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HENRY BESSEMER AND THE STEEL REVOLUTION

Dr. Alan Birch, University of Sydney

This article is written to commemorate the 150th anniversary of the birth of the man — not himself an ironmaster or metallurgist — whose invention transformed the iron and steel industry of Europe and the world. The monuments of this achievement are to be found wherever we look around us. On land, the ubiquitous motorcar, bridges, steel-framed buildings; in fact nearly all the durable consumer goods of this present age of mass consumption — and many of the expendable ones, too; for example, the tin cans for food, drinks, sprays etc. etc. On the seas, almost every ocean going vessel, from the 100'000 ton tankers, down to the floating, abandoned oil-drum. One could say too, that all the multifarious machinery required for shaping, turning and constructing these objects of metal is itself made of steel[1]). Now of course, the products of the world's steel furnaces and rolling mills — electronically controlled and the culmination of automation processes — measure many millions of tons, but it is a train of development springing from the experiments conducted in Bessemer's small converter from 1855 onwards.

The salient features of Henry Bessemer's career as an inventor are well-known and need no rehearsal here. Indeed seven years ago tributes were paid in all the leading metallurgical journals on the occasion of the centenary of the epoch marking paper read by Bessemer to the British Association for the Advancement of Science at Cheltenham in 1856. Since the editors brief to the writer is to be original, all that one can do here is to make preparatory critical scrutiny of the facts which can be confirmed by independent evidence, subjecting Bessemer's *Autobiography* — still the chief source of any account of his work — to whatever light is thrown on its obscurities from other contemporary sources.

Bessemer's own character is apparently as unyielding to the careful historian as his steel to the impact of one of the shells from a Krupp's gun, itself fastened of Bessemer steel. Since it has not been possible to trace Bessemer's own private papers, nor of the patent-exploiting partnership of the inventor with Robert Longsdon, nor of the pioneering Sheffield works of Bessemer and his partners there, it is not yet possible to present a definitive portrayal of Bessemer and his work in the steel industry. However, it is now possible to look a little more closely at the experience of one of the British firms which took out an early licence and attempted to pioneer the pneumatic steel process. Once again, a good deal of the vital correspondence between the Trustees of the Dowlais Iron Company and Messrs. Bessemer and Longsdon, is no longer extant, but we can demonstrate with exact detail the results of this innovation when it was applied to the manufacture of steel rails by one of the largest concerns in the British iron and steel industry.

THE DEVELOPMENT OF MILD STEEL

In the 1860's the iron and steel industry experienced revolutionary technological innovations — the Bessemer and openhearth processes which created the heavy steel industry. From being an expensive and indispensable raw material of the cutler and to be used in small quantities, steel, or rather the new product 'mild steel', was transformed into the subject of mass-production techniques and was used

[1]) This general statement is not intended to suppress the fact that a greater part of present day steel manufactures have their origin in the Open-Hearth furnaces; however, the impetus for the establishment of the large scale massproduction of steel sprang from the Bessemer innovation in the first place.

as the ubiquitous source of strength for the architect, the engineer, the shipbuilder and armaments manufacturer. Even today its indispensability and universality is only slightly challenged by aluminium, necessary for man's technological exploits in the air.

Bessemer, surveying these innovations on the threshold of the era of their impact, in 1861, asserted: "Steel, to the engineer, has hitherto stood in much the same relations as granite to the builder." Its qualities of toughness were becoming more and more vital to the railways as well as to the makers of cannon and armour-plate; but two major difficulties stood in the way preventing the metal's use on a massive scale. First, the cost and risks involved in making steel by the available techniques — of co-ordinating a melting of many small crucibles of cast steel, itself the costly refined product of expensive wrought iron, for large metal forms. The consequences of an unfortunate extrusion of impurity in the metal could render a casting weak and useless. The second disadvantage was the difficulty in having it worked or shaped by the forge-hand or engineer. Although cast steel was regarded as a pure and homogeneous metal (and on that account superior in strength to the scoriae-grained wrought iron which often pelled off in layers), it was until recent improvements considered by the smith as hard and brittle, and incapable of being welded together. It is significant that as certain improvements, particularly those introduced on the Continent by Fischer in Switzerland and Krupp in Prussia[1]), could be utilised to make the metal 'milder' and weldable, steel became to be used more and more, particularly in high-class machinery. These then were the inducements to inventors to produce a steel, stronger yet more pliable than cast steel and, of course, cheaper to make by dispensing with the dependence on bar-iron as the raw material for the conversion process.

