Effervescing Steel

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For the purpose of this paper all steels will be divided into two divisions: effervescing and non-effervescing. This classification must be borne in mind as many statements true of one class are not true of the other.

Effervescing steels are those that effervesce in the molds, evolving large volumes of gases, which, in escaping, throw up a spray of molten particles of steel and give the molten metal in the mold a rapid stirring or churning motion until it freezes, or, at least, becomes pasty. This effervescing is intended and proper. The non-effervescing steels, which are more or less completely killed, should not evolve any gas in the molds. Many years ago the writer proposed to call the two classes of steels evolution and solution steels, depending on whether the gases in the molds are evolved or kept in solution, but the present designations seem to be better.

In America, at least, effervescing steels are in a class by themselves and include steels made for boiler, tank, and ship plates, steel pipe, soft steel wire, wire nails, soft machinery, and structural steels. These are all low-carbon steels with less than 0.40 per cent. carbon. Low-carbon steels that do not effervesce but are killed are also made; these are put into ingots and castings but they are outside the limits of this paper. Effervescing steel is cast into square or slab molds, either top or bottom poured.

Most of the effervescing steel is made in the basic open-hearth furnace, though much is made by the acid Bessemer process and a little is made in the acid open-hearth. It is not made by the crucible or electric-furnace process, in which the volume of gas required cannot be produced in the steel and evolved from it in the mold to give the effervescence desired.

Any steel ingot, when teeming is finished, is of a certain size or volume. Leaving out of consideration for the moment the lessening of the over-all dimensions of the ingot through contraction due to loss of heat, the ingot may be placed in one of three classes: It may settle, losing in volume; it may stand, that is, remain constant in volume; it may rise, that is, increase in volume.

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Into which class an ingot will fall depends on the gases of the steel, their escape from the metal during solidification, and the holes they form in the ingot. These three classes have no strict lines of demarcation but can be distinguished from one another sufficiently well for practical purposes.

Gas Holes

The gas holes in effervescing steels are of three kinds, each of which occurs in a distinctive manner. Skin holes are at or near the outer surface. Intermediate holes, sometimes called deep-seated holes, are in a zone between the surface and the center. Central holes are located at random in the central portions.

Skin holes constitute defects and are not desired. Intermediate and central holes exist in good standing and settling effervescing steel but are of such size and are so located as to give no trouble; neither do they lower the quality. The gases in the three kinds of holes have not been separately analyzed. There is some ground, however, for believing that the skin holes are formed chiefly by hydrogen, the intermediate by carbon monoxide, CO, and the central by nitrogen and ammonia, NH_3.

The correct behavior of good effervescing steel in the mold is this: As soon as the first of the steel enters the mold, whether top or bottom cast, it evolves a myriad of gas bubbles, the evolution continuing until the ingot has become solid. Each bubble, as it reaches the surface and escapes, is followed by small drops of melted steel thrown up perhaps 2 or 3 ft. (0.6 or 0.9 m.) by the inrushing metal as it fills the evacuated space. These drops burn more or less completely in the air and collectively make a brilliant, if small, pyrotechnic display. This effervescence reaches a maximum when teeming ceases and then gradually lessens until the ingot is covered or, may be, it is all solid. The steel begins to freeze in contact with the mold almost at once after teeming is finished and the freezing walls progressively grow in thickness by accretion from the still liquid and effervescing central metal. This process of solidifying is called in the shop "rimming in;" and when everything is right, the rim has a level top. When the rim is 1 or 2 in. (2.5 or 5 cm.) thick a cast-iron cover an inch or more thick is laid to prevent a rising of the central metal, which would usually take place (if it were left to itself) just before final freezing, and the ingot has a flat top. In such an ingot there will be practically no skin holes. The ingot will consist of clean solid steel to a depth of 2 or 3 in., depending on its size and carbon percentage, then will come the zone of intermediate holes, and within them the central part containing a few scattered gas holes; see *B*, Fig. 1.

The proneness of steel to effervesce in the molds is in a way a function of its carbon content. The lower the carbon the more its rimming-in capability, and when the carbon is extremely low, say 0.04 per cent. or less, the steel does not pass through a mushy stage before final freezing and the ingot may rim in to the center and not require to be capped as is customary with most effervescing steels.

