cast in their final shape, and therefore not subsequently forged or rolled, there is no such opportunity for closing up blowholes. The conditions therefore should be such that the blowholes shall neither be externally visible and thus disfiguring (not to say liable to easy detection), nor so placed as to weaken the casting seriously; and in general even the deep-seated blowholes are objectionable. Further, the casting temperature often has to be very high, in order to permit the steel to fill the intricacies of the mould before freezing.

Besides the foregoing elements, temperature, composition, *etc.*, which affect blowholes, moisture in the moulds tends to cause serious external blowholes, and this is one serious difficulty in the way of using moulds of "green," *i. e.*, moist or unbaked sand for making steel castings.

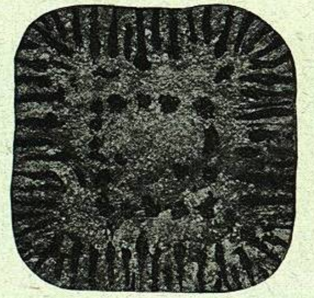

Fig. 111.

Structure *H*. Many external blowholes and a ring of internal blowholes. Cast at too low a temperature.

291. SEGREGATION. (See §§ 76 and 77, pp. 86 and 87.) — The solidification of a large ingot of steel takes place gradually from without inwards, and each layer in solidifying tends to expel into the still molten interior the impurities which it contains, especially the carbon, phosphorus, and sulphur, which by this process are in part concentrated or *segregated* in the last freezing part of the ingot. This is in general around the lower part of the pipe, so that here is a second motive for rejecting the piped part of the ingot. While segregation injures the metal here, often fatally, by giving it an indeterminate excess of phosphorus and sulphur, it clearly purifies the remainder of the ingot, and on this account it ought, under certain conditions, to be promoted rather than restrained.

The following is an extreme case of segregation:

	CARBON	SILICON	MANGANESE	PHOSPHORUS	SULPHUR
Composition of the initial metal per cent	0.24	0.336	0.97	0.089	0.074
Composition of the segregation . .	1.27	0.41	1.08	0.753	0.418

292. "DRAFT" FLUID COMPRESSION OF STEEL INGOTS.* — In the common or Whitworth method of closing the pipes and blowholes in a steel ingot by strong pressure applied to it while solidifying, this pressure is applied to the top of the cylindrical ingot. If undisturbed the ingot would contract both longitudinally and transversely during and because of its cooling, and the mould would simultaneously expand because of its heating through the heat which it receives from the ingot. The transverse contraction of the ingot draws it away from its mould and the transverse expansion of the mould draws it away from the ingot. There is thus a double tendency to leave the sides of the ingot unsupported by the walls of the mould. The Whitworth system compresses the ingot lengthwise and shortens it and bulges it enough to compensate both for the lengthwise and transverse contraction of the ingot and for the expansion of the mould. In thus bulging, the ingot acts like a cylinder of soft india-rubber in part, but only in part. For in passing from the molten to the solid state the metal passes through an intermediate mushy state, when it has already lost the mobility of the molten state, and has not yet acquired the ductility of the solid state. It is while passing through this state that metallic castings tend to pull themselves asunder, and in this stage our bulging ingot tends to act like an unhooped barrel strongly compressed lengthwise, and to crack lengthwise as the staves of our barrel yawn apart. This splitting, doubtless, lessens very greatly the power needed for compressing the ingot, for the shell of the ingot when thus split should

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* Extract from a contribution by the author to the Report of the Commissioner-General for the United States to the International Universal Exposition, Paris, 1900, Vol. V.

offer much less resistance to lengthwise compression than it would if it were an unbroken annular column. A disadvantage of this is that, when these rifts open through the shell of the ingot, the still molten central metal near the axis of the ingot, which has been enriched in carbon and phosphorus by segregation, is forced through these rifts to the surface, where it forms longitudinal ribbons of composition different from the rest of the crust. But for this extrusion the segregated impurities would have remained in the axis. If they remained there permanently they would be relatively harmless for most purposes, because they would be so close to the neutral axis, and in many cases they would be removed when the compressed ingot was finally bored out along its axis. In short, the bulging of the ingot leads to cracking, which is beneficial in that it lessens the power needed for compression, but harmful in that it allows the extrusion of the segregated axial metal. And this bulging is due to the tendency of the ingot to shrink away from its mould.

