

Man, Metals and Magic: The Ancient History of Metallurgy

1500 A.D. – 1850 A.D.

Chapter VIII

In Chapter 6 we left England's iron industry in a perilous position caused by the Acts of Parliament, which severely restricted the cutting of timber for charcoal burning. Critical situations are particularly interesting to examine retrospectively, and this one is peculiarly significant. Between the end of the 16th century and the beginning of the Industrial Revolution (about 1760), iron making in England passed through a phase that may be experienced again, when in no more than 100 years, Britain will be faced with a coal famine far more critical than the timber shortage of 1580.

The use of coal as a substitute for charcoal had never been seriously considered, although its value as a fuel had been exploited since Roman times and possibly before. The objection to coal for iron making was based upon the volatile constituents that are evolved on heating and which contaminate the iron. It was through a strange oversight that, while man knew how to drive the volatile matter from wood by burning it to charcoal (a familiar process since the very first days of smelting), the idea of applying the same technique to coal was so long unrealized. Charcoal was made by incompletely burning a pile of wood covered with earth and leaves. When the bottom of the pile was fired, some of the wood burned completely and heated the rest of the pile, which surrendered its volatile constituents, thereby producing charcoal – in an inefficient but happily rural way.

This was the sort of process that the early patentees may have had in mind at the beginning of the 17th century when they suggested, as Simon Sturtevant did in 1612 when he said, "*coal could be ridded of those malignant properties which are averse to the nature of metallique substances.*" Whatever these processes were (for they were all mysteriously disguised), they failed. Then, in 1620, Lord Dudley took out a patent on behalf of his son, Dud Dudley, for "*melting iron ewre and of making the same into caste workes or barrs with sea-coles or pit-coles in furnaces with bellows.*" From the text of the patent rights, it seems that Dud Dudley suggested using coal and not any semi-burnt product. He tried out his scheme in some of his father's furnaces in Worcestershire but with indifferent success. The iron makers were averse to the scheme, and it is said that they instigated riots at his foundries and slit the bellows of Dudley's furnaces – taking the wind, as it were, out of his sails. A further setback was caused by Britain's Civil War of 1642-49, when Dudley joined the Royalists. He later tried again to smelt iron with coal but was unsuccessful.

Dudley has his place in history in spite of ill-success, for his efforts eventually led to more fruitful attempts to use coal in iron making. However, it was not until about 1715 that Abraham Darby produced coke. Another 30 years passed before it was regularly used in any ironworks. By this time, England's iron industry had deteriorated sadly. During that Civil War many of the Sussex forges and furnaces were destroyed, and the continued fear that England's navy would suffer from a lack of timber caused ironworks in the Forest of Dean to be dismantled soon after the Restoration in 1660. From this time onwards iron production dropped progressively, until in 1740 there were only 59 furnaces in the whole of England and Wales, each making less than 300 tons of iron per year. Britain's previous abundance of iron had made her so dependent upon it that she consumed much more per head of population any other country in Europe. Now, to meet her demands, imports had increased enormously – to approximately 30,000 tons in 1740.

Imported iron was largely obtained from Sweden, Russia and Norway, and, in the 18th century, from North America. The first English colonists who settled there (Jamestown, Virginia) lost no time in exploiting the natural resources of the country, for in 1608, only a year after their

arrival, they exported a few tons of iron ore to England. And in 1619 there began an ill-fated scheme to build an ironworks in Virginia. This was first delayed by the deaths of the men in charge, and later the attempt was abandoned completely after the Indian massacre of 1622 at Falling Creek, near Richmond.

The first rating producer of iron in the United States was a plant established at Hammersmith, Massachusetts. Although this ironworks suffered continual financial setbacks during most of its existence (1644-78), it was an ambitious venture. Even though it did not remain in operation for many years, it trained men who subsequently constructed and operated other, better fated, ironworks. Less tangibly, it represented a remarkable industrial exploit whose eventual issue was the thriving contemporary iron and steel industry of the United States. Other plants had been built by 1678, and they were producing enough iron to export to England. The American iron industry has not looked back since.

