CHAPTER XII.

ARMOUR PLATE MANUFACTURE.

This branch of the steel industry involves several metallurgical processes peculiar to itself, and has now assumed such large proportions that it is of sufficient importance to merit special notice.

Varieties of Armour Plate.—Armour plates formerly could be divided into two classes—viz., compound armour plates and face-hardened armour plates—but now the face-hardened plate is exclusively used. In all cases the object aimed at is the production of a plate which shall be sufficiently hard to prevent its being pierced by the shot, and at the same time of such toughness that it will not crack or break.

When armour plates were first made, they consisted simply of plates of wrought-iron, and the first great improvement was the adoption of the compound armour plate, which was made up of a soft iron plate united to a face-plate of hard steel. In 1888 the first British all-steel plate was made by Messrs. Vickers with very satisfactory results, and not long afterwards plates made entirely of nickel steel were introduced.

One of the most important improvements in armour plate manufacture was Harvey's invention of a method of face-hardening mild steel plates, by what is known as Harveyising, which consists of carburising one side of a mild steel plate by a process akin to that of cementation, while the other side is allowed to remain in its original condition, or is decarburised by Oxide of Iron; the carburised side is afterwards hardened by sudden chilling with water.

Modern armour is universally made of one or other of the ferro-alloys, usually Nickel-Chromium low in Carbon, with small percentages of Manganese, and occasionally of Molybdenum and Vanadium, &c.; the proportions are usually considered a trade secret, and in all probability vary with the thickness of the plate. Plates may be cast up to 6 or 7 inches in thickness, and may or may not be cemented. Cementation enables a glass-hard surface to be obtained without affecting the tough qualities of the remainder of the plate, and seems to give the best results with a 6-inch plate, the hardening effect extending about 2 inches inwards, gradually diminishing from the outside, and the 2 to 1 proportion between the tough back and the hard face represents good practice. It has been found that the steel for cemented and water-hardened face armour must be much more carefully selected and treated than that for the early chilled armour, and it is very important that the plate should gradually grade from the hard face to the soft back, otherwise under attack the skin flakes off or cracks.*

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* H. J. Jones, *Engineer*, vol. ciii., pp. 361-362.

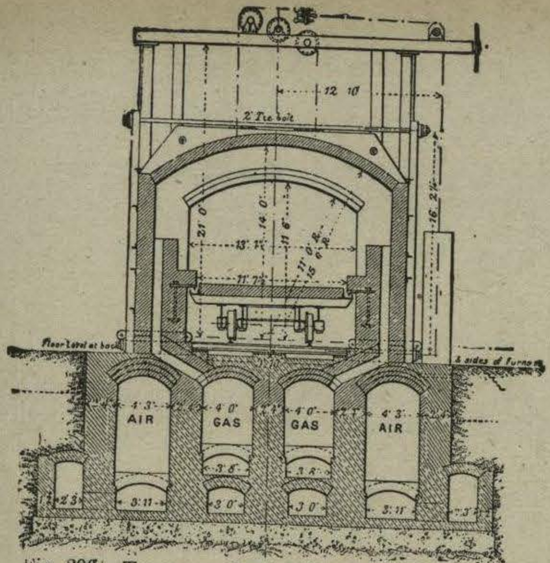

Fig. 206.—Transverse Section showing Car in Furnace.

