60-ton steam hammer, has been reduced at one heat to less than 14 inches square. This means two and a-half times as long taken in working, without reckoning the time taken up by the extra heating.

The following are some instances of the work done by forging presses:—At Messrs. Vickers' Works in Sheffield an ingot 4 feet 3 inches in diameter has been drawn down to 14 inches in diameter at one heat, the size of the press being 4,000 tons. According to *The Engineer*,* Messrs. Firth's 3,000-ton press has reduced a 30-ton ingot from 49 inches to 28 inches in diameter in half an hour, and the same press is reported on another occasion to have reduce an ingot 51 inches in diameter to 26 inches in diameter in 65 minutes. It is within the author's own knowledge that an ingot 52 inches in diameter and 12 feet long has had one end drawn down under this press to 25 inches diameter by 21 feet long, at one heat, in less than an hour. A 50-ton armour plate has been reduced 2 inches in thickness at each squeeze, and has been advanced 6 inches after each squeeze, under the 10,000-ton press at the Homestead Works.†

Hollow Shafting.—The weakening effect, which a trifling notch has on a piece of metal, is clearly seen in the method which every smith employs for cutting a piece off the end of a bar of iron or steel: when nicked with a chisel the toughest bar can be easily broken by bending it over the edge of the anvil, because the extension of the fibres caused by the bending is concentrated in one small spot, instead of being distributed over a larger area, as is the case when the bar has not been notched. Now, a shaft when in use is bent backwards and forwards through a trifling angle at each revolution, and small though this bending may be, so small indeed as to be invisible, yet it may suffice to develop any flaw originally existing in the centre of the ingot from which the shaft has been forged, until the crack may extend through nearly the whole section of the shaft without betraying its presence on the surface. In such cases the shaft fails, to all appearance, quite suddenly. To render impossible the presence of such a flaw, which may serve as a starting point for a crack, a hole is bored axially right through the centre of large steel shafts, the removal of doubtful material more than compensating for the loss of some portion of the section.

Removing the centre, even if the core is perfectly sound, reduces the strength of the shaft very little, because the portions removed are too near to the centre to add appreciably to the power of the shaft to resist twisting. The strength of a circular shaft is proportional to the cube of its diameter, so that removing metal, by boring a hole as large as half the diameter of the shaft, only reduces its torsional strength 6¼ per cent., while the weight of the hollow shaft is 25 per cent. less than the solid one—a reduction in weight which, under many circumstances, would alone justify the boring. When the shaft is forged under the steam hammer, this hole is bored out of the solid by a drill or trepanning tool, after the shaft has been turned to nearly its finished size, leaving sufficient metal to be removed by the finishing cut to true up the outside, in case the removal of the centre portion should, by relieving internal stresses, cause the shaft to spring out of the straight. When the hollow shaft is forged under a press the ingot is usually bored before reheating, and then threaded while hot on to a slightly tapered mandril cooled by water running through it, upon which it is pressed. This latter method is preferable, because the mandril serves as an internal anvil, so that when forging a hollow shaft in this manner the squeeze has to be conveyed through less than one-third the thickness through which it has to be transmitted when the shaft is forged solid, and the material is, therefore, much better worked throughout. The taper of the mandril enables it to be easily withdrawn from the hot forging by a small hydraulic jack.

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* June 22, 1894, p. 550.

† *Engineering News*, New York, vol. xxxv., p. 159.

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CHAPTER XLI.

COMPRESSING STEEL WHILE FLUID.

History of the Introduction of the Process.—The first suggestion for increasing the soundness of metals by compression while in a fluid condition, would seem to have emanated from Mr. James Hollingrake,* whose patent describes the "casting of metallic substances into various forms and shapes, with improved closeness and soundness of texture," by pouring the metal into suitably shaped moulds and applying pressure by means of movable pistons or plugs. According to Mr. Reynolds,† the process had been used regularly at the works of the Broughton Copper Company, Manchester, for twenty years before Sir Joseph Whitworth took out his patent in 1865,‡ while Bessemer had obtained a patent in 1856§ for compressing the ingot while in a plastic state. Sir Joseph states in his patent that he knew fluid compression had been proposed, but the moulds employed were too weak to withstand such pressures as he considered were necessary, and to him the credit is due, not only for first applying the process to steel on a commercial scale, but also for having perfected the process and the appliances by which the operation is at present carried out. His first endeavour was to shape the steel shell, intended to be fired by his steel guns, by pouring fluid steel into an iron mould of the requisite form, and to produce

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* Patent No. 4,371, 1819.