Attempts to make steel by a direct process had, indeed, attracted the efforts of inventors for a long time. In 1800, David Mushet, whose son was to play an important role in the perfection of the Bessemer process by the re-introduction of the use of manganese, had taken out a patent. His efforts to produce steel at the Calder Works in Scotland and to satisfy the requirements of Peter Stubs with his cast steel, have been described in Ashton's *Eighteenth Century Industrialist*[2]). The primitive Catalan process was the only successful way of accomplishing the task of by-passing the blast furnace, but this only operated on a very small scale. There were several attempts made during the century, but all were unsuccessful. In 1825, Charles MacIntosh, the Scottish industrialist, who was more successful in other fields of industrial chemistry, experimented with an ingenious method of using carburetted hydrogen gas to effect the conversion[3]). The aim of this was to improve upon the ordinary methods of cementation; however, the process did not work upon a large scale. "It was found impossible to keep the chambers in which the bars of iron were suspended air-tight, at the very high temperature to which it was necessary to raise them[4])."

With many of these patents, of course, it is difficult to decide whether the principles they contained were valid and more so, to decide if the subsequent development owed anything to the claims of these early experimenters. A case in point is that of Joseph Heath. In 1839, as a result of some metallurgical researches in India, he patented the use of 'carburet of manganese' in the conversion of iron into cast steel. The following year, he is said to have gone to Sheffield and have "made a valuable improvement in the quality of the steels for which Sheffield, even then was famous[5])." His patent was quashed in the law courts and Heath was finally ruined by long litigation against the Sheffield steel manufacturers who infringed his patent. He died in unfortunate circumstances, just before making a last and desperate demonstration of his contribution to the industry by exhibiting at the 1851 exhibition. To some historians of the iron and steel industry he thus belongs to that trinity of metallurgical martyrs — Cort, Heath and Mushet — who were sacrificed by the greed of their fellow ironmasters to that fate which overtakes the unsuccessful, poverty and bitterness. Yet, all the same, some of the claims which have been made upon their behalf, seem somewhat exaggerated.

1) See below . . .

2) *Op. cit.*, pp. 48—50. In 1867, R. Jordan listed sixteen different processes of steel-making practised in Europe. (Jordan, *Revue de l'industrie du Fer en 1867* (n. d.) p. 281.

3) J. Percy, *Metallurgy: Iron* (London, 1863) p. 773. G. Mac Intosh, *Biographical Memoir of Charles MacIntosh* (Glasgow, 1847) pp. 94—7.

4) D. Mushet, *Papers on Iron & Steel*, p. 671.

5) F. M. Osborn, *The story of the Mushets* (London, 1952), p. 58.

It is claimed, for instance, that, "Heath was thus the author of an invention conferring commercial profits to be reckoned in millions . . .[6])" Such statements only obscure the real significance of these contested inventions.

One method of making steel, which became important as a competitor to the pneumatic process, was the puddling of steel by the ordinary methods as patented by Cort except that the pig iron was not decarbonised to the same extent as when making wrought iron. The stumbling block would, of course, be the question of deciding at which stage in the process a new manufacture came into being. Steel, it should be remembered, had no specific identity to be indicated by a definite carbon content, at that time. The puddling process, strangely enough, had been confined to the Westphalian steel industry for roughly twenty years before it was taken by the Low Moor Company in 1858[7]). Thereafter its output appears to have been considerable, but no statistics are available to measure its production in this country. This metal, of course, suffered from the same imperfections as natural steel; indeed, in 1854, Sanderson noted that its price was only £ 14 per ton as compared with £ 18 per ton for charcoal natural steel[8]).

However, until Bessemers's process got under way in the late 1860's, the steel industry was still based upon the cementation and cast steel processes. Moreover, although the amount of British bar iron which was being used was increasing, the greater part of this raw material of Sheffield's industry came from Sweden. The import of Swedish wrought iron in the 1850's was as follows[9]).

