorough coating of the base steel sheet. Ordinarily made in gages No. 16 to No. 38 (55 lb. base weight) inclusive; principally in base weights from 135 pounds to 80 pounds, inclusive.	Tin cans to contain preserved food. Also, gasoline and oil cans; numerous varieties of cans and boxes for coffee, tea, tobacco, candy, etc., bottle caps; various articles and parts where the bright, non-poisonous and easily soldered tin coating is desired. For lithographing and decorating.

II-A-1-b	**"Best Cokes."**	Tin coating heavier than on standard cokes.	Where slightly better grade than standard cokes is needed.
II-A-1-c	**Special Cokes.**	Heavier coating than "Best Cokes," but not so heavily coated as "1A charcoals."	Where a grade intermediate between "Best Cokes" and "1A Charcoals" is required.
II-A-2	**"Charcoals."** Various grades, from 1A to 6A. Amount of coating indicated by the number of A's, or by special names.	The amount of tin coating on charcoals is heavier than on any coke grade. 1A has the least coating, 2A has more, and so on through 3A, 4A, 5A and 6A.	Where a very bright, extra good quality tin plate is required, as for special cans, boxes, gas meters, lanterns, kitchenware, etc.
II-B-1	**Short Ternes.** "Light coated"—for manufacturing. "8-pound coating." "15-pound coating." "20-pound coating." "25-pound coating." "30-pound coating." "40-pound coating."	Coating is terne mixture, an alloy of lead and tin. Dull gray color. The amount of terne coating, except on "light coated," is expressed in pounds per double base box. Ordinarily made in gages No. 24 to 100 pounds base weight. Roofing Ternes in 107 pounds and 135 pounds.	The lighter coatings are used for cans and packages where the brightness and non-poisonous nature of a tin coating is not required, also for numerous drawn and fabricated articles. The heavier coatings are used for roofing purposes, for which no lighter than 20-pound coating should be preferably 30- to 40-pound coating.
II-B-2-a	**"Long Ternes"** (regular grade).	Same as short ternes, but made in larger sizes and heavier gages. Ordinarily produced in gages from No. 16 to No. 30.	Automobile gasoline tanks; fire doors; metal furniture; and numerous drawn or soldered articles.
	i. Standard coating.	Coating as light as consistent with thorough coating of the steel base sheet	(See **above.)**
	ii. 12-pound coating.*	Heavier coating than regular.	Where heavier coating desired.
	iii. 15-pound coating.*	Heavier coating than 12 pounds.	Where still heavier coating is desired.

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* **Weight of coating expressed in pounds per double base box, as with short ternes.**

Table 16.—Classification, Description and Application of the Principal Grades and Finishes of Sheet Steel Products—*Continued.*

GRADE			
Group and Class.	Trade Name or Designation.	Remarks on Characteristics.	General Application and Typical Uses.
II-B-2-b	**"Long Ternes-Auto Body Grade."**	Similar to regular grade except that a denser and closer surfaced base sheet is used, resulting in a finer surface on the coated sheet.	Where the work requires a more perfect surface than is obtained with ordinary grade, as for fine metal furniture and cabinets. Not much used for auto body work at present.
II-C-1	**"Galvanized Sheets"** (regular "spangled" coating). Various weights of coating are supplied.	The zinc coating exists in the form of large, bright crystals called "spangles," which are characteristic of this type of coating. Ordinarily made in gages No. 10 to No. 30.	In general, these sheets are used wherever it is desired to provide the best cheap protection against iron rust caused by water and air, provided the zinc coating is not objectionable (as it would be for food containers) and is not damaged by fabrication or use.
	Extra heavy coatings (specified in ounces per square foot).	Coating heavier than standard. Not suitable for seaming operations because the thicker the zinc coating, the more it tends to crack and flake off when bent. The thicker the zinc coating, provided it is not cracked, the better it protects the underlying steel base sheet against the appearance of rust.	Corrugated sheets for roofing, culverts and other uses where forming is not severe enough to cause serious flaking of the heavy coating, and where a thicker and more protective coating is desired than is obtained on standard galvanized sheets.

II-C-1 (*cont.*)	**Galvanized Sheets** (*cont.*)		
•	Standard coating (automatically furnished unless otherwise specified).	The coating applied to these sheets is well standardized among sheet manufacturers and is of the thickness which both provides good protection, and also permits moderate forming without serious flaking.	Corrugated and other roofing and siding sheets; furnace casings; ventilating ducts; tanks and galvanized sheet metal work in general where forming is not severe.
	Tight coatings.	These coatings are lighter and more tenacious than the standard coating. They permit severe forming, seaming and even drawing with a minimum of flaking. These coatings, while spangled, are not so bright and glossy as standard galvanized sheets.	All galvanized articles and sheet metal work which involves severe forming and seaming operations where objectionable flaking would be encountered with standard coating. They should only be used where heavier coatings would be undesirable on account of flaking or for other reasons. A thin, sound coating is better protection than a thick coating which has been fractured at vital points.
II-C-2	*Non-spangled galvanized sheets.* Also called: **"Dull Coated Galvanized"** **"Oven Lining Stock"** and various special trade names.	The zinc coating on these sheets is of a dull gray appearance, not spangled like regular galvanizing. However, small patches of spangled coating are sometimes found on some grades, generally near the edges of the sheets. This type of coating does not flake off when subjected to heat, whereas spangled galvanizing does. Also, it withstands severe forming without flaking, although the coating may "dust off" in small particles when the sheet is severely distorted.	Oven linings—because it does not flake off when heated. Drawing and forming work which would produce objectionable flaking of spangled galvanizing. Articles to be painted, but which are desired to have the excellent rust protection of a zinc coating under the paint; examples: metal cabinets (for refrigerators, etc.), signs, metal covered panels for doors, etc.

TABLE 16.—CLASSIFICATION, DESCRIPTION AND APPLICATION OF THE PRINCIPAL GRADES AND FINISHES OF SHEET STEEL PRODUCTS—*Continued.*

GRADE			
Group and Class.	Trade Name or Designation.	Remarks on Characteristics.	General Application and Typical Uses.
III-A-1-a	**"Blued Stove Pipe Stock."** (Sometimes inaccurately called "Uniform Color Blued Sheets").	Usually sold in gages No. 25 and lighter. Common steam-blued sheets, not polished. Fairly uniformly blued all over the sheet surface, but with some variation in the shade of the color. Slightly stiff, making it well adapted for forming cylinders.	Stove pipe and stove parts, and wherever a common, cheap blued sheet is desired having a certain amount of stiffness.
	"Blued Elbow Stock."	Similar to above, but somewhat softer.	Elbows for stove pipe; ovens and where a soft, common blued sheet is desired.
III-A-1-b	**"Full Cold-rolled Blued Stove Pipe Stock."**	Same as "III-A-1-a" except polished by cold-rolling.	Where somewhat better finish than "III-A-1-a" is needed.
III-A-2	*Special brands of high grade "un-pickled, air-blued, polished sheets."*	These are smooth, dense surfaced, un-pickled sheets on which a uniform but heavy oxide is built up by air-bluing and this is rolled in and polished by cold-rolling. The oxide thus formed is the most protective of all blued coatings but being thick, tends to flake under severe forming.	High grade stove parts, stove pipe, roasting and baking pans, oil heater bodies, locomotive jackets, etc. In general, any purpose requiring a fine, polished blued surface with greatest possible resistance to heat, rust and abrasion, but where severe forming is not involved.
III-B-1-a	**"Blued Stove Pipe Stock-Pickled"** and **"Blued Elbow Stock-Pickled."**	Usually made in gages No. 24 and heavier. Similar to "III-A-1-a," except that the steam bluing is applied to a pickled surface to guard against the loose scale which tends to form on the heavier gages of unpickled, steam blued sheets.	For purposes requiring common blued sheets in gages heavier than No. 25, such as stove parts, roasting pans, etc.

III-B-1-b	**"Cold-rolled Blue-Pickled"** and special brands of pickled, steam-blued and full cold-rolled sheets.	Smooth, polished, blued sheets, with a relatively light oxide coating which will withstand forming with less flaking than unpickled.	Where a more polished surface than "III-B-1-a" is desired and where a thinner oxide coating than "III-A-1-b" is needed to stand forming.
III-B-2	*Special brands of high grade "pickled, air-blued, polished sheets."*	Blued sheets of this class have the most uniform color and finest appearance of all, due to the air bluing on a clean, dense, polished, pickled surface. However, the blue oxide coating is necessarily thin, and while this permits it to withstand forming without flaking better than the heavier oxide on the unpickled blues, the latter are better protected when flaking is not a factor.	Best adapted of all blued sheets for work involving severe forming, and where a better appearance and more uniform color is needed than is secured in pickled steam blues such as "III-B-1-a and b." Typical uses are: high grade portable ovens, drawn stove parts and miscellaneous light gage stampings where a nice blue oxide is desired on the finished piece.
IV-A-1	**"Copper-bearing Steel."**	Normal, low-metalloid steel alloyed with copper. It has been customary to specify 0.20 to 0.30 percent copper, by ladle analysis, to insure the full effectiveness of a copper content in retarding atmospheric corrosion. Some claim that higher copper contents, even up to 1 percent, are desirable for resisting certain corrosive influences, other than atmospheric.	Where, at small extra cost, it is desired to prolong materially the life of sheet steel exposed to corrosive attack, as from moist air or any alternately wet and dry conditions. Typical uses: roofing; railroad cars; tanks, stacks, culverts; barrels; window frames; etc.
IV-A-2	**"Deep Drawing Quality"** —and— **"Extra Deep Drawing Quality."**	Special analysis or selected quality steel, receiving special treatment and attention for the purpose of improving the drawing and forming properties of the finished sheets.	Severe forming and difficult drawing operations.