It was not until the mid 18th century, however, that iron production in Britain showed any improvement, and this new life was to be short-lived. The use of coke in iron making was now accepted, and new furnaces and forges were established – not in the forest, but on the coalfields. As a result of the good quality of coal and increased demand for iron, the industry expanded rapidly. During the next 100 years Britain was the greatest iron producer in the world.

The important aspects of these 200 years of iron making are: (1) the manufacture of coke overcame the problem of timber shortage, and without coke making it is difficult to believe that industrialization would have occurred, and (2) North America has already and so early crept into the picture.

But in presenting this account of the fall and recovery of British iron making and the birth of American industry, we have skimmed rapidly a period of two centuries, which included many other important advances that were to contribute during the next 100 years or so to the spectacular progress of European industry.

The Reign of Western Europe

From this point our account becomes geographically centered on Western Europe. As far as metallurgical advance is concerned, the East, which last shone brightest during the Arab conquests, has long passed its heyday. The North American continent has not yet predominated the scene. Western Europe, led by Britain, is to enjoy a period of a few hundred years when it leads the rest of the world in production as well as in the research and discovery, industrial and more purely scientific, that made its industries thrive.

One achievement was the establishment of the steel making process that was to be the forerunner of modern day techniques. This was the crucible process, introduced in 1740 by Benjamin Huntsman, a Doncaster clock maker. Although it was basically similar to the Indian method of making Wootz steel (and therefore, like almost everything else, cannot be said to be entirely new), this was the first steel melting process sufficiently reliable to be accepted and used in many parts of the world.

In making his clock springs, Huntsman was obliged to use “shear steel,” which was produced by forging bars of “blister” steel together until the irregular carbon content across the section had been fairly well evened out. Despite these efforts, however, the steel was not sufficiently homogenous for Huntsman’s purposes. As a result, he reconceived the idea of melting and casting the metal to produce a uniform product. To keep his secret he moved to the small village of Handsworth near Sheffield and conducted his researches there. His greatest obstacle was to find a sufficiently refractory material for making his melting crucibles.

At length this difficulty was overcome, and by 1770 the steel made in Huntsman’s factory near Sheffield was acknowledged to be far superior to blister steel. The process involved melting blister steel with a flux in a clay crucible about one foot high, which was surrounded by an air-blown coke fire to produce the necessary high temperature. After five hours or so, the metal was cast into ingots and subsequently forged. It was hard and strong and would take a fine edge. It therefore came to be used for making knives, blades, and razors,

Sheffield, already known for its steel, became famous and many legends grew around it. One of these was that the water in Sheffield was superbly efficient for quenching purposes, and that this was in some way responsible for the good properties of Sheffield steel. Until the late 19th

century, water was sometimes shipped from Sheffield to steelmakers in other parts of the world, who attached an almost religious belief to its powers.

Huntsman's steel was very expensive, and its use was necessarily limited to tools and special machine parts. It had no constructional application as no one thought seriously of using steel in a big way. But the process was more than a method of making high-quality steel for it showed the way to the more economic processes introduced by Bessemer and Siemens in later years.

Crucible steel was first made in the United States about 1812. The early experiments were not successful. However, when good quality clay was found for making the crucibles, the situation appeared more hopeful. It was not until two brothers named Garrard emigrated from England to Ohio where they established the Cincinnati Steel Works that a good grade of crucible steel was being regularly made by 1832. The financial disturbances of 1837 were responsible for closing the plant, and after that date and for many years thereafter, imported steel undersold the American product. Crucible steel making reached an all-time high in the United States at the surprisingly late date of 1916, when 130,000 tons were made. But this represented only 0.3% of the total steel production of that year.

As illustrated by this brief account of the development of iron making and the introduction of steelmaking in the 17th and 18th centuries, western Europe only gradually became ready for what is so inappropriately called the Industrial Revolution – inappropriate, because the process of industrialization was essentially evolutionary.

