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1866

ON THE MANUFACTURE OF MALLEABLE CAST STEEL,

Its Progress and Employment

AS A

SUBSTITUTE FOR WROUGHT IRON.

Printed for distribution

BY HENRY BESSEMER.

POTTSVILLE:
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E.W.C. Jan 26 '04
W.S.C. 8 Jun '08

ON THE

MANUFACTURE OF CAST STEEL.*

On the 13th of August, 1856, the author had the honor of reading a paper before the Mechanical Section of the British Association at Cheltenham. This paper, entitled "The Manufacture of Malleable Iron and Steel without Fuel," was the first account that appeared shadowing forth the important manufacture now generally known as the Bessemer process.

It was only through the earnest solicitation of Mr. Geo. Rennie, the then President of the Mechanical Section of this Association, that the invention was, at that early stage of its development, thus prominently brought forward; and when the author reflects on the amount of labor and the expenditure of time and money that were found to be still necessary before any commercial results from the working of the process were obtained, he has no doubt whatever but that, if the paper at Cheltenham had not then been read, the important system of manufacture to which it gave rise would to this hour have been wholly unknown.

The diagram A shows in section the original fixed converting vessel, as patented and erected in London for experimental purposes in 1856. It will be observed that the tuyeres were passed through the sides of the vessel in a horizontal direction; the result was that the blast of air entered only a short distance into the fluid mass, and much of it escaped upwards between the sides of the vessel and the metal. The effect of this was the rapid destruction of the brick lining, caused by the excessive temperature generated in the process and the solvent property of the resulting silicate of protoxide of iron, which sometimes destroyed a lining of half a brick in thickness during the blowing of two charges of metal for about twenty minutes each. Another difficulty arose from

* Read before the British Association.

the impossibility of stopping the process without running out the metal, for if the blowing ceased for one instant the fluid metal would run into the tuyeres and stop them up.

A great inconvenience of the fixed vessel also arose from the danger and difficulty in tapping out the fluid malleable iron with a bar, after the manner of tapping an ordinary cupola furnace, for the blast had to be continued during the whole time the charge was running out of the vessel in order to prevent the remaining portions from entering the tuyeres. A similar difficulty arose while running in the crude metal from the melting furnace, since it was necessary to turn out the blast before any metal was run into the vessel, the first portions so run in were, in consequence, partially decarbonized before the whole of the crude metal had left the melting furnace.

These were among the more prominent difficulties that had to be remedied. It is, however, satisfactory to know that even in this, its infant state, the process and apparatus were practically successful, in proof of which there is placed upon the table part of a malleable iron railway bar made from pig iron, at Baxter House, by blowing air through it in the apparatus just described, the fluid malleable iron having been run into a 10 inch square ingot mould and the bloom so made rolled direct into the bar shown. The small malleable iron forged gun will serve as an example of the clearness and freedom from cracks or flaws in malleable iron so made and forged under the steam hammer. It is one of the early productions of the process, and like the malleable iron rail, was made wholly without any re-carbonizing of the metal or the employment of spiegeleisen or manganese in any form whatever.—Malleable iron so made from hematite pig iron is red short, like all other wrought iron made wholly from hematite; but that it is perfectly malleable and extremely tough when cold may be seen on examination of the iron rope exhibited, which consists of four rods of 1½ inch round iron twisted cold into a close coil. These bars extended 13 inches in length in 4 feet, and were reduced nearly ⅛ inch in diameter in the operation of twisting, thus showing that malleable iron so made possesses an extraordinary degree of ductility.

It may be remembered that an important part of the process, as described at Cheltenham, in 1856, consisted in tapping the fluid crude iron from the blast furnace, and allowing it to flow direct into the converting vessel, and be there blown to the extent only of decarbonizing it so far as to produce cast steel. This part of the original programme has been most successfully carried out in Sweden, where an extensive establishment for its manufacture has been erected by M. Goranson of

Geffle. The large steel circular saw plate exhibited is an example of the conversion of crude cast iron run direct from the blast furnace into the converting vessel, and there blown for nine minutes, in which period it had been converted into cast steel of the desired quality, and was then poured into an ignot mould without being recarbonized, and wholly without the employment of spiegeleisen or manganese in any form whatever.

With these few illustrations of the capabilities of the process as originally described at Cheltenham, the author will proceed to show how the disadvantages of the old fixed converting vessel were remedied and other improvements introduced. Many forms of converting vessels were tried on the large scale before this desirable object was attained. In some of them the lining was too easily broken down by the violent motion of so heavy a fluid as iron; in some of the forms tried the angles allowed the metal to solidify in them, and so clog up the vessel; in others the mouth of the vessel being too small, caused the metal to be thrown out by the force of the escaping blast. It was also found that if the mouth was too large the heat escaped, so as to cause part of the converted metal to solidify in the vessel; the relative height and diameter of the vessel was also found to produce important differences in the working of the process; finally, and after many long and expensive trials, the form of vessel shown at B and C was adopted. This vessel is made in two parts, so as to admit easily of its being lined up with a pulverized silicious stone known as "ganister," which so resists the action of the heat and slags as to last for fully 100 consecutive charges of steel before it is worn out. Its form is that of the arch in every position which prevents the lining from falling down by its own weight. There are no angles in which the splashes of metal can solidify and accumulate. Its mouth directs the flame and sparks away from the workman, and from the moulds and other apparatus; while the throat of the vessel, and the position of the mouth, almost entirely prevents the throwing out of the metal. The vessel is mounted on trunnions supported on stout pedestals, so that a semi-rotary motion may be communicated to it at pleasure. The tuyeres are placed at the bottom of the vessel, so as to force the air vertically upward through the metal, as shown, without coming in contact with the sides of the vessel. When the crude metal is to be run into the vessel it is turned on its axis nearly into the position shown at C, the mouth being a little higher up; a gutter will then conduct the crude cast iron from the melting furnace into it. It is not necessary to turn on the blast until the whole of the metal is run in, because the tuyeres occupy a position

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above the level of it. As soon as the air is admitted through the tuyeres the vessel is turned into the position shown at B, when its decarbonization immediately commences. As soon as this is effected as much molten pig iron made from spathose iron ore is added to it as will restore the quantity of carbon necessary to produce the desired quality of steel, which is then run into the casting ladle in the manner shown, and from whence it is transferred to a series of iron moulds ranged in a semi-circular pit, each mould being placed within the sweep of the casting crane; the filling of these moulds is regulated by a cone valve made of fire-clay and fitted in the bottom of the casting ladle, so as to be opened or shut at pleasure by means of a handle on the outside of the ladle.

"It will be readily understood that in the fixed vessel first described any giving way of a fire-clay tuyere would stop the process and cause much inconvenience; but with the movable vessel it is not so, for at any moment of time during the process the vessel may be turned on its axis and the tuyeres raised above the level of the metal; the blast may then be turned off, the tuyere box opened, and the faulty tuyere stopped up or removed, after which the process may be again resumed. The movement of the vessel on its axis, the rise and fall of the casting crane, and the other cranes employed for removing ingots from the casting pit, are all effected by a simple hydraulic apparatus, so that the whole process is under the perfect control of a single operator, placed far away from the heat and showers of splashes that accompany the process.