† *Min. Proc. Inst. C.E.*, vol. xcviii., p. 169.

‡ Patent No. 3,018, 1865.

§ Patent No. 1,392, 1856.

the central hollow intended to contain the bursting charge, by forcing into the centre of the molten mass, to the depth required, a mandril covered with a non-conducting composition. The press employed had a compressive power of 250 tons. The process was not successful, and the experiment was then tried of casting larger masses into the form of ingots which could be compressed while fluid, and be afterwards reheated and forged into shape. A press having a power of 2,000 tons was installed for this purpose, and the results were such as to encourage Whitworth to put down a second press of 8,000 tons capacity, which still remains one of the most powerful in existence.

Theory of Fluid Compression.—Fluids possess the power of absorbing gases and retaining them in solution, the amount so held depending upon the temperature and pressure of the fluid. Molten steel is no exception to the rule, and takes up some of the gases with which it is in contact, or generates others during the process of manufacture. What the chemical reactions involved and the gases produced are has been explained in a previous section of this work. The occluded gas is given off in the form of bubbles as the metal cools and solidifies, and such as form when the metal is in a plastic condition, being unable to rise to the surface, are entangled in the ingot, and appear as blowholes, which considerably detract from the strength of the material. The same phenomenon may be observed when ice is made in a freezing machine. The air and other gases which the water holds in solution are released as the liquid sets, forming bubbles which are so numerous that the blowholes in a block of artificial ice give it an opaque, milky appearance, if the bubbles of gas are not made to rise to the surface by continually agitating the fluid during the freezing process.

The volume of gas which a fluid will hold in solution increases as the pressure rises; an instance familiar to every one is common soda-water, which holds in solution several times its own bulk of Carbon Dioxide gas, which the water has absorbed when the gas was compressed in contact with it. All such waters, when in the bottle, are quite clear and free from bubbles, but on releasing the pressure the occluded gas escapes with such rapidity as to throw the water into a violent state of ebullition. Fluid compression may be supposed to take advantage of this property of fluids which enables them to retain more gas in solution as the pressure is increased, so that steel which, if subject to atmospheric pressure only, would be saturated with gas, which would escape as the metal sets, may, by subjecting it to excessive pressure, be made artificially to retain the gas in solution, until the fluid has changed to the solid state; if any bubbles are formed they will be compressed into the smallest possible compass by the intense pressure to which the material is subjected, so that they shall form as small a proportion as possible of the total volume of the ingot.

The original, and still commonly accepted, theory of fluid compression was, that the gas was squeezed by the intense pressure from between the molecules of fluid steel, as water may be squeezed out of a sponge; a theory which, as will be seen a little later, was stoutly contested by Mr. Vickers. Granting his views to be correct, it cannot be denied that such heavy pressures would at least serve to reduce enormously the size of any bubbles of gas which did form, and would inevitably serve to force the contracting particles of steel into such continuous intimate contact, as to prevent the formation of cracks due to irregular cooling in a mass, which has practically no tensile strength, while in a semi-plastic condition.

Whitworth's Process.—Many methods of fluid compression have been proposed, but the oldest and best known is that introduced by Whitworth. The metal is subjected to a pressure of not less than 2 tons on the square inch.

Sir Joseph himself considered 6 tons necessary;* while Mr. Greenwood thinks pressures of 12 to 15 tons are "desirable."† Whitworth states in his patent that he contemplated pressures of 20 tons per square inch.

The ordinary cast-iron ingot moulds would obviously be unable to withstand safely such pressures even as 2 tons per square inch, and costly special moulds have, therefore, to be used for the purpose. These moulds consist of forged steel hoops, rough turned and bored, in one or more thicknesses, lined inside with a lagging of cast-iron bars placed on end side by side; the edges at the backs of the bars, next the outer rings, are chamfered off so as to form air passages from top to bottom of the mould, into which open radial grooves formed on the sides of the bars, in order to carry away the air and gas from the inner lining of the mould; this

