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 $\frac{5}{8}$ to $1\frac{1}{4}$ 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 $\frac{3}{4}$ to 1 inch in diameter is drilled right through the length of the billet.

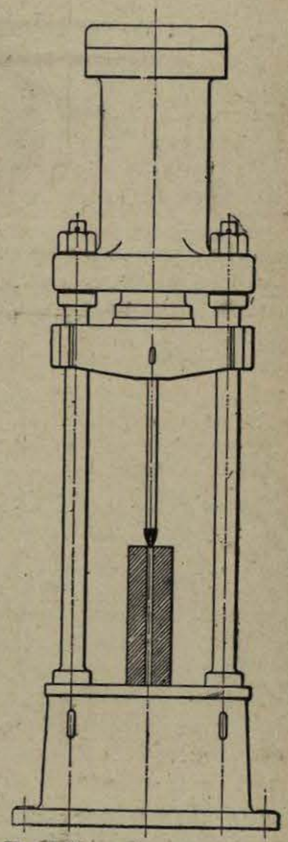

Fig. 548.—Press for Piercing Billets to form Weldless Tubes.

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.

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

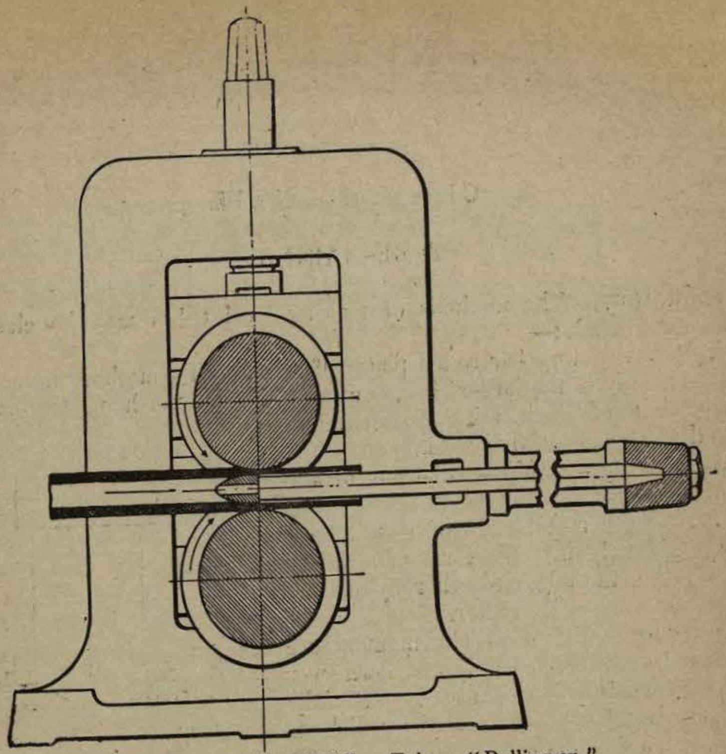

Fig. 549. —Rolling Weldless Tubes—"Rolling-on."

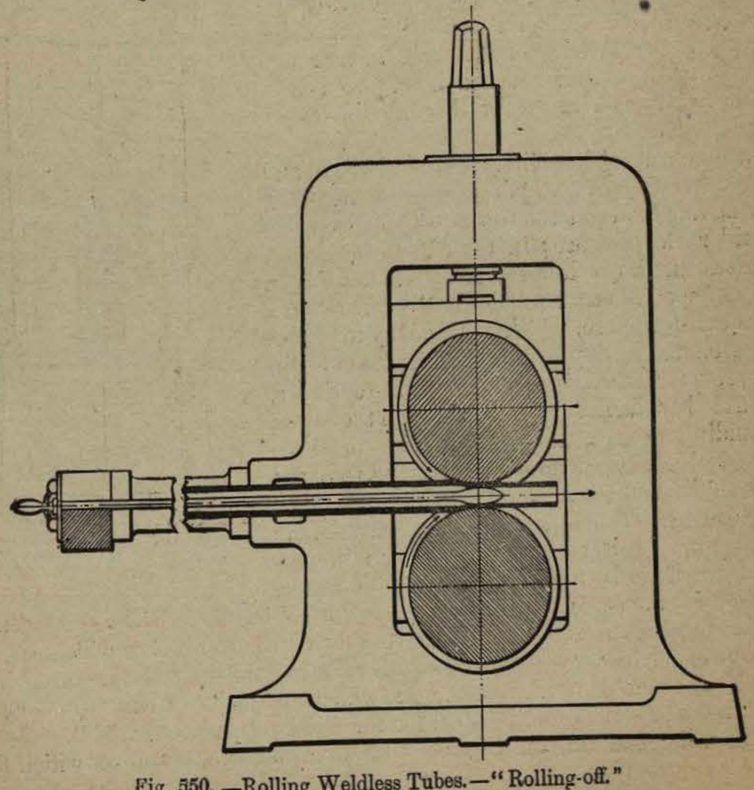

Fig. 550. —Rolling Weldless Tubes.—"Rolling-off."

mandrils are secured, enters the billet between the rolls, which force it over the nose of the mandril lying in the centre of the groove. The hole in the centre of the billet is increased and the outside of the billet decreased at each pass, the thickness of the walls of the tube being reduced every time it goes through the mill. This process is called by the workmen "rolling-on."

When the bore of the tube is less than ⅝ inch, the mandril is not stiff enough to resist the thrust, and must therefore be used in tension, the process then being technically known as "rolling-off." The method of procedure is as follows :—The workman is furnished with a mandril having at one end an enlarged bulb-shaped nose (fig. 550), and at the other a handle with a disc in front of it, the arrangement suggesting a fencing foil, the nose taking the place of the button, and the disc the guard; threading the bulb through the central hole in the hot billet, the workman enters the billet into the pass, and to prevent the mandril passing through, he drops it into a notch in a bar fastened across the front of the mill on his side. The disc is arrested by the bar, and the billet drawn off the mandril by the pull of the rolls, the process being repeated as often as necessary.

Cold Drawing.—When a tube is wanted longer than can be conveniently handled on the mandril, or thinner than can be rolled hot—say over 8 feet long, or less than ⅛ inch thick—it is drawn cold by means of a tube-drawing bench; the process is also applied to short or thick tubes when it is desired to impart to them the additional stiffness which cold working confers.

The roughly-rolled tube is reduced for a short distance at one end in a swaging machine, consisting of small power-driven hammers, or power-actuated dies, till in a small tube the hole is almost closed up and obliterated; it is then annealed in a muffle or close annealing furnace, which is so constructed that a central chamber is maintained at a red heat by the products of combustion which pass from the grate two or three times along the whole length of the outside of the chamber, while the chamber itself can be maintained nearly air-tight. The importance of heating the tube in a closed chamber increases with every reduction in its thickness, for the thinner it is the greater is the percentage of weight lost by a given thickness of scale, while the tube itself is more valuable every time it is drawn; so that to expose thin tubes, such as are used for bicycles, directly to the current of the products of combustion would make their cost prohibitive, even if their production were possible. Where a good muffle is not available, thin tubes must be stacked in a large pipe, which is capped at each end so as to be nearly airtight, before it is placed in the furnace.

