(Paper No. 2936.)

“American and English Methods of Manufacturing Steel Plates.”¹

By JEREMIAH HEAD, M. Inst. C.E.

THE steel-plate² industry of the United States of America has not yet attained the dimensions which it has in Great Britain, where about 300,000 tons³ are consumed per annum for shipbuilding alone, exclusive of armour-plates. In the United States, the yearly consumption for ordinary shipbuilding has so far not exceeded 36,000 tons. But there are other purposes for which steel plates are used to a much greater extent in the United States, such as the fire-boxes of locomotives, where steel of a specially mild character is almost universally employed; while in Great Britain copper has always been considered the most suitable material. In the construction of large buildings, steel is largely made use of in the United States. Frameworks supporting numerous floors are frequently erected to heights of 150 feet, and even more, before any walls are commenced; the framework, and not the walls, being relied on for strength and stability. Such structures often include a considerable quantity of plates. In the construction of overhead railways, which are becoming increasingly popular in American cities, steel plates are also largely used.

Steel-Making Processes.—Mild steel is made from pig-iron by the Bessemer acid, the Bessemer basic, the open-hearth acid, and the open-hearth basic processes. In the two acid processes, any phosphorus contained in the materials operated on is found in the finished product. These processes are therefore applicable only where pig- and scrap-iron can be obtained virtually free from that injurious metalloïd. The two basic processes, by aid

¹ The discussion upon this communication was taken in conjunction with that upon the following one by Mr. Wellman on “Four American Rolling Mills.”

² “Ingot-iron” is perhaps a better term, but the Author has in this Paper preferred to use the more familiar one of “steel” or “mild steel.”

³ Based on Lloyd’s Returns for 1894.

of the basic-lined vessels which alone are employed, are able to remove phosphorus, and can, therefore, make use of the more impure and cheaper qualities of pig-iron. The open-hearth acid process is practically the only one in general use in Great Britain for the manufacture of ingots for plates. The other three processes have been employed, but only to an insignificant extent. For rails and bars of various sections, the first three processes are largely used.

In the United States, the first, third and fourth methods are used for plates, and the first for rails and structural shapes. The Bessemer basic process has scarcely yet obtained a footing for any purpose. This is somewhat remarkable, in view of the fact that, on the continent of Europe, and especially in Germany, the Bessemer basic process seems to have outstripped all others for section bars; and it is steel thus produced which has of late competed so successfully with English steel and iron, not only in foreign markets where the latter formerly held a monopoly, but even in English inland cities.

The cause of these marked preferences for, or neglect of, one or more of the four processes which exist in different countries, it is not easy to determine with certainty; but it is no doubt usually due to local circumstances. Steel works on the seaboard, like most of those in Great Britain, or beside navigable rivers such as some in Germany and Belgium, are well placed for obtaining the rich and pure ores of Spain and elsewhere, which gives them an advantage in carrying on the two acid processes. Those situated inland, such as the remainder of the German works and those in the English Midland counties, are less accessible to foreign ores, and to pig-iron made from them. They are therefore obliged to make the most of the local phosphoric ores, which involve one or other of the basic processes.

Joist or H-section steel, which is now widely known on both sides of the Atlantic, is usually made in America by the Bessemer acid, in England by the open-hearth acid, and in Germany and Belgium by the Bessemer basic process. This variety in modes of arriving at the same result seems to indicate that all are good enough for at all events ordinary purposes, if sufficient care be observed. But as Bessemer ingots are not at present rolled into plates on either side of the Atlantic, except where cheapness is the only or chief consideration, the Author will, for the purposes of this Paper, assume that open-hearth furnaces alone are used.

In the northern States of America, such as Pennsylvania, Ohio and Illinois, the pig-iron forming the basis of the operations

is almost entirely made from Lake Superior ores, brought by way of the great lakes to ports on Lakes Erie or Michigan, and thence by rail to the blast-furnaces. These ores are generally, though not uniformly, very rich in iron and very free from impurities. The resulting pig-irons are distinguished in the market as "Bessemer" if they contain less, and "non-Bessemer" if they contain more than 0.1 per cent. of phosphorus. Although two qualities of pig-iron may vary but little in this respect, yet if that variation is on opposite sides of the limit, it is sufficient to make a considerable difference in the market value.

For working non-Bessemer pig-iron, and so drawing supplies from a wider market and at lower prices, basic-lined furnaces are required. Miscellaneous scrap-iron, which is usually cheap, can then be utilized; whereas with acid-lined furnaces Bessemer pig-iron and best selected scrap, which is relatively expensive, must be used. These considerations have carried such weight that one of the principal American steel-plate makers, who five years ago had only one basic-lined and seven acid-lined furnaces, has now adopted basic-linings to all. Lower carbon, silicon, sulphur and phosphorus can generally be obtained by using a basic- rather than an acid-lining, and the resulting steel is more suitable for such purposes as locomotive fire-boxes. Details are given in the Appendix.

