FERRO CARBON-TITANIUM
IN
STEEL MAKING

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FERRO CARBON TITANIUM IN STEEL MAKING

1916

THE TITANIUM ALLOY MANUFACTURING CO.

NIAGARA FALLS, N. Y.

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FERRO CARBON-TITANIUM IN STEEL MAKING

A<small>N</small> average analysis of Ferro Carbon-Titanium as manufactured by this Company for the treatment of Steel is as follows:

Silicon.	1.41
Titanium	15.79
Carbon	7.46
Manganese.	0.11
Aluminum	0.80
Phosphorus	0.05
Sulphur	0.08
Iron (by difference)	74.30
	100.00

This material, as sold, is guaranteed to contain at least 15 per cent Titanium.

The present prices on Ferro Carbon-Titanium are as follows:

In carloads (56,000 pounds minimum), eight cents per pound.

In lots from one ton to carload, ten cents per pound.

In less than ton lots, twelve and one-half cents per pound.

All F. O. B. Suspension Bridge, N. Y.

Terms—30 days, net.

The material is subject to 5th Class Rate in carload quantities and 4th Class L. C. L., in official classification territory.

To provide for its convenient and efficient use in the various methods of Steel Making Ferro Carbon-Titanium is stocked in the following sizes:

Standard Medium through $1\frac{3}{4}''$ opening—On $\frac{3}{4}''$ screen.
F Size through $\frac{3}{4}''$ opening—On $\frac{9}{16}''$ screen.
E Size through $\frac{9}{16}''$ opening—On $\frac{5}{16}''$ screen.
D Size through $\frac{5}{16}''$ opening—On $\frac{1}{8}''$ screen.
C Size through $\frac{1}{8}''$ opening—On $\frac{1}{16}''$ screen.
A Size through $\frac{1}{16}''$ opening.

For use under certain conditions, the finer sizes C and D are packed in twenty-five pound cans. These containers serve to carry this fine material through the slag and provide a means for quickly disseminating it through the metal, when it is not convenient or possible to hold the steel longer than three or four minutes in the ladle. This method of adding Ferro Carbon-Titanium has proved of especial value in the treatment of Converter Steel.

The value of Titanium Treatment of Steel is now so well recognized and the use of Ferro Carbon-Titanium so general that it is unnecessary to refer to the properties of Titanium, which are well known to all metallurgists and practical steel men.

Titanium alone of all the deoxidizers leaves practically no product of its oxidation in the finished steel. In rail steel, for instance, which has been treated with 0.10 Titanium the total Titanium in the finished steel has never been found to exceed .03 and any such amount as this is very unusual. This minute quantity is always evenly distributed throughout the ingot and has never been found in streaks or segregated areas as are Alumina, Manganese Sulphide, or Iron Silicates.

When Manganese or Silicon is added to a ladle of steel in the form of Ferro Alloys from 65 % to 85 % of the total Manganese or Silicon will be found in the final product. These metals do not remain in the steel uncom-

bined. They occur as Manganese Carbide, Oxide or Sulphide, Iron Silicates, etc., and all of these impurities, except the Carbide, are known to form streaks or agglomerations which cause weak spots to develop in the metal.

Aluminum is a powerful deoxidizer, the most powerful known, but to use Aluminum in Steel without considering the results of its use, in so far as the formation of Alumina is concerned, is now well recognized as a dangerous practice.

Alumina, formed by the oxidation of Aluminum, is probably the most harmful of all products resulting from the use of a deoxidizer. This oxide is absolutely infusible at the temperature of molten steel and agglomerations of it are found in all steels, in which any noticeable quantity of aluminum has been used.

Many engineers to-day absolutely prohibit the use of Aluminum in the manufacture of their Steel as their experience has convinced them that the products of its oxidation remaining in the Steel are weakening elements too dangerous to be safely disregarded.

It is apparent that of these well-known deoxidizers Titanium is the only one that can be used without adding to the Steel oxides or slags, which segregate to a possibly dangerous extent.

As the foregoing facts have been clearly demonstrated in practice the reasons for calling Ferro Carbon-Titanium the "Final Cleanser" are clear. These facts, however, are not easily demonstrated and many Steelmakers have tried Titanium in a superficial way and have been convinced, to their entire satisfaction, that Titanium is of no value in their practice.

That judgment of this sort is of no real importance— except as a retardant element—is proven by the fact that the firmest believers in and largest users of Ferro Carbon-Titanium are those who have used it for the longest time

and in the largest quantities after thorough and painstaking investigation.

To-day Titanium is being used in practically every grade of Steel, from the lowest to the highest carbon, in alloy and other special steels.

The use of Titanium in Steel must not be confused with that of Nickel, Chromium, Vanadium and other alloying elements which are added primarily to introduce a certain definite quantity of the special element to the Steel for the purpose of imparting to the metal certain specific and well-known qualities. Titanium on the other hand, is used solely as a deoxidizer and scavenger and in the case of alloy steels it cleanses the steel not only of its initial impurities but also of those introduced by the oxidation or the combination of a part of the alloying elements.

The functions of Titanium vary in degree in various grades of steel—in low carbon steel such as sheet or wire—small quantities varying from two to four pounds of Ferro Carbon-Titanium per ton of metal are used primarily for scavenging purposes to remove impurities and produce a superior surface to which spelter or tin will adhere more tenaciously, while in high carbon steels the use of larger quantities in addition to cleansing the steel by thorough deoxidation greatly reduces segregation thus insuring a sound, clean steel of uniform composition.

A FEW GENERAL POINTS REGARDING THE USE OF FERRO CARBON-TITANIUM IN STEEL

Make the Steel in the Furnace. That is what the furnace is for—and complete its deoxidation and cleansing in the ladle—which is the proper place.

Slag is charged with oxide—therefore to throw a powerful and costly deoxidizer into a ladle of steel into which slag is flowing is a most wasteful practice.

See that the Ferro Carbon-Titanium is all added before the slag begins to "run." It is the steel you wish to improve not the slag.

In High Carbon Steels where Titanium is used keep the silicon content on the low side and do not over-heat the steel in the furnace. If these points are observed there will be no excessive piping in the ingots.

No results of physical tests are given in these pages because no claim is made that a Titanium Treated Steel will have superior physical qualities to a clean, thoroughly deoxidized untreated steel of the same chemical composition.

It is claimed, however, that Titanium Treatment by "leveling up" practice from heat to heat will produce regularly a clean, uniform steel, to which each of the component elements will impart its maximum physical properties.

This condition is made possible by the uniform distribution of the various elements throughout the ingot and by the practical elimination of entrapped slags and oxides.

IN OPEN HEARTH PRACTICE

For large heats of over twenty-five tons use "Standard Medium" Ferro Carbon-Titanium.

In heats between fifteen and twenty-five tons use "F" size.

In heats between five and fifteen tons use "E" size.

For heats of less than five tons use "C" or "D" size.

IN BESSEMER PRACTICE

Use "C" and "D" sizes, which are packed in 25-pound cans.

In small converters, such as the Tropenas furnace having a capacity of from one to five tons, the "C" and

"D" sizes may be used without containers and should be added in the ladle. Care must be taken, however, to keep the slag back in the converter by means of a skimmer or other device until all the Ferro Carbon-Titanium has been added.

Our staff includes a corps of trained metallurgists and practical melters, whose gratuitous services are offered to all users and prospective users of this Company's products.

The unique opportunity which these men have had of studying the use of these products in a great variety of steels, made at different plants, has resulted in the development of a thoroughly experienced force of technical and practical men splendidly equipped to assist in solving steel mill problems through the use of Ferro Carbon-Titanium and other products of this Company.
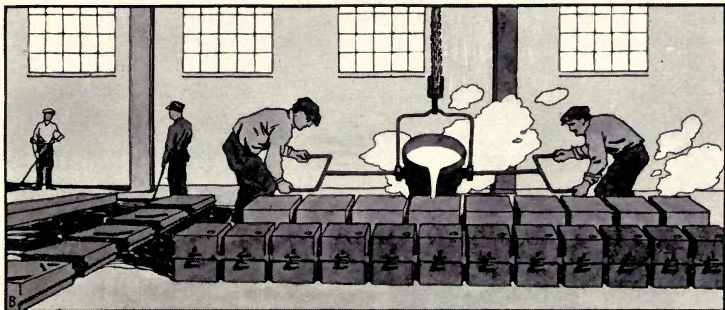
STEEL CASTINGS

S TEEL for castings is made in acid and basic open hearth, in converter and electric furnaces, and also in crucible pots.

The most common sources of annoyance in the manufacture of steel castings are cracks and unsoundness.

Cracks can sometimes be attributed to molding conditions for in cooling in the molds the steel will contract and there is a point where it has lost its fluidity and is more or less viscous. If there is any resistance offered to the metal during the cooling cracks are inevitably formed. In the case of over-oxidized metal at the range of temperatures where viscosity is manifest the tendency to tear is increased and a greater number of cracks will be found than in thoroughly deoxidized steel.

Unsoundness is manifest usually in steel castings in the form of blow holes, of varying formation.

Shrinkage holes due to the contraction of the metal during cooling can be properly taken care of by sink heads.

Blow holes may exist all through a casting or only near the surface. They are due to the presence of gas and their shape may be oblong, lenticular or spherical. If oblong in shape they are usually due to the metal being incompletely deoxidized or "killed," in which case they will be found near the surface. If globular or spherical they are caused by the presence of vapor or air and not

by chemical reaction taking place in the metal during its solidification in the molds. These last two types of blow holes can be attributed to damp sand or imperfect molding.

The oblong type of blow hole frequently found near the surface of steel castings can be traced to the presence of oxides in the steel and in particular to that of manganese oxide.

In the preliminary deoxidation of steel ferrosilicon and ferromanganese are used.

Their functions may be expressed as follows:

$$2FeO + Si = Fe_2 + SiO_2$$
$$FeO + Mn = Fe + MnO$$
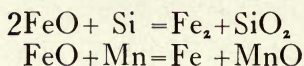
The products of these reactions, Silica and Manganese Oxide, being of lower specific gravity than steel will have a tendency to rise to the top of the ladle. Some portion of these oxides, however, will be entrapped in the steel.

Unfortunately Silicon in addition to combining with oxygen will also be found by microscopic examination in combination with iron as iron silicates.

Chemical analysis will not disclose in what combination the manganese exists, i. e., as carbide, sulphide or oxide. This last combination is the most deleterious of the three for the following reason: If a steel containing manganese oxide has been poured in a sand mold there is a reaction between the oxide and the carbon of the steel when the steel has almost reached the point of solidification, resulting in the formation of carbon monoxide, as expressed in the following equation:

$$MnO + C = Mn + CO$$
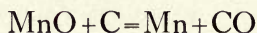
The same general reaction takes place between iron oxide and carbon as follows:

$$FeO + C = Fe + CO$$
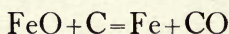
This carbon monoxide by expansion will be forced near the surface of castings, resulting in the formation of oblong blow holes. At the time such blow holes are formed, particularly in light castings, the base of the sink head or riser will already have been chilled so that no further feeding therefrom is possible and the entrapped gas must inevitably remain in the finished casting.

The physical qualities of a casting will be affected not only by unsoundness or blow holes in the steel but also by such impurities as slags and oxides as well as by segregation and improper annealing or heat treatment. It is well known that steel which is segregated will not give uniform results in annealing or heat treatment.

It will also be found that poor physical qualities can be traced to defective annealing, which must be considered a waste of time and money unless it is done with proper care. Theoretically all steel castings should be annealed although it is believed by some metallurgists that for steel low in carbon, and in particular basic open-hearth steel under .21 carbon, annealing will not improve the grain and does not affect the physical qualities to any important extent.

TREATMENT OF STEEL FOR CASTINGS WITH FERRO CARBON-TITANIUM

Assuming that by whatever process it has been made the steel is in proper condition in the furnace, vessel or pot and that the addition of Ferromanganese has been made prior to the tapping or pouring. If 50 per cent Ferrosilicon is to be used it will be added to the steel as it flows or is poured from the furnace and this addition is followed immediately by that of from four to six pounds of Ferro Carbon-Titanium per ton of steel. In making the addition of Titanium care must be taken that it is
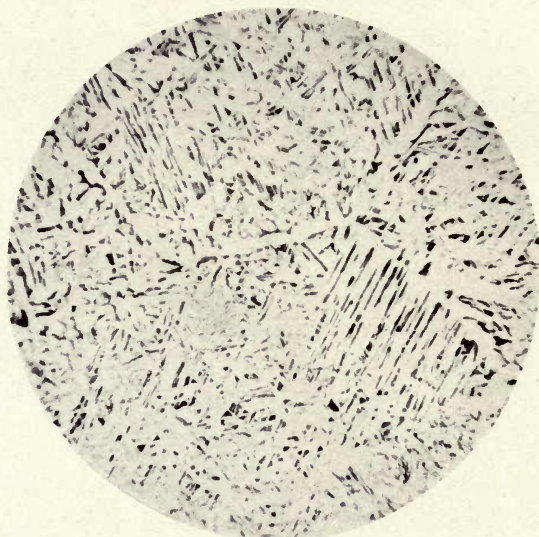
Fig. 1 — Structure of a soft steel casting, as cast, magnified 20 diameters. This steel had good physical properties in tension without annealing.
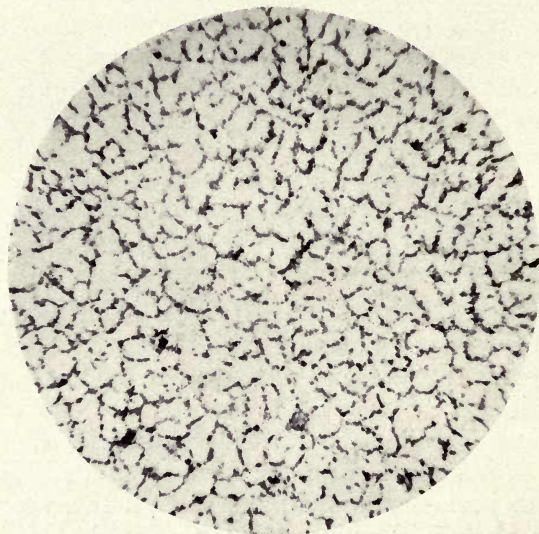

Fig. 2 — Structure of an annealed test-bar from same heat as Fig. 1, magnified 20 diameters. This bar had practically the same physical properties in tension as the unannealed steel.
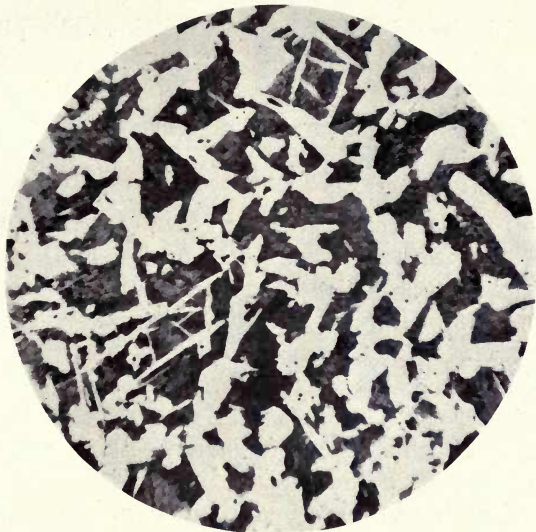
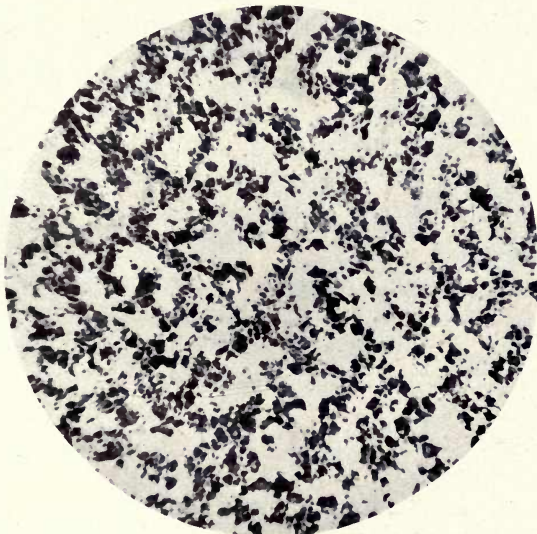FIG. 3—Structure of a steel casting that was badly annealed, magnified 50 diameters.

FIG. 4—Structure of a properly annealed steel casting, magnified 50 diameters.

completed before the slag begins to flow or the Titanium will be acted upon by the slag and thus be wasted.

In Open Hearth Steel six to eight minutes should elapse between the final addition of the last of the Titanium and the pouring of the steel into the first mold.

In Converter Steel where the finer sizes of Ferro Carbon-Titanium are used this time may be reduced to from three to four minutes.

This holding of the steel in the ladle is essential so that sufficient time may elapse for the slags and oxides always present in molten steel to rise to the surface. The combination of these slags with titanic oxide renders them more fusible and possibly by increasing their volume reduces their specific gravity. This lapse of time will not cause the metal to chill in the ladle because the oxidation of Titanium is an exothermic or heat producing reaction.

Immediately upon its addition the Titanium will react on the oxides of iron and manganese, as per the following equations:

$$2FeO + Ti = 2Fe + TiO_2$$
$$2MnO + Ti = 2Mn + TiO_2$$
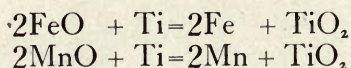
It will be noted, therefore, that Titanium acts not only as a deoxidizer but that the titanic oxide formed by the oxidation of Titanium is in addition a thorough scavenger and cleanser.

The use of aluminum as a deoxidizer must be discarded because by its oxidation alumina, an oxide absolutely infusible at the temperature of molten steel, is produced. The fact that alumina has a great tendency to remain in the steel to the detriment of the latter is well known and data substantiating this fact is presented on pages 84 to 105.

Steels of the following compositions will, when properly made and treated with Ferro Carbon-Titanium, set quietly in the molds and give good, sound castings. If

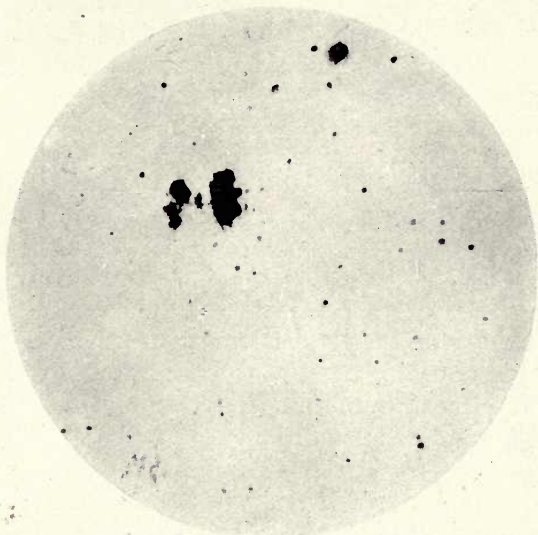Fɪɢ. 5 — Non-metallic inclusions in a Bessemer steel casting that was deoxidized with aluminum, magnified 200 diameters. The large dark spots are alumina.
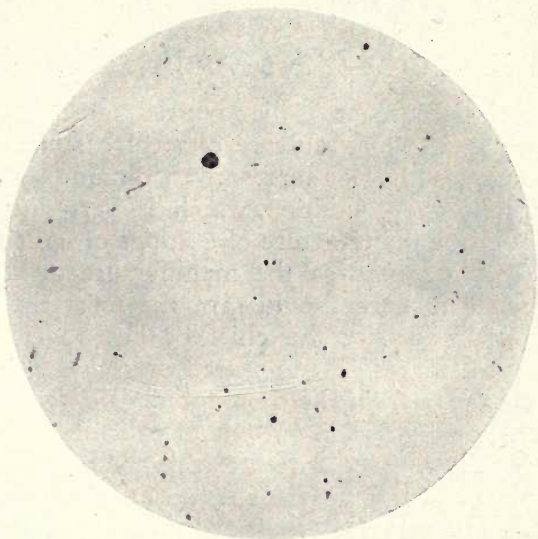

Fɪɢ. 6 — Non-metallic inclusions in steel like Fig. 5, but treated with titanium instead of aluminum, and magnified 200 diameters. Only small sulphides and silicates are present here.

properly annealed such castings will have the maximum physical properties obtainable for steels of their particular chemical composition.

	C	Si	S	P	Mn
Soft	.17 to .20	.30 to .35	.015 to .050	.020 to .040	.50 to .75
Medium	.20 to .30	.30 to .35	.015 to .050	.020 to .040	.50 to .75
Hard	.30 to .40	.30 to .35	.015 to .050	.020 to .040	.75 to 1.00

In castings of heavy section, such as steel pinions, rolls, etc., the use of Ferro Carbon-Titanium will reduce segregation to a minimum in addition to thoroughly deoxidizing and cleansing the steel.