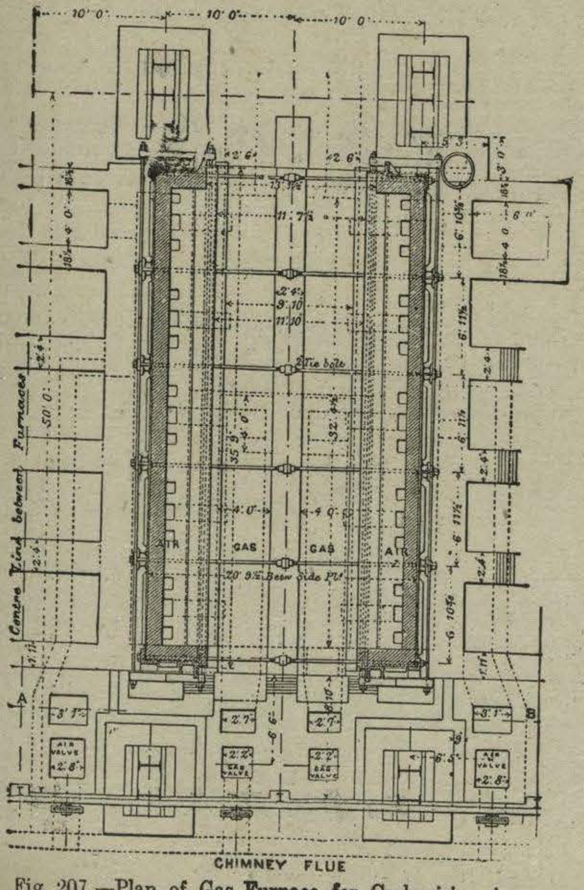

Fig. 207.—Plan of Gas Furnace for Carburising Armour Plates.

Below 4 or 5 inches in thickness, which is usually considered to be the low limit of ordinary **Ni, Cr,** cemented armour, the Charpy high nickel cemented plates appear to be the best as these may be made down to about 1 inch in thickness, and are thus of great value for destroyers, the shields of light guns, etc.*

Krupp-Harveyised Plates.—The manufacture of armour plates at Messrs. Vickers' Works, Sheffield, is a good example of modern practice, and may be thus shortly described. Mild steel, made in open hearth furnaces, alloyed with varying percentages of Nickel, Chromium, &c., is cast into large ingot moulds, and when set, the ingots are taken to a reheating furnace and reheated for slabbing. When sufficiently heated—the largest ingots of 80 tons requiring 18 to 24 hours—the ingot is taken out and placed under an 8,000-ton hydraulic press, and slabbed to a definite thickness. Plates which are to be more than 12 inches thick pass direct from slabbing to the planing shop, where they are accurately machined to the required thickness; but if they are to be less than 12 inches thick they are, after slabbing, again heated, and rolled to the proper thickness. Forging under the press is now often dispensed with, the ingot being rolled direct.

The plate is then supported on knife edges some distance from the ground, to allow a free supply of air to pass round, and when cooled to a certain temperature is placed in a furnace and maintained at a low temperature, and then plunged into water. Pneumatic scaling hammers remove the scale, and the plate is then machined.

The next operation is the carburising, performed in a gas-fired furnace of the car type—*i.e.*, a furnace with movable hearth on wheels, 36 feet long and 21 feet wide (figs. 206, 207, 208, and 209). The outer walls of the furnace are of brickwork cased round with rolled steel plates, supported by rolled joists, and braced together by steel bolts. The car is built up of rolled **H** beams, the sides being of channel iron filled with sand. The top of the car is covered with several thicknesses of fire-brick to protect it from the heat of the furnace, and upon them a series of flues is constructed extending the full length of the car, for the passage of the hot gases. Two plates, with a layer of a mixture of powdered animal and vegetable charcoal between them, are placed on the brickwork forming the flues, walls are built on all four sides, and the whole covered with sand. When the car is thus loaded it is run into the furnace, and the doors closed and made airtight. The hot gas enters at the back, the flames pass over the top, down the front, and through the flues under the plates to the chimney. The heat of the furnace is gradually increased, and kept at a suitable temperature for two or three weeks. The depth to which carburisation extends depends on the temperature of the furnace and length of time of treatment; it is also probably facilitated by continuous firm compression of the carbonaceous material against the surfaces by the weight of the upper plate.

Krupp in some cases modify the above method by using hydrocarbon gases such as paraffin vapour, petroleum gas, illuminating gas, &c., for cementation, but to what extent it is difficult to say, as the details of armour plate manufacture at Krupp's works are not published. After cementation the plate is allowed to cool slowly in the furnace, and is then oil-hardened to break down the coarse crystalline structure produced by the prolonged heating. It is then softened to permit of bending and machining, and any holes which

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* Tressider, *Naval Annual*, 1905, pp. 366-371.