TABLE 16.—CLASSIFICATION, DESCRIPTION AND APPLICATION OF THE PRINCIPAL GRADES AND FINISHES OF SHEET STEEL PRODUCTS—*Continued.*

GRADE			
Group and Class.	Trade Name or Designation.	Remarks on Characteristics.	General Application and Typical Uses.
IV-A-3	**"High Carbon Sheets."** (Various carbon contents.)	True carbon steel. Carbon contents over 0.15 percent and upwards, but sheets are seldom made with over 0.90 percent carbon. The carbon adds strength and hardness together with unavoidable brittleness.	Articles requiring greater strength or a harder surface or greater stiffness than is obtainable in normal, low-metalloid steel.
IV-A-4	**"Electrical Sheets."** (Several grades, of different silicon content and analysis.)	Silicon alloy steel. The silicon content and special annealing of each grade is calculated to produce the guaranteed electrical properties under which each separate grade is sold.	Laminated structures of electrical motors, generators and transformers.
IV-A-5	Special vitreous enameling sheets. (Sold under various trade names.)	Usually made of extra-low-metalloid open hearth steel (see pp. 25, 35, 56.) Experience indicates that such metal warps less under the heat of vitreous enameling than normal low-metalloid steel, from which common enameling stock is made. These special vitreous enameling sheets are carefully manufactured and assorted to avoid blisters, seams and other obstacles to good results in vitreous enameling practice. They are always pickled, usually in such manner as to be entirely free of oxide. The surface is relatively dense but is designed to be somewhat porous.	Large, flat vitreous enameled parts for stoves, ranges, refrigerator linings, refrigerator cabinets, table tops, etc.
IV-A-6	*Stainless or rustless iron or steel.* (Various trade names.)	Chromium alloy steel. Practically rust-proof for ordinary purposes, although some acids will attack it. Also heat resistant. Non-tarnishing when perfectly clean and highly polished.	Where rust-proofing, or stainless white metal, or heat resistance is desired and the higher cost of sheets of this character is warranted. (See pp. 28 and 56.)
IV-A-7	**"Tack Plate."**	Special analysis and treatment.	Manufacture of tacks and shoe nails.

IV-B	*Special finishes;* among which are:		
	"Common Enameling Stock"...	Variety of "I-B-1-a," usually light gages.	Relatively small, drawn vitreous-enameled ware.
	"Milk Can Stock"	Refinement of "I-B-1-b."	Milk cans.
	"Show Card Stock"	Refinement of "I-B-1-b."	Lithographed cards, cans, etc.
	"Metallic Furniture Stock"	Refinement of "I-B-2-b-i."	First grade metal furniture.
	"Auto Running Board Shield Stock"	Variety of "I-B-2-b-ii-(3)."	Auto running board shields.
	"Auto Hood Top Stock"	Variety of I-B-2-b-ii-(3)."	Auto hood tops.
	"Galvanized Sign Board Stock"	Variety of "II-C-1."	Sign boards, etc.
	"Galvanized Refrigerator Lining Stock"	Variety of "II-C-1."	Refrigerator linings.
	"Full Cold-rolled Japanning Stock"	Variety of "I-A-2."	Japanned stove parts, etc.
V	***Extra finishing operations*** (added to certain grades when desired).		
	A. White Finish {Pickling last —or— de-oxidizing.}	All oxide eliminated from pickled grades (even the light "border" from box annealing) either by pickling and drying after the last annealing or by de-oxidizing during box annealing following pickling. De-oxidizing of un-pickled, box-annealed grades removes oxide fairly well, but not well enough to produce a true "white finish."	Where pickled grades must not carry any oxide at all, not even the light box-annealing "border," as for particular electrical spot and lap-seam welding, to save wear on dies, etc. De-oxidized sheets are not suitable for tinning.
	B. Roller Leveling.	Produces sheets flatter than ordinary standard, but not so flat as "stretcher-leveled" sheets. Also benefits in certain drawing operations. (See p. 172.)	Where something more than ordinary flatness is desired, but where stretcher leveling is not necessary or desirable.

TABLE 16.—CLASSIFICATION, DESCRIPTION AND APPLICATION OF THE PRINCIPAL GRADES AND FINISHES OF SHEET STEEL PRODUCTS—*Continued.*

GRADE			
Group and Class.	Trade Name or Designation.	Remarks on Characteristics.	General Application and Typical Uses.
V (*cont.*)	*Extra finishing operations.* **C. Stretcher Leveling** (*i.e.* patent leveling).	Produces greatest possible degree of flatness. Stiffens sheets somewhat. Leaves "grip marks" on ends of sheets which may be removed, if desired, by "resquaring." (See pp. 173-174.)	Where greatest possible degree of flatness is required, and where the forming involved is mainly bending, not deep drawing. Examples: metal furniture, cabinets, door panels, table tops, etc.
	D. Resquaring.	Produces greatest accuracy to size which is practicable in bulk production. Removes "grip marks" from "stretcher-leveled" sheets. Tends to leave slight "burr" on edges of sheets. (See pp. 118, 171.)	Where extreme size accuracy is desired and when it is desired to have the grip marks removed from "stretcher-leveled" sheets. The user often can resquare sheets himself more accurately or more economically than the mill, however, especially when cutting small blanks.
	E. Oiling.	Places a light film of oil on surfaces of sheets. (See p. 175.) Lubricates somewhat in drawing operations. Affords moderate protection against indoor rusting.	Where it is desired to provide sheets some protection against rusting while in transit or in storage, particularly pickled grades. On sheets to be drawn.
	F. Liming.	Places a film of lime on surfaces of heavy-gage pickled sheets. Affords moderate protection against indoor rusting. (See p. 150.)	Where, in lieu of oiling, it is desired to provide heavy-gage pickled sheets some protection against rusting while in transit or in storage.

VI *Formed products* (made in Black, *i.e.*, uncoated and unpainted, Painted or Galvanized).		
A. Corrugated Sheets.	Corrugations produce the greatest possible strength and rigidity of any form of sheet metal; also permit making a side joint by lapping one or more corrugations. Standard sizes of corrugations are: "5-inch, 3-inch, 2½-inch, 2-inch, 1¼-inch, ⅝-inch and 3/16-inch "crimped." Made in various gages.	Flat corrugated: for steep pitch roof covering and for siding. Curved corrugated: for culverts (full circle curved), and for arches, awnings, etc. (partly curved). Corrugated sheets provide economical, fire and lightning-proof roofing and siding for industrial buildings, barns, sheds, etc., also make tight fences.
B. V-Crimped Sheets.	The crimps impart rigidity to the sheets and improve their appearance for roofing purposes; also provide means of making side joint by lapping. Usual patterns are "2-V," "3-V," "4-V" and "5-V." Generally made in light gages, not heavier than No. 20 gage.	Used for steep pitch roofing and for siding, much the same as corrugated sheets. Not so strong and rigid as the latter but being of better appearance, are used more for dwellings, garages, etc.
C. Ridge Roll, Plain or Corrugated. (Also Ridge Angle, Flashing, etc.).	These various formed pieces are made in different patterns, with corrugations to fit the corrugated sheets with which they are used if desired.	Ridge roll and ridge angle are used for capping the ridges of roofs. Flashing is used where the roof sheets meet a wall, gutter, etc.
D. Roll Roofing.	Sheets seamed together, end to end, and rolled up, ready to unroll on the roof and seam along the sides. Not generally made heavier than No. 24 gage.	Used for medium steep roof where seamed joints are desired usually on dwellings or on rural buildings.
E. Weatherboard Siding, Plain Brick Siding, Rock Face Siding.	Sheets formed to imitate weatherboarding, bricks and stone facing. The forming stiffens and strengthens the sheets.	Used for siding where such patterns are desired, usually on dwellings, garages, barns, etc.

APPENDIX "A."

THE NATURE AND EFFECTS OF THE ANNEALING OF SHEET STEEL.

A complete description of the nature and effects of annealing, even of a single form of steel like sheet steel, cannot be given in a few pages. However, an attempt will be made below to summarize, for the layman, the most commonly accepted theories relating to the annealing of sheet steel and their application in practice. A short outline of such a complex subject necessitates great condensation and the omission of numerous details of great importance to the metallurgist but which would be confusing to the layman. Therefore, for the sake of brevity the following discussion will be confined to the rudiments of the annealing theory, and, to avoid unnecessary complications, will be restricted to only one type of steel, *viz.*, normal low-metalloid steel containing over 99 percent iron and less than 0.13 percent carbon, which is the material used for the great bulk of sheet steel products today.

After steel has solidified from its molten state, and while it is cooling in its solid condition down to atmospheric temperature, it undergoes various changes in its structure and properties. These changes are termed "allotropic transformations" and occur at certain temperatures called "critical temperatures," or "thermal critical temperatures," or simply "critical points." The range of temperature within which these critical points occur is called the "critical range."

When steel is heated from atmospheric temperature through the critical range, these changes (allotropic transformations) again take place, but in the reverse order. As already indicated, the critical points occur below the melting point of the steel. These phenomena permit the alteration of the properties, without changing the shape, of steel articles and therefore make possible what is called the "thermal refining" of steel objects. Thermal refining embraces annealing, hardening, tempering, and various special kinds of heat treatment.

