America has accomplished so much in the past, which the best authorities on the subject considered impossible, and has developed her steel industry with such enormous rapidity and energy, that it is not surprising that makers on this side the Atlantic should feel some anxiety, as to what she may accomplish in the future.

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CHAPTER XXXIX.

FORGING STEEL BY THE STEAM HAMMER.

Rolling Mills and Hammers Compared.—The rolling mill is a most efficient appliance. It turns out work in large quantities with great rapidity, and with remarkable economy in fuel and labour; all the pieces made by it are true to gauge and precisely alike, but it can only produce those of regular shape having a uniform cross section throughout their entire length, while a fresh and costly set of special tools, in the form of rolls, are needed for every new section it is required to produce. Hence a draughtsman, preparing designs for constructional work, must select those rolled sections, for the production of which he knows that rolls already exist, unless so large a quantity of a new section is needed as will justify the preparation of a set of rolls wherewith to make it: and if he studies economy and rapidity of construction, he will confine himself to those common sections which are obtainable at short notice from a considerable number of works.

The hammer, on the other hand, is much more adaptable, and can work material into practically any shape, with the aid of very few and simple tools. Only in exceptional cases is it expedient to provide special tools, and then only as a means of economising labour, not as an indispensable condition of production; nor are such tools anything like so costly as the rolls required for use in a rolling mill. Consequently articles can be made under the hammer for much the same price per piece, whether one or many are required, and the designer is therefore not so limited in his choice of the form of forged articles.

On the other hand, the cost of any piece shaped under the hammer is much greater than that of the same piece rolled in a mill. The hammer has an intermittent, not a continuous action, and therefore shapes the ingot much more slowly than a rolling mill, with the result that it cannot finish off the work at one heat, as a mill usually does. The increased number of heats necessitates the consumption of more fuel, and involves a greater loss of metal by oxidation in the furnace. A hammer also requires more steam and many more men to work it, while its output is much less than that of a mill; nevertheless, each has its own field for profitable employment.

Tilting Tool Steel.—The first steam hammers employed on steel were those used in Sheffield for tilting tool steel, all the best qualities being still finished by this means. A bar, if hammered, is much superior to another made from the same ingot by rolling, because the workman, guided by his eye, can work the metal by a rapid succession of light blows, right up to the instant when the blue heat appears, thus preventing the formation of large crystals during cooling, and imparting to the bar that extreme regularity and closeness of grain found in the velvety fracture of a high grade tool steel.

The cold ingot is "topped" by breaking off from the top one-third to one-fifth of its length which contains the pipe; the remainder is carefully examined, and before it goes to the hammer any surface defects, however trifling, are cut out with a hammer and chisel, or by pneumatic chipping tools, which do three or four times more than can be accomplished in the same time by hand labour. The belief common in Sheffield, that ingots which have been long in stock and are well rusted make the best tool steel, is probably based, among other things, on the fact that exposure to the weather has removed the skin, and exposed flaws just below the surface, which otherwise would have escaped detection, and would have been worked up into the bar. Occasionally ingots are pickled in acid with the object of discovering such flaws.

The ingots are heated in what in Sheffield is called "a muffle." It is not really a muffle, but a hollow fire made with large coals and blown with a fan blast, a few bricks and a plate of iron being used to confine the heat, the arrangement differing little from an ordinary smith's hearth, and being provided with a similar form of hood and chimney to carry away the products of combustion. The workman, when finishing the bars under the smaller hammers, usually sits on a small board slung from the roof by a long link, which enables him to remain seated, and yet leaves him free to move to and from the hammer as is necessary. The workmen become exceedingly expert, and get the bars so beautifully true and neatly planished that it is not easy to distinguish, on a casual examination of the surface, those bars which have been hammered from those which have been rolled. The bars are improved in appearance by rubbing with blacklead, which, moreover, seems to retard the action of rust.

Fig. 523 shows a tilting hammer, by Messrs. B. & S. Massey, of Manchester. The conditions essential in a good steam hammer for this purpose are, that the stroke shall be short, and the cylinder of very ample diameter, to ensure that the hammer shall make from 150 to 300 blows per minute, this rapidity of action being required to give the necessary planishing action. Such a speed of work cannot be obtained with valves actuated by hand, and the hammers must be driven by a self-acting gear, consisting usually of a curved lever, kept by a spring in contact with a pin secured in the square forged mass known as the "tup"; this is pressed firmly on the piston-rod, carries the upper tool, and slides up and down between standards; the other end of this curved lever moves the valve.

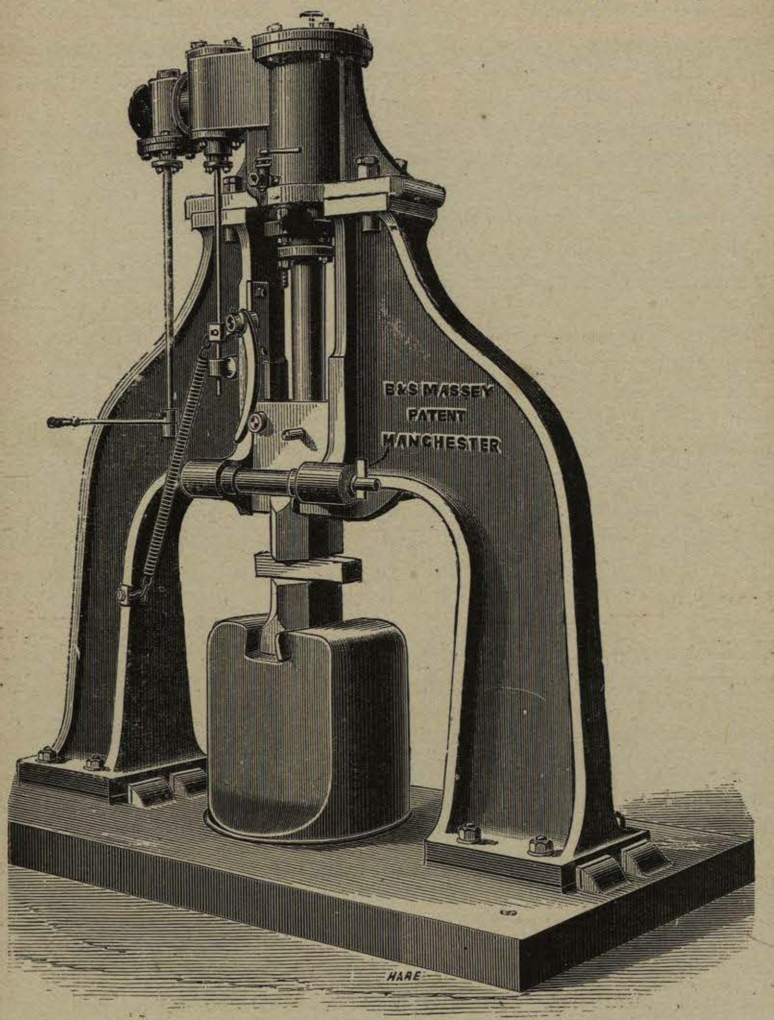

Fig. 523.—Steam Tilting Hammer.