This drawing away and its consequences are avoided by the St. Etienne "draft-compression" process (procédé de compression par tréfilage, Fonderies, Forges et Aciéries de Saint-Etienne, France). In this process the ingot to be compressed is cast as the frustum of a slightly tapering cone, in a conical mould, and is then driven along this tapering mould by means of pressure applied to its base. Just as when we drive a tapered plug into a tapered hole the radial pressure against the sides of the hole is very great; so here the centripetal radial pressure of the sides of the mould against the walls of the ingot is very great; a moderate pressure applied to its base creates an enormous radial pressure along its sides, buckling them in and forcing the metal centripetally to fill up the pipe as fast as it tends to form.

A critical discussion of the relative merits of this system and those of Whitworth and S. T. Williams* would be beyond the scope of this work. But we may note that the draft-compression, if properly applied,† should avoid the extrusion effect

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* United States patent 331856, December 8, 1885.

† I say if "properly applied," because if there is to be compression and therefore draft at the top of the ingot, the whole ingot must move bodily along through the mould, and if the draft at the top of the ingot is to equal that at the bottom, the walls of the mould must not only taper but must have a curved taper.

which is to be expected in the Withworth process, and also in the Williams process if applied to large ingots; and that it does not or should not need by any means so great a pressure applied from without to the end of the ingot as that required for the Whitworth system; for in the draft process the increase in the radial pressure due to the tapering should outweigh the increase of the resistance due, (1) to the tapering itself, (2) to the ingot walls remaining unbroken instead of splitting as in the Whitworth process, and (3) to the resistance of the solid base of the ingot to radial compression. But the pressure needed should be much greater than in the Williams system, which attacks the ingot in a most effective way.

293. HEATING FURNACES. — The introduction of the "soaking" or Gjers pit and the development of the continuous or Eckman type of furnace have been of great importance. When the outer crust of a large ingot in which a lot of molten steel has been cast has so far cooled that it can be moved without breaking, the temperature of the interior is still far above that suitable for rolling or hammering — so far above it that the surplus heat of the interior would more than suffice to reheat the now cool crust to the rolling temperature, if we could only arrest or even greatly retard the further escape of heat from that crust. Bringing such an ingot, then, to the rolling temperature is not really an operation of heating, because the average temperature of the ingot is already above the rolling temperature, but one of equalizing the temperature by allowing the internal excess of heat to "soak" through the mass. Gjers did this by setting the partly-solidified ingot in a well-closed "pit" of brickwork, preheated by the excess-heat of previous lots of ingots. The arrangement, shown in Fig. 112, has three advantages, (1) that the temperature of the ingot is here adjusted with absolutely no consumption of fuel; (2) that the waste of iron due to the oxidation of the outer crust of the ingot is very slight, because the little atmospheric oxygen initially in the pit is not renewed, whereas in a common heating furnace the flame brings a constant fresh supply of oxygen; and (3) that the ingot remains upright during solidification, so that its pipe is concentrated at its upper end, which can be cut off. (See § 289, p. 367.) In this form the system is rather inflexible, because if the supply of ingots is delayed the pits grow unduly cool, so that the next ensuing lot of

ingots either is not heated hot enough or is delayed too long in soaking. This defect is now usually remedied by heating the pits by the Siemens regenerative system (see § 276, p. 350); the greater flexibility thus gained outweighs both the cost of the fuel used and the increased loss of iron by oxidation by the Siemens gas flame.