According to Sauveur, as a piece of steel containing about 0.10 percent carbon is heated to high temperatures, critical points are noted at approximately 1,300° F., 1,400° F. and 1,600° F., to use round figures. Therefore, the critical range of this steel, for annealing purposes, would be approximately from 1,300° to 1,600° F. The critical range will vary with steels of different carbon content. As steel is heated past the different critical points, different effects are produced.

It is believed that the following effects, among others, take place during the annealing of sheets of steel containing less than 0.13 percent carbon and with a normal content of other metalloids.

When cooled down after hot-rolling, steel sheets are made up essentially of free ferrite grains, together with a small proportion of pearlite particles (see pp. 124-125) all more or less crushed and elongated, as a rule. Upon heating past the first critical point, which marks the lower limit of the critical range, the pearlite is immediately transformed into another state called "austenite." As the temperature rises past the second critical point and approaches the third critical point, the austenite (which, it will be remembered, contains the carbon since it was formerly pearlite) tends to absorb more and more of the free ferrite. Finally, upon passing the third critical point, which marks the upper limit of the critical range, the ferrite has all been absorbed by the austenite, which is a homogeneous solid solution of iron and carbon, and the previously existing grain structure is completely obliterated.

Now, let us start with a sheet which is at a temperature slightly above the critical range and reverse the process, cooling the sheet relatively slowly down through the critical range. When the steel cools past the upper limit of the range, the formation of a new grain structure commences and continues as the steel cools down through the critical range, the excess ferrite gradually crystallizing out of the austenite, forming new grains of free ferrite which tend to grow larger, the slower the cooling progresses. Finally, when the temperature descends below the first critical point, which marks the lower limit of the critical range, the remaining austenite forms into grains of pearlite and these pearlite particles locate themselves between and at the junctions of the grains of free ferrite. The more carbon present, the greater the amount of pearlite which will form.

The foregoing gives a very general and necessarily incomplete description of what is supposed to happen upon heating completely through and above the critical range, then allowing the steel sheet to cool relatively slowly down through the range.

We have still to consider two other types of annealing which are employed in the making of sheet steel, *viz.:* at temperatures within the critical range (*i.e.* between the upper and lower critical points) and at temperatures below the critical range.

Slow and uninterrupted cooling from temperatures within the critical range will permit the recrystallization of deformed ferrite and pearlite grains. Howe claimed that (to quote Sauveur) as hypo-eutectoid (under 0.90% carbon) steel is heated from Ac_1 (lower critical point) to Ac_3 (upper critical point) a new crystalline growth takes place which is the coarser the less carbon in the steel, so that by the time the old structure has been obliterated, *i.e.* at Ac_3, a new grain has been formed. However, while the grains may reform themselves during annealing at temperatures within the critical range, they are not regrouped into an entirely new structure as in the case of annealing above the critical range. Also, it is believed that the presence of strain in the steel is a factor in this type of annealing.

If low-carbon steel is strained from mechanical work, annealing effects may be accomplished at temperatures considerably below the critical range. Sheet steel is frequently in a mechanically strained condition, both from not-hot-enough hot-rolling as well as from cold-rolling. Also sheet steel generally contains the small amounts of carbon which are conducive to the growth of the ferrite grains in critically strained steel when this is heated to temperatures below the critical range. Sauveur states that unless the carbon content is in the range of 0.04 percent to 0.12 percent, the ferrite grains will not grow appreciably below the critical range, and further that a certain degree of strain (this has been called "Sauveur's critical strain") is one of the conditions of grain growth of this character and that if the steel is over-strained or under-strained the ferrite grains will not grow appreciably below the critical range. Annealing of this type, involving temperatures below the critical range, does not affect the pearlite particles, which, if elongated, will remain so.

Besides the temperature itself, there are other factors which greatly affect annealing results, such as the length of time at the annealing temperature, and the rate of cooling from that temperature. Generally speaking, the longer the time at the annealing temperature and the slower the rate of cooling, the larger will be the grain size produced. Furthermore, if the steel has been deformed and strained, the degree of strain influences the growth of the grains during annealing, affecting both the size to which they will grow and the temperature at which the grain growth will begin (germinative temperature). Sauveur writes: "The more severe the deformation the lower the germinative temperature, but the growth is greater at a high germinative temperature, that is, in but slightly deformed metals."

In the case of sheet steel, the most rapid cooling is accomplished by cooling immediately in the open air, as in ordinary open annealing;

slower cooling is effected by cooling in the diminishingly heated air of a chamber which is the continuation of the heating chamber of the open-annealing furnace, as in special "normalizing" types of open annealing; and the slowest cooling is brought about in box annealing, by cooling down in the furnace and in the box after this has been withdrawn from the furnace.

The above described principles are employed in the annealing of sheet steel in the following ways:

I. Annealing Above the Critical Range. Sheet steel is only annealed above the critical range (*i.e.* above about 1,600° F.) by the "open annealing" method, in which only one or two sheets are being heated at one time. (See pp. 133-135.) Either ordinary open annealing furnaces or special normalizing open annealing furnaces are used. (Box annealing is never carried on at temperatures above the critical range, for fear of sticking the sheets, and for fear of coarse granulation due to the very slow cooling through the critical range during box annealing.)

Such open annealing above the critical range produces an entirely new grain growth of both the free ferrite and pearlite, as well as an entirely new arrangement or grouping of the grains which replaces the previously existing structure. Cooling is effected relatively rapidly in the open air for the smaller grain size which gives the strongest and toughest structure together with marked ductility. When a somewhat softer sheet is desired, a slightly larger grain size is produced by cooling less rapidly in a continuation of the open annealing chamber.

II. Annealing Within the Critical Range. Sheet steel is annealed at temperatures within the critical range, that is, below the upper critical point but above the lower critical point, either by the open annealing or by the box (close) annealing method.

A. Ordinary Open Annealing within the Critical Range.—The annealing temperature in ordinary open annealing may be above the critical range, but generally is at lower temperatures, in order to avoid excessive scaling of the surface of the sheet for one thing, so that usually the temperatures for ordinary open annealing are somewhere between the upper and middle critical points, or from 1,400° to 1,600° F. approximately. This permits a reformation of the ferrite and pearlite grains which may have been crushed and elongated in rolling. Most of the hot-rolling strains are removed, but a complete new grain structure is not formed. The sheets are cooled relatively rapidly in the open air, although when the sheets are piled up immediately after removal from the furnace the cooling is less rapid. Such annealing produces sheets which are strong, tough and ductile, but these properties are not so highly developed nor so equal in all directions as in sheets annealed by method (I) above.

B. Box Annealing within the Critical Range.—Certain kinds of sheets are box annealed at temperatures which are just within the critical range, say from about 1,300° to 1,400° F., the temperature depending upon several factors, including the gage and the results sought. Such a treatment produces a reformation of the pearlite and ferrite grains, and usually growth of the latter. The cooling is always relatively slow owing to the mass of the pile of sheets and generally is made slower still by keeping the lid over the sheets for some time after the box has been withdrawn from the furnace. This very slow cooling promotes grain growth. Box annealing at temperatures much above 1,400° F. tends to stick even unpickled sheets (except high-silicon steel) into an almost inseparable mass; consequently temperatures much in excess of 1,400° F. are seldom used except for electrical sheets, the high-silicon content of which prevents sticking the sheets at the higher temperatures.

This type of box annealing within the critical range is employed for most unpickled sheets lighter than about 17 or 18 gage, for which open annealing would be unsuitable; it is used for heavier gages when open annealing would be undesirable because of the heavy scaling from open annealing or for other reasons. It is used for pickled, but not cold-rolled, sheets at tin mills where some sticking is expected and is provided for. To a less extent it is employed for pickled, but not polished, sheets at sheet mills—when special precautions against sticking must be taken.

Box annealing of this type removes a great part of the hot-rolling strains and produces a large, although sometimes irregular, grain size which gives extreme softness, pliability and ductility, but tends to make the sheet weaker and less tough than methods (II-A) and (I).

Heavy gage sheets ordinarily must be box annealed at lower temperatures and cooled less slowly than light gages for fear of the growth of very large grains which would cause coarse granulation with its resultant brittleness under shock and lack of strength. This is not so much to be feared in the lighter gages because the very thinness of the gage confines the grain growth within limits.

III. Annealing Below the Critical Range. This method utilizes the phenomenon of grain growth produced in sheets of steel containing from 0.04 percent to 0.12 percent carbon which have been critically strained by cold work. It is employed only for box annealing, as a rule, at annealing temperatures ranging from about 1,000° to 1,200° F. It is used principally in treating pickled and cold-rolled sheets, which would be stuck together at higher temperatures.

The main function and use of this type of annealing is to remove cold-rolling strains in sheets which have previously been annealed either above or within the critical range (methods I or II), when the hot-rolling strains have been removed or reduced, but which have later been strained and stiffened by cold-rolling.

This treatment will remove cold-rolling strains by causing a reformation of the free ferrite grains which have been somewhat deformed in cold-rolling. It is not effective in removing hot-rolling strains, however, because it does not affect the pearlite, which, if crushed and elongated, will remain so. The reformation of the strained free ferrite grains into more normal, balanced (and sometimes larger) grains, renews the ductility, pliability and softness of the sheet after cold-rolling.