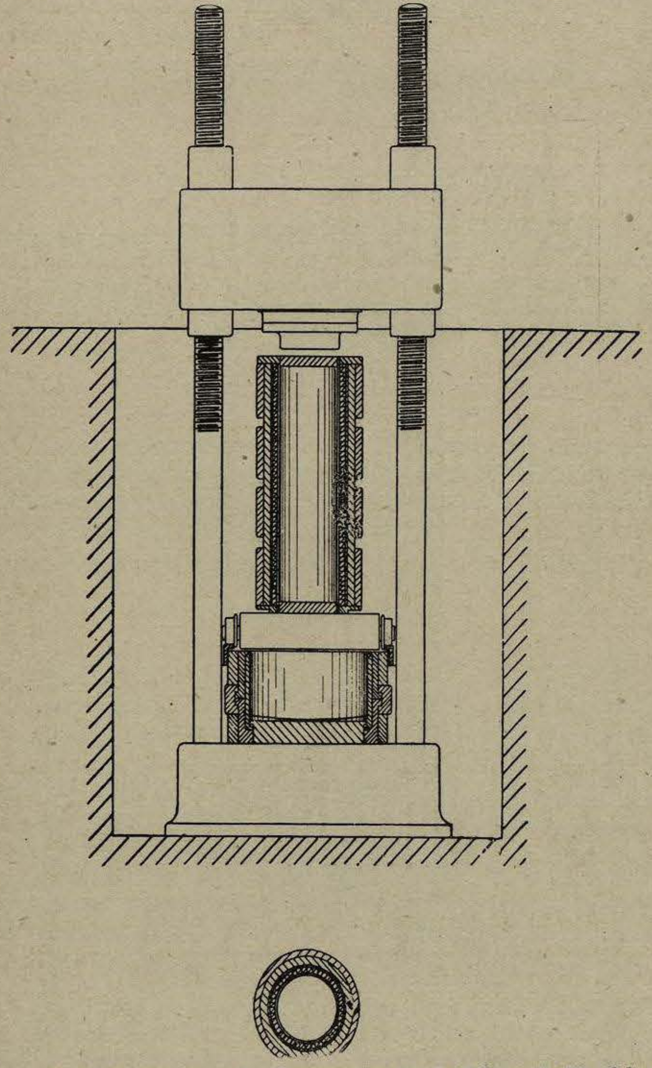
Fig. 545.—Hydraulic Press for Compressing Steel while in the Fluid State.

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* Evidence of Sir Joseph Whitworth, Bart., in the matter of his petition for prolongation of Letters Patent, 1879.

† *Min. Proc. Inst. C.E.*, 1889, vol. xcviii., p. 108.

consists of refractory material plastered on the inner faces of the bars to a thickness of about ¾ inch. The bottom is closed with a metal plate covered with fireclay tiles, while the top of the mould is finished with a cast-iron plate, into which will fit, with a clearance of $\frac{1}{20}$ inch all round, a cast-iron plug faced with firebrick, which is attached to the upper entablature of the press (fig. 545). The mould having been dried, washed inside with a coat of