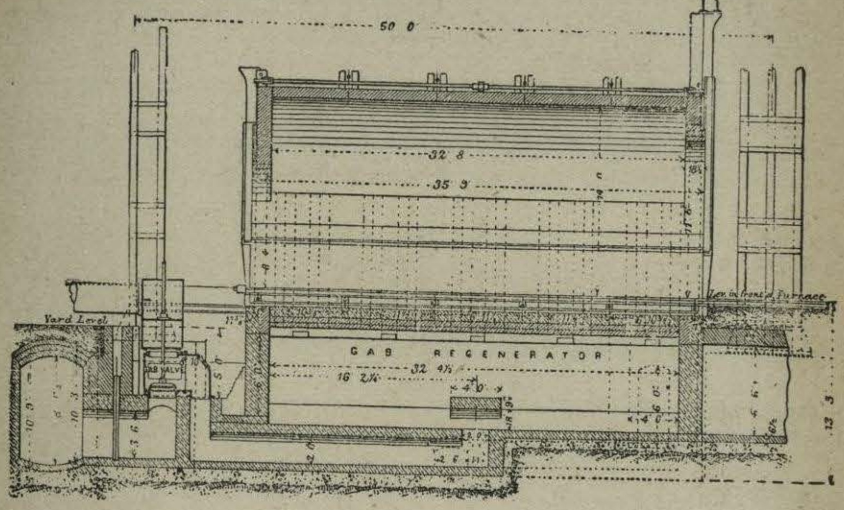

Fig. 208.—Longitudinal Section.

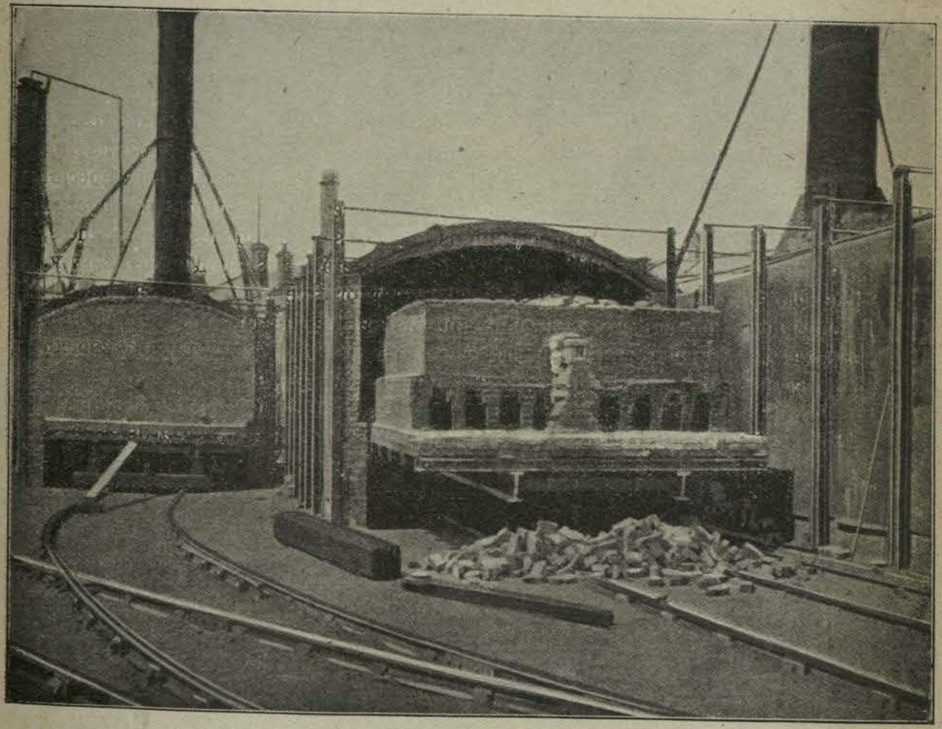

Fig. 209.—General view of Carburising Furnace for Armour Plates, showing Armour Plates in position on car, built in with brickwork, with flues for circulation of the gases.

have been drilled are plugged with clay to prevent injury during the subsequent hardening process.

The hardening is the next important part of the process, and for this the plates are reheated to cherry redness, and are placed on an iron grid, and jets of water "squirted" on both top and bottom of the plate simultaneously. The pressure of water is about 10 lbs. per square inch—sufficient to prevent the formation of steam under the water, which would interfere with the chilling effect. The jets of water are delivered from a number of tubes, distributed over the whole of the upper and lower surfaces of the plate by holes drilled in the tubes, ¼ inch in diameter, and 4 inches pitch. The upper system of tubes is supported on a movable carriage, so that they can be run out of the way when the plate is lifted on or off the gridiron. For a 14-inch plate the sprinkling takes three hours, and requires four to five thousand tons of water.[*] The depth affected by hardening is from 1½ to 2 inches. The hardening by means of jets of water is really Tressider's[†] process, in which the plates to be hardened are subjected to a douche or spray of cold water, which is supplied by a great number of small jets at sufficient pressure to prevent the retarding effect of an envelope of steam.