When thoroughly annealed the tube is pickled in a dilute solution of acid to remove any scale, washed in clean water, and dried. The drying is usually done in chambers constructed in the annealing furnace above those used for annealing, the heat radiated from the annealing chamber being sufficient for the purpose. The dry tube is oiled and taken to a draw-bench (fig. 551), which consists of a small carriage drawn along a bench by a pitch chain running over a sprocket-wheel driven slowly by gearing. In benches used for very large tubes the carriage is often pulled by a direct-acting hydraulic cylinder, or, occasionally, by a heavy steel rack driven by a pinion coupled by gearing to the crank-shaft of a pair of engines. The swaged end of the tube is held by grips or wedges in the travelling carriage, much as a test piece is held in the testing machine, and the tube is drawn through a die secured on the bench.

Two methods of drawing the tube are possible. The first consists in securing in one end of the bench a mandril having a bulb-shaped head, which lies concentrically within a trumpet-shaped die; the tube is threaded on the mandril and drawn between the surfaces of the head and die. In the second method the tube is threaded on a mandril having a uniform diameter throughout its entire length, one end is closed in over the end of the mandril, which is usually a cold-drawn or reeled bar, and the mandril with the tube on it is drawn through the die, the process being known as "drawing on the bar," or "with a solid mandril."

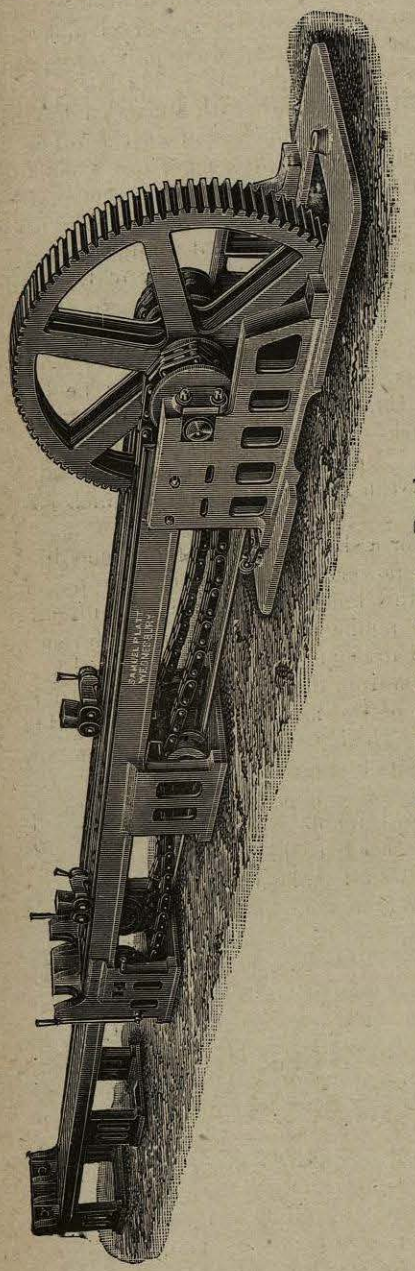

Fig. 551.—Tube-drawing Bench.

In the first method of drawing the pull is taken on the tube itself, and the power which can be employed to draw it through the die is limited to that force which would tear in two the thin tube, both inside and outside of which are rubbing surfaces to cause frictional resistance; but in the second method the pull is not taken on the tube, but on the mandril, which has a much greater sectional area, and there is only one rubbing surface to cause resistance, so that three passes by this plan can always effect at least as great a reduction in thickness as required four passes by the previous method. Seeing that the tube must be annealed and pickled between every pass, causing a waste of material on each occasion, it becomes an important matter to reduce the number of passes for thin tubes to the smallest possible number, the loss, by even the thinnest scale, being always a heavy percentage of the total weight.

Reeling.—The tube, in the process of drawing, is so firmly squeezed on to the mandril that it cannot be removed from it, until both are passed together through the reeling machine (fig. 552). This consists of a pair of conical rolls, revolving both in the same direction, and lying side by side, their axes being placed, not horizontally, but inclined to the horizon a few degrees in opposite directions, so as to cross each other at a slight angle in the middle of their length. The mandril, with the tube on it, is entered horizontally between the rolls, nearly parallel to their axes, and is supported horizontally in a central position between them by resting on small loose carrying rollers. It is kept down on to these rollers by the acting face of the particular roll which travels downwards, moving slightly faster than the opposing surface of the other roll, which is travelling upwards. The mandril and tube are squeezed between the rotating rolls and revolved rapidly on their axes, but, owing to the form of the rolls and the angle at which they are set to each other, there is imparted at the same time to the mandril and tube a slow movement in a longitudinal direction, which carries them quietly through the mill.

The effect of reeling is to squeeze the wall of the tube between the mandril and the rolls, so that it is rolled out or reduced in thickness; the thinning of the metal necessarily involves an increase in circumference, whereby the diameter of the tube is enlarged, and the mandril can then be readily withdrawn.

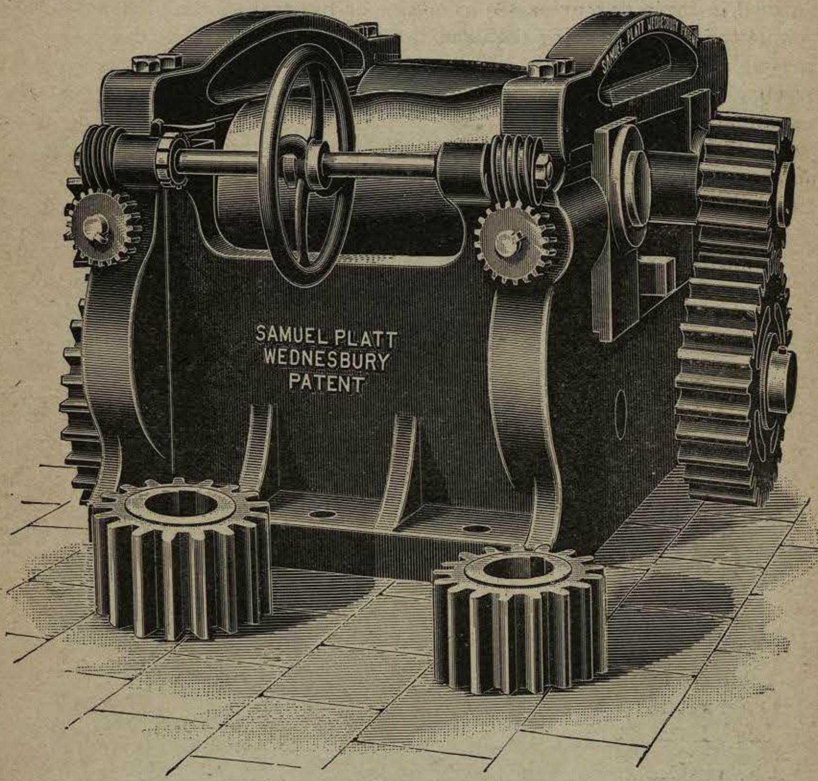

Fig. 552.—Reeling Machine.