"Up to this period the manufacture of cast steel by the old as well as the new process is still so far imperfect that steel of the highest quality cannot be made from inferior iron. In the old Sheffield process the original quality of the Swedish charcoal iron employed governs the quality of the cast steel made; consequently, £36 per ton is freely given for the high class Danamora iron, while other brands of Swedish charcoal iron may be bought for £15. In either case these are expensive raw materials for the cast steel maker.

"In 1839 the trade of Sheffield received an enormous impulse from the invention of Josiah Marshall Heath, who patented in this country the employment of metallic manganese, or, as he called it, 'carburet of manganese.' The addition of a small quantity of this metal, say from one-half to one per cent., rendered the inferior coke-made irons of this country available for making cast steel; it removed from these inferior qualities of iron their red-shortness, and conferred on the cast steel so made the property of welding and working soundly under the hammer.

This invention was of immense importance to the town of Sheffield, where its value was at once appreciated. Mr. Heath, supposing himself secure in his patent, told his licensees that if they put oxide of manganese and coal tar or other carbonaceous matter into their crucibles along with the blister steel, that it would do as well, and be much cheaper than the carburet of manganese he was selling them; in effect it was the same thing, for before the steel was melted the carbon present reduced the oxide of manganese to the metallic state, so that his patent carburet of manganese was formed in the crucible in readiness to unite with the steel as soon as it became perfectly fused. But the law decided that this was not Heath's patent, and so the good people of Sheffield after many years of litigation were allowed to use it without renumeration to the inventor.

"Manganese has now been used for many years in every cast steel works in Europe. It matters not how cast steel is made, since manganese added to it necessarily produces the same beneficial changes; no one better appreciated this fact than the unfortunate Mr. Heath, as evidenced by his patent of 1839, in which he declares that his invention consists in 'the use of carburet of manganese in any process whereby iron is converted into cast steel.' Had Heath seen in his own day the Bessemer process in operation, he could not have said more; he well knew the effect produced by manganese on steel, and, therefore, claimed its employment in any process whereby iron is converted into cast steel.

"With this patent of Heath's expired and become public property, coupled with the universal addition of manganese and carbon to cast steel, it would naturally be supposed that the author, in common with the rest of mankind, would have been allowed to share the benefits which Heath's invention had conferred on the whole community, but it was not so.

"The reading of the author's paper at Cheltenham in 1856, was by the powerful agency of the press communicated in a few days to the whole country. Great expectations of the value of the new process were formed, both by scientific and practical men, in proof of which it may be stated that licenses to manufacture malleable iron under the patent were purchased by iron masters to the extent of £25,000 in less than twenty-five days from the reading of the Cheltenham paper.—Great excitement existed at that moment in the iron trade, and many persons seemed to covet a share in an invention that promised so much; there was, consequently, a general rush to the patent office, each one intent on securing his supposed improvement. It was thought scarcely

possible that the original inventor should at the very outset have secured in his patents all that was necessary to the success of so entirely novel a system, he must surely have overlooked or forgotten something; perhaps even left out all mention of some ordinary appliance too well understood to really need mentioning; so in the jostle and hurry to secure something, any point on which a future claim could be reared was at once patented. Some of these gentlemen even repatented portions of the writer's own patents, while others patented things in daily use, in the hope that they might be considered new when added to the products of the new process.

"Within six weeks of the date of the Cheltenham paper, Mr. Robert Mushet had taken out three patents, which form part of that long series of patents by which he hoped to secure to himself the sole right to employ manganese in combination with iron or steel made from pig iron by forcing atmospheric air through it. In this long series of patents almost every conceivable mode of introducing manganese into the metal is sought to be secured. It was claimed if used in combination with pitch, or other carbonaceous matter; it was claimed if simply used in the metallic form, or, as Mr. Heath calls it, a carburet of manganese; it was also claimed if combined with iron and carbon—as in spiegeleisen. Manganese, in any of these states of combination, was claimed if put in with the metal prior to the commencement of the process; it was claimed if put in during the continuation of the process, and claimed if added to the steel after the process had been completed; it was also claimed if put into any furnace, crucible, or vessel, that the converted metal might be run or poured into; in fact, manganese and its compounds were so claimed under all imaginable conditions that if this series of patents could have been sustained in law it would have been utterly impossible for the author to have employed manganese with steel made by his process, although it was considered by the trade to be impossible to make steel from coke-made iron without it.

"In the *Mining Journal* of September 24th, 1853, just four years before the first of Mr. Mushet's series of patents, a letter was published on the subject of Heath's invention. The writer of that letter says: 'I am a steel maker, and deny that steel was ever made with the addition of carbon and manganese or carburet of manganese previously to Heath's invention, and I confidently assert that no cast steel maker can now carry on his business to profit without the aid of carburet of manganese.' 'There are,' he says, 'a hundred methods of improving steel with manganese, but they all involve the same principle. Put carbon and manganese into the steel pot in any form you please and at any

time you like, and if the steel be thoroughly melted the carburet of manganese melts also and is alloyed, and the improvement is unerringly effected, and by the use in every instance of carburet of manganese."

"This letter clearly shows how well the subject was understood in the steel trade thirteen years ago.

"Very soon after the reading of the Cheltenham papers, several rough trials of the Bessemer process were made privately by persons in the iron trade, and defects discovered which were supposed by practical men to be perfectly fatal to the invention. Once more the press teemed with accounts of the process, but this time it spoke only of its utter impracticability, and of regrets that the high expectations originally formed were so fallacious. The storm, however, gradually subsided, and the process and its author were soon entirely forgotten. Imperfections in the process there certainly were, but the author had had the most irrefragable proofs of the correctness of the theory on which his invention was based, and also that the reasoning on which it was so utterly condemned by the trade was in itself wholly fallacious; he, therefore, decided not to argue the question against a hundred pens, but to energetically prosecute his experiments and to remain silent until he could bring the process to a commercial success. When, at the expiration of about three years' incessant labor on the part of himself and his partner, Mr. Longsdon, and an expenditure of more than £10,000, the process was again brought before the public, not the slightest interest was manifested by the trade; it had been for years agreed on all sides that it was a total failure, and was looked upon simply as a brilliant meteor that had suddenly flitted across the scientific horizon, leaving the subject in more palpable darkness than before. This entire want of confidence on the part of the trade was more discouraging; one of two things became imperative, either the invention must be abandoned or the writer must become a steel manufacturer; the latter alternative was unhesitatingly accepted, and Messrs. Henry Bessemer & Co., determined to erect a steel-works at Sheffield, in the very heart of that stronghold of steel making. At these works the process has ever since been successfully carried on; it has become a school where dozens of practical steel makers received their first lessons in the new art, and is the germ from which the process has spread into every state in Europe, as well as to India and America.

"By the time the new works at Sheffield had got into practical operation the invention had sunk so low in public estimation that it was not thought worth paying the £50 stamp due at the expiration of three

years on Mr. Mushet's large batch of manganese patents; they were, consequently, allowed to lapse and become public property.

