

INDUSTRIAL PROCESS

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SESSION 9 IRON AND STEEL

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Early production of iron was from meteorites, or as a by-product of copper refining. Heating iron ore and carbon in a crucible at 1000 K produces wrought iron. This process gained popularity during the Iron Age. Temperatures of 1300 K were produced around the 8th century by blowing air through the heated mixture in a bloomery or blast furnace (12th century); producing a strong but brittle cast iron. Furnaces were growing bigger, producing greater quantities; a factor contributing to the Industrial Revolution. In 1740 the temperature and carbon content could be controlled sufficiently to consistently produce steel; very strong and very workable. The 19th century saw the development of electric arc furnaces that produced steel in very large quantities, and are more easily controlled.

- Smelting - the generic process used in furnaces to produce steel, copper, etc.
- Catalan forge, Open hearth furnace, Bloomery, Siemens regenerative furnace - produced wrought iron
- Blast furnace - produced cast iron
- Direct Reduction - produced direct reduced iron
- Crucible steel
- Cementation process
- Bessemer process
- Basic oxygen steelmaking, Linz-Donawitz process
- Electric arc furnace

Smelting



Electric phosphate smelting furnace in a TVA chemical plant (1942)

Smelting is a form of extractive metallurgy; its main use is to produce a metal from its ore. This includes production of silver, iron, copper and other base metals from their ores. Smelting uses heat and a chemical reducing agent to decompose the ore, driving off other elements as gasses or slag and leaving just the metal behind. The reducing agent is commonly a source of carbon such as coke, or in earlier times charcoal. The carbon (or carbon monoxide derived from it) removes oxygen from the ore, leaving behind elemental metal. The carbon is thus oxidized in two stages, producing first carbon monoxide and then carbon dioxide. As most ores are impure, it is often necessary to use flux, such as limestone, to remove the accompanying rock gangue as slag.

Plants for the electrolytic reduction of aluminium are also generally referred to as aluminium smelters.

Process

Smelting involves more than just melting the metal out of its ore. Most ores are a chemical compound of the metal with other elements, such as oxygen (as an oxide), sulfur (as a sulfide) or carbon and oxygen together (as a carbonate). To produce the metal, these compounds have to undergo a chemical reaction. Smelting therefore consists of using suitable reducing substances that will combine with those oxidizing elements to free the metal.

Roasting

In the case of carbonates and sulfides, a process called "roasting" drives out the unwanted carbon or sulfur, leaving an oxide, which can be directly reduced. Roasting is usually carried out in an oxidizing environment. A few practical examples:

- Malachite, a common ore of copper, is primarily copper carbonate (CuCO_3). This mineral undergoes thermal decomposition to CuO and CO_2 in several stages between 250°C and 350°C . The carbon dioxide is expelled into the atmosphere, leaving copper oxide which can be directly reduced to copper as described in the following section titled Reduction.
- Galena, the most common mineral of lead, is primarily lead sulfide (PbS). The sulfide is oxidized to a sulfite (PbSO_3) which thermally decomposes into lead oxide and sulfur dioxide gas. (PbO and SO_2) The sulfur dioxide is expelled (like the carbon dioxide in the previous example), and the lead oxide is reduced as below.

Reduction[

Reduction is the final, high-temperature step in smelting. It is here that the oxide becomes the elemental metal. A reducing environment (often provided by carbon monoxide, made by incomplete combustion, produced in an air-starved furnace) pulls the final oxygen atoms from the raw metal. The required temperature varies over a very large range, both in absolute terms and in terms of the melting point of the base metal. A few examples:

- iron oxide becomes metallic iron at roughly 1250°C, almost 300 degrees below iron's melting point of 1538°C
- mercuric oxide becomes vaporous mercury near 550°C, almost 600 degrees above mercury's melting point of -38°C

Flux and slag can provide a secondary service after the reduction step is complete: They provide a molten cover on the purified metal, preventing it from coming into contact with oxygen while it is still hot enough to oxidize readily.

Fluxes[edit]

Fluxes are used in smelting for several purposes, chief among them catalyzing the desired reactions and chemically binding to unwanted impurities or reaction products. Calcium oxide, in the form of lime, was often used for this purpose, since it could react with the carbon dioxide and sulfur dioxide produced during roasting and smelting to keep them out of the working environment.

History

Of the seven metals known in antiquity only gold occurred regularly in native form in the natural environment. The others – copper, lead, silver, tin, iron and mercury – occur primarily as minerals, though copper is occasionally found in its native state in commercially significant quantities. These minerals are primarily carbonates, sulfides, or oxides of the metal, mixed with other components such as silica and alumina. Roasting the carbonate and sulfide minerals in air converts them to oxides. The oxides, in turn, are smelted into the metal. Carbon monoxide was (and is) the reducing agent of choice for smelting. It is easily produced during the heating process, and as a gas comes into intimate contact with the ore.

In the Old World, humans learned to smelt metals in prehistoric times, more than 8000 years ago. The discovery and use of the "useful" metals — copper and bronze at first, then iron a few millennia later — had an enormous impact on human society. The impact was so pervasive that scholars traditionally divide ancient history into Stone Age, Bronze Age, and Iron Age.

In the Americas, pre-Inca civilizations of the central Andes in Peru had mastered the smelting of copper and silver at least six centuries before the first Europeans arrived in the 16th century.^[1]

Tin and lead[edit]

In the Old World, the first metals smelted were tin and lead. The earliest known cast lead beads were found in the Çatal Höyük site in Anatolia (Turkey), and dated from about 6500 BC, but the metal may have been known earlier.

Since the discovery happened several millennia before the invention of writing, there is no written record about how it was made. However, tin and lead can be smelted by placing the ores in a wood fire, leaving the possibility that the discovery may have occurred by accident.