Before the introduction of the modern reeling machines, which are capable of dealing with tubes of large size and as much as ¾ inch thick, the tubes were occasionally drawn on solid mandrils having a very slight taper to facilitate the removal of the tube; but with tapered mandrils the thickness of the tube necessarily increased from one end to the other, and the process had, therefore, to be confined to much shorter lengths than are now made. The preparation of these taper mandrils, which needed very careful turning, was expensive, while with the present method of removing the tube, ordinary reeled or cold-drawn rods can be employed. The tubes were sometimes released from parallel mandrils by rolling them in an ordinary bar-mill, the rolls being grooved to a radius somewhat greater than that of the outside of the tube; by repeating the process a sufficient number of times with different portions of the tube upwards, the wall of the tube was slightly thinned and increased in circumference, but the process was tedious, and the straightening effect of the reeling machine, which serves at the same time to straighten and round the tube, was not obtained.

The process of drawing, reeling, annealing, pickling, drying, and oiling, and again drawing, is continued as often as may be needed to reduce the tube to the size and thickness required.

When drawing a tube by this means for use in a Belleville boiler as used in His Majesty's Navy, the tube is rolled to about $4\frac{3}{4}$ inches outside diameter by $\frac{5}{16}$ inch thick, and is drawn on the bench to $4\frac{1}{2}$ inches outside diameter by $\frac{3}{16}$ inch thick in four passes on a plug mandril, or in three on a solid one. Ordinary boiler tubes of about $2\frac{1}{2}$ inches diameter are now finished in three or four passes by means of the reeling machine, more than double that number being required before these machines were introduced. Bicycle tubes, which are finished in lengths of 18 to 20 feet, were, some six or eight years ago, rolled down to $1\frac{1}{2}$ or $1\frac{3}{4}$ inches outside diameter, with a wall 9 to 10 S.W.G. thick, and then drawn on the bench in 10 or 12 passes to 22 gauge and $1\frac{1}{4}$ inches outside diameter; since the introduction of the reeling machine the same work is done in 6 passes on the solid mandril. Bicycle tubes thinner than 22 gauge are sometimes made for constructing extra light machines.

Weldless Tubes made from Sheets.—Weldless tubes are also made from flat circular sheets by pressing the sheet between successive pairs of conical dies, each pair being deeper than the previous ones, until the sheet is reduced to a parallel tube with one end closed, the operation being very similar to the drawing of seamless brass cartridge cases. Fig. 553 shows the various stages of the operation. The weldless steel cylinders used for storing air under a pressure of about 1,500 lbs. per square inch for the purpose of charging the Whitehead self-moving torpedo, and the gas bottle employed for carrying compressed gases (fig. 554) for use in connection with the limelight for magic lanterns, or for other similar purposes, are made in this way, the open end being closed in to take the connection and valve through which the flasks are filled and emptied.

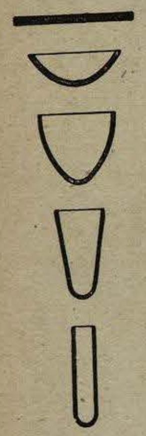

Fig. 553.—Successive Stages in Forming a Weldless Tube from a Steel Sheet.

Fig. 554.—Weldless Steel Cylinder for Storing Gases under High Pressures.

In this case the operation is performed on heated sheets, the finished bottles being from $\frac{1}{4}$ to $\frac{3}{8}$ inch thick, but thin tubes for use in bicycles are produced by some makers in a similar manner from sheets 0·11 inch thick, which are cupped cold in three or four successive presses until they are about 2 inches in diameter and 2 feet long, when they are finished by cold drawing in the ordinary manner.

Material Used.—The material used for making weldless boiler tubes is either a mild Swedish Bessemer steel, or English steel made by the open hearth basic process, and of exceptional purity, the Carbon being frequently as low as 0·06 to 0·07 per cent., the Manganese about 0·35 per cent., and the Phosphorus and Sulphur each about 0·02 to 0·03 per cent. Until quite recently the steel employed for making tubes for the boilers in the Navy had to be of British manufacture, and a steel having a tensile strength of less than 22 tons per square inch was selected. In English steel, made on a basic bottom, there is only a trace of silicon, but the Swedish material contains as much as 0·2 per cent. to 0·3 per cent. For bicycle frames, or other exceptional purposes requiring great strength and stiffness combined with little weight, steel is used with Carbon as high as 0·3 to 0·4 per cent., and, occasionally, as high as 0·5 per cent., the Manganese running from 0·4 to 0·6 per cent., and the Silicon from 0·3 to as much as 0·5 or 0·6 per cent. The Phosphorus and Sulphur are occasionally as high as 0·04 to 0·05 per cent., but in the best steel run from 0·02 to 0·03 per cent. Nickel also is sometimes added to increase the stiffness.

Since Mr. Yarrow's experiments* showing that the life of tubes, when exposed to conditions similar to those which are present in water-tube boilers, was lengthened several fold by the addition of 20 to 25 per cent. of Nickel to the steel from which the tubes were made, Nickel steel tubes have been employed for the purpose in the water-tube boilers used in the Navies of several of the European powers.

Weldless tubes are necessarily costly, and are therefore only used for specially high-class water-tube boilers, for carrying heavy hydraulic pressures, or for bicycle frames and similar purposes. They are as a rule sold by outside diameter, and of such thickness as may be specified when ordering them.

Tests.—In testing steel tubes, one of the finished tubes is selected from a heap, and a piece cut from it is tested in an ordinary tensile testing machine. Bicycle tubes are expected to stand flattening cold, till both sides touch, without the metal showing any signs of cracking; a short length placed on end under a steam hammer should flatten down into a flat ring without signs of cracks anywhere. The British Admiralty demand that an annealed strip, cut from the billet from which the tubes are made, shall have a tensile strength of 21 to 24 tons per square inch before rupture, with an elongation of 33 per cent. in 2 inches. Pieces cut from the finished tube must have a tensile strength not exceeding 26 tons per square inch, and must give an extension of not less than 27 per cent. Two per cent. of the tubes must be tested, a 2-inch length must flatten to 1 inch cold under the steam hammer without showing signs of cracks, and those under $\frac{3}{16}$ inch thick, laid on the side, must flatten down without any signs of cracking at the fold. They are also subjected to a hydraulic test of 1,500 lbs. per square inch. Of course, only tubes carefully made from the finest material will stand such treatment; indeed, the mere ability to stand cold drawing is in itself no trifling proof of the good quality of the material employed.

Lap-welded Tubes.—Lap-welded tubes are made from flat rolled strips of iron or soft steel, whose width is slightly more than the circumference of the finished tube, and the thickness equal to that of its walls. The strip is passed through a draw-bench in which the two edges of the strip are bevelled by means of a series of planing tools fixed in sockets at one end of the bench close together, and one behind the other; the bevelled strip is heated to a dull red, and a few years ago was placed in a machine known as a "crocodile," having a long semicircular groove in its bed, over which the strip was laid, and into which it was pressed by the descent of a long round-nosed die on the end of a lever, which, by pressing down the middle, turned the two sides of the strip upwards, giving it the section of the

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* "Some Experiments having reference to the Durability of Water-Tube Boilers," by A. F. Yarrow. Read before the Institution of Naval Architects, 20th July, 1899.

letter U, the operation being termed "skelping." Now, however, this work is usually performed by drawing the strip through a die, the sides of which are gradually twisted round and upwards, so that the strip is bent into a rough tube, with the bevelled edges lying close to each other.

