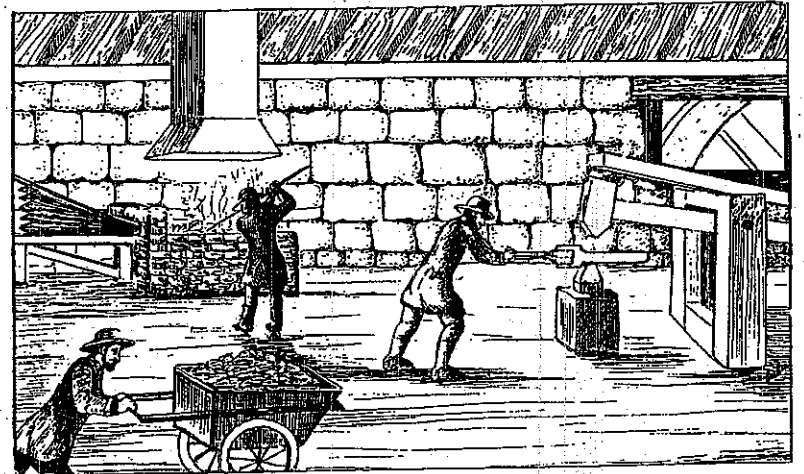


# Making Iron & Steel

THE HISTORIC PROCESSES  
1700 – 1900

JACK CHARD



SECOND EDITION

Published by the North Jersey Highlands Historical Society  
P.O. Box 248, Ringwood, N.J. 07456  
Copyright 1995

2-21625  
EASTERN NATIONAL

\$ 3.95

## **Preface**

When visiting or reading about an old ironworks it is often difficult for many people to understand the processes involved and the differences between the various types of iron and steel. This little book gives a brief but understandable description of the early processes and how they developed and the metallurgy involved in making iron and steel.

This booklet was first issued in 1986 and reprinted in 1989. This edition has been much revised and contains much new material. I hope you will find it informative and interesting.

I wish to express my thanks to Robert B. Gordon and Bierce Riley for their encouragement and for their many helpful comments and suggestions. I wish also to record my thanks to Charles Blick, David Crossley, Helen Schenck and Bierce Riley in compiling the bibliography.

Jack Chard  
Ringwood, New Jersey  
1995

## **About the Author**

Jack Chard was born in England and graduated in metallurgy from the Royal School of Mines, University of London. He worked in the Firth-Brown Steel Research Laboratory in Sheffield, England, and later in the Government Scientific Service in London during World War II. He was later Chief Metallurgist at the Royal Navy Torpedo Experimental Establishment in Scotland and in 1954 emigrated to a similar position at the Canadian Armament Research and Development Establishment at Quebec. In 1957, he joined the International Nickel Co. Research Laboratory in Bayonne, N.J., later relocated in Sterling Forest, N.Y. He has for many years been an active member of the North Jersey Highlands Historical Society and has served as its President.

## **Making Iron & Steel The Historical Processes (1700-1900)**

When we visit the sites of old iron furnaces or read about historic iron-making there is often a very understandable confusion, even among archaeologists who are not metallurgical specialists, regarding the differences between the various forms of iron— bloomery iron, pig iron, cast iron, wrought iron, puddled iron, malleable cast iron, crucible steel, Bessemer steel and open hearth steel. This brief account describes the essential features of the various processes involved and the differences between the products. As we shall see, the key to the very different properties of these materials is the amount of carbon they contain, and the form in which it is present.

### **Making Iron from Ore**

First, though, we must make iron from the ore. Most important iron ores are oxides - compounds of iron with oxygen. In some mountainous regions of the United States, such as the foothills of the Appalachians, the ore is generally dense, magnetic, black magnetite ( $\text{Fe}_3\text{O}_4$ ); in many areas it is red hematite ( $\text{Fe}_2\text{O}_3$ ). In other regions it is limonite ( $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$ ), an hydrated iron oxide, which, in flat, marshy areas, forms yellowish *bog iron deposits*.

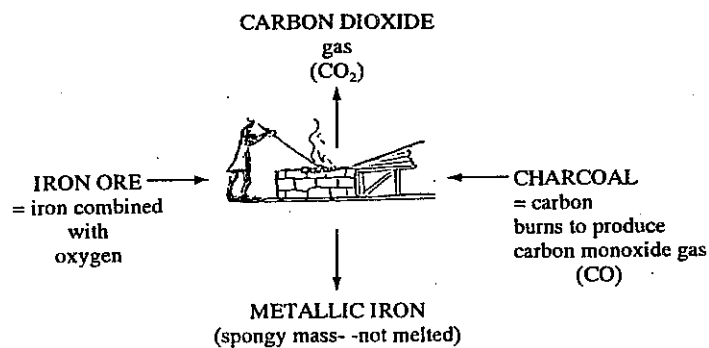
We have to seduce the oxygen away from the iron; and luckily carbon, in the form of charcoal, has a great affinity for oxygen, which is why charcoal and coal burn. (Burning is the combination of carbon with the oxygen in the air). So, if iron ore is heated with charcoal, the charcoal removes the oxygen and leaves metallic iron. Charcoal is essentially pure carbon, produced by burning wood with a limited air supply. Charcoal burns approximately twice as hot as wood since the volatile substances have already been removed. This heat is necessary to process iron ore into metallic iron.