Effects of Too Mild an Effervescence.—When the effervescence is too mild, the steel rises in the mold after teeming has ceased. This shows that skin holes are forming, which displace their bulk of metal and cause the rising. In pronounced cases, the steel continues to rise, when teeming is finished, for several minutes. The holes are covered by only a thin wall of steel, or, as they say in the shop, the ingot is "thin skinned." The holes may be 2 in. (5 cm.) or even more in length and as close together as the cells of a bee's honeycomb, see Fig. 6. Steel containing such holes must be scrapped as it cannot be used for any purpose where any regard is given to the surface. A plate or bloom rolled therefrom is covered with defects such as tears, pits, seams, and scabs.

Such a profusion of skin holes results from a much too high casting temperature and insufficient oxygen in the metal, which latter is evidenced by too gentle boiling of the bath. In the mold there is little or no effervescence and the steel has an oily appearance. The displaced metal that rises may amount to 12 or 15 per cent. of the volume of the ingot and perhaps overflow the mold. If the ingot is bottom cast, the spot where the sprue is broken from the ingot will show long skin holes radiating from the center to the circumference of the fracture.

In less pronounced cases, the skin holes may be numerous and extend somewhat irregularly over the whole ingot surface but deeper seated with thicker skins over them than in the worse cases. Then, if they are not burnt into in the heating operation, the rolled product may have a good surface; or a part may be burnt into by irregular heating, which will cause pits in the plate or seams in the bloom in that part; see *C*, Fig. 1. In other mild cases, a few small skin holes may occur in a small fraction of the ingot surface, but the pits they cause will be enough to condemn any plate containing them; see *A*, Fig. 1.

Steel that Pipes or Settles After Teeming.—Piping or settling of effervescing steel after teeming is caused by the escape of such volumes of gases that a greater bulk of the liquid is displaced than is represented by the residual gas holes. Steel has been made by the writer that settled to about one-half the volume it had at the end of teeming leaving a shell, pipe, or "bootleg," that had solidified against the ingot wall. That was an extreme case in the early days of the basic open-hearth process, when the effect of free oxide of iron in the slag was not foreseen from the results of acid practice. Such an ingot will have intermediate and central holes below the shell or pipe and may behave well when rolled but it will weigh less than was intended and will give an unduly large percentage of scrap.

Genesis of Gas Holes.—The actual genesis of the gas holes in effervescing steel is a matter for speculation but, assuming the gases forming them to be as previously stated, the following suppositions may seem reasonable as some of the facts support them. Of course, the gases that escape from the metal in the mold, or at least their ingredients, are contained in the steel when it enters the mold. The atmosphere takes little part for it is immediately expelled from the mold by the gases evolved from the first metal to enter after which only the stream from the ladle is exposed to it, and that for a small fraction of a second.

Carbon monoxide, whether in solution as such in the liquid metal or formed just before it escapes, as has been claimed, plays the most important part. In a normal case, this gas begins to be evolved as soon as the first steel enters the mold, because apparently the solvent power of the metal for it is lessened by the lowering of its temperature. This escape of carbon monoxide continues until all the metal of the ingot has congealed, when the last of it is expelled.

Müller found that carbon monoxide is insoluble in cold steel. As the ingot walls thicken, the liquid central metal (with carbon over 0.10 per cent.) becomes somewhat mushy and the evolution of gas therefrom gradually diminishes. The bubbles forming the intermediate holes are then made, presumably of the last carbon monoxide to be liberated, and lodged along the face of the solid wall entrapped by lack of fluidity of the mushy metal. It might be thought that these intermediate bubbles, as well as the skin holes, are formed by hydrogen, which looks reasonable in some cases where they are nearer the surface than usual, were it not for the fact that sometimes both skin holes and intermediate holes exist in the same ingot distinctly apart, which is fair evidence that they are formed by different gases, see *C*, Fig. 1 and Fig. 3. The intermediate holes have clean bright surfaces and, ordinarily, when not unduly large are closed and welded by rolling.