The skelp is placed in the tube furnace, raised to welding heat, and entered between a pair of grooved rolls (fig. 555) standing immediately opposite an opening in the furnace, and having between them a mandril with a loose nose similar to those used for rolling weldless tubes, by which means the skelp is completely welded. For the better class of work the steel tube is returned at once to the furnace, and immediately passed again through the welding rolls, these rolls being considerably bellmouthed to prevent the formation of fins; and then the tube is passed at once through another pair having grooves of nearly semicircular shape, which give it a good finish; from these it is taken to be straightened in the reeling machine, the rolls of which are kept flooded with water, so that the tube leaves them at a blue heat perfectly round and straight.

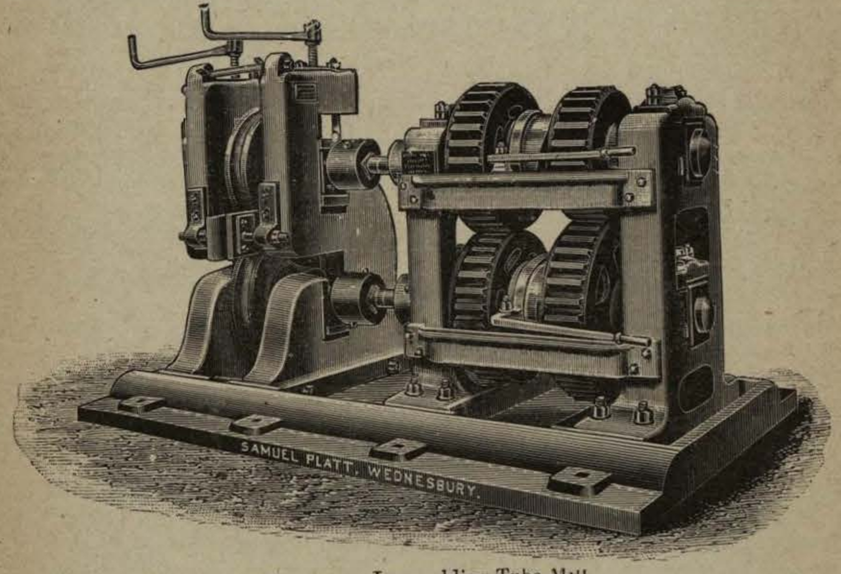

Fig. 555. —Lap-welding Tube Mill.

The process just described is the English method of making lap-welded tubes; on the Continent, when the tube leaves the welding rolls, the end is rapidly swaged down, and the tube drawn while hot in a draw-bench, by which is imparted a somewhat neater finish, but no improvement in quality.

Sometimes tubes are sold as "cold-drawn" which are produced by drawing a lap-welded tube cold in a draw-bench, in the same way as weldless tubes are drawn; by this means considerable stiffness and a beautiful smooth surface are imparted to them, but the weakness due to the weld running the whole length of the tube still remains.

Lap-welded tubes are intended for use in tubular boilers, and are known by their outside diameter, a 3-inch boiler tube being a tube which is 3 inches in diameter *outside*, and would therefore fit a hole of this size drilled in the tube plate; they are ordered of the various thicknesses desired in standard gauge or in sixteenths of an inch. The ordinary gauge employed for 3-inch boiler tubes is No. 11 Gauge = 0·116 inch, but to prevent the tube plates being blown apart by the pressure of the steam, a proportion of the tubes are usually made thicker, and, after they are placed in position in the boiler, have a nut screwed on at each end. These tubes are known as "stay tubes," and are usually from $\frac{5}{16}$ to $\frac{7}{16}$ thick.

Butt-welded Tubes.—Butt-welded tubes are made from a rolled strip whose width is practically equal to the circumference of the tube; the edges of this strip are left square, just as received from the rolling mills, and these edges are welded together, forming a butt- or jump-weld, instead of the lap weld obtained when the edges of the bar were scarfed. The strip is skelped in the same way as for a lap-welded tube, except that it is not bent round into a complete circle, but the edges are brought near together at an angle of about 90° (A, fig. 556). Rather more than one-half the length of the skelp is placed in the heating furnace, and the skelp is withdrawn, when at a welding heat, by means of a pair of gripping tongs attached to the carriage of a draw-bench, which seize the end, for this purpose left cold. As the skelp leaves the furnace, the workman closes over *the middle of its length* a pair of welding tongs, which rest against a stop in the bench, the hole in these tongs being of such a form that the inner edges of the skelp are pressed closely together (B, fig. 556), so that a weld is made on the inner side of the tube; it is immediately returned to the furnace and drawn a second time, this time through a pair of tongs which press down the angular crest, thus welding the other edges (C, fig. 556), when the tube will be found to be welded throughout its full thickness both on the inner and outer sides. It is then passed to a second man, working at a bench parallel and close to the first, who passes it through a pair of tongs having an opening of complete circular form; or the first workman returns it to the furnace and draws it for the third time through the third pair of tongs with the circular opening. As the welding tongs are placed on the middle of the length of the skelp, only one-half has been formed into a tube by these three drawings; this half is laid on a fixed iron table, parallel to which, a short distance above it, is slung, by four long links from the roof, a plate which can be moved backwards and forwards by means of a crank and connecting-rod, so that the plate rises slightly at each end of its travel, but when in the centre of its stroke is at a distance above the table equal to the outside diameter of the finished tube. The workman lays the hot tube on the table when the plate is at one end of its stroke, and, as the plate travels on its way, it descends upon the tube, and rolls it to and fro on the table, until it is quite round and straight. When the one-half of the skelp is thus completely finished it is "back-ended," the other half being put into the furnace and treated in a precisely similar manner. This is the old Staffordshire method of manufacturing wrought-iron tubes, as patented by Mr. Cornelius Whitehouse, of Wednesbury, in 1825, and carried on locally without material alteration ever since.

Fig. 556.—Successive Stages in the Formation of a Butt-welded Tube.

In Scotch and Continental works, instead of finishing one-half of the tube before beginning on the other, the whole length is welded at one time. To enable this to be done, one end of the skelp has a tapered tongue left on it, or, in the case of large skelps, a narrow bit of metal is welded on, these ends being allowed to remain outside the heating furnace to furnish the means of gripping the skelp, which is drawn through a short cast-iron trumpet-mouthed pipe known as a "bell." The first pass through the first bell bends up the skelp into a rough form of tube, the second brings the edges together and welds them, and the third finishes the tube, which is removed to a reeling machine to be straightened. The operation of welding in this way is shorter, but the tag left on the end of the skelp is so much waste material.

The pressure employed to weld the particles together, by forcing them into intimate contact, is used in a less effective direction, when the edges of the strip do not lap one over the other, but are merely arranged to face each other; moreover, the extent of the welded surface is smaller, so that any defect in the weld destroys a larger proportion of its total strength. Hence the butt-welded tubes are not so strong as the lap-welded, and are only used for conveying gas, water, or steam at moderate pressures, and for purposes in which the tube is not exposed to fire. They are measured by the diameter of the bore. "A 2-inch gas tube" will have a bore 2 inches diameter, and is made from material of No. 8 Gauge = ·160 inch thick, and is thus nearly $2\frac{3}{8}$ inches diameter outside. The tubes used for conveying water, and known as "water tube," are always 1 gauge thicker than the "gas tube" of the same size; 2-inch water tubes are made from No. 7 Gauge = ·176 inch thick, while the 2-inch steam tubes are 1 gauge thicker again, and are made from No. 6 Gauge = ·192 inch thick. To avoid having three sets of screw threads, all the tubes are of the same diameter *outside*, the extra thickness of the walls reducing the bore in the case of the last two sizes to slightly less than its nominal size. A screwed socket will consequently fit a tube of any thickness. This arrangement, of one and two additional gauges in thickness respectively, applies to all sizes from $\frac{1}{2}$ inch to 4 inches in diameter, after which only two thicknesses are commonly made.