The Gjers system is not applicable to small ingots or "billets,"* because they lack the inner surplus heat of large ingots; indeed, they are now allowed to cool completely before rolling. To heat these on the intermittent plan for further rolling, *i. e.*, to charge a lot of them as a whole in a heating furnace, bring them as a whole to rolling temperature, and then withdraw them as a whole for rolling, is very wasteful of heat, because it is only in the first part of the heating that the outside of the ingots is cool enough to abstract thoroughly the heat from the flame; during all the latter part of the heating, when the temperature

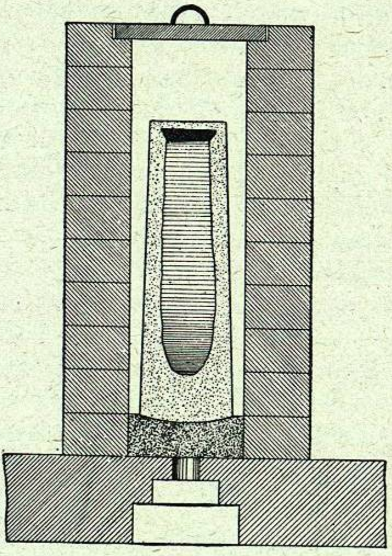

Fig. 112. Gjers Soaking Pit.

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* Billets are bars from 2 to 6 inches square, an intermediate product into which large ingots are rolled, to be further rolled into wire rods, sheets, small round and square rods, *etc.*

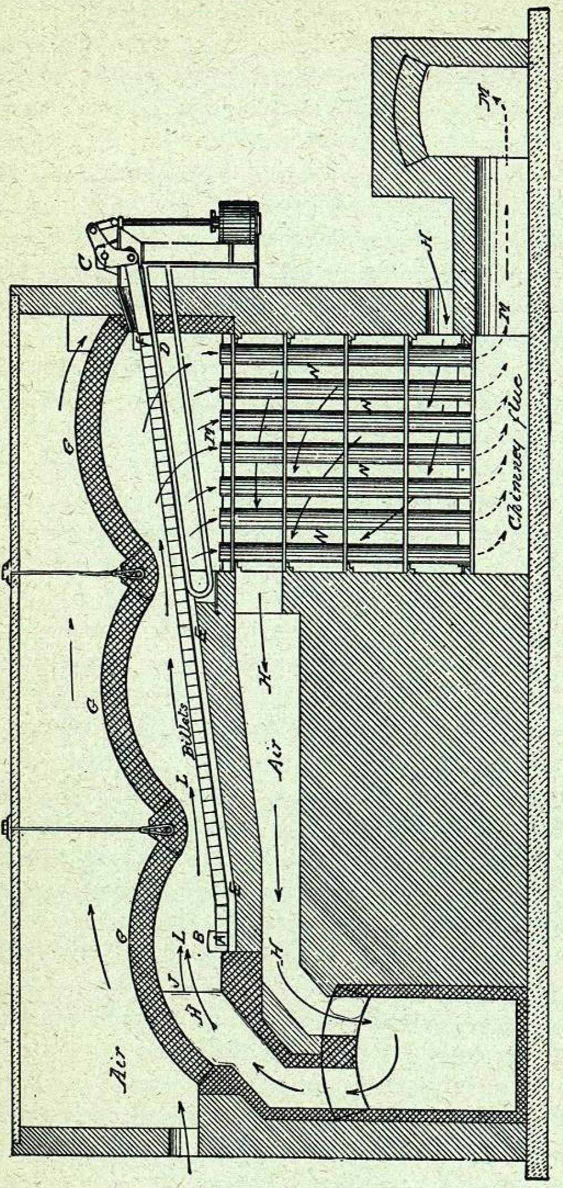

Fig. 113. Diagram of C. H. Morgan's Continuous Heating Furnace for 2-inch Billets 30 Feet long.

A, hottest billet ready for rolling; *B*, exit door; *C*, pusher for forcing billets forward; *D*, water-cooled pipe on which billets are pushed forward; *E*, magnesite bricks on which the hot billets slide forward; *F*, the billet last entered; *G*, the suspended roof; *H*, the incoming air preheated in *G* and by the pipes *N*; *J*, the incoming gas; *L*, the flame; *M*, the escaping products of combustion; *N*, pipes through which the products of combustion pass. In many of these recuperative furnaces, the products of combustion pass around the outside of the pipes, while the air to be heated passes through the interior of the pipes.

of the ingot has approached that of the flame, only an ever smaller part of the heat of that flame can be absorbed by the ingots. Hence in the intermittent system most of the heat generated within the furnace escapes from it with the products of combustion. The continuous heating system (Fig. 113), recovers that heat by bringing the flame into contact with successively cooler and cooler billets, *A — F,* and finally with quite cold ones, of consequently great heat-absorbing capacity.