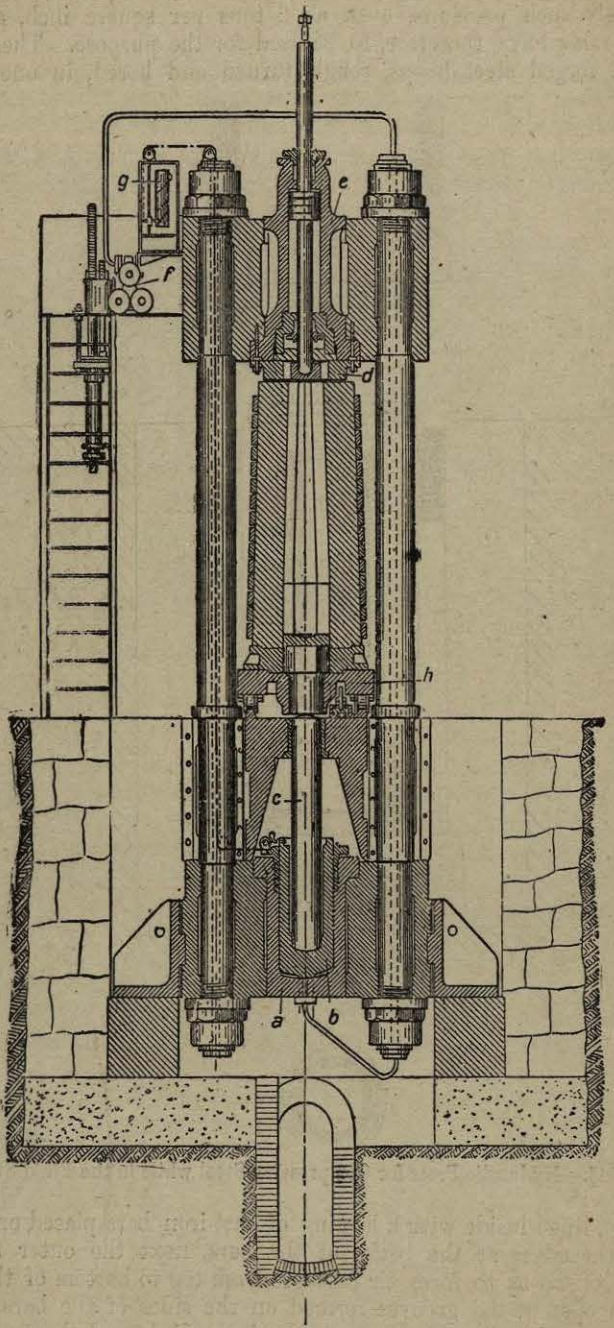

Fig. 546.—Harmet's Press for Compressing Steels while Fluid.

Plumbago, and warmed to remove any trace of moisture, is placed on a small truck in the casting-pit close to the press, and when full of melted steel is pushed on rails into position in the press. Pressure is admitted to the hydraulic cylinder situated in the base of the press, when the ram lifts the truck with the mould on it, so that the plug enters the mouth of the mould, and any pressure within the limits of the power of the press can be applied to the steel. A small quantity of fluid metal squirts up between the plug and the cover of the mould, but chills so rapidly that it sets immediately and forms a perfectly tight joint.

When the pressure is put on, enormous volumes of gas are driven from the openings in the mould with a loud roaring sound. These gases, which are accompanied by a fine metallic rain, take fire when they reach the atmosphere, and the ingot shortens, at first rapidly, but later on more slowly, the entire shortening amounting to about 1½ inches per foot. The total length of fluid-compressed ingots when cold is about 8 to 12 per cent. less than those cooled in the ordinary manner. The pressure is continued long after the metal has set, to prevent the formation of cracks. Attempts have been made to produce fluid-compressed ingots with a central hole formed by a core, but it has been found cheaper to cast the ingot solid and to bore out the centre.

Harmet's Process.—It will be seen that in the Whitworth process just described the press compresses the ingot on its end, in the direction of its greatest dimension, but a method recently invented by M. Harmet, and called by him "compression by wire drawing," enables the ingot to be compressed laterally. An open topped mould is used (fig. 546), having a short parallel portion at the lower end. Into the parallel portion fits a cast-iron plug which can be raised by a ram below it, so that the ingot can be forced upwards into the tapered portion, by which the sides of the ingot are forced inwards, closing up any axial pipes. By taking advantage in this way of the tapering shape of the ingot mould, a comparatively small pressing cylinder may be made to exert a very considerable lateral pressure. M. Harmet claims considerable economy owing to the reduced amount which needs to be cut away from the top of the ingot before finding sound metal. The process has been in operation at the St. Etienne Works for some time, and is now being adopted at the Parkhead Works in Glasgow, and at several other large works.

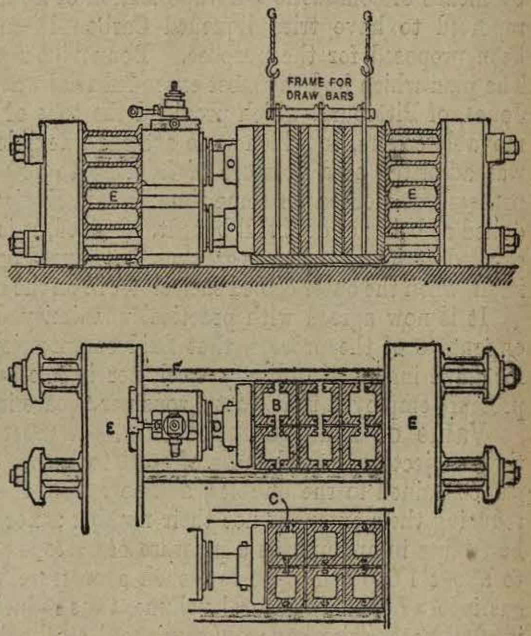

Fig. 547.—Robinson & Rogers' Method of Fluid-compression.

Robinson and Rogers' Process.—The methods above described have been suitable only for large ingots, but that to be now described is applicable to ingots of much more moderate dimensions, such as are run from crucible or other very high-class steels intended for the manufacture of cutting tools. Fig. 547 shows the press used for the purpose. The pressure is applied horizontally instead of vertically, so that the ingots may be cast in position in the press, and the time taken in transferring to the press after filling the moulds is saved. The ingots can be run in groups from the bottom, so that one large or several small ingots can be cast and pressed simultaneously, and, as these are pressed in series, the press may be of very moderate size and power.