Open-hearth Furnaces.—The capacity of American open-hearth steel furnaces varies between 15 tons and 50 tons, with an average yield of ten charges per week. A production of even 350 tons per week seems large, especially for a basic-lined furnace. In Great Britain, where highly phosphoric pig-iron is commonly used in basic open-hearth furnaces, the slag to be dealt with may amount to about one-third of the weight of the steel produced. Such slag, containing about 16 per cent. of phosphoric anhydride, is a very valuable by-product. But in American practice a marketable by-product has not so far been looked for or produced. The pig is not purposely phosphoretted; consequently such large basic additions are not necessary during conversion. The weight of the slag is not more than about one-fifth that of the steel produced, and nearly as heavy an output can be obtained from a basic- as from an acid-lined furnace of similar dimensions. The metallic yield, or ratio between the iron in

¹ As much as three-fourths of the production in the northern States can be classified as Bessemer pig-iron.

the ingots and in the materials charged, is about 86 per cent. for acid, and 84 per cent. for basic furnaces.

Natural Gas.—In the Pittsburg district natural gas is available both for the melting- and the heating-furnaces. Containing as it does 92 per cent. by weight of combustible matter, instead of say $27\frac{1}{2}$ per cent. for producer-gas,¹ and possessing over twelve times the calorific value, it gives an important advantage in command of heat. Its richness enables the regenerators to be devoted entirely to heating the air, which therefore enters the furnace at a higher temperature than usual. Natural gas is, however, much less plentiful than formerly, and the price has risen until, all things being considered, it is no longer cheaper than producer-gas.² Where the latter heating agent is employed, about 9 cwt. of coal are usually required per ton of ingots in acid, and 13 cwt. in basic furnaces.

Furnace-Charging.—In some cases the introduction of materials into the open-hearth furnaces is facilitated by a charging apparatus which travels along the furnace platform, and comprises hydraulic or pneumatic cylinders for performing the necessary operations. The most recent machines are actuated by electricity. Charging a large furnace by hand requires at least two hours, or by machines say one hour, so that there is obviously ample room for labour- and time-saving apparatus in this direction.

Ingot-Casting.—Steel ingots intended for plates (always excluding armour-plates) vary in weight between 10 tons and $1\frac{1}{2}$ tons and even less, according to whether they are intended to be passed through a cogging-mill, or sent direct to the plate-mill. In the former case they are cast from above, in the latter case from below. The practice of bottom-casting was first devised by Mr. Richard Pink, of the Hörde Works, Germany, and was subsequently adopted at several steel works in England. It was thought to be specially adapted for plate-ingots, because, being undisturbed by pouring at the upper end, they were less likely to be spongy and unsound. It also facilitated partial filling, and so ingots could be obtained of different sizes from the same mould.

Cogging.—The development, and now universal adoption in Great Britain, of powerful cogging machinery, superseding the earlier practice of hammering and cutting by knives, has enabled larger ingots to be dealt with. It has minimised the ill-effects of

¹ Paper on "Fuel Gas" read by Mr. E. McMillan before the American Gas Light Association, 27th October, 1887.

² At present 10 cents (or 5*d.*) per 1,000 cubic feet is paid at Pittsburg for natural gas, and 65 cents (or 2*s.* 8*d.*) per gross ton for coal.

pouring from above, because the disturbed and unsound portion is smaller in proportion to the whole ingot. It has also enabled the ingots to be made of two or three standard sizes, whatever the sizes of the finished plates, thereby greatly reducing the number of moulds in use. By aid of the cogging-mill, and its necessary adjunct the hot-bloom shears, the individual pieces required for plates can be cut with greater exactness than by partial pouring in the ingot moulds, and a somewhat smaller waste in scrap is the result. It has frequently been urged in favour of the cogging-mill and the larger ingots which it renders possible, that it enables more work to be done upon the metal, and that the quality is thereby necessarily improved. An ingot 30 inches thick rolled in the cogging-mill to a slab 5 inches thick, and further reduced in the finishing-mill to a plate $\frac{1}{2}$ inch thick, might be expected to

Fig. 1.

Scale, 1 inch = 40 feet.

TYPICAL AMERICAN STEEL MELTING-HOUSE.

give better results than a flat ingot 12 inches thick rolled in one mill to a similar finished plate. Careful tests, however, fail to reveal any marked advantage of one method over the other,¹ and experience shows that plates of excellent quality can be produced by either method.

Melting-Houses.—At one works only in the United States has the English practice of cogging been adopted. There the open-hearth furnaces, each of which is capable of producing 35 tons of ingots per heat, have basic linings. The ingots are cast to weigh as nearly as possible 10 tons each. The floor of the melting-house, as shown in *Fig. 1*, is on one level, both behind and in front of the furnaces, with the exception of a small pit in front of each furnace, in which stands a ladle large enough to hold the full charge. The ladle when filled is lifted bodily out of the

¹ Journal of the Iron and Steel Institute, 1887, No. 1, p. 126.

pit by an electric overhead crane, and is brought over a row of ingot-moulds into which the metal is successively poured. Each mould stands on a four-wheeled bogie running on a narrow-gauge railway. When empty the ladle is prepared for the next charge and replaced in the pit. The row of freshly-poured ingots is at once hauled by an endless rope out of the melting-house, and into the stripping-house, which is a separate building. Each bogie in succession is there brought under the "stripper," Fig. 2, Plate 1, consisting of a hydraulic ram of two diameters, moving in a vertical overhead cylinder, and carrying on its upper end a second cylinder having independent motion. Suspended from this cylinder is a pair of links engaging with lugs on the ingot mould. The lower end of the ram is planted on the top of the ingot, while the upper cylinder is caused to rise, carrying the mould with it. As soon as

Fig. 3.