Any final adjustment that may be necessary after hardening can only be done by grinding, as it is not possible to machine the plates.

It was originally the custom to cover the backs of the plates, when in the cementing furnace, with Oxide of Iron instead of sand, to burn out or oxidise the Carbon, and thus insure a very soft steel at the back, but in practice sand has been found to give good results, and, so far as the author is able to obtain reliable information, seems to be generally employed.

Cast Armour Plate.[‡]—Cast armour plate is now only used for small irregular structures which cannot be built up with plates, and good results can be obtained. The metal is cast into moulds to produce a plate having ridges and channels. The hot casting is allowed to cool slowly in a special furnace, then removed to the cementing furnace, and upon the corrugated surface a carbonaceous composition is placed several inches in thickness, the furnace is raised to 900° to 1,100° C. for several days, then cooled slowly. The plate is again reheated and cooled four or five times with a gradual reduction of temperature each time, and at the final heating it is dipped into or sprayed with oil or water, so that the corrugated face, being rapidly cooled, will become hard, whilst the back remains soft and tough.

Materials Employed.—As regards the material now used for armour-plates, each manufacturer has a particular metal which he regards as best for his purpose; but, generally, it is a Nickel-Chrome steel, with varying percentages of Nickel and Chromium, containing sometimes Vanadium, Molybdenum, and possibly other metals. The hardness, toughness, and power of the plate to resist penetration depend very largely upon the special heat treatment to which it is subjected, and there is no branch of metallurgy in which intelligent discriminating treatment has been more systematically applied, or has produced such remarkable results, as in armour-plate manufacture. Hadfield[*] states that the Nickel-Chrome Steel as forged may, by suitable heat treatment, have its tenacity increased from 40 to 90 per cent., and its ductility from 8 to 30 per cent.

The armour plates made for the United States Navy are said to contain about 3·25 per cent. of Nickel, and some analyses of an American armour plate made some years ago gave the following composition:—Carbon varied from 0·26 to 0·90 per cent.; Manganese, from 0·79 to 1·10 per cent.; and Nickel, from 2·39 to 2·50 per cent. A good average Krupp plate contains[†] Nickel, 3·5 per cent.; Chromium, 1·5 per cent.; Carbon, 0·3 per cent.; and Manganese, 0·7 per cent.

It is very important to remove both the bottom and the top of the ingot before forging down, and in practice nearly one-third of the ingot is removed from the top and about 5 per cent. from the bottom. According to Mr. S. E. Stuart,[‡] it was the custom in America in 1893 not to use more than one-half the ingot, and, in any case, every precaution is taken to ensure that only the sound portions are forged down for the plates.

Wilson's Compound Armour Plates.—Although compound armour plates are now practically obsolete, some short indication of the methods of their manufacture may be of interest. By Wilson's process a soft tenacious wrought-iron plate is united with a hard steel plate in the ratio of ⅓ steel to ⅔ iron.

The iron plate, built up by welding together wrought-iron plates, is carefully manufactured to fit an iron mould of the shape of the compound plate required. The space between the iron plate and the inside of the mould is then filled with molten steel, which unites with the iron plate so well that the line of contact can hardly be seen. The compound body, when sufficiently cool, is removed from the mould and gradually reheated in a furnace. The mass is then subjected to hydraulic pressure, after which it is rolled and reduced to the required thickness. The plate is next bent under the hydraulic press, and finally machined and drilled.

The Ellis process consists in combining a soft, tough iron back with a hard steel plate, by casting a layer of steel between the two.

A process for making what may be called compound armour, and avoiding the tedious process of cementation, was patented some years ago by Messrs. Beardmore, of Glasgow. Ingots, consisting of layers of hard and soft steel perfectly united, were cast in the following manner:—

A layer of hard steel is run into a horizontal mould, the bottom of which is kept cool by a number of pipes through which cold air circulates. The bottom layer of the steel consequently sets very quickly, and while its upper part is still to some extent fluid, a second layer of softer metal is poured from the sides over the first, flows gently over it, and unites with it. Similarly, a third layer may be added, a considerable head of metal being allowed to give soundness. These ingots are pressed and rolled into plates, which can at once be bent to shape, machined, and chilled.