Two common impurities, phosphorus and sulphur, cause problems if present even in quite small amounts. Sulfur made the iron "hot short" (brittle at forging temperatures), and phosphorus made it "cold short"

(brittle at room temperature). In the case of phosphorus, however, provided the iron was essentially free of carbon (as in bloomery iron), a small amount of phosphorus could be tolerated, and strengthened the iron without embrittling it. It has been found recently that the wires of some early harpsichords were made of iron strengthened in this way. But for the most part phosphorus, like sulfur, was an undesirable impurity, and the control or removal of these elements was an important part of ironmaking.

In the early days before the development of chemical analysis the only way to determine the quality of an ore was to make up a sample batch of iron from it and test it for hot and cold brittleness.

### The Bloomery



The earliest and simplest way of making iron was the bloomery, dating back to prehistoric times. Iron ore was mixed with charcoal in a small hearth and the fire was urged on by a simple bellows. The carbon reacted with the oxygen in the air blast to form carbon monoxide gas, which in turn reacted with the oxide ore to remove the oxygen and leave metallic iron. The temperature never got high enough to melt the iron, which accumulated as hot pasty particles which were agglomerated by the operator into a lump of iron. This was pulled out and hammered to consolidate the iron and squeeze out most of the adhering and entrained

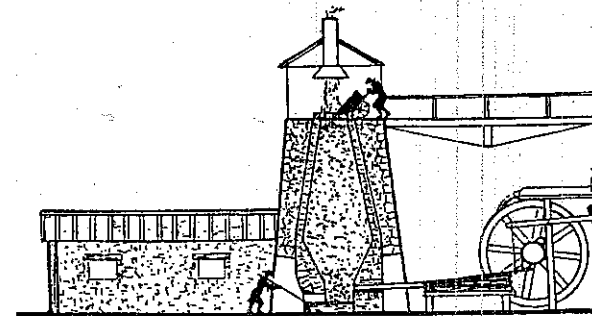
slag. This was *bloomery iron*, very low in carbon content and hence ductile. It could be forged by the blacksmith and would bend cold without breaking.

The word *slag* needs some explanation. Ores are not pure chemical compounds of iron and oxygen, but contain a proportion of earthy impurities, notably silica. In fact, quite a lot of the iron in the ore ended up as a glassy iron silicate slag, rather than metallic iron, in the bloomery process. Bloomery slag, when found at old ironworks, is dense, black, and heavy.

The original bloomery was a small and inefficient process, producing only a few pounds of iron at a time after some hours of operation. (It was cause for celebration in about 1775 when a 28-pound bloom was produced in North Jersey.) A simple process that required little capital investment, the bloomery persisted in remote and less-developed regions of the U.S. into the late nineteenth century.

Around 1840 the bloomery process underwent a remarkable development, as will be described later. The improved process became known as the American Bloomery Process.

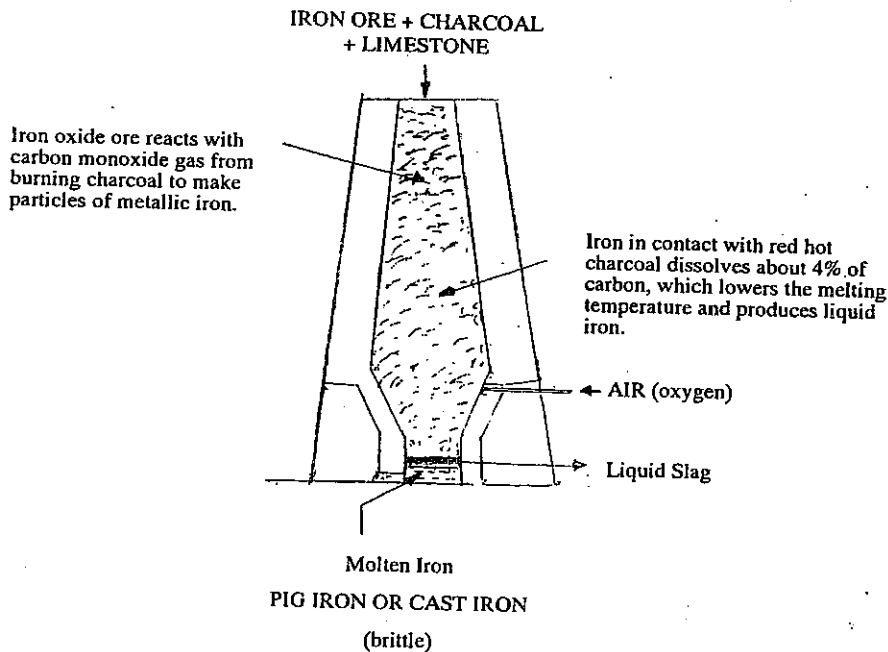
### The Blast Furnace



The next major development was the blast furnace, in use since the fourteenth century in Europe. Iron ore and charcoal, with some limestone as flux to produce an effective fluid slag, were charged into the top of a *high furnace* which was about 25 feet high, while a blast of air was pumped in at the bottom by large water-powered bellows. Many of you

may have seen the square stone furnace ruins of old ironworks. In operation, the furnace was the center of a group of roofed buildings, with the bellows room on one side and the casting house on the other side. There was a charging bridge, usually running from an adjacent hillside, over which the workers brought the ore, charcoal and limestone to fill the furnace. The ore was usually roasted in a fire or low stone kiln to burn off the sulfur in the ore before the iron-making process.