The old tilt hammer, which consisted of a timber beam turning on a pivot, and armed with an iron hammer head, which was raised by tilting the beam, and then allowing the head to fall, is practically extinct, because it can give one weight of blow only; whereas the direct-acting steam tilting hammer can be adjusted to give any weight of blow desired, and is able to make many more strokes in a given time.

The anvil blocks of these hammers are usually wider at the top than shown, and have a wrought-iron hoop shrunk round the upper edge to strengthen them, the bottom tool dropping into a tapered socket cast in the block to receive it. The tools which come in contact with the steel being worked are known as "pallets" or "bitts"; they are made of cast iron, with their faces chilled and ground smooth on a stone; chilled iron tools impart a much better surface to the bar than can be put on by tools made of steel. The total weight of the falling mass is about 20 cwts. in the larger, down to 5 cwts. in the smaller, hammers; the bars are generally finished under the smaller sizes.

Crucible Steel Forgings.—Until comparatively recent times, all steel ingots made were intended for the production of tool steel, for which purpose small ingots are the most suitable; so that the hammers employed for working steel were of considerable weight in proportion to the weight of the piece being worked by them. The small steel forgings made 40 years ago were all of crucible steel, and were made under such hammers. In the manufacture of large ingots and forgings Krupp of Essen led the way; he exhibited in London at the International Exhibition of 1851 an ingot of crucible steel weighing 5,000 lbs., the largest mass of steel produced up to that time, and at the Exhibition in London in 1873 he showed an ingot weighing 115,000 lbs., the metal forming which had all been melted in crucibles, from which it was poured by men drilled to follow each other and work together with military precision. Such material was necessarily costly, and was employed mainly in the production of steel ordnance, though occasionally crank-shafts and axles for locomotives were made from it. It was not until Bessemer's process provided a sufficiently cheap ingot that steel forgings could be produced at such a price as to take the place of ordinary wrought iron, and their use for some time was confined to crank-pins, piston-rods, and those parts of steam engines requiring a harder and smoother surface than is afforded by wrought iron. The Siemens process, however, provided a soft material at a moderate cost, admirably adapted for the manufacture of forgings, and not much more difficult to machine than wrought iron. Engineers soon were anxious to take advantage of the stronger material thus afforded them, and forgings made from open hearth steel are now almost universally employed for all important purposes, such as the moving parts of steam engines, wrought-iron forgings being seldom demanded save for exceptional reasons.

Difficulties in Producing Large Ingots.—There are considerable difficulties, both chemical and physical, in producing sound ingots of very large size. The centre remains fluid so long that liquation may occur to a serious extent, and Phosphorus and Sulphur accumulate in such quantities in the central portion, as to render the metal in that part seriously unreliable. The stresses incidental to cooling (the nature of which has been explained in Chapter xx.) are much greater in large ingots, in which the outer layers may be so much colder than the interior, that the latter tear apart while contracting on to it, and if the ingot is reheated too rapidly, so that the outside expands faster than the interior can follow it, the inside is torn apart. Moreover, in large ingots the temperature of the different layers may vary so much, that while the chilled outer layer is contracting, a ring just inside it may have reached the temperature where recalescence and consequent re-expansion sets in, and if such an annulus is of sufficient thickness it may rupture either inside or outside. Little relief can be expected from casting the ingot square, a form convenient enough for rolling, but not so suitable for large forgings, most of which consist of engine shafts or gun tubes of circular cross-section. Consequently large ingots are usually cast of hexagonal or octagonal section, with the sides fluted, as in fig. 524, so that any internal thrust may flatten the curve between the cooler and stiffer ribs, and thus tend to compress the surface instead of tearing it open.

The top of any ingot is necessarily less dense than the bottom, which is compressed by the pressure of the fluid metal above it, amounting to 3⅓ lbs. per square inch for each foot in depth. The top must, therefore, be rejected in any case, and defects or impurities should be confined as far as practicable to this waste portion. To ensure this the ingot must cool gradually from the bottom upwards, so that fluid metal may be pressed down to fill up the pipe, and make up for the shrinkage in volume which goes on as the metal is cooling. Should the steel set in the upper or middle portions before setting at the bottom of the mould it causes an obstruction to the downward flow of metal to make good the shrinkage, and a looseness of texture must result, or an actual cavity form in the body of the ingot. Owing to liquation the impurities, particularly Sulphur and Phosphorus, are found in excess in those portions which remain fluid longest, and the slower the rate of cooling, the greater the extent of this segregation. In large ingots which cool comparatively slowly, it is particularly important to maintain the head fluid to the very last, so that no portion of the ingot which will be used may contain an excess of impurities.

Fig. 524.—Section of Large Ingot for Heavy Forgings.

Superheating the Top of the Ingot after Casting.—The ingots, if of moderate size, are most frequently cast in iron moulds, in the same way as those intended for the rolling mill, but the larger ones are generally made in moulds formed of sand, firebrick, or other refractory material. When large ingots are cast in iron moulds, the ingots are usually of the "bottle-neck" shape, the upper and smaller part of the mould being formed in loam, and the lower only in iron; the object of this is that while the steel in contact with the iron mould is cooled rapidly, that contained in the upper portion made of sand may be kept hot and fluid, and so feed the pipe formed in the lower part; the volume of the waste head is thus reduced, while its height, which gives the necessary hydrostatic pressure, is retained.