By this means any desired depth of hard metal was obtained on the face of the plate, while in the cementation process it is very difficult and costly to carburise to a greater depth than 2 inches; the process had the further advantage that the time required to manufacture an armour plate was reduced to one-half.

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[*] *Engineering*, vol. lxiv., 1897, p. 608. This supply is obtained, by special pumping machinery, from the Don, which runs past the works.

[†] Weaver, "Notes on Armour," *Journ. U.S. Artillery*, vol. iii., 1894, p. 417.

[‡] H. J. Jones, *Engineer*, vol. ciii., p. 362; *ibid.*, vol. ci., p. 20.

[*] Presidential Address, *Iron and Steel Inst. Journ.*, 1905.

[†] H. J. Jones, *Engineer*, vol. ciii., pp. 361-362.

[‡] *Report of the Chief of Ordnance*, 1893, pp. 645-657.

This process is quite distinct from the old method of casting a layer of hard steel on to a wrought-iron plate, in which there was always some risk of the two metallic surfaces being somewhat imperfectly united, so that they were liable to part on receiving the impact of a shot. It has, however, never been largely used, and practically the Krupp cementation is the one universally employed.

CHAPTER XIII

DIRECT PROCESSES OF STEEL MANUFACTURE.

NUMEROUS attempts have been made to produce wrought iron and dead soft steel direct from the ore, and it might at first sight appear that this was a more rational proceeding than to first make an impure cast iron, and subject this to a refining process to convert it into steel. Iron can be reduced in a very pure state from its ores at a comparatively low temperature, and even in the case of Phosphoric ores a metal can be obtained almost free from Phosphorus, the latter being removed as Phosphate of Iron at the low temperature employed, at the cost, however, of a considerable loss in iron.

Difficulties Involved.—The great difficulties, however, of reducing large quantities of ore by any of the known processes, coupled with the fact that the product is obtained as a spongy mass and not in a fluid state, have prevented any of the direct processes ever proving serious rivals to either the Bessemer or Siemens processes, the advantages that the latter possesses in the way of immense outputs, with resulting small labour costs per ton of material produced, being too great. Professor Howe, writing in 1892, expressed the opinion that the only future for direct processes was, as scrap producers, to prepare a metal for Siemens furnaces, or similar purposes, but events since then do not point to any serious development even in this direction.

The more probable development, in the author's opinion, lies in a combination between the direct and indirect processes on the lines proposed by Mr. Twynam (p. 203), by which the metal will be obtained as ingot iron or dead soft steel. The ordinary Siemens furnace is a direct process in so far that a small quantity of ore is reduced during the working of the charge, and if this could be increased to 50 per cent. of the charge without seriously decreasing the output of the furnaces, considerable economy would result, and further experiments on these lines will be watched with great interest. The processes, however, which we have to consider, known as "direct processes," are defined by Howe* as follows:—"Direct processes are those in which wrought iron or spongy iron is made direct from the ore, and either used as such or converted into steel usually by melting it with cast iron, more rarely by cementing it with carbonaceous material, or in which weld or even ingot steel is made direct from the ore."

These processes can only be used either in new countries, where small quantities of material are required, or where some other special conditions exist, such as very rich ores and fuel unsuitable mechanically for blast furnace work, or when the latter is exceptionally dear.

The following are descriptions of the better known direct methods of reduction, starting with the more primitive processes:—

Native Forge or Bloomery Processes.—Iron by these primitive processes is still made in some parts of India, Burmah, and the East Indian Islands. The furnaces used are of two kinds—those worked with natural draught and those with artificial blast. Those worked with natural draught

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* Howe, *Metallurgy of Steel*, p. 259.

are usually situated on the exposed side of a hill, and have a stack of about 10 feet high cut in a bank of sandy clay, the breadth of the stack being about 1¾ feet at top and 5½ to 6 feet at bottom, and depth 1¾ feet at top, 1 foot at bottom, and widening at about the middle to 2 feet. The front of the stack is formed by a solid wall 3 feet thick. An arch cut in the foot of the bank communicates with the rectangular aperture at the bottom of the stack of the full width of the latter and about a foot high. This aperture is filled up with soft clay, through which about twenty nozzles or twyers of burnt clay are inserted. The furnace is dried, and then a bed of charcoal at the bottom is ignited, and ore and charcoal charged alternately (total, 420 lbs. ore, 437 lbs. charcoal). The slag is tapped eight or nine hours after starting and every half-hour until flow ceases. The furnace is then allowed to cool, the clay stopper removed, and the reduced iron (90 to 120 lbs.) taken out and freed from slag and unconsumed charcoal by reheating.