The moulds are split, the vertical joints being filled with tongues as at B, which are lifted out when the surface of the ingot is just set, and pressure is then admitted to the pressing cylinders, F, which steadily squeezes the halves of the moulds towards each other, as at C, at such speed as will keep the surface of the fluid metal to its original level, and prevent the formation of pipes, the last drops, which are said to contain four times as much impurities as the body of the ingot being squirted out. The final pressure amounts to about 2 tons per square inch on the ingot, and is said, by Mr. Capron, to densify the metal sufficiently to permit milling cutters being made from the upper part of the ingot direct, which is found to be as good and sound as the rest.

The process has been in operation at the Works of Messrs. Jessop, in Sheffield, and elsewhere, and is said to have given perfect satisfaction.

Abortive Attempts at Fluid Compression.—Several other methods of compression have been proposed and attempted, but all except Whitworth's, Harmet's, and Robinson's have been abandoned, some owing to mechanical difficulties, but most to the fact that the pressures employed were insufficient to produce any beneficial effect whatever.

Bessemer is said to have tried gaseous pressure generated in the mould by means of combustion or vaporisation of liquids or solids, while Krupp is reported to have tried liquefied Carbon Dioxide. Even gunpowder has been proposed for the purpose. Bonneville's patent* was of this nature. The plan which had the most extended trial was that introduced by Captain Jones, of Pittsburg, which provided the tops of ordinary ingot moulds with movable covers, to which were attached flexible hose through which steam was admitted at a pressure of from 80 to 250 lbs. per square inch. This process was worked for some time both in England and America,† but abandoned as being of doubtful benefit. Indeed, it is not likely that the pressure exerted by steam can be as great as that caused by the contraction of the ingot itself, when the outer cooled shell closes in on the hot fluid interior of the ingot.

It is now agreed with practical unanimity, both by the supporters and opponents of the process, that fluid compression is of practically no value for small ingots of ordinary steel, nor in the case of large ones, unless the pressure employed is at least 2 tons per square inch.

Value of Fluid Compression.—It must be conceded by every one that subjecting a fluid mass of steel to heavy pressure must compress the gas contained in the bubbles, and so reduce the size of the blowholes, thus reducing their extent if not their number; nor would the reduction in size be trifling in amount, as a pressure of $6\frac{1}{2}$ tons per square inch is equivalent to about 1,000 atmospheres; such a pressure would compress a bubble of gas into $\frac{1}{1000}$ of its natural volume, thus reducing it to $\frac{1}{10}$ of the diameter it would otherwise have. Experienced steelmakers say that, when the top of the ingot has been removed, the blowholes which are found in large ingots cast from steel which is properly melted are so few in number and trifling in extent as to be practically negligible, and that the costly process of fluid compression is therefore superfluous. The advocates of the process, on the other hand, say that imperfections are sufficiently serious to render this the only scientific and certain method of producing large masses of steel of the highest class, suitable for large shafts or ordnance. Its application to ordinary commercial rolled steel is in any case so slow and costly, as admittedly to be entirely out of the question.

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* Patent No. 3,300, 1865.

† *Iron and Steel Inst. Journ.*, 1879, p. 476.

Mr. W. H. Greenwood, with the view of determining the value of the process, cut in half, longitudinally, two ingots made at the Russian Government Works at Abouchoff. One of these had been cast in the ordinary way, and one had been compressed while fluid. He took tests from the surfaces thus exposed in both ingots, using only the lower $\frac{6}{10}$ of the unpressed ingot, $\frac{4}{10}$ of which would have been rejected in the ordinary course, but using the whole of the pressed ingot. The test pieces were cut both longitudinally and transversely, and the results, which he sums up in the following tables, are given in great detail in the paper he read before the Institution of Civil Engineers in May, 1889*:—

TABLE CXXI.—TESTS OF FLUID-COMPRESSED AND UNPRESSED INGOTS.