The use of Ferro Carbon-Titanium in steel for castings is now the regular practice in a great number of foundries where it has been found that this practice not only improves the quality of the castings but actually reduces costs by increasing the yield of salable product.

ELECTRIC FURNACE STEEL CASTINGS

The electric furnace is being used more and more extensively in the manufacture of steel castings as this process enables the foundryman to obtain a very hot steel without over-oxidation, which is very important, especially in the manufacture of castings of light section. Of all processes used in the manufacture of steel the basic electric furnace should give the most thoroughly deoxidized product as the chief or basic claim made when these furnaces first appeared on the market some eight years ago, was for the thorough deoxidation possible with a slag or blanket of carbide of calcium.

In order, however, to produce this thorough deoxidation the slag, formed on the surface of the metal under the high temperature of the arc by carburizing a good basic slag with coke, must remain in contact with the
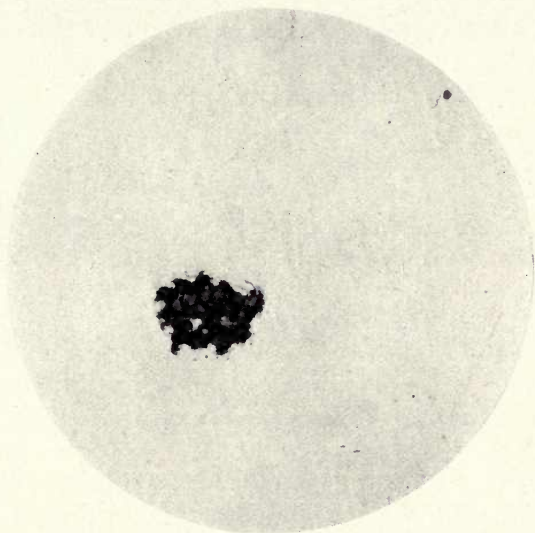
FIG. 7 — Segregated group of alumina particles in an electric steel casting, magnified 200 diameters.
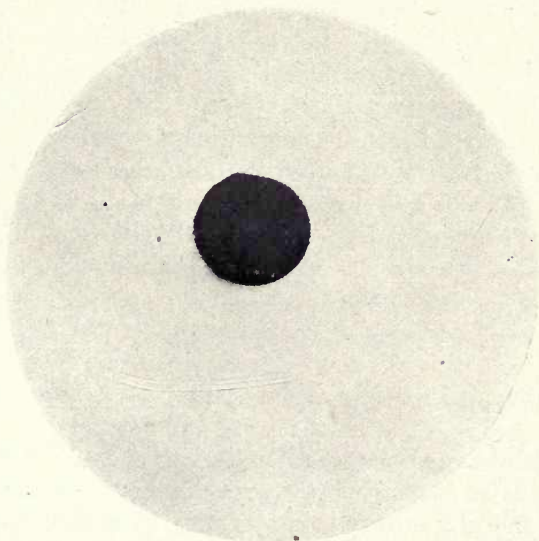

FIG. 8 — Slag globule in an electric steel casting, magnified 200 diameters.

bath sufficiently long to accomplish the purpose. The presence of silica falling from the roof of the furnace, or impurities in the lime might prevent the formation of carbide of calcium, in which case the slag would not completely deoxidize the steel.

Admitting, however, that the steel has been thoroughly deoxidized in the furnace it will be reoxidized to a certain extent during the tapping into the ladle and also become contaminated with slag as the latter usually flows into the ladle before the steel in this process.

In case the hearth of the electric furnace is acid instead of basic the process becomes simply a melting operation and the deoxidation must be effected as in the case of open hearth steel.

In much of the electric steel that is now made aluminum is added in the ladle to overcome the reoxidation where a basic lining has been used or to deoxidize the steel in the case of an acid lined furnace. The use of aluminum is just as objectionable in electric steel as in any other because of the formation of its infusible oxide, alumina, some of which segregates and remains in the steel to the great detriment of the latter.

If, however, from four to six pounds of Ferro Carbon-Titanium are added during the tapping of the steel into the ladle, it will in the case of a basic lined furnace complete deoxidation, which may not have been thorough due to impurities in the carbide of calcium slag, and take care of any reoxidation during the tapping and in the case of an acid lined furnace complete the deoxidation of the steel, and it will also in both cases by the fluxing action of titanic oxide free the metal from slag and oxide inclusions.

In this case as in others the steel should be held in the ladle from six to eight minutes to permit the slags and oxides rendered more fusible by combination with titanic oxide to rise to the surface.
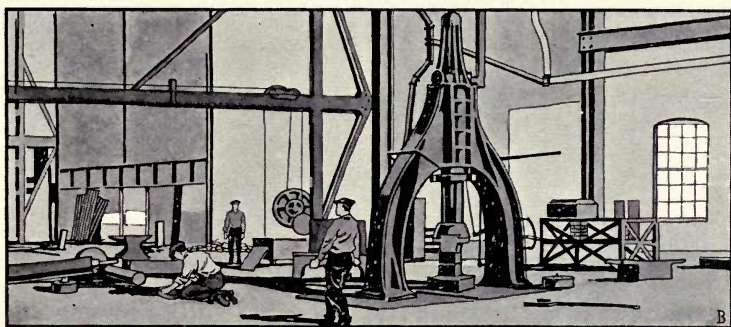
FORGING STEELS

STEEL for forging is usually made with a range of carbon of from .18 to 1.50, either with or without a content of silicon. The three most serious defects in steel forgings in the order of their importance are: segregation, seams and surface defects. Until lately very little attention was paid to segregation but some very severe specifications have been adopted recently by a number of railroads and other large users of steel not only for rails, which are really forging steels, but also for axles, tires, etc. These specifications have focused attention upon the question of segregation in medium and high carbon forging steels.

Most plants use chipping hammers which are operated constantly to remove seams and other surface defects from the billets. The causes of these defects can be traced to the ingots, which contain small globules of slags, oxides, etc. These are elongated in rolling and later are forced to the surface during the various reductions of the section.

The chipping of the surface of a billet removes the visible seams but when the billet is further reduced to a smaller section more seams are forced to the surface.

This fact clearly demonstrates that the air hammer does not furnish a proper remedy for the removal of seams but that this can only be accomplished by the

production of a cleaner steel, i. e., the elimination of globules of slags and oxides in the ingot.

FORGING STEELS WITH AND WITHOUT A SILICON CONTENT

In the manufacture of steel forgings two distinct grades are used; the one with and the other without a content of silicon.

FORGING STEEL WITHOUT SILICON. Forging steel made without a content of silicon will work when poured into the molds. It is the usual practice for steel manufacturers to practically "kill" such steel by an addition of aluminum to the steel in the mold and then to cap the mold, or to make an addition of powdered 50 per cent ferrosilicon, which is added in the top of the ingot.

This grade of steel will necessarily show more segregation than when the steel has been completely "killed" by the addition of a deoxidizer in the ladle. Blow holes and ingots with spongy heads are usual in this grade of forging steel.

FORGING STEEL HAVING A CONTENT OF AT LEAST .10 SILICON. In the manufacture of forging steel with at least .10 silicon the latter being added to the ladle in the form of 50 per cent ferrosilicon, the metal will lay quiet or "dead" and no addition of aluminum or powdered silicon in the mold will be necessary nor will there be any necessity for capping the molds.

Ingots so manufactured will show a shrinkage cavity or pipe, which should never extend below 15 per cent, from the top of the ingot.

In case the steel is made in acid open-hearth furnaces the silicon content can be obtained by an addition of 12 per cent ferrosilicon in the bath, it being preferable that any addition of ferromanganese shall also be made before the steel is tapped into the ladle.

FIG. 9 — Streaks of alumina in a billet of forging steel deoxidized with aluminum. Section cut parallel to direction of rolling, not etched, and magnified 200 diameters.

FIG. 10 — Typical small sulphide and silicate fibres in a billet of forging steel treated with titanium. Section cut parallel to direction of rolling, not etched, and magnified 200 diameters.

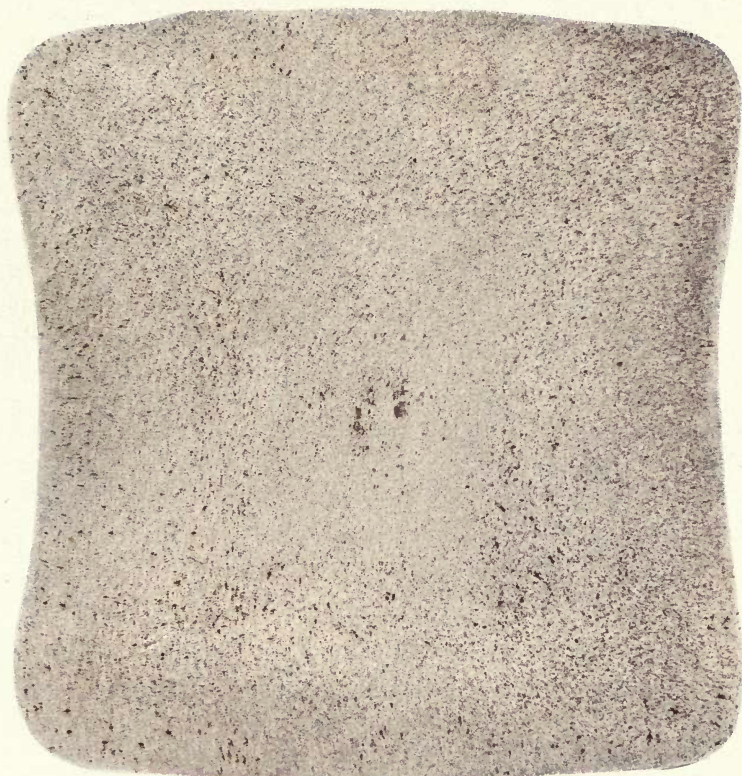FIG. 11 — Sulphur print of segregated untreated forging steel.

FIG. 12 — Sulphur print of homogeneous Titanium treated forging steel.

The use of aluminum added either in the ladle or in the molds will necessarily introduce alumina into the steel. This oxide is infusible at the temperature of molten steel and for this reason a large part of it will become entrapped in the metal and if it either segregates or forms streaks of small particles it will, as has been clearly shown, exert a seriously weakening influence upon the steel.

Unless forging steels are thoroughly deoxidized and cleansed microscopic examination will disclose the presence of slags, oxides, silicates, etc., all of which contribute largely to the formation of seams, which of themselves are weakening elements.

If there is serious segregation in a forging it cannot be properly annealed or heat treated for the very simple reason that the carbon content varies from the outside to the center and as is well known the same treatment will not be applicable to steel of different carbon contents.

THE USE OF FERRO CARBON-TITANIUM IN STEEL FOR FORGINGS

BASIC OPEN HEARTH. When the steel is in condition and ready to be tapped from the furnace the 80 per cent ferromanganese is added to the bath and the heat tapped. During the tapping the 50 per cent ferrosilicon is added (provided the steel is to have a silicon content). For reasons of economy some manufacturers prefer to make the addition of ferromanganese in the ladle at the time of tapping, but this practice will result in the production of steel of inferior quality.

In the manufacture of all grades of steel for forgings the carbon should be caught coming down unless the steel is recarburized in the furnace with hot metal so that no large addition of barley coal in the ladle will be necessary. Such addition of coal in the ladle will result

in non-uniformity of carbon and also add non-metallic inclusions to the steel from the ash, the latter usually amounting to from 15 to 25 per cent of the total weight of the coal.

The addition of from six to thirteen pounds of Ferro Carbon-Titanium per ton of steel (the variation in the amount depending upon the class of forging steel being manufactured) should be made as the final addition in the ladle, care being taken, however, that all the Titanium is added before the slag begins to flow. The Titanium will reduce all oxides present, such as those of iron and manganese, to metallic form and the titanic oxide formed by the oxidation of the Titanium will combine with all slags, silicates, etc., in suspension in the steel. These combinations, being more fusible than the original impurities prior to being combined with the titanic oxide, will rise more readily to the surface, leaving a thoroughly deoxidized, clean steel in the ladle to be teemed into the molds.

In order that this action of titanic oxide may be complete the steel should be held in the ladle from six to eight minutes.

ACID OPEN-HEARTH. As already stated, the silicon content can be obtained in Acid Open-Hearth practice (where a content of silicon is required) by the addition of 12 per cent ferrosilicon to the bath. It is also preferable that the 80 per cent ferromanganese be added in the furnace and that the carbon be caught coming down, or that the steel be recarburized with hot metal in the furnace.

The addition of Ferro Carbon-Titanium is made in this grade of steel in the same manner as in basic forging steel with or without a silicon content.

AXLE STEELS

The grade of steel used for axles is of forging composition and is made with and without a silicon content by both the basic and acid open-hearth processes.

FIG. 13 — Sulphur print of titanium treated 8-inch axle, showing entire absence of segregation.

An addition of Ferro Carbon-Titanium of from six to ten pounds per ton of steel will not only improve the surface of the axles but the physical qualities as well. Little segregation will be found, which is an especially important consideration in the case of steels which are subject to heat treatment.

ALLOY FORGING STEELS

Every grade of alloy steel, such as chrome, vanadium, nickel, chrome nickel, chrome vanadium and manganese steel can be considered as a forging steel, as they are manufactured practically the same as a plain carbon steel except that the addition of the ferro alloys is usually made in the furnace.

Alloy steels are equally subject to segregation and more subject to seams than plain carbon steel and for this reason it is especially necessary that forging alloy steels should be treated with from eight to thirteen pounds of Ferro Carbon-Titanium per ton of steel, the addition being made as usual in the ladle.

STEEL FOR TIRES

This steel is also a forging steel and is made in both basic and acid open hearth furnaces. An addition of from six to ten pounds of Ferro Carbon-Titanium per ton of steel will give a clean, thoroughly deoxidized metal, which will be free from excessive segregation and will give uniform results in annealing or heat treatment.

STRUCTURAL STEEL

STEEL for the rolling of structural shapes is usually cast in molds of large size, the resulting ingots being first reduced to blooms, billets or slabs and then to finished shapes which are usually I beams, channels, tees, plates or angles.

The larger shapes are generally rolled from the ingot to the finished material without reheating.

There are a great number of specifications for structural steel. The limits for sulphur and phosphorus are generally .04 and .05 respectively. The contents of carbon and manganese depend largely on the purpose for which the steel is to be used. There are also specifications for different physical requirements, such as tensile strength, elongation, character of fracture and cold bending without fracture.

The following is an average chemical analysis for structural steel:

Carbon	.20 to .22
Manganese	.32 to .40
Sulphur under	.04
Phosphorus under	.05

Segregation is a very serious defect in structural steel, but in the past it has not received anything like the attention that it should have either from structural steel makers or users.

MANUFACTURE OF STEEL FOR HEAVY STRUCTURAL SECTIONS

This steel is made by the Basic Open-Hearth process —no addition of silicon being made when the steel is poured from the furnace to the ladle. When the steel is teemed into the molds it will "work" or "rim in." This steel is usually poured into open top molds and "killed" during the pouring by an addition of aluminum. In many instances from six ounces to one pound of aluminum is used per ton of steel. The object of "killing" the steel in this way is to remove the blow holes and to a certain extent the segregation. In many instances a small amount of aluminum is also added to the steel in the ladle.

The addition of aluminum in the molds is more detrimental to the steel than an addition to the ladle, because alumina, produced by the oxidation of aluminum, will remain in the steel to a much greater extent and will be, as has been previously shown, a weakening element.

In the manufacture of structural steel we recommend the use of from two and one-half to three pounds of Ferro Carbon-Titanium per ton of steel, the Titanium being the last addition made to the ladle. Care must be taken that all the Titanium is added before the slag begins to flow and the steel should be held in the ladle from six to eight minutes after the last of the Titanium has been added to allow time for the Titanium Oxide formed by the oxidation of the Titanium to combine with any particles of slag and by lowering their melting points and decreasing their specific gravity cause them to rise to the surface.

To "kill" the steel in the molds we strongly recommend instead of the use of aluminum the addition of from two to three pounds of powdered 50 per cent ferrosilicon, the exact quantity to be determined by experiment.

There must be sufficient, however, to produce a flat
top on the ingot but not enough to seriously increase
the depth of the pipe. This ferrosilicon should be
added when the steel has reached about four or five
inches below the top of the mold.

COMPARISON OF TWO HEATS OF STEEL MADE FOR 20-INCH I BEAMS

Heat No. 1 was treated with four ounces of aluminum
per ton of steel, added while the steel was being poured
from the furnace into the ladle and an additional four
ounces of aluminum per ton added during the teeming
of the steel into the molds.

Heat No. 2 was treated with three pounds of Ferro
Carbon-Titanium per ton of steel in the ladle and the
steel was subsequently "killed" in the molds by an addi-
tion of three pounds of powdered ferrosilicon added near
the top of the molds.

The ingots in each case were 25″ x 25″ section and
weighed approximately 10,000 pounds.

A discard of approximately 8 per cent was made from
the top of each ingot, after which an ingot from each
heat was bloomed into billets of 6″ x 6″ section for the
purpose of making segregation comparisons.

The sulphur prints on pages 32 and 33 show the
segregation of that element and the chemical determina-
tions of carbon and sulphur are also given.

The microscopic examination of samples from heats Nos. 1 and 2 discloses the fact that the steel from heat No. 2 is free from alumina and generally cleaner than that from heat No. 1, the latter showing a considerable inclusion of alumina, which very naturally would unfit it for severe duty.

The reasons for the use of Ferro Carbon-Titanium in structural steels are the same as for steel for other rolled products, such as rails, axles, etc., i. e., the production of a cleaner steel of more uniform quality, because of its freedom from segregation, and one which is dependable in service because its chemical constituents are uniformly distributed and, therefore, impart to the steel their maximum physical properties.

Fɪɢ. 14 — Sulphur print of heat No. 1, killed with aluminum.

	Chemical Analyses	
	Sulphur	Carbon
Point A	.024	.18
Point B (center)	.043	.24
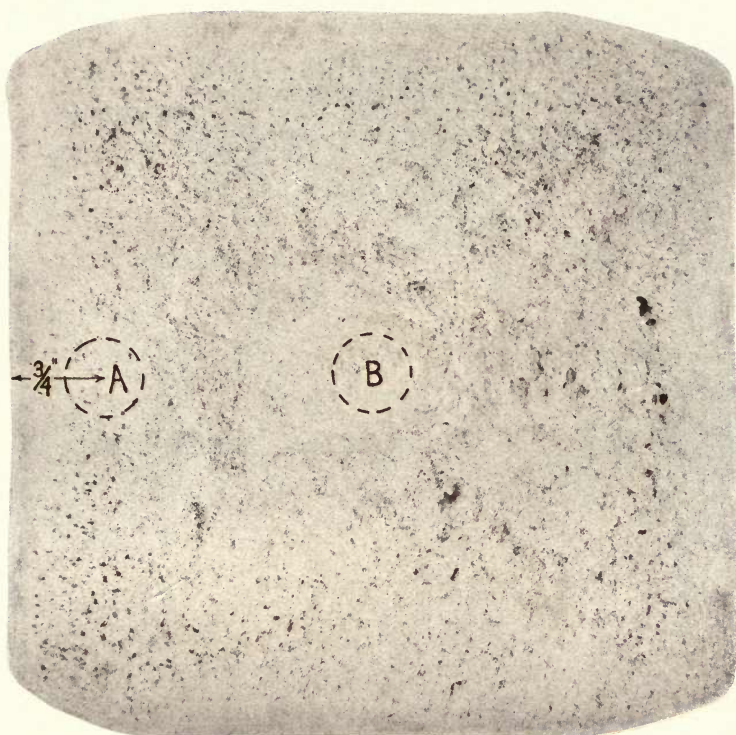
FIG. 15 — Sulphur print of heat No. 2, treated with Titanium.

	Chemical Analyses	
	Sulphur	Carbon
Point A	.026	.23
Point B (center)	.029	.245

Fig. 16 — Photomicrograph of a longitudinal section of a billet of heat No. 1 (Fig. 14), cut midway between center and edge, unetched, and magnified 200 diameters, showing part of a long streak of alumina particles.
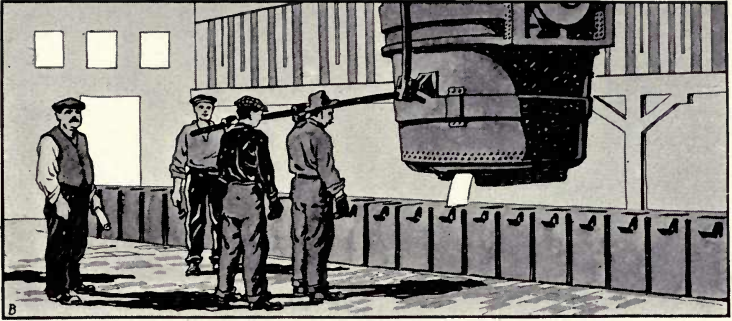
RAILS

IN the United States, practically all rails of the heavier sections, for main line track, are now made of Open-Hearth Steel, either by a direct process in the Basic Open-Hearth Furnace, or a combination of Bessemer and Open-Hearth processes, known as the "Duplex" method. A discussion of the Bessemer rail in these pages is, therefore, hardly necessary.