IV. Combination, Multiple Annealing Treatments. For producing sheets with a fine surface, requiring cold-rolling, but which also must possess certain desired degrees of strength, toughness, ductility and pliability, as well as for producing special physical properties regardless of the surface, various combination annealing treatments are used, which include two or more annealings of different types, such as the following:

Combination of (I) with either (II-B) or (III).
Combination of (II-A) with either (II-B) or.(III).
Combination of (II-B) with (III).

These combination, multiple annealing treatments, involving different types of annealing should not be confused with a simple double annealing which only involves repeating the same type of annealing operation for the sake of thoroughness and uniformity, as when sheets are box annealed, then piled up again to reverse the order of the sheets in the pile, then box annealed again in much the same manner as at first.

It might be added as a general commentary on the subject of annealing, that if we believe in the amorphous cement theory, one of the results of effective annealing of steel is the transformation of the strong, brittle, amorphous cement which is present in strained steel into the crystalline state, thus increasing the softness and ductility of the metal at the sacrifice of strength.

(Note—The reader who desires to learn the complete details of what is supposed to take place during the annealing of steel will find a very clear description of this in Albert Sauveur's well known work "The Metallography and Heat Treatment of Iron and Steel." While Sauveur's chapters on annealing are written in precise, scientific language, like the rest of the book, the text is expressed and illustrated so admirably that it is intelligible to a layman who has a genuine desire to study the subject.)

APPENDIX "B."

DEFINITIONS OF THE TERMS USED HEREIN FOR DESCRIBING THE TEXTURE OF SHEET STEEL SURFACES.

"Rough" Surface.

Rough to the touch; numerous and pronounced projections; loose or uneven oxide.

Opposite of "Smooth" surface.

"Smooth" Surface.

Smooth to the touch; no pronounced projections; no loose or uneven oxide. (Sometimes inaccurately used in the sense of "dense.")

Opposite of "rough" surface.

(The following have to do mainly with pickled-sheet surfaces.)

"Pitted" Surface and **"Open"** Surface.

Both these terms describe the presence of noticeable depressions, and are opposed to "dense" surface, but there is a distinction between them.

"Pitted" refers to the presence of relatively deep crevices, depressions or "pits," somewhat isolated.

"Open," although sometimes used in the same sense as "pitted," more properly describes a condition where there are depressions, not always very deep, yet quite evident and rather numerous, either grouped in patches or extending all over the sheet. (Includes the hot-mill defect "open surface" but has many other causes.)

"Dense" Surface.

Compact "sub-surface"; no deep crevices, depressions or "pits" and no pronounced "open" condition of the surface.

Opposite of both "pitted" surface and "open" surface.

"Porous" Surface.

Having small, shallow depressions or spaces between the units of metal making up the surface texture, in other words "open pores," uniformly distributed all over the surface, producing a slightly "pebbled" condition.

Opposite of "close" surface.

"Close" Surface.

A high degree of density; the units of metal making up the surface being very closely packed together.

Opposite of "porous" surface.

(Note: "Close" is sometimes used interchangeably with "dense," but it seems preferable to reserve this word for the above meaning.)

"Dull" Surface.

Having a slight degree of porosity; not lustrous or glossy

Opposite of "polished."

(In this sense, this term is used mainly with reference to highly finished cold-rolled sheets. Of course, any "rough" or "porous" surface is naturally of dull appearance, but the word "dull" has the above special meaning in contrast with "polished.")

"Polished" Surface.

Having a high degree of smoothness; glossy and lustrous; not at all porous.

Opposite of "dull" surface in the case of highly finished cold-rolled sheets.

The relationship of these terms, as here defined, is illustrated by the following, in which the word "surface" refers to any given area, perhaps only a small part of the whole surface of a sheet, and does not refer to the entire surface of a sheet. When considering the entire sheet, our definitions cannot be so definite because several conflicting conditions may, and generally do, exist in the whole sheet's surface, as will be referred to later.

Relationship of Surface Conditions.

"Dense" surface cannot be "pitted" or "open," but may be either "porous" or "close," as the case may be; and if "close," it may be either "dull" or "polished." "Dense" surface is generally "smooth," although it may be slightly "rough" if not cold-rolled at all.

"Close" surface must be "dense," and may be either "dull" or "polished," but cannot be "porous," "pitted" or "open." Since a "close" surface, in the meaning used here, would practically always have to be produced by cold-rolling a surface already dense, the resultant surface would be "smooth" and not "rough."

"Dull," in the special meaning given here, is only used in reference to the "top-surface" (See p. 165) of highly finished surfaces, and therefore, a "dull" surface must be "smooth" and not "rough," although the "sub-surface" may be "pitted" or "open," "dense" or "close" as the case may be. But "dull" cannot be "polished" since it is necessarily slightly "porous."

"Polished" surface must be "smooth" (unless there is loose oxide), and cannot be "porous" or "dull," but the "sub-surface" of a "polished" "top-surface" may be "dense," "close," "pitted" or "open," as the case may be.

"Porous" surface is very "dull" and cannot be "close" or "polished," but may be either "rough" or relatively "smooth," and its "sub-surface" may be "dense," "pitted" or "open," as the case may be.

A surface which is "pitted" or "open" cannot be "dense" or "close," but may be "porous," and its "top-surface" may be either "rough" or "smooth," "dull" or "polished."

When speaking of a whole sheet, its surface cannot be classified as "dense" or "close" if it contains pits or openness, even though most of it actually is dense or close. It will readily be seen that, since pits and openness may occur in sheets intended for almost any finish, "pitted" sheets and "open" sheets, which is to say—any sheets containing these irregularities, will not necessarily have any similarity in other respects, for aside from the areas where the pits or openness occur, the sheets may be "dense," "porous" or "close," "dull" or "polished." Different surface conditions may and do exist in different parts of the whole sheet's surface. Thus we see that in the practical description of whole sheets it is necessary frequently to qualify our statements; for example, we may have to describe a sheet's surface in some such ways as the following:

(See I-B-1-a, No. 17 and lighter, p. 231.)

"Surface less open than "open annealed and pickled" grade, but still quite porous, not dense and not polished."

(See I-B-1-b, p. 231.)

"The surface is smooth and polished, but subject to some pits and therefore not so dense as double pickled grades."

APPENDIX "C."

DEFINITIONS OF TERMS RELATING TO THE PHYSICAL PROPERTIES OF SHEET STEEL.

Stress and **Strain.**

"Stress" is a force put upon a body.

"Strain" is the deformation produced in a body when a stress is applied to it.

Tensile Strength.

The resistance which a body offers against being pulled apart. In other words, the maximum pulling load or stress which a body will withstand before it pulls apart. In mild steel it is considerably greater than the "elastic limit." (In tensile testing the "tensile strength" is usually referred to as the "ultimate strength" and is expressed in pounds per square inch.)

Tenacity.

Tensile strength is one form of "tenacity"; other forms are compressive strength, shearing strength, torsional strength, etc. (See Tiemann, "Iron and Steel," 1919, p. 330.)

Elastic Limit and **Yield Point.**

Ductile metals, like mild steel, when subjected to great pulling force will first stretch minutely, ready to spring back to the original shape, and so long as the metal will thus return to its original form as soon as the pulling force is removed, the stretch or strain is said to have been within the elastic limit of the metal. As more force is applied, however, a point is reached beyond which the metal can no longer spring back to its original shape, but will begin to be permanently elongated; this point is called the "elastic limit" of the metal. It is not possible to determine the elastic limit accurately, in most cases, but it is considered, for practical purposes, to be almost identical with what is called the "yield point" in tensile testing. This yield point is the point at which the stretch produced by pulling begins to take a "permanent set," and is measured by the force in pounds per square inch which is necessary to produce this first permanent set.

Elasticity.

The ability of a substance to return to its original form after having been temporarily deformed (after Tiemann).

Plasticity.

The property of a substance permitting it to be permanently deformed.

Elastic Deformation.

The temporary deformation (strain) produced in a body by a stress within the elastic limit.

Plastic Deformation.

The permanent deformation (strain) produced in a body by a stress exceeding the elastic limit, up to the point of rupture.

Percentage Elongation.

When a piece of mild steel has been pulled beyond its elastic limit, it becomes permanently elongated. This stretch may be very appreciable and before the piece finally breaks, the elongation may be 25 percent or even 50 percent of the original length. The increase in length, divided by the original length, gives the percentage elongation (after Stoughton).

Reduction of Area.

As a piece of mild steel is being stretched out and elongated, its cross-sectional area becomes less and finally, just before breaking, it "necks down" on either side of the point of rupture. The original area, minus the area of smallest cross section after rupture, is termed the "reduction of area" and this divided by the original area, gives the "percentage reduction of area" (after Stoughton).

Ductility.*

The property of a metal permitting it to be elongated or drawn out. Usually measured by the percentage elongation and percentage reduction of area, taken together.

Malleability.

The property of a metal permitting it to be hammered or rolled out into thin sheets. It is practically synonymous with "ductility," except that it depends on both softness and tenacity, whereas ductility is much more dependent upon tenacity, as Hiorns states.

Toughness.*

The resistance a metal offers to breaking after the elastic limit has been passed. It is the opposite of "brittleness" (after Stoughton).

A tough sheet of steel must be more or less ductile, but toughness is not a true measure of ductility. A very tough sheet will draw under great force suddenly applied, but a less tough sheet may draw out equally as far if less force be applied slowly and gradually.