"The author has, therefore, used without scruple any of these numerous patents for manganese without feeling an overwhelming sense of obligation to the patentee.

"At the suggestion of the author a works for the production of manganese alloys was erected by Mr. Henderson, at Glasgow, who now makes a very pure alloy of iron and manganese, containing from twenty-five to thirty per cent of the latter metal, and possessing many advantages over spiegeleisen, which it will doubtless replace. Two bright rods of 1¾ inch diameter will be found on the table, they were folded up cold under the hammer. This extremely tough metal is made by using Mr. Henderson's alloy in lieu of spiegeleisen, which is incapable of making steel of such a quality.

"A Prussian gentleman, M. Preiger, has been also successful in manufacturing a new alloy, which he calls ferro-manganese, consisting of sixty to eighty per cent. of metallic manganese. It is extremely useful in making malleable iron by the Bessemer process, in which spiegeleisen cannot be employed on account of the large proportion of carbon it contains.

"It is gratifying to turn from a review of the troubles and impediments of the past, and briefly notice some of the more important applications of steel as a substitute for wrought iron.

"In no case is this change of material more important than in the construction of ships, for in no instance are strength and lightness more essential.

"The Bessemer cast steel made for ships' plates by the several eminent firms now engaged in that manufacture is of extremely tough and ductile quality, while it possesses a degree of strength about double that of the inferior kind of iron plates usually employed in ship building, hence it is found that a much less weight of material may be employed, and at the same time a greater degree of strength may be given to all parts subjected to heavy strains.

"Most prominent among the builders of steel ships is the firm of Jones, Quiggin & Co., of Liverpool, who have now constructed no less than 31,510 tons of shipping, wholly or partially built of steel. Of these, thirty-eight vessels are propelled by steam with an aggregate of 5,910-horse power, besides this the principal masts and spars of eighteen sailing ships have been made by them wholly of steel.

"Vessels of a large size, constructed to class AA twelve years at

Lloyd's weigh, when built of iron, about 12 cwt. per ton measurement; whereas similar vessels built of steel weigh only about 7 cwt. per ton measurement; thus an iron ship, to take first class at Lloyd's for 1,000 tons measurement, would weigh 250 tons more than a steel one of the same class. Such a vessel could, therefore, take 250 tons, or 25 per cent., more freight at the same cost, or could avail herself of the difference of immersion to leave or enter port when the tide would not permit an iron vessel to do so.* As a steamer she would carry 250 tons more of coal, and thus be enabled to lengthen her voyage or take her coal for the return trip. The two steel paddle-wheel steamers launched at Liverpool by Messrs. Jones & Co., on the 13th ult., for Dublin and Liverpool service, will draw from 3 feet to 4 feet less water than iron steamers built on the same lines, and being thus enabled to leave port at all states of the tide, will not require a tidal train in connection with them. If the employment of steel for the construction of merchant vessels is found to be so important, how much more so is it for ships of war. Some of the larger class of armor plated vessels require 6,000 tons of iron for their construction, and an addition of 1,800 tons in the shape of 4½ inch armor plates. Now, if the frames and inner skin of such a vessel were constructed of steel it would be much stronger even if reduced to 4,000 tons in weight; this would admit of 9 inch armor plates being used in lieu of 4½ inch, and would still leave the vessel 200 tons lighter than the present ones, and hence, as the resistance of the armor to impact is as the square of the thickness of the plate, we should have a vessel capable of resisting four times the force of those at present constructed, while it would be 200 tons less in weight.

"These important facts have not escaped the attention of Mr. Reid, our present talented constructor of the navy, and we shall, doubtless, soon have substantial proof of what may be effected by the employment of steel in the construction of ships of war.

"The application of steel for projectiles has now become a necessity since the introduction of armor plates. We have before us a 110 pound shot, that has passed with very slight injury through a 5 inch armor plate, and also some specimens of bent angle iron, made of Bessemer

* The well-known blockade runners, the Colonel Lamb and Hope, each 281 feet long, with engines of 350-horse power; the Cora Bell, Wasp and Hornet, each 250 feet long, and the Lynx, Fox, Bat and Owl, varying from 532 to 771 tons, were built of Bessemer steel For the reason above-mentioned no other material would have enabled the construction of a vessel combining light draught with great carrying capacity, and hence so eminently fitted for the service for which they were destined. No builder would have employed a material in the strength and uniformity of which he had not the utmost confidence, to build a vessel to be propelled by such heavy machinery, and to be engaged in such a precarious and dangerous trade.—[*Note by Editor of Register.*

iron, and rolled at the Millwall Ironworks, in London, and from the same works a portion of one of Hughes' patent hollow steel beams for supporting the armor plating in course of construction for the forts at Cronstadt; both these are interesting examples of what the rolling mills of the present day can effect, and of the facility with which cast malleable iron and cast steel admit of being worked in the most difficult forms.

There is no department of engineering in which the peculiar toughness of steel and its strength and power of resisting wear and abrasion are of such vital importance as in its application to railway purposes. This fact had long since impressed itself strongly on the mind of Mr. Ramsbottom, of the London and Northwestern Railway, who commenced experiments with this material in 1861, carefully, though trustingly, he tried it step by step, not even at first venturing to employ it for passenger trains, but as proofs of its safety and economy crowded upon him, he carefully applied it to the most important parts of passenger engines, and even to the manufacture of the formidable engine cranks (at the time entrusted only to the most eminent iron making firms in the kingdom), these iron cranks are now being replaced by steel ones forged from a single mass. One of these steel cranks, manufactured at the new steel works at Crewe, has been obligingly lent by Mr. Ramsbottom as an illustration of the use of steel for this purpose; that gentleman has also taken out of use a plain steel axle that has run a distance of 112,516 miles, and now exhibits very slight signs of wear.

"The tires of wheels, on which so much of the public safety depends, were then tried, but the exact amount of difference between the endurance of wrought iron and Bessemer steel for this purpose is not yet ascertained, as none of these steel tires are yet worn out; but enough has been shown to prove the advantage of entirely replacing iron by steel for this purpose.

"In order to show how a steel tire will resist the most violent attempts to produce fracture, an example is given of a steel tire manufactured by Messrs. Bessemer & Co., of Sheffield; it was placed on edge under a six ton steam hammer, and subjected to a series of powerful blows until it assumed its present form, that of a figure of eight, a degree of violence immensely more than it could ever be subjected to in practice. These tires are made without weld or joint, by forging them from a square ingot partly under the improved plan invented by Mr. Ramsbottom, and partly by an improved mode of flanging and rolling, invented by Mr. Allen, of the Bessemer Steel Works, Sheffield.

"So important were found to be the advantages of employing cast

steel as a substitute for wrought iron at the works of the London and Northwestern Railway Company, that the directors, acting under the advice of their able engineer, determined on building a large steel works at Crewe, which is now in active and successful operation. In the design and arrangement of their plans for working up the steel several important improvements have been introduced by Mr. Ramsbottom, among others his duplex hammer, which strikes a bloom on both sides of the ingot at once, in a horizontal direction, and thus renders unnecessary the enormous foundations required for ordinary hammers. Here, also, he has put up his improved rolling mill for rolling blooms of large size, the enormous machine being reversed with the greatest rapidity and ease by the attendant, without any shock or concussion whatever.