In the upper part of the furnace the same reactions occurred as in the bloomery; the iron oxide ore was reduced by carbon monoxide gas to metallic iron. However, as the iron particles worked down through the hot charcoal, they absorbed about 4% of carbon. Iron containing this much carbon has a much lower melting point than carbon-free iron; so the iron melted and collected as liquid in the *crucible* at the bottom of the furnace, while the slag floated on top, giving a clean separation. In the high temperatures of the furnace, the lime in the charge reacted with the silica in the ore to form a fluid calcium silicate slag which was run off and discarded.



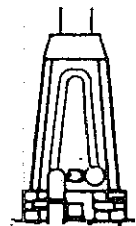
The iron was run out, usually every 12 hours, into channels in the sand floor of the casting house. The main channel, with a number of side channels at right angles, resembled a sow with suckling piglets. This is thought to be the origin of the term pig iron.

Unfortunately for the hopeful blacksmith, this *pig iron*, or cast iron, was brittle and could not be worked by hammering. It could, however, be cast into shaped cavities in the sand to make cast pots and firebacks and other useful products. It was found later that it was better to remelt pig iron for such purposes in a separate *cupola*, a small cylindrical blast furnace in which iron, selected from the appearance of its fracture, could be used, providing better uniformity and better control of casting temperature. Pig iron was brittle due to the presence of carbon as big, weak, flakes of graphite throughout the structure. To make it malleable, it was necessary to remove this carbon by a second process, called *fining*.

Under certain conditions, depending on the charge, operating temperature, and the amount of silicon present in the iron ore, the carbon in pig iron was present as iron carbide, rather than graphite. This was so-called *white iron*, from the appearance of the fracture. It was extremely hard and terribly brittle. So the problem of removing the carbon remained if a malleable product was desired.

For hundreds of years blast furnaces were open at the top, and the gases flared to the sky. It was not until 1845 that J.P. Budd in England devised a way to collect the gases without upsetting the operations of the furnace. The gases were burned to generate steam or used in *stoves* to preheat the blast.

These stoves consisted of a set of closely spaced inverted U-shaped cast iron pipes connected to manifolds through which the blast was passed. The pipes were oval with a major diameter of about five inches, and formed an arch about 5-6 feet high. They were enclosed in a refractory-lined furnace. The pipes were heated originally by a coal fire, and later by the hot gases from the furnace. Hot blast stoves were often mounted on top of the furnace,



where the hot gases could be readily used. Some furnace ruins still have stoves mounted in what appear to be precarious positions on the top of the furnace; stoves could not be mounted centrally as that would have interfered with charging.

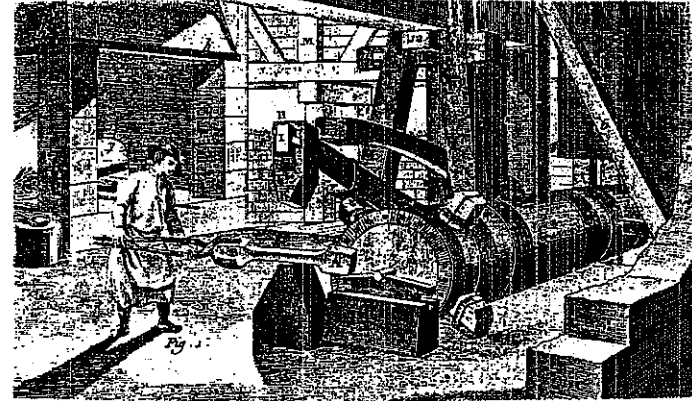
The idea of heating the blast was a relatively late invention. The inventor was J.B. Nielson in Scotland, and the year was 1828. It gave striking improvement in furnace efficiency. The first application of hot blast in America was at the Oxford furnace, in New Jersey, in 1834. Production was said to have increased 40% in consequence.

A prejudice in favor of cold blast persisted for quite a while, however, because it had been observed that furnaces generally made better iron in the colder months. But it was finally realized that the real reason for this was that the air at such times was drier; moisture in the furnace could cause problems.