Spirally-welded Tubes.—With the view of avoiding the weakness to resist an internal pressure inevitable with a continuous longitudinal seam, the barrels of sporting guns have always been formed from strips wound spirally and welded edge to edge. By first twisting together in various manners different classes of iron, and then welding them up to form a bar, which is then wound into a spiral, and its edges welded together, a barrel is produced which shows a great variety of patterns when it is carefully etched with a weak acid; much importance is attached, by those cunning in the trade, to the nature and regularity of these marks, which certainly go to show careful workmanship.

The original Armstrong guns were made on a similar principle. A heated square bar was wound into a spiral on a revolving mandril, and the coils then closed by hammering the block on end under a steam hammer; but, except for sporting guns, such methods are now abandoned. Indeed, as early as 1866, Messrs. Deakin & Johnson, of Bilston, were making weldless rifle barrels from a steel block about $2\frac{1}{4}$ inches diameter and 8 inches long, by punching a hole from each end under a steam hammer, and then rolling the blank presumably in the same way as weldless tubes are now rolled in the process of "rolling off" previously described. The old patterns of military rifle barrels, having a bore over $\frac{1}{2}$ inch diameter, were thus made until quite recently; but the barrels of the modern rifles, having bores only about half this diameter, must be drilled entirely out of the solid.

The first gas pipes employed were made from old welded musket barrels screwed end to end, and attempts have been made to construct tubes on a large scale on the spirally-welded plan, the most successful process being one by which the strip is heated by gas as it passes through the machine, which twists and welds the strip continuously, but the process has not come into any extensive use. Tubes up to 24 inches diameter are made in this way in Germany. Tubes for bicycles are also made from spirally-twisted strip, the overlapping edges being brazed. The makers claim for the process certain advantages, but the heat to which the strip is subjected in the process of brazing must destroy any stiffness imparted to the strip by cold working.

Close-jointed Tubes.—Close-jointed tubes are intended for use in making bedsteads, and for similar purposes where no great strength is necessary; they are merely strips of metal bent round to form a tube, the edges not being welded at all, so that there is a long slit the full length of

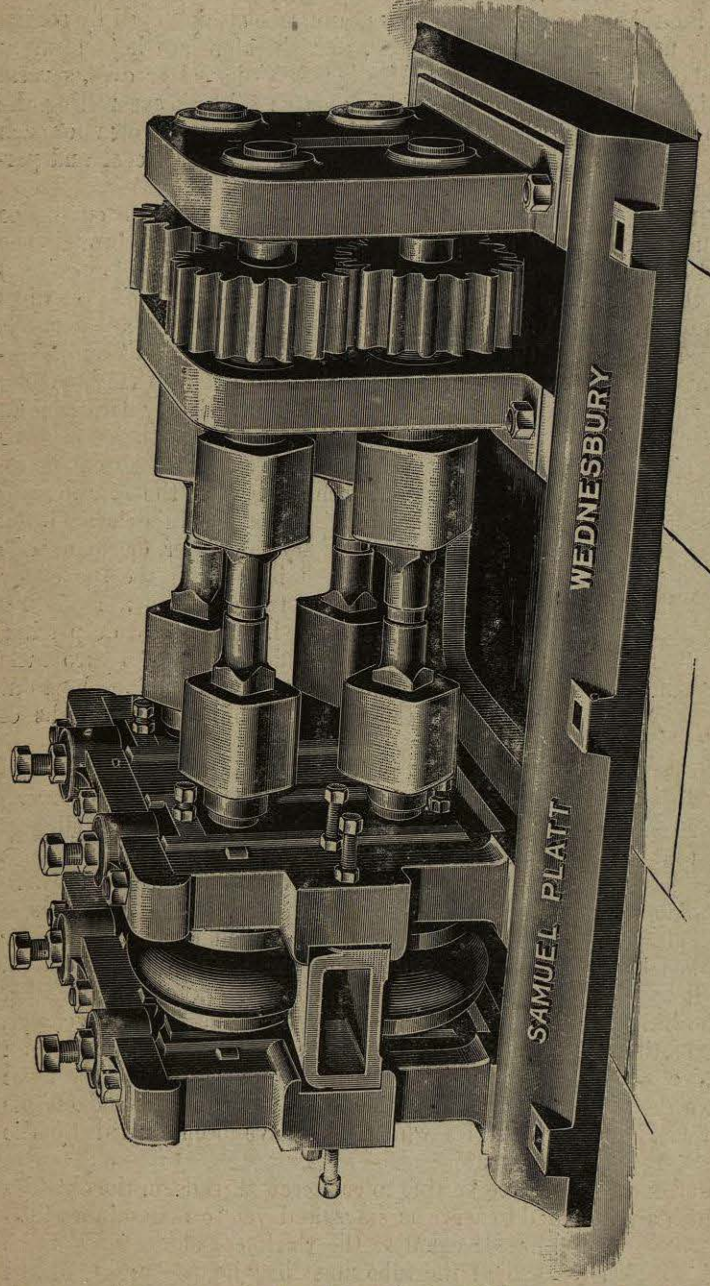

Fig. 557.—Mill for Rolling Close-jointed Tubes.

the tube on one side of it, making it, of course, useless for withstanding internal pressures. They are produced in the following manner :—A strip of metal is raised to a blood-red heat and passed through two pairs of rolls (fig. 557) having a die placed between the pairs; the first pair of rolls bend the strip into a U-shape, the die placed next bends the upper edges of the U inwards so as to form a circle, and the second pair of rolls, which have semicircular grooves cut in them, complete the closing up of the joint and round the tube to shape. Such tubes cannot be straightened by rolling in a reeling machine, or between plates, and therefore are kept straight after manufacture by laying them while hot in V-shaped grooves, several of which lie side by side in a wide sloping plate; a boy keeps rolling the tube down from one groove to the next in order to make room for each succeeding tube as it leaves the rolls, so that each tube is cool and perfectly straight by the time it arrives in the last groove.

Finishing the Tubes.—After the tubes are made they are cut off to length, usually in hollow spindle lathes, the tube passing through the spindle and being held in a three-jawed chuck; all, except the close-jointed tubes, are then taken to the prover's bench, which consists of two discs facing each other, covered with leather or india-rubber to form a watertight joint between the end of the tube and the discs. One disc is secured permanently at one end of the bench, while the other can be moved along the bench and secured at a distance from its fellow, slightly greater than the length of the tube to be tested, and is provided with a screw or other convenient means by which the slight difference in position can be rapidly adjusted; the tube being pressed firmly between the discs, water of the pressure required to prove the soundness of the tube is admitted through the centre of the fast disc. The ordinary gas, water, or steam tube is screwed at both ends, upon one of which is screwed the socket by which the tubes are coupled together, and the tubes are then ready for market, or, if required, are painted or galvanised. Tubes are despatched in lengths of 14 feet from the majority of the older works, or 16 from the newer works in this country, some of the Scotch works sending them out in lengths of 20 feet; in America the tubes are finished in lengths of 30 feet.