Scale, 1 inch = 40 feet.

TYPICAL ENGLISH MELTING-HOUSE.

the ingot is free and no longer needs holding down, the ram ascends, carrying with it the upper cylinder and the mould. The entire stripper is then pushed sideways in V-grooves by a third hydraulic cylinder, and deposits the mould on another bogie on a parallel line of rails, to be returned to the melting-house for refilling. The ingot itself having lost but little heat, is hauled forward to the cogging-house, where it is promptly seized by an electric crane. The brickwork cover having been drawn aside, it is plunged into a vertical soaking furnace to await there its turn at the cogging-mill.

A melting-house such as is usual in steel-plate works in England is shown in cross-section in *Fig. 3*, the ingot-moulds being manipulated by bogie steam-crane, and never leaving the melting-house. The ingots require separate loading upon bogies by the same or a similar crane. They are then drawn by a small locomotive or otherwise to the vertical heating-furnaces, into

which they are deposited by radial hydraulic, or bogie cranes. In some cases the bogie crane performs all the operations. The greater heat in summer, and the less need for economising space, in America, have no doubt led to the removal of the moulds from the melting-house immediately after pouring, and to stripping in a separate building. The plan of keeping both ingots and ingot-moulds always on bogies facilitates the work in several ways.

It will thus be seen that much handling of material is avoided in the American as compared with the English system, as is also shown by the following comparison, in which no account is taken of horizontal hauls of lifts, from the time the raw materials arrive at the works until the ingot is stripped ready for the soaking-furnaces.

English System.

- (1) The raw materials are lifted by an incline or hoist to the level of the charging-platform.
- (2) The ingot-mould is stripped and deposited on the ground.
- (3) The ingot is lifted and deposited on a bogie.
- (4) The ingot-mould is lifted and replaced in the casting-pit.

American System.

- (1) The ladle of molten steel is lifted for pouring and returned to the casting-pit.
- (2) The ingot-mould is stripped and deposited on a bogie.

Ingot-Soaking Furnaces.—The Author has described the course of a 10-ton ingot as far as the vertical soaking-furnace. The additional heat here required is produced in the Pittsburg works by natural gas, the air alone being heated by the regenerators. Soaking-pits without extraneous heating, as introduced by Mr. John Gjers,¹ do not seem to be in use in the United States, and indeed they are but little used in Great Britain. It should however be mentioned that Mr. James Riley, of Glasgow, working with large ingots, adopted, some time ago, eight such pits, in combination with four fired by gas, and operated them without difficulty, notwithstanding the loss of heat at week-ends. On Monday mornings the first round of ingots was placed in the non-fired pits which they heated to the proper working temperature, and they were

¹ Journal of the Iron and Steel Institute, 1882, No. 1, p. 565.

then passed through the gas-fired pits before being rolled. For the rest of the week no external heat was applied, the molten interior of the ingots supplying quite sufficient when evenly distributed throughout the mass. The weight of these ingots was between 5 tons and 7 tons each. Mr. Riley considers that heavy ingots, in which the store of heat is large compared with the radiating surface, can easily be worked as described; whilst for lighter ingots, extraneous heat must always be added.

In Fig. 4, Plate 7, is shown a vertical soaking-furnace heated by producer-gas, as used in America in districts where natural gas is not available, with covers on wheels which are drawn aside by hydraulic cylinders; and in *Figs. 5 and 5a* is shown a vertical ingot soaking-furnace fired by coal, as frequently used in England. In this furnace the door is lifted by a steam or hydraulic radial

Scale, 1 inch = 10 feet.

ENGLISH VERTICAL INGOT-HEATING FURNACE (COAL-FIRED).

crane, or by a long lever on wheels called a "janger." Either of these methods involves more labour than the American plan, which is usually operated by the furnace-man. From the soaking-furnace the ingot, when sufficiently heated, is lifted by the overhead electric crane, and placed in a tippler from which it is tipped upon the end of the cogging-mill live rollers, when cogging proceeds. The cogging-mill contains one stand of two-high steel rolls with live-roller frames at the back and front; it is supplied with tilting gear, and is driven by a pair of geared reversing-engines. It does not materially differ from English practice, and therefore need not be further described. At one of the newest steel-rail works in the United States, the reversing-engine, driving a large cogging-mill, is coupled direct to the train without the intervention of any diminishing gearing. This appears to be a new feature, indicating an increasing tendency

towards direct working. The engine in question has two cylinders 55 inches in diameter with a stroke of 60 inches.

Hot-Bloom Shears.—American hot-bloom shears are usually of the hydraulic type, the cut being effected by forcing upwards the lower blade. In this way the necessity of having one of the roller-frames pivoted, which is essential when the cut is downwards, is obviated. In England the usual practice is to cut with a triple-gearred, double-cylinder engine of sufficient power without a fly-wheel.

Direct Rolling.—The Author proposes now to describe an American works in which ingots of various sizes are cast from open-hearth furnaces, and after being re-heated (or soaked), are supplied direct to the plate-mill, without passing through the preliminary process of cogging. As before explained, the open-

Fig. 5a.