Many methods have been tried for keeping the head hot to the last possible moment. Sometimes a fresh supply of hot steel can be poured on the top to fill up the shrinkage in the head, and "liven up a bit" what fluid metal still remains, but it is not often that a second heat is ready sufficiently soon to allow of this. It might, perhaps, be worth while in works where large ingots are cast to provide means for supplying regularly small quantities of molten steel for this purpose. Krupp used to pour molten slag on the top to prevent cooling. Charcoal or coke-dust is sometimes put on the top of the molten steel with the same object, and is supposed, by its combustion, to produce additional heat. The Carbon certainly combines with the upper surface of the steel, and so reduces the temperature at which that portion solidifies, but if it follows a pipe too far down, it may cause trouble by unduly raising the Carbon in that portion of the ingot which it is intended to use. Another patented method is to heat sand in a crucible to a very high temperature, and invert the crucible, when the heated sand retards radiation.

But the most recent and the most effectual remedy would seem to be Riemer's method, which consists in placing on the top of the ingot directly after casting a small gas furnace of the blow-pipe type (fig. 525), which is supplied with preheated gas and air under pressure This entirely prevents the formation of a crust on the surface, and maintains the metal fluid in the top of the ingot as long as desired. One German firm have employed this method extensively, and it is reported that sound work can be made from ingots treated by this process, from the upper end of which only 10 per cent., or even less, has been cut to waste.

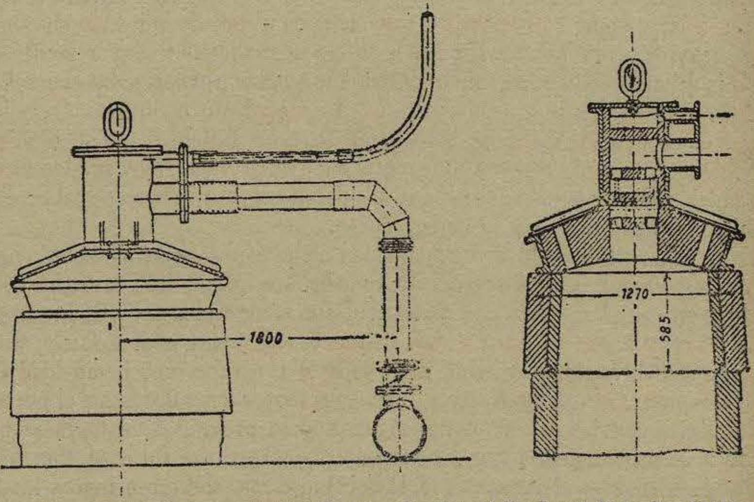

Fig. 525.—Reimer's Apparatus for Keeping the Top of the Ingot Hot after Casting.

Ingots for Forgings.—It may be taken as a general rule that no ingot should be less, under any circumstances, than one and a-half times the diameter of the shaft intended to be made from it, while for work of any importance two diameters should be the minimum; the ingot is generally three to four times the diameter of the finished shaft.

For the best work most forgemen prefer an ingot cast in sand. Although it is piped more extensively than one cast in an iron mould, often requiring 40 per cent. or more to be cut to waste from the top end, there is less risk of those external cracks running horizontally across the surface of the ingot, which are not uncommon in ingots of large size run in iron moulds. As it is impossible to weld up such cracks, and their presence in the forging would form dangerous flaws, they must be cut out before the ingots are worked under the hammer. It is not always easy to work such grooves out of the forgings, while there is always some doubt if the crack has been cut out to the very bottom. The British Admiralty require that 30 per cent. shall be cut to waste off the top of any ingot and 3 per cent. off the bottom, 66 per cent. remaining from which to make the forging; in practice seldom more than 60 per cent. is used for work of that nature.

Risk in Reheating.—The centre of any ingot is always more or less in a state of initial tension, which is greater the larger the ingot, and increases as the ingot cools. If a cold ingot, whose centre is in a state of maximum tension at a low temperature, is charged into a hot furnace, the outside rapidly expands, and the internal stresses are further increased. This may readily lead to the formation of a dangerous flaw, or the enlargement of one which already exists; the flaws may be considerably increased by injudicious hammering, and will remain concealed in the centre of the finished forging. On the other hand, if the heating is very rapid, the surface may expand so suddenly as to crack away from the colder portion below, forming flaws on the surface.[*]

It is of great importance, therefore, that the ingot should not be heated too fast. One of 4 tons weight may be raised to a forging heat in about four hours; a larger one, of 10 to 15 tons weight, is usually put into the furnace before leaving work at night time, so as to soak quietly at a gentle heat, which is raised slowly to that required for forging purposes, by the time the men return to work in the morning. Ingots of 30 to 50 tons are allowed one, two, or even three days to come to their full heat. The higher the Carbon contents of the steel, the greater the risk of fracture by sudden heating. Some makers do not like the ingot to cool at all, but, where possible, charge it while still hot into the heating furnace.

Nearly all risk in reheating is avoided if the ingot has a hole bored through it axially before it is charged into the furnace, as in that case the heating proceeds from the inside and outside at the same time, and the heat having to travel only about one-fifth the distance, the metal is at a fairly uniform temperature throughout, while the walls of the tube, not being held in by a cold centre, can expand freely. Boring, moreover, affords an opportunity of examining the interior of the ingot, and of proving its soundness before labour is expended upon it; consequently where the form of the finished forging is such as will permit of this being done, the large ingots intended for the best work are all bored before they are put into the heating furnace.

Early Difficulties with Large Forgings.—Iron forgings were made by the process of continuously welding on to the end of a bar a succession of small pieces laid on one at a time, so that a large forging could be built up and yet the thickness of the piece through which the impact of the blow had to be exerted need never exceed a few inches. By the process known to the workman as "finishing the work before him"—that is, completely finishing every foot or two of his work correctly to size and shape before adding more material at the end—only the end of the bar had to be heated, so that a small furnace and small hammer sufficed for the production of pieces of very considerable dimensions. As no metal can be welded on to an ingot, its weight must exceed that of the forging to be made out of it, as must also every other dimension save length. As such a forging requires to be put into the heating furnace whole, a much larger furnace is necessary than sufficed when only one end of a forging needed heating. Again, to work satisfactorily, the hammer-head needed its greatest fall just when the ingot was thickest, but the ingot occupied so much of the space under the head that, when the hammering began, very little space remained through which the head could fall; while the effect of the blow had to be transmitted, not through 4 inches of soft iron at a welding heat, but through 1 or 2 feet of hard steel, which could not, without danger of spoiling it, be raised to anything like the same temperature as the iron.

[*] See "Sheet Mill Rolls" on p. 789.