"While matters were thus steadily progressing in the engine department of the company, the engineer of the permanent way, Mr. Woodhouse, took in hand a thorough investigation of a no less important problem, viz: the substitution of cast steel for wrought iron railway bars. For this purpose some 500 tons of rails were made, and put down at various stations where the traffic was considerable, so as to arrive, at the earliest period, at a true comparison of the respective endurance of wrought iron and cast steel rails. It will be unnecessary here to enter into the numerous details of the extensive series of experiments systematically carried out by Mr. Woodhouse; the trials made at Camden will suffice to show the extraordinary endurance of steel rails. It is supposed that there is not one spot on any railway in Europe where the amount of traffic equals that at the Chalk-farm bridge at Camden Town. At this spot there is a narrow throat in the line, from which converges the whole system of rails employed in the London termini of this great railway. Here all passenger, goods, and coal traffic have to pass; here, also, the making-up of trains and shunting of carriages is continually going on. At this particular spot two steel rails were fixed on May 2d, 1862, on one side of the line, and two new iron rails were on the same day placed precisely opposite to them, so that no engine or carriage could pass over the iron rails without passing over the steel ones also. When the iron rails became too much worn to be any longer safe for the passage of trains, they were turned the other way upwards, and when the second side of the iron rails were worn as far as the safety of the traffic would allow, the worn out rail was replaced by a new iron one—the same process being repeated as often as was found necessary. Thus we find, at the date of the last report on March 1st, 1865, that seven rails had been entirely worn out on both faces. Since then another rail has been worn out up to July,

making sixteen faces worn out, the seventeenth face being in use on August 22d, when the steel rail that had been placed opposite to them was taken up in the presence of the writer, and, by the kind permission of Mr. Woodhouse, now lies on the table before the meeting. The first face of the rail only has been used, and this is now become much thinner than it was originally, but, in the opinion of the platelayers, is still capable of wearing out another half dozen faces. Taking its resisting powers at three more faces only, it will show an endurance of twenty to one in favor of steel.

"Mr. Woodhouse has ascertained, by careful and continued testing for twenty-four hours at a time, that an average of 8,082 engine tenders or carriages pass over the steel rails every twenty-four hours, equal to 16,164 wheels every day for 1,207 days, making a total of 9,754,974 wheels passed over the rail. Subject to this excessive wear the rail appears to have been reduced 7½ pounds per yard, hence, for every grain in weight of steel lost by abrasion, no less than 371 wheels had to pass over it. Another steel rail, put down also in May, 1862, at a place much less subject to wear, has had four faces of iron rails worn out opposite to it, and still appears as if very little used; this rail is also placed on the table. An iron rail wears out by the giving way at various parts of the imperfectly welded mass, and not by the gradual loss of particles of metal, as in the case of the steel rail, which no amount of wear and tear seems capable of disjointing. It must be borne in mind that this enormous endurance of cast steel is not owing to its hardness or brittleness, as some have supposed, for, in fact, Bessemer steel possesses an extreme degree of toughness. There is before the meeting an example of this fact: one of the same quality of steel rails having been attached at one end to the main driving shaft of a steam engine so as to twist it while cold into a long spiral, measuring 9 feet in length at top and bottom, and only 6 feet if measured along the centre of the web. A single glance at this spiral rail, will, it is presumed, dispel any idea of brittleness that may have been entertained.

"In conclusion, it may be remarked that cast steel is now being used as a substitute for iron to a great and rapidly increasing extent.

"The jury reports of the International Exhibition of 1851 show that the entire production of steel of all kinds in Sheffield was, at that period, 35,000 tons annually, of which about 18,000 tons were cast steel, equal to 346 tons per week; the few other small cast steel works in the country would probably bring up this quantity to 400 tons per week as the entire production of cast steel in Great Britain. The jury

report also states that an ingot of steel, called the 'monster ingot,' weighing 24 cwt., was exhibited by Messrs. Turton, and was supposed to be the largest mass of steel manufactured in England. Since that date a great change has been made, for the largest Bessemer apparatus at present erected at Sheffield, at the works of Messrs. John Brown & Co., is capable of producing with ease every four hours a mass of cast steel weighing 24 tons, being twenty times larger than the 'monster ingot' of 1851.

"There are now seventeen extensive Bessemer steel works in Great Britain. At the works of the Barrow Steel Company 1,200 tons per week of finished steel can easily be turned out, and when their new converting house, containing twelve more five ton converters, is completed, these magnificent works will be capable of producing weekly from 2,000 to 2,400 tons of cast steel. There are at present erected and in course of erection in England no less than sixty converting vessels, each capable of producing from three to ten tons at a single charge. When in regular operation these vessels are capable of producing fully 6,000 tons of steel weekly, or equal to fifteen times the entire production of cast steel in Great Britain before the introduction of the Bessemer process. The average selling price of this steel is at least £20 per ton below the average price at which cast steel was sold at the period mentioned. With the present means of production, therefore, a saving of no less than £6,240,000 per annum may be effected in Great Britain alone even in this infant state of the Bessemer steel manufacture."—*London Engineer, September* 15.

The cost of maintenance of permanent way on railroads has become such a serious item of expense that the managers of our important routes have been looking with great solicitude for some means of reducing it. Rails of iron are found under our present gigantic machinery to last scarcely four years, and during that period to be far from secure against fracture under the blows of the rapidly passing wheels. Grave thoughts have been expressed by our best engineers of lowering the average weight of engines from 28 and 30 tons, to a standard more nearly that in vogue 30 years ago, when it was believed that an iron rail would last 25 to 30 years, accompanying such reduction with a reduction of the size of trains and a diminution of speed, solely for the purpose of diminishing the sum necessary to be paid each year, for relaying worn out rails; a sum which tells most seriously upon the re-

ceipts of stockholders, upon dividend day. But reduction in size of trains and diminution of speed is not in accordance with the requirements of trade, and they would entail other sources of expense, such as an increase in the number of cars and locomotives, which it is important to avoid. The railway managers, hence, turn with interest, heightened by that continually increasing traffic which so often astonishes even the projectors of the roads themselves, to the successful efforts of the English engineers to overcome the difficulty, by substituting a new and more durable material in place of the iron bars which now cost them so many hundreds of thousands of dollars annually. The account given above (which emanating from a body including many of the most honorable, scientific and practical men of Great Britain, scores of whom are personally cognizant of the facts stated, cannot be but correct,) shows that the season of experiments is over, and that of successful prosecution of a settled manufacture has arrived. And at this present time not only are the leading railway men and mechanicians of England alive to the fact that the era of steel has dawned upon the world, but metallurgists, business men and government officers throughout Europe have, during the last three or four years, turned their attention to the introduction and perfection of systems of producing cheap steel, among which the Bessemer process is the most important, and we now have accounts of its regular use in the production of railway material, etc., in Germany, Russia, Sweden, France, Austria and India. In Russia works were erected in 1863, by the chief metallurgist of the empire, on the banks of the Kama, about 1,000 miles east of St. Petersburg; they grew from a one ton vessel to a three ton vessel, and then to one of a capacity of five tons, in a little over two years, and are now in regular operation. The vast works of F. Krupp, in Essen, Prussia, employ 8,000 men in their various departments, and turn out 50,000 tons of cast steel annually. The founder of the works, Mr. Krupp, who still lives, slept by the fire of his single furnace when making his earliest efforts in the manufacture. In 1862 he sent a single block of steel, weighing 21 tons, to London; it was nine feet long and three feet eight inches in diameter, and the closest scrutiny with a lense did not detect any flaw. There are at least two establishments making Bessemer steel in France. The Italian Government has recommended through its Commissioners, and after extended investigation in England, the introduction of the process into Italy; an apparatus has been sent to India to establish works for making this sort of cast steel, while the most thorough description we possess of the Bessemer process was published by an engineer who practiced it in Sweden,

