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Historic Ironmaking

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HISTORIC IRONMAKING

by

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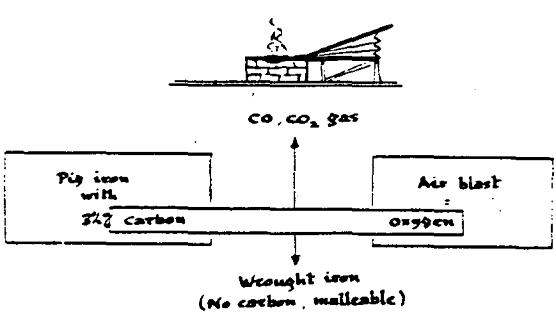
When we walk through the woods and suddenly come across an old ruined stone blast furnace; or read in an old book about bloomeries, chaferies, "forges with three fires", etc., I imagine many of us may have wondered what activities went on in these places.

To understand the problems and processes involved we have to know something of the metallurgy of iron. Iron is a reactive metal, as we all know from the way our tools rust if given half a chance. So, it is not surprising that iron is never found in nature as the metal itself, but always as oxides or other compounds. Essentially, iron ores are oxides– that is, iron combined with oxygen.

Now carbon, say in the form of charcoal, when heated, likes to combine with oxygen to produce carbon monoxide and carbon dioxide gas. This is what happens when it burns. And if charcoal is mixed with iron oxide ore and heated the carbon of the charcoal will combine with the oxygen in the iron ore to produce metallic iron and the gaseous oxides of carbon.

We can imagine early man building his campfire within a circle of stones as campers do today. It chanced that one day the stones he used happened to be iron ore, and among the hot charcoal embers next day some observant man noticed a strange looking thing– a stone that could be bent. Man had discovered iron!

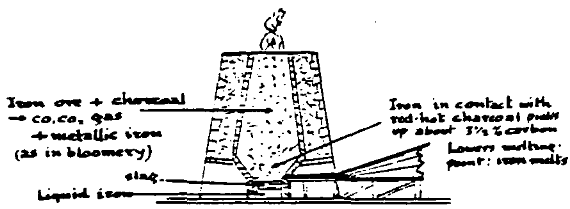
The earliest ironmaking process, the bloomery, was not much more sophisticated than this primitive campfire. It was a simple hearth on which selected chunks of iron ore were heated with charcoal in a blast of air. Probably originally the blast was no more than the prevailing wind on a hilltop; but soon some genius developed the bellows– a bag made from an animal skin between two hinged boards which could be worked to produce a blast of air.



Finery Reactions

As the carbon of the charcoal reacted with the iron oxide ore, metallic iron was produced— as a spongy mass mixed up with partly fused slag and earthy matter. This pasty mass was dragged out from the hearth and hammered to consolidate it and squeeze out the foreign matter. This primitive bloomery process persisted in less developed areas right down until the early part of the last century. It required little capital investment and no very elaborate equipment— although the labor-saving improvements of water-wheel driven bellows and a drop hammer were usually employed. It was not a very efficient process and produced only a few pounds of iorn for a day's work.

The bloomery was improved in Europe as early as the 13th and 14th centuries by adding a low vertical shaft (perhaps six to ten feet high) to feed the charcoal and ore to the hearth, and get the benefit of some preheating of the charge. By about 1400 improved water-wheel driven bellows were developed and furnaces were built higher. This resulted in a striking change in the product of the furnace. The blast furnace was born. (It is still called "the high furnace" in French and German.)



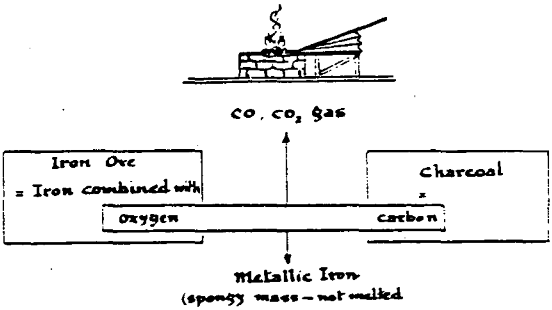
The Blast Furnace

(produces pig-iron (cast iron) which is brittle – cannot be forged)

In the upper part of the furnace the same reactions occurred as in the bloomery. But now the spongy iron first produced remained in contact with the hot charcoal for a relatively long period as it worked its way down the furnace, and the iron dissolved carbon up to about 3½%. Now, the addition of this amount of carbon lowers the melting point of iron from 2800^{0} to 2100^{0} F., and so the carbon-containing iron melted and trickled down to collect in the crucible at the bottom of the furnace. This separated it from the earthy matter which floated on top as a slag. The molten iron was tapped out, usually every twelve hours, and run into channels in the sand of the casting floor. There were side channels fed from a main channel and this suggested a pig suckling her young. Hence the phrase "pig iron". This pig iron, or cast iron, was brittle and could not be forged or hammered to shape. But it could be cast into sand molds to make firebacks or cannons or other things. Probably it was a sad shock for the first pioneer ironmaster who built

his furnace high enough to get this brittle pig iron running out instead of a pasty but forgeable mass of wrought iron such as the bloomery produced.