Year	Tons	Year	Tons
1845	18,607	1850	28,096
1846	30,840	1851	35,467
1847	28,264	1852	23,817
1848	20,438	1833	23,540
1849	26,605	1854	24,436

The Swedish iron was absorbed by the many small converters, who still specialised in the old process of steel-making, despite the competition of the large works in Sheffield, at the end of 1860's. One of the largest of these, Vickers, indeed, had no cementation furnaces, it concentrated upon the making of cast steel in its 384 melting holes holding two crucibles each. Each crucible held about 40 lbs of blistered steel. But, of the other large-scale steel makers mentioned by Jordan, in his review of the British Steel industry, made between 1862–9[10]), Turton's possessed 13 cementation furnaces, each containing 22 to 23 tons of bar iron for conversion; John Brown's in 1867 had 18 cementation furnaces. It is apparent the manufacture of crucible steel was booming at this time. Indeed, between 1851 and 1861, the production of crucible steel at Sheffield was expanded from 18,500 tons to 51,500 tons.

It was in the technique of casting from the crucibles, however, that the greatest advances had been made. None of the Sheffield cast steel makers concerned with bell-casting among other things, came quite up to the level of achievement of Krupp. Nevertheless, thanks to the military discipline of the organisation, Vickers could teem ingots weighing 20,000 kilogrammes from 500 crucibles[11]). Krupp, on the other hand, with an output of about 62,500 tons in 1866, was a year later, making ingots weighing 40,000 kilogrammes[12]).

One point, however, which had not greatly concerned the British manufacturers, was the possibility of making cast steel direct from bar iron without the intermediate process of cementation. In this Britain lagged behind the continental steelmakers, especially, Johann Conrad Fischer of Schaffhausen. His diaries describe the details

[6]) *Ibid*, p. 58. (Bessemer, however, also paid tribute to Heath's experiments with manganese in a lecture "On the manufacture and uses of Steel" given to the Cutler's Company, London, in 1880.

[7]) J. Percy, *op. cit.*, p. 793.

[8]) C. Sanderson, "On the manufacture of steel, as carried on in this and other countries" (*Journal of the Royal Society of Arts, 1854—5*, Vol. III, p. 454).
Not less than 15,000 tons were made in 1854; and it was largely used for railway springs. Puddled steel was made by Firth's.

[9]) *Ibid*, p. 451.

[10]) S. Jordan, *op. cit.*, Vol. II, pp. 297—304.
He notes that Vickers also possessed Siemens gas-heated furnaces. The steel industry also survived in Newcastle (at the Newburn works of John Spencer and Son) and in Scotland (at Hawksworth's cast steel works, Linlithgow).
There are also brief details of several of the Sheffield works, particularly from the point of view of the labour employed, in the 4th Report of the *Children's Employment Commission* (1865, C. 3548) Brown's and Cammel's together employed about 6,000 workpeople.

[11]) It was this feat of organisation which pointed to the need for a major innovation making large scale production possible. As Pollard, *op. cit.*, p. 160 says "There can have been few movements in industrial history when a technical revolution to create a new basis for largescale production as in steel making in the 1860's, when "a little army of men" had to be co-ordinated to beat and then to teem 672 crucibles into one mould, one every half second, within five minutes to maintain a constant flow and produce a faultless ingot."

[12]) Jordan, *op. cit.* pp. 300 and 307.

of several visits to Sheffield, and to the Huntsmans in particular, for he was on the best of terms with the family[13]). Fischer's own experiments — with a hot blast furnace to fire crucibles of improved ceramic material to produce cast alloy steel from wrought iron[14]) — also brought him in contact with the great scientist Michael Faraday in the 1820's. Faraday was the first of British scientists to give his attention to metallurgical problems, and his experiments in collaboration with Stodart attempted to produce a synthetic meteor iron by adding minute quantities of other metals[15]). Fischer was working upon the same problem independently and achieved some measure of practical success; Faraday's experiments were the product of disinterested curiosity, although he did consult John Josiah Guest of Dowlais. Hence the work of the scientist is to be regarded rather as a precursor of metallurgical research. Fischer was working towards a more scientific method in the manufacture of steel[16]), and it is significant that in January 1846 he was supplying the Royal Mint at London with his special steel[17]). Competition of this sort was to be very dangerous to the British steel industry. Nevertheless, despite the competition of Alfred Krupp and experimenting foreigners, the British steel industry was in the ascendancy for the next forty years. This was due in the first place to the invention of the pneumatic process of making steel.

The story of Sir Henry Bessemer's sensational paper read to the British Association at Cheltenham in 1856, which seemed to herald the approach of the age of steel, is well known. Nevertheless, the part actually played by Bessemer has been frequently misunderstood and what is more, there is a need for the invention to be put into perspective against the development of the wrought iron industry, which was to be rendered obsolescent by steel. The adoption of the Bessemer process was a much slower process than is sometimes recognised.