and wrote his book in Stockholm. As yet the process has exerted but little practical effect upon American industry, but its reign is just commencing. While thousands of tons of metal in various forms are now ordered of English houses, and our gold is going abroad to pay for it, our ore is laying in boundless profusion in almost every State in the Union—ores of a purity unknown in the experience of the English ironmaster. Our unadulterated coals are awaiting the miner in a thousand hills, our charcoal waves in the form of trees on millions of acres of cheap land. Will our railroad men and machinists remain patient much longer, and be content to cross the Atlantic for what they should have cheaper and better at home? Will our skillful workers in metals allow us to be the latest nation in the civilized world in bringing to perfection a set of processes which must regenerate the whole iron and steel business?

THE BESSEMER OR PNEUMATIC METHOD OF PRODUCING STEEL DIRECT FROM PIG IRON.

In view of the increasing appreciation with which all classes of manufacturers and consumers of iron and steel are coming to regard the method of producing steel by what is known as the Bessemer or Pneumatic Process, the following excellent description and discussion has been taken from the *Annales des Mines* (5th Livraison, 1863), where it appears as the production of M. de Cizancout, *ingenieur des mines*, and is entitled "Studies upon Steel."

Prof. Lesley, while Secretary of the Iron Association, foreseeing the ultimate value of the new method of making steel, devoted much of the space of the Bulletin of that Society published in October, 1856, to its discussion, and the lapse of eight years has proven that the hopes then entertained were in many respects well founded.

That the question of priority of invention and the right to use various processes generally deemed essential in producing good steel by the new method, are claimed by different parties in this country, is well known, but this description avoids all mooted points, and confines itself to the purely technical view of the question. In Europe, where capital through the course of centuries has concentrated in the hands of successful manufacturers, experiments such as those required for developing the Bessemer or Pneumatic Process, are undertaken with more alacrity than in this country; this in part accounts for the more rapid progress of the invention there than here. The manufacture of steel by the old method further has been fostered by wise protective laws

until, as at Sheffield, highly skilled steel-producing communities have come into existence, and they furnish experienced men prepared to conduct experiments in untried departments of their business.—The attention of the rulers of great nations, too, has been drawn by the vast promise of the process, to give it thorough trial, for the purpose of securing its successful introduction into their own dominions; choosing, with a sagacity the result of long and painful experience, to practice, even at some preliminary expense, the business of making an article of prime necessity in national advancement, at home, rather than obey the persuasive reasoning of the British free traders, and buy in the market which for the moment seemed to be capable of supplying that article at the lowest rate. The new Italian nation, vigorous with youth, and anxious to introduce among its people every industry that would tend to strengthen it among European powers, sent out a Commission, for the purpose of investigating the subject of producing steel by the Bessemer Method.—The Commission proceeded to Sheffield, where they were afforded every facility for determining, firstly, the practical value of the process itself, and, secondly, the applicability of various sorts of Italian pig iron to the purpose of making steel by the new method. The result of this investigation is given in the following report, which I translate with some condensation, as follows:

REPORT.

The Commission, composed of A. Ponsard, Engineer and Director of the Royal Forges of Tuscany, Chevalier C. Perazzi, E. Graban, Engineer of the Royal Mining Corps, and M. Devincenzi, General Commissioner to the London International Exposition, pursuant of the instruction given by the Royal Committee, to make certain experiments for the transformation of Italian pig iron into steel by the Bessemer Process, proceeded to Sheffield on the 6th of October, 1862, and remained there six days, and they present to day to the same Royal Committee the following description of their operation, and the results obtained.

The Italian pig iron sent consisted of

3000 kilogrammes* of gray iron (manganiferous) from the Royal Tuscan furnaces.
3000 kilogrammes of mottled iron " " " "
Do. of gray iron (non-manganiferous).
Do. of gray iron from the Valle-Camonica furnace.
Do. of mottled iron from the Pisogue furnace.
Do. of gray iron from the furnace of Mongiana.
Do. of mottled iron " " "
Do. of white iron " " "

* The kilogramme is equal to about 2 1-5 English pounds.

Mr. Bessemer's apparatus at Sheffield will hold about 1500 kilogrammes of cast iron. The air is thrown into it with a pressure of 15 lbs. per square inch, and the quantity of air is about 54 cubic metres* per minute. The iron is fused in a common reverberatory furnace, and the fuel used is common stone coal. In all the experiments the same method was followed, viz: The metal was fused in the reverberatory furnace, run into the converter, air blown through it for the proper period, and then, before pouring it from the converter into the moulds, about 7 per cent. of spiegeleisen from Siegen,† or iron holding manganese from Tuscany, was melted in a little compartment of the reverberatory furnace, and poured into the converter. The following table shows the characteristics of the operations, and the results obtained.‡

* The metre is equal to about 39¾ English inches.
† The Siegen iron is very similar to our Franklinite iron.
‡ All the iron produced in Italy is made with charcoal.

Table showing the details of Thirteen Trials of Italian Pig Iron by the Bessemer or Pneumatic Process.