So the blast furnace produced pig iron with 3½% carbon in it, and this carbon had to be removed if forgeable wrought iron was to be produced. How was this done?



Bloomery Reactions

The pig iron was remelted in a finery on a hearth with an airblast– a setup very similar to the original bloomery. But now the oxygen in the airblast reacted with the carbon in the iron to produce carbon monoxide and carbon dioxide gas, leaving essentially pure iron which could be forged. Of course, this process was much more efficient than the original bloomery as it used pig iron which had already been seaprated from slag and earthy matter. The output of forgeable iron was therefore much greater. But considerable skill was needed to control the process so that oxidation was not carried too far. Even so, there was very considerable loss of iron as a black, glassy slag of iron silicate.

The finery with its water powered bellows and drop hammer produced rough forged billets of iron called "anconies". These rough billets were reheated in yet another similar hearth for forging down to wrought iron bars of finished size. This reheating and final forging was done in a chafery, a name derived from the French word meaning "to heat".

Wrought iron from finery reheated and forged to finished bars

Chafery

Fig. 26– A Colonial finery in action. –*From a sketch by the Author.*

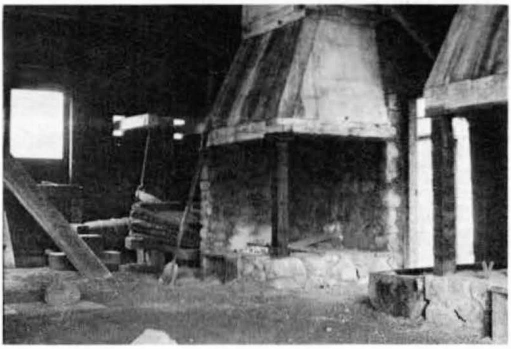


Fig. 27– Reconstructed finery hearth, Saugus Ironworks, Saugus, Mass. –*Author's photo.*

Sometimes the whole operation from blast furnace to chafery was referred to in contemporary documents as a "forge". Usually the various operations were strung out for a considerable distance along a stream for the very practical reason that there was not enough water power at any one point to drive more than one or two water-wheels.

To complete the picture one more step must be mentioned in this seesaw game between carbon and oxygen. You will recall that the 3½% carbon had been removed from the pig iron in the finery to produce forgeable wrought iron, which was essentially carbon-free. Iron with no carbon in it could not be hardened to make cutting tools. But, if a controlled amount of carbon (between ½ and 1%) was re-introduced by heating pieces of wrought iron in sealed boxes for a rather long time in contact with suitable carbonaceous material, the resulting product would harden if heated to a red heat and quenched in water or oil. As quenched it would be extremely hard but brittle. However, reheating to a lower temperature, 350 to 750^{o} F., would impart toughness and resilience with little loss in hardness. This operation was known as "tempering" or "drawing". It was, as you will appreciate, a slow and expensive business to produce steel for tools in this way and only small amounts were available and it was precious. For scythe blades, for example, thin strips of steel were forge-welded to a wrought iron frame to provide the cutting edge.

Wrought iron was not only used as forged bars. It was also hot rolled to sheets between rollers in a rolling mill. And some of these sheets were passed through a slitting mill in which spaced cutting discs on a roller cut these sheets into narrow strips. These were used for such purposes as making nails. You may have heard of the slitting mill at Boonton in Colonial times. It was illegal because British trade policy forbade the colonists to have equipment for producing finished iron products— the idea being that the colonies should produce raw iron for export to England where British industry would have the profit of turning it into finished goods for re-export to the colonies. So, the Boonton slitting mill was hidden in the cellar below a grist mill. It is said that the Royal Governor heard reports of the slitting mill and came to investigate; but was regaled with such a fine feast that he did not pursue his inquiries.