It was the stimulus of warlike demand which spurred on the development of the steel industry. During the Crimean War, Bessemer was working upon artillery guns. Already in 1853 he had patented an automatic breech loading gun to be operated by steam under pressure. This apparently was only an idea on paper. After being spurned by or himself ignoring the War Office, he had taken his invention — a self-rotating shot to be fired from a smooth-bored gun — to France to the Emperor Napoleon III. However, it was suggested at the trials at Vincennes that his guns needed to be made of a stronger material than the iron then available. In order to perfect his artillery invention, Bessemer turned to the problems of metallurgy.

Inside three weeks he applied for a patent in which he anticipated the Siemens-Martin process, using the open hearth furnace, in which blister steel was fused in a bath of molten pig iron to produce a tougher kind of iron[18]). Throughout 1855 he was occupied with the problems of casting steel and malleable iron made by the new process for cannon.

His experiments had left him with traces of decarbonized iron, the carbon having been burnt out by the blast during the smelting operations. According to R. D. Allen, his brother-in-law, who had been in charge of the practical operations at Baxter House, London, they had found difficulty in generating sufficient heat to melt the pig iron, and Bessemer had directed "the nozzle to be put in, to try and convert that which was melted[19])." Bessemer, it should bo noted, at this time was trying to make malleable iron, but it was during these experiments that the basic principle of the converting pneumatic process was discovered. Noticing some pieces of apparently unmelted pig iron, and discovering they were "merely thin shells of decarbonized iron" he deduced that air alone was capable "of converting it (pig iron) into malleable iron

[13]) J. C. Fischer, *Tagebücher* (Schaffhausen, 1951) pp. 537 and 592, ff.

[14]) *The Metallurgist Johann Conrad Fischer (1773—1854) and his relations with Britain* (Schaffhausen, 1947) pp. 12 and 28. Fischer was also experimenting with nickel steel.
W. O. Henderson "J. C. Fischer, A Swiss Industrial Pioneer", *Zeitschrift für die gesamte Staatswissenschaft*, 119, April 1963.

[15]) See C. R. Fay, *Round About Industrial Britain, 1830—60* (Toronto, 1952), pp. 201—2 quoting Sir Robert Hadfield's, *Faraday & his Metallurgical Researches* (1931).

[16]) He exhibited at the 1851 Exhibition in London, a model of a furnace, which acted upon regenerative principles.

[17]) *The Metallurgist*, J. C. Fischer, p. 36.

[18]) It will be remembered that this was an ancient continental method of steel making. Patent No. 66, 10th Jan., 1855 "Improvements in the manufacture of Iron and Steel".
Dredge confirms this was not the Bessemer process "only the first practical step toward it." Bessemer claimed his metal had the appearance of steel and, according to Bessemer, he was then on the point of building a furnace at Ronelle, France, with the encouragement of the French Government.

[19]) Presidential Address of R. D. Allen, *Jnl. of Iron & Steel Inst.* 1890.

without puddling", Bessemer claimed this discovery gave a new direction to his thoughts. In October, 1855, Bessemer patented the use of air to remove impurities from melted iron[20]). By this time, as Dredge claims, "Bessemer appreciated the end in view and the general way of obtaining it, though his mechanical details were still crude and imperfect." In December of the same year he patented what was in essence the tilting Bessemer converter. Now, the molten pig iron was run from the blast furnace into a large vessel, into which the air was introduced by tuyeres, and this could be tipped for receiving and ejecting its charge. The characteristic blowing of the charge in the converter is described in the specification of this Patent. "During the operation the metal undergoes ebullition and increases in temperature; the appearance of the flame, sparks and slag issuing from the top of the crucible indicate the state of the metal. After the operation has continued for about half an hour the flame gradually diminishes, and this indicates to the workman that the process is completed, and that the crude metal has been converted into a nearly pure malleable iron." Earlier, Bessemer hat tried using a fixed converter, possibly adapted from his glass-furnace experiments[21]).