Carbon monoxide, in escaping from the steel in the mold, very likely carries off some of the hydrogen, nitrogen, and ammonia, but the small residues of these gases are sufficient to form at least a few holes when conditions are favorable therefor. The explanation why no carbon monoxide is evolved in the mold when the metal is too hot is not apparent.

Of the hydrogen dissolved in the metal, a relatively minute quantity, compared with the enormous volume of carbón monoxide in normal steel, seems to remain in the metal until the instant of solidification. It is then set free and forms bubbles that cling to the ingot wall; these are small at first but, if not dislodged, grow on the inside as the ingot wall thickens by progressive freezing. Each bubble thus acquires an elongated shape with its axis normal to the ingot wall. When, however, the evolution of carbon monoxide is sufficiently brisk, these hydrogen bubbles are washed off mechanically as they form by the rising carbon monoxide bubbles, which they join and rise with them to the surface and escape. All or only a part of them may be so eliminated, according as the casting conditions are correct or not but any that remain form skin holes. This explanation is supported by the fact that skin holes are found sometimes at or near the bottom of the ingot, where the washing action of the carbon monoxide is weakest, when there are none higher up in the ingot; see Fig. 2. In extreme cases skin holes continue to grow until the unfrozen metal in the central portion of the ingot has set free all its hydrogen and has become pasty.

Residual nitrogen and ammonia may be present in even smaller quantities than hydrogen and be progressively concentrated in the last metal to remain liquid at the center of the ingot, separating then to form the central holes. These always have bright surfaces and are not to be readily detected in the rolled product being, as a rule, probably welded in rolling, the gases being reabsorbed by the metal under the great pressure of the rolls.

Between the ordinary, or normal, and the extreme cases cited any gradation may occur. If the steel is slightly too hot or not sufficiently active in the furnace, effervescence may apparently be as brisk as in the normal case but the metal rises slowly as it "rims in" forming a frustum top having a volume of 2 or 3 per cent. of that of the ingot. In this case the skin holes will be small and few in number and may have a fairly thick skin of sound metal outside, say, ½ or ¾ in. (12.7 or 19 mm.) thick, enough to hold during heating and rolling so that the plate or bloom has a clean surface.

If the temperature is still higher or the boil is still less active or if some gas solvent is present, the effervescence at first may be retarded somewhat and then become more brisk. The steel rises in the mold faster at first than "rimming in" proceeds so that that operation only begins to show after a minute or two or perhaps even longer, when the rising is slackened. A frustum top is then formed, as in the case just cited, and the total rise may equal 5 or even 10 per cent. of the ingot volume. A tendency to skin over may be noticed as soon as teeming has ceased, floating islands forming and then remelting more or less completely. Steel that behaves in this manner is likely to have surface defects in the rolled product; and pretty sure to if the ingots are allowed to become cold and then reheated for rolling. The time this takes in the heating furnace is longer than when the ingots are put in hot from the casting heat, causing a deeper oxidation of the surface metal, which is likely to uncover the skin holes present, oxidize their interiors, and cause surface defects in the product. The skin holes will be larger and more numerous than in the previously cited case as well as being nearer the surface, sometimes within ¼ or ⅜ in. (6.35 or 9.52 mm.).

Effect of Stirring Steel Bath.—According to these explanations the carbon monoxide plays an important and beneficial part in making good effervescing steel. An effort has been made to "shake out" this gas before casting by stirring with many cold steel bars or rods, which will cause the outrush of great volumes, but such practice has been abandoned or cut down to the use of a few, not over five or six rods. At one works, many years ago, it was customary to use thirty rods to a 20-ton heat to drive out the gases that, it was assumed, injured the quality of the steel; but the results were not any better and the practice was discontinued. At that works the custom was, as soon as teeming was completed, to fill a mold with sand over which a steel plate was clamped down by a wedge driven under a bar passed through the lugs. Therefore it was not known if the steel would have effervesced and rimmed in properly or not, but it is a fair presumption that the steel was not properly made or the haste with which the molds were filled with sand would have been found unnecessary. The object of such haste was to prevent the steel rising in the mold, which the gas in forming bubbles in the steel tended to cause. This evolution of gas proceeds with considerable force so that jets of liquid steel were sometimes forced out through the sand endangering the workmen; at other times the molds were lifted from their stools and even toppled over, which required a pressure of at least 50 lb. per sq. inch.