Staving and Thickening.—To facilitate the introduction or withdrawal of tubes through the tube plate of a boiler, it is often necessary to swell up one end of the tube, for a short distance, to a diameter slightly more than that of the remainder; this is done by holding the tube in a pair of dies having one end bored out for a short distance to the size which the outside of the tube should have; as much of the tube as it is desired to enlarge projects into this space, and a ram, equal in diameter to the enlarged bore of the tube, is forced into the heated end of the tube, expanding it to the extent desired. This operation is known as staving. Fig. 558 shows a press used for the purpose. By a recent improvement, the portion of the dies having the larger diameter are made separate from the remainder, which grip the tube; as the ram is withdrawn these loose dies also are drawn back, thus smoothing over the enlarged end of the tube and removing any wrinkles which may have been caused by the operation.

It is also often desirable to be able to cut screw threads on the outsides of tubes which are intended to serve as stays, and yet to maintain a thickness at the roots of the threads equal to the thickness of the rest of the tube, to effect which the end of the tube must be "jumped up" to afford the necessary thickness. This is effected by holding the tube in a pair of dies similar to those previously employed, one end of the dies being bored out as much larger in diameter as will allow for the required thread; a plunger, having one part of the diameter equal to the bore of the tube, and the other to that of the enlarged portion of the dies, is then forced into the end of the tube, when the longitudinal pressure compels the metal to flow laterally and fill up the enlarged part of the dies. This process is known as "thickening."

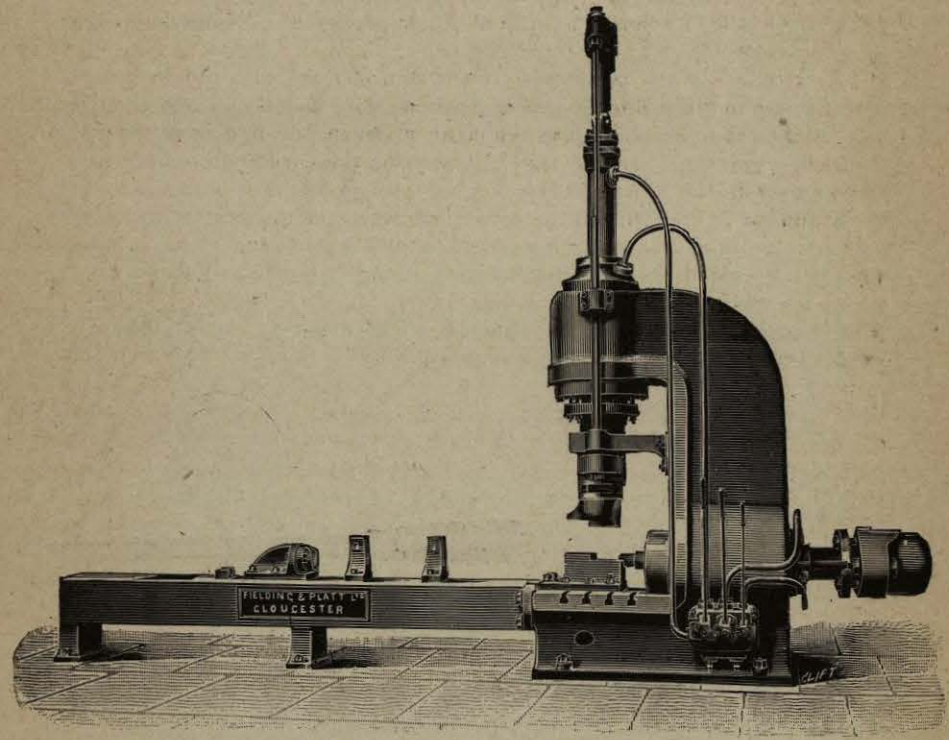

Fig. 558.—Hydraulic Tube-staving Press.

Fittings.—The sockets, tees, bends, &c., employed to unite the straight tubes, are known as "fittings." They are made from pieces cut out of flat bars of the requisite thickness welded up by hand; considerable skill is shown by the fitting smiths in the operations, which are executed with astonishing rapidity.

Flanges are drop-stamped under a press or hammer, and are screwed on, but of late years, for the best class of steam pipes for heavy pressures, the flanges have been cut out of thick plate and welded solid on to the pipes; pipes from 3 to 15 inches diameter, and from ¼ to ½ inch thick, welded up, and with flanges from ¾ to 1¼ inch thick welded solid on to the ends, are now obtainable as an ordinary commercial product. If pipes are required over 15 inches bore, they are usually formed from plates rivetted together, some makers rivetting those over 12 inches diameter, but very much larger pipes are obtainable from more than one firm, which are made by welding together the edges of the plates, a few inches at a time, by means of coke or gas fires, in the same way as the welded flues of Lancashire boilers are produced. Pipes are also made by folding the edges of the plates over each other in various ways, instead of welding the edges, such pipes being usually known as "lock-jointed tubes."

Special Processes.

Perrins' Rolling Process.—A most interesting process for rolling tubes, originally devised for rolling iron tubes direct from puddled bars, but applicable also to soft weldable steel, has been recently perfected by the holders of the Perrins Patents at their works at Wednesfield, near Wolverhampton.

Bars rolled to the sections shown in fig. 559 are cut into lengths of about 2 feet to 2 feet 6 inches for ordinary sizes of tubes, and laid one over the other so as to break joint in the manner shown, the pile being roughly 7 inches or 8 inches diameter, and flattened on the lower side to prevent it rolling over in the furnace. It is brought up to a full welding heat, and rolled on to a mandril in the same manner as in the first stage of the process of rolling a billet for a weldless tube; the pile, perfectly welded in its first or second pass through the rolls, forms a thoroughly sound tube, which leaves the roughing mill, after four or five passes, as a rough tube, say 4 or 5 inches diameter outside and 2½ inches diameter inside, whence it passes, while still hot, to the finishing mill.

Fig. 559.—Section of Bars used to make Tubes by the Perrins Process.

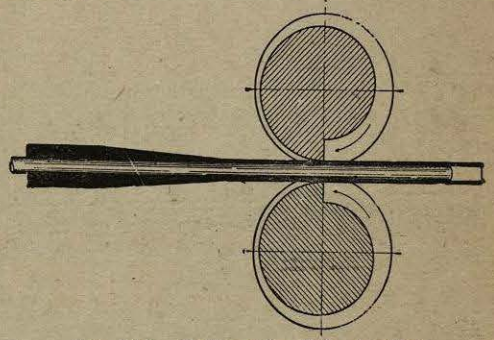

Fig. 560.—Rolling the Tube by the Perrins Process.

The finishing mill (fig. 560) consists of a pair of rolls having tapered semicircular grooves cut in them, the larger end being bell-mouthed and tapering gradually towards the smaller end, which, for a short distance, is nearly parallel and of the diameter to which it is desired to finish the outside of the tube. These rolls revolve continuously, not in the usual direction, away from the workman, but *towards* him, so that anything gripped between them, instead of being carried away from the operator, travels in his direction.