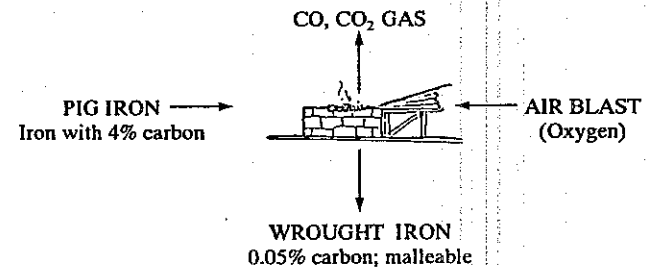
By the end of the seventeenth century, charcoal was becoming in short supply in England, and unsuccessful attempts were made to use the available bituminous coal. It was not until 1709 that Abraham Darby succeeded. He partially burned the coal to drive off the volatile constituents and much of the sulfur to produce *coke*, which he called *de-sulfurized coal*. However, it was another fifty years before the use of coke became general; but by the end of the century most furnaces in Britain were using it. The improved blast made possible by James Watt's newly invented steam engines certainly helped.

In America, where there were plenty of forests, charcoal continued to be used until a way was found to use anthracite coal. The first successful anthracite-burning furnace was established at Catasauqua, Pennsylvania, on July 4, 1840 by the Lehigh Crane Iron Company: the first anthracite furnace in New Jersey was set up by the Musconetcong Iron Company at Stanhope in 1841. The new anthracite furnaces were considerably larger and higher than the old charcoal furnaces, with correspondingly greater outputs.

## The Finery



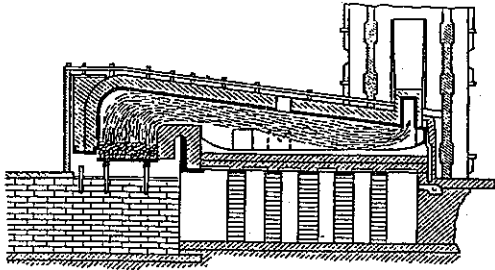
No amount of beating the brittle pig iron under a hammer even if it were red hot would remove the unwanted carbon, but would only produce a pile of useless fragments. The iron had to be remelted in a *finery*, a small charcoal-fired hearth with a bellows, similar to the old bloomery, and stirred in an air blast to burn out the unwanted carbon, until essentially carbon-free iron was produced. The melting point rose as the carbon content was reduced, and the refined iron was a pasty lump which was hammered to a usable shape under a water-powered hammer, of the type called a *helve*, in which the cam which lifted the hammer shaft was located close to the hammer.



This was *bar iron* or *wrought iron* like that made in a bloomery (as compared to pig iron or cast iron), and it had a very low carbon content. It could, therefore be forged by the blacksmith and would bend cold without cracking. It contained only about 0.05% carbon.

Fineries associated with blast furnaces often might have three hearths and a water wheel powered hammer in one building, as in Charlottesburg Middle Forge in New Jersey ("A forge with three fires"). In the early days the term "forge" was loosely applied to almost any ironmaking activity.

### The Puddling Process



In 1784, Henry Cort in England developed the *puddling process* to make wrought iron from pig iron. In the puddling furnace the fire was in a separate compartment from the iron, the flame being brought over the surface of the iron by the stack draft in a reverberatory furnace. As in the finery, the iron was still melted and stirred with long rods to oxidize, and thus remove, unwanted carbon. The decarburized *ball* was brought out and worked under the hammer to squeeze out most of the slag and form a bloom, which was then further processed in a rolling mill to produce a useful bar or plate.

The original Cort process was inefficient; as much as 30% of the iron was lost in the slag produced. In 1830, Joseph Hall introduced *wet puddling*, so-called from the large amount of slag produced. Hall incorporated mill scale (iron oxide which had fallen off red-hot iron when it was being rolled into rods, rails or plates) into the sand hearth of the

furnace, where it reacted with the carbon in the molten high-carbon pig iron. The bubbling of the reaction gases through the molten iron gave rise to the name *pig boiling*.

It took about two hours to work a 500-pound charge. It was an obvious improvement over the old finery not to have the iron mixed with the charcoal fire; it was possible to use less expensive pit coal in the separate hearth. Much of the wrought iron used in the nineteenth and early twentieth century was puddled iron. Typically ironworks had batteries of many small puddling furnaces. Puddled wrought iron had a very low carbon content, 0.08% or less.

### Steel

Hard steel was known and prized for its hardness for centuries. It was very expensive and used sparingly. Often small steel cutting edges were welded to wrought iron axes and scythes, and other edge tools.

Carbon-free or low-carbon iron cannot be hardened by heating to red heat and quenching; it stays soft. But if a controlled amount, about 1%, of carbon is present, quenching does result in great hardness. Tools, knives, chisels, springs, and other items requiring hardness are made from steel with carbon in the range of 0.8% to 1.5%, depending on the properties required. On quenching, the carbon results in a structure known as martensite; it is very hard, but brittle. The structure, however, can be modified by reheating to a relatively low temperature, between 400° and 600°F. This imparts toughness at a slight sacrifice of hardness; the higher the *tempering temperature* the greater the toughness and lower the hardness, so that a range of properties can be produced for specific uses. The tempering or *drawing* could be controlled by the blacksmith, as the steel was heated, by watching the progressive development of oxidation *temper colors* on a shiny spot ground on the surface of the tool. The color ranged from yellow at about 400°F through purple to blue at 570°F. When the desired color was reached the part was cooled in water.