ENGLISH VERTICAL INGOT-HEATING FURNACE (COAL-FIRED).

hearth furnaces are either acid- or basic-lined, according to the steel-making materials available, and to the purpose for which the plates are intended. When the ingot is to be rolled direct into a plate, ascensional or bottom casting is always resorted to. To save space and time the ingots are not cast separately, but in groups of six as shown in *Figs. 6*. There is one central runner, from which the metal is led through radial ducts of fire-brick embedded in a cast-iron base-plate into the bottom of each mould. The top end of the ingot is usually more even and freer from sponginess and side-splashing than if cast from above; but it is never quite equal in shapeliness to a cogged and sheared bloom. It will be observed that only one re-heating is necessary where ingots are rolled direct, as compared with two where cogging is resorted to, and for this natural or producer gas may be used in a vertical furnace, similar to that already described.

Between one and five ingots may be placed in each pit. The charging and drawing are effected by an overhead electric crane. The surface of the plates made direct from ingots seems to be as good as in the case of those made from blooms; and both makers and consumers agree that rejection, either on that account or on account of failure of tests, are now very rare. The tests to which ship- and boiler-plates are subjected in the United States are similar to those required in Great Britain. Particulars of these tests are given in the Appendix.

Plate-Mills.—Whether supplied with ingots or coggled blooms one type of plate-mill (for plates of ordinary dimensions) is in universal use in the United States; whereas in Great Britain another type materially differing from it is almost exclusively

employed. The American standard plate-mill, of which an example is shown in Figs. 7, Plate 7, is driven by a non-reversing non-condensing single-cylinder horizontal engine, working with steam at 90 lbs. per square inch, and furnished with automatic cut-off gear. It has a fly-wheel weighing 50 tons and cylinder measuring 54 inches by 72 inches. This engine turns the central helical pinion of a stand of three rolls. The diameters of the upper and lower rolls are equal, but larger than that of the central one in the ratio of 3 to 2. The upper and lower pinions are coupled to the upper and lower plate rolls, which are each 34 inches diameter and 124 inches long. The middle roll is 24 inches diameter and is driven only by frictional contact with the top or

bottom rolls. The three rolls are of chilled cast-iron, and are kept cool by water flowing continuously upon them. It will be noticed that although the crank-shaft of the engine is coupled direct to the train, or to the middle pinion, the effect of diminishing gearing is obtained by the above arrangement of pinions, and any further gearing is dispensed with. Before and behind the rolls are pivoted live-roller tables, which are lifted and lowered simultaneously by a hydraulic cylinder, through a system of counterweighted bell-cranks. The middle roll is at the same time lowered or raised by hydraulic power to admit the piece through the upper or lower opening. The screwing-down gear is often worked by an electric motor. An ingot such as is usually rolled to a plate in this mill measures 48 inches by 36 inches by 12 inches, and weighs about $2\frac{1}{2}$ tons. There are no roughing-rolls, the reduction from the ingot to the finished plate being performed in this stand of three chilled rolls, and therefore no side transfer-gear is needed.

A standard English plate-mill is shown in Figs. 8, Plate 7. It consists of two stands of two-high rolls, each 30 inches in diameter by 96 inches long; one pair being grain or unchilled rolls for roughing, and the other pair chilled for finishing. The two pairs of rolls, used in succession for each plate rolled, involve two fixed live-roller tables on one side of the rolls, and one traversing live-roller table on the other side. The screwing-down gear is actuated by a small steam-engine. The mill is driven by a pair of non-condensing, reversing engines, having cylinders 42 inches in diameter, by 60 inches stroke, and geared in the ratio of $2\frac{1}{4}$ to 1. The second-motion shaft is coupled direct to the lower of two equal helical pinions, which drive the top and bottom rolls respectively.

Speed-Reduction.—It will be noticed that in the English practice the two functions of speed-reduction and distribution of power to the top and bottom rolls are performed by two separate sets of toothed wheels, or four wheels in all. In American practice the same functions are performed by one set of three pinions. Assuming the same average pressure on the pistons, and the same number of revolutions per minute, it will be found that the single engine which drives the American standard plate-mill exerts about double the indicated horse-power developed by the pair driving the English standard plate-mill. Taking into account the ratios of gearing and diameters of the rolls, it will be further found that the total thrust at the surface of the rolls is about the same in either case, and that the extra power of the American engine is expended in producing higher speed. Where plates are

rolled from ingots without intermediate reheating, speed is evidently of great consequence, to avoid undue cooling. Where they are made from cogged blooms, which are much thinner at the commencement, the high speed of the American mill results in large outputs, as shown in the Table at page 149.

Re-heating Blooms.—The English plate-mill deals with blooms which have been cogged, hot-sheared, and re-heated in a heating-furnace, which may be either horizontal or vertical. In the latter case the blooms are usually brought from the bloom-shears by a bogie steam-crane, and placed two deep, with fire-bricks between, into one of the heating-furnace chambers; and when ready are lifted out separately by a similar crane, and placed for rolling on the live-rollers of the roughing-rolls.

METHOD OF ROLLING A TAPERED INGOT TO A RECTANGULAR SLAB.