In order that those not entirely familiar with the subject may better understand the object of Titanium Treatment in this grade of steel, we give below a brief outline of the usual practice obtaining for the manufacture of Open-Hearth Steel for rails.

In making rail steel by the Duplex process, the molten pig iron is desiliconized, and partially decarburized in an Acid Bessemer Converter, and the steel is then transferred to a Basic Open-Hearth Furnace where the final refining takes place, in the same manner as in the direct process after the steel has been melted down and carbon and silicon reduced to the same degree. The Duplex Process is much more rapid than the direct, as a seventy-five to one hundred ton heat can be made in two to four hours by the former, as against nine to twelve hours by the latter.

The chemical specification for Open-Hearth rails of the heavier sections is approximately within the following

limits, the exact range depending upon the size and section of the rail.

Carbon . . . . .55 to .85
Manganese . . . . .60 to .90
Phosphorus under . . . . .04 to .06
Silicon under 25

The steel in the Open-Hearth Furnace is usually melted down to from .08 to .20 carbon, when the additions of ferromanganese or spiegel or both are made in the furnace to deoxidize the metal, after which a sufficient quantity of molten pig iron (low phosphorus Bessemer if possible), known as recarburizing iron, is added to the bath in the furnace to raise the carbon to the desired point. (In some cases these additions are made in the reverse order.) The steel is then tapped into a ladle, at which time further additions of ferromanganese, spiegel, or both, and usually ferrosilicon, are made. The steel is then poured into molds, varying in size from 19″ x 19″ to 22″ x 25″, with ingots weighing from 4,000 pounds to 10,000 pounds, depending on the number of rails in the ingot, and the section of rail to be rolled, as well as the length of tables in the mill.

SOLIDIFICATION OF INGOTS

If the content of silicon in rail steel is up to .15 per cent to .18 per cent, the metal will usually be "dead" in the molds and will slowly solidify without boiling. If, on the other hand, the silicon content is much lower, or the steel very hot or over-oxidized, it is necessary to add aluminum to quiet the metal and prevent boiling. The deleterious effects of using aluminum with the resultant formation of alumina in steel subjected to strains, shock, abrasive wear, etc., are well known to many metallurgists. That alumina remains in steel in a segregated condition is clearly shown under the subject of "A Study of Alumina in Steel" on pages 84 to 105

in this booklet. Some railroad engineers specify that no aluminum shall be used in their rail steel.

SEGREGATION AND ITS PREVENTION BY USE OF ALUMINUM AND TITANIUM

In accordance with the well known theory of "selective freezing," the central portion of the upper part of an ingot of ordinary high carbon steel is generally segregated. The amount of segregation of carbon, phosphorus and sulphur will average at least 17 per cent, and is very often as much as 50 per cent. The usual discard of a 9 per cent crop from the top of the ingot does not eliminate the segregated portion, and, therefore, the top rails (A and sometimes B) of the ingot usually show this segregation very plainly by chemical analysis, sulphur prints or microscopical examination. The metal in the central portion (middle of web or junction of web and head), representing the central core of the top ("A") rail of the ingot will contain from 15 per cent to 40 per cent higher carbon, phosphorus and sulphur contents than the metal near the surface of the head, in at least 65 per cent of the heats made by the usual Open Hearth Process, that is, without the use of a powerful deoxidizer, such as aluminum or Titanium. These deoxidizers, when used in sufficient quantities to eliminate all gases, oxides, etc., cause the steel to solidify quickly and quietly with a minimum of segregation. As above stated, however, the use of aluminum in this respect results in occlusions of alumina in the steel, which are equally as undesirable as segregated metal. The products of deoxidation with Titanium *do not* remain in the steel, as pointed out elsewhere in this booklet. Titanium is the only powerful deoxidizer which can eliminate serious segregation, and give a clean, uniform metal throughout the ingot.
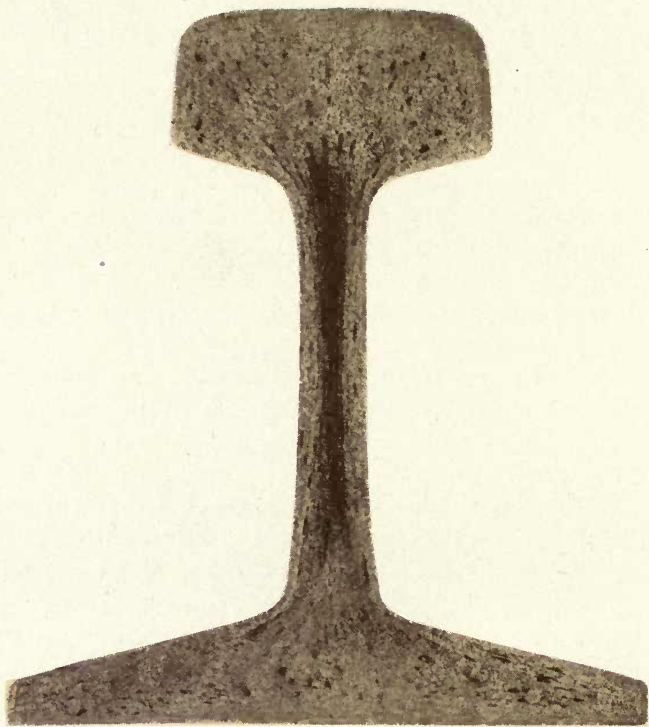
FIG. 17—Sulphur Print of a typical untreated Open-Hearth "A" Rail.
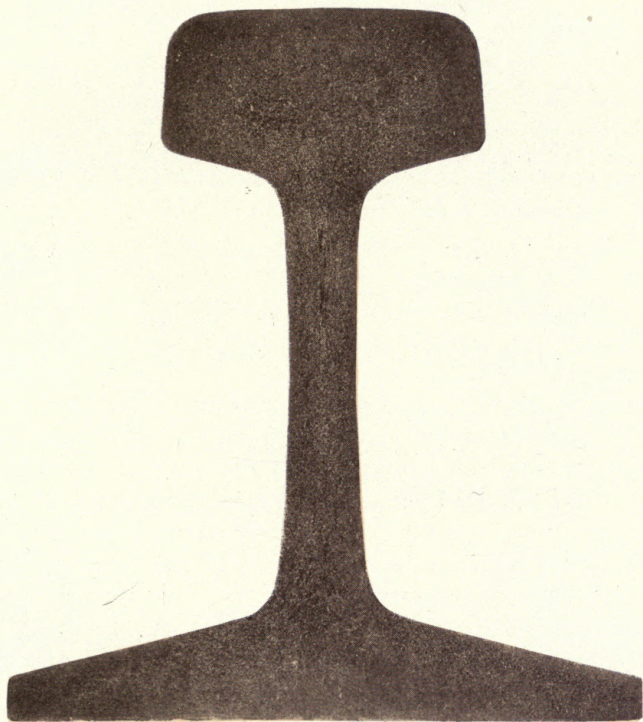(Reduced to $\frac{2}{3}$ size.)

FIG. 18—Sulphur Print of a typical Titanium treated Open-Hearth "A" Rail.
(Reduced to ⅔ size.)

OTHER BENEFITS OF TITANIUM

The elimination of oxides of iron, manganese, silicon and other slag occlusions by the use of Titanium will give to the steel the maximum physical properties possible from its component elements.

BLOW HOLES, SEAMS, ETC.

An ingot containing gases, oxides, etc., will solidify with a certain amount of blow holes from the center to the surface, especially in the upper portion. These blow holes will elongate into seams during the rolling, some showing at the surface, and others being deeper will not be seen when the rails are inspected. Some processes have recently come into use for removing surface defects, including seams on the billet, such as the Deseaming Machine. These methods of improving the surface of the metal, however, do not reach any defects, such as seams or slag occlusions, below the surface deeper than the cut of the machine, and in order to have sound metal all through the rail, it is necessary to have a sound ingot free from internal blow holes, and the steel must be entirely free from gases and oxides. Titanium eliminates these gases and oxides and insures sound metal, free from blow holes, in the ingot.

DENSENESS OF GRAIN, ETC.

Ingots of Titanium Treated Rail Steel have a closer or denser grain than those of untreated steel of the same chemical composition, due to their more rapid solidification. The grain structure of the finished rail is, of course, influenced by the finishing temperature at the time of rolling. If the rails are finished hot the grain structure will be much coarser than if the finishing is completed at a much lower temperature. The fineness of grain of Titanium Treated Steel, in conjunction with its freedom

from excessive segregation, slag occlusions and seams, gives a steel which resists abrasive wear much more than a steel of the same hardness with a coarser grain and containing minute oxides or slag occlusions.

The absence of seams and serious segregation and the cleanliness and close grained structure in Titanium Treated Rails naturally insure a minimum of rail failures in track from breakage, split heads, broken bases, battered ends, etc

PIPING OF INGOT

The impression that Titanium Treatment results in increased piping in the ingot, and also rails, has spread among some railroad engineers not entirely familiar with the metallurgical action of this deoxidizer. A few words of explanation may therefore be desirable.

Any powerful deoxidizer which when added to steel tends to increase the denseness or solidity of the ingot naturally causes the shrinkage cavity formed near the top of the ingot during solidification to be larger than such a cavity would be in an ingot with a more spongy structure and full of small blow holes. The size of this cavity is not important, providing it can be held close to the top of the ingot, and therefore eliminated when the 9 per cent or 10 per cent discard is cropped from the "blooms." The depth of the cavity, however, is a very important feature, and this is influenced to a great extent by the temperature at which the steel is tapped from the furnace and also by the silicon content. If the metal is poured at a moderate or normal temperature, the cavity will be very close to the top of the ingot and eliminated with the top discard. If, however, the steel is poured at a very high temperature, the cavity is liable to take the shape of an inverted cone, the point extending far down into the ingot, with the result that the rails from the top portion of the ingot are piped. This is true of both plain

and Titanium Treated rail steel when poured in ordinary molds, that is, molds without "hot tops" or other devices to prevent piping.

When Rail Steel is treated with 0.10 Titanium the silicon content in the finished steel should be from .06 to .12—preferably about .09 to .10. As both Titanium and silicon are deoxidizers—a content of more than .12 silicon is unnecessary and will only increase the tendency to piping.

Among melters of Open-Hearth rail steel, who were not very familiar with Ferro Carbon-Titanium, there was at first a tendency to tap the steel, to be treated with Titanium, at a high temperature, on account of the steel having to dissolve the Titanium in the ladle, and also being held a few minutes before pouring. This was unnecessary and undesirable because the oxidation of Titanium is an exothermic or heat producing reaction which raises the temperature of the steel in the ladle. The combination, therefore, of over-heating the metal and the oxidation of Titanium necessarily results in a tendency to develop deep shrinkage cavities in the ingots. Melters who have used Ferro Carbon-Titanium regularly have now learned that steel to be treated with Titanium should be tapped at normal temperatures as usual and they have, therefore, overcome the abnormal piping in the ingot which was at first experienced.

RAIL DATA

Data in reference to a large number of comparative service tests, both as to rail wear and rail breakage has been compiled for this Company, most of the work having been done by R. W. Hunt & Co. or by the engineering departments of railroads for which Titanium Treated Rails have been rolled.

In addition to this work there has been examined in

this Company's physical and chemical laboratories an enormous number of samples of both Titanium Treated and Standard rail steel.
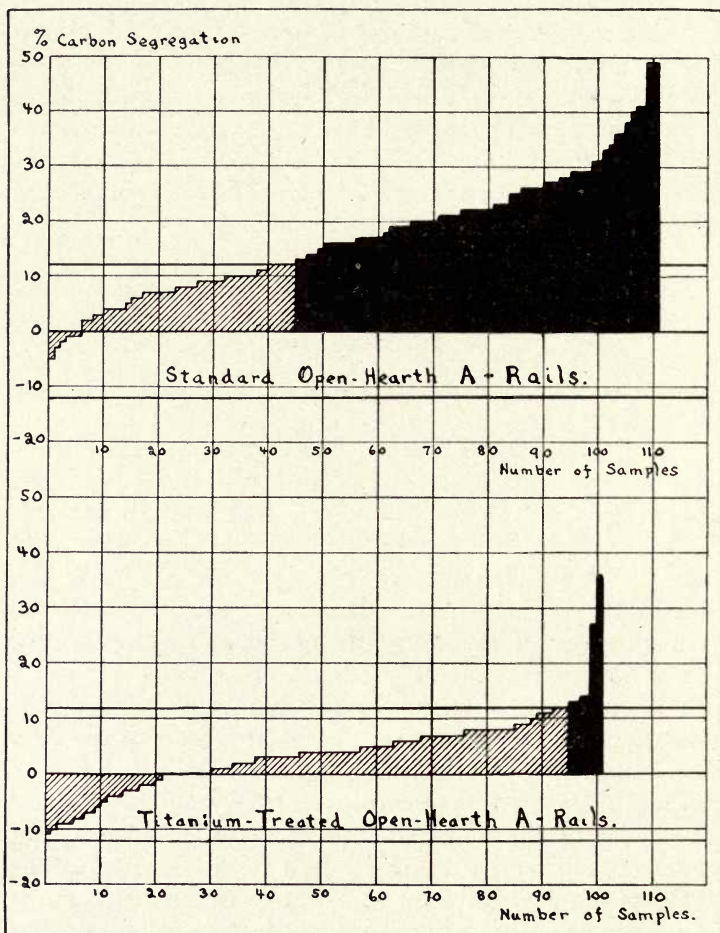
Where rails have failed in service on various lines samples of the defective rail have been sent to our laboratories for examination and in a number of instances we have been able to positively demonstrate the cause of failure for the benefit of railroad officials.

One particularly interesting case was the failure of a D-Rail on a Southern railroad system. It so happened that a three foot sample of an A-Rail from this same heat of Titanium Treated steel had been previously sent to our laboratories for examination—this sample is reported on page 11, Bulletin No. 5, as Heat U.

Reference to this Bulletin will indicate that the chemical and physical properties of this rail were excellent. The sample of the D-Rail which had been broken in track was more uniform both physically and chemically than the A-Rail sample previously examined, and the conclusion of the report which was submitted to the chief engineer of the railroad by our metallographist, was as follows:

"No defect was found in this sample which would indicate that the failure was due to any fault of the rail. On the whole the physical properties and structure of this sample, which has been in service, seem even better than those of the new rail reported in the bulletin, but whatever superiority there is, is, of course, due to the fact that the new rail was an A-Rail while the other was from a lower position in the ingot. The results show that this sample had not deteriorated to any marked extent from having been in service and it seems most probable that its failure was due to some external injury."

Service of this nature must inevitably be of benefit to railroad engineers in determining the causes of failure of their rails. It is apparent that in this particular case

% Carbon Segregation

Standard Open-Hearth A-Rails.

Number of Samples

Titanium-Treated Open-Hearth A-Rails.

Number of Samples.

Samples showing less than 12% segregation of carbon between upper corner of head and junction of head with web.

Samples showing over 12% segregation between same points.

Fig. 19—Carbon Segregation Percentage Diagram as per Pennsylvania Railroad specification. This diagram was plotted from the results of over 400 chemical analyses, each analysis being double checked.

it would have been unfair to have blamed the quality of the steel for the failure of the rail.

It is because of the impossibility of definitely determining the cause of many rail failures in track that careful students of the rail problem seriously question the value of such statistics as those presented in general rail failure reports.

Literature referring specifically to the question of Rail Steel will be mailed upon request.

On account of limited space no attempt has been made to include data in this booklet.

METHOD OF USING FERRO CARBON-TITANIUM IN RAIL STEEL

Ferro Carbon-Titanium is the last addition made to the steel in the ladle and specifications covering its use are given below:

IN BASIC OPEN-HEARTH STEEL FOR RAILS

(1). All recarburizers (except small additions of coal or coke) and the major portion of deoxidizers, except Titanium, shall be added to the steel in the furnace before tapping, and the Ferro Carbon-Titanium shall then be gradually added to the steel in the ladle as the metal flows from the furnace. (See paragraph 3.)

(2). All necessary additions to the steel in the ladle, except Titanium, shall then be added as quickly as practicable after the steel begins to run into the ladle.

(3). Immediately thereafter the addition of Ferro Carbon-Titanium shall be made, adding gradually and completing before the slag begins to run.

(4). The Titanium addition in all cases shall be the last one made to the steel.

(5). After the ladle is filled it shall be held at least eight minutes before commencing to pour the steel into the ingot molds.

IMPORTANT RECOMMENDATIONS
(Not definitely specified.)

(A).   The quantity of Ferro Carbon-Titanium recommended for use in rail steel of usual composition is such as to introduce into the molten metal as nearly as practicable 0.10 per cent metallic titanium.

(B).   It will be of advantage to both the railroad and the mill if the Silicon content be kept as near 0.10 per cent as practicable. We suggest as limits 0.06 to 0.12 per cent.

(C).   The use of aluminum in connection with Titanium rail steel is unnecessary for all normal heats.

Why we recommend the addition of recarburizer in the furnace instead of in the ladle in the manufacture of high carbon steel for rails.

It is the practice in many steel plants to add molten recarburizer in the ladle instead of in the furnace. We object to this practice for the following reasons:

When the recarburizer, which is usually molten iron or ferro spiegel, the latter carrying from 1.50 to 1.75 of silicon and from 5 to 7 per cent of manganese, is added gradually in the ladle during the tapping of the furnace the Ferro Carbon-Titanium is shoveled in at the same time.

The basic reason for treating steel with Ferro Carbon-Titanium is to complete the deoxidation after preliminary deoxidation has been effected by the use of such inexpensive deoxidizers as manganese and silicon. The function of the Titanium is to remove any oxides remaining in the steel and also those introduced by the manganese or silicon. The oxide of Titanium produced by the oxidation of that metal will also flux any particles of slag in the steel by combining with them and lowering their melting point.

It is apparent, therefore, that if the recarburizer is added to the steel in the ladle during the tapping of the

furnace and Ferro Carbon-Titanium is introduced at the same time the more powerful deoxidizer, Titanium, will perform the initial deoxidation which should be accomplished by the less expensive recarburizing iron or molten spiegel.

Melters, generally, are in favor of adding the recarburizer in the ladle as this practice provides a more convenient control of the content of manganese and silicon in the final product, but there can be no doubt that the practice is detrimental to the quality of the finished steel.   If care is taken to start digging out the tap-hole when the addition of recarburizer is made so that the steel can be tapped from the furnace within seven or eight minutes after the recarburizer has been added, it will be found that there will be little greater loss of silicon and manganese than when the addition of recarburizer is made in the ladle at the time of tapping.

It is generally admitted that the open-hearth furnace, and not the ladle, is the proper place to make steel.   It must be appreciated that for heats varying from 150,000 to 200,000 pounds an addition of from 20,000 to 35,000 pounds of metal as recarburizer must be made, also that the higher temperature of the furnace compared with that in the ladle necessarily facilitates the chemical reactions during the period of deoxidation.

There could be no objection to the addition of the recarburizer in the ladle, except that the temperature would be less than in the furnace, if after such addition the steel was poured into a second ladle in which the addition of Ferro Carbon-Titanium could be made while the steel flowed from the first to the second ladle.

Although the above explanation seems logical of itself it was found necessary to make a demonstration which would prove our contention.

During the past year there were made at one of the large rail mills twenty-eight heats of Basic Open-Hearth

Steel; nine of these heats were of untreated steel, the recarburizer being added in the ladle and no Titanium being used; ten heats with the recarburizer added in the ladle and .10 Titanium added in the form of Ferro Carbon-Titanium at the same time as the recarburizer, and nine heats with the recarburizer added in the furnace, as per our recommendations, and .10 Titanium in the form of Ferro Carbon-Titanium added in the ladle.