An industry that was later to flourish with steel manufacture was that of making tin-plate. The date at which tinning was first practiced is as obscure as the date at which tin was first made. However, in 1620 the art was introduced into Saxony from Bohemia where it had sprung up, and according to Andrew Yarborough, it was brought by him to England in 1670, when a plant was opened on Monmouthshire Wales that was not to become firmly established until 1720. (Perhaps it should be made clear here that tin plating is not an electrical process like, for example, chromium plating. It essentially involves dipping sheet iron or steel into molten tin, which adheres to the sheet, solidifying to form a protective and fairly non-corrosive film.) During the late 18th century the canned food industry developed, and contributed very largely to the expansion of the world's tin trade, and grew to eventually consume about one half of the world's tin production.

The manufacture of tin-plate was only one of the industries that grew in Wales. The wire drawing trade was expanding as well. This was largely made possible by the erection at Tintern, Monmouthshire in 1567 of the first water powered works. In 1566, very rich copper deposits were discovered in Cumberland and zinc was found in Somerset. The Society of the Mineral and Battery Works was granted the monopoly of manufacturing brass and iron wire (1568) and by 1605 many different grades of wire were made by them or by their lessees. Most of the wire was used for wool carding – for the wool industry was flourishing. In 1630, a Royal Proclamation prohibited the importation of any foreign wool cards and also the trimming and resale of old ones. The remainder of the brass wire was used for making pins. It is a remarkable fact that, although pins were made by hand, a good worker produced up to 24,000 pins each day.

The monopoly, however, eventually resulted in a lack of development in the industry. This led to an Act of Parliament in 1689, which removed restrictions on the mining and use of copper. Authorities have not always acted so commendably. Increased accessibility of copper resulted in the erection of many battery works – so called because of the way the metal was hammered into sheets. These increased the exploitation of and founding of more uses for copper and its alloys bronze and brass.

Most of the copper ores mined in England, as well as the imported ones from Spain, were smelted in South Wales at Neath, and later at Swansea, where by the middle of the 18th century, coal was used instead of charcoal. It was in Wales that the reverberatory furnace was developed. Its essential difference from the blast furnace is that the fuel and ore are not in contact with each other. The early reverberatory furnace consisted of a shallow rectangular hearth over which hot gases from a coal fire were drawn by a good draft, and the heat was reflected on the charge by a low roof. It was particularly suited to the smelting of sulphide ores (where treatment was a complex operation) because it was easy to control. Whereas the descending charge of a shaft furnace could not be readily adjusted, the reverberatory furnace allowed conditions of temperature and atmosphere to be altered, and each charge could be dealt with separately.

Although the copper smelting process has changed considerably since those times, the reverberatory furnace continued to be quoted in textbooks as being the better process.

Britain became by far the largest producer of copper, and during the 18th century found a greater use for the metal in the alloy with zinc. Heating copper surrounded by zinc ore and charcoal first made this alloy, brass. Since that time it had been discovered that brass could be produced by melting metallic zinc and metallic copper together. This necessitated the production of metallic zinc, a process that Europe learned from the Chinese about 1730.

Zinc smelting is complicated by the fact that the temperature at which reduction takes place is above the boiling point of the metal. Zinc vapor is there produced, which is so readily oxidized that the production of pure metal is difficult. The process that became established in England about 1740, involved heating the carbonate ore of zinc with charcoal in a sealed clay pot with a tube inserted through its base. The vapor did not oxidize, for the atmosphere in the pot was mainly of carbon monoxide, and metallic zinc trickled down the tube. By 1760, a process had been patented in England for roasting the sulphide ore of zinc to convert it to oxide, which was subsequently reduced to metal in the same way. The distillation process developed in Silesia and in Belgium, and eventually consisted of heating clay retorts containing the charge, while the metal was collected in clay condensers that were luted on the mouths of the retorts. For some time European use of zinc was limited, and the metal was of greatest value as an export. Gradually, it found applications, particularly in brass, which is fairly strong, easily cast and will withstand corrosion. So it became used in engine parts, valves, pumps, and in the machinery that was rapidly finding use in expanding industries.

Just as zinc production in England depended upon an art learned abroad, so the development of England's lead industry during this period was largely due to foreign skill, for Germans had been brought to the country during the reign of Queen Elizabeth I (1558-1603) to improve the techniques and production of that industry.