The active boil in the furnace necessary to give good effervescence in the molds is the escape of carbon monoxide, so it would seem that unlimited stirring should not be given the bath lest the action in the molds may lack the necessary vigor and skin holes in the ingots result. The carbon monoxide, no doubt, carries off other dissolved gases when it escapes in the furnace so there will presumably be more hydrogen, nitrogen, and ammonia present in the unfinished steel when the boil is gentle; consequently, the holes they form are liable to be larger and more numerous. Thus a normal or proper boil in the furnace gives in the mold little hydrogen, which is easily eliminated, while a slack or weak boil gives too much hydrogen, which forms the profusion of skin holes with thin skins.

All three kinds of gas holes may exist in one ingot, but usually only when the skin holes are comparatively small and few in number, see Fig. 3. An ingot with a pronounced case of skin holes may be quite sound within, see *A*, Fig. 1. Whether or not the central metal has good physical properties cannot be told as the ingot is always remelted. The stirring due to the effervescence aids apparently the agglomeration of the sonims (sulfides and silicates) in the metal, which then rise to the surface leaving the steel so much the cleaner and thereby improved in quality. It has been considered that good thick-skinned steel without skin holes has better physical properties, particularly ductility, with the same amount of hot-working than steel containing them or killed steel of the same composition both of which will retain a substantial part or all of the sonims in the steel when it entered the mold. Proof of this is lacking and is perhaps only to be had from the averages of a large number of tests of all three kinds of steel.

When larger ingots are made, requiring an additional heating and rolling operation, the extra hot deformation resulting tends to improve the ductility. Such larger ingots are more liable to have surface cracks than smaller ones but the extra hot-working tends to obliterate these by scaling and rolling so that the product, either bars or plates, is merchantable. Segregation is generally more marked in the larger ingots, which fact must always be considered.

The presence of sonims probably increases the susceptibility of steel to corrosion as each non-metallic particle forms an electro-negative spot, which becomes a center of corrosion when conditions favor that operation.

Whether a tear or crack in a bloom of low-carbon steel is due to red-shortness or to skin holes may usually be told by examination of the walls of the break, at least in blooms 6 in. square or more. If the steel is red-short the sides of the flaw will show granular surfaces while if skin holes have caused the defect they will not be wholly obliterated but may be seen within even though distorted and drawn out by the elongation of the piece in the hot-working operation.

Testing Soft Steel for Homogeneity.—To show the lack of homogeneity of soft steel, a flat bar or strip may be bent 180°, shut down, and then the bend opened until the piece breaks. The fracture shows something of the structure at that point and a plate may show flattened seams that have opened and are the remains of gas holes in the ingot. They may or may not be welded. Another way is to soak the bar or strip for several days, or a week, in a beaker of hydrochloric acid made by diluting, say, 250 c.c. of commercial acid with an equal bulk of water. Each piece should be treated by itself in a separate vessel to prevent electrolytic action between different pieces. The acid will penetrate deeply where the metal is electropositive and show the lack of uniformity the ingot possessed.

Making Effervescing Steel in the Basic Open Hearth

Running the furnace in making effervescing steel is like ordinary practice except that the kitchen, or laboratory, must be hotter at the end to provide for the higher fusion point of low-carbon steel. One per cent. of carbon lowers the fusion point of iron about 90° C. A bath with 0.10 per cent. of carbon should be about 72° C. hotter than if it contained 0.90 per cent. To ensure this the kitchen must be still hotter, perhaps 90°, than when 0.90 per cent. carbon steel is being made.

When melting a cold charge, the full power of the furnace should be employed. When all is melted the temperature should be raised gradually to the proper degree for tapping at the end. The carbon content, when melted, is preferably about 0.50 per cent. Ore is added from time to time to oxidize the excess of carbon until the content of that element is 10 or 15 points above that desired in the finished steel, which excess is oxidized and boiled out by the oxide of iron present in the slag. The final boil desired is not easily described; but with 0.20 per cent. carbon, the whole surface of the slag is in motion from the bursting bubbles of carbon monoxide. For steel to be killed, such action would be too vigorous. The briskness of the boil lessens as the carbon in the metal diminishes; and when it is very low, the boil consists in relatively few scattered bubbles over the surface.