Rolling Tapered Ingots.—When a plate-mill deals with cogged blooms which are rectangular in every direction, rolling into a plate of uniform breadth and thickness is an easier operation than when, as in America, flat ingots, tapered say to the extent of an inch in both breadth and thickness, are used. The taper is necessary to enable the ingot mould to be stripped, and must afterwards be eliminated by manipulation during rolling. In American practice the ingot first enters the rolls flatwise, with the thin end leading. The effect of rolling is always to elongate in the direction of motion, to an extent proportional to the reduction in thickness; the breadth is not affected. The tapered ingot is thus reduced to one of uniform thickness, with increased length, but still tapered in breadth, as shown in *Figs. 9*. This side taper cannot be removed by rolling the ingot edge-

wise, as in a cogging-mill, because the top roll cannot be sufficiently raised to admit it. It is therefore passed through the rolls with the broad end first, and cornerwise, allowing first one corner and then the other to lead. In this way the narrow end is spread out sideways to right and left, and a rectangular slab is the result. On the return passes the narrow end must be made to enter the rolls square. The manipulation is managed by the roller and his assistant, who operate with bars and suspended levers.

Cooling and Shearing.—In English iron-plate mills, a few of which still exist, each plate when rolled is received on a two-wheeled flat-topped hand-bogie, and deposited in a vacant place on the iron-plated floor of the mill. There it is flattened by wooden mallets, and by running the bogie over it. Then it is stamped, and, when sufficiently cool, is turned over for inspection of the under side, and marked for shearing according to specification. It is then lifted at one end by the forkers (or shearman's assistants), whilst a bogie is pushed beneath it, and it is wheeled to the shears and placed on the table (or "horse") in front. A portion of the weight of the plate is carried during the process of shearing by the forkers, each of whom holds the edge between the prongs of a fork. When finished it is again placed on the bogie and deposited in the railway-wagons or in a pile for loading as soon as it is passed by the inspector.

In modern English steel-plate mills this somewhat laborious process of handling has been altered. The live rollers on the delivery side are fixed with their upper surfaces nearly level with the floor, and consequently the finished plate can be delivered thereon without the intervention of the hand-bogie. This is an improvement of considerable importance, as the hand-bogie, carrying part and trailing the remainder of a long red-hot plate, is very apt to cause an amount of buckling which cannot easily be eradicated. A pair of gripping-tongs, connected with a chain and steam-winch, is now fixed to the plate, and by means of movable snatch-blocks it can be hauled to any part of the floor which may be vacant, and there left to cool. The marking, lifting, and shearing are, however, still carried out as described above.

The points in the English method of dealing with plates, after leaving the finishing rolls, which are open to objection, are as follows :—

- (1) The plates are cooled on a floor, which necessitates subsequent lifting by hand, an awkward operation at the best.
- (2) As the floor soon becomes hot, and as the top side only of the

deposited plates can be relied on to give off heat, the time of cooling is unduly prolonged.

(3) As a considerable portion of the weight of the plate must be supported by the men during shearing, a large gang of exceptionally strong men (about twelve in all) is required for the work.

To diminish the strain on the forkers, a truck, *Fig. 10*, was devised some years ago at one of the northern plate works, where, the Author believes, it is still in operation. It has four wheels running on a pair of rails level with the floor, and parallel with the shear-blades. The truck-frame carries a pair of rails at right angles with the shear-blades, and on these runs a secondary truck with turn-table top and screw adjustment for height. By the use of this truck instead of the ordinary fixed

Fig. 10.

UNIVERSAL TRUCK FOR PLATE-SHEARS.

table, the men are able to quickly move heavy plates horizontally in any direction, without themselves carrying any considerable portion of the weight. Nevertheless, the firm has not been able to reduce the number of its forkers nor its piece-work rates, though probably it is less dependent on a few picked men. This may to some extent account for the device not having been generally adopted.

As regards plate-shearing American practice differs considerably from English, and in some ways it seems superior to it. Thus, in the United States, when a plate is finished as far as rolling is concerned, it is carried forward by the live rollers, on the delivery side of the plate-mill, to a further series of live rollers placed in continuation of them. This extends, in some instances, for no less a distance than 360 feet from the centre of the plate-mill, and terminates at

the shears. The finished plate, arriving red-hot on the first rollers of this series, remains there cooling on both the upper and lower surfaces, until the next plate is finished, when it is moved forward a stage to make room for the latter. There it remains, still cooling, until another plate is finished, when it is moved on a further stage. In current work the entire series of rollers is covered with plates from end to end. If the plates be 20 feet long on the average, and require three minutes each for rolling, then eighteen stages of three minutes, or fifty-four minutes in all, would be necessary for a plate to traverse the whole length of the series, and that time is sufficient to reduce them to a temperature which admits of their being examined and marked off before arriving at the shears. It might naturally be supposed that plates which, whilst still red-hot, are supported only by rollers, would become buckled. That, however, does not appear to be the case, at least with such as are $\frac{1}{4}$ inch thick and upwards. When cool they are nearly as flat as if they had been laid on an iron floor as in the English method. Should they show any tendency to buckle owing to being finished very hot, they are moved by the live rollers backwards and forwards until they are sufficiently cool to remain level.