<table>
<tr><th colspan="5">AVERAGES OF THE LONGITUDINAL TEST-PIECES FROM UNPRESSED AND PRESSED INGOTS, NEITHER FORGED NOR ANNEALED.</th></tr>
<tr><th></th><th>Elastic Limit in Tons per Square Inch.</th><th>Breaking Tensile Stress in Tons per Square Inch</th><th>Contraction in Area at Point of Fracture.</th><th>Elongation per cent. in 4 inches immediately before Fracture.</th></tr>
<tr><td></td><td></td><td></td><td>Per cent.</td><td></td></tr>
<tr><td>Unpressed ingot (35 tests),</td><td>11·11</td><td>29·18</td><td>4·41</td><td>8·76</td></tr>
<tr><td>Pressed ,, (49 ,,),</td><td>11·45</td><td>29·53</td><td>7·90</td><td>12·51</td></tr>
<tr><th colspan="5">AVERAGE RESULTS OF THE TRANSVERSE TEST-PIECES FROM UNPRESSED AND PRESSED INGOTS.</th></tr>
<tr><th></th><th>Elastic Limit in Tons per Square Inch.</th><th>Breaking Stress in Tons per Square Inch.</th><th>Contraction in Area at Point of Fracture.</th><th>Percentage of Elongation immediately before Fracture.</th></tr>
<tr><td></td><td></td><td></td><td>Per cent.</td><td></td></tr>
<tr><td>Unpressed ingot, - -</td><td>11·43</td><td>28·64</td><td>3·61</td><td>7·91</td></tr>
<tr><td>Pressed ,, - -</td><td>12·38</td><td>30·07</td><td>7·57</td><td>12·74</td></tr>
</table>

Unfortunately the ingots differed somewhat in size, and considerably in Carbon content, so that the results are not as strictly comparable as is desirable. The result seems to show that the compressed ingot is the better of the two in the raw state, probably because the metal has had some work put on it since it set, although nominally in an unforged condition; this would seem to be borne out by the fact that the specific gravity of the unpressed ingot was 7·8542, and that of the pressed ingot 7·8791. There was a saving in waste, because 30 to 50 per cent. had to be rejected from the top of the unpressed ingot, while practically the whole of the pressed ingot (except the inevitable waste in the heating furnace, and the allowance which must be made for machining) was available to form forgings; moreover, it was considered that there was less risk of cracking the ingot when heating it.

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* *Min. Proc. Inst. C.E.*, vol. xcviii., p. 125.

Mr. Greenwood's paper was very fully discussed by many of the largest steelmakers and users, opinions being very divided. Mr. Vickers was positive that gas was not driven out of the ingot, and that the volumes of gas coming from the mould were merely those which always escape, when the carbonaceous and organic matters contained in the refractory lining of any mould are burned; he attributed the greater rapidity with which they were given off, when the ingot was pressed, to the forcing of the hot steel into more intimate contact with the lining.

Perhaps the most important contribution to the discussion was that made by the late Colonel Dyer, who was for some years associated with the firm of Whitworth & Co., where the process originated. He said "that the excellence (of the Whitworth steel) did not depend upon fluid-pressure. . . . He had had daily opportunities of testing both fluid-pressed steel and steel made without fluid pressure, and the results of many hundreds of tests showed that, provided the chemical composition was practically the same, there was not an atom of difference between the forged fluid-pressed steel and the forged unpressed steel; the ductility, the strength, and everything else were as nearly as possible identical. . . . The facts connected with that subject should be enough to do away with some of the unreasonable statements that had been made—statements which, he was sure, those who had most to do with fluid-pressed ingots would be the first to deny. What was claimed for the fluid-pressed steel ingot by Whitworth & Co. was, that by means of fluid pressure they could get a larger quantity of the ingot for useful purposes; but no one would profess that he could alter the quality of the steel by pressure."

Howe * gives a large number of tests which he has collected, which go to show that as good tests have been obtained from uncompressed as from compressed steel, and the matter would seem to resolve itself into a question whether the saving in cost due to the ability to use a larger proportion of the ingot compensates for the heavy first cost of the plant required. The Board of naval and military officers appointed by the United States Government to enquire as to the advisability and cost of establishing gun factories in America, reported in 1884 that the cost of a plant to compress gun ingots when fluid, exclusive of masonry, and apart from furnaces for making, or appliances for forging steel, would be $175,000, or, say, £35,000.† The cost of the plant renders any idea of employing fluid compression for common steel, such as rails or bars are made from, out of the question. It is believed that only three works, one in France, one in Russia, and one in America, all employed by their respective governments to supply forgings for heavy guns, have so far supplied themselves with a Whitworth fluid-compression plant, while nearly all makers of large steel forgings (even those already provided with large steam hammers) have supplied themselves with hydraulic forging presses. It would seem, therefore, that the practical steelmakers of the world do not consider that fluid compression offers sufficient advantages to justify its employment in the making of ingots for heavy forgings, for which purpose alone the system is adapted.