In the next year, in January and February, 1856, patents were taken out for improved and new mechanical details of the process. As Bessemer wrote to Krupp, an eager seeker of information, at this time, "In our daily experiments every trial gives rise to some suggestions for improvement of the process[22])." In March, he added another patent to his name for returning the necessary amount of carbon to "the burnt metal" to produce the quality of steel required. On this point, it should be mentioned that, as Bessemer was at pains to point out in his claims, the idea of blowing air or steam into molten iron to refine it was not new. Bessemer, indeed, acknowledged his debt to James Nasmyth, the inventor of the steam-hammer, who was one of several men working upon this plan, and offered him one-third of the value of his own, i.e. Bessemer's patent[23]). In America too, by a strange coincidence, the Pneumatic process had also been evolved by a Kentucky ironmaster, William Kelly, between 1847 and 1851, and his biographer puts forward suggestions of Bessemer travelling to the United States to steal Kelly's secret[24]). There does not, however, appear to be much foundation for these stories.

Bessemer claimed not only to make refined iron, but to convert crude pig iron into steel or malleable iron *without the use of additional fuel;* and almost certainly it was this feature of his invention which attracted so much attention when, overnight, after the reading of his paper at the Cheltenham meeting in August, 1856, the invention was taken up by the Press and Bessemer became a nine days' wonder.

Nor was the eager reception confined to journalists; Thomas Brown of Ebbw Vale offered Bessemer £ 50,000 for the outright purchase of his patents which was refused. Within a month he had received £ 27,000 from ironmasters for licences[25]). Among them was the Dowlais Iron Company, upon the following terms: "On condition of the Dowlais Iron Company undertaking to at once erect the necessary apparatus for carrying into practical operation Henry Bessemer's new process of manufacturing malleable iron, and on the Dowlais Company paying to Bessemer and Longsdon the sum of £ 10,000 and 10/— per ton up to 20,000 tons[26])." Thus, it will be seen, expectations were high on both sides.

[20]) Steam, then air, was forced into the iron in this process melted in crucibles with a perforated pipe down the centre. Dredge quotes Bessemer. «Air is used to complete the operation... the metal... will rapidly brighten up, and increase of flame will be observed, and a rapid increase in the temperature of the metal will take place."

[21]) W. M. Lord, "The development of the Bessemer Process in Lancashire", *Trans. Newcomen Soc.*, 1945—7.

[22]) *Krupp MSS.* H. Bessemer to A. Longsdon (Krupp's Agent in London), 25th Jan., 1856.

[23]) Nasmyth had taken out a patent for steam-puddling in 1854.

[24]) J. W. Boucher, *W. Kelly: A true history of the so-called Bessemer Process* (Greensburg, Pa. 1924). For a recent appraisal of the Kelly contribution see Philip W. Bishop "The Beginning of Cheap Steel", United States National Museum *Bulletin* 218, 1959, pp. 42—44. Again, there is the familiar situation of the difficulty of reconciling his biographer's claims with the few ascertainable facts. The successful operation of the first "Bessemer" plant in the United States at Wyandotte owed a great deal to the information on the French application of the Pneumatic Process brought over from St. Seurin by L. M. Hart.

[25]) Cf. Erickson, *Brit. Industrialists*, pp. 141—2. "Bessemer himself planned to grant such licences to one firm in each area at a reduced royalty." W. H. Chaloner, "John Galloway 1864—1904" *Trans. Lancs & Ches. Antiquarian Society*, 1954, noting that this engineering firm, which was closely associated with Bessemer in his experiments and in perfecting the converter, makes the suggestion that even as early as 1855 an ingot of Bessemer steel — the first in the world — had been made at these works. Galloway, in fact, took out a licence before Bessemer announced his discovery to the world in August 1856.

[26]) *Dowlais MSS.* Agreement dated 27 August, 1866, reciting the earlier terms.

Then came failure which threatened to discredit Bessemer, who had appeared like "a brilliant meteor that had flitted across the metallurgical horizon, dazzling a few enthusiasts, and then vanishing forever in total darkness[27])." At Dowlais, experiments had been conducted to attempt to perfect the process, for Bessemer himself had not at this time secured consistent results nor discovered how to control the chemical changes in the process. The course of the events was described by E. P. Martin, who later migrated from Dowlais to Bolckow Vaughan's and played an important part in the perfection of the later Thomas process. "When Mr. Bessemer came to Dowlais to continue the experiments, a convenient refinery happened to exist opposite the furnace making cinder and pig, and the iron from this furnace was by a most singular and unfortunate mischance employed for Mr. Bessemer's trials[28]). "Thus working with this inferior quality pig iron Bessemer's process would not repeat what it had successfully done before. His experiments showed that, only from the very best descriptions of foundry iron could wrought iron be produced which had at all the character of ordinary bar-iron . . . with ordinary forge pig — nothing could be done with it . . . it crumbled to powder and dust or else the bar was as brittle as glass[29])."