To all of these samples the Pennsylvania Railroad specifications for carbon segregation were applied with the following results:

PLAIN OPEN-HEARTH, RECARBURIZER IN THE LADLE
ANALYSIS

Heat No.	Ladle	Head	Web	Per Cent Increase	
1	.665	.605	.667	10.2%	
2	.649	.640	.652	1.9%	
3	.685	.636	.774	21.7%	56% of the heats do not meet the specifications.
4	.685	.607	.683	12.5%	
5	.750	.730	.767	5.1%	
6	.620	.544	.632	16.2%	
7	.682	.589	.663	12.6%	
8	.665	.613	.632	3.1%	
9	.713	.644	.747	16.0%	

RECARBURIZER IN LADLE AND .10 TITANIUM IN LADLE

Heat No.	Ladle	Head	Web	Per Cent Increase	
10	.620	.574	.743	29.5%	
11	.655	.618	.783	27.5%	
12	.633	.606	.789	30.2%	
13	.733	.696	.976	40.2%	
14	.745	.755	.738	Negative	70% of the heats do not meet the specifications.
15	.620	.583	.731	25.4%	
16	.700	.662	.769	16.1%	
17	.635	.617	.625	1.3%	
18	.675	.651	1.000	53.6%	
19	.665	.627	.686	9.4%	

RECARBURIZER IN FURNACE AND .10 TITANIUM IN LADLE

Heat No.	Ladle	Head	Web	Per Cent Increase	
20	.620	.586	.629	7.3%	
21	.750	.748	.707	Negative	
22	.730	.693	.695	.3%	
23	.710	.645	.665	3.1%	All heats within the specifications.
24	.645	.590	.589	Negative	
25	.625	.613	.619	1.0%	
26	.655	.621	.670	7.9%	
27	.675	.677	.643	Negative	
28	.655	.629	.663	5.4%	

After the regular discard of 9 per cent, including that at the shear and hot saw, samples were taken from the top of the A-Rail, i. e., at a point immediately following the discard.

These figures show very distinctly the advantage of adding the recarburizer in the furnace instead of in the ladle and it is our belief that the practice is preferable in steel making whether Ferro Carbon-Titanium is used or not.

One other disadvantage of adding Ferro Carbon-Titanium in the ladle at the same time as the recarburizer is that a heavy slag covers the recarburizing iron in the ladle from which it is poured. As it is the usual practice to top pour the recarburizer the tendency of this slag is to flow into the large ladle with the iron and in this way the Ferro Carbon-Titanium being added at the same time becomes covered with a heavy coating of slag, which prevents the action of the Titanium on the steel and thus the addition of the Titanium is practically wasted.

In addition to the number of heats noted above we have had the opportunity of making a similar experiment at another plant on two heats of steel. Heat "A" was made in a stationary furnace, the recarburizer being added in the furnace and the Ferro Carbon-Titanium in the ladle, while heat "B" was made in a tilting furnace, both the recarburizer and the Ferro Carbon-Titanium being added in the ladle.

	HEAT A (Having recarburizer added in furnace and .10 Titanium in ladle.)		HEAT B (Having recarburizer and .10 Titanium added in ladle.)	
	Top	Center	Top	Center
Carbon	.743	.650	.690	.937
Phosphorus	.015	.013	.008	.017
Sulphur	.050	.048	.039	.072

Here again the advantage of adding the recarburizer in the furnace and the Ferro Carbon-Titanium in the ladle is clearly shown.

$$\begin{array}{c} .650 \\ .743 \\ \hline \text{Negative.} \end{array}$$

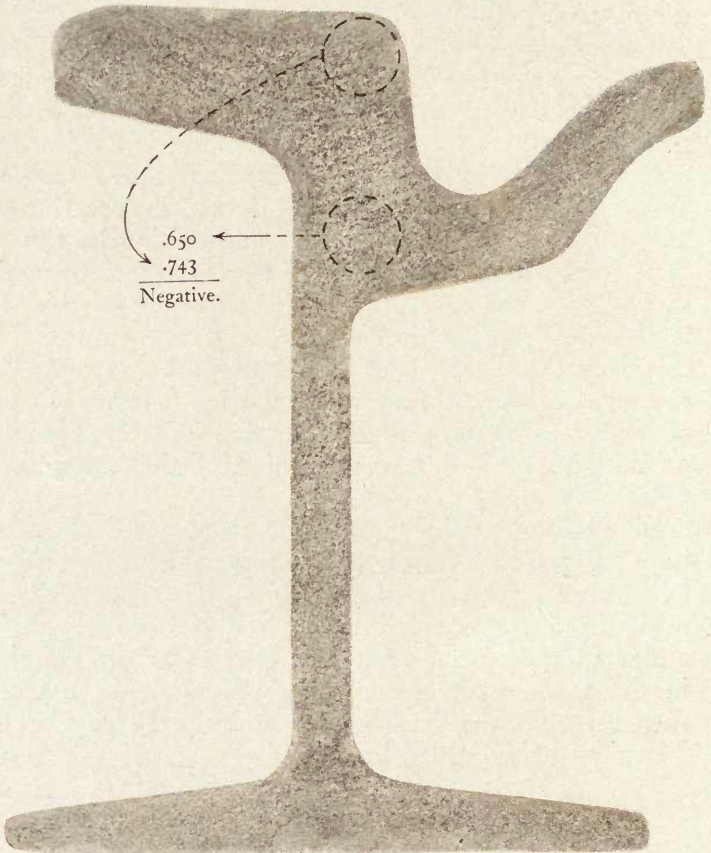Fig. 20 — Heat "A"— Sulphur print of "A" rail from heat which was recarburized in the furnace and properly treated with titanium.
(Reduced to ⅔ size.)

THE SULPHUR PRINTS HEREWITH SHOW THE POINTS AT WHICH SAMPLES WERE TAKEN FOR ANALYSES OF CARBON, PHOSPHORUS AND SULPHUR AND THE FOREGOING SCHEDULE GIVES THE RESULTS OF THESE DETERMINATIONS.
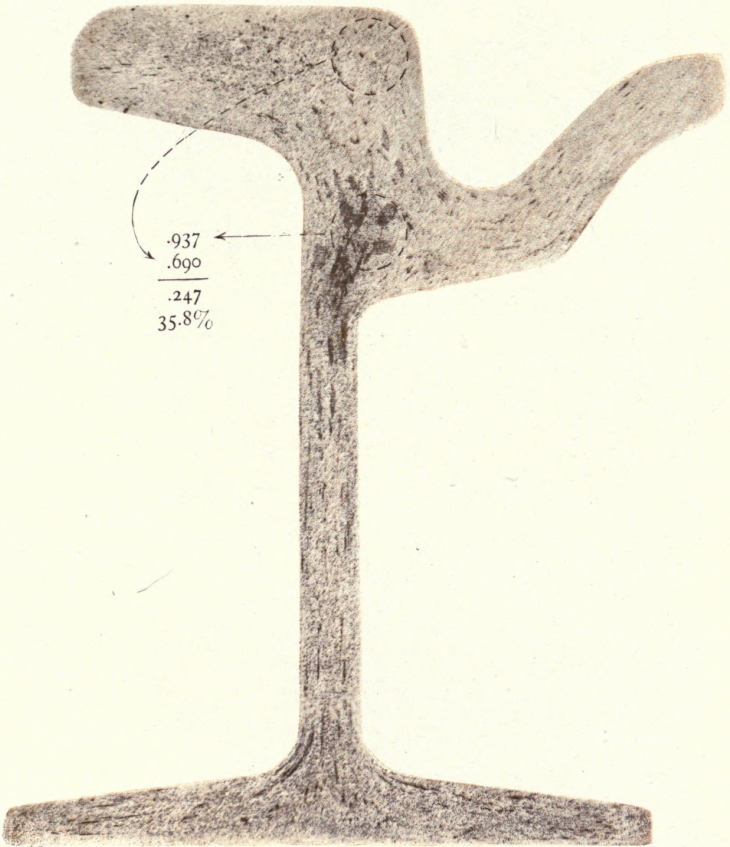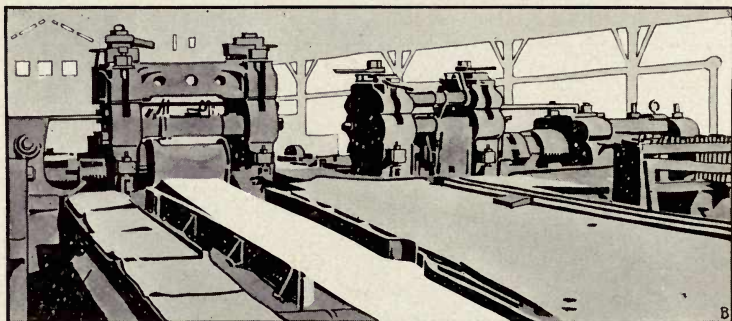
.937
.690
———
.247
35.8%

FIG. 21 — HEAT "B"— Sulphur print of "A" rail from heat which was treated with titanium, but recarburized in the ladle.

(Reduced to ⅔ size.)

SHEET AND PLATE STEELS

THIS general class of products is rolled from steel to thicknesses varying from about one inch down to very thin sheets of No. 39 gauge. The heavier gauges are used for boiler plate, fire box plate, etc., while sheets of lighter gauge are used for deep stamping and other purposes as black plate, terne plate, galvanized or tinned.

The steel used for all of these different grades of plate or sheet is made in approximately the same way with a slight variation in carbon content, either in acid or basic open-hearth furnaces or in Bessemer converters, the last grade being used generally for sheets of light gauge only.

DEFECTS IN STEEL FOR SHEETS AND PLATES

The defects in this grade of steel may be classified as follows:

First. Those due to the quality of the steel.

Second. Mechanical defects, such as roll scale caused by poor rolling.

Third. Defects due to improper annealing.

Fourth. Mechanical defects arising from careless immersion of the sheets in the bath where they are galvanized or tinned, or due to inadequate pickling and washing of the surfaces.

As we are dealing with the quality of the steel it is

Fig. 22 — Natural size photograph of a black sheet showing mill scale on the surface.
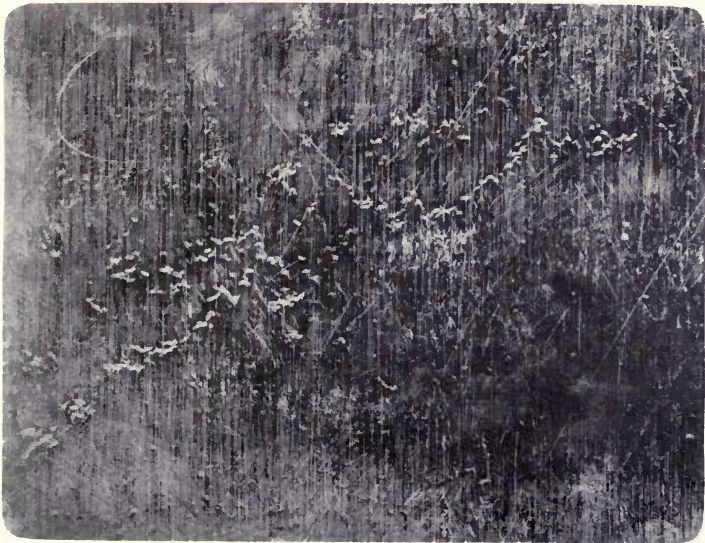

Fig. 23 — Natural size photograph of a tinned sheet, into whose surface mill scale had been rolled (compare with Fig. 22).
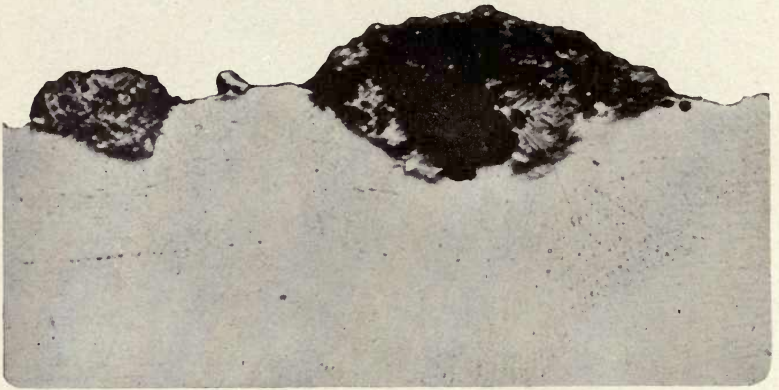
FIG. 24 — Section of black sheet magnified 157 diameters, showing two fragments of scale rolled into the surface, and forming indentations.
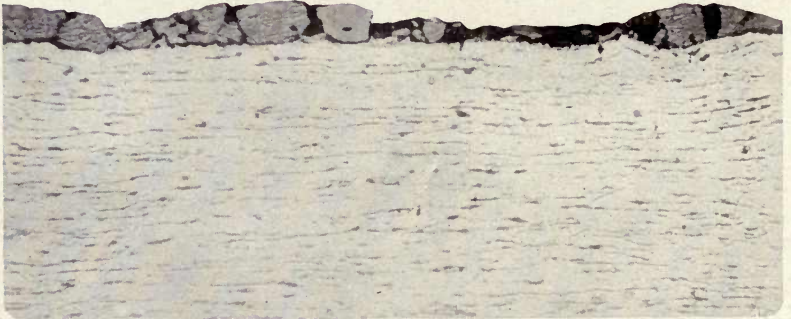

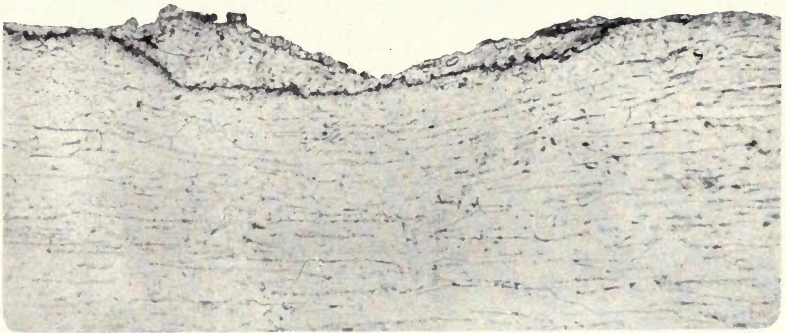FIG. 25 — Section of sheet shown in Fig. 22, magnified 200 diameters, showing scale adhering to the surface.

FIG. 26 — Section of sheet shown in Fig. 23, magnified 200 diameters, showing one of the hollows formed by the scale in the surface, but now filled with tin.
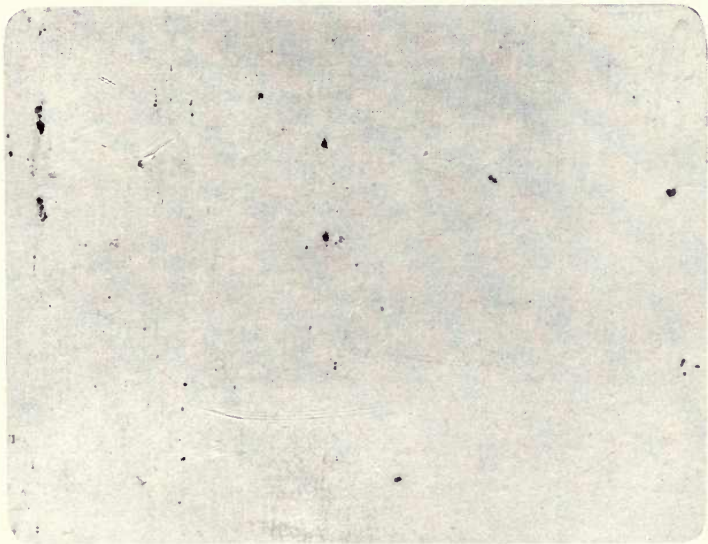

FIG. 27 — Natural size photograph of a tinned sheet, showing uncoated spots caused by scale not removed from the surface by pickling.

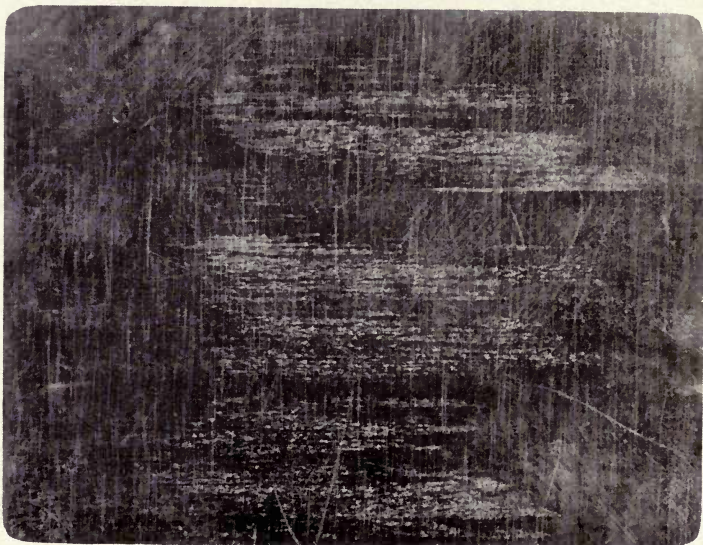FIG. 28 — Natural size photograph of tinned sheet showing defective surface.

FIG. 29 — Natural size photograph of another tinned sheet with a defective surface.

FIG. 30 — Section through one of the spots shown on Fig. 27, magnified 200 diameters, showing scale on the surface interrupting the tin coating.

FIG. 31 — Section of sheet shown in Fig. 28, magnified 200 diameters, showing uneven tin coating and rough steel surface.

FIG. 32 — Section of sheet shown in Fig. 29, magnified 200 diameters, showing impurity in the tin, causing an uneven coating.

only necessary to point out that the second, third and fourth classes of defects can be corrected by careful operation in the rolling and finishing departments. The use of a pyrometer and frequent microscopic examination of samples will enable the manufacturer to control the annealing of the steel, and the latter method will indicate very often that a good quality of steel has been seriously injured by improper annealing.

In many finishing departments the defects in class one are considered inevitable as it is necessary for these departments to make the best possible product from the steel which is furnished them and they are often forced to show a very high percentage of "wasters" and a correspondingly low percentage of "prime" sheets, due to conditions for which the finishing departments are in no way responsible.

The specific defects which fall under class one and which are due to the presence of slags and oxides in the steel are laminations, surface defects, etc., such as small slag or oxide spots and blisters, the latter occurring more generally in galvanized and tinned sheets. In galvanized sheets another defect, which is very often encountered, is that called "gray coating" where the spelter has not crystallized in large spangles because of a pitted surface on the sheet caused by spongy steel, slags or oxides.

Such surface defects as laminations and porosity usually arise from blow holes being too near the surface of the ingots, which causes them to break through during the rolling, producing scabs and the defect commonly known as "snakes."

Laminations are often found in shearing plates and these can be traced to blow holes which were not welded in the preliminary rolling because their surfaces were oxidized or coated with slag. Frequently the presence of such slags or oxides can be detected without the use of a magnifying glass.

FIG. 33 — Natural size photograph of a " gray coating," showing variation in size of spangle on a galvanized sheet.

FIG. 34 — Section of galvanized sheet with " gray coating," showing uneven steel surface that caused the small spangle. The zinc has been blackened in this case by ammonia.

Blisters on sheets, although found in black sheets, are more frequently encountered in those which are galvanized or tinned. Many explanations have been given for their formation in coating sheets with spelter or tin. The following seems to be the most rational. If the steel contains oxides, such as those of iron and manganese, these oxides will be reduced by the hydrogen absorbed by the sheets during pickling, the formation of water resulting as per the following equations:

$$FeO + H_2 = Fe + H_2O$$
$$MnO + H_2 = Mn + H_2O$$
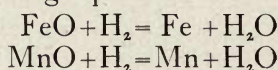
During the passage of the sheet through the bath of spelter or tin this water will vaporize, which will necessarily produce blisters. These blisters are from infinitesimal size up to one inch or more in diameter.

When galvanized or tin plated sheets are subjected to deep stamping or sharp bending, the coating very often cracks or peels off. This is caused invariably by the fact that the coating has been deposited on an oxidized or dirty surface.

MANUFACTURE OF SHEET AND PLATE STEEL

Let us assume that the steel is to be made in an open-hearth furnace of at least thirty-five tons capacity and that it is to be poured into open top molds, which are to be capped after the steel has been allowed to "rim in."

When the heat of steel is in condition the furnace is tapped and additions of ferrophosphorus, which will be used if the steel is to be rolled into light gauge, and of 80 per cent ferromanganese are added in the ladle. The practice of adding the 80 per cent ferromanganese in the ladle is followed by the average mill in this country at the present time. A better practice, however, is to add the ferromanganese in the furnace just before tapping, which will diffuse the manganese uniformly and eliminate what are commonly called "hard" spots on the sheets, which

FIG. 35 — Natural size photograph of surface of a tinned sheet in which slag was found below the defective spots.