When Whitworth began his experiments on fluid compression, the use of alloys for preventing the formation of bubbles of gas in steel ingots was not understood. Manganese only was used, and for many years after even traces of Silicon were supposed to have most detrimental effects. It is now known that Silicon can be safely used in quantities up to 0·2 per cent. without harm to the highest grades of steel, and that this amount will

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* *The Metallurgy of Steel*, pp. 159, 160.

† *Proceedings of the United States Naval Institute*, vol. x., No. 4, 1894, p. 831.

suffice to ensure sound ingots if the steel has been properly melted. Lately the still more powerful effects due to the employment of Aluminium have been available, and, as chemical knowledge has increased, the field which, at one time, seemed open for fluid compression, has largely closed.

Other Mechanical Contrivances for Reducing Blowholes.—The exact reverse of the method of fluid compression—namely, the use of an exhausting pump to draw out whatever gas may be present in the fluid metal, which is then cast in a vacuum—was proposed by Mr. William Church, of Birmingham, who was granted a patent for the process in 1825.* He further proposed to employ the same pump to force air on to the surface of the fluid metal, with the object of compressing it. The Ellis-May process, a system of casting *in vacuo*, was reported to be under trial a few years ago at one large steel works in this country and one on the Continent, but no information would appear to have been made public as to the results obtained with it. Gases might perhaps be sucked out of the metal with some prospect of success, if they were removable while the metal was in a thoroughly fluid condition, but there is reason to believe that they are only set free at the moment when solidification commences. In that case it is questionable if the bubbles of gas entangled in the metal would not be larger or more numerous than in metal cast in the ordinary way, owing to the increased volume which the gas would have when the atmospheric pressure was removed, just as the volume of the bubbles decreases as the pressure increases in a steam boiler, when it is evaporating a constant weight of water per hour.

Several attempts have been made to remove occluded gases, or other impurities, by centrifugal action, based on the following consideration:—If in a liquid, a given volume of which weighs 2 lbs., is immersed a body or bodies an equal volume of which weighs 1 lb., a force of 1 lb. would be needed to prevent the lighter bodies floating up to the surface of the heavier liquid, the force of gravity exerting a force of 1 lb., equal to the difference between the specific gravity of the two bodies. But if we can artificially increase the force of gravity, we can increase the power tending to separate the lighter body from the denser liquid. By placing the fluid in a vessel revolving on a vertical axis, the particles tend to fly outwards from the centre with a force proportional to the square of the speed with which they are made to travel, thus immensely increasing the tendency to separation between two bodies of varying specific gravity.

An instance, familiar to most people, of the separation by this means of two liquids of different specific gravities, is the skimming of milk by machinery. As it comes from the cow, milk has a specific gravity of 1·032, and consists of the cream with a specific gravity of 1·015, and the "skimmed milk" having a specific gravity of 1·034. If new milk is left to stand quietly, the difference in the specific gravity of the constituents causes about 75 per cent. of the cream to rise to the surface in twelve hours: but if the milk is poured into a separator, which consists of a bowl with a neck about half the diameter of the body, revolving, on a vertical axis, at 6,000 to 6,500 revolutions per minute, the heavier milk is flung to the outside of the bowl, and flows steadily over the upper edge; the lighter cream lines the hollow mass of revolving milk, and is continuously skimmed off by a tube which points in a direction contrary to that of rotation. By this means, in spite of the very slight difference in their specific gravities, nearly the whole of the cream is separated as fast as the new milk is fed in a thin stream into the centre of the bottom of the bowl.

Considering how great is the difference in specific gravity between gas

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* Patent No. 5,084, 1825.

and molten metals, it was natural to anticipate that they could be profitably separated by such a method. Eckhardt took out a patent for revolving moulds with this object in view in 1809,* and, according to M. Tresca,† the process was in operation in France on Bessemer steel before 1867, and rails had been rolled from ingots so treated.

About twenty years ago persistent attempts were made at a steel works in South Wales to cast, in rotating moulds, circular hoops for use in the tire mill. It was uncertain if any speed sufficed to drive out the gases, but the centrifugal forces generated tore apart the contracting ring while in the plastic state, and the attempt was abandoned.