Locality from which Iron was obtained, and kind of Iron.	Quantity used. In kilogrammes.	Time required. Time required to melt the iron in a reverberatory furnace.	Time required. Time required to transform the Cast Iron into Steel.	Cast Iron poured into the Converter at the end of the operation. Locality from which Iron was obtained, and quality of Iron used.	Quantity. In kilogrammes.	Per cent. added compared with the quantity of Iron converted.	Total quantity used of both kinds of Cast Iron. In kilogrammes.	Quantity of Steel obtained. Ingots. In kilogrammes.	Residue. In kilogrammes.	Total. In kilogrammes.	Difference between iron employed and steel produced (loss). Per cent. of loss in making the ingots.	Per cent. of loss, counting ingots and residue.	See following notes.
		H. Min.	Min.										
Fellonica, near Elba	1,226.8	2 10	22	First quality of Siegen Iron, manganiferous & crystalline,	88.8	7⅓	1,315.5	1,032.9	101.4	1,134.3	21½	14	1
Gray	1,217.6	2 28	13	Fellonica white christalline and manganiferous	126.9	10	1,344.5	1,092.7	164.9	1,257.5	19	7	4
Mottled	1,225.3	2 00	11	Do.	98.8	7½	1.314.1	1.024.6	.....	1,024.5	21½	21½	7
Mottled	1,230.3	2 30	13	Do.	88.8	7¼	1,319.1	1,124.3	76.1	1,200.4	14¾	9	10
White Crystalline	1,293.8	2 40	11½	Do.	88.8	7	1.382.5	1,094.8	101.4	1,196.2	21½	14	9
Mottled and Gray	1,344.4	2 32	11	Do.	95.1	7	1,439.6	1.107.1	.....	1,107.1	22½	22½	11
Lombardy, Gray	1,223.1	2 40	12	Do.	88.8	7⅓	1,311 9	1,040.1	101.5	1.141.6	20	13	3
Gray	1,369.9	2 15	17	Do.	98.3	7¼	1,468 1	1,286.9	30.9	1,317.8	12½	10¼	6
Mottled	1,217.7	2 00	9	First quality of Siegen Iron, manganiferous & crystalline,	76.1	6¼	1,293 8	861.6	38.0	899.7	33½	30½	5
Mottled and Gray	1,382.5	2 30	13	Do.	95.1	6 4-5	1,477.7	1,325.9	.....	1,325.9	10	10	12
Lombardy Gray and Fellonica non-manganiferous	1,331.9	2 25	12½	Do.	88.8	6⅔	1,420.6	1,167.9	50.8	1,218.7	18	14½	13
Mongiana, Gray	1,219.0	2 53	13	Do.	88.7	7⅓	1,307.9	768 2	279.0	1,047.3	41	26	2
Mottled	1,217.7	2 35	10½	Do	76.1	6¼	1.293.8	898.8	164.9	1,063.7	30½	17½	8
Total	16,500.0	"	"		1,199 1	6¾	17,689.1	13,825.8	1.108.9	14,934.7	17½	14	

(1) The process of the conversion was regular. A wrought ingot, 5 9 inches square, broken cold, exhibited a gray, silvery fracture, compact and homogeneous, with little scales and cavities slightly oxidized on the borders of the mass. The sheets obtained by rolling, and small rods drawn under the hammer, came out perfectly.

(4) The progress of the conversion was regular; the steel was similar to the above, but with a fracture perhaps a little darker.

(7) The conversion took place rapidly with numerous eruptions. An ingot weighing about a ton, was cast, from which a cannon marked No. 3 was made.

(10) The progress of the conversion was regular. Two ingots were cast, weighing over a ton, from which the cannon marked No. 3 was made.

(9) The progress of the conversion was regular.

(11) The cast iron used was two-thirds mottled and one-third gray, non-manganiferous. Abundant eruptions took place during the operation.

(3) The progress of the conversion was rapid, but sufficiently regular. The ebullition was violent, and accompanied by an abundant eruption. The steel was similar in appearance to 1. It drew well under the hammer, but rolled imperfectly.

(6) The conversion proceeded regularly. An ingot weighing a ton was cast, and a cannon made from it. Under the hammer the steel behaved well.

(5) The conversion went forward with extraordinary activity, two minutes from the beginning of the operation violent eruptions commenced, and did not cease until the end. A steel of a good quality, however, was produced.

(12) The pig used was two-thirds mottled, and one-third gray. An ingot, weighing one ton was cast, and a cannon made therefrom.

(13) The pig employed was three-fifths from Lombardy, and two-fifths from Fellonica. The conversion went forward regularly.

The steels obtained from the pig iron brought from Fellonica are all of the same quality, and experiments in tempering, drawing under a large and small hammer, and by rolling, have shown them to be of an excellent quality. The same may be said of the steels produced from the gray pig sent from Lombardy. That produced by the mottled pig from Lombardy, is but little inferior to the first mentioned. The mottled pig from Mongiana produces an inferior steel.

It was even impossible to obtain steel from the gray pig from the last named locality, and no attempt was made to convert the white pig, on account of the bad result of the operations with the other sorts. In order that Italian manufacturers may themselves examine the results obtained by the process, the Commission have directed four cannon to be made by the new process, and a number of ingots will be sent to the Royal Committee.

After this brief description of the results obtained, the Commission believes that it is its duty to express the opinion it has formed upon the very important question of introducing the Bessemer Process into Italy. The numerous experiments made prove that the irons of Tuscany and Lombardy, and especially those that contain manganese, will produce excellent steel by means of the Bessemer process.

When we consider that by means of this process, by the single operation of submitting the fused cast iron during a few minutes to the action of a strong current of air, it is possible to obtain from Italian pig iron a cast steel of an excellent quality in ingots of all dimensions, and without the consumption of any fuel, it is easy to believe that an immense advantage will result from its introduction.

It is incontestable that the iron business of Italy, which is now limited by the want of abundant fuel, will find in this process a new life, since it will enable us to make cast steel in Italy at a cost not greater, and with a smaller consumption of fuel, than is now necessary for the production of wrought iron.

European iron and steel-makers, at first restrained by the thought of the revolution in their department of the arts, which the Bessemer Process must produce, have at length clearly decided to adopt it. It is already in operation in several English establishments, among which the Commission visited the very important one owned by John Brown & Co., at Sheffield. In Prussia, it is in use at the great steelworks of Frederick Krupp. In France, in the works of M. Jackson, at Seurin-sur-l'Isle, it was introduced three years ago; while at the establishments of Schneider and Petin Gaudet at Rive-de-Gier, licenses have already been taken out for its use. The process is also introduced into

Sweden, and applied with excellent results. The method there adopted is to run the fused iron directly from the blast furnace into the converter, thus saving the expense of a second fusion. The constantly increasing application of steel for making ordnance and smaller guns, and the great tendency in the arts to substitute steel for iron in the construction of vessels, of steam-boilers, of driving wheels and important axles, in the materials used for railways, and for agricultural tools, assures for this industry the most brilliant future.

The commission, convinced that this process can be made a branch of industry of national importance, cannot refrain from expressing the wish that Italian manufacturers will give it their most serious consideration, and they hope that the Government will undertake a series of experiments upon the products sent to it from Sheffield, and publish the results.

In conclusion, they must return to Messrs. Bessemer and Longsdon their thanks for the frankness with which they put their establishment at the disposal of the Committee, showing that they have nothing to fear from a close and practical investigation.

(Signed) G. Devincenzi, *President.*

A. Ponsard, C. Perazzi, E. Graban.

Sheffield, October 11, 1862.

THE MACHINERY REQUIRED BY THE BESSEMER PROCESS.