A similar sorry experience was repeated at the Mersey Forge in Liverpool; at Butterley in Derbyshire; at the Coats Iron Company and at William Dixon's Govan Ironworks in Scotland[30]). This failure came to Bessemer like "a bolt out of the Blue[31])" for where he had been working with Blaenavon pig iron, almost free of phosphorus (which was the unknown cause of the trouble), he had not yet realised the special qualities of pig iron necessary for success. Baffled and frustrated, all that Bessemer could do was to begin new experiments (and employ a chemist, which was not a great help) to discover the cause of the failure. Meanwhile, the British Association refused to print his paper on the grounds that so great a fallacy ought not to be encouraged by its publication in their Report. The *Mining Journal* in November of 1856, wrote, "The excitement of the Bessemer process, by which we were to have had malleable iron at the price of pig iron, has now nearly subsided[32])." However, as Dredge says, if Bessemer was temporarily discredited, he did not accept the verdict passed on his invention. He knew "the defects which had presented themselves did not touch the principle on which the invention was based . . . He addressed himself to overcome the difficulties of detail." "Furnace machinery and apparatus were constructed at the Baxter House works, to be pulled down and rebuilt or altered; thousands of pounds were spent in experiments, and some two years passed away in incessant preliminary work[33])."

The first step towards getting the Pneumatic process perfected was to discover which kinds of pig iron would work and give consistent results in the converter, and then possibly to find out the chemical cause of failure. Bessemer had, in fact, been buying his raw materials "simply as pig iron" without ever apparently suspecting that iron from other sources was so different.

Eventually he discovered that the haematite pig irons, and iron from the Forest of Dean, Weardale and Blaenavon, best suited the process, but it was the success of his Swedish licensee, Göransson, in 1858, after many trials with Swedish charcoal iron, which pointed to the cause of failure — the presence of phosphorus and sulphur[34]). As Carlberg claims, Göransson "put Bessemer's ingenious invention on a sound industrial footing, thereby inaugurating the age of steel". Göransson brought over to Sheffield, where Bessemer had recently commenced his steel works in partnership with W. D. Allen, Robert Longsdon and others, fifteen tons of steel ingots

[27]) Boucher, *op. cit.* pp. 67—76 quoting a letter of Henry Bessemer to Sir James Kitson, 10 September, 1890.

[28]) Presidential Address of E. P. Martin, *Jnl. of Iron and Steel* Inst. Vol. Ll, 1895, p. 22.

[29]) E. Riley, *On the Manufacture of Iron* (Society of Engineers, London, 1862) p. 79.

[30]) Erikson, *British Industrialists*, p. 142. It would be interesting to know exactly how many licences were taken out in the first place. Allan Nevins, *Abram S. Hewitt*, (N. York, 1935) p. 129 discussing an early trial at the Trenton Ironworks in Dec., 1856, mentions that five firms had become licensees and all had met with failure. In Germany, Krupp's efforts to take out the Bessemer patents for making malleable iron in Prussia from January 1856, were unsuccessful on account of the priority given to Nasmyth's and Martin's processes. Krupp did not enter into an agreement to become licensed to use the Bessemer process until August 1861. ("Alfred Krupp and Henry Bessemer", *Stahl und Eisen*, Heft 13, July 1962, pp. 911, ff.

[31]) Bessemer, *op. cit.* p. 170.

[32]) *Loc. cit.* Nov. 29, 1856.

[33]) Dredge, "Henry Bessemer, 1813–1898", *loc. cit.* pp. 922–3.

[34]) E. F. Lange, "Bessemer, Göransson & Mushet, a Contribution to Technical History", *Mems & Procs. of Manchester Literary & Philosophical* Society, 1912—13. Per Carlberg, "Early Industrial Production of Bessemer Steel at Edsken", *J. I. S. I.* Vol. 189, July, 1958.

made at Edsken in the Converter. This steel was successfully hammered and tilted and made up into artillery, tools etc. Göransson initiated Bessemer into the Swedish way of blowing; as a result the tiresome and profit-consuming Sheffield process of granulating the steel and remelting it could be eventually abandoned. Bessemer & Co. bought 100 tons of the Edsken pig iron for conversion and on June 18th, 1859, W. D. Allen was able to record in his diary "First made Steel direct[35])."