Although lead is a common metal, its discovery had relatively little impact in the ancient world. It is too soft to be used for structural elements or weapons, excepting for the fact that it is exceptionally heavy, making it ideal for sling projectiles. However, being easy to cast and shape, it came to be extensively used in the classical world of Ancient Greece and Ancient Rome for piping and storage of water. It was also used as a mortar in stone buildings.

Tin was much less common than lead and is only marginally harder, and had even less impact by itself.

Copper and bronze

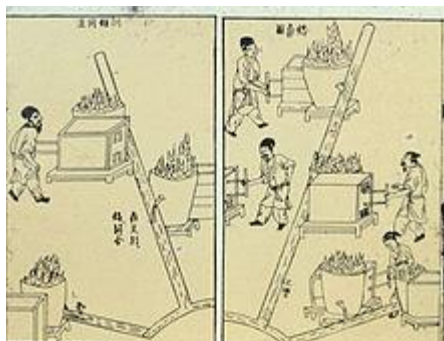
After tin and lead, the next metal to be smelted appears to have been copper. How the discovery came about is a matter of much debate. Campfires are about 200 °C short of the temperature needed for that, so it has been conjectured that the first smelting of copper may have been achieved in pottery kilns. The development of copper smelting in the Andes, which is believed to have occurred independently of that in the Old World, may have occurred in the same way.^[1] The earliest current evidence of copper smelting, dating from between 5500 BC and 5000 BC, has been found in Pločnik and Belovode, Serbia.^{[2][3]} A mace head found in Can Hasan, Turkey and dated to 5000 BC, once thought to be the oldest evidence, now appears to be hammered native copper.^[4]

By combining copper with tin and/or arsenic in the right proportions one obtains bronze, an alloy which is significantly harder than copper. The first copper/arsenic bronzes date from 4200 BC from Asia Minor. The Inca bronze alloys were also of this type. Arsenic is often an impurity in copper ores, so the discovery could have been made by accident; but eventually arsenic-bearing minerals were intentionally added during smelting.¹

Copper-tin bronzes, harder and more durable, were developed around 3200 BC, also in Asia Minor.^[citation needed]

The process through which the smiths learned to produce copper/tin bronzes is once again a mystery. The first such bronzes were probably a lucky accident from tin contamination of copper ores, but by 2000 BC, we know that tin was being mined on purpose for the production of bronze. This is amazing, given that tin is a semi-rare metal, and even a rich cassiterite ore only has 5% tin. Also, it takes special skills (or special instruments) to find it and to locate the richer lodes. But, whatever steps were taken to learn about tin, these were fully understood by 2000 BC.

The discovery of copper and bronze manufacture had a significant impact on the history of the Old World. Metals were hard enough to make weapons that were heavier, stronger, and more resistant to impact-related damage than their wood, bone, or stone equivalents. For several millennia, bronze was the material of choice for weapons such as swords, daggers, battle axes, and spear and arrow points, as well as protective gear such as shields, helmets, greaves (metal shin guards), and other body armor. Bronze also supplanted stone, wood, and organic materials in all sorts of tools and household utensils, such as chisels, saws, adzes, nails, blade shears, knives, sewing needles and pins, jugs, cooking pots and cauldrons, mirrors, horse harnesses, and much more.^[citation needed] Tin and copper also contributed to the establishment of trade networks spanning large areas of Europe and Asia, and had a major effect on the distribution of wealth among individuals and nations.^[citation needed]



Casting bronze ding-tripods, from the Chinese *Tiangong Kaiwu* encyclopedia of Song Yingxing, published in 1637.

Early iron smelting

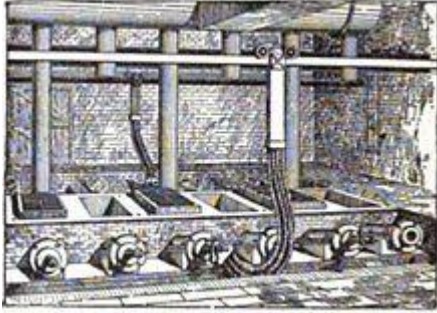
Where and how iron smelting was discovered is widely debated, and remains uncertain due to the significant lack of production finds. Nevertheless, there is some consensus^{[[citation needed](#)]} that iron technology originated in the Near East, perhaps in Eastern Anatolia.

In Ancient Egypt, somewhere between the Third Intermediate Period and 23rd Dynasty (ca. 1100–750 BC), there are indications of iron working. Significantly though, no evidence for the smelting of iron from ore has been attested to Egypt in any (pre-modern) period. There is a further possibility of iron smelting and working in West Africa by 1200 BC.^[5] In addition, very early instances of carbon steel were found to be in production around 2000 years before the present in northwest Tanzania, based on complex preheating principles. These discoveries are significant for the history of metallurgy.^[6]

Most early processes in Europe and Africa involved smelting iron ore in a bloomery, where the temperature is kept low enough so that the iron does not melt. This produces a spongy mass of iron called a bloom, which then has to be consolidated with a hammer. The earliest evidence to date for the bloomery smelting of iron is found at Tell Hammeh, Jordan (see also external link), and dates to 930 BC (C14 dating).

From the medieval period, the process of direct reduction in bloomeries began to be replaced by an indirect process. In this, a blast furnace was used to make pig iron, which then had to undergo a further process to make forgeable bar iron. Processes for the second stage include fining in a finery forge and, from the Industrial Revolution, puddling. However both processes are now obsolete, and wrought iron is now hardly made. Instead, mild steel is produced from a bessemer converter or by other means including smelting reduction processes such as the Corex Process.

Base metals



Cowles Syndicate of Ohio in Stoke