The furnaces worked by a blast from bellows are manipulated in a way similar to those worked by natural draught. The furnaces are made of sandy clay, and have stacks, 3 to 5 feet high, and 18 to 20 inches diameter, slightly conical in shape, with an arch cut out at the bottom for the blast nozzle. The ore and fuel are fed into the furnace, from an inclined platform at the top of the furnace. The operation lasts four to six hours, and the slag is tapped at intervals. The ores treated are usually brown hematites, broken small, and previously calcined with charcoal or brushwood. The reduced metal (a ball of iron 20 to 40 lbs. in weight) is preferably taken from the furnace by a pair of tongs from the top. In Borneo the furnace used is built of yellow clay, tied round by hoops of bamboo. It is a little more than 3 feet in height, and 10 feet in external diameter, with walls about 2 feet thick; it is square on the inside, narrowing towards the hearth, which is 2 feet long, and 1 foot 7 inches wide. "Each furnace has three twyers, an opening for running off the slags, and an external basin for their reception." "The blast is not obtained by bellows, but by a blowing-engine, consisting of a single-acting cylinder of wood, open at the top and closed at the bottom, the blast being conveyed to the twyers by means of bamboo tubes." The ore treated is clay-ironstone, which is first roasted in heaps with wood, and then broken into small pieces the size of nuts, and charged into the furnace, ten times the bulk of fuel being used.

The slag is tapped off every twenty minutes, and the lump of iron obtained weighs about 100 lbs. It contains much intermingled slag, which is removed by dividing the piece into ten pieces, and hammering. Both soft and steely iron can be made in these furnaces, by altering the proportions of charge and nature of fuel used.

Wootz or **Indian steel** is manufactured from iron made in the ordinary Hindoo furnace, in the following way:—Small crucibles of refractory clay are used, in each of which about a pound of metal is placed, with a certain proportion of finely-chopped wood (*Asclepias gigantea* or *Cassia auriculata*). The crucibles are then covered with one or two green leaves (*Convolvulus laurifolius*) and wetted clay, and placed in the sun to dry. When the plugs have hardened, twenty to twenty-four of the crucibles are built, in an arched form, on the bottom of a small blast furnace, blown by bellows, and strongly heated for two to three hours. The furnace is then allowed to cool, the crucibles taken out and broken, the steel having melted down to a rounded button at the bottom of each pot. Probably in order that it may be completely melted the steel is over carburised, and before drawing out into bars the buttons are heated for several hours in a charcoal fire, urged by bellows, to a temperature not much below their melting point, and turned over before the blast, so that the metal may be partially decarburised.

Puddled Steel.—Though the production of steel by puddling is not, strictly speaking, a direct process, it is, nevertheless, convenient to refer to it in this chapter.

There is no essential difference between the manufacture of puddled iron and puddled steel, except that the puddled iron is decarburised to a greater extent than is the case with the steel. Highly carburised manganiferous pig-iron is generally used, and gives the best results. The furnace is similar to that employed for the manufacture of ordinary puddled iron, but the hearth is smaller in proportion to the grate, in order that a very high temperature may be attained. The charge is generally about 3 cwts., and consists of one kind of pig only. It is introduced in small fragments of uniform size, and is spread evenly, so as to insure uniform fusion without much oxidation. The charge is rendered perfectly fluid and covered with molten slag, in order that the fining may go on slowly. It is very important that the slag should be very fluid, and this is the reason for selecting a manganiferous pig, so that the presence of Protoxide of Manganese in the slag may increase the fluidity, without increasing the oxidising effect. The slag must be less basic than that used in the puddling of iron, and the stirring period lasts longer. The balling should be performed in a neutral or non-oxidising atmosphere, and the shingling done at a comparatively low temperature. Puddled steel is no longer manufactured to any extent, although thirty years ago considerable quantities were made.