Thereafter, Bessemer himself made steel worth, again according to his own estimates which were disputed, £ 50 or £ 60, from Swedish pig iron costing only £ 7 a ton. Bessemer proclaimed the end of the age of iron: "I could now see in my mind's eye, at a glance, the great iron industry of the world crumbling away under the irresistible forces of the facts so recently elicited. In that one result the sentence had gone forth, and not all the talent accumulated in the last 150 years . . . no, nor all the millions that had been invested in carrying out the existing system of manufacture, with all its accompanying great resistance — could reverse that one great fact."

But that is not the end of the story, for in reality the development of the process was not just the work of Bessemer and his associates to perfect and realise a brilliant idea, but rather of a series of complicated, and not yet completely unravelled set of circumstances in the contemporary metallurgical world. Moreover, although Bessemer, as we have seen, recognised "the powerful resistance" of the iron industry with the large amount of capital tied up in its puddling furnaces and forges, he too easily dismissed the difficulties and obstacles to a large-scale changeover to steel.

We have already noted the coincident invention of Kelly, who used the same principle as Bessemer, but who used different machinery for the conversion. The American courts, incidentally, gave Kelly's patent priority over Bessemer's. But although metallurgists themselves have recognised the value of the contribution of Robert Forester Mushet, the son of David Mushet, the famous metallurgist of the first half of the century, historians have, too often, been dazzled by the limelight which Bessemer threw upon himself.

[35]) Lange, *loc. cit.* pp. 13—17 quoting a letter from Göransson to Professor Richard Ackermann, dated 6 November, 1879. Carlberg, *loc. cit.* p. 204. Dredge, *loc. cit.* p. 928.

This section is therefore intended to consider briefly the part played by Bessemer's rival in metallurgical invention.

At the outset, it can be said that Mushet, a steelmaker in the Forest of Dean, was in possession of the knowledge and experience which, given co-operation between the two inventors, could have solved Bessemer's problems sooner than he did. In fact, Mushet who had been given some of the samples available at the Cheltenham meeting by Thomas Brown, of Ebbw Vale Iron Works, was able to forecast Bessemer's difficulties, and what is more, he had been able to improve bars of metal made by a Bessemer converter in South Wales into steel which was forgeable[36]).

What was the secret of Mushet's success? One cause of the metal crumbling and being unsuitable for forging was the superabundance of oxygen in the metal. Here, Mushet, who had been using a manganese compound, "spiegeleisen", since 1848, to remove the oxygen as an oxide in the slag and at the same time to replace the carbon which had been burnt out, was able to produce ingots of steel equal in quality to cast steel.

The ensuing story of the relations between Mushet and Bessemer — Bessemer's approach to Mushet to share his secret with him; the consequent rivalry upon Mushet declining the offer and the lapsing of Mushet's patents, which finally gave Bessemer the use of the spiegeleisen secret, need not be related here[37]).

In 1858, the problems of production having been solved by the use of Swedish phosphorus — free iron and Swedish techniques; practical trials of the product having been put to the test at Gal-

[36]) See my article on the first steel rail in *Engineering*, 8 Febr., 1952. This rail was rolled and laid in 1857.

[37]) See F. M. Osborn, *op. cit.*, Lange, *loc. cit.* and Bishop, *loc. cit.* pp. 33—35. The clarification of Bessemer's position over the rival patent claims of Joseph Martin to purify pig iron by forcing currents of air under it, which were taken up by Brown of Ebbw Vale is also a difficult matter. Eventually, Bessemer was glad to pay £ 30,000 for the Ebbw Vale patents and Ebbw Vale took out a licence for the manufacture of steel by the Bessemer Process, «which from the peculiar resources they possess they will be enabled to produce in very large quantities." (Bishop, *loc. cit.* p. 37).
Lange's comment is appropriate: «This agreement removes the last barrier to the quiet commercial progress of Bessemer's invention throughout Europe and America, and showed Bessemer in the light of a very astute business man. In fact, the Ebbw Vale royalties eventually amounted to between £ 50,000 and £ 60,000. This was Bessemer's last battle." (Lange, *loc. cit.* p. 23).
In America, Kelly's patent stood in the way of the exploitation of Bessemer licences and steelmakers had to take out licences from both interests.