The Crown also encouraged mining enterprises. Restrictions on felling timber were more completely removed and the burdens of taxation were eased. As a result, Derbyshire and Cumberland became fairly productive regions for a time of both copper and lead. Many of the ventures petered out, however, by the middle of the 17th century, due to a number of factors to which Britain's Civil War were contributory. After a period of inactivity, lead smelting was revived and from about 1750 for the next 100 years, England experienced her brightest period in lead production.

The reverberatory furnace was introduced into Derbyshire lead smelting in the mid 18th century, and replaced the "ore hearths" that had previously been used there. The ore hearth was essentially a small shaft furnace with an opening on one side from which some of the charge could be pulled out onto an iron plate, where it was worked to remove slag and encourage the oxidation of the sulphide. As the ore hearth required the use of charcoal, the coal-fired reverberatory furnace was a popular innovation. In some localities the ore hearth remained in use and with the advent of coke it regained a little popularity. English lead production was already great and increasing. From the early 17th century, metal and ore were exported to the Continent where the Dutch (who were more skilled in these matters than the British) extracted silver from them.

Progress was not limited to industrial production, however. In 1751, Cronstedt in Sweden isolated nickel. The metal had been unwittingly used from very early times in iron of meteoric origin, but Cronstedt was the first to produce it as a metallic element. Like several other metals, the possible uses for nickel were not realized for many years.

Although compounds of arsenic and cobalt had been known for a long time, it was not until the turn of the 17th century that the existence of the elements was appreciated. Schroder prepared arsenic in 1694, and Brandt recognized cobalt as an element in 1735. Antimony and bismuth, mentioned by Agricola in *De Re Metallica*, had been investigated and their properties determined by the middle of the 18th century.

In 1754, Marggraf (a German chemist, better known for his detection of sugar in beet) recognized that alumina (aluminum oxide) was a distinct mineral, and some authorities hold that he identified the metal aluminum. This is somewhat doubtful for metallic aluminum was first produced by Wohler 70 years later, in 1828. And aluminum production on a commercial scale was not made an economic proposition until 1887.

These discoveries and investigations had direct effects that are readily apparent, but it is more difficult to analyze the results that other scientific research of the period had on metallurgical practice.

The 200 years from 1550 were rich with scientists and philosophers – Newton, Galileo, Boyle, Huygens, Gilber and many others – who contributed to the natural sciences. Since the days of the early alchemists (the later ones had become so obsessed with hopes of finding the Philosopher’s Stone that their factual observations and logical argument suffered) this was the most fruitful era in scientific and philosophic thought.

Perhaps, in a metallurgical context, Boyle should be specially mentioned, for if he was the father of modern chemistry, then he was certainly the unsuspecting godfather of the metallurgical sciences. Although many of the scientists and thinkers of the time were able to take the Greek philosophies as a starting point, Boyle fortunately rejected the Four Element theory, which had grown so out of hand, and differentiated between elements, compounds and mixtures. Confusion between elements and compounds was apparent in the comparatively lucid *De Re Metallica*. A distinction between them was vital before there could be an understanding of the chemical reactions during metallurgical processes.

The Industrial Revolution

This summarizes the state of affairs before the Industrial Revolution overtook Britain. Then, the inventions of Hargreaves, Arkwright, Crompton and others mechanized the textile business, and spinners and weavers were forced to abandon home industry to contribute to the output of the factory where the new machinery had been installed. At first the mills were water driven, and they were built in the northern counties of England, where such power was available. Before long the steam engine was introduced, and the industries, already firmly established and fortunately placed with respect to coalfields, remained.

The first application of a steam engine, so primitive that we would probably not recognize it as such, was in draining coalmines in the early 17th century. Through the work of Savery, Newcomen, Boulton, Watt and Murdoch (not to mention Polzunov, the sole Russian inventor) the machine was developed and improved. By the end of the 18th century it had been applied to mining for pumping machines, to smelting for actuating the blowers, and to driving the looms and other equipment of the textile industry. The engine, itself depending largely upon iron components, increased iron production in pit and smelter as well as increasing the iron consumption in the factories.