A similar process was tried a few years later at some steel foundries in the North of England for casting locomotive wheel centres, the slag and other imperfections being expected to flow into the feeding head provided in the centre of the wheel. It is now abandoned, although some success seems to have attended the use of this process at Crewe.‡

Ashley's patent for producing shells and tubes by pouring liquid steel into a revolving ingot mould, with which three steel works in the Midlands experimented a few years later, was not any more successful, though a French company has at last succeeded in producing tubular blanks by such means. A horizontal mould, with a bore 6 or 8 inches diameter by 1 meter long, and with a removable ledge at each end, revolves in ball bearings at over 1000 revolutions per minute, and into this a known weight of molten steel is poured. A tube is thus formed, having walls ⅝ to 1¼ inch thick, with the surfaces inside and out sufficiently smooth to permit of the blank being rolled or drawn down into finished weldless tubes, by one of the methods to be described in the next chapter.

Mr. Sebenius, of the Nykoppa Works, Sweden, constructs his moulds with trunnions which rest in bearings at the end of arms projecting horizontally from a central vertical shaft. When the moulds are filled the shaft is set revolving until a speed of 125 to 200 revolutions per minute is attained, under the action of which the ingot moulds, with their contents, assume a horizontal position. Several of these machines are in use in Sweden.§ This arrangement is precisely the same as casting ingots vertically, but, with the force of gravity enormously increased. The ingots are entirely free from the destructive stresses which under the previous systems tend to tear one part of the ingot from another.

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* Patent No. 3,197, 1809.

† *I. Mech. E.*, 1867, p. 150.

‡ *Iron and Steel Inst. Journ.*, 1882, p. 522.

§ *Iron Age*, 15th December, 1892.

CHAPTER XLII.

TUBE-MAKING.

Introductory.—The methods of making steel tubes may be classified under three heads:—

1. Rivetting together rolled plates of steel. This method, necessarily applicable only to the larger sizes, and not being a branch of steel-making proper, but of engineering construction, is beyond the scope of this work.

2. Working a weldless tube out of a solid billet.

3. Taking a rolled strip of metal, bending it approximately into the form of a tube, and then welding the edges together by one of the methods to be described later.

Weldless Tubes.—The manufacture of weldless steel tubes, entirely unknown twenty-five years ago, is conducted as follows:—A billet of some high-class steel, usually Swedish, from 6 to 8 inches in diameter, and about 18 to 24 inches long, according to the size of tube required, is placed in a horizontal drilling machine having a self-centring chuck lying in a trough filled with soap-suds, when a hole ¾ to 1 inch in diameter is drilled right through the length of the billet.

Piercing.—The billet is then heated and placed vertically in a hydraulic press (fig. 548), having a cylinder at the top capable of exerting considerable pressure; in the end of the ram a bar is secured, the lower end of which forms a pin arranged to enter a hole in the centre of a loose cast-iron nose, which is lifted by a pair of tongs on to the top of the billet as it stands in the press; on admitting pressure to the cylinder, the nose is driven right down through the billet, expanding the central hole in two or three passes, with a larger nose for each pass, to about 3 inches in diameter.

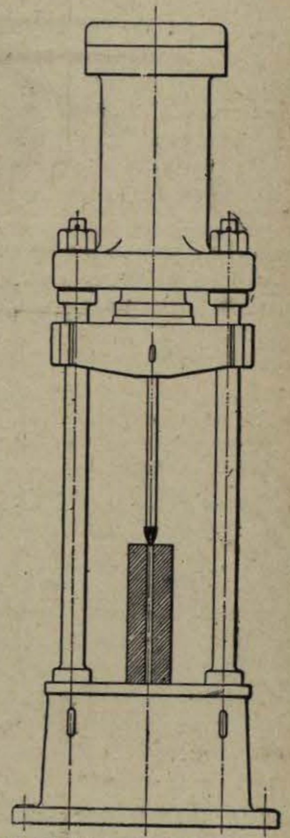

Fig. 548.—Press for Piercing Billets to form Weldless Tubes.

Rolling.—The billet, with the central hole thus expanded, is taken to a rolling mill provided with rolls about 18 inches diameter, grooved in the same way as those used for rolling round bars. Attached to the housings at the back of the rolls is a strong cross-bar which carries a set of mandrils, one pointing towards each pass in the rolls, arranged like the piercing ram to take loose noses, which are made of cast iron for the roughing, and self-hardening steel for the finishing passes (fig. 549).

The roller, standing on the side of the mill opposite to that on which the