FIG. 36 — Section of sheet shown in Fig. 35, magnified 200 diameters, showing large slag enclosures just below the steel surface.
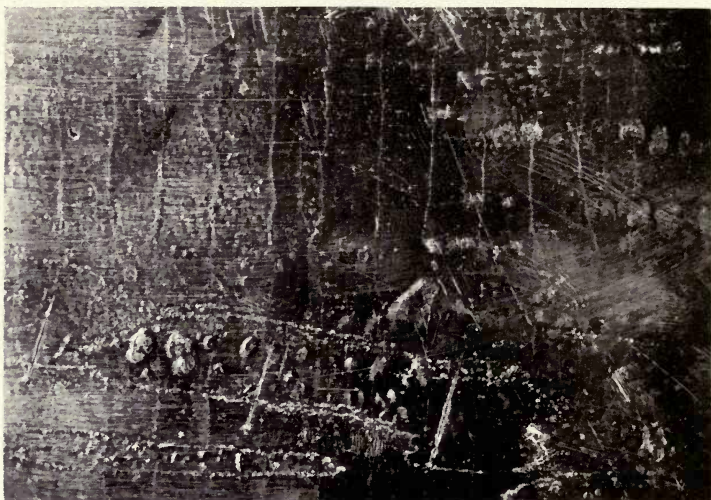
FIG. 37 — Natural size photograph of surface of a tinned sheet having large blisters.

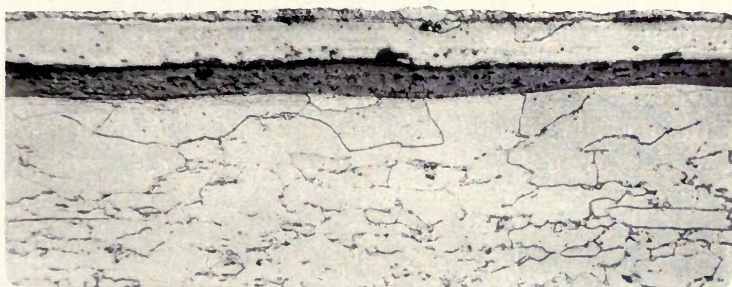FIG. 38 — Natural size photograph of a typical blistered tin sheet.

Fig. 39 — Section of sheet shown in Fig. 37, magnified 200 diameters, showing layer of slag or oxide below the steel surface in which blisters formed.

Fig. 40 — Section through one of the blisters shown in Fig. 38, magnified 200 diameters, showing traces of oxide remaining in the blister.
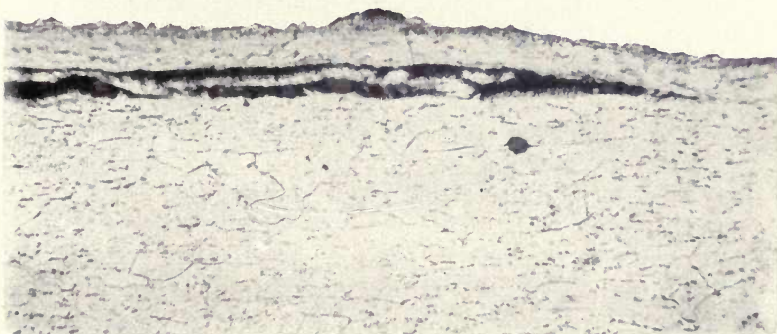

Fig. 41 — Section through one of the blisters shown in Fig. 38, magnified 200 diameters, showing traces of oxide remaining in the blister.

are due to lack of proper distribution of this element.

If the steel has not been properly worked in the furnace and the slag is not in good condition at the time of tapping the metal will act sluggishly in the molds and will rise. A steel which is too hot when tapped from the furnace will have this same tendency and in both cases the steel will not "rim in" properly in the molds, which will result in the blow holes forming about $\frac{1}{4}$-inch inside the walls of the ingots. When the ingots are rolled these blow holes will be elongated and forced through the surface, producing cracks, scabs and laminations on the sheet bar.

After the steel has been tapped into the ladle and the ferromanganese added the manganese will act upon the iron oxides always in solution in steel and rob them of their oxygen. This will result in the formation of manganese oxide, as per the following equation:

$$FeO + Mn = Fe + MnO$$
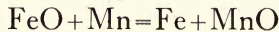
A considerable proportion of this manganese oxide will be entrapped in the steel and its presence is responsible for a large percentage of blisters.

In order to further deoxidize their steel and to keep it from rising in the molds certain manufacturers add aluminum in the ladle. This use of aluminum is the source of numerous defects in sheets and plates. The aluminum will oxidize, being transformed into alumina, an oxide infusible at the temperature of molten steel (alumina melts at 2050° C. while steel is usually poured at about 1600° C.).

Reference to pages 84 to 105 will show that alumina may be identified in steel and that it segregates in streaks or agglomerations.

If from two and one-half to four pounds of Ferro Carbon-Titanium per ton of steel is substituted for aluminum and the addition of the former is made as the last in the ladle and care is taken to see that all the Titanium is added before the slag begins to flow from the furnace,

the Titanium will by oxidation reduce not only iron oxides but also the oxides of manganese as follows:

$$2FeO + Ti = 2Fe + TiO_2$$
$$2MnO + Ti = 2Mn + TiO_2$$
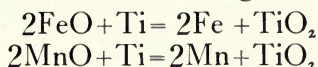
Titanic Oxide, the product of oxidation of Titanium, has a melting point of approximately 1700° C. This oxide will combine immediately with particles of slag entrapped in the steel and the combination having a lower fusibility than the original slag will rise to the top of the ladle, thus freeing the steel from entrapped slags and oxides. It will be seen, therefore, that Titanium acts not only as a deoxidizer but as a thorough scavenger as well.

In order that this scavenging action of titanic oxide may be thorough the steel must be held in the ladle for from six to eight minutes, which will give sufficient time for freeing it from entrapped slags.

It must be constantly remembered, however, that Ferro Carbon-Titanium is only a deoxidizer and scavenger and that it cannot be relied upon to produce steel of first quality from heats which have not been properly made in the furnace and which are tapped possibly because the chemical analysis is satisfactory and because the holding of such a heat in the furnace sufficiently long to put it in good shape for tapping would diminish the production of the department. In other words, the steel must be well made in the furnace in any event.

THE ACTION OF THE STEEL IN THE MOLDS

Steel for sheets is both top and bottom poured. In most of the large mills it is top poured and allowed to "rim in" in the molds, which are over 14″ x 14″ section. It would be impossible for the steel to "rim in" if top poured in smaller molds, probably on account of the thinness of the walls of the molds, so that soft steel when top poured in small molds has to be "killed."
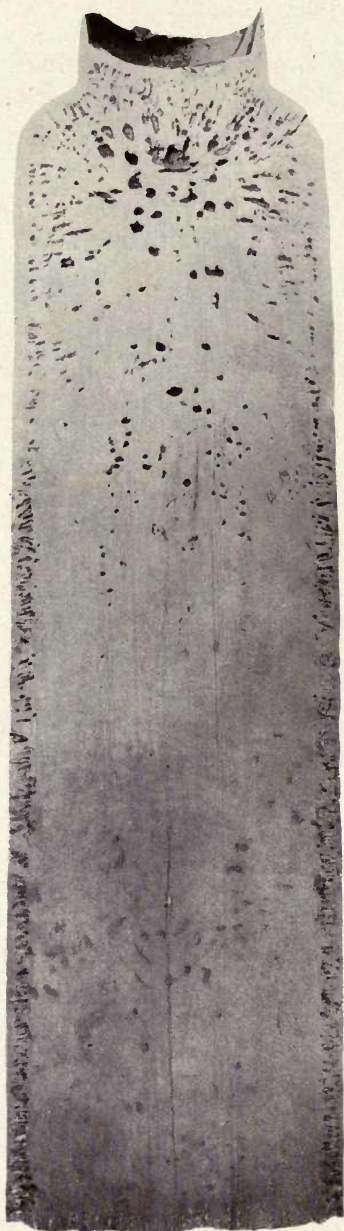
Fig. 42 — 6,000 pound ingot, 18 x 22 inches, with blow holes near surface.
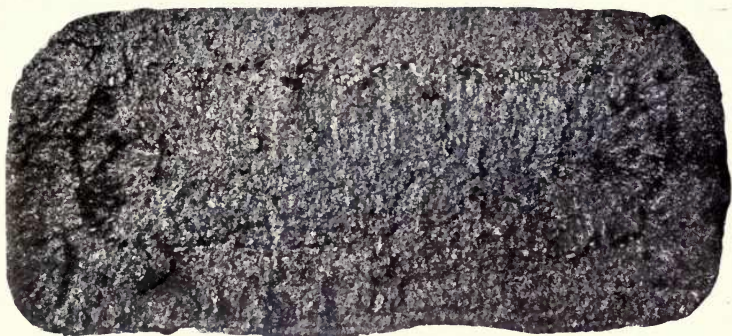
FIG. 43 — Fracture of ingot 14 x 30 inches.

FIG. 44 — Polished section of ingot 14 x 30 inches.

FIG. 45 — Sulphur print of ingot 14 x 30 inches.

This is usually done by an addition of aluminum shot during the pouring of the steel into the molds.

If, as is done in some mills, the steel is bottom poured into small ingots on a plate it will "rim in" satisfactorily.

In "rimming in" steel it is essential that the blow holes be forced as far toward the center of the ingot as is possible and if the steel "rims in" properly the blow holes will be found at least three quarters of an inch from the walls of the ingot.

If blow holes are too near the surface, as in Fig. 42, they will break through during the blooming, producing bars which will show scabs and sheets or plates having laminations or other surface defects.

Fig. 43 is a cross section of an ingot 14″ x 30″ and shows the fracture where the ingot was broken.

Fig. 44 is a reproduction of a photograph of a polished cross section 2″ from the fracture shown in Fig. 43, and Fig. 45 shows a sulphur print made from this section. The line of blow holes shown in Fig. 44 is $3\frac{1}{2}″$ inside the walls of the ingot. It will be noticed that in this $3\frac{1}{2}″$ skin there is no segregation although a little is visible in the center of the ingot, which was the last part to solidify.

If these blow holes are clean, being free from slags and oxides, they will weld during the blooming of the ingots and cause no further trouble.

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Probably in no other grades of steel, with the possible exception of wire, are defects so apparent as in sheets or plates. On account of the great surface area of these products any internal defects are forced to or near the surface by repeated rolling. To scrap a large percentage of the steel from an ingot in order to obtain metal that will make good sheet or to try to coat defective steel with tin or spelter are expensive practices.

Both can be obviated by the proper use of Ferro Carbon-Titanium in making the steel.
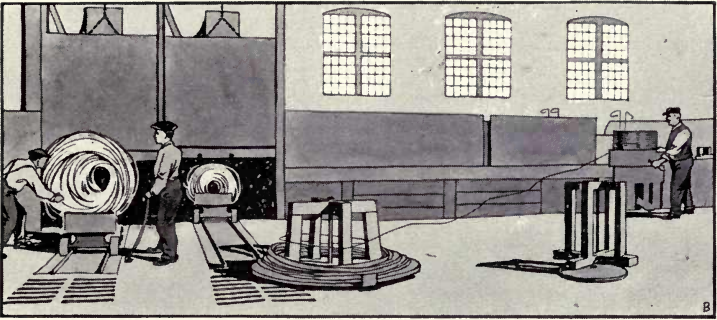
WIRE STEELS
MANUFACTURE

Two general grades of steel are produced for wire making, i. e., High and Low Carbon. From the former such articles as springs, rope and piano wire are made, while the latter is used for a great variety of wire products, nails, spikes, screws, rivets, tacks, etc.

In the manufacture of both grades the ingots are cast in open top molds and are rolled into billets, then into bars and rods or into rods direct from the billets in the case of heavy gauge wire.

The drawing of the wire, which follows, is done on a draw-bench consisting of a die and a power driven reel for pulling the wire through the die. Drawing may be done by the wet or dry process, the latter on sizes down to No. 18—soapstone or tallow being used as a lubricant to reduce friction to a minimum.

After various reductions in diameter the steel will become hard and must be annealed. It is then pickled and washed to remove the scale before it is drawn any further.

If a copper finish is required it is secured by immersing the coil in a solution of copper sulphate, but if the wire is to be galvanized it is pickled and cleaned and then passed first through a fluxing bath and then through a

bath of spelter. The excess spelter is removed by passing the wire through asbestos wipers.

MANUFACTURE OF THE STEEL—LOW CARBON OPEN-HEARTH STEEL FOR WIRE

For discussion it is assumed that the steel is to be made in an Open-Hearth Furnace of at least thirty-five tons capacity, teemed into a receiving ladle and then into open topped molds, which are capped after the steel has been allowed to "rim in."

When the heat of steel is in condition the furnace is tapped, and an addition of 80 per cent ferromanganese is made in the ladle. While the general practice is to add the ferromanganese in the ladle it is preferable that it be added in the furnace just before tapping, as this latter practice will prevent the unequal distribution of manganese, which causes the defects commonly termed "hard spots."

The manganese, no matter how added, will rob the iron oxides of their oxygen giving manganese oxide, as per the following equation:

$$FeO + Mn = Fe + MnO$$
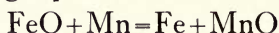
A part of this manganese oxide will rise to the slag but a certain amount will inevitably remain in the steel and its presence will account for a large percentage of surface defects on the finished wire.

At many mills it is the practice to add aluminum, as a deoxidizer, in the ladle. Such an addition is the cause of numerous defects in Wire Steels. The aluminum, by oxidation, is transformed into alumina, an oxide infusible at the temperature of molten steel (alumina melts at 2050° C. while steel is usually poured at about 1600° C.).

If instead of aluminum from two and one-half to four pounds of Ferro Carbon-Titanium per ton of steel were added to the ladle after all other additions and before the

slag begins to flow from the furnace the Titanium, like the aluminum, will by its oxidation reduce the oxides of both manganese and iron as per the following formulæ:

$$2FeO + Ti = 2Fe + TiO_2$$
$$2MnO + Ti = 2Mn + TiO_2$$
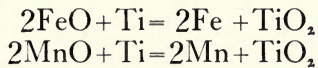
Unlike aluminum, however, Titanic Oxide, the product of oxidation of Titanium, has a melting point only slightly higher than that of molten steel (The Bureau of Standards has determined the melting point of Rutile containing 99.22 TiO_2 to be 1700° C.). This Titanic Oxide acting as a flux will combine immediately with particles of slag always in suspension in molten steel and such new combinations having a lower melting point will rise to the top of the ladle more readily than the initial slag before the addition of Titanium. In this way Titanium acts not only as a deoxidizer but also as a cleanser and scavenger.

After the addition of Ferro Carbon-Titanium has been completed the steel should be held in the ladle for at least eight minutes before the first ingot is poured to allow sufficient time for the slags, rendered more fusible by combination with Titanic Oxide, to rise to the surface.

A great majority of the soft wire steel made in this country is cast in open top molds which are capped after being filled. These molds are 18″ x 18″ or over.

Steel with practically no silicon content will "rim in" in the molds and in so doing build a heavy skin forcing the blow holes toward the center of the ingot.

If the surfaces of these blow holes are free from oxides and slags they will weld during the blooming of the ingots. If, however, the blow holes are too near the surface, which would be the case if the steel was not in condition when tapped, or if it was poured into the molds when too hot and if, in such cases, the steel was dirty from slag and oxide inclusions, bars covered with scale and
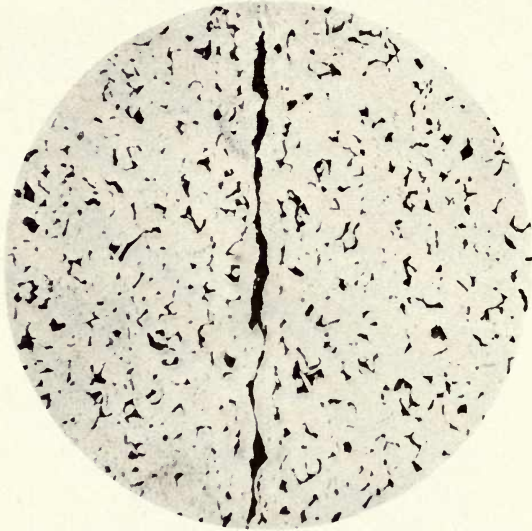
Fig. 46—Longitudinal section of wire rod of untreated steel, magnified 100 diameters, showing an elongated slag fibre.
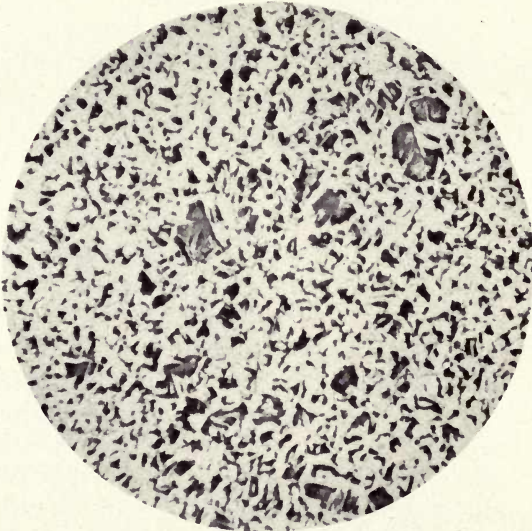

Fig. 47—Section at center of wire rod of untreated steel supposed to be of same carbon content as Fig. 46, showing much higher carbon at this point due to segregation. Etched like Fig. 46, and magnified 100 diameters.
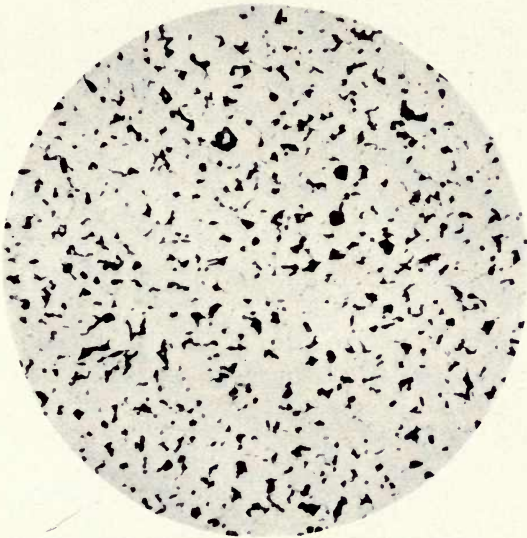
FIG. 48 —Section at center of wire rod of titanium treated steel of same carbon content as rods shown in Figs. 46 and 47, and etched and magnified in the same way. This steel is clean and uniform in composition.

metal which will sliver in the rods will result. Heavy scale on the rods is an indication of spongy steel.

At some of the smaller rolling mills it is the practice to cast small ingots 12″ x 12″ or less which are top poured. Under these conditions the steel will not "rim in" in the molds and it is usually "killed" with aluminum, added in the form of shot during teeming in the molds. When this same grade of steel is bottom poured into small sized ingots on a plate, many manufacturers prefer to "kill" the steel with an addition of aluminum in the center of the plate.

In both cases where Ferro Carbon-Titanium is used the practice is the same as if the steel "rimmed in."

HIGH CARBON OPEN-HEARTH WIRE STEEL

Assume that the steel is in condition to be tapped from the furnace and that if possible the addition of 80 per cent ferromanganese has been made in the furnace just before tapping or has been added in the stream of metal as it flows into the ladle. This addition is followed immediately by an addition of 50 per cent ferrosilicon. If Ferro Carbon-Titanium is to be used from six to eight pounds per ton of steel are added, following the ferrosilicon, care being taken that all the Titanium is in the ladle before the slag begins to flow. The steel is held for from six to eight minutes to give time for the slags, rendered more fusible by the combination with titanic oxide, to rise to the surface.

This grade of steel usually has a high manganese content in addition to its content of silicon and when poured either into top poured molds or bottom poured plated molds it will lay "dead." A pipe or shrinkage cavity will be found and discarded.