## Cementation

The classic method to get a controlled amount of carbon into the iron to make steel was to heat bars of carbon-free wrought iron, packed in a carbonaceous powder in a sealed refractory box, to a red heat for several days, followed by slow cooling. The iron absorbed about 1% carbon from the powder during this process. The progress of carburization could be checked by fracturing small test bars and visually examining the grain; the carburized area showed a finer grain. The gases produced by this process resulted in a blistered surface. This *blister steel* was not homogeneous and had to be carefully forged at red heat to refine the structure and shape the tool. This process for incorporating the required carbon was known as *cementation* and was typically carried out in a conical, brick *cementation furnace*.

## Crucible Steel

In 1740, Benjamin Huntsman, an English clockmaker, developed a method of melting the blister steel in crucibles to obtain a uniform product for springs and tools. The metal was cast into small ingots for forging at red heat into small bars.

The crucible melting process underwent a surprising development in the mid-1800s. It was used not only for tool steels, but for lower-carbon high-quality forging steel. Some plants had batteries of pit furnaces holding hundreds of the relatively small crucibles, each capable of being lifted out and handled by one man. To make a large forging ingot, as many as several hundred crucibles were heated at the same time to melt the steel. These were rapidly carried over to be poured into the same ingot— a remarkable example of choreographed industrial activity. To make an ingot for a large gun forging in 1874 required 584 crucibles!

## Natural Steel

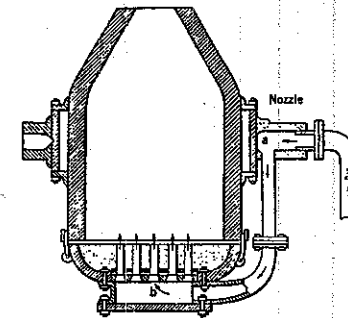
You may well ask why the original ironmaking process could not be stopped when some carbon was still present to make steel directly. This was, in fact, done in the bloomery to a limited extent to make high-carbon tool steel, but the process was very difficult to control and the product was

highly variable in carbon content. The process, known as the *German process*, was rarely used in England and America. The product was known as *natural steel*.

## Malleable Cast Iron

There was another way in which the high carbon in cast iron could be rendered innocuous— without removing it. In the *black heart malleable process*, developed in 1826 by the resourceful and versatile Seth Boyden of Newark, N.J., castings were made in *white iron* (see page 5) and then heated for several days in a sealed retort at a temperature well below the melting point. The white iron carbide was transformed by this treatment so that the carbon precipitated out as little graphite spheres or *rosettes* in an essentially carbon-free iron matrix. A structure of this kind was malleable because the soft iron matrix, if deformed, could flow around the isolated spherical graphite particles. This so-called *malleable cast iron* was widely used in the nineteenth century for small structural parts, and is still used for such items as pipe fittings.

## The Bessemer Process



Around 1850 Henry Bessemer in England and William Kelly in America independently conceived the idea that it might be possible to burn out the unwanted carbon in pig iron by blowing air through the molten



iron. In the Bessemer process, molten iron from the blast furnace was further processed in a cylindrical iron vessel that was about eight feet high, lined with refractory material, and mounted on trunnions. The vessel, or *converter*, was charged while in an essentially horizontal position, then turned to a vertical position, and air was blown in through holes in the base. A great flame was produced as the oxygen in the air burned out the silicon and other elements present in the iron, as well as the carbon. The heat produced, primarily by burning out the silicon, raised the temperature sufficiently to keep the resulting low-carbon iron in a molten state.

The progress of the *blow* was controlled by watching the appearance of the flame. The concept worked; but it took several years after Bessemer's first announcement to develop the method into a practical process. If the blown iron was too full of oxygen, it would froth with the gases present.

Robert Mushet developed a way to deoxidize or *kill* the metal by adding manganese, which reacted with the excess oxygen. The manganese was added as *spiegeleisen* or ferro-manganese, which was made in a blast furnace from ores high in manganese. These materials also contained carbon, so that a controlled amount of carbon was introduced into the blown Bessemer metal with the manganese, typically in the range of 0.25% to 0.50%. Consequently, Bessemer steel was substantially stronger than wrought iron (which had a carbon content of 0.08% or less) and it did not have the slag streaks which were always present in wrought iron.

Manganese had another virtue. It would combine with any sulfur present in the iron to form manganese sulfide inclusions, which were more or less spherical and, therefore, on small amounts, did not adversely affect the ductility of the iron. Without manganese, the sulfur, if present in any significant amount, would form films around the grain boundaries of the iron, which would soften and melt at forging temperatures, causing the iron to be *hot short* and useless.

As originally developed, the Bessemer process was successful only with selected low-phosphorus pig iron, as was discovered, to their consternation, by some early pioneers trying to make the new process work. Phosphorus, if present above a very small amount, rendered the metal brittle at room temperature.