Brittleness.*

If a piece of steel breaks easily after being strained beyond its elastic limit, that is, takes little or no permanent elongation, the steel is said to be "brittle." A perfectly brittle metal has no ductility. Brittleness is the opposite of toughness. Some metals are more brittle under a sudden shock or impact than under a stress which is slowly and uniformly applied (after Stoughton).

Hardness.

The ability of a metal to resist being indented, worn away under friction, or scratched. Sometimes hardness is improperly used in the sense of "brittleness," but this usage is not advisable because steel may be both hard and tough, hence not brittle (after Stoughton).

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* The terms "ductility," "toughness" and "brittleness" are mutually related and, in the case of sheet steel at least, are all relative, not absolute. The degree to which, as well as the form in which, these properties may be said to exist in a given metal depends in no small measure upon the conditions under which they are manifested and determined. For example, it has been shown that a piece of low-carbon steel with a very coarse grain may be so brittle under sudden shock that it will break in pieces if dropped on the floor from a height of only a few feet, but that a similar piece, when subjected to a slow and uniform pull, as in tensile testing, will exhibit normal ductility, elastic limit and tensile strength. Such metal, therefore, would possess a form of ductility and toughness, under certain conditions; yet it would be brittle under other conditions. Sauveur states (his. p. 189, "The Metallography, etc.") that while the tensile test "may detect brittleness resulting from defective chemical composition, it will not generally reveal brittleness caused by a coarse structure" and therefore recommends that both the microstructure and macrostructure be examined, in addition to tensile testing, when the physical properties must be accurately determined.

Hardness—Continued

Also, in the case of sheet steel, some people speak of a "hard" sheet when they mean a "stiff" sheet; a sheet of mild steel may be somewhat stiff, according to the ideas of the trade, without being really hard or brittle.

Softness (see "Pliability").

Correctly, "softness" means the property of a metal permitting it to be scratched, abraded or indented easily, wherein it is the opposite of "hardness."

In the case of sheet steel, "softness" has the special meaning of "pliability. In this sense, it is the opposite of "stiffness."

Stiffness.

A sheet of steel is said to be "stiff" if it is relatively rigid and cannot easily be bent and deformed. "Stiffness" is the opposite of "pliability."

A sheet may be somewhat stiff and yet have greater toughness and ductility than a more pliable sheet. However, more force would be required to deform the stiffer sheet.

Pliability.

A sheet of steel is said to be pliable if it can easily be bent and deformed. "Pliability" is the opposite of "stiffness."

The pliability of a sheet, however, does not determine its ductility, necessarily. One sheet may be more pliable than another, and while the more pliable sheet will require less force to deform it, it may not exhibit as much ductility as the less pliable sheet.

"Workable."

"Workable" is a term often used in the sheet steel trade and implies "pliability" as well as "ductility." A "workable" sheet is one which can be bent and deformed easily and without breaking.

APPENDIX "D."

ABBREVIATIONS.

Some of the abbreviations commonly used in expressing treatments, finishes and quality of sheet mill and tin mill products. An understanding of these will be helpful in specifying orders and in interpreting mill stock lists.

A.	Annealed.
Ann.	Annealed.
Ann. Last	Annealed last (means sheets have been annealed after final cold-rolling).
A-1PCR*	(Box) annealed, one pass cold-rolled.
Bl. Ann.	Blue annealed (*i.e.* open annealed).
B.C.*	Best cokes.
Bess.	Bessemer.
B.G.	Birmingham Sheet and Hoop Iron Gage, or British Standard Gage for Iron and Steel Sheets and Hoops.
B.S.P.S.	Blued stove pipe stock.
B.W.G.	Birmingham Wire Gage.
Bx. Ann.	Box annealed.
C.B.	Copper-bearing.
C.R.	Cold-rolled.
C.R. Last	Cold-rolled last (means sheets have been cold-rolled after final annealing).
D.D.	Deep drawing.
Deox.	Deoxidized.
E.D.D.	Extra deep drawing.
FP-CR-ReAnn. FPk-CR-ReAnn.	Full pickled, cold-rolled and reannealed.
Ga.	Gage.
Galv.	Galvanized.
H.	Heavy to gage (5% H means "5% heavy to gage").
H.R.A.*	Hot-rolled and (box) annealed.
L.	Light to gage (6% L means "6% light to gage").
O.H.	Open hearth.
Oil	Oiled.
Op. Ann.	Open annealed.
O.P.C.R.&A.	One pass cold-rolled and (box) annealed (also written "1PCR&A").
P.	Pickled—in connection with annealing, usually. (But in conjunction with "CR," the letter "P" stands for "pass," as in O.P.CR.&A.).
P.&A.*	Pickled and (box) annealed. (Also written "PA"*).
P.A.CR.A.*	Pickled, (box) annealed, cold-rolled, (box) annealed.

Pk.	Pickled (this is a better abbreviation for "pickled" than "P," because it cannot be confused with "pass").
Pat.Lev.	Patent leveled (*i.e.* stretcher leveled).
P.L.	Patent leveled.
P.L.&R.	Patent leveled and resquared.
P.L.Not R.	Patent leveled, not resquared.
Pr.	Primes.
R.	Resquared.
R.&S.*	Resquared and stamped.
Resq.	Resquared.
R.L.	Roller leveled.
S.	Seconds.
S/A.	Seconds arising.
Sec.	Seconds.
S.L.	Stretcher leveled (*i.e.* patent leveled).
SP-CR-ReAnn. SPk-CR-ReAnn.	Single pickled, cold-rolled and reannealed.
Stk.	Stock (as in "metallic furniture *stock,*" etc.).
U/A	Unassorted.
U.S.S.G.	United States Standard Gage.
White	White finish.

(Note: * indicates tin mill term.)

Abbreviations used in expressing analysis of steel:

C., or "Carb."	Carbon
Mn., or "Mang."	Manganese
S., or "Sul."	Sulfur
P., or "Phos."	Phosphorus
Si., or "Sil."	Silicon
Cu., or "Cop."	Copper

For example, the numbers being percent or decimal fractions of one percent:

C	0.08 (meaning 8/100 of 1%)
Mn	0.35 (meaning 35/100 of 1%)
S	0.05 (meaning 5/100 of 1%)
P	0.04 (meaning 4/100 of 1%)
Si	0.01 (meaning 1/100 of 1%)
Cu	0.28 (meaning 28/100 of 1%)

The remainder is supposed to be iron, practically speaking.

APPENDIX "E."

HOW TO SPECIFY SHEET STEEL PRODUCTS.

Clear and complete specifications will save time, trouble and expense. When a buyer is in doubt as to how to specify, he should discuss his problems freely with the manufacturers' representatives, securing recommendations as to the proper grade and manner of specification.

GENERAL FEATURES TO BE COVERED WHEN SPECIFYING ALL KINDS OF SHEET STEEL PRODUCTS, BOTH SHEET MILL AND TIN MILL.

1. **Name or Designation of Product:** (See Table 11, pp. 94-95; and Table 16, pp. 230-243.)
   a. Quality of steel.—In case special steel is desired, as deep drawing, high carbon, copper-bearing, special analysis, etc.; or if either Bessemer or open hearth is specifically required.
   b. Grade and finish.—Trade name or treatment desired. Extra finishing operations, such as roller leveling, stretcher leveling, resquaring, oiling; or, on pickled sheets—white finish; must be specified when desired unless understood to be in the treatment of the grade ordered.

2. **Quantity, Gage and Size:**
   a. Quantity: Tin plate and short ternes.—Number of packages and sheets per package; or number of base boxes.
   All other products.—Number of sheets or bundles; or weight in pounds or tons.
   b. Gage: Tin plate and short ternes.—Base weight or gage number.
   All other products.—Gage number; or weight per square foot; or thickness (in decimal or fractional parts or an inch).
   c. Size: All products.—Width and length in inches.

3. **When Shipment Is to Be Made, and Destination:**

4. **Manner of Shipment:**
   a. Packing: Tin plate and short ternes.—Packing other than in regular wooden boxes or other than standard sheetage must be specified if desired.
   All other products.—Whether loose, bundled, crated or boxed.
   b. Marking: Tin plate and short ternes.—If special marking desired.
   All other products.—Whether and where gage, size or brand is to appear; whether paint or chalk marking is desired.
   c. Loading: When special loading or bracing methods are desired, these must be specified.
   d. Routing: Any special routing or delivery must be specified.

5. **Special Mill Inspection:** When material is ordered made to a special specification, it should be stated whether special inspection by buyer's representative will be made at the mill. There usually is an extra charge made for this, to cover handling, labor, etc.

6. **Purpose for Which Used:** It is helpful to the mill in supplying suitable material to have noted on the order for what purpose the sheets will be used.
7. **Special Instructions** as to finish and properties desired should appear on the order; for example: "Flat as grade permits," "Soft, for double seaming," etc.

In addition to the general features above given, there are special points, peculiar to certain grades and finishes, which should be covered in a specification. These are listed below, under the heading of the grade to which they refer.

Double Pickled, Highly Finished Grades.

(Including automobile finishes; metallic furniture stock; full pickled, cold-rolled and reannealed; etc.)

Designation: Clear and complete, trade name or treatment desired, whether DD, EDD, white finish, stretcher leveled, resquared, oiled, etc.

Assortment: Whether primes only, primes with seconds arising or seconds only desired.

Special Instructions: As to finish and physical properties desired.