If we consider the size of the hammers in existence in the forges of the country at the time that Siemens steel was first available, it is not surprising that the use of iron was so long continued, or that mysterious fractures of steel shafts occurred, seeing the plant used, though quite capable of doing good work on iron, was far too small to deal efficiently with the new material.

We are even now occasionally advised to return to the use of hammered iron by some one who has been alarmed by the unexpected fracture of a steel shaft, which will usually be found to have been made from an ingot of insufficient size or under a hammer not sufficiently heavy to ensure that the centre of the piece has been properly worked. As a case in point, we have the breaking of the shaft of the United States despatch boat "Dolphin" after being in use a very short time. The shaft, 16 inches in diameter, had been made from a 30-inch steel ingot under a 10-ton hammer. Test pieces cut from the outside of the shaft after its failure showed an elongation of 21·4 per cent. before fracture, while others taken successively nearer to the centre gave extensions of 5·5, 4·9, and 2·0 per cent. respectively, confirming the appearance of the fracture, which indicated that the outer surface only had been properly worked, the centre remaining in its original raw condition, because the hammer did not possess sufficient power to break up the large crystals for more than a short distance from the surface. Other pieces were then cut from the shaft occupying the same relative positions as those which had given such poor results, but those were forged down before testing, and gave extensions respectively of 25·4, 28·2, 26·4, and 24·1 per cent., or an average of 26 per cent., conclusively proving that the material had not been effectively worked.[*]

Comparative Effect of Heavy and Light Hammers.—The energy exerted by a hammer is made up of two factors—the weight of the falling mass, and the velocity at which it is moving at the moment of impact.

Though the total energy absorbed in bringing to rest a heavy weight moving at a low velocity, may be precisely the same as that absorbed in bringing to rest a light weight moving at a high velocity, yet the effect produced on the object struck may differ materially. Take the following three cases:—(1) A weight of 16 tons falling through 1 foot; (2) a weight of 4 tons falling through 4 feet; (3) a weight of 1 ton falling through 16 feet. In each case the work done in raising the weight, which re-appears in the energy absorbed by the material struck at the moment of impact, is precisely 16 foot-tons, but the velocity at the moment of impact will vary as follows:—

TABLE CXIX.—WORK DONE BY STEAM HAMMERS UNDER VARYING CONDITIONS.

Weight in Tons.	Falling through Distance in Feet.	Work done in Foot-tons.	Speed at Moment of Impact. Feet per Second.	Time of Fall in Seconds.
16	1	16	8	¼
4	4	16	16	½
1	16	16	32	1

[*] "Fatigue of Metal in Wrought Iron and Steel Forgings." *Journal of the Franklin Institute*, Dec. 8th, 1897.

It will be seen that the weight in the last case is travelling four times as fast as in the first, but as the work expended in each case is equal, the time available for the flow of the metal under the influence of the blow will be four times as long in the first case as in the last. The more slowly the weight comes to rest, the more time is afforded for the particles of the metal to flow and transmit the pressure to the centre of the mass under treatment; and, therefore, in proportion as the speed component of the work done is less, and the pressure component greater—in short, the more the action of the hammer partakes of the character of a squeeze, and the less it resembles a blow—the deeper does the effect of the operation penetrate into the body of the material struck. The effect of a very light hammer travelling at a high speed may be so instantaneous that all the energy is absorbed in extending the surface, and so the central portions may remain entirely unaffected.

The Double-acting Hammer.—Up to the present we have been considering the case of a weight lifted by the pressure of steam below a piston, the weight being allowed to fall freely by gravity. But in nearly all modern hammers the falling weight is not only lifted, but also driven down again by the pressure of steam admitted above the piston for this purpose. We will examine the second instance given above, that of a hammer weighing 4 tons falling through a distance of 4 feet, which is just about the effective fall which a hammer of this size usually has. Such a hammer would be furnished with a steam cylinder about 26⅛ inches in diameter, and if steam be admitted on the top of the piston having a mean effective pressure of 50 lbs. on the square inch, the additional load thus obtained on the upper side of the piston will equal a further 12 tons, which will cause the hammer to strike the object with a velocity of 64 feet per second, the same speed which a 4-ton hammer would have if allowed to fall freely from a height of 64 feet, instead of only from a height of 4 feet; and the fall will have taken place in one-eighth of a second, instead of in one-half of a second, which would be required to enable a weight to fall through a distance of 4 feet under the action of gravity alone.

The effect, therefore, of adding, by means of the steam, a live load equal to three times the dead weight, has been to quadruple both the work done and the speed of impact, and to reduce the time available for transmitting the power exerted to one-fourth. Admitting steam above the piston greatly increases the power of a steam hammer, and enables it to work much larger pieces, but the tendency is to increase its power of working the surface, much more than its ability to work the centre of the mass treated.

The following table compares the action of the 4-ton double-acting hammer, worked with such a steam pressure as will afford a mean effective pressure of 50 lbs. on the piston, with other single-acting hammers giving the same energy:—

TABLE CXX.—COMPARISON OF SINGLE- AND DOUBLE-ACTING HAMMERS.

Weight in Tons.	Falling through Height of Feet.	Work Done.			Speed at the Moment of Impact. Feet per Second.	Time of Fall in Seconds.
		By Weight. Foot-Tons.	By Steam. Foot-Tons.	Total Foot-Tons.		
4	4	16	48	64	64	⅛
4	16	64	Single-Acting.	64	64	2
16	4	64	,,	64	16	½

The great advantage of the double-acting hammer is, that being more rapid, it makes more strokes in a given time, and gives a total power much in excess of the single-acting hammer, when both are of the same weight, thus giving a much greater capacity for work from a given size of plant; but for working the centre of a thick piece, the 4-ton double-acting hammer, though more rapid, does not deliver so effective a blow as the 16-ton single-acting hammer, when both fall through a height of 4 feet.

Various methods, more or less empirical, have been proposed for calculating "the weight of the blow struck" by a steam hammer. By the formula used by one well-known maker of steam hammers, the 4-ton double-acting hammer we have been considering, would be said "to strike a 768-ton blow."

Another maker says:—"The question is sometimes asked, 'What weight of blow does the hammer strike?' The force of a blow cannot be stated in terms of weight at all, because the pressure of a weight is continuous, whereas the force of a blow is expended in a moment. It has, however, been ascertained by careful experiments that the maximum blow of a 5-cwt. double-acting steam hammer, with moderate steam pressure, produces a crushing effect upon a piece of hot iron as great as that produced by a load of about 30 tons, and a ½-cwt. double-acting steam hammer a crushing effect equal to that produced by a load of about 2½ tons."