Rods and Wire of High Carbon Steel are subject to all the defects of Low Carbon Steel as well as to the
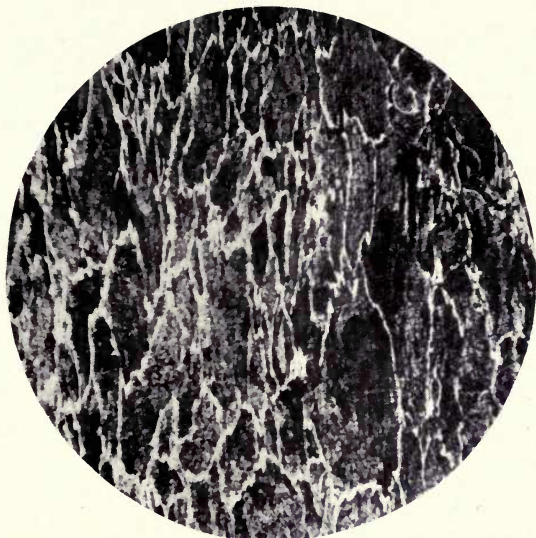
Fig. 49 —Section of broken wire spring showing uneven composition due to segrega-
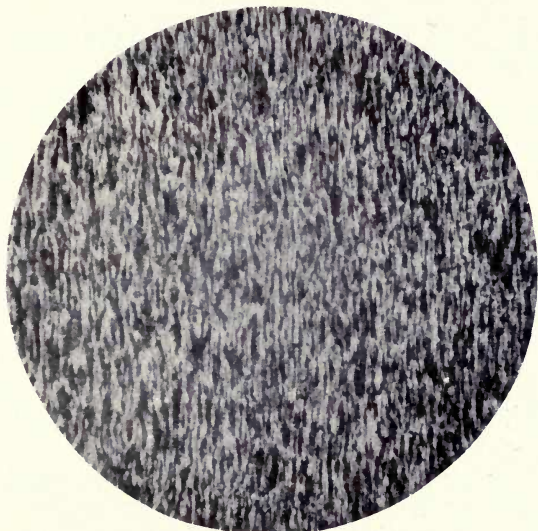tion and coarse structure due to too hot annealing, magnified 100 diameters.

Fig. 50 — Section of wire spring like that shown in Fig. 49, but having a finer and
more uniform structure.   Magnified 100 diameters.

very serious defect of segregation. Segregation is responsible for the extreme variation of steel from different parts of the ingot—that from the lower part may be soft and ductile while from the upper part of the same ingot the wire may be hard and brittle.

The user of such wire is assured that the ladle analysis of the heat is as was specified but if he would analyze for carbon in the two samples of wire he would often find a difference of over 30 per cent. This would also be true of sulphur and phosphorus.

In this grade of steel Ferro Carbon-Titanium, acting as a deoxidizer and scavenger, will make possible the production of a uniform steel throughout the ingot, from which can be drawn wire which will be clean and of uniform composition, will not scale or sliver, to which spelter will cling tenaciously and which will be almost free from any segregation whatever.

BESSEMER STEEL FOR WIRE

In general what has been written above will apply for Bessemer Wire Steel—either High or Low Carbon. As it is not possible to hold the steel so long in the ladle in this process we recommend the use of "C" and "D" sizes in Cans—the cans serving to carry the Titanium through the heavy Bessemer slag so that when the fine material is released it will not become coated with slag and thus be wasted.

The finer sized material dissolves more rapidly than our Standard Medium, "E" or "F" sizes and as only from three to four minutes elapse between the addition of the Titanium and the pouring of the first mold we consider the use of the former much more efficient and dependable in Converter Practice.

The same quantities of Ferro Carbon-Titanium are recommended for Bessemer as for Open Hearth Wire

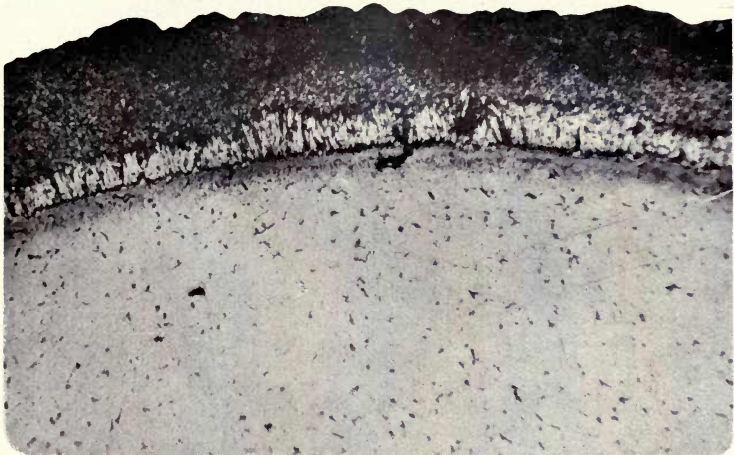FIG. 51 — Cross-section of galvanized wire, magnified 200 diameters and etched with picric acid, showing fairly clean and well annealed steel. Note the smoothness of the contact surface between the wire and the zinc-iron alloy.

FIG. 52 — Cross-section of No. 11 gauge galvanized wire, magnified 200 diameters and etched with picric acid, showing a very light coating, with fairly clean and well annealed steel.

FIG. 53 — Cross-section of No. 11 gauge galvanized wire, magnified 200 diameters and etched with picric acid, showing a thick coating. On the surface of the wire some scale is shown, which was not removed by the picking, and some dross is also shown in the zinc coating. The steel was not well annealed.
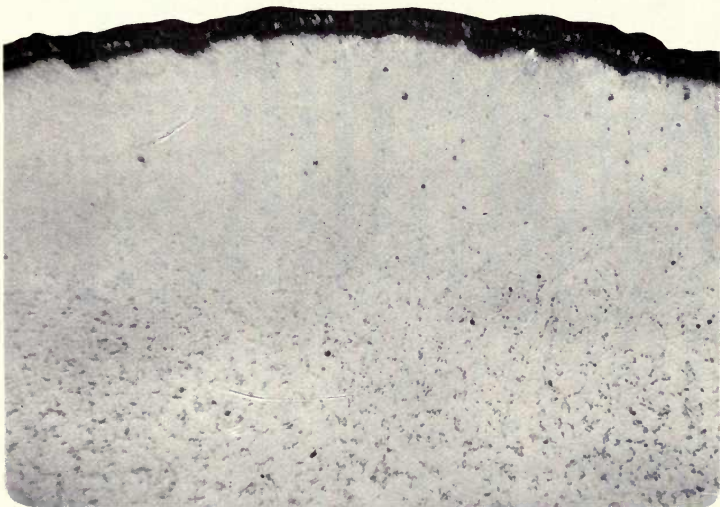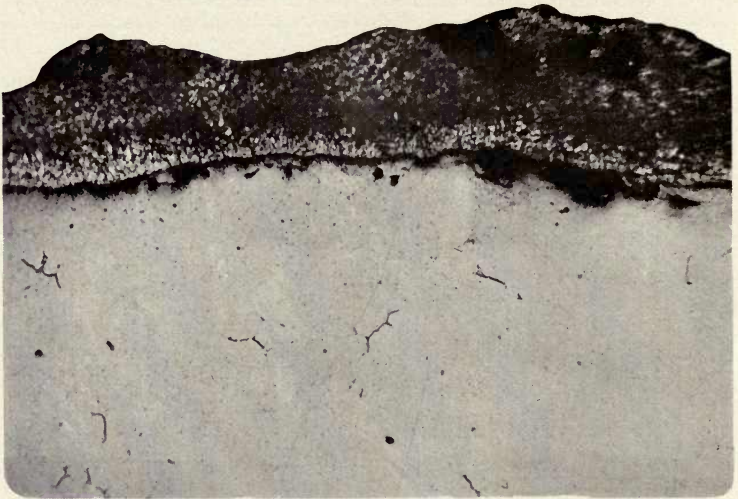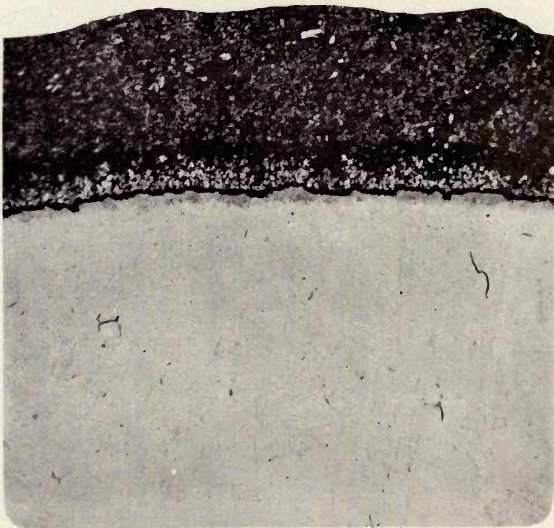

FIG. 54 — Cross-section of No. 11 gauge galvanized wire, magnified 200 diameters and etched with picric acid, showing a thick coating. The wire was clean and smooth before it was coated, as is shown at the boundary between the steel and the zinc-iron alloy.

FIG. 55 — Cross-section of a high-carbon steel wire rod, magnified 200 diameters and unetched, the inclusions of alumina showing clearly that aluminum was used in treating this steel.

FIG. 56 — Longitudinal section of a low-carbon and low-manganese steel wire rod, magnified 200 diameters and unetched, showing a bad streak of slag (silicate) inclusions. Numerous cracks had started along other streaks like this in this sample.

Steel—viz., two and one-half pounds to four pounds per ton of Low Carbon and six pounds to eight pounds per ton for High.

SUMMARY—WIRE STEELS

While there are numerous defects in wire, which are occasioned by other causes than defective steel, there is no doubt that those for which the quality of the steel is responsible are numerous and important—such as scale and slivers on the surface, failure of spelter to adhere tenaciously in Low Carbon Wire and as well as these lack of uniformity due to excessive segregation in High Carbon.

Another very annoying trouble in wire drawing is the cutting of the dies, which will at times show an increase in diameter during the running of a single bundle. A microscopic examination of the wire causing this difficulty will usually indicate a dirty steel containing slags, silicates, alumina and other non-metallic substances.

The deoxidizing and cleansing effects of Ferro Carbon-Titanium, if used as recommended, will, provided always that the steel is properly made in the Furnace, eliminate these defects or reduce them to an inconsequential minimum.
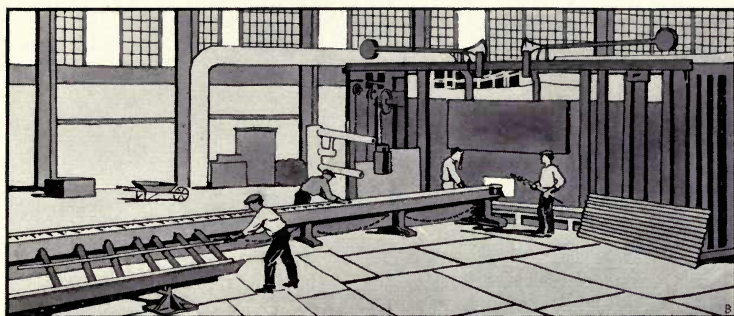
PIPE OR TUBE

STEEL for pipe is made by both the Bessemer and Open Hearth processes. Pipes or tubes are made either by welding or by the seamless tube process. Welded pipes are of two varieties, butt or lap welded. Butt welded pipes are made from skelp, heated to a welding temperature, by pulling it through a bell-shaped die, which forms the edges of the plate and welds them together. Lap welded pipe is made from heated skelp, the edges of which are straightened, and then passed through bending rolls. This process forms the skelp into the shape of a pipe. It is then reheated to a welding temperature and passed through a pair of welding rolls, between which is fixed a mandrel on the end of a long rod.

Seamless tube is being more and more generally used for heavy pressure pipe. The manufacture of this variety, however, causes the maker much trouble.

Seamless tubes are manufactured from solid steel billets. While there are many different processes for its manufacture, the usual method is to heat the billet and then pass it through a piercing machine over a mandrel, which pierces a hole through the center of the billet. The tube is then passed through a series of rolls and over mandrels until the required diameter and thickness are obtained.

Defects mentioned for sheet will be found in pipe as the making of the skelp can be likened to the manufacture
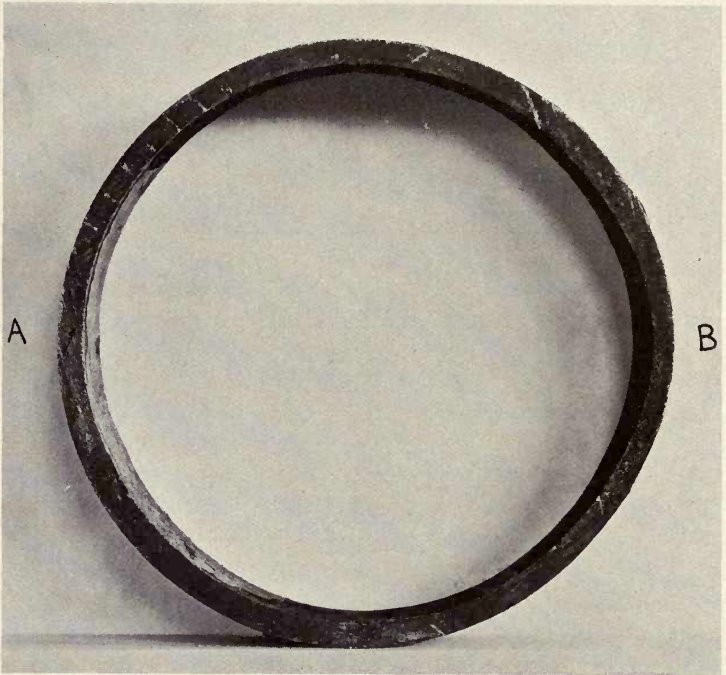
FIG. 57 — Section of swollen boiler tube. Normal outside diameter = 4 inches. Outside diameter from A to B = $4\frac{3}{32}$ inches.

of sheet bar. Frequently the presence of oxides and slags in the steel will prevent the welding of the edges at certain points resulting in defective pipe. Oxides or slag inclusions in the billets used in the manufacture of seamless tubes will be detected, usually during the piercing of the billets, as laminations, and such tube will be rejected.

In the treatment of steel for skelp or for billets for seamless tubing, an addition of two and one-half pounds to four pounds of Ferro Carbon-Titanium per ton of steel will, as already explained in the discussion of the manufacture of sheet steel, remove the defects noted above. For the manufacture of steel see pages 60 to 68.

FIG. 58 — Section of boiler tube at swollen part, B, showing streaked structure and nonmetallic inclusions, magnified 50 diameters.

FIG. 59 — Section of boiler tube at A, showing cleanness and homogeneous structure, magnified 50 diameters.

A STUDY OF ALUMINA
IN STEEL

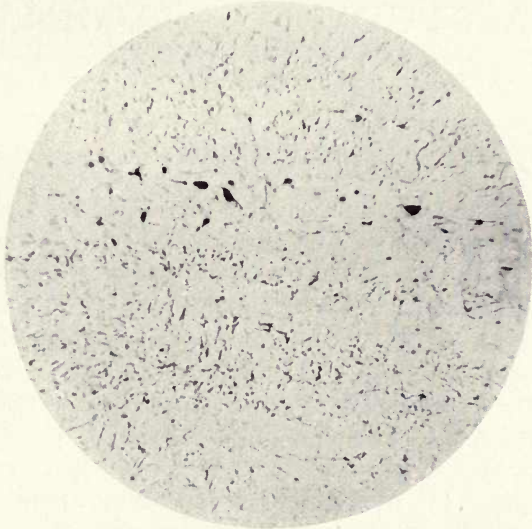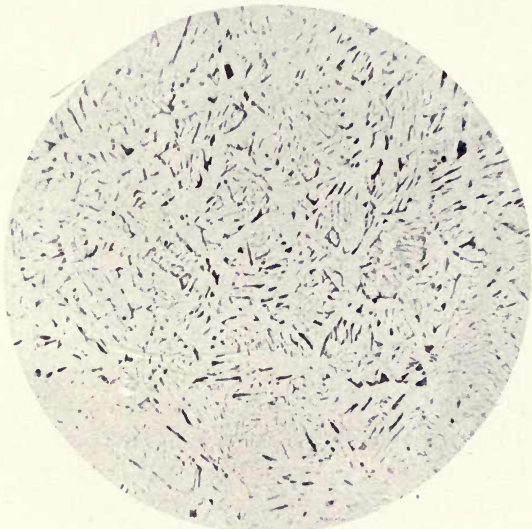ONE reason for the value of the microscope in the examination of steel is its ability to give evidence as to the cleanness of the metal, or as to the number and character of the non-metallic inclusions embedded in it. By preparing a surface with a sufficiently perfect polish, not only the number of inclusions per given area can be ascertained, but their shape, color, and arrangement through the metal can also be plainly seen if lenses of good quality and fairly high magnifying power are used. After examination of many samples of steel with especial regard to the non-metallic inclusions, experience is acquired by which these inclusions may be classified into several different types based on their appearance in a well-polished, unetched steel surface.

The sulphides are the most common inclusions in steel, and their appearance is well known to all metallographers. Inclusions of this type used to be known as "manganese sulphide," but investigations made in recent years have shown that iron sulphide also enters into their composition to a considerable and variable extent. Next to the sulphides, the most common inclusions are the silicates, or true slag inclusions. These are always darker than the sulphides, and usually of more irregular form. To some writers, all inclusions except sulphides are "slag," and others do not even make this exception, calling everything "slag" in a polished section that is not metal. From evidence obtained recently in these laboratories, however, it has seemed justifiable to differentiate between slag or silicate inclusions and those

consisting wholly or chiefly of titanium nitride, or of alumina, respectively.   The titanium nitride inclusions were described in the "Metallurgical and Chemical Engineering" for September, 1914, Vol. XII, page 577, and are easily distinguished from all other inclusions in steel by their pink color.   In this report is presented the evidence on which the identification of alumina in steel has been based.

A few years ago an ingot of good steel was treated, in the mold, with a large excess of aluminum, and the bars forged from this ingot were very seamy. Fig. 60 (on page 91) shows the appearance of the inclusions in this steel, which must evidently be alumina, since nothing but this was added to the molten metal. These inclusions are in the form of small rounded spots, arranged close together in an elongated streak.   They are of a very dark bluish-gray color, when examined with the white light of an electric arc, appearing black unless highly magnified, and it is practically impossible to polish them without forming little pits around each inclusion.   If the polishing is done very carefully, these pits may be kept very small; but with certain methods of polishing the pits are made so large that the original inclusions cannot be seen at all.   Titanium nitride inclusions will form pits in the same way if poorly polished.   If the specimen is not rotated constantly during the final polishing, the pits take the form of short scratches, and each inclusion will have a little tail, like a comet.   It will be noticed in Fig. 60 that although this shows a longitudinal view of a bar, the individual inclusions have not been elongated by the forging at all, but merely the group as a whole has been drawn out into a streak.   Compare this with Fig. 61, which shows some silicates in the web of a rail, and a great difference will be apparent, for the silicates have been elongated even by the cross-wise

pressure of the rolls forming the web, while the drawing effect of the forging did not elongate the alumina particles even in the same direction that the bar was drawn out.

The difference between inclusions of alumina and ordinary slag or silicates in steel may then be summarized as follows:

(1) Silicate inclusions will generally take a fairly smooth polish in a section prepared for microscopic examination, while alumina is very hard to polish without pitting. (2) Silicate inclusions are always elongated in the direction of rolling or forging, while alumina particles are not (the *groups* of particles are, of course, elongated, but not the particles themselves). (3) Silicate inclusions are often found of quite large size (as well as very small), while particles of alumina are always small, and do not seem to coalesce into larger bodies even when closely grouped together. These characteristics of the alumina inclusions agree with what is known of the properties of alumina. Its great hardness and brittleness would account for the pitting effect; its infusibility would account for the small size of the particles and the tendency not to coalesce; and both of these properties together would account for the particles not being elongated by forging or rolling of the steel in which they are embedded.

Inclusions having all the characteristics of those seen in steel known to contain alumina have been found in many samples of steel examined in the course of our work here, but it could not be stated positively that any of these were alumina, until a method was found for determining this substance quantitively by chemical analysis. Eventually such a method was found, not only in our laboratory, but also independently by Mr. F. O. Kichline, Chemist at the Saucon Plant, Bethlehem Steel Co. (published in the September, 1915, issue of the

"Journal of Industrial and Engineering Chemistry") and the results from it have been very interesting. All samples in which more than the merest trace of alumina was found by analysis were seen to contain the typical inclusions as described above, and those in which alumina was not found by analysis, did not contain these inclusions. Furthermore, those in which more alumina was found by analysis contained more of these inclusions than those in which only a very little was found. These facts have been considered as a good confirmation of the theory that the typical small inclusions, as described above, found in so many commercial steels, are chiefly, if not wholly, alumina. Of course the purity of the alumina in these inclusions is not known, but even if it is fluxed with some impurity it would seem proper to call the inclusions "alumina" when it is known that their character is determined by the presence of this substance.