About 1875 Sidney Thomas and Percy Gilchrist in Britain developed a dolomite lining for the reaction vessel which was compatible with the use of a lime-rich slag, which would remove the phosphorus. In this method, the *basic Bessemer process*, ironically, a high phosphorus content in the pig iron was now an advantage, as the oxidation of this element provided much of the heat needed to keep molten the low-carbon iron produced. The basic Bessemer process never became popular in the United States since low-phosphorus iron was generally available, although it was widely used in Britain and Europe.

A major feature of the Bessemer process was the speed in which a batch could be produced. Twenty tons of steel could be made in twenty minutes. The process made possible the production of great quantities of *mild steel*, or *structural steel*, containing about 0.3-0.5% carbon, stronger than wrought iron but with acceptable ductility.

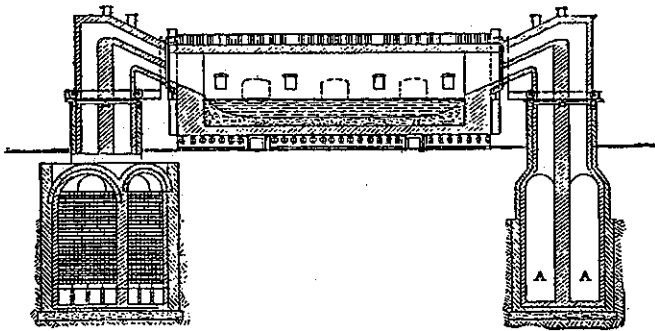
### Puddled Steel

The puddling process assumed a new importance in about 1850, especially in Europe. A technique was developed which removed most of the silicon, sulfur and phosphorus from the pig iron charged, but, by using a fluid slag high in manganese and a smoky (non-oxidizing) atmosphere in the furnace, slowed down the removal of the carbon so that iron could be produced with any desired carbon content in the range of 0.4 to 1.25%. This was steel. The carbon content could be determined by examining the fractures of broken specimens. Steel with the higher carbon contents could be heated, quenched and tempered as tools, while iron with up to about 0.5% carbon could not be hardened for edge tools but was much stronger for structural purposes than very low carbon wrought iron. It was known as improved wrought iron and found applications especially in boiler making and shipbuilding. Great quantities of puddled steel were produced in Europe but the process was little used in America, where the Bessemer process was widely adopted at this time. Until the development of the basic converter in 1878, the Bessemer process required low phosphorus pig iron which was readily available in America made from low phosphorus hematite ores. This was not the case in Europe, and this made

the puddling process very attractive there because it could use iron with high phosphorus content and remove this undesirable impurity.

It may well not have been a coincidence that this development took place at a time when chemical analysis of ores and metals first became available, making much clearer the nature of the reactions involved.

### The Open Hearth Process



Not long after the Bessemer process became established, the *open hearth* process was developed in 1865 by William Siemens in England and, independently in France by Emile and Pierre Martin. It largely superseded the Bessemer process by the end of the century. In this process the pig iron to be refined was melted in a shallow hearth in a double-ended reverberatory furnace, or introduced as molten iron from the blast furnace. Heating was from a gas-air flame, which was drawn over the hearth by the chimney stack draft. The gas was *producer gas* made from coal.

After leaving the hearth the hot gases were passed through a honeycomb arrangement of firebrick, raising the brickwork to white heat. About every twenty minutes the direction of flow was reversed and the incoming air and gas were preheated by being passed through the white-hot brickwork, resulting in a very intense flame. This *regenerative furnace* was the invention of Siemens.

The oxygen needed to react with and remove the unwanted carbon in the molten iron was provided by throwing in lumps of high-quality iron ore; the oxygen in this oxide ore reacted with and removed the carbon in

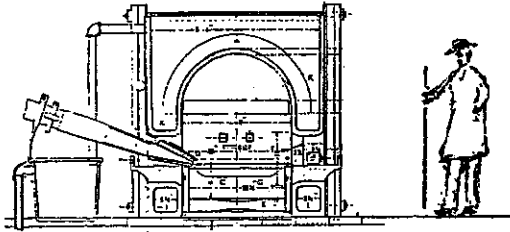
the pig iron. (The ore, in consequence, was reduced to metallic iron to supplement the iron in the pig iron.) The carbon monoxide gas resulting from the reaction of the added ore with the pig iron gave the appearance of boiling to the molten metal, and the operation was called a *carbon boil*. The process continued for several hours until samples showed, by their fracture, that the carbon content was low enough. The reaction was stopped by adding ferro-manganese and ferro-silicon deoxidizers. The metal was then run into ladles, as in the case of the Bessemer process, and taken to be poured into large cast-iron ingot molds. The ingots were heated to a uniform temperature in *soaking furnaces* and then rolled into bars, rails, or plates.

Originally the open-hearth furnaces were lined with silica-rich firebricks; this was the *acid open hearth process*. Phosphorus could not be removed, so that specially selected raw materials had to be used. Later, following the work of Thomas and Gilchrist, furnaces were lined with dolomite, which was compatible with a lime-rich slag which would react with and remove phosphorus. This was the *basic open hearth process*. The *basic slag* produced was a good agricultural fertilizer.