The Bessemer Process is exceedingly simple. The whole process rests upon the action which a strong current of air exerts upon the elements with which it meets when forced through a mass of melted pig iron. The stirring and combustion which it produces, transforms certain qualities of cast iron into a malleable metal that may be wrought like cast steel. The Bessemer Process is, therefore, a method of refining. The operation is performed in a large egg-shaped vessel; the cast iron is poured in in a liquid condition, and then the air is forced beneath it at a high pressure. The metallic mass remains fluid while the air acts upon it. The resulting malleable product is obtained in certain cases by stopping the air while the process is yet incomplete, or, more generally, by prolonging its action until the iron is converted into a sort of burned or over-refined mass; and then transforming this product immediately into a malleable metal by means of the simple ad-

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dition of a crystalline and steely iron. The process was at first carried on in a sort of fixed cupola furnace, into which air was driven by tuyeres passing through the bottom ; but on account of the trouble caused by the tuyeres clogging, another arrangement was substituted, where the vessel in which the process is executed is called the *Converter*, and is a moveable egg-shaped pot, with a short neck. It is made of plates of iron riveted together, and protected inside with a sheeting of refractory clay, 20 to 30 c. in thickness. At about the height of its centre of gravity, this vessel is suspended upon two trunnions, to which are geared wheels that enable the apparatus to be turned by hand or by machinery on a horizontal axis. An air-box, which occupies the lower part of this converter, communicates with the interior by means of a number of small holes passing through the fire-brick bottom. The air passes from the blowing engines through a hollow trunnion, thence into the bottom of the converter, and may be thrown in small jets into its interior, no matter in what position the vessel may be turned. The capacity of the converter is usually from five to six times the amount of the cast iron to be treated. The throat should be large enough to let out the gases when the process is in operation, and to enable the fluid metal to be poured in and out without danger of obstruction. During the operation of converting, the mouth of the converter passes under a hood of sheet iron, which carries the fumes to a chimney. When the operation is terminated, the converter is turned over, and all the metal it contains is poured into a ladle, at the bottom of which is a hole, out of which the fluid mass can be tapped. The metal has a tendency to cool rapidly, and must be poured into the moulds soon, and with care that it shall not touch the walls of the mould. In order to accomplish this, an hydraulic crane is used, of which the pivot is a piston playing in a cylinder, and at the end of a horizontal arm extending from this pivot is fixed the ladle ; the moulds are placed in a circle around the pivot at such distance, that a hole in the bottom of the ladle can be brought directly over the centre of each of them by revolving the crane, while the height of the ladle above the mould may be fixed by raising or lowering its piston-pivot by hydraulic power.

The blowing engines are of various patterns. They should furnish about 25 cubic metres of air (reckoned at the tension of the atmosphere) per minute and per ton of pig iron used. The average pressure of this air should be 76 c. mercury, and it should be thrown into the converter through thirty-five tuyeres each, 1 c. in diameter.

It is, however, always best to have a considerable surplus of power in the blowing apparatus. When the cast iron is not taken directly from the blast furnace in a liquid state, it is necessary to have a reverberatory furnace for remelting; this should be placed at such a height above the level of the converter, that the liquid iron will flow readily from the former into the latter. The iron should be introduced into the converter as hot and fluid as possible.

THE METHOD OF OPERATING THE MACHINERY JUST DESCRIBED,

To produce Bessemer or Pneumatic Steel.

During the treatment of cast iron in the Bessemer apparatus, the operator concentrates his attention upon the following points: The character of the flames and sparks that flow from the mouth of the converter; the character of the smoke that rises from the top of the chimney, which by reason of the abundant sparks generated in the operation, cannot be studied below; the noise of the cast iron in the converter, the height of the air-gauge, which indicates the pressure necessary to force the air from the tuyeres; and, finally, upon the duration of each of the phenomena of the process, and the total duration of the blowing.

Let us watch, for an example, the converting of a charge of 1226 kilogrammes of red-hematite charcoal iron, from the Island of Elba, through the process of conversion into steel. The air is blown at a pressure of 0·76 c. of mercury, and 27 cubic metres are thrown in per minute per ton of iron.

The converter is first heated white hot before the metal is poured in, by filling it with coke, and blowing into it gently with the blast engine. The coke is poured out, and the vessel returned to its erect position; the metal from a reverberatory furnace is then run by a trough into the converter, and the blast turned on. The blowing is continued twenty-two minutes, until over refined iron is produced. The vessel is then turned to a horizontal position, the blast stopped, and an addition of 7½ per cent. Siegen spiegeleisen, in a fused condition, is made; this is mixed thoroughly, and the mixture poured into the ladle above described, and thence into the moulds. In looking more closely into the process, we may divide the twenty-two minutes during which the blast is being driven into the fused metal into four periods.

First. Lasting seven to eight minutes, being the period of sparks, and until flames commence.

Second. Period of eight minutes, during which flames augment and the "dart-like" flame is formed.

Third. Period of two minutes, of detonations and eruptions.

Fourth. Period of four or five minutes, increase of amount and brilliancy of flame until the flame falls.

FIRST PERIOD.

Upon the air reaching the fused metal, large numbers of sparks are projected through the neck of the vessel and into the chimney by the violent blast. These are combustible particles, that burn brilliantly in the oxidizing currents. The chimney as yet produces no smoke. The noise formed in the converter is dry and crackling, and indicates that the metal raised by the blast falls back upon itself. The noise grows gradually into a regular and dull clapping. The iron, during this period, becomes more and more hot and liquid. The combustion, however, is accompanied by no visible flame.

During this period the combustion, which causes the metal to grow hotter and hotter, does not appear to produce any combustible gas. The current flowing from the converter appears to be still oxidizing, since the sparks continue to burn in the midst of the current. If the iron is poured now, it has the appearance of pig partly refined, and having lost but little in weight. These facts lead us to believe that a part of the oxygen passes through the iron uncombined, and that the combustion is caused by the oxidation of a body more oxidizable than iron, without attacking sensibly as yet the carbon or the iron. The sparks are, indeed, as characteristic of the combustion of silicum and metallic manganese, as of iron.

We may, then, conclude that the heat at the beginning of the operation is furnished by the oxidation of a body more combustible than iron; that the carbon, if it burns at all, produces carbonic acid gas; and that the temperature of the mass is not high enough to absorb all the oxygen.

SECOND PERIOD.

The sparks diminish, and are masked and replaced by flame. At six or seven minutes a red, dull, short flame begins to show itself; at eight minutes it is more distinct, and begins to be yellowish and bright. At first only a few inches long, it gradually grows to be three

feet in length. About the middle of the period a dart-like flame shows itself at the throat of the converter, resembling the flame of a candle, and continues during the remainder of this and a part of the following period. The noise in the converter becomes drier and drier, and less perceptible, and is replaced by a sound like the formation of innumerable bubbles of gas. No smoke yet issues from the chimney. The back pressure of the air diminishes.

During the second period, the presence of a flame, like that of a candle, proves that the combustion of carbon is followed by the production of carbonic oxide, and the oxygen is now entirely absorbed by the combustible matter in the fluid mass, since the jet of gas at the mouth of the converter burns only on the surface when it comes in contact with the air.

THIRD PERIOD.

The flames remain ; strong detonations take place in the apparatus; they are accompanied by the projection of viscid portions of the interior mass, mixed with metallic grains, against the wall of the chimney. The flames appear more clear during several seconds after each explosion. These explosions do not seem to be essential to the process, and a skillful operator will at length succeed with most irons in working without them. The noise produced at this time is similar to that of a fluid mass in a state of violent ebullition. Much smoke now issues from the chimney. At this period the iron burns directly, and its combustion is very lively. The oxide of iron is carried off as smoke, and the loss in weight is considerable.