Fig. 62 shows the inclusions in an ingot of soft steel in which chemical analysis showed the presence of a much larger amount of alumina than of all other insoluble oxides, thus proving the presence of a considerable quantity of free alumina. Fig. 63 shows some ordinary slag inclusions in a cross-section of the head of a rail. This photomicrograph, Fig. 61 and Fig. 71, are included to show the difference between silicates and alumina. Fig. 64 shows a section of a splice-bar, which broke in a railroad track, and was found by analysis to contain 0.019 % of alumina. Fig. 65 is an alloy made on a very small scale of Swedish iron and aluminothermic ferrotitanium, and shows alumina which was not present in the original iron. Fig. 66 shows a spot where alumina particles are segregated in the web of a rail in which 0.003 % was found, and Fig. 67 is an average view of the head of another rail containing 0.010 % of alumina. Fig. 67 shows the most common mode of

occurrence of these particles, that is, scattered thinly through the metal.   In Fig. 66 most of the specimen showed very few inclusions, but the small segregated streaks shown in the photomicrograph are more dangerous to the life of the rail than the larger total amount of alumina in Fig. 67, where it is arranged differently. Figs. 68 and 69 are photomicrographs of the same streak, differently polished; the former shows the comet-tails mentioned above, while in the latter the pitting has been more successfully avoided.   Fig. 70 is a view of some streaks that caused the top of the head of a rail to shell off from the rest of the section.   The form of the alumina is well contrasted with the sulphides, and with the large slag inclusion in Fig. 71, which is a large but typical silicate streak in the web of another rail. All these photomicrographs show open hearth steel, except possibly Fig. 64, which may be Bessemer, and Fig. 65 which is an electric furnace melt.   All show unetched surfaces, and all except Fig. 65 were taken with a magnification of 200 diameters.   Fig. 65 was magnified twice as much as the others.

As a final check on the accuracy of the assumption that all inclusions in steel, having exactly the same characteristics as those shown in Fig. 60, are alumina, several experimental melts were made of rail steel with the addition of various oxides.   The steel used was seen by previous microscopic examination to be practically free from non-metallic inclusions except sulphides, and ten-pound ingots were cast from it each treated with one of the following oxides: alumina, titanium oxide, chromium oxide, and nickel oxide. The tops of these ingots were forged from the original 2-inch square section to 1-inch square, and longitudinal sections were cut and carefully polished for microscopic examination.   The treatment with alumina was not successful, as this treated bar appeared just as clean as the

original steel, so this melt was made over again with the use of metallic aluminum. Characteristic inclusions of alumina were then found in the forged bar, as shown in Fig. 72. Fig. 73 shows part of a small streak found near the top of the bar made with titanium oxide. The rest of this bar was clean, and the inclusions shown would ordinarily be classed as silicates or slag. They show a peculiar duplex composition, and would not be mistaken for alumina.

The steel treated with chromium oxide had small smooth purplish spots scattered all through it, but they were especially segregated in some streaks at the top of the ingot. Some of these inclusions were angular and some rounded, and like alumina they were not elongated by the forging. Where they were not too thickly segregated, however, they took a good smooth polish easily like the silicates, and from this fact and their purplish color they may be easily distinguished from alumina. Fig. 74 shows the end of one of the segregated streaks, where small particles of this oxide seem to be breaking away and entering into the steel, and the difference between these and alumina is readily apparent. The steel around these inclusions was very readily stained or tarnished during the polishing, and this effect, though noticed also with the nickel oxide and sometimes with titanium nitride, has not been seen by the writer around streaks of alumina.

The last Photomicrograph, Fig. 75, shows some of the steel treated with nickel oxide, but these inclusions look exactly like iron oxide, and it may be that the nickel oxide was reduced by the metallic iron present, forming metallic nickel and iron oxide. At any rate these inclusions are entirely different in appearance from alumina. They look very much like sulphides, but are a little darker, and stand out more in relief from the surrounding metal.

The evidence available is thus seen to point uniformly to the conclusion that it is proper to identify as alumina all inclusions, seen in polished steel surfaces, that have exactly the characteristics of the alumina inclusions shown in Figs. 60 and 72. At present no other substance is known to the writer which has the same appearance in a polished steel surface as alumina. Ordinary slag inclusions, as well as the oxides of titanium, chromium, and nickel, have been shown to be very different. Of course there is a possibility that some substance may be found at some future time that has identically the same appearance, but the writer sees no reason to expect such an event, and believes that the work described above renders the identification of alumina in steel with the microscope a matter of as much certainty as the similar identification of sulphides or silicates, which has long been considered reliable.

FIG. 60—Inclusions of alumina in section parallel to direction of forging of steel treated with a large excess of aluminum. The few gray spots are sulphides.

FIG. 61—Silicate or slag inclusions (with a few gray sulphides) in the cross section of the web of a rail.

BOTH MAGNIFIED 200 DIAMETERS AND UNETCHED

FIG. 62—Alumina inclusions in a soft steel ingot in which more alumina was found by chemical analysis than all other oxides.
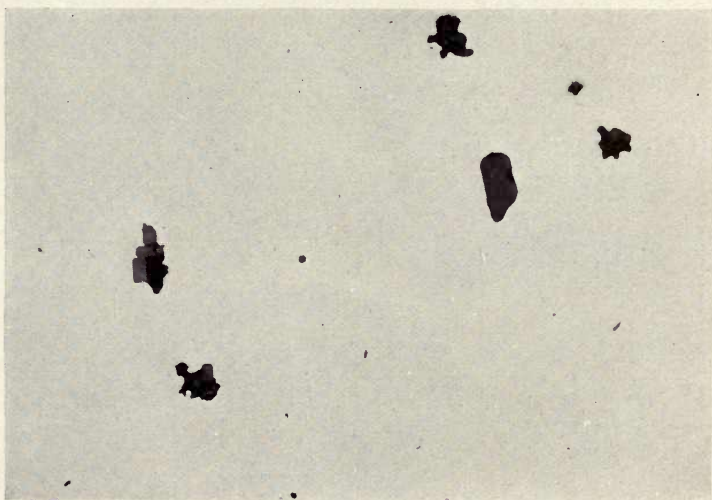
FIG. 63—Silicate or slag inclusions in the cross section of the head of a rail.

BOTH MAGNIFIED 200 DIAMETERS AND UNETCHED
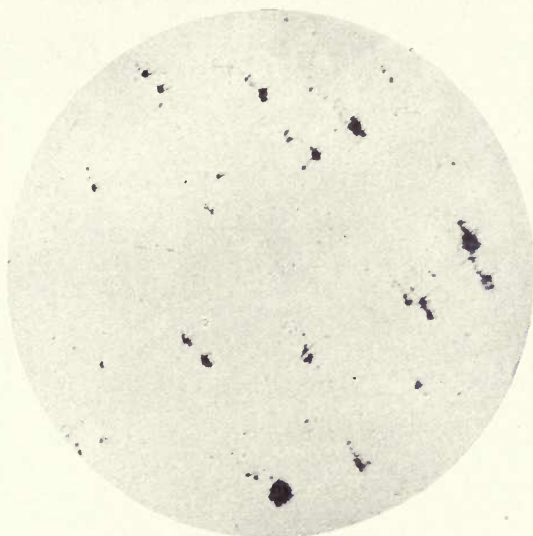
Fɪɢ. 64—Section of broken splice-bar in which 0.019% of alumina was found by chemical analysis.   Magnified 200 diameters.
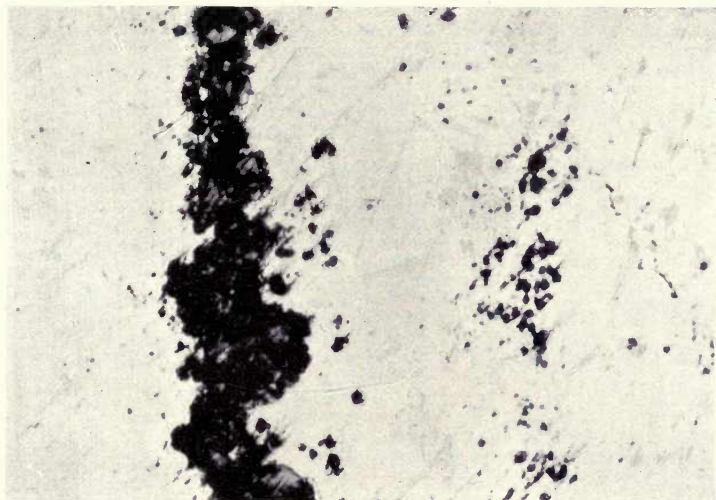
Fɪɢ. 65—Alloy, made in small electric furnace, of aluminothermic ferrotitanium with Swedish iron.   Magnified 400 diameters.

BOTH SHOW TYPICAL ALUMINA INCLUSIONS IN UNETCHED SECTIONS

FIG. 66—Group of segregated inclusions in cross section of the web of a rail in which 0.003% of alumina was found by chemical analysis.   Magnified 200 diameters.
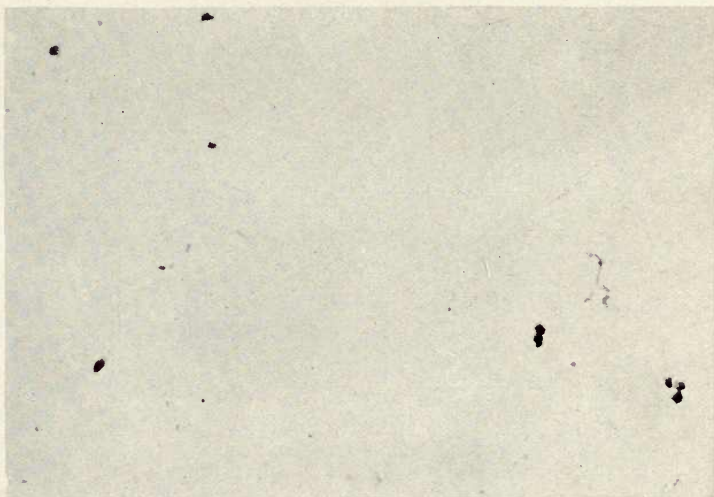
FIG. 67—Average view of the cross section of the head of a rail in which 0.010% of alumina was found by chemical analysis.   Magnified 200 diameters.

BOTH SHOW TYPICAL ALUMINA INCLUSIONS IN UNETCHED SECTIONS
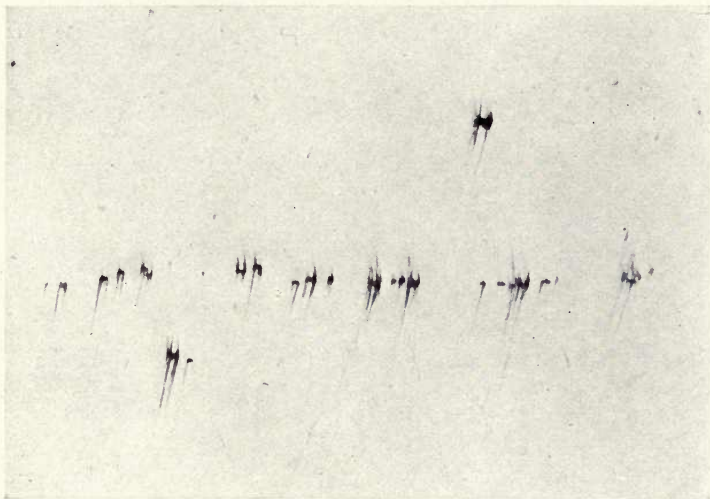
Fig. 68—Streak of alumina inclusions badly polished, showing pits and scratches.
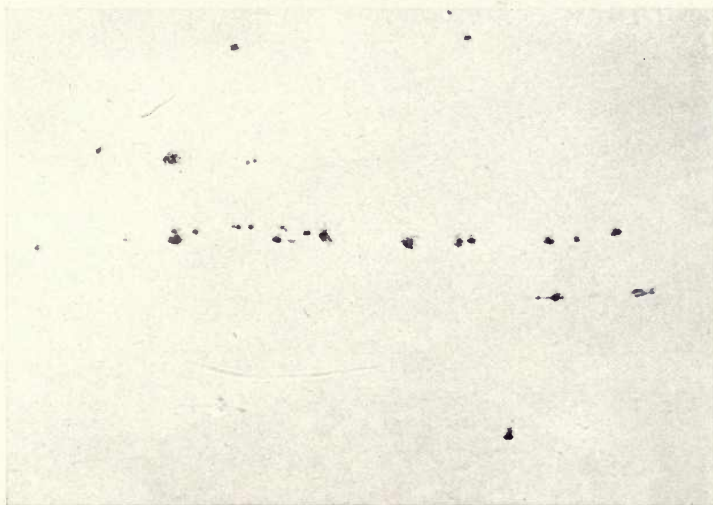
Fig. 69—Same streak shown in Fig. 68, after grinding and more careful polishing.
BOTH MAGNIFIED 200 DIAMETERS AND UNETCHED
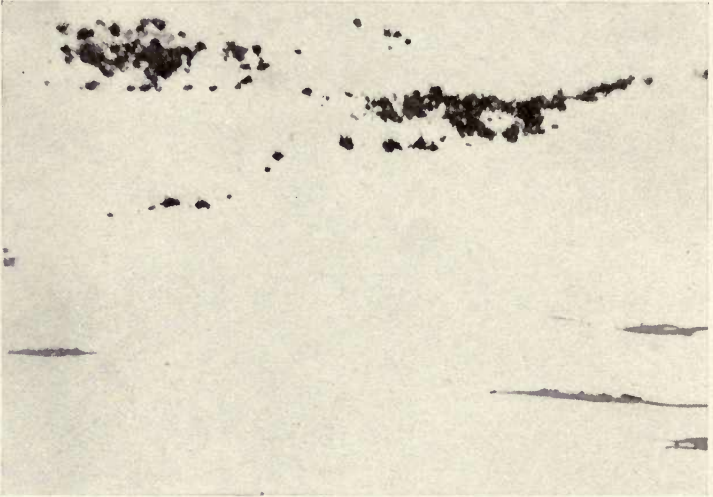
Fig. 70 — Longitudinal section of a streak that caused the top of the head of a rail to shell off, showing alumina inclusions above and sulphides below.
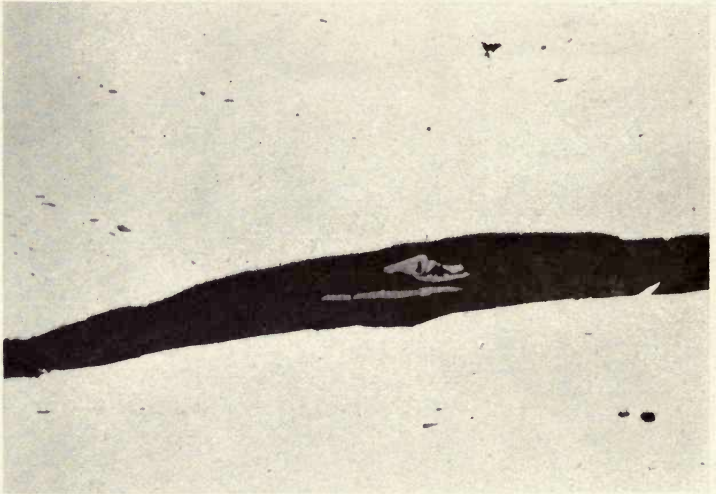
Fig. 71 — Typical large silicate or slag streak in the cross section of the web of a rail, showing also two particles of alumina and some fine gray sulphides.

BOTH MAGNIFIED 200 DIAMETERS AND UNETCHED
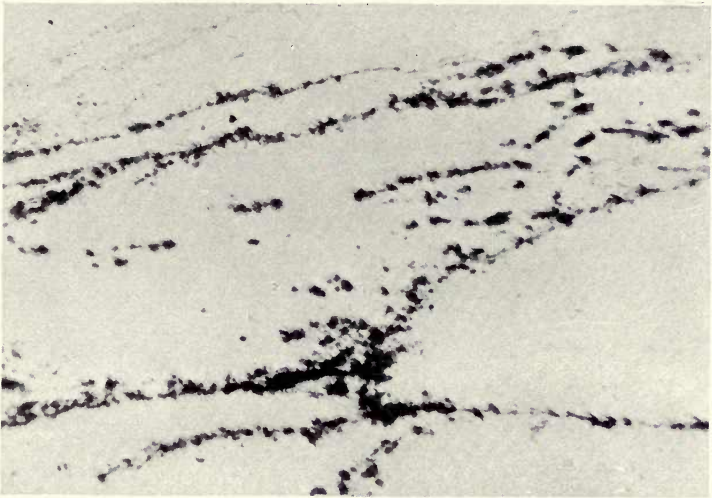
FIG. 72—Alumina inclusions in clean rail steel treated with an excess of aluminum.

FIG. 73—Slag inclusions in similar steel treated with oxide of titanium before casting. BOTH SHOW LONGITUDINAL SECTIONS OF THE FORGED ENDS OF SMALL INGOTS CAST FROM 10-LB. MELTS OF THE SAME STEEL, UNETCHED AND MAGNIFIED 200 DIAMETERS
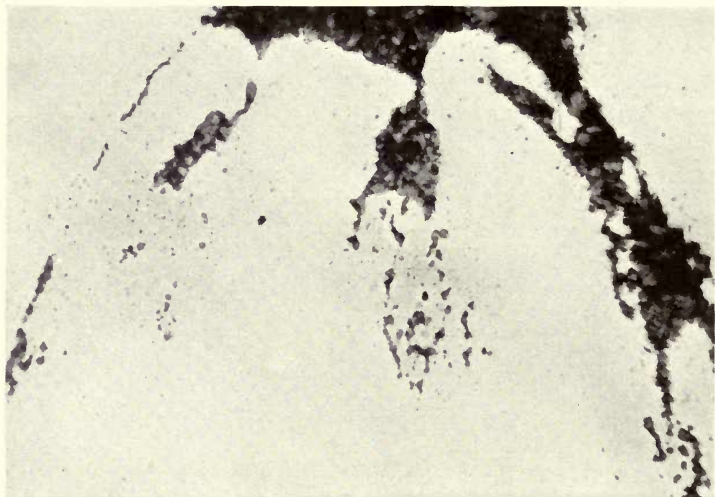
FIG. 74—Steel treated with oxide of chromium, showing end of a broad streak, with typical small particles embedded in the metal.
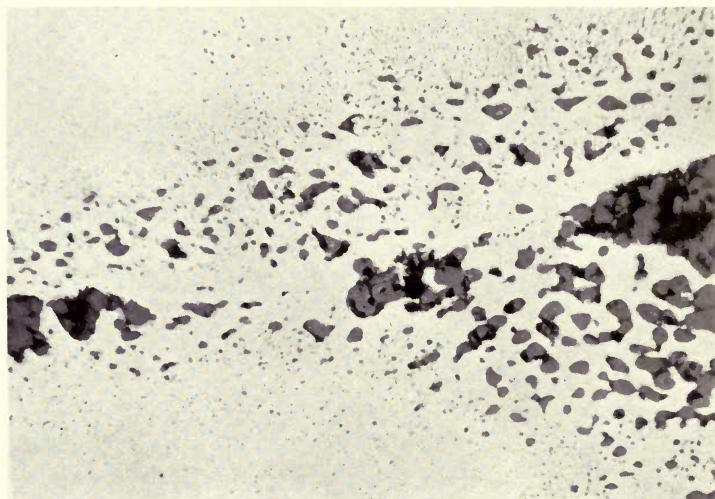
FIG. 75—Steel treated with oxide of nickel, showing typical inclusions of either nickel oxide or iron oxide.

BOTH SHOW LONGITUDINAL SECTIONS OF THE FORGED ENDS OF SMALL INGOTS CAST FROM 10-LB. MELTS OF THE SAME STEEL, UNETCHED AND MAGNIFIED 200 DIAMETERS

THE DETERMINATION OF ALUMINA
IN STEEL

During the years 1913 and 1914 our chemical laboratory was on several occasions requested to determine, if possible, alumina in steel; particularly free alumina resulting from the addition of aluminum or ferro alloys containing aluminum.

Since no available methods were found in the literature on the analysis of steel, the development of a method for the determination of alumina was attempted.

Alumina formed at the high temperature of molten steel, as would be the case when aluminum was used as a deoxidizer would certainly be rather refractory to the action of acids. This fact suggests the probability that an acid solvent may be used in which the steel will dissolve leaving a residue of alumina, contaminated perhaps with other oxides resulting from incomplete decomposition of slag particles which might also occur in the steel.

Twenty per cent sulphuric acid was selected as the solvent which would be most likely to dissolve most of the slag inclusions while having little or no action on the alumina particles.

Since the alumina content of steel would under the usual practice be very low, it was decided to use very large samples for analysis, thus greatly increasing the accuracy and certainty of the results. Usually either 50 or 100 grams of sample were used.

The residue insoluble in 20 per cent sulphuric acid was collected by filtration and calcined. The calcined residue which consisted of a mixture of alumina particles and constituents derived from slag inclusions was fused with potassium bisulphate in a platinum crucible. The fusion was dissolved in water with addition of sulphuric and hydrochloric acids, evaporated to fumes of sulphurtrioxide, taken up with water and hydrochloric acid and

silica filtered out. The filtrate was precipitated by ammonia, filtered and the precipitate redissolved in hydrochloric acid to obtain the alumina and contaminating impurities in a hydrochloric acid solution.