The major advantage of the open hearth process was that it could melt scrap steel. This was possible because it had an external heating system, whereas the Bessemer process was limited by the heat generated by burning out the silicon and other elements present in the iron. The open hearth process was much slower than the Bessemer process, but this provided better control. Open hearth furnaces could be made very large, with capacity of several hundred tons, resulting in high daily output.

The Bessemer and open hearth processes made it possible to produce vast quantities of strong, relatively low-carbon structural steel, with carbon content in the 0.3% to 0.5% range. This was a new, stronger structural material— a quantum leap from the world of puddled wrought iron and cast iron which had marked the first half of the nineteenth century. As metallurgy progressed, alloy steels were developed with special superior properties, making possible the tremendous technical advances of the twentieth century.

## The Charcoal Hearth Process

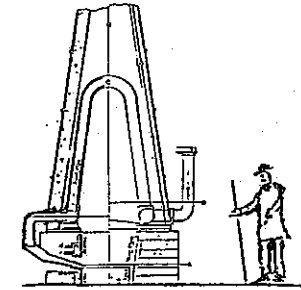


Some of the older ironmaking processes, modified and improved by the adoption of hot blast, persisted for a long time after the development of the newer process. The nomenclature employed is often confusing. There were a number of plants during the 1800's that remelted scrap iron and/or pig iron in small charcoal hearth furnaces and oxidized out the carbon in a process similar to the old fineries to produce low-carbon "charcoal iron" bars and blooms. These small furnaces used heated blast. Charcoal iron was used to make sheet iron, wire, boiler plate, and other similar products. It was preferred for applications requiring high ductility.

The remarkable fact is that, although many charcoal hearths had been abandoned prior to the 1880's, charcoal hearth capacity in 1887 was still listed as 54,000 tons, well after the development of the Bessemer and open hearth processes. By comparison, U.S.A. Bessemer capacity was 4,750,000, and open hearth 815,000 tons at that time. An important and interesting fact is that, in addition to plants making and selling charcoal iron, many plate, sheet and wire makers had charcoal hearth furnaces in their own plants making low carbon iron for their own needs. Their capacity was in addition to the figure quoted above.

The Bessemer and open-hearth processes could not produce iron with very low carbon content and consequent high ductility to compete with charcoal iron for some applications. And charcoal iron, like other types of wrought iron, rusted less readily because of its low content of impurities.

## The American Bloomery Process



The bloomery process underwent remarkable development around 1840 by the adoption of hot blast. This was known as the *American bloomery process*. Hot blast greatly increased the output. A single bloomery hearth could produce 400 pounds of iron in three hours, or 3,200 pounds in 24 hours. Sometimes a number of bloomery hearths were constructed side by side to provide a substantial ironmaking output.

The American bloomery process persisted in one exceptional area: the Adirondack Mountains in Upstate New York, where, with a supply of high-quality-ore and plenty of forests for charcoal, Adirondack bloomery iron was competitive until the late 1800's. Capacity of bloomery iron in 1887 was 63,000 tons, 80% of which came from the Adirondacks.

Much of this low-carbon Adirondack iron was used for making tool steel, as it had a low-level of deleterious impurities, notably phosphorus. Of course, tool steel had to have a high, but controlled, carbon content and this was added by the cementation process. Later, when high-purity Swedish *white iron* became available, the required carbon was added to the bloomery iron as white iron and the resulting mixture melted and cast into small ingots, which were carefully forged into bars for tools.

## The End of an Era

In the late 1800's, the American Iron and Steel Association published a directory listing all types of ironmaking operations. (This is today a very useful guide for the industrial archaeologist). The 1888 edition had a short summary of the process under each heading. Nomenclature had changed from earlier periods. The descendant from the old finery process was called a *charcoal hearth* or bloomery (note spelling change from older process), whereas the furnaces making wrought iron directly from ore, which were earlier called bloomeries, were now listed as forges. This directory contains an interesting comment on these operations:

*In the mountainous districts of East Tennessee these forges are usually operated by farmers, who only make bar iron from ore whenever it is needed in their immediate neighborhood.*

This directory lists a surprisingly large number of bloomeries and forges, but comments that "most of the forges and bloomeries are now idle. Within the past few years many forges and bloomeries have been abandoned. Modern processes and these primitive methods run an unequal race."

## Afterword

We must have a tremendous amount of respect for the old ironworkers, both those making iron from ore and the highly skilled blacksmiths who made steel tools, knives and a multitude of other parts essential to their community. It was not until the latter half of the nineteenth century that accurate chemical analysis was developed, providing, for the first time, quantitative information regarding the composition of ore and iron, as well as the presence of possible deleterious impurities. Previously, everything was a matter of trial and hope. All temperatures of furnaces and metal had to be judged by the experienced eye of the operator because there were no instruments. (The experienced eye can be quite good at this). Also, until this period there was no valid scientific theory as to the role of carbon or how sulfur and phosphorus caused trouble.