A porter bar, carried in bearings in a carriage travelling on rails laid on the mill floor, is situated to the left of the rolls in the figure. This carriage is provided, on each side, with a hand wheel and gearing, which drive pinions meshing into fixed racks, thus affording to the workmen, who stand on each side of the carriage, sufficient purchase to enable them to feed it forward against considerable resistance. The porter bar is free to move to and fro for a foot or two, in the bearings provided in the carriage for this purpose, but is thrust forward towards the rolls by a powerful spring. In the end of the bar is a socket having a fastening of the bayonet-clutch type, for the purpose of holding a mandril some 4 or 5 feet long, having nearly the same diameter as the bore of the tube to be made. On this mandril, previously covered with oil and plumbago, the hot tube blank is slipped and brought against the nose of the porter bar. The carriage is then fed forward by the workmen, so that the mandril, with the tube blank on it, is thrust forward by the spring against the revolving rolls. When the rolls have travelled round a little further than the positions they occupy in the cut, the pass in the rolls suddenly opens out, because the wide portions of the grooves in both rolls are then facing each other, and the spring immediately shoots the mandril forward between the rolls.

As these rolls, however, do not run in the usual direction away from the workmen, but, on the contrary, turn towards them, as shown by the arrows in the cut, it follows that when the blank is gripped by the narrow portions of the groove the blank does not pass through the mill away from the workmen, but is pushed back towards them, until such time as the larger portions of the grooves in the rolls once more face each other. When this happens the grip of the rolls is suddenly relaxed, and the spring again shoots the mandril forward, and enters the blank once more between the wide open pass. This operation is repeated with each revolution of the rolls, and as the carriage is fed forward steadily by the workmen, a fresh short length is reduced at each revolution. The finished portion of the tube is thus squeezed forward regularly over the mandril to the right, between the nearly parallel portions of the groove, which planishes it. Thus, though the rolls at each revolution thrust back the blank to the left, the squeeze they give the blank extends it as regularly to the right, so that it leaves the back of the mill as a tube, perfectly finished both inside and out.

The porter bar has a quick-pitched thread cut on its rear end, by means of which it is rotated on its own axis through a portion of a circle, every time it is driven backwards, and by an arrangement of pawls is prevented from rotating when again driven forward by the spring; thus fresh portions of the tube are being continuously brought to the top, and any fin formed in one squeeze is flattened down in the next one. Although the mandril is only about 4 feet long, a tube 20 feet long is made on it, and there is nothing to prevent this length being considerably increased, for the tube, as finished, is continuously pushed off the mandril by the next portion squeezed forward behind it. When nearly the whole of the metal has been thus rolled out, the clutch at the end of the bar is opened, the mandril and tube on it are passed straight through the mill, and the tube is at once stripped off the mandril by a draw-bench or some other suitable means.

The action of the machinery is similar to that which would be obtained by putting the mandril into a pair of reciprocating rolls, which took it in for a short distance, reduced a short length to size and then rejected it, the tube being entered again to reduce a further short length, and the mandril and tube being rotated through a portion of a circle between each operation. The result is a perfect tube free from the inherent weakness of a continuous line of welding, such as must always occur when a strip of metal is bent round and its edges welded together. For iron tubes, the process promises considerable economy of production, as the tube is made direct from the rough puddled bar instead of from a finished tube strip, so that the cost of piling the puddled bar to form the strip, the waste in the furnace, the fuel to heat it, and the labour and power expended in rolling it are alike saved. The difference in price between puddled bar and strip is about £3 per ton. It is remarkable how perfect a tube can be made in this manner from puddled bar with ragged edges, which, it would be expected, would lead to defects in the tube, but nothing of the kind occurs, and perfectly good tubes are produced from material of the most unpromising appearance. The process is also used, with satisfactory results, to make steel tubes, employing very mild welding steel for the purpose. Some half dozen firms are working the process in this country, and one in France, mostly on puddled bar.

The Mannesmann Process.—By this process a tube is formed from a solid bar of steel by the action of two rolls which exert pressure only on its surface. The action of the rolls is neither easily described, nor readily understood, and perhaps the best way of following the nature of the operation is to consider what happens when a bar is hammered on the anvil. To reduce the diameter of a round bar, the smith uses a pair of swage tools which have grooves in their faces of an approximately semicircular shape, or of some other shape having surfaces sufficiently inclined from the vertical to compress the outer portions inwards towards the centre of the bar when the swage is struck by the hammer If, instead of such tools, the smith were to use only two flat surfaces touching the bar top and bottom, the force of the blow would spread the sides of the bar laterally, and cause the particles to flow outwards from the centre, instead of inwards towards it, and would set up a tensional strain near the centre of the bar. How vertical pressure can cause horizontal tension may be shown by placing on edge a hoop having a thread stretched from side to side in a horizontal direction; by applying a downward pressure to the upper side of the hoop, the change in the form of the hoop will snap the thread in two. In the same way, if the outer layers of the bar offer more resistance to compression than the hotter centre offers to tension, the particles near the centre will be stretched, and, if the strain is repeated sufficiently often, a rupture will occur in the centre forming a flaw running longitudinally right down the bar, which will be hollow in the middle.

The Brothers Mannesmann took advantage of this tendency of a bar to work hollow, the danger of which is well known to all hammermen. They employed conical rolls (fig. 561) set at an angle to each other, much in the same way as the rolls are set in the reeling machine, which has been previously described. A solid round billet, brought up to a good red heat, is entered between the rolls in the same direction as the tube enters the reeling machine, and as the rolls keep turning it round between them they compress it at two points which are continually changing, but which are always on opposite sides of the centre, so that during its slow longitudinal travel through the first few inches of the rolls a flaw forms in the middle of the billet, which flaw it is the function of the remainder of the rolls to enlarge. This enlargement is due to the fact that the farther ends of the rolls are larger in diameter than the ends at which the bar enters, and their surfaces travelling faster twist the outer portions of the bar round circumferentially more rapidly than the smaller ends will permit the outer surface at their end to revolve; and as the axes of the rolls are not parallel to that of the bar, but are inclined to it, they at the same time, pull forward the outer skin of the bar longitudinally, drawing out and twisting the surface in a spiral direction, much as the strands of a rope are twisted. As the bar does not decrease in diameter as fast as it increases in length, metal must be withdrawn from somewhere, and the place from which it is drawn is the centre of the bar, enlarging the flaw already formed and converting the solid billet into a hollow tube. As the tube leaves the rolls it is fed over a mandril having an enlarged nose, which rounds and smooths the central hole; the mandril is not essential to the formation of the tube, but is a convenient means of enlarging the bore. The hollow billets are rolled between rolls, in much the same manner as in the Perrins process. The rolls were called "Pilger" rolls, from the German word pilger, a pilgrim, on account of their step by step action. The tubes are finally drawn on a bench in the ordinary manner. The process is used by the inventors to form hollow axles and various tubular articles of a like nature.