The casting temperature is the chief concern of the furnaceman. The proper degree is that which permits the metal to be teemed cleanly into the molds with the formation of an incipient skull in the ladle not large enough to cover the ladle bottom. Appearances in the kitchen and taking tests give the knowledge for its control.

The proper effervescence in the molds demands the proper boil in the furnace. If it is too gentle, more ore must be added; if too brisk, more time with perhaps the addition of pig iron or manganese alloy, preferably spiegel, is required. The addition of aluminum in the ladle will check a too brisk action and, in some works, it is added regularly up to 5 oz. to the ton. If the steel shows a settling tendency in the molds, the excessive effervescence that causes it may be checked by throwing in a little aluminum, say, 1 or 2 oz. to the ton.

Making Effervescing Steel in the Acid Open Hearth

In the acid open hearth, the boil is, as a rule, not so vigorous as in basic steel of the same carbon content; and while sufficient effervescing action can be had, it rarely happens that such action is excessive. Hence the precautions and treatment to prevent settling or piping followed in basic steel are rarely or never needed in acid steel. No aluminum or silicon are needed or used.

To get a proper boil there must be in the slag enough unspent oxide of iron to give it an earthy fracture and black color when poured in a cake ¼ or 5/16 in. (7.9 mm.) thick on an iron floor, while that which chills on the handle of the test cup, about 1/16 in. (1.5 mm.) thick, will be black and vitreous. With a green or yellow vitreous slag, the steel is likely to rise in the mold and have skin holes because of too gentle effervescence.

Method of Casting Effervescing Steel

While effervescing steel may be either top or bottom cast, that does not mean that it is a matter of indifference how any given steel is cast. A melt may behave well when bottom cast that would rise in the molds if top cast. The chief difference in the two methods is in the rate of filling the mold. A group of bottom-cast ingots weighs perhaps 15 to 20 tons so that the slow rate of filling allows the metal to cool and in so doing to evolve the carbon monoxide that causes the effervescence. If the steel is to be top cast, it must be more strongly oxidized in the furnace and so have a more vigorous boil and be cast slower either by pouring two or more molds at once, so as to fill them more slowly, or by the use of a nozzle of small diameter relative to the cross-section of the ingot or ingot group if the steel is bottom cast. A 2-in. diameter nozzle is right for a 10- to 15-ton ingot or group.

Plate steel that is to be rolled into a finished product at one operation is bottom cast because that favors the production of thick-skinned ingots and lessens wrinkles and cold shuts in the ingots, which might make defects on the surface of the plate.

If the steel stands and rims in properly, the covers may be put on when the rim is 1 in. (25.4 mm.) thick, which requires 2 or 3 min. After ½ hr. the ingots may be stripped.

Bessemer Effervescing Steel

Soft effervescing steel for pipe, wire, and other purposes is made by the Bessemer process, its low carbon content particularly favoring its use for purposes when it is to be welded, as in pipe. The two important conditions of manufacture of such steel are that it shall be blown "full" and "close." "Full" means that it be more fully blown than steel for other purposes for which the Bessemer process is used, blowing continuing 2 or 3 sec. after the last luminous streaks have disappeared from the flame. This slight overblow gives the metal the proper proportion of oxygen, which makes and liberates the necessary quantity of gas to give good effervescence. If turned down "younger," the steel is likely to rise in the molds. "Close" means that the casting temperature is near the freezing temperature, as in the case of open-hearth steel mentioned previously. This calls for close control of the temperature by accurate scrapping and blowing. A tendency for the steel to effervesce excessively so as to settle in the mold may be corrected by the addition of a little gas solvent, say 6 oz. of silicon or ½ oz. of aluminum to the ton for mild cases and more for more pronounced ones. If the steel settles moderately it will probably roll all right without developing surface defects, but flat-topped ingots are preferable for they will work up into finished forms with less scrap. When soft Bessemer steel, like pipe steel, fails to effervesce properly in the molds, a few small pieces of limestone thrown in cause a sputtering and keep the top "open," favoring the evolution of gases from the metal.