No formula could in any case take account of the extent to which the anvil block springs under the blow. If the blow were struck on an absolutely unyielding substance the time element would be entirely absent, and there is no possible way of accurately comparing the action of a blow with a steady pressure.

For causing a flow on the surface, the lighter hammer, having the higher velocity, is more effectual, and hence we find that for stamping work, the object of which is to shape pieces in dies, and to bring the edges up sharp, by causing the metal to flow into the corners of the mould, a light block is used falling from a considerable height, or, if a short stroke is employed, the piston is driven violently upwards against a powerful spring, and as it rebounds, its downward travel is further assisted by steam pressure, so as to obtain the highest possible velocity.

Handling the Ingot.—The work done by a steam hammer is the same as that performed by the smith, but on a larger scale, and the piece to be worked must likewise be held in correct position on the anvil; the smith's tongs will serve for very small pieces, but for large pieces, heavier than a man can lift with at the most two assistants, some more massive contrivance equivalent to the tongs must be employed.

For iron forgings the difficulty was got over by using an iron bar of large section, known as a "porter bar," and building up the forging required on the end of this, by continual accretions of material welded together, until the forging was completed; it was then cut off the porter, which was ready to receive additions for the manufacture of the next forging. As steel cannot be welded, the porter bar for a steel ingot, D (fig. 526), is provided with suitable jaws, E, at the outer end, in which the ingot, B, is held by a strap, F, and bolts, G G; or two bars are employed with a piece of timber placed between them to reduce the vibration, which is apt to snap the bolts. The porter bar, with the ingot secured to it, is supported from a crane, usually a jib crane, with a runner on the upper horizontal leg, capable of travelling along it a few feet, to facilitate the adjustment of the piece on the anvil; the hook of the crane is usually provided with springs to relieve the framework of the crane as far as possible from the jar of the blow delivered by the hammer. From the hook, H, of the crane hangs a sheave, J, round which passes an endless loop of chain, K, which is slipped over the porter, D, and adjusted to the centre of gravity of the combined mass; balance weights, A, are added at the further end of the porter bar, if required, to balance the weight of the ingot, B. To the bar are secured horns, C, by means of which the bar and ingot may be rotated in the loop of chain, so as to turn any side of the ingot upwards. A considerable number of men are needed to steady and direct the weight and turn round the bar, and to assist in the latter operation, the cranes serving some large hammers are fitted with appliances for mechanically rotating the sheave carrying the chain, the power being conveyed to it by suitable telescopic and jointed shafts.

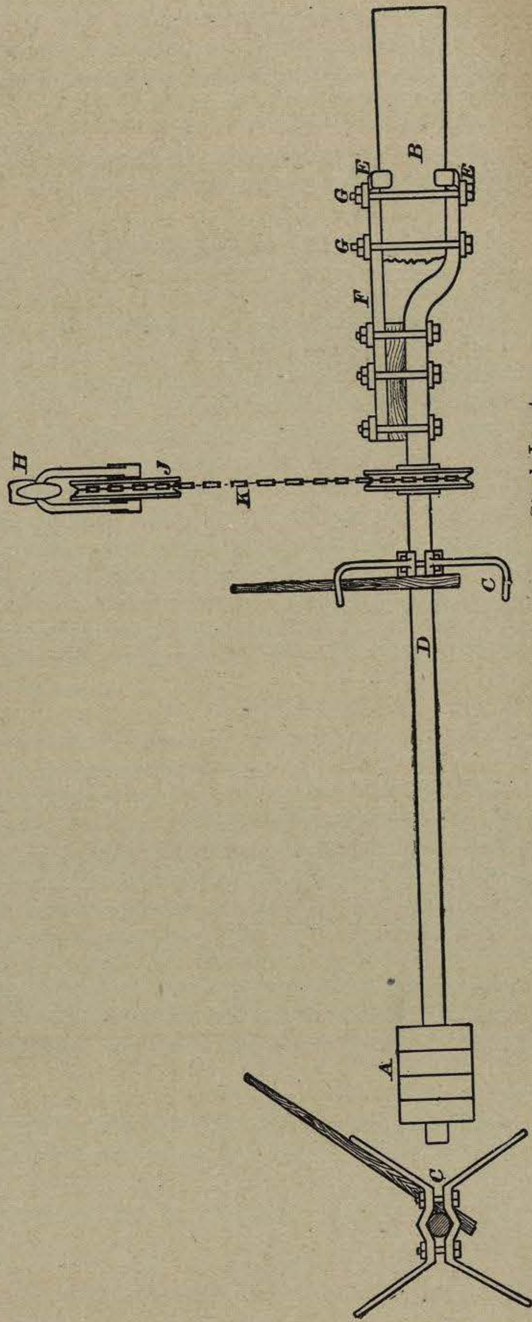

Fig. 526.—Porter Bar for holding a Steel Ingot.

Heating Furnaces.—One end of the ingot thus held on the end of the bar is put into the furnace, the door of which is lowered as far as the forging will permit; the remainder of the space between the ingot, and sides of the opening, is filled in with a wall of loose bricks, and the joints are daubed over with wet loam to prevent the entrance of air which would cause scaling; if the forging is a small one, which can be soon heated, the door is merely closed with a shovelful of small coal, which, if it does not entirely exclude air, burns with it, and by consuming it protects the forging from scaling. The furnaces are of much the same construction as those used in the rolling mills, and have grates from 4 to 7 feet square, and a hearth of about the same width, according to the size of forgings it is intended to produce. They generally have a large door on each side so that if necessary a heat may be taken on the middle of a long bar; other furnaces, for smaller work, may have several small doors, in each of which a forging may be heated. The doors, through which fuel is fed on to the grate, are closed with one or two shovelfuls of fine slack to prevent the entrance of free air, and the fire is usually blown by a steam jet under the grate; in those forges where both iron and steel forgings are made, the large coal is picked out for heating the iron, to raise which to a welding heat needs the long flame given off by large coal, the fine slack sufficing to produce the lower heat required for steel.

The hot products of combustion, on leaving the furnace, are led through the flues of a steam boiler, which furnishes all or most of the steam required to work the hammer.

In the largest forges, more particularly those dealing with very large masses, Siemens reversing gas furnaces are employed for heating the ingot, which differ in no material respect, save in the size of the doors, from those employed for a similar purpose in the rolling mills.