In this way, and in the mechanization of many industries transplanted from the home, the demand for iron grew. While cast iron was suitable for many purposes, its brittleness prevented really extensive use. The process introduced during the 16th century for “fining” cast iron was mentioned in Chapter 7. Its inherent disadvantage lay in the conflict between the air blast decarburizing the iron, and the charcoal in intimate contact recarburizing it.

Understandably, it was necessary to use a powerful air blast to keep things going the right way. This in turn burned up a large amount of charcoal. To add to this metallurgical struggle the hearth was often water cooled, and water was thrown on the charcoal to prevent it burning too quickly. All these factors make up so difficult a balance sheet to explain away, that it is relieving to find that in 1784 Henry Cort patented an alternative process.

The essential difference of his process was that contact between the fuels and iron was avoided, for Cort successfully introduced the reverberatory furnace into iron metallurgy. Probably the earliest application of the reverberatory furnace to iron making was in 1766 by the Cranege brothers. However, Cort effected so many improvements that the process became an accepted practice, rather than a curious exception. The possibility of carburization was eliminated and with it, the extensive blowing machinery that had been necessary.

In Cort’s process – the “puddling process” as it came to be called – the hot gases from a coal fire were drawn over pig iron that was charged on the furnace hearth. The charge melted and was oxidized by additions of iron oxide (in the form of iron ore or mill scale). These additions also contributed to the bulk of iron that was produced. As oxidation progressed, the charge was

stirred by the furnacemen using long iron rabblers. As it became pasty, it was worked into balls weighing about 80 pounds each, which were subsequently forged into salable shapes.

Cort's process yielded the metal that we have come to accept as wrought iron. It was not only low in carbon, but in silicon, manganese and phosphorus – elements that are present in pig iron and contribute to its brittleness. This new material unavoidably contained slag, just as the earliest smelted iron did. However, as this was strung out into fibers by the forging operation, it was not harmful. On account of its malleability, wrought iron found many applications, and until the late 19th century, it was the most valuable constructional metal.

Another equally important development due to Cort was the use of grooved rolls to make wrought iron bars, which he patented in 1783. Rolling mills, like reverberatory furnaces, were known before Cort applied them to the iron industry. Indeed, it is questioned whether he was, in fact, the first to introduce them to iron rolling. Whether he did or not, he did not benefit by his ingenuity.

When he contracted to make rolled iron for the Royal Navy, Cort invested his entire fortune in expanding and developing his process. He went into partnership with Samuel Jellicoe, whose father, the Deputy Paymaster to the Navy, contributed over 50,000 pounds, and was to receive half the profits that accrued to the partners. In those days, apparently, such a transaction was more openly made than in modern times. In this case, the British Government itself sanctioned the partnership. But even contemporary opinion did not allow Mr. Jellicoe Sr. to borrow 27,000 pounds of his capital from the Navy accounts. On his death in 1789, when this was discovered, Cort's patent rights were confiscated and Cort was removed from his rolling mill. Strangely enough, Samuel Jellicoe was put in charge. This action led both to the prosperity of British ironmasters (for the no longer had royalties to pay) and to Cort's ruin. But Cort's contribution to British industry, unrewarded as it was, resulted in vastly increased iron production – from about 18,000 tons a year in the mid 18th century to 4,000,000 tons in 1820.

While the causes of the Industrial Revolution to Britain are as complex as the historian cares to make them, there could have been no subsequent effects had it not been for the manufacture and use of wrought iron. Britain showed her metallurgical ability, too, in developments in extracting metals, the exploitation of mineral wealth, the manufacture of steel and a growth of industries that depended upon basic metal making processes. These, although they did not precipitate a revolution, at any rate induced the new era. Britain was the first country to experience the glories and infamies of industrial prosperity.

Summary

The years that we have covered so far – from an uncertain date thousands of years ago to the beginning of Europe's industrial era – complete what may be called Metallurgical Ancient History. As time permits, we hope to add a profusion of developments that took place between 1850 and the close of the 20th century. Until then, we hope you have enjoyed this brief journey along the metals road and the survey of the ancient history of metallurgy.

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