Instead of having to send his men with a bogie to lift the plates from the floor one by one, whilst he and the shears are idle, the shearman in America stands with his gang of eight men only, including himself, in front of the shears. His first sight of a plate is when it appears between the blades of the machine, marked for shearing. The live rollers run it through, and when the scrap has been removed from the after end, the plate is turned until each of the other three edges have successively been sheared. In this operation the shearman is assisted by a novel appliance which has as yet been adopted only in one instance in Great Britain. The floor-plates in front of the shears and for some distance around it are perforated with holes about $2\frac{1}{2}$ inches in diameter and 18 inches apart. In each of these holes is fixed an upright stanchion with a castor-roller at the top called a "goose-neck," *Fig. 11*, resembling to some extent an ordinary dinner-table leg inverted. The castor-rollers are level with the lower shear-blade. The plate, as it comes through, is at once received on these goose-necks, which carry its weight, and at the same time allow it to be moved about horizontally in any direction without serious effort on the part of the men, who hold it with their hands protected by leathers. When sheared it is pushed forward, still on the castors, to be weighed, lettered and inspected.

Finally, an electric crane, which spans the whole building, seizes and places it in the truck for shipment, or elsewhere, as may be required. From the ingot to its final resting-place in the truck it is always upon the wheels or rollers, except when it is being re-heated.

Electro-magnets have been used in the United States for lifting plates as shown in *Figs. 12*. They were suspended from an overhead electric crane and electrically connected therewith. The two poles were brought into contact with the plate to be lifted and the current applied. It was found, however, that, if the plate to be lifted happened to lie upon others, some of the latter were apt to adhere to it. Further, when the plate was lowered to the ground and the current cut off, it was not immediately released, a result due to residual magnetism. These

“GOOSE-NECKS” FOR PLATE-SHEARS.

disadvantages and the risk of accidents involved by them have largely led to the discontinuance of the use of electro-magnets for this purpose, even though it was found possible to carry loads of 50 tons by their aid.

Waste in Plate-rolling.—In the manufacture of iron plates from piles made of puddled bar and scrap-iron, a pile weighing 35 cwt. is required to make a finished plate of rectangular shape weighing 20 cwt., which is equivalent to a yield of 57 per cent. But as about 5 per cent. of the iron plates made are found to be defective before leaving the works, and have to be cut into scrap, the proportion should rather be 35 cwt. to 20 cwt. — 1 cwt. = 19 cwt., which is equivalent to a yield of 54·3 per cent. The maximum weekly output of the largest iron-plate mill with which the Author is acquainted is about 820 tons.

In the manufacture of steel plates, the proportion of unmarketable plates is now exceedingly small on both sides of the Atlantic. There is also less waste than in the case of iron, because (1) A steel ingot exposes less surface to the flames during re-heating than a pile of the same weight. (2) Larger masses are dealt with, which involves less surface in proportion to weight. (3) It is not necessary to obtain a welding heat. (4) Less allowance for shearing is needed. A somewhat greater margin must be allowed where ingots are to be worked in the plate-mill than when coggled and sheared blooms are supplied; but this advantage is partly

compensated by the one re-heating in the place of two, with proportionately less furnace waste.

The Table on the following page shows yields from ingot to salable plate in typical mills which have come under the Author's notice.

The following deductions seemed to be justified, viz. :—

(1) A plate-mill worked with a cogging-plant will produce (other things being equal) about double the quantity obtainable from a plate-mill alone, worked direct with ingots.

(2) The loss from re-heating is greater in the former case because of the two heatings instead of one.

(3) But owing to the less margin for scrap, which is necessary when blooms are used in the plate-mill instead of ingots, the former is the more economical of the two methods.

Letter Indicating Mills.	Ingots or Cogged Blooms.	Maximum Weekly Output.	Saleable Plates Per Cent. of Ingots.	Number of Re-heats.	Re-heating Agent.	Total Furnace Waste of Ingots.	England or America.	
<i>Steel Plates.</i>								
(d)	Cogged	Tons. 1,440	71	Average 70.00	2	Coal	5	England
(e)	"	900	65½		2	"	5.65	"
(f)	"	1,120	75¼		2	{ Producer gas	3.12	"
(g)	"	1,867	68		2		{ Natural gas	3.5
(h)	Ingots	850	66	Average 67.62	1	{ Natural gas	3	"
(k)	"	526	69¼		1	{ Producer gas	3	"
<i>Iron Plates.</i>								
(l)	{ Iron piles composed of puddled bars and scrap. }	820	54.3	2	Coal	16.25	England	

The following figures may be taken as representing fair average results:—One hundred tons of steel in the condition of ingots will yield 69 tons of saleable plates and 26 tons of scrap, whilst 5 tons are lost in re-heating. One hundred tons of iron in the condition of piles will yield about 54 tons of saleable plates and 30 tons of scrap, whilst 16 tons are lost in re-heating.

Fuel used in Re-heating.—The quantity of fuel needed for soaking ingots depends (1) on the quantity of heat contained in them when they arrive at the furnace; (2) on the tonnage passed through the latter in a given time; (3) on the method of heating; and (4) on the calorific value of the fuel employed. It varies between almost none at all, as exemplified by Mr. Riley's practice and, say, 2 cwt. per ton where the circumstances are not very favourable. The quantity of fuel needed for re-heating cogged blooms is dependent on similar conditions. It may be taken to vary between 2 cwt. and 4 cwt. per ton of blooms heated. In the manufacture of iron plates from piles in ordinary mill-furnaces, 5 cwt. of good coal is required for the first heating (from cold), and 1½ cwt. for the second heating, making a total of 6½ cwt. per ton of piles heated. Assuming two re-heatings in either case, the total amount of fuel

would average for steel about 6 cwt., and for iron about 12 cwt. per ton of finished plates.