The iron has now reached a period when it is somewhat viscid, having been refined till it has reached a condition of malleability. Bubbles are formed, and when they receive oxygen and carbonic oxide in proper proportions, they become explosive.

FOURTH PERIOD.

A calm now succeeds. A long white flame extends from the mouth of the converter. Soon this flame experiences an entire change. It becomes torn on the edges, trembles, and suddenly falls, as though the blowing engine had, in a moment, lost nine-tenths of its power. After this fall the flames are not bright, and much smoke issues from the converter. The operation is now stopped. If it be continued, there will be a rapid formation of silicate by the fused lining of the converter combining with the oxidized metal, and ultimately an oily fluid silicate of iron will fill the converter.

Practice teaches how to seize the exact moment to stop, that the required degree of hardness may be produced. It is always a delicate point to determine the exact moment when the operation shall be discontinued.

When the flame falls, the converter has within it a very fluid metal holding much gas in solution, which, if allowed to cool, is not malleable, and resembles in its fracture what is known as "burned iron." The action of the blast is terminated by reversing the apparatus and shutting the air valve.

During the fourth period, the continuance of the flame proves that the combustible gas is produced in abundance; but the cessation of detonations shows that the iron has acquired a temperature sufficiently high to absorb all the oxygen thrown into it. The combustion of the last portions of carbon (probably the graphite) appears to take place indirectly by the decomposition of the oxide of iron, free or combined. The iron has become almost exclusively the combustible substance. Its affinity for oxygen increases with its temperature, and the action of the mass is in favor of its combustion, in preference to the sulphur, the phosphorus, and other bodies that have escaped burning at former periods. The refining, therefore, can be carried no further. The flame produced at this period is white and brilliant: it falls generally when the last particles of carbon have disappeared.

The final product is always very liquid. The slags formed toward the last of the operation run easily, are glassy black without, and yellowish green within.

Seven and one-third per cent. of fused spiegeleisen, from Siegen, melted in a special compartment of the reverberatory furnace, is then introduced by means of a small crane and ladle. The addition of this metal always produces a tumultuous action, which is more or less violent in proportion to the amount of air that has been driven in, and varying with the different irons treated.

After allowing the metal to mix thoroughly, it may be poured into the ladle on the crane without turning up the converter; but if it is desired to make the mixture still more complete, it may be done by bringing the converter again to a vertical position, and blowing air into it for a few seconds. The metal is then poured into the distributing ladle. During this last blast, the flame passes from red to yellow, and the same phenomena are seen to occur in rapid succession, as have been described above.

From the distributing ladle the fused metal must be run, before it cools, into the ingot mould.

COMPARATIVE ECONOMY OF THE BESSEMER OR PNEUMATIC PROCESS.

By this method of making steel, a great saving of fuel is secured. The product is in a cast condition, and hence, in comparing it with the cementing process, we will consider the expenditure in producing ingots by each plan.

It requires for 1 unit of steel 2½ units of coal to produce from the pig the cemented or blister steel; and for 1 unit of steel, 2½ units of coke to fuse this cement steel, and form therefrom ingot cast steel. Supposing the coke to represent 60 per cent. of the original coal, we have, upon addition, 7 units of coal necessary to produce 1 unit of common cast steel.

In the Pneumatic process, using iron directly from the blast furnace, no fuel is absolutely required except what may be necessary to heat the interior of the converter; the power to drive the blowing machine may be water. To heat the converter, requires 2-10th of a unit of fuel to a unit of steel.

If, however, we suppose it necessary to remelt the cast iron in a reverberatory furnace, it requires 60 per cent. of the weight of iron in coal to perform this office. Hence we may conclude, that 1 part of fuel in the Bessemer Process will produce as much steel as 6 or 7 parts in the old method by cementation; and that hence there is a saving of 5-6ths to 6-7ths in the amount of fuel necessary.

The labor, the keeping up of the machinery, the consumption of fire-clay, are items small in amount when summed up and compared with the same in other processes. At Woolwich, Bessemer estimated that steel could be sold at $34 per ton, when pig iron was costing $18 per ton. Of course, this proportion will vary with different countries. The chief economy is in the fuel, which is an important fact to be considered by the inhabitants of those regions where fuel is dear, or of inferior quality; and the process may lead to some most important revolutions in the iron industry of the world, by transferring the business to regions hitherto unfrequented by iron manufacturers.

The discovery of this method of making steel was peculiarly opportune. No process ever was invented at a moment more favorable for its development. The metallurgic era in which we live demands vast quantities of steel in large masses. We have left behind us the day when quality alone was considered,—quantity is now our uppermost

idea. We are clamorous for processes to economize time. This furnishes the most sanguine with all he can desire. In less than an hour the liquid cast iron can be converted and drawn into a merchantable steel; the process of cementation requires, to produce the same results, the tedious lapse of several weeks.

The usual method supplies ingots of from 40 to 80 pounds weight, which only by great efforts may be increased to several thousand pounds. With this plan we may cast, with ease, an ingot of 10,000 pounds, and by using several converters at the same time, masses may be obtained of a size the limits of which we cannot assign. Finally, nearly all the movements of the apparatus may be accomplished by steam; the labor of the puddler has no counterpart; muscle is everywhere supplanted by skill; man ceases to be the beast of burden, and assuming his truer sphere, observes, judges, and directs.

CASTING STEEL IN FRANCE.

Those familiar with the interior arrangement of the steel works of Krupp at Essen, in Westphalia, say that one of the reasons for his great success in producing the immense masses of cast steel for which his works are celebrated, is the excellent discipline of the regiment of men that pour the metal from crucible to crucible at the moment of casting. The following paragraph from an account of the casting of the ram or *eperon* of the new armor plated French ship, the *Cheops*, at the Assailly Works, near St. Chamond, shows how necessary this intelligent discipline must be. This great ship's dagger weighs 7¾ tons. In order to cast it, 36 furnaces were brought into requisition, each furnace containing 9 crucibles, and each crucible containing 24 kilogrammes of steel. They were all heated at once, and when ready, 200 men were simultaneously employed in pouring out the contents of the crucibles into the great ladle which had been lined with refractory clay, and brought to a cherry-red. All this had to be done in ten minutes. As soon as the ladle was full, a stopper was drawn, and the fluid metal flowed into the mould.

Two Bessemer converters are constantly in operation at these works. They make two castings per day of six tons each.

The steel works of Assailly, where steel was first cast on the continent, about sixty years ago, are but part of the immense establishment of Petin, Gaudet & Co. This company produces annually 23,000 tons of charcoal cast iron, 27,000 tons of coke cast iron, 58,000 tons of wrought iron for armor-plate, tires, boiler-plates and bars, 15,000 tons of cast steel, 4000 tons of wrought iron "shapes," and 2500 tons railway springs; 6000 men are employed; 150,000 tons of coal, and 30,000 tons of coke are burned, and an annual product, worth 10,000,000 of dollars, is turned out.

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