As soon as a hot billet *A* is withdrawn by pushing it endwise out through the exit door *B,* the whole row is pushed forward by a set of mechanical pushers *C,* the billets sliding on the raised water-cooled pipes *D,* and, in the hotter part of the furnace, on the magnesite bricks *E,* on which iron slides easily when red-hot. A new cold billet is then charged at the upper end of the hearth, and the cycle begins by pushing out through *B* a second billet, and so forth. To lessen the loss in shape of "crop ends" and for general economy, these billets are in some cases 30 feet long, as in the furnace shown in Fig. 113. It is to make this furnace wide enough to receive such long billets that its roof is suspended, as here shown, by two sets of iron tie-rods.

As the foremost end of the billet emerges from the furnace it enters the first of a series of roll-trains, and passes immediately thence to others, so that before half of the billet has emerged from the furnace its front end has already been reduced by rolling to its final shape, that of merchant-bars, which are relatively thin, round, or square rods, in lengths of 300 feet.

In the intermittent system the waste heat can, it is true, be utilized either for raising steam (but inefficiently and inconveniently because of the intermittency), or by a regenerative method like Siemens; but this would probably recover less heat than the continuous system, first, because it transfers the heat from flame to metal indirectly instead of directly; and, second, because the brickwork of the Siemens system is probably a poorer heat-catcher than the iron billets of the continuous system; for when brickwork as a heat-catcher is compared with cold iron its disadvantages of low conductivity and low specific heat probably outweigh its advantages, roughness and porosity.

294. THE CONTINUOUS ROLLING-MILL. — The use of the continuous or Bedson type of rolling-mill has been much extended, so that it receives billets as large as 4 by 5¾ inches, and rolls sheets, skelp, merchant-bars, cotton-ties, and other important products. In this system several roll-trains stand one behind another in column (as distinguished from the usual arrangement in line), so that the forward end of a given steel billet, which is under treatment, passes immediately from one pair of rolls into the next, and so on, and emerges from the last reduced to a diameter of say three-quarters of an inch, before the rear end of the same billet has entered the first pair of rolls, or indeed has emerged from the furnace in which it has been heated for rolling. By practically eliminating the loss of time between the successive reductions, large billets can be rolled at one operation into small rods of great length, so that the proportion of metal wasted in the form of crop ends is greatly reduced. Once the rod is so very thin as to be flexible, further reduction may be made by the Belgian system, in which the successive roll-trains stand in line instead of in column, and the front end of the rod as it emerges from one pair of rolls is turned 180° in a loop by hand or mechanism, and so returned to undergo another pass in the same train. By a combination of these two systems, as developed by C. H. Morgan and W. Garrett respectively, billets 3 inches square are rolled at one operation into bars three-quarters of an inch in diameter and about 230 feet long.

295. HAMMERS AND HYDRAULIC PRESSES. — The demand for very large forgings, especially for armor-plate and ordnance, has led to the erection of enormous steam-hammers. The falling parts of the largest of these, that at Bethlehem, Pa., weigh 125 tons. But even so great a hammer is an ineffective tool for making large forgings, chiefly because the effect of its blow is concentrated on the outside of the forging, and does not penerate well towards the interior; indeed the days of large hammers seem to be over. The use of this particular one has been abandoned for that of an enormous hydraulic press which exerts a pressure of 14,000 tons. It is moved by water under a pressure of 7000 pounds per square inch, supplied by pumps of 16,000 horse-power. For forging shafting and other objects not readily made in rolling-mills, because their cross-section is not uniform, the hydraulic press seems to be firmly established as by far the most efficient tool. But though the great 14,000-ton Bethlehem press is used with great success for forging armor-plate also the cross-section of which is uniform, the rolling-mill certainly has special