Expansion of Rolls.—So long as plates were made of iron the great widths now obtained in some steel-plate mills were not attempted. In iron-plate mills it usually devolves on the chief roller to turn his rolls and keep them in proper form and condition. This custom still prevails in many steel works in Great Britain. It is not so simple a duty as may appear at first sight. The object aimed at is that the thickness of a plate should be uniform throughout, whatever its width. If the rolls (say in a two-high mill) are turned truly cylindrical, and are worked dry and allowed to become hot, and plates of various widths are, as is usually the case, passed through, the middle portion of the rolls gradually becomes hotter than the ends, and the consequent expansion produces there a greater circumferential velocity. This tends to elongate the central portion of a broad plate more than the sides, and a central ribbon-like buckling is the result. To avoid this trouble, it is customary in England for a roller to turn his rolls slightly smaller in the middle than at the ends. At the beginning of each week he rolls only strips, too narrow to be themselves affected by the tendency to buckle, whilst they serve to heat and expand the middle portion of the rolls. When the latter have sufficiently expanded and become parallel throughout, he is able to roll wide plates without fear of central buckling. In America the difficulties arising from roll expansion are overcome by turning them equal in diameter throughout their length, and keeping a plentiful supply of cooling water running over them. This seems to answer perfectly for all plates except those less than $\frac{1}{4}$ inch thick, which are relegated to a separate mill where the rolls are short in proportion to their diameter, and are worked hot and dry. The water falling on the plates in the larger mill does not cool them as much as might be expected. It always assumes the spheroidal condition, and rolls off without sensible evaporation or absorption of heat, carrying with it any loose scale which may have formed.

In such extreme widths as are now occasionally demanded and made, such as say 13 feet, fresh difficulties arise from the springing apart of the rolls in the middle. If they were turned of slightly larger diameter there than at the ends, the springing would be compensated for, and a plate of even thickness would be produced. This is, however, inadmissible, since it would involve differential velocities, and buckling would result as before described. A plate 13 feet wide, if rolled to a thickness of say $\frac{5}{8}$ inch at the edges, would

certainly be $\frac{1}{16}$ inch thicker in the middle. This spring in the rolls can only be minimized by having them as large in diameter as possible and taking such means as have been described to keep them uniformly cool.

Scrap.—It is obvious that in any works designed for the manufacture of steel plates, the financial results must depend largely on the yield or weight of saleable plates obtained from a given weight of ingots. To reduce the proportion of scrap without running the risk of imperfect edges, is always a principal duty of the plate-mill manager. As the scrap allowance is in the form of a certain margin all round the plate, it is clear that some forms involve more scrap than others. A plate of large area in proportion to the length of its sides, such, for instance, as one square in shape, involves less scrap than one in which the area is small compared with the length of its sides, such as a long narrow strip. The yield of a plate-mill depends, therefore, much on the specifications on which it has to work. The best yield is obtained where a steady flow of large square or oblong plates can be secured, and the worst where long strips are mainly needed. The total output of the mill is similarly affected to some extent. But outputs are still more affected by the average weight of the ingots or slabs rolled. It is manifest that an ingot or slab weighing 1 ton, and rolled into a thick plate, would not necessarily occupy the mill longer than one weighing $\frac{1}{2}$ ton and rolled into a thinner plate. Yet the output reckoned by weight in the former case would be double that in the latter. This points to the advantage of laying out plate-making works in such a way that orders may be sorted, and each size or shape made in a mill adapted to it. Where a works contains one mill only, it must often be employed wastefully on sizes and thicknesses unsuited to it.

Supplementary Mills.—The American standard plate-mill is most advantageously used in conjunction with a universal or “Belgian” mill. This mill is able to roll strips up to 100 feet long, and down to $\frac{1}{2}$ inch thick by 3 feet broad, or $\frac{1}{4}$ inch thick by 1 foot broad, and its total output has reached 900 tons per week. It has two horizontal plain chilled rolls, and two pairs of similar rolls of smaller diameter arranged vertically, one pair being at the front and the other at the back of the horizontal rolls. The universal mill is driven by a pair of horizontal geared reversing engines with 30-inch cylinders. The screw-down gear of the upper horizontal roll is actuated by a hydraulic cylinder with intervening rack and pinions. The vertical rolls are driven by spur- and mitre-gearing from the train pinions, and are adjusted

horizontally by hand-gear. This mill is fed with ingots from two ordinary horizontal heating-furnaces specially allotted to it. The ingots are drawn out by hydraulic rams and delivered to the live rollers on the entering side by hydraulic swing-cranes. The live rollers on the delivery side pass the finished strip, which requires no side shearing, into a straightening press where it can be straightened horizontally. It is then sheared at both ends to the required lengths, and is ready for loading up.