Method of Working.—The shaping of large steel forgings under a steam hammer is conducted on the same principle as the working of small steel forgings by hand at the smith's fire; the smaller the hammer and the piece being worked under it, the more closely is the hand process reproduced. A smith, when using a small steam hammer for work in a smithy, uses the same kind of tools as he employs at his anvil, and in all cases tools of a very similar nature are employed, merely modified to suit the larger scale on which the operations are conducted.

Most readers will have some acquaintance with the ordinary procedure at a smith's anvil, and the chief difference to be observed between the use of the sledge and that of the steam hammer, is that the former can strike at almost any angle, while the steam hammer must always fall directly perpendicularly to the plane of the face of the anvil. The smith can move the piece on which he is working to any part of his anvil, and the sledge will strike it fairly, but when striking heavy blows with a steam hammer, the piece to be worked must be kept near the centre of the bitt, or severe cross strains are set up which may break the hammer framing. The permanent relative positions of the hammer bitts prevent the bending of a large bar in the way adopted when working by hand, according to which the smith leaves the end of the piece projecting beyond his anvil to be hit by the striker's sledge, and so bent over the edge of the anvil. If a bar is of small section it may be bent at the steam hammer by lowering the hammer head upon it, and then turning the full pressure of steam on the top of the piston, by which means the piece is held as in a vice, and the projecting part may be bent over by hand sledges; but a large piece requires more power than can be obtained by hand, and is bent by laying it across two sets placed at a suitable distance apart on the lower bitt, and laying on the top of the bar, midway between them, a third set, which is struck by the steam hammer.

As there is only a short space between the bitts when the hammer is at its highest point, "jumping" a bar—that is, striking it on end so as to swell it in diameter—is only practicable where pieces are short; and if for any reason the operation must be performed on a long piece, the piece is held by the steam pressure as previously described, and the end swelled up by the tedious process of "tupping" it. This is performed by means of a weight known as a "tup" or "monkey," slung from the roof, and drawn back by men pulling on ropes, who allow it to swing against the work in the manner of the ancient battering ram. A very few forges have horizontal hammers, or hydraulic presses for swelling up the end of a shaft to form a flanged coupling, but generally collars of that nature have to be worked out of the ingot.

Half round swages are often used for finishing circular work, but tools of this nature, which are easily handled when of the dimensions required on the smith's anvil, become awkward to move when of the large size required for use at a big hammer; consequently round shafts are frequently finished by lightly hammering with the naked bitts, giving them the form of a polygon with a great number of sides, a matter of no moment when the shaft is intended to be turned afterwards. The place of the "flatters," used by the smith, is taken by the ordinary bitts falling truly together, which is a matter of convenience in this respect, but prevents taper articles being hammered, unless a taper swage is used on the upper side of the bar, or a loose taper face is dropped over the bottom tool.

For light work, bottom sets or swages are employed, which are dropped into sockets on the sides of the lower bitt, much in the same way as they are used in the smith's anvil, but any bottom swages for heavy work are made to sit on the lower bitt, and provided with projections which fit over the bitt on each side.

Where a great number of forgings are required, all of one pattern, they are stamped in special dies fitted in the place of the tools, and by this means complicated forgings can be produced very cheaply in large quantities.

Output of Hammers.—A steam hammer employed to make forgings requiring to be finished to dimensions with care and accuracy, naturally turns out less weight than one employed for merely roughly cogging down ingots for rolling in a mill. Few forgings can be finished right out at a single heat, most having to enter the furnace several times before completion, and as the reheating occupies considerable time, two furnaces are almost always provided for each hammer, and three or four where the space and the arrangement of the cranes permit. The weight of the work produced naturally depends on its character, but taking one class of forgings with another, a 3-ton hammer, supplied by two furnaces, may be expected to turn out 2 tons of general engineers' forgings per shift, and a 12-ton hammer, with the same number of furnaces, 3 or 4 tons. If the work is plain or requires few heats, double this output may be obtained in each case. On average work 100 tons of ingots will produce 70 tons of finished forgings, and 20 tons of scrap suitable for remelting, 10 tons being lost in the form of scale in the heating furnace; the fuel required will be on an average about 200 tons for each 100 tons of finished work, more being naturally required for heavy work, and less for small forgings.

Tendency of Modern Practice.—Given sufficient time, a skilled hammerman can turn out most forgings, direct from the hammer, wonderfully true to shape and size. By finishing the work at, or a little above, a blue heat, he can produce a neatly planished surface having a very attractive appearance. But as this method involves hammering the forging at a heat dangerously near to the temperature where working produces a coarsely crystalline structure, which may extend for some distance below the surface, and render the metal brittle and unreliable, this style of finish is not to be commended unless the forging is annealed after completion, to restore the fine grain which was produced in earlier stages of the work. When lathes were only strong enough to take cuts for roughing-out work, which would now be considered light even for finishing, the cost of machining was such that engineers were obliged to design their forgings so that as much of the surface as possible could be left black from the hammer, and as little as possible should need machining, and therefore forgings had to be finished by the hammer very closely to form and dimensions. There is, however, always a risk that the black scale may hide flaws which can serve as starting points for cracks, and consequently engineers now insist that forgings of any importance shall be machined all over. Since the introduction of heavy lathes having two, four, or more tools, all cutting simultaneously, and each capable of removing from 2 to 5 cwts. of chips per hour, the cost of turning a shaft all over is little more, and in some cases actually less, than when portions are left black from the hammer, while the soundness of the surface is proved by turning it.

Hammers are much more costly to run than the machine tools in the machine shop; the steam required by a 2-ton hammer would drive the heaviest lathe ever made, while hammers further require furnaces which burn a great deal of coal. Lathes, planing, and sawing machines will run for years without repairs, if their cutting tools are reground occasionally, but the hammer often breaks its piston-rod, and is frequently standing while it or its furnaces are being repaired. One man can look after a machine tool, or, in some instances, more than one tool, but a large gang of men are necessary to work a steam hammer and look after its necessary furnaces and boilers, and the hammer and hammermen are constantly standing idle while the forging is heating. There is therefore an increasing tendency to shape forgings less by the hammer and more by some cutting process. As the wages of the machine-tender are the same, whatever the size of the pieces the machine removes, and as large pieces pay for remelting, while small shavings expose so much surface to oxidation as to make them almost valueless for this purpose, all makers of large steel forgings have found it pay to put down very powerful lathes, and to forge the ingot much less closely to size than was formerly customary, trusting to the lathe or planing machine to bring the forging to shape and dimension by removing superfluous metal in the form of cuttings heavy enough to be remelted. The recent improvements in tool steel to be hereafter described are powerful inducements to still further develop this tendency.