Purpose for which sheets are to be used: Orders for automobile parts or other exacting purposes should indicate the purpose for which each item is to be used, since this materially assists the mill in supplying sheets best suited for the particular use involved.

Galvanized Sheets.

Coating: In the absence of other instructions, the mill will supply the standard, commercial coating. If a special coating is desired, whether tight or extra heavy, this must be indicated. Coatings heavier than regular should be specified in ounces per square foot and method of testing for weight of coating should be given, *i.e.*, weight test, triple spot test or single spot test.

Seconds: If seconds are desired, they must be specified. Primes will be furnished in the absence of other instructions.

Short Ternes.

Weight of coating: Whether 8-pound, 20-pound, etc.

Type of coating: Flux method plates will be furnished unless pure palm oil method plates are specified.

Mottle: (15-pound and heavier coatings)—Whether small, medium or large mottle.

Brand: Whether to be stamped with special brand; otherwise will be stamped with mill brand and weight of coating, except manufacturing ternes.

Assortment (8-pound and light-coated manufacturing ternes): Whether primes only, primes with seconds arising, unassorted or seconds only.

Finish: Oil or dry finish.

Resquaring: Whether to be resquared or not.

Long Ternes.

Weight of coating: Regular standard coating will be supplied unless 12-pound or 15-pound is specified.

Auto body grade: Regular treatment will be given the base sheet unless auto body grade is specified.

Finish: Oil or dry finish.

Assortment: Whether primes only, primes with seconds arising, unassorted or seconds only.

Wasters: Only furnished when specifically ordered.

Tin Plate.

Grade: Whether cokes, best cokes, 1A charcoals, etc.

Assortment: Whether primes only, primes with seconds arising, unassorted or seconds only.

Grain direction: If severe seaming is involved, the direction of the seam should be indicated so that mill may arrange grain direction properly, or else the grain should be specified to run parallel to the proper dimension to bring the seam across the grain.

List edge: For very particular work, the list edge (*i.e.*, drip edge) should be specified on the side where it will give least inconvenience.

Formed Roofing Products.

Corrugated sheets: Size of corrugation and width *after* corrugating.

V-crimped sheets: Whether "2-V," "4-V," etc., and whether sticks desired.

Ridge roll, ridge angle and flashing: Whether plain or corrugated, girt, length of sheets (or lineal feet desired). When corrugated, size of corrugations. Diameter of roll for ridge roll. Quantity in lineal feet or sheets.

Roll roofing: Whether double cross lock; whether desire end lock turned; whether cleats desired. Quantity in lineal feet or number of rolls.

Weather board, plain brick and rock face siding: Length of sheets of weather-board siding; others generally made in only one length and all usually made in one width only. Size of stone in rock face siding.

Some typical examples of the proper way to build up designations describing the particular kind of sheet steel or tin plate product desired, as well as illustrations of the specification of quantity, gauge and size, are given below.

Copper-bearing Bessemer Blue Annealed Sheets

(*Copper content 0.20 to 0.30%*)

400 sheets—5 lb. per sq. ft.—50″ x 146″

(For smoke stacks)

Box Annealed—Roller Leveled

4 tons No. 20 gage—34″ x 120″

(For shelving)

Full Cold Rolled Japanning Stock—Deoxidized

800 sheets No. 26 gage—22″ x 89″

(For japanned stove parts)

Extra Deep Drawing Open Annealed, Pickled and Dried—Oiled

750 sheets 0.123″—37″ x 74″

(For auto frame pressed parts)

Open Hearth Pickled and Annealed

4,000 lb. No. 30 gage—14″ x 31″
(For stamping and galvanizing)

Deep Drawing—Single Pickled, Cold Rolled and Reannealed—Oiled

1,000 sheets 0.061″—29″ x 108″
(For drawn switch box covers—to be japanned)

Full Pickled, Cold Rolled and Reannealed—White Finish—Stretcher Leveled and Resquared

Seconds Arising up to 15% included in amounts specified
20 tons—0.049″—30¼″ x 67¾″
(For filing cabinets—to be spot welded)

Auto Hood and Fender Stock—Oiled

Seconds Arising up to 15% included in amounts specified
1,500 sheets—0.037″—31″ x 82″
(For hood sides—Model No. 64)

Coke Tin Plate

Primes with Seconds Arising included in amounts specified
4,000 packages (112 sheets per package)—95 lb.—13¾″ x 25½″

Open Hearth 4A Charcoals—All Seconds Arising Included—Primes and Seconds Packed Separately

100 packages (56 sheets per package)—D3X—19″ x 24″
(Soft—for gas meters)

Copper-bearing Open Hearth Terne Plate

40-lb. Coating, Medium Mottle, Oil Finish, Resquared and Stamped
"—(name of brand)—"
400 packages (112 sheets per package)—IX—20″ x 28″

Open Hearth Long Ternes—Dry Finish—Unassorted

1,000 sheets—20 gage—28″ x 93″
(For gasoline tank ends)

Open Hearth Galvanized Sheets—Tight Coated

10,000 lb.—28 gage—26″ x 104″
(Soft—for double seaming)

Copper-bearing Galvanized 2½″ Corrugated Sheets, 2-oz. Coating, Triple Spot Test

Copper Content 0.20 to 0.30%
Specified Widths Are After Corrugating
600 sheets—No. 18 gage—27½″ x 96″
400 sheets—No. 20 gage—26″ x 120″

Painted 3-V Crimped Sheets—without Sticks

24″ Covering Width
50 bundles—No. 24 gage—84″ long

Full Cold Rolled Blued Stove Pipe Stock—Oiled

30 bundles—No. 26 gage—24″ x 101″

APPENDIX "F."

TOLERANCES.

THE ASSOCIATION OF AMERICAN STEEL MANUFACTURERS.

A. A. S. M.

Standard Permissible Variations of Sheets in Gage Weight, Gage Thickness, Size, and Flatness.*

1929, March 28th.

Gage Weight.

> "The United States Standard Gage for Sheet . . . Iron and Steel is the legal standard used in determining duties and taxes levied by the United States, and is the recognized commercial standard for all uncoated sheet . . . iron and steel. It is a weight gage, having been based upon weights in ounces per square foot. . . . The thicknesses given in the law as approximate equivalents were based upon the density of wrought iron of .2778 lb. per cu. in., or 480 lb. per cu. ft. . . . The density of steel is generally agreed by various authorities to be .2833 lb. per cu. in., or 489.6 lb. per cu. ft. Tests also have shown this value to be representative of commercially pure open hearth iron sheets."

In other terms, more suitable for the sheet maker and user, steel weighs 40.80 lb. per sq. ft. per in. thick, 2 percent heavier than wrought iron, which weighs 40.00 lb. per sq. ft. per in. thick.

In view of this, sheets ordered by gage number will be supplied of the gage weight for that number in the United States Standard Gage table and the average thickness will be correspondingly less than the thickness shown in the table for that gage number.

"Manufacturers have had considerable difficulty in keeping within the tolerance of plus or minus 2.5 percent specified in the law . . . the law does not make this tolerance mandatory for commercial purposes, . . ." and more than a quarter of a century ago it became standard practise to apply a tolerance of 5.0 percent to No. 16 and heavier. As both consumers and producers gradually paid more attention to gage variation, it was found necessary to graduate these tolerances, and almost ten years ago they took substantially their present form, as follows:

When ordered by weight per unit area, sheets shall conform to Table 1. If ordered by gage number, the gage weights shall be those of the United States Standard Gage table for uncoated sheets and for long ternes, and of the Galvanized Sheet Gage table for zinc coated (galvanized) sheets.

Table I.

Gage Range Weight in oz. per sq. ft.		Permissible Variation in Weight of Sheets, Plus or Minus, in Percentage of Theoretical Weight			Gage Range Weight in lb. per sq. ft.	
Less than	Not less than	All of One Gage and Size in Shipment	Single Package	Single Sheet	Less than	Not less than
....	40(No. 16)	5.0	7.0	10.0	....	2.5 (No. 16)
40(No. 16)	20(No. 22)	3.5	5.5	10.0	2.5(No. 16)	1.25(No. 22)
20(No. 22)	....	2.5	4.0	10.0	1.25(No. 22)	....

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* Quoted by permission.

"All of One Gage and Size in Shipment" shall apply to lots of not less than 6000 lb.

References are to gross weights of bundled material and to net weights of crated and boxed material.

If minimum or maximum weight per unit area be ordered, double tolerance is to be taken on permissible side; that is, the tabular tolerance from the mean of which the ordered limit is minimum or maximum. Ordering by minimum or maximum weight per unit area should be discouraged as it is liable to cause error in manufacture and gage classification.

Sheets are not weighed singly at mill and ten percent limit is not guaranteed, but any sheets found by purchaser that are outside this limit may be rejected.

Sheets ordered by weight per unit area are subject to weight gage tolerances only—not to thickness gage tolerances.

Should weight variations be considered more important, yet sheets be so used that uniform thickness is desirable, sheets should be ordered by weight gage, and order should bear instructions "Make of as nearly uniform thickness as practicable." It should be understood that sheets so ordered will be of less average thickness than sheets ordered by the theoretically equivalent thickness.

Both resquared and non-resquared sheets, by custom of long standing, are subject to these weight gage tolerances, based upon the ordered area; though, logically, non-resquared sheets should have smaller minus and greater plus tolerances.

Gage Thickness.