The Catalan Process.—This process is now practically obsolete, but is of historical importance, having been used for centuries, and having only recently gone out of use. A low hearth, with one inclined twyer, is used, and the charge of ore and charcoal added separately, the charcoal on the twyer side of the hearth, and the ore in lumps not more than 2-inch cube on the other. The Carbon Monoxide, from the combustion of the charcoal, has a freer passage through the pile of lump ore than through the thick body of charcoal, and thus passes out this way, and so reduces the ore. A gentle blast is used at first, but after about two hours the lump ore is gradually pushed downwards, and blast increased; the ore, as it becomes reduced, is pushed down to the hot region near the twyer. As the charcoal burns away, more charcoal, mixed with some fine moistened ore, is added. Most of this fine ore passes down the twyer unreduced, and together with other unreduced ore, of which there is always a certain quantity pushed down with the reduced lump ore, forms a slag with the gangue, the temperature of the twyer region being sufficiently high for this purpose. The slag, which is essentially a basic ferrous silicate, when highly ferruginous, tends to dephosphorise and decarburise. The reduced part of the charge becomes pasty in the twyer region, and welds readily into a bloom. When the whole of the charge is worked down the blast is stopped, the bloom taken out, and hammered. In this process, by keeping the conditions as reducing as possible, so that the metal is not decarburised during the operation, steely iron can be produced, but this depends largely on the skill of the workmen; in any case the steel produced is of very uneven degrees of carburisation.

The American Bloomery Process.—This is still used in some parts of Canada and the United States, but is only applicable where rich, fine ores, charcoal, and labour, are cheap. In this process fine ore and charcoal are charged together; otherwise, in general features, it resembles the Catalan process. The hearth is nearly square, the bottom is formed by a water cooled cast-iron plate, and is covered by a hood of brickwork, enclosing a series of three or more syphon pipes, in which the blast is heated by the waste gases.

Stückofen (The Old High Bloomery).—This was a shaft furnace, 10 to 16 feet high, round or rectangular in section, about 2 feet 6 inches wide at the top, 4 feet 2 inches midway, and 1 foot 6 inches at the bottom. The furnace had one twyer 1 foot 2 inches to 1 foot 8 inches above the bottom, and a drawing hole about 2 feet wide at bottom, which was closed except when removing the bloom. In these furnaces there was a great tendency to make cast instead of malleable iron, and to guard against this the carburising tendencies were purposely restrained—*e.g.*, by charging a large proportion of ore to charcoal.

Husgafvel's High Bloomery or Continuous Stückofen.—This furnace is 26 feet high, 5 feet wide at boshes, and 4 feet wide at the throat. It has double air-cooled wrought-iron walls, separated by a continuous spiral diaphragm plate, thus enabling the blast to be heated by travelling circuitously downwards between the two walls. The air-way thus formed is connected at two or three places with the cold-air main above and with the hot-air main and twyers below. The lower 5 feet (between the top of the hearth and the boshes) are lined with fire-brick, the remainder of the shell being unprotected, and a movable air-cooled cast-iron section is provided between shaft and hearth. The hearth is a movable cast-iron box mounted on wheels and standing on a lifting platform. It has four water-cooled twyer-holes on each of two opposite sides and at two different levels, into which the blast nozzles can be adjusted by telescopic pipes and goose-necks; also four slag notches at different levels, trunnions for dumping, and a false bottom to save the hearth proper from accretions. Ores (chiefly Phosphoric bog-ores) and hammer scale are smelted in these furnaces with charcoal, both coarse and fine, in the following manner:—Charcoal and ore are charged in uniform horizontal layers, fine charcoal being added to fill up the interstices in the lump charcoal, and so prevent the fine ore sifting down too quickly. A fresh hearth is fitted into place, the twyers inserted in the lower twyer-holes, and the blast turned on. The burden descends gradually, and reaches the hearth quite reduced, and probably considerably carburised. The slag is tapped at intervals, but its level is kept slightly above that of the gradually-forming bloom, so that being highly ferruginous it assists the decarburising action of the blast. When the bloom has almost reached the level of the lower twyer-holes, the twyers are removed, the holes plugged, and the twyers raised to upper holes. When the bloom has reached the upper twyer-holes the blast is stopped, the hearth is lowered and immediately replaced by a fresh one, so that the furnace works continuously. With slow driving and light burden the slag becomes less ferruginous, less Phosphorus is eliminated, and the product becomes steely, or even cast iron. The composition of the slag varies greatly—with very slightly carburised blooms it contains 52·46 per cent. **FeO** (40·8 per cent. metallic iron), and with highly carburised blooms about 9·91 per cent. **FeO** (7·15 per cent. metallic iron).