Influence of Improved Machine Tools.—The increase in the power of machine tools has enabled crank-shafts to be modified in design with considerable advantage to all concerned. Twenty years ago the portion of the crank-shaft driven by each cylinder of a marine engine, capable of developing 1,000 horse power, had the two parts of the shaft running in the bearings, the two crank webs, and the crank-pin joining them, all made in one piece. This forging measured over all about 8 × 4 × 2 feet. To get enough work on the material in the 4-feet direction required the use of a larger ingot than most steel works could run, or forges could deal with under their hammers. By building this shaft up in five pieces, no single piece need have a greater section than 2 × 2 feet, instead of 4 × 2 feet; this enables much more work to be put on the material. The built-up shaft is not only sounder, but with modern machine tools can be made more cheaply, and if broken can be replaced in less time, a matter often of more importance to the shipowner than its cost. The webs of these built-up cranks are cut by band saws out of blocks of cold steel, the machines admitting material up to 2 or 3 feet thick, and cutting through the metal always at the rate of 30 square inches of section per hour, some saws doing nearly three times this amount of work on soft steel, with an almost nominal cost for saws, which will run for a day or two without resharpening.

The use of band saws, able to cut closely to any curved line, is considerably modifying forge practice; complicated forms, which prove expensive if forged to shape and slotted to size, are cut cheaply to size and shape at one operation from rough blocks cogged by the hammer or the mill; even forgings which cannot be sawn to shape are often roughed out by the machine and sent to the hammer to be forged. For instance, a crank-shaft 6 inches in diameter having two double cranks at right angles to each other forged in one piece with it, can be economically made from a slab a little longer than the completed shaft, whose width is a trifle more than the length of the crank cheeks, and its thickness a little more than their depth. On this the outline of the shaft, with both cranks at present in the same plane, is cut out by the band saw: when the blank is heated, a small hammer will suffice to round those portions which are intended to form the circular portions of the shaft; one of the cranks is then twisted through an angle of 90°, and the forging is finished. If the ingot from which the blank was originally made, and the hammer which roughed it out, were sufficiently large to ensure that enough work was put on it in the first instance, the crank will be quite reliable when finished under the smaller hammer, and the use of a much more costly tool is saved.

Machining Forgings.—The time required to remove a given weight of metal by any cutting process is determined by the amount of heat generated by the act of cutting; when this heat is sufficient to soften the point of the tool, it no longer cuts, but is itself ground away. The harder the metal to be cut the greater the force expended in tearing it apart, and the greater therefore the heat generated at the cutting point; and so the harder the material operated on, the slower must be the travel of the tool, and the lighter the portion removed by it. The intensity of the heat produced depends chiefly upon the speed at which the tool travels over the metal (or the metal over the tool), and in a less degree upon the size of the shaving removed, because the rate at which "work" is done, and heat generated on a unit of cutting surface is exactly proportional to the speed. The surface at the cutting edge being insufficient to dissipate this heat, it can only escape by conduction from the edge to the colder mass of metal behind it, where there is enough surface to get rid of it, the rate of flow depending upon the section of the metal immediately behind the point. A broader cutting edge provides more area for the escape of this heat, and the width of cut could be increased indefinitely without unduly heating the tool (in fact, until the belt driving the machine is unable to transmit the power with sufficient steadiness, or the framework of the machine is incapable of retaining the work and tool in correct relation to each other with sufficient rigidity) were it not that usually some of the heat generated at the active portion of the cutting edge escapes laterally through the metal at the back of the additional portions which are not brought into play. Machine tools intended to remove a large weight of material from a steel forging in a given time, must be run at low speeds and with tools having broad cutting faces, which means the provision of a coarse traverse for the tool; to withstand the stress of such cuts, the machines must be massive enough to ensure sufficient rigidity, and the belt power must be ample to effect a steady cut.

When the cutting is done by a series of tools moving past the piece cut, the tools taking up the cutting one after the other in succession, so that each tool has time to cool when not actually cutting, the speed of travel of tool may be increased; and though each tool may take a comparatively light cut, yet if they follow each other in succession, or if several are cutting at one time, a vast quantity of metal may be removed. Machines, in which a number of tools are fixed in a revolving disc, are very efficient on this account, and may be run at fairly high speeds. The maximum of work done by light cutting at high speeds is arrived at in the band saw, which is so thin, and the shavings removed so small individually, that it is possible to keep down the temperature of the cutting points by means of a stream of soap and water. Band saws may therefore be run with a speed three to four times higher than is possible for an ordinary turning or planing tool.

Machining at High Speeds.—A powerful lathe taking a heavy roughing cut subjects each tool to a pressure of nearly 10 tons, to sustain which, without vibration, needs a very massive frame. An increase in the size of the cut involves a corresponding increase in the stresses on the machine, and additional strength to withstand it; but if a steel can be had which will stand an increased speed of cut without softening under the heat produced by the cut, an increased amount of work can be got through without any increase in the stresses on, or strength of, the machine, and consequently much ingenuity has been expended in the effort to produce such steels.

Ordinary Carbon steel depends for its hardness on being finally quenched when at a suitable heat, which in the case of turning tools is about 450° to 480° F. When tools rise to this temperature during the process of cutting they become soft, and are therefore only suitable for light cuts and low speeds. The so-called "self-hardening" steels, which owe their hardness to the presence of Tungsten, need no quenching to harden them, but are sufficiently hard when allowed to cool in the air after forging, or at most need only to be cooled in an air blast. When at work they will, therefore, stand much higher temperatures without softening, and by their use it is possible to take cuts so heavy that the shavings are raised to a temperature which will change their bright surfaces to a full straw colour. This involves working the tool at a temperature which, were the tool made of Carbon steel, would "draw" its temper and entirely spoil it. With self-hardening steels heavy roughing cuts can be taken on hard steel forgings at a speed of 8 to 10 feet per minute, rising to 15 feet on soft steel; when running on steel of varying degrees of hardness, machines which maintain a uniform speed, such as planers, are on the whole best speeded to run at about 12 feet per minute, or if there is a great preponderance of hard steel, 10 feet may be found as much as is advisable to attempt.