Various gage tolerance tables have been in existence for some time, most of those issued by the sheet makers, having been intended not so much as rejection limits, but rather as guides to sheet users as to what the large proportion of sheets should be expected to be. This subject has recently engaged the serious attention of the sheet makers, with the result that it was considered desirable to indicate limiting thicknesses more definitely, as follows:

When ordered by thickness, sheets shall conform to Table II.

TABLE II.

Ordered Thickness Range inch	Permissible Variation from Ordered Thickness inch	Ordered Thickness Range inch	Permissible Variation from Ordered Thickness inch
.... to 0.250	0.016	0.099 to 0.080	0.009
0.249 to 0.220	0.015	0.079 to 0.070	0.008
0.219 to 0.190	0.014	0.069 to 0.060	0.007
0.189 to 0.160	0.013	0.059 to 0.050	0.006
0.159 to 0.140	0.012	0.049 to 0.040	0.005
0.139 to 0.120	0.011	0.039 to 0.030	0.004
0.119 to 0.100	0.010	0.029 to	0.003

Thickness variation range in any one sheet shall not exceed (to the nearest thousandth) one and one-fifth times the tabular limit for the ordered thickness.

If minimum or maximum thickness be ordered, double tolerance is to be taken on permissible side; that is, the tabular tolerance from the mean of which the ordered limit is minimum or maximum. Ordering by minimum or maximum thickness should be discouraged, as it is liable to cause error in manufacture and gage classification.

Sheets are not all gaged at mill and limits shown are not guaranteed, but any sheets found by purchaser that are outside the limits may be rejected, except in extreme widths.

Sheets ordered by thickness are subject to thickness gage tolerances only —not to weight gage tolerances.

Should weight variations be more important than thickness variations, and sheets be ordered by thickness by preference or custom, order should bear instructions "Make of equivalent weight per unit area," in which case sheets shall be subject to weight gage tolerances only.

Gage Thickness—Expected Average and Limiting Weights.

While sheets ordered by thickness are not subject to weight gage tolerances, weights of sheets are affected by certain considerations, as follows:

Sheets ordered by thickness should have their theoretical weight calculated on the basis of the ordered size and ordered thickness at 40.80 pounds per square foot per inch thick; to this should be added 2 percent for greater cross-section of sheet than represented by mean of thickest and thinnest points.

When resquared, no adjustment need be made to the weight as calculated in accordance with the foregoing. (41.62 pounds per square foot per inch thick.)

When neither resquared nor cold rolled after annealing (blue annealed, black, one pass, hot rolled pickled), 1.5 percent should be added to account for excess width and length within standard tolerance limits. (42.24 pounds per square foot per inch thick).

When not resquared but cold rolled after annealing (full cold rolled, pickled and cold rolled), 3 percent should be added to account for excess width and length within standard tolerance limits. (42.86 pounds per square foot per inch thick).

Estimated weights on orders and in records and correspondence should be calculated as shown above.

The weight calculated on the proper basis with proper adjustments as explained, is, of course, affected by the usual permissible variation of 5.0 percent for not lighter than No. 16 gage, of 3.5 percent for lighter than No. 16 but not lighter than No. 22 gage, and of 2.5 percent for lighter than No. 22 gage, as applied to all of one gage and size in a shipment.

These considerations are expressed in tabular form in Table A.

Size.

All sheets shall be sheared not less than widths and lengths ordered.

Width of sheets not cold rolled (blue annealed, hot rolled pickled) shall not exceed that ordered by more than

¼ inch for sheets ordered 48 inches wide and less and 144 inches long and less,
5/16 inch for sheets ordered 48 inches wide and less and more than 144 inches long,
⅜ inch for sheets ordered more than 48 inches wide and 144 inches long and less,
7/16 inch for sheets ordered more than 48 inches wide and more than 144 inches long.

Width of sheets cold rolled shall not exceed that ordered by more than

¼ inch for sheets ordered 36 inches wide and less and 120 inches long and less,
5/16 inch for sheets ordered 36 inches wide and less and more than 120 inches long,
⅜ inch for sheets ordered more than 36 inches wide and 120 inches long and less,
7/16 inch for sheets ordered more than 36 inches wide and more than 120 inches long.

Length of sheets not cold rolled (blue annealed, hot rolled pickled) shall not exceed that ordered by more than

½ inch for sheets ordered 120 inches long and less,
¾ inch for sheets ordered more than 120 inches long to 180 inches, inclusive,
1 inch for sheets ordered more than 180 inches long to 240 inches, inclusive,
1¼ inch for sheets ordered more than 240 inches long to 300 inches, inclusive,
1½ inch for sheets ordered more than 300 inches long.

TABLE A.

GAGE THICKNESS—EXPECTED AVERAGE AND LIMITING WEIGHTS.

If ordered thickness times 40.80, giving pounds per square foot, be taken as base, this gage weight, or sheet weight or total weight derived therefrom may be multiplied by—		Base of Estimated Weight lb. per sq. ft. per in. thick		Base of Estimated weight lb. per sq. ft. per in. thick	If sheets be ordered by approximate thickness (to full number of decimal places) of USSG table, and corresponding USSG unit weight erroneously taken as base, gage weight or sheet weight or total weight may be multiplied by—	
		40.80	steel 2.0%	40.80	1.0200	
		41.62	thickness 2.0%	41.62	1.0404	
5 = 1.0710 3½ = 1.0557 2½ = 1.0455	1.0200	41.62	resquared 0.0%	41.62	1.0404	.... 1.0924 = 5 1.0768 = 3½ 1.0664 = 2½
5 = 1.0871 3½ = 1.0715 2½ = 1.0612	1.0353	42.24	not cold rolled after annealing not resquared 1.5%	42.24	1.0560	.... 1.1088 = 5 1.0930 = 3½ 1.0824 = 2½
5 = 1.1031 3½ = 1.0874 2½ = 1.0769	1.0506	42.86	cold rolled after annealing not resquared 3.0%	42.86	1.0716	.... 1.1252 = 5 1.1091 = 3½ 1.0984 = 2½
to obtain expected limiting weight for percent indicated	to obtain expected average weight	expected average gage weight		expected average gage weight	to obtain expected average weight	to obtain expected limiting weight for percent indicated

Length of sheets cold rolled before annealing (black, one pass, light gage pickled) shall not exceed that ordered by more than

¾ inch for sheets ordered 96 inches long and less,
1 inch for sheets ordered more than 96 inches long to 120 inches, inclusive,
1¼ inch for sheets ordered more than 120 inches long to 144 inches, inclusive,
1½ inch for sheets ordered more than 144 inches long.

Length of sheets cold-rolled after annealing (full cold-rolled, pickled and cold-rolled) shall not exceed that ordered by more than 2 percent of ordered length.

Out-of-square of sheets not cold-rolled shall be not more than 1/16 inch per 6 inches, or fraction thereof, of sheet width, along end edge.

Out-of-square of sheets cold-rolled shall be not more than 1/16 inch per 4 inches, or fraction thereof, of sheet width, along end edge.

Camber shall not exceed the tolerance given in Table III.

TABLE III.

Camber	Sheets Not Cold Rolled of Ordered Lengths		Camber	Sheets Cold Rolled of Ordered Lengths	
Not more than	More than	Not more than	Not more than	More than	Not more than
¼ in.	. . .	144 in.	¼ in.	. .	72 in.
⅜ "	144 in.	180 "	⅜ "	72 in.	96 "
½ "	180 "	216 "	½ "	96 "	120 "
⅝ "	216 "	240 "	⅝ "	120 "	144 "
¾ "	240 "	264 "	¾ "	144 "	156 "
⅞ "	264 "	288 "	⅞ "	156 "	168 "
1 "	288 "	. . .	1 "	168 "	. . . "

Sheets required of accurate size shall be ordered "Resquared," and such sheets shall be in excess of ordered width and length and shall be out-of-square or cambered by not more than 1/16 inch, if not more than 48 inches wide and 120 inches long, and ⅛ inch if wider or longer. For widths 12 inches and less and for all circle diameters, excess tolerance shall be ⅛ inch.

Resquaring excess allowance for sheets not stretcher leveled (patent leveled) shall be ⅛ inch for each intended cut, in addition to foregoing tolerances.

Resquaring excess allowance for sheets stretcher leveled (patent leveled) shall be in accordance with Table IV.

TABLE IV.

Width

Not less than ordered and in excess by—

Not more than	Length of Sheet More than	Length of Sheet Not more than
¾ in.	. . .	120 in.
1 "	120 in.	156 "
1¼ "	156 "	204 "
1½ "	204 "	. . . "

Length

Not less than ordered between grip marks, and not in excess by more than 6 in.

If "No allowance for grip marks" be ordered—not more than 3 in. for not more than 120 in. long, and 4 in. for longer sheet.

In addition, ⅛ inch for each additional intended cut.

Flatness.

Sheets not ordered "Stretcher Leveled" ("Patent Leveled") shall have buckles not more than the limits shown in Table V.

TABLE V.

Gage Range		Width Range—inch		Maximum Height of Buckles * inch
Less than	Not less than	More than	Not more than	
......	80 oz. 5.00 lb. 0.123 in. No. 11 USSG	..	48	⅝
		48	60	¾
		60	72	1
		72	..	1¼
80 oz. 5.00 lb. 0.123 in. No. 11 USSG	40 oz. 2.50 lb. 0.061 in. No. 16 USSG	..	48	¾
		48	60	1
		60	72	1¼
		72	..	1½
40 oz. 2.50 lb. 0.061 in. No. 16 USSG		..	36	¾
		36	48	1
		48	60	1¼
		60	..	1½

* Height of buckles refers to maximum rise from a flat surface on which sheet lies.