A high level of empirical skill was handed down from the master to the apprentice; there were no reliable textbooks to consult even if the smith could read. Many processes were controlled by viewing the fractured surfaces of test bars. Indeed, it is remarkable how much a fracture can reveal to the practiced eye; in making steel by the open hearth process in the 1930's, we used to judge the process of the carbon boil by the appearance of fractured specimens.

It was not until the 1880's that the microscope, which had been used to examine minerals, was first applied to examining the structure of polished and etched sections of iron and steel, revealing the structures corresponding to the mechanical properties of the different types of material. This, together with chemical analysis and the development of testing machines, which provided quantitative information on strength and ductility, provided the basis for a sound theory underlying the production of iron and steel.

Great skill was required to operate the small hearth type processes. The temperatures had to be judged by eye; and the progress of the reactions had to be determined by the "feel" (viscosity) of the liquid iron as the operator stirred it and the carbon content changed, with consequent change in melting temperature. This is a lost skill. We must have the greatest respect for the old ironworkers who could carry out these operations so successfully.

It is remarkable that the old ironmasters and blacksmiths were able to achieve so much without the benefit of sound metallurgical theory to guide them; and we must salute the skills and remarkable physical endurance of the ironworkers who labored at the hot furnaces for many long hours every working day.

## Bibliography

- The American Iron and Steel Association: *Directory to the Iron and Steel Works of the United States*. Philadelphia, 1888
- Bining, Arthur. *Pennsylvania Iron Manufacture in the 18th Century*. Harrisburg: Pennsylvania Historical & Museum Commission (Reprint), 1973
- Boyer, Charles S. *Early Forges and Furnaces in New Jersey*. Philadelphia: Univ. of Pennsylvania Press, 1931
- Boylston, H.M. *Introduction to the Metallurgy of Iron and Steel*. New York: John Wiley & Sons, 1928
- Clark, Mary Stetson. *Pioneer Ironworks*. Philadelphia: Chilton Book Co., 1968
- Hartley, E.N. *Ironworks on the Saugus*. Norman, OK: Univ. of Oklahoma Press, 1957
- Lewis, W.D. *Iron and Steel in America*. Greenville, DE: Hagley Museum, 1976
- McHugh, Jeanne. *Alexander Holley and the Makers of Steel*. Baltimore: The Johns Hopkins University Press, 1980
- Mulholland, J.A. *A History of Metals in Colonial America*. University, AL: Univ. of Alabama Press, 1983
- Ransom, James M. *Vanishing Ironworks of the Ramapos*. New Brunswick, N.J.: Rutgers University Press, 1966
- Stoughton, Bradley. *Metallurgy of Iron and Steel*. New York: McGraw Publishing Co., 1908
- Swank, James M. *Iron in all Ages*. Philadelphia: The American Iron and Steel Association, 1892
- Walker, Joseph E. *Hopewell Village*. Philadelphia: Univ. of Pennsylvania Press, 1966

A number of the above are, unfortunately, now out of print, but may be available through your local library. Some describe the history and operation of the sites rather than the metallurgical processes involved.

## Additional Readings

Some excellent books dealing with the historical metallurgy of iron and steel are available from The Institute of Metals in London, England. The Institute distributes in the U.S.A. and Canada through its North American Publications Center, Old Post Road, Brookfield, VT 05036 while the main address is 1 Carleton House Terrace, London, SW1 5DB, United Kingdom. Listed below are publications pertaining to the history of iron and steel:

- Barraclough, K.C. *Steelmaking 1850-1900*. 1990
- Barraclough, K.C. *Steelmaking Before Bessemer - Vol. 1: Blister Steel*. 1984
- Barraclough, K.C. *Steelmaking Before Bessemer - Vol. 2: Crucible Steel*. 1984
- Bessemer, Henry. *Sir Henry Bessemer, F.R.S., An Autobiography*. (Reprint) 1989
- Mott, R.A. *Henry Cort: The Great Finer*. 1983
- Tylecote, R.F. *A History of Metallurgy*. (Second Edition) 1991
- Tylecote, R.F. *The Prehistory of Metallurgy in the British Isles*. 1986

## THE FURNACE

When through the leafy silence of the trees,  
Walking along some long-forgotten way  
With whispering wind and birdsong all around,  
Surprised, the traveller in the stillness sees  
A stone arched pile amid the rocky ground,  
The once proud furnace of a distant day.

It's hard to picture with a modern eye  
The bustle and action of the past;  
The great wheel turning for the bellow's blast,  
The shouts of colliers with their creaking wain,  
The flaming furnace and the molten iron,  
Painting the dark night with a crimson sky,  
Where now the leafy trees in silence reign.

Will our proud works return to silence, too?  
Our throbbing culture lost in bush and briars?  
Will some far distant traveller in the woods,  
Coming upon our ancient ruins, pause  
And wonder what we valued in our day,  
Thinking about our triumphs and our desires,  
Now turned to empty stillness and decay.

J.E.C.