The speeds mentioned above refer only to heavy roughing cuts intended to remove the maximum quantity of metal in a given time. Light finishing cuts can be taken with most steels in a lathe at surface speeds of 20 to 25 feet per minute, and in milling machines at 30 to 40 feet per minute.

Taylor-White Process.—The above represented the best practice since the introduction of self-hardening steel by Mushet, half a century ago, until Messrs. Taylor & White, of the Bethlehem Iron Works, discovered, nine or ten years ago, that steel tools could be produced whose power of resistance increased with the rise in temperature, such tools working satisfactorily when the points were red hot, and the shavings were raised to such a temperature as to leave the work at a purple colour. It was known that if self-hardening steels were raised to more than a cherry red—*i.e.*, about 815° to 845° C.—when smithing the tool,* that the steel was spoiled, but Messrs. Taylor & White, as the result of a most painstaking investigation extending over two years, discovered that if the heating was carried above 940° C., right up to the point where the metal commences to crumble when touched (which occurs at 1,040° to 1,100° C.), and the tool was cooled steadily from these high temperatures, its cutting powers were enormously increased. The fall in temperature must, however, be absolutely continuous, the slightest

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* *Journal of the Franklin Institute*, No. 3, Sept. 3rd, 1901, vol. clii.

rise during the cooling process spoiling the effect. The best result for hard materials was secured by cooling the tool rapidly in a bath of melted lead, and when that temperature was reached allowing the tool to cool slowly in the air. Steel suitable for this method of heat treatment must contain not less than 0·5 Chromium and 1·0 Tungsten, or Molybdenum, or both; the amount of Carbon being comparatively unimportant. Elaborate instructions are given in the patent,[*] and a suitable composition for such a tool is given[†] as follows :—

Cr, ...	2·00	Si, ...	0·15
W, ...	8·50	P, ...	0·025
C, ...	1·85	S, ...	0·030
M, ...	0·15		

Such steel, thus treated, can be run at speeds of 1½ to 2½ times that of ordinary self-hardening steels. The Bethlehem Steel Company, who had had the process in operation in their own works for over a year, exhibited a lathe at the Paris Exhibition of 1900, at work cutting mild steel at 150 feet, medium hard steel at 60 feet, and very hard steel at 15 feet per minute. The result of the introduction of the process in their own works was that the speed of the shafting driving the machines was increased from 90 to 250 revolutions per minute, the average depth of cut from 0·23 to 0·30 inch, the average feed from 0·07 to 0·087, and the pounds of metal removed per hour from 31·18 to 137·3, a gain, over all, of 340 per cent.; and the Company expected to obtain even better results when the driving power of the machines had been increased.[‡]

The method of treatment outlined above is too elaborate for the ordinary tool smith, but the results arrived at have stimulated the makers of tool steel, and during the last two years several English and Continental firms have produced steels which are immense improvements on the ordinary self-hardeners of the Tungsten class, and have obtained results approaching those achieved at Bethlehem. One Sheffield firm are even turning hardened Chrome steel shell with such tools. The modern high-speed steels vary widely in composition. They generally contain less Carbon than the analysis above given, but are higher in other alloys, Tungsten running from 15·0 to 25·0, and Chromium up to 6·0. The instructions for treating them vary very widely.

The leading machine tool makers now supply special lathes, expressly designed to work with these new steels. To reduce vibration, these lathes are unusually massive, and have a spindle, the front neck of which, in the case of the smaller sized machines, is equal in diameter to about half the height of the centres above the bed; they are driven by extra large cone pulleys, wide enough to accommodate a belt run at a very high speed, and of a width equal nearly to the diameter of the spindle; while the gearing for traversing the saddle along the bed is of very exceptional strength. With such machines, cutting speeds of 40 to 50 feet per minute on hard steels, up to 70 or 90 on mild steels, are rapidly becoming every day practice in the best English works. At about these speeds the maximum weight of material is removed in a given time, though speeds 30 to 40 per cent. faster may be employed, if the feed or depth of cut are reduced.

The author recently had the opportunity of seeing a lathe with 16-inch height of centres, made by the Tangye Tool and Electric Co., Limited, tested at the maker's works. Instead of the usual speed cones, this lathe has a plain pulley 21 inches diameter, which is driven at speeds varying between 250 and 500 revolutions per minute by an electric motor, the speed of which can be varied at will, a belt 8 inches wide being used to transmit the power. The motor is constructed to give out 25 horse-power, and to withstand with safety an overload up to 40 horse-power, and on one occasion a cut was put on heavy enough to stop the motor.

The lathe, with only one cutting tool in the slide-rest, performed the following work :—

Material Turned.	Diameter Reduced.		Speed of Cutting in Feet per Minute.	Tool Traversed 1 Inch in Revolutions.
	From Inches.	To Inches.		
Wrought Iron, .	12	10½	50	6½
,, .	12	10½	72	10
Steel Shaft, . .	8	7	65	6½
,, . .	8	7	84	10

At first these tool steels were too hard to be machined, and their use was therefore confined to tools which could be smithed to shape and then ground; but within the past year means have been discovered for softening them by a special annealing process, so that milling cutters can be cut out of them, which can be hardened by merely raising them to a red heat, and allowing them to cool quietly. Seeing how many large cutters, made from ordinary Carbon steel, fly into pieces while being hardened by quenching them in water, this property of becoming hard when heated and cooled in this gentle manner, would be of the greatest value, even if the tools had no greater cutting power. From experiments made at the works of Messrs. Yarrow & Co., Limited, in London,[*] it is clear that twist drills 1¾ inches in diameter, made from such steel, can, when working on mild steel, be run without difficulty at a speed of 100 revolutions per minute, which means a cutting speed on the outer edge of the drill of nearly 46 feet per minute; and that these drills require less frequent grinding than similar drills made from ordinary steel running at the standard speed of 33 revolutions per minute. Both drills made the same advance per revolution—namely, $\frac{1}{200}$ of an inch. One Sheffield firm, who are still experimenting with these drills, claim to have obtained even more striking results, and it is impossible to say what developments in machine tools may not follow when further experience is gained with this new material.

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[*] *English Patent*, R. W. James, 10,738, of 1900.

[†] *Practical Engineer*, May 24th, 1901, p. 485.

[‡] *The Iron Age*, August 2nd, 1900, p. 19.

[*] *Engineering*, January 16, 1903, vol. lxxv., p. 81.