Chenot's Process consisted in reducing iron ore in retorts either by *direct* heating with charcoal or *indirectly* by hot Carbon Monoxide from a gas producer. The furnace consisted of one or two vertical rectangular retorts, 28 to 33 feet high, 1 foot 4 inches to 1 foot 8 inches wide, and 4 feet 9 inches to 6 feet 6 inches long, heated by means of external fires. Below each retort was a sheet-iron water-cooled "refroidissoir," or cooler, in which the sponge was allowed to cool out of contact with the air. The charge of a furnace was about $1\frac{1}{2}$ tons of calcined iron ore and about $\frac{1}{2}$ ton of charcoal. The charge remained three days in the retort and three days in the cooler, a part of the sponge being withdrawn each day from the bottom of the cooler. The sponge was worked into blooms in a charcoal hearth or melted in crucibles. The above applies to the *direct* process; in the *indirect* process the retorts were connected with gas producers and an upward current of gas maintained through the charge in the retorts.

Blair's Process, a modification of Chenot's process, was introduced in 1870. In this process it was attempted to overcome the difficulty of heating a large body of ore in the retorts, with consequent waste of fuel, by passing very hot producer gas through the ore and charcoal in the retorts, but this process has not been a commercial success.

Eames Process (Carbon Iron Company's Process).—In this process iron ore is reduced by mixing it with "retarded" (or "protected") coke or graphitic anthracite, and heating it by natural gas on the bed of a reverberatory furnace, which is covered with a layer of anthracite about 4 feet to 6 feet thick; the furnace is about 19 feet long, 6 feet broad, and 18 inches from roof to hearth, and is heated with natural gas at both ends, the products of combustion escaping through a flue in the middle of the roof. The charge consists of 1 ton dry rich ore (containing 62 to 65 per cent. iron) and about 5 cwts. of graphitic anthracite or retarded coke, all ground to pass a 16-mesh screen, mixed with water to render it plastic, and spread over the hearth in a layer about 4 inches thick. The metal is reduced at a low heat, and as reduced is protected from re-oxidation by the retarded coke with which it is mixed. If the metal is required for the open hearth furnace it is balled after about an hour and a-half, but if for rolling, balling takes longer, and the temperature must be raised to welding heat.

This process is said to have been worked successfully by the Carbon Iron Company, Pittsburg, U.S.A., where cheap fuel is obtainable. The spongy iron was partly taken direct to, and used in, the open hearth furnace (50 per cent. cast iron, 10 per cent. scrap, and 40 per cent. sponge-balls), and partly rolled into bars for use in crucible and open hearth processes.

Siemens Process, introduced in 1873, consisted in the reduction of fine ore by mixing it with coal and heating in a rotating furnace. The furnace was gas-fired and regenerative. The lining was of brick or bauxite, and fettled about 6 inches deep with hammer or roll scale or mill cinder, and then soft lumps of hematite or rich cinder were thrown in to roughen the surface and divide the charge while rotating. The rotator was charged at one end through a door, and the entrance for gas and air and exits for the products of combustion were at the other end. The charge consisted of pea-sized ore, bituminous coal for reduction, and limestone to form a moderately basic slag, and varied, according to size of furnace, from 24 to 50 cwts. For the first $2\frac{1}{2}$ hours the temperature was comparatively low and rotation slow—12 to 15 revolutions per minute. The charge then began to clot, slag formed, the temperature and rate of rotation were increased, and the slag tapped from time to time. Finally the temperature was raised to a white heat, and except for stoppages for balling and withdrawal the rate of rotation further increased. The whole operation lasted $4\frac{1}{2}$ to 6 hours. The fuel consumption was high and the loss heavy, while the iron was unsuitable for use as wrought iron, owing to its spongy nature and difficulty of separating it from entangled slag, but was suitable for use in the open hearth furnace.