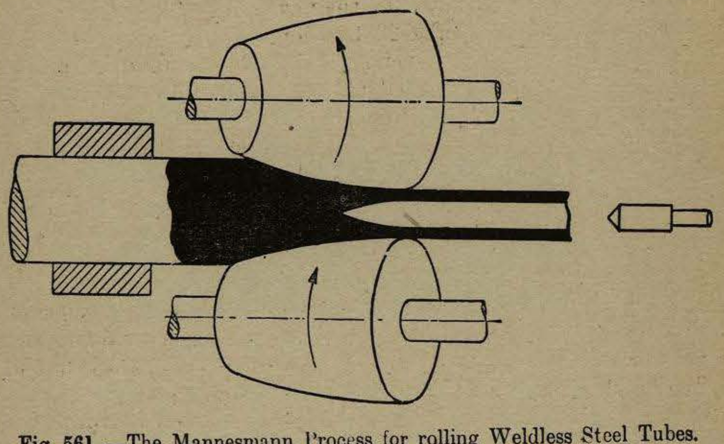

Fig. 561.—The Mannesmann Process for rolling Weldless Steel Tubes.

Stiefel's Process, an American invention, is another method of forming a central flaw by external pressure, and consists in passing a solid circular billet between the opposite faces of two revolving discs (fig. 562). The axes on which the discs revolve, if produced, would not coincide but would be parallel to each other, the shafts being moved so far apart that the axis of each, if prolonged, would fall outside the circumference of the other disc, so that little more than one-third of the diameter of each disc faces the other. The faces of both discs are slightly chamfered for a short distance from the edge, and the billet enters a little below the centre of the shafts, and at a slight inclination to the plane in which the discs revolve. Both turn in the same direction and revolve the billet rapidly between them, and, as it enters below the centre, feed it slowly forward on to a pointed mandril which pierces it.

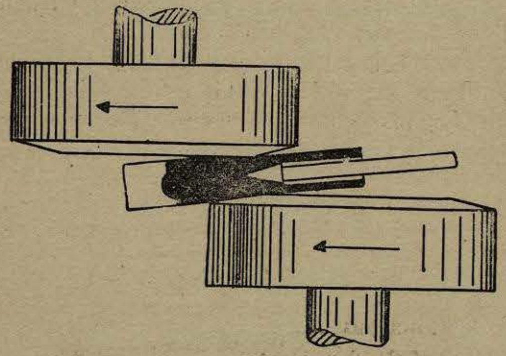

Fig. 562.—The Stiefel Process for rolling Weldless Steel Tubes.

This, and the Mannesmann process, avoid the necessity for drilling the billet before piercing. By drilling the billet, however, it is possible to ensure that the bore shall be perfectly concentric with the outside, but when the position of the flaw, which forms the starting point for the bore, is determined by the exact spot at which the metal gives way under tensile strain, any irregularity in the composition of the material, or want of uniformity in the heat of the billet, may cause the rupture to occur on one side of the centre, in which case the thickness of the walls of the tube will not be uniform. The irregularity once introduced cannot afterwards be rectified. Some weldless tube makers also consider that the severe stresses set up by these processes are liable to damage the material, and as the percentage wasted by the drill is so small, while the drilling ensures the removal of the most impure and unsound portion, they prefer to adhere to the original drilling process.

The Erhardt Process, used in Germany,* consists in forcing a mandril through a solid billet raised to a full red heat, in much the same way as the drilled billet is pierced in fig. 548. The blank is square in cross section, and is placed on end in a circular mould; the wall of the mould forming a circle circumscribed around the corners of the billet, centres and supports it against the thrust of the mandril, while the material displaced by it fills up the vacant spaces between the blank and the mould. The tubes are finished as in other processes, except that the very large ones are rolled like tyres, but between rolls having plain barrels, laid horizontally as in an ordinary mill. To avoid a continuous heavy pressure over the whole length of the barrels, the lower roll has its ends rocked backwards and forwards horizontally, so that, when looked at from above, the top roll, on which the blank is threaded, is constantly crossing the bottom one to and fro.

The Erhardt Company exhibited a weldless shell for a locomotive boiler made by this process at Dusseldorf Exhibition in 1902, and it is said are prepared to supply weldless rings for forming boiler shells up to 15 feet in diameter, made in this manner (see also p. 772).

Robertson's Process, used in this country, is another method of piercing a solid blank, which in this case fits the mould and is pierced horizontally, a pressure plate being kept in contact with the end of the billet to prevent the pressure of the mandril tearing its end open.†

Many other processes have been patented, and some worked, but not on such a scale as to give them much commercial importance.

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* English patents—3,116, 1891; 7,497, 1892; 854, 1896.

† English patents—1,627, 1890; 11,436, 1891.

CHAPTER XLIII.

WIRE-DRAWING.

The Process of Wire-drawing.—The rods intended to form wire are usually rolled down to No. 5 Gauge = 0·212 inch diameter, though some makers roll them as small as No. 8 Gauge = 0·160 inch. Any further reduction must be effected by drawing the rods cold through a series of round tapered holes in a die, each hole being smaller in diameter than the previous one.

The coils of rod as received from the rolling mills, are pickled in dilute Sulphuric or Hydrochloric Acid to remove any scale, and the acid removed by washing the pickled coils in lime-water, which neutralises any remaining acid, and the washed coil is sometimes dried in an oven. If the rod were drawn unpickled, the dies would be very rapidly cut by the scale; but care must be taken in the pickling, for, if carried too far, the rod becomes "rotten" and breaks in the drawing.

The prepared coil is taken to the drawing shop and dropped on to a drum running loose on a vertical spindle in convenient proximity to the drawing-bench, which consists of a series of revolving drums, technically known as "blocks," slightly tapered from the bottom upwards. Each block revolves on a vertical spindle which projects through the top of the bench, and all are driven by means of bevel wheels from one horizontal line shaft running beneath the bench. Each block can be started or stopped independently without stopping the line shaft.

Fig. 563, Plate xlvii., shows a wire-drawing block as made by Messrs. John Hands & Sons, of Birmingham, which is worked as follows:—One end of the coil of rod, if it has not been already pointed by heating and hammering at a smith's fire, or with small swaging hammers driven at a high speed, is pointed at the bench by means of a small pair of hand rollers having a pair of tapered grooves cut in them; or, for certain qualities of wire, by means of a file. The sharpened end is passed through the hole in the die placed to the left of the stops, A, and is gripped by the pair of pincers, B, attached to the chain, C; by placing the foot on pedal, D, the clutch, E, sliding on a feather on the shaft, F, is connected, by means of the teeth on their adjacent surfaces, to the small drum, G, loose on the line shaft, F. The chain is thus wound up and draws the end of the rod through the die placed at A, until the pincers, B, strike the eye on the end of the lever, H, and thus throw the clutch, E, out of gear with the drum, G. The pincers are then made to take a second grip of the wire as close as possible to the die at A, and a further length is drawn through, and the operation repeated until enough wire is drawn to go nearly twice round the circumference of the drum. That part of the wire squeezed in the pincers is spoiled, but most of this loss may be avoided by giving to the drawing-in gear enough travel to pull through the dies, with one grip, as much wire as will wrap far enough round the drum to prevent its slipping.

When this has been done the die is removed to the left of the stop, J, and the end of the wire secured in the grip, K, on the top of the block, L. During this operation the block remains stationary, having been raised for