Sheets ordered "Stretcher Leveled" ("Patent Leveled") shall not have buckles exceeding ¼ inch in height. Sheets less than 20 ounces per square foot (1.25 pound per square foot, No. 22 USSG, 0.030 inch) cannot be guaranteed to meet this standard of flatness.

These limits are for not more than two buckles in a side or in the middle. If more, height limit must be proportionately lower, but an approach to corrugation requires rejection.

APPENDIX "G."

MISCELLANEOUS NOTES.

NOTE ON USE OF THE WORD "METALLOID." (See p. 23.)

It is recognized that the term "metalloid," although quite generally employed in the steel industry, is inaccurate from the scientific standpoint for describing all these elements. But since, for the sake of brevity, a word is needed in practical parlance to denote those solid elements which are almost always present, in greater or less degree, in all iron products, in the absence of a word more correct technically, the term "metalloid" is here used to denote the carbon, manganese, sulfur, phosphorus and silicon contained in a particular steel.

The only way to avoid the use of this word (or some other equally inaccurate scientifically) in the sense of "non-iron, solid constituent" of steel, would be to coin a word for this meaning, possibly utilizing initials, such as "niscon." Thus, we could refer to these elements in the steel as "niscons" and could substitute the name "low-niscon steel" for "low-metalloid steel," thereby avoiding scientific inaccuracy but retaining simplicity of statement. Not being entitled to utilize such a word, however, we must, as above stated, use the word "metalloid" in this special sense for the sake of brevity and practical clarity of expression.

Although correct in the laboratory when dealing with iron as an element and not as a commercial product, it seems incorrect and misleading when speaking of finished steel or iron to call these elements "impurities." The word "impurity" implies something detrimental and as normally present in steel or iron, these elements are not necessarily detrimental to the product from the practical standpoint and may even be beneficial, aside from their effects when used as alloying elements.

NOTE ON "PRACTICALLY INEFFECTIVE CARBON CONTENT."

To illustrate that it has long been commonly accepted that the very-low-carbon open hearth and Bessemer steels are not "steel" in the sense of being metals which can be materially hardened and tempered, the following extract is given from "Iron and Steel Manufacture," by A. H. Hiorns, Macmillan & Co., London; first published in 1889:

> "When the carbon present in iron exceeds 0.15 per cent, the iron is sensibly harder: this may be considered the greatest amount of carbon which can be present in malleable iron without diminishing its softness and malleability. Steel may be considered as iron containing from 0.25 to 1.8 per cent. carbon. When the proportion of carbon is low, the metal is termed 'mild-steel' or ingot-iron, and in like manner those with the higher proportions of carbon are termed 'hard-steels.'"

Thus, this author stated, 40 years ago, that iron metal containing less than 0.15 percent carbon should be classified as "mild-steel" or "ingot-iron."

In classifying the arbitrary range of 0.05 percent to 0.12 percent carbon content as "practically ineffective" in steel, the writer does not lose sight of the fact that, other things being equal, even a few points of carbon produce appreciable effects. It is estimated that each increase of 0.01 percent carbon (up to 0.90 percent) produces an increase in the tensile strength of the steel of a little over 900 pounds per square inch (936 pounds), so that starting with a tensile strength of, say, 45,000 pounds at 0.05 percent carbon (the lower limit of our range) as the carbon content is increased to 0.12 percent (the upper limit of our range) the tensile strength is increased by the carbon, other things remaining the same, to say, 51,000 pounds per square inch, with a decrease of ductility, of course. This theoretical variation of approximately 6,000 pounds per square inch in the tensile strength of this range which might be brought about by the variation between 0.05 percent and 0.12 percent carbon is extremely small for practical purposes and what is more important, all of this variation in strength due to varying carbon content in this range may be offset by variations in other chemical constituents or in manufacturing operations, such as finishing temperatures of hot-rolling and annealing and cold-rolling practice. In other words, aside from the effect of variations in the phosphorus and manganese on the strength, it is not uncommon for a low-metalloid normal steel sheet of 0.08 percent carbon content to be rolled and treated in such a way as to be stiffer and less workable than a sheet of otherwise similar analysis but with a carbon content of 0.12 percent which accidentally has been rolled and treated somewhat differently.

The writer, in selecting this range of carbon content for classification as "practically ineffective," has merely endeavored to fix an arbitrary, practical range to cover the type of steel in which carbon is not wanted and is reduced as low as is economical for ordinary purposes (see quotation from Howe, p. 125), and which, therefore, may logically be considered the standard for comparison as to the effects of carbon content, from the practical viewpoint, at least, if not from the scientific. This being especially true on account of the commonness of this type of steel, which is produced in so much greater proportion to the total steel production than any other type. It comprises the soft iron by which we judge other products today, everything being relative. Other types may be found to be softer, or harder, as the case may be, and to vary otherwise, but such a comparison merely serves to establish this main type as the standard.

If, therefore, we take the mean of this range as a standard, we find that the variation in tensile strength due to carbon variations alone, other things being equal, would amount to less than 7 percent to either limit of the range; truly a small variation considering the scope of the field, the tonnages used and the variety of products made in this carbon range.

The upper limit of 0.12 percent has been selected as the top of the usual ladle analysis used in aiming at the ordinary 0.10 percent carbon content. The lower limit of 0.05 per cent has been selected as being about as low as is produced by ordinary open hearth methods when aiming at the lower carbon contents of this type of steel. Of course, extraordinary open hearth methods, at considerable extra expense, will produce lower than 0.05 percent carbon, but this results in a somewhat special type of steel which is sub-classified here as extra-low-metalloid steel; but here, too, the dividing line between this latter type and normal-low-metalloid steel is indefinite and cannot be scientifically defined.

This range also corresponds closely with the carbon range within which, according to Sauveur (see Appendix "A," p. 247), are confined certain low temperature annealing effects much employed with mild steel products, particularly sheets and wire.

Although properties of the steel, other than strength and ductility, such as electric conductivity, magnetic permeability, and power of welding, are somewhat affected by small variations in the carbon content, these variations likewise would be relatively small within this range and are special considerations to be taken into account in connection with certain uses to which some particular products are applied, and need not influence a broad classification based on the average, common utility of the bulk of the enormous tonnage annually made in the very-low-carbon type.

NOTE ON "LADLE ANALYSIS" *vs.* "CHECK ANALYSIS." See p. 25.

A "Ladle Analysis" is made in the following way,—as the molten steel is being poured from the ladle into the ingot molds, a long-handled spoon is held in the stream of molten metal and the metal thus caught is poured into a small mold and allowed to solidify, forming what is called a "test ingot." This test ingot is then taken to the chemical laboratory where it is drilled and the drill turnings are then analyzed, the result of which is the "ladle analysis." This is taken to represent the average of the heat of steel before it segregates upon cooling.

The term "Check Analysis," in the steel trade, has come to mean the analysis of a sample cut from a piece of a finished product, such as a sheet. This will not coincide with the "ladle analysis" of the steel from which the sheet was made; the variation being largely accounted for by the non-uniform segregation of the elements other than iron during the solidification of the steel ingot. There are other reasons why the "check analysis" naturally will not agree exactly with the "ladle analysis." A certain variation is always permitted between these two types of analyses.

NOTE ON "CRYSTALLINE GRAINS." See p. 123.

This sentence is intended to convey briefly an approximate concept of the structural composition of metals. Naturally, such a complicated subject cannot be exactly stated in so few words. The following quotations may be of interest to those desiring a more complete and scientific concept of the nature of what are called "grains" of metal:

> ". . . a grain would rather be defined as a crystal form which started to follow the regular crystalline habit but was prevented from becoming a perfect crystal by interference on its edges through the growth of other crystals." (Bradley Stoughton, in private communication.)

The following from H. M. Howe, "Metallography of Steel and Cast Iron":

> "Each Grain or Cell of a Pure Metal a Crystal.—Any common metallic mass, even when it lacks or is irrelated to the dendritic structure, is in a sense as truly crystalline as the rare idiomorphic crystals, with this difference, that instead of being made up of single idiomorphic crystals it consists, like a loaf of sugar or a block of crystalline marble, of an aggregation of little crystalline grains or cells, which can be separated from each other under favorable circumstances." (p. 266.)
>
> "Each of these polyhedral grains, in spite of lacking the outer form of a crystal, is a true crystal as regards its internal structure, having by definition uniform orientation throughout, with uniformity of cleavages and all the other consequences of this uniformity of orientation." (p. 267.)
>
> "Meaning of Grain.—It is important to recognize that 'grain' is used here in the sense in which it applies to a 'grain' of maize or other cereal. It includes the whole of a structural unit, and is not applicable to part of such a unit. Fragments cut from a grain of maize are not grains in this sense, nor are fragments broken from a single uniformly oriented grain of metal. Indeed a grain is a cell, and there are strong arguments for calling it a cell rather than a grain. Nevertheless, the word 'grain' is so firmly established, and 'granular' applies so aptly to an assemblage of such grains, and to a fracture passing along the grain surfaces, that I retain it." (p. 268.)
>
> "No one crystalline grain is able to develop the geometrical outer shape toward which it tends, because the space which it needs for that development is already occupied by its neighbors on all sides." (p. 268.)

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