The alumina was then separated from iron by the well known phenylhydrazine method, collected by filtration and calcined.

The residue thus obtained may be contaminated with iron and phosphoric acid and also with titanium if this element is present in the steel. To purify the alumina the calcined precipitate was fused with one to three grams of sodium carbonate depending on the amount of material to be fluxed. The fusion was dissolved in water in the platinum crucible and filtered, collecting the filtrate in a platinum dish. The residue on the filter was calcined and again fused with sodium carbonate, dissolved in water, filtered and the filtrate added to that reserved from the first treatment.

The solution thus obtained contains the alumina free from iron or titanium, but may still be contaminated by phosphoric acid. The solution was then acidified with hydrochloric acid and the alumina and phosphoric acid precipitated by ammonia; the precipitate filtered out, calcined and weighed. Phosphoric anhydride (P_2O_5) was then determined in the weighed material and the amount found deducted from the first weight before calculating the percentage of alumina.

Using the method described it is not always possible to decide if the alumina in the steel was in the free state or was wholly or partially combined with other oxides as slag inclusions; though in some cases the conditions and results were such as to indicate that the alumina was mostly in the free state; and in such cases our analytical work was usually confirmed by metallographic examination by which means typical inclusions were found which were thought to be alumina.
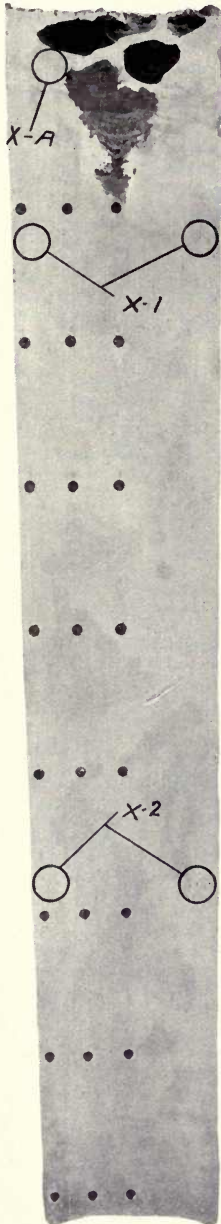
Recently during investigations on some soft steel ingots it was observed that the solution of the steel in hydrochloric acid was slightly opalescent due to suspended particles of some light colored material. The suspended matter was collected by filtration, dried and microscopically examined by transmitted light. The material had the appearance of alumina particles and by subsequent qualitative chemical analysis was proved to be such.

Special samples were then taken from one of the ingots by drilling, the locations of which are shown in the accompanying photograph. From the same locations in the ingot specimens were cut for metallographic examination.

Duplicate analyses of the samples were made for alumina, using the method before described, and also by solution of the sample in hydrochloric acid (1 to 1) and examination of the residue by the usual methods.

To better compare the merits of the two methods of analysis and also to gain more information on the form of occurrence and characteristics of alumina in steel; the residue insoluble in acid was examined for other elements which would be liable to be derived from slag inclusions or other sources.

As usual, large samples of steel

were taken to obtain enough residue on which to work, and to increase the accuracy of the results.

The results of analysis are shown in the following table.

	Sample X-1		Sample X-2		Sample X-A
	Residue from Hydro-chloric Acid	Residue from Sulphuric Acid	Residue from Hydro-chloric Acid	Residue from Sulphuric Acid	Residue from Hydro-chloric Acid
Silica	.017	.023	None	.002	None
Copper	None	.093	None	.099	None
Iron Oxide	.012	.034	.010	.028	.052
Phosphoric anhy-dride	None	.0008	None	.0004	Trace
Alumina	.052	.071	.042	.061	1.120

The results in the above table indicate that a sharper separation of free alumina from impurities can be made by solution in hydrochloric than in sulphuric acid. The method depending upon solution of sample in hydrochloric acid is being further studied as opportunity permits with a view of making it a standard method for determination of alumina in steel.

The results also show conclusively that alumina may occur in the free state in steel and greatly strengthen the probability that free alumina may be detected by metallographic examination.

Regarding the accuracy of the methods outlined it may be said that while the determination of alumina presents some difficulty on account of the small amount usually present in steel, we have, on account of the special precautions taken and the large sample used, felt justified in reporting a definite percentage of alumina, but in the interpretation of results we are inclined to consider the determination more particularly as an

accurate qualitative test, positively establishing the presence of alumina in the steel and indicating the quantity approximately.

After the above described work was completed; through the courtesy of Mr. F. O. Kichline, Chemist, Saucon Plant, Bethlehem Steel Co., an advance copy of his work on the determination of alumina in steel was received.

Mr. Kichline's paper has since been published in the "Journal of Industrial and Engineering Chemistry;" issue of September, 1915.

The following is a copy of that part of the paper dealing with the determination of alumina in steel:

NOTE ON THE DETERMINATION OF ALUMINUM OXIDE AND TOTAL ALUMINUM IN STEEL

"It has long been known that aluminum oxide when freshly precipitated is readily soluble in acids and when strongly ignited is very difficultly soluble in acids.

"When metallic aluminum is added to steel while casting, its tendency is to unite at once with the oxygen existing in the steel, both as metallic oxides and as CO gas. The products of this reaction are Al_2O_3, the metals of the oxides reduced, and carbon. Since in regular practice there is only sufficient aluminum added to 'quiet the steel,' the aluminum added is nearly all converted to the oxide Al_2O_3. This aluminum oxide is, during the operation, heated to the temperature of pouring steel, about 1600° to 1650° C. (2912° to 3000° F.), whereby it is rendered almost entirely insoluble in dilute hydrochloric acid.

"In order to test the effect of high temperature on the solubility of Al_2O_3 the following experiment was carried out: ten grams metallic aluminum were dissolved in

hydrochloric acid, boiled low and replaced three times with nitric acid. This solution of aluminum nitrate was evaporated to dryness to drive off acid fumes; the residue was transferred to a platinum dish and placed into a muffle furnace where the temperature was gradually raised to a high heat, taking out a portion at intervals, and noting the temperature each time with a Scimatco optical pyrometer. Portions of aluminum oxide were removed at 815°, 900°, 980°, 1065° and 1150°C. Solubility tests were made by taking one gram of each portion and digesting for one hour with 100 cc. hydrochloric acid (1 : 1), filtering, and determining Al_2O_3 in the filtrate.

Portion heated to	815°C.	900°C.	980°C.	1065°C.	1150°C.
Gram soluble Al_2O_3	0.9317	0.3962	0.2377	0.0472	0.0390

"The increase in temperature was at the rate of eight to ten minutes between observations. Another portion of the same Al_2O_3 prepared above, was placed in a boat in the silica tube of an electric furnace and held for one hour at a temperature of 1000° C.; one gram of this was treated as above with 1 : 1 hydrochloric acid and showed 0.0285 gram soluble Al_2O_3. One gram alundum, 120 mesh, was treated with hydrochloric acid as above and showed a mere trace of soluble Al_2O_3.

"The solubility diminished with increase of temperature and length of time to which the Al_2O_3 had been exposed to the heat. If Al_2O_3 exposed to 1000°C. will yield 2.85 per cent of its Al_2O_3 content, and alundum exposed to a little over 2000°C. yields a trace, it is safe to assume that the Al_2O_3 formed in molten steel would yield only 1 or 2 per cent of its content on treatment with dilute hydrochloric acid, which on such low figures as obtain with percentages of Al_2O_3 in steel is certainly negligible.

"The above assertion has been borne out in practice, by adding just enough aluminum to deoxidize the steel,

avoiding an excess.   By employing the method as given below on such steels, all of the aluminum was found to be in the insoluble residue as oxide.

"The method is as follows: Dissolve 50 grams drillings in a mixture of 200 cc. strong hydrochloric acid and 300 cc. water at gentle heat, bring to a boil, allow insoluble matter to settle and filter through a double Baker & Adamson grade A paper or Schleicher & Schull No. 590, and wash with hot dilute (1:2) hydrochloric acid and hot water.   Ignite the residue in a platinum fusion crucible.   Add $\frac{1}{2}$ gram pure sodium borate calcined, and heat gently a few minutes till Al_2O_3 is in solution.   Now add 5 grams pure sodium carbonate and fuse a few minutes longer until all is melted and in a state of quiet fusion.   Dissolve fusion in hot water in a platinum or nickel dish, and determine Al_2O_3 in the usual manner."

This method for determination of alumina has been tried out in our laboratories and found very convenient and reliable if proper precautions are taken.   In some cases the alumina precipitate may contain phosphoric acid and in such case it is necessary to determine and deduct it from the weight of Al_2O_3 plus P_2O_5 before calculating the percentage of alumina.

With this precaution the method is recommended in preference to those first given.

PREPARATION OF THIN WIRE SAMPLES FOR MICROSCOPIC EXAMINATION

CROSS-SECTIONS of thin wires may be conveniently polished for the microscope in three (or possibly more) ways: (1) By casting fusible metal around them; (2) by inserting them in holes drilled in bronze or some other metal; (3) by holding them in clamps made of red fibre. The experience gained in our laboratory with these three methods is described below:

(1) For this method $\frac{1}{4}$-inch sections of brass tubing ($\frac{3}{8}$-inch inside diameter and $\frac{5}{8}$-inch outside) were cut, placed on moist sand, and the wire samples stuck into the sand through the rings. Some of Wood's fusible alloy was melted and poured into the rings carefully so that they were entirely filled. The wires were then trimmed off, and the samples were ground flat and polished as usual. This is the easiest method to use, the only objection to it being that owing to the softness of the fusible alloy, it wears away to a lower level than the wire during polishing, and the edges of the wire are thus not flat and sharp, but are rounded off and cannot be brought into good focus in the microscope. This is a serious disadvantage with galvanized wire, where the edge is the place to be examined, but the fusible metal has not been found to alloy with the zinc coating of the wire as its temperature when cast is very low.

(2) This method is very simple and gives good results, but the hole must be drilled *exactly* the right size for the wire, and the wire must be truly circular and smooth in outline. These conditions, of course, are not always fulfilled, so that it is not often possible to use this method.

(3) The photomicrographs of galvanized wires in this booklet were made from samples polished in red fibre

clamps. To make one of these clamps two pieces of electricians' insulating red fibre, each about $\frac{1}{2}''$ x $\frac{1}{4}''$ x $\frac{3}{8}''$, are held firmly together and a hole a trifle smaller than the wire sample is drilled through the middle of the plane of contact. The two pieces are then taken apart, the wire sample is inserted between them, and they are again clamped together by a small holder made of two pieces of steel about $\frac{3}{32}''$ x $\frac{5}{16}''$ x $\frac{7}{8}''$ and two screws $\frac{1}{8}''$ in diameter and $\frac{7}{8}''$ long. The wire sample is trimmed off, and the red fibre and wire are polished together like an ordinary specimen for the microscope. The clamps must be kept very tight, for the results will not be good unless there is perfect contact between the wire and the red fibre. The disadvantage of this method is that the red fibre expands when wet and contracts when dry, so that if, as is done here, the polishing is done dry at first, but finished with wet rouge, the fibre expands and rises higher than the steel, hindering the final polishing of the latter. Of course, this necessitates repeating some of the coarse polishing by wet methods, and not allowing the fibre to become thoroughly dry before the final polishing and etching are accomplished. The polishing is more difficult with this method than with the others, but it is possible to get better results with it in regard to sharpness of outline at the edges of the wire section.

SPECIAL BRONZE CASTINGS FOR STEEL PLANTS

O N the following pages are listed our Standard Bronzes as cast in our Foundry Department. Of especial interest to steel manufacturers is our Titanium Aluminum Bronze for such castings as worm gears, large nuts, pickling crate frames, etc. The great strength, toughness and wearing properties and the superior acid resisting qualities of this Bronze are are well and favorably known.

Our Bronze Foundry is equipped to make a general line of brass and bronze castings.

It is as specialists in high-grade bronze, however, that we appeal for an opportunity to figure on unusual and difficult casting requirements.

SPECIFICATIONS OF OUR TITANIUM ALUMINUM AND OTHER STANDARD BRONZE CASTINGS

Alloy Number	Approximate Composition Per Cent					Physical Properties					
	Copper	Aluminum	Tin	Lead	Zinc	Ultimate Tensile Strength, lbs. per sq. in.	Elongation, per cent in 2 in.	Sp. Gravity at 20° C.	Brinell Hardness No., 500 kg. for 30 sec.	Shrinkage, in. per ft.	Wt. per cu. in., lbs.
1	90	10	...	...	...	70000	20	7.5	90—100	.22	.27
3	89	...	11	...	...	35—40000	6—10	8.5	70—79	.125	.31
5	90	10	...	...	...	77000	24.5	7.5	92—96	.22	.27
9	90	...	10	...	...	35—40000	15—18	8.6	65—70	.125	.31
10	88	...	10	...	2	32—38000	14—18	8.7	70—75	.125	.32
11	90	...	6.5	1.5	2	34—40000	25—33	8.8	50—60	.14	.32
14	88	...	10	2	...	30—35000	15—20	8.8	65—70	.125	.32
15	80	...	10	10	...	28—32000	5—7	9.0	55—60	.125	.33
16	81	...	7	9	3	30—35000	15—18	8.9	50—55	.125	.33
18	85	...	5	5	5	27—33000	16—20	8.5	50—60	.14	.31
19	83	...	4	6	7	28—33000	15—20	8.5	55—60	.125	.31
24	70	...	1	2	27	28—31000	22—28	8.4	50—55	.186	.30
28	99.6—	...	...	...	...	......	...	...	......	...	..
..	99.9	...	...	...	...	17—20000	40—51	8.8	30—40	.25	.32
29	56	0.5	...	...	43.5	70000	22—35	8.4	104—119	.25	.30
32	8	92	...	...	...	16—20000	1—2	2.8	50—55	.186	.10
33	3	82	...	...	15	20—26000	1—3	3.1	60—65	.186	.11

DESCRIPTION AND USES

ALLOY No. 1 — May be used wherever castings of strength or toughness are required, especially where they must resist wearing action, as in a worm or thread. It resists the corrosive action of salt water, tanning and sulphite liquors better than any of our other bronzes. Its physical properties compare closely with those of a Swedish Bessemer steel with .35 carbon.

This bronze is 10% lighter than either yellow brass or manganese bronze, 17% lighter than phosphor bronze and 15% lighter than red brass composition. Its coefficient of friction is .0018. Reduction of area 21%.

ALLOY No. 3 — Commonly known as Stone's English Gear Bronze and extensively used in this country and abroad. It is very serviceable for gears and worm wheels where requirements are severe, especially when quiet running is a desired feature. It should be used against nicely finished high carbon or alloyed steels.

While this bronze is very well considered and adequately meets present requirements of all high-grade gears, the greater strength and hardness and the lower specific gravity of our Alloys Nos. 1 and 5 are factors which should be very carefully considered by all users of this type of bronze. Its reduction of area is 7-9%.

ALLOY No. 5 — A Titanium Aluminum Bronze very similar to our No. 1 but having slightly better machining properties. We recommend this alloy for large, heavy work where great strength and resistance are required.

The machining properties of this alloy and of No. 1 must be compared to high tin alloys and not to the ordinary commercial bronzes. The Titanium Aluminum Bronzes are unusually tough and hence somewhat harder to machine. Its reduction of area is 27.3%.

ALLOY No. 9 — An acid resisting bronze, used in place of cast iron where acid is present, as in mine pump bodies and other similiar locations. It is suitable for thrust collars or discs where high pressure occurs. Like Alloy No. 3, this bronze is often used where compression is a factor, as both are stronger than Alloy No. 15. Where this condition is to be met the bearing surface of either of these alloys must be very carefully prepared so as to prevent scoring.

ALLOY No. 10 — This is practically the "G" bronze of the Bureau of Steam Engineering of the U. S. Navy Department.

A strong general utility alloy widely known as "Gun Metal"—where heavy pressures and high speeds obtain or for superheated steam hydraulic work, thrust collars, etc., it gives satisfactory results. The absence of granular structure in this alloy has caused it to be widely recommended for high-grade bearings. If so used it must be closely fitted and run against hardened and ground pins only.

ALLOY No. 11 — An excellent medium soft bronze, extensively used in the automobile industry for small bearings when lined with genuine babbitt. It is recommended for bearings where non-corrodibility is required, for high speeds and heavy pressures or for severe service steam work to resist leakage. The lead content is sufficient to give this bronze conformability so that if the adjacent part is not closely fitted the alloy should come to a bearing without cutting.

ALLOY No. 14 — A gear bronze which is softer than either Alloys Nos. 1 or 3. The presence of lead makes it machine more easily. It is applicable for small gears where the service is not too severe.

ALLOY No. 15 — The standard phosphor bronze for high speed and heavy pressure. It is one of the most serviceable bearing metals of the so-called phosphor bronzes, and is extensively used for bearings subject to shock and vibration, heavy work and high speeds, such as locomotive cross head bearings, crank pins, bridge bearings, roll necks,

mill table, grinder, blower and road machinery bearings. Heavy work of this character is not usually as closely fitted as small work so that the high lead content of this alloy materially aids in the conformation of the bearing.

ALLOY No. 16 — This bronze is very similar to Alloy No. 15, the lower tin content making it slightly lower in price. It is also somewhat softer and where service conditions will permit the use of brass ingot in its manufacture, a very considerable saving can be effected.

ALLOY No. 18 — This is a high grade red brass, generally known as the standard "Red Composition," or "Ounce Metal." It is a good steam metal; used widely for pump bodies, valves and similar articles. For general service it is regarded as an excellent bearing metal. In the estimation of the trade it is rated between the red brasses and the cheaper phosphor bronzes.

ALLOY No. 19 — Commercial Red Brass, recommended where conditions permit the use of a cheaper "Red Metal" than Alloy No. 18. As in Alloy No. 16, if conditions permit, a considerable saving can be effected in the manufacture of castings of this alloy by the use of ingot brass.

ALLOY No. 24 — A good grade yellow brass which casts well, takes a good polish and is very suitable for light castings, such as ornamental work where strength is not an important factor.

ALLOY No. 28 — Pure copper for use on electrical installations and for die blocks on electric welding machines. This alloy has high electrical conductivity, due to the special deoxidization. So called pure copper castings are ordinarily accepted with from 1% to 3% zinc and their conductivity runs well under 60%, whereas the conductivity of Alloy No. 28 is over 70% and may run as high as 85%.

ALLOY No. 29 — This alloy is commonly known as Manganese Bronze and is of value for castings where great strength and toughness are required. Manganese Bronze is one of the two high tensile bronzes, the other being Aluminum Bronze. It is extensively used for propeller blades and hubs, valve stems, engine framing and other parts requiring great strength.

In our opinion Titanium Aluminum Bronze is superior to any manganese bronze for practically all requirements. This opinion is substantiated by many eminent authorities and the only reason for the more extensive use of manganese bronze has been the well recognized difficulty of making the copper-aluminum alloys. Alloy No. 29 is not a good bearing bronze.

ALLOY No. 32 — This is the standard aluminum alloy for crank cases, housings, automobile castings, etc.

ALLOY No. 33 — An aluminum alloy which, due to its zinc content, is tougher than No. 32. It takes a high polish and can be bent slightly without breaking.

The foregoing series of Alloys covers those most frequently made in our Foundry, but we are constantly making Brasses or Bronzes for special requirements. Our organization is prepared to study any unusual problems which may be present, and to recommend, as a result of research work, the most suitable Alloy for each specific requirement.

THE TITANIUM
ALLOY MANUFACTURING CO.

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NIAGARA FALLS, N. Y., U. S. A.

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As confirmatory of the novelty and utility of the results of our researches and progress, and the appreciation thereof by Patent Office experts, we append a particular list of our Letters Patents of the United States relating to the subjects referred to in the preceding pages, or to others of kindred nature, involved in this Company's operations. For brevity, this list omits reference to our foreign patents, many of our domestic patents, and all of our numerous pending applications for patents.

648,439	1,019,529	1,028,389
668,266	1,019,530	1,029,637
700,244	1,019,531	1,039,672
713,802	1,020,512	1,056,125
721,467	1,020,513	1,080,718
802,941	1,020,514	1,080,721
822,305	1,020,515	1,084,036
877,518	1,020,516	1,085,488
R–12,764	1,020,517	1,094,022
905,232	1,022,595	1,104,317
935,863	1,022,596	1,105,308
979,393	1,022,597	
979,394	1,022,598	
986,504	1,022,599	Canadian
986,505	1,022,600	Patents
986,645	1,022,799	
1,003,805	1,023,331	96,012
1,003,806	1,023,332	130,196
1,017,807	1,023,333	132,718
1,019,526	1,023,334	132,880
1,019,527	1,024,476	133,014
1,019,528	1,025,426	145,718