The main mill is usually further supplemented by a sheet-mill of ordinary construction, and supplied with small ingots from two heating-furnaces similar to those last described. In this mill sheets 5 feet wide and between $\frac{1}{4}$ inch and $\frac{1}{16}$ inch thick, and smaller widths down to No. 24 gauge, can be produced; thus relieving the standard mill of all work below $\frac{1}{4}$ inch thick. A similar sheet-mill is often used as an adjunct to English plate-mills, and, indeed, in this respect, there is no difference in practice in the two countries. The American plate-mill, relieved of narrow and thin work, is in a much better position for making large outputs than would otherwise be the case. As before stated, it usually has rolls 34 inches in diameter by 124 inches long, and therefore cannot roll plates more than 9 feet 6 inches wide; but, as has been shown, it deals with plates of all smaller widths down to 3 feet, and all thicknesses down to $\frac{1}{4}$ inch. The standard English plate-mill, having rolls 30 inches in diameter by 96 inches long, cannot roll plates more than 7 feet 8 inches wide; and as universal mills are but little used in England it deals with all smaller widths and thicknesses down to $\frac{1}{4}$ inch.

The English practice is, in fact, to use a smaller mill for general work than is the custom in America. But this smaller mill has, of late years, been usually supplemented by a very large one, Figs. 15, Plate 7. This has but one stand of chilled rolls 162 inches by 40 inches, and is driven by a pair of reversing engines with cylinders 48 inches in diameter by 60 inches stroke, geared in the ratio of 3 to 1. Plates 13 feet wide can here be rolled. Such plates are occasionally required for marine boilers, but their proportion to the rest is very small. Whether the American 124-inch mill, supplemented by a universal mill and a sheet-mill, or the English 84-inch mill, supplemented by a 162-inch mill and a sheet-mill, is most likely to compass the usual market demands with greatest economy, is a difficult question to answer. The two systems, which manifest a considerable difference of opinion and of practice, are possibly reflections of the different requirements of the market on the two sides of the Atlantic.

Plate-Shears.—In Figs. 13, Plate 7, is shown a modern plate-shears as used in England. It will shear a plate 2 inches thick, will pass one 13 feet wide between the frames, and, having 37-inch gaps, will split one 6 feet wide and of unlimited length down the middle. It is driven by a pair of reversing engines of such power that, aided by triple gearing, the maximum cut can be commenced or recommenced and continued without a fly-wheel. It will be noticed that the whole stress of the cut is taken by strong bolts, the intervening castings being made in sections and acting merely as distance pieces. In the United States the largest plate-shears seen by the Author are not adapted to pass plates of greater width than 11 feet between the frames. They can, however, shear up to a thickness of 2 inches. The shears are there usually driven by a single cylinder aided by a fly-wheel, as was formerly the practice in this country.

In Figs. 14 and 15, Plate 7, are shown a typical American steel-plate works laid out as described, and an English works, each capable of a total average output of, say, 1,500 tons per week.

Summary of Conclusions.—The Author is of opinion that the following conclusions may be drawn from this comparison between American and English methods of manufacturing steel plates, viz. :—

(1) There being no extensive demand for ship and marine boiler-plates in America such as obtains in Great Britain, several other important uses have been developed.

(2) American practice supports the view that equally good steel may be made by any of the four modern processes if equal care be taken ; and that basic linings to open-hearth furnaces are advantageous, even where high-class pig-iron is plentiful.

(3) It also shows that, as regards the quality of product and economy of production, the intermediate process of cogging is by no means indispensable.

(4) By the extensive adoption of labour-saving appliances (more especially electric motors), and by keeping the work in progress almost continually on wheels or power-driven rollers, labour is minimized in America to an extent seldom reached in Great Britain.

(5) The American standard plate-mill is, in the Author's opinion, superior to that usual in this country, because it admits of a quicker reduction in the thickness of the ingots or blooms submitted to it, a more economical engine, and less intermediate gearing. The single stand of three chilled rolls, worked always

wet, is simpler and better than two stands of rolls, with one traversing and two fixed roller-frames.

(6) The American plan of cooling the plates on live rollers, and inspecting and marking them in transit, appears to be a decided improvement on English practice, and so also does the use of castor-rollers in front of the shears.

(7) The best performance in the United States does not differ greatly from the best performance in this country, as shown in the Table at p. 149. Steel in both cases compares very favourably with iron-plate making.

(8) The modern English plate-shears, actuated by a pair of cylinders without a fly-wheel, is an improvement on the existing American practice.

There are many other points in which English practice still takes the lead. But the Author refrains from referring to them at greater length, his object being rather to direct the attention of English engineers to American improvements. In conclusion, he desires to record his thanks to various gentlemen who have assisted him with information, especially Messrs. McIntosh, Hemphill & Co., of Pittsburg, Mr. A. Lamberton, of Coatbridge, Mr. H. W. Hollis, of Spennymoor, Mr. John Hill, of Middlesbrough, Mr. George Bartol, of Cleveland, Ohio, and his son, Mr. Archibald P. Head, who has throughout given him valuable aid in preparing the communication.

This Paper is accompanied by nineteen drawings, from which Plate 7 and the *Figs.* in the text have been prepared.

MANUFACTURE OF STEEL PLATES.

Minutes of Proceedings of The Institution of Civil Engineers Vol. CXXVI. Session 1895-96. Part IV.