It has been claimed that the presence of sulfur, say 0.06 per cent., aids greatly in making soft Bessemer steel effervesce properly in the molds. At one works where direct metal with 0.02 per cent. sulfur was blown, it was difficult to get a good action in the molds, but when the same metal was remelted in a cupola and had thereby been given more sulfur, the desired effervescence was obtained.

Plate Steel

A steel plate must have, in addition to the desired physical properties, a clean surface free from visible defects of all kinds. There are two ways

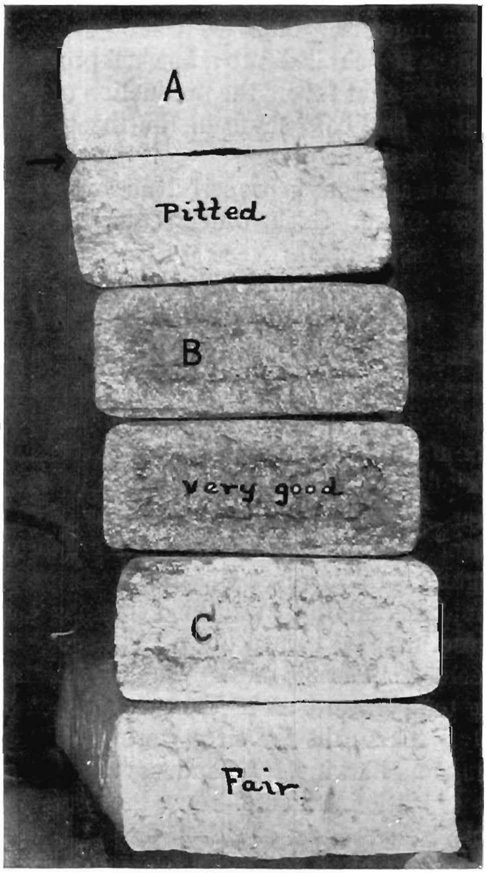

Fig. 1.—Fractures of soft plate steel ingots made by the author at the Linden Steel Works in 1888.

of rolling plates: the ingot may be of such size and shape that it may be rolled direct from the ingot to the finished plate at one operation, or the ingot may be larger and so must be rolled into a slab, which is cut up into pieces which are reheated and rolled into finished plates on another mill.

For direct rolling the structure and surface of the ingot must be right. It must contain no skin holes and the intermediate holes should be, at least, 1 inch, and preferably 2 inches, from the surface. The ingot should have a flat top and no surface cracks.

For double rolling, the soundness of the ingot or the perfection of its surface is not so important, as small defects, such as shallow pits, snaky cracks, and cold shuts, will usually be obliterated by the two heatings and rollings. So the steel need not be so carefully made for double as for direct rolling. The double rolling tends also to improve the physical properties and so make up for some lack of quality. The larger ingots made for double rolling are liable to have more pronounced segregation and irregularity of composition than smaller ingots.

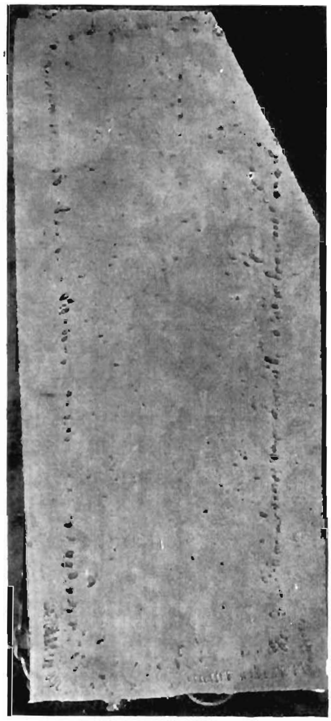

FIG. 2.