loway's works in Manchester, the next step was to establish a steel works at Sheffield, the headquarters of the steel industry. As Bessemer told the Institution of Civil Engineers in May 1859, "It was then decided to discontinue for a time all other further experiments, and to erect steel works at Sheffield, for the express purpose of fully developing and working the new process commercially[38])." According to Dredge, the resources of the firm were very small — less than £ 12,000 in all. Messrs. Bessemer & Longsdon subscribed about £ 6,000, Messrs. W. & G. Galloway £ 5,000 and W. D. Allen £ 500. "These were the narrow means with which to enter on so great a struggle . . ." According to Bessemer they were "determined to beard the lion in his den, and to undersell the trade, until we forced them in self-defence to take a licence under my patents and carry on my process[39])."

In June, 1859, *The Mining Journal* remarked that Bessemer tool steel had become a recognised article of manufacture; the Bessemer works using the new methods could sell the best quality steel at "little more than two-thirds the normal price[40])." Accordingly, "It would appear almost impossible for success to be wanting to the seller." In the making of rails, too, the new firm introduced stiff competition, cutting its prices by £ 10 per ton. Bessemer was now probably justified in asserting: "This soon brought the trade to a proper frame of mind."

In 1860, John Brown, the leading Sheffield heavy steel maker took out a licence; Charles Cammell's followed suit and began rolling rails in 1861[41]). By that time, the output of Bessemer steel was estimated at 3,000 tons a week and the process adopted in Liverpool, Crewe, South Wales, Manchester, Cumberland and in the North-East, besides Sheffield[42]).

Of course, the Bessemer process was by no means perfected, even then. Indeed, the basic problem remained, to convert steel from pig-iron made from phosphoric ores. As Miss Erickson says "None of the existing firms of iron or steelmakers had either the staff, the ingenuity or the foresight to try to solve the problems that Bessemer's original idea posed[43])." But, apart from that line of development, there were problems to be overcome arising from the rapid rate at which the linings were consumed by the intense heat — Bessemer used a locally available gannister; the tuyeres needed to be replaced; the waste of metal during the explosive chemical reaction amounted to as much as 18%. These technical problems were the subject of discussion at Sheffield at the meeting of Mechanical Engineers in 1861, when demonstrations of the largest 4 ton converter at the Atlas works and at Bessemer's iron works began to silence critics. Significantly enough journalists seized upon the potentiality of Bessemer steel as making it possible for English steel cannon to outnumber "the vast batteries of the same material already mounted on the Continent" — at one-third the cost. Bessemer himself spoke of an 18 pd. gun being cast at 11.20 in the morning and ready for the boring mill at 7 in the evening. He claimed the cost of his furnaces and the plant to make forty such guns would not exceed £ 5,000.

This was realistic, perhaps, but certainly his appraisal of the position in the world of iron and steel shewed a greater sense of the future. It is significant that he could now set out the specifications of the new industrial material, mild steel: "The problem we have now before us, is how to produce cast steel that will take any form in the mould, or under the hammer; that will yield quickly and readily to all our present cutting and shaping machines; will retain all the toughness of best iron with a much greater tensile strength; and all the cleanness of surface, beauty of finish and durability, that so eminently distinguishes the harder and more refractory qualities of steel in common use[44])." This steel had been already used for marine engine shafts, cranks, propellers, anchors and the like; Bessemer urged its use in girders, bridges and viaducts. "The manufacture of cast steel has only to produce at a moderate cost, the various qualities of steel required for constructive purposes to ensure its rapid introduction, for we may be assured that, so certain that the age of iron superseded that of bronze, so will the age of steel reign triumphant over iron."

To be concluded

[38]) Dredge, *loc. cit.* p. 927.
[39]) Letter of Bessemer *[no date]* cited Dredge, *loc. cit.* p. 929.
[40]) £ 2.4.0. per cwt. as against the usual price of £ 2.15.0. to £ 3.5.0.
[41]) See Erickson, *British Industrialists*, pp. 143—5 for an analysis of these firms.
[42]) L. Grüner, *The Manufacture of Steel* (London, 1872) p. 49.
[43]) Erickson, p. 143.
[44]) H. Bessemer, "On the manufacture of Steel and its application to Constructional Purposes", *The Engineer*, Vol. 12, 1861. pp. 62—3.