The early furnaces had great leather bellows to produce the airblast, such as you can see at the reconstructed Saugus iron works near Boston. However, they were a continual source of trouble, as the leather cracked and leaked. By the end of the 18th century they were largely replaced in England by blowing engines using iron pistons and cylinders. Isaac Wilkinson obtained a patent on March 12, 1757. To quote his own words, "I grew tired of my leather bellows, and determined to make iron ones. Everybody laughed but I did it, and applied the steam engine to blow them."

The crucibles of the early blast furnaces in which the molten iron collected were rectangular in section, probably because they were lined with big slabs of heat-resisting stone or slate and it is much easier to make a rectangular than a round crucible. It was not until about 1845 in the so-called Black Country of England that John Gibbons made the observation that a newly constructed furnace always worked better after it had been in use for some time and the internal shape had worn and become rounded. A rectangular crucible is therefore a sign of a relatively early furnace.

It took an enormous amount of wood to keep an iron works going with charcoal for the blast furnace, and for the finery and chafery hearths. In England by the beginning of the 18th century charcoal was in short supply and the future of the industry was threatened. Repeated efforts were made to use the available bituminous pit coal, but it was not until 1709 that Abraham Darby succeeded. He partially burned the coal first to drive off the volatiles and much of the sulphur, and used the resulting coke in the furnace. (It was called "de-sulphurized coal".) However, it was another 50 years before the use of coke became general. But, by the end of the 18th century charcoal furnaces were becoming relatively rare in England, although the problem of charcoal supply did not become acute in the colonies until some 50 years later. Over here the anthracite coal of Pennsylvania was the obvious alternative, but it was not until 1841 that the first successful anthracite furnace was brought into operation at Stanhope, New Jersey. The big problem was to provide a more effective blast than the old water-wheel driven blowers could give. The answer was steam power.

Incidentally, the greater crushing strength of anthracite compared with charcoal enabled furnaces to be built higher without pulverizing the charge by the weight above. This was a further step forward in increasing the efficiency of the blast furnace.

The air blast for the blast furnace was originally cold; and indeed it was considered a virtue to have it as cold as possible. But a major technical advance was made in 1828 in Scotland by J. B. Neilson, who proved that preheating the air blast resulted in great economy and increased efficiency. The air was heated by passing it through U-shaped cast iron pipes in a separate small furnace heated by a fire. Some of these cast iron U-pipes can be seen at Ringwood Manor, New Jersey, near the well at the west end. The first successful hot blast furnace in this part of the world was at Oxford in 1834. Production was said to have been increased by 40%.

The use of better blast gave higher temperatures in the furnace which enabled some of the sulphur to be removed from the iron by using a lime-containing slag. (The slag from the old charcoal furnaces is black and glassy, whereas from the later anthracite furnaces it is more grey and stony.)

The early furnaces were open-topped and gas flared and burned by day and

night. It was a long and difficult development to find an effective way to collect the gases without upsetting the working of the furnace. The earliest patent for an effective system to collect the furnace gases and use them to burn in boilers, or to heat the blast stoves, was granted in England to Budd in 1845. By the last quarter of the century the gases were being collected and used in all the newer American furnaces.

The ruins of the old stone blast furnaces stand today like isolated towers. But in the days when they were in action the blast furnaces were the core of a cluster of buildings, with the casting house built adjoining the furnace, an enclosed water-wheel house (to prevent freezing in winter), and a covered charging bridge at the top.

I hope that in this short article I have been able to give some idea of what went on in these old iron works, once so busy with the wheezing of bellows, the thud of hammers, the shouts of workmen, and the flames and smoke of action; but which are today no more than crumbling, silent ruins and historical curiosities.

Jack Chard was born in Kent, England, in 1912. After attending Westminster School he obtained his degree in metallurgy at the Royal School of Mines, University of London. After a year or two in the research laboratory of a steel company he joined the government scientific service, and served in the Ministry of Supply in London during World War II. He then transferred to the Royal Naval Scientific Service and was Chief Metallurgist at the Torpedo Experimental Establishment, Greenock, Scotland, for ten years. In 1954 he moved to the Canadian Armament Research and Development Establishment near Quebec City in a similar capacity. In 1957 he joined the research laboratory of the International Nickel Company, and is now Supervisor of Mechanical Testing at the Paul D. Merica Laboratory in Sterling Forest, Suffern, N.Y. His interest in historical metallurgy was increased and stimulated since living in this area so rich in the history of ironmaking. He is Chairman of the Historical Landmarks Advisory Committee of the American Society for Metals, and is active in the North Jersey Highlands Historical Society.