Figs. 1 to 6 show split and broken ingots and slabs illustrating some of the internal features of plate ingots. Fig. 1 shows the six broken fractures of three bottom-cast slab ingots, 8 by 20 in. (20 by 50 cm.) in cross-section made by the acid open-hearth process. The steel had about 0.12 per cent. carbon, 0.35 per cent. manganese, 0.05 per cent. sulfur, 0.06 per cent. phosphorus, and 0.01 per cent. silicon and was intended to effervesce in the mold. The ingots were broken in two under a drop. The top ingot *A* had a few skin holes near the corners indicated by the arrow-heads, which caused pits in plates rolled from the other ingots of the same heat. The remainder of the ingot was practically solid and the ingot probably weighed more per unit of height than the other two, which were thicker-skinned, such holes as they contained being located deeper in from the surface.

The next ingot *B* was about ideal, there being no skin holes and the intermediate holes having an outer covering of over 2 in. (5 cm.) of clean solid steel. Such an ingot may be rolled into a practically perfect plate.

The bottom ingot *C* had a zone of skin holes with ½ in. (12.7 mm.) skin of solid steel outside. Within the skin holes is a zone of intermediate holes. This steel was cast slightly too hot and rose a little in the mold but not ruinously so. Unless the time in the heating furnace is prolonged unduly, which might cause the outer skin to be burned through, such an ingot may be rolled into a marketable plate.

Fig. 2 is a vertical section through the center of a good slab ingot 18 in. (45.7 cm.) wide. This ingot has a flat top and the usual zone of intermediate holes, while across the bottom and a little way up on each side is a partial zone of skin-holes with ½ in. (12.7 mm.) of sound steel outside. This ingot furnishes evidence of the explanation previously given as to the mechanical action of the carbon-monoxide bubbles in washing off the forming hydrogen bubbles. Such action is manifestly weaker on and near the bottom than farther up. The size and number of rising bubbles increases as the top is approached.

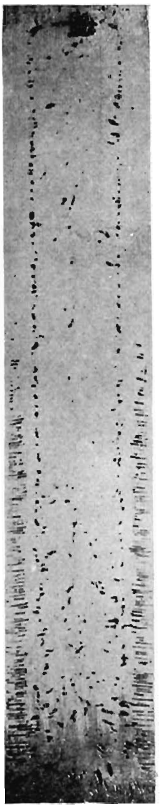
FIG. 3.—LARGE OPEN-HEARTH INGOT.

Fig. 3 is the vertical section of an ingot 13 in. (33 cm.) wide of soft, basic, open-hearth steel having 0.08 per cent. of carbon. This ingot has all three kinds of gas holes previously referred to though the skin holes are so deeply located as to impair but little the quality of the steel and its suitability for its intended purpose. This steel had too feeble effervescence in the lower part of the ingot to dislodge the hydrogen gas bubbles forming the skin holes.

Fig. 4 shows the broken section of a slab 4 in. (10 cm.) thick, which was rolled from an ingot 13 by 22 in. (33 by 55.8 cm.) in a two-high mill running one way, the ingot being passed back over the top. This was an excellent ingot without skin holes, the zone of intermediate holes being 2 in. in from the surface and the bubbles small and relatively few in number.

Fig. 5 shows another slab of the same size and from the same sized ingot as Fig. 4. This ingot was only fair as the skin is but ½ in. (12.7 mm.) thick though the plate rolled from it might be merchantable. The right-hand side of this slab shows a heavy zone of skin holes, such as sometimes will not be completely welded up in the rolling operation. When that happens, they are liable to be cut through in shearing the plate to size and a split edge is disclosed, which is a serious defect. Traces of intermediate holes may be discerned but the holes on the top and bottom sides have been obliterated by rolling.

Fig. 6 is of a typical badly pitted ingot 12 by 42 in. (30 by 106 cm.) in cross-section with skin holes extending 2 in. in from the surface. It contained 0.20 per cent. carbon, 0.036 per cent. sulfur, 0.011 per cent. phosphorus, and 0.40 per cent. manganese. It was cast too hot and was useless, except as scrap.

When a soft ingot having a section or area infested badly with skin holes is stripped red hot, such a section or area will show because it loses heat and becomes black quicker than the remainder of the ingot. Such a quicker cooling part, having less metal per unit of length, will, when the ingot is rolled to a plate at one operation, cause the plate to be narrower there than elsewhere where skin holes are fewer or absent, and the plate will be of irregular shape. A good slab ingot will, when properly rolled,

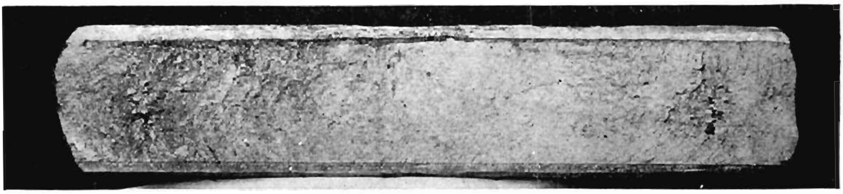

FIG. 4.—SLAB MADE AND PHOTOGRAPHED AT NORWAY STEEL & IRON CO.'S WORKS. PLATE STEEL ROLLED ONE WAY FROM 13 BY 22 IN. TO 4 BY 22 IN. EXCELLENT SLAB. BLOWHOLES VERY FAR IN. MADE IN 1884.

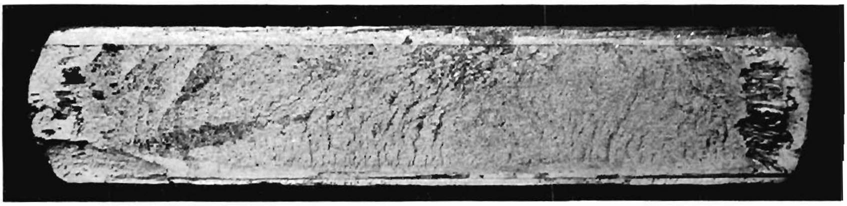

FIG. 5.—SLAB MADE AND PHOTOGRAPHED AT NORWAY STEEL & IRON CO.'S WORKS, SO. BOSTON, MASS. PLATE STEEL (BOILER) ROLLED ONE WAY ONLY FROM 13 BY 22 IN. TO 4 BY 22 IN. RATHER POOR STEEL; BLOWHOLES TOO NEAR SURFACE, BUT NO PITS. MADE IN 1884.

give a rectangular plate as wide at the top as at the bottom, showing a substantially even distribution of such gas holes as it contains.

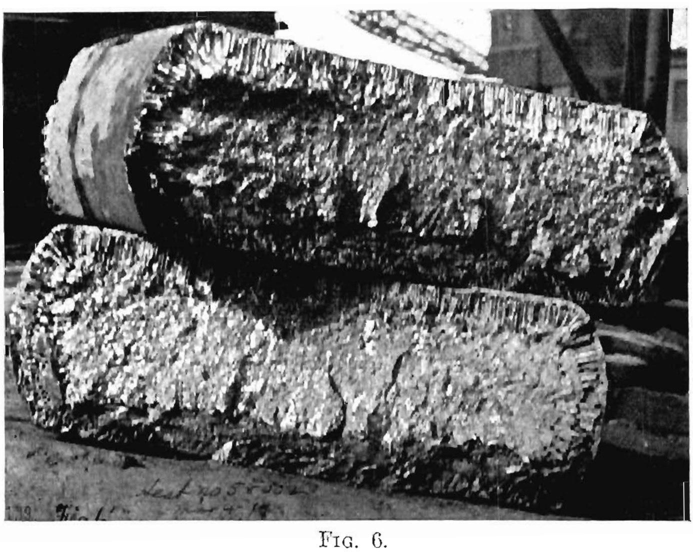

FIG. 6.

The appearance of the rolled plate gives some indication of the temperature at which the rolling was finished. If at a bright red heat, say about 750° C., the scale will be set and be of the dark slate color of magnetic oxide of iron (Fe_3O_4); plates ⅜ to ½ in. (9.52 to 12.7 mm.) thick should have such a color. Finishing at a lower temperature, but still visibly red, will cause the scale when cold to have the red color of Fe_2O_3; plates ¼ in. (6.35 mm.) thick or less usually have this color. On heavy plates, 1 in. thick or more, which are likely to be finished hotter, say, up to 900° C., the scale may rise and loosen itself more or less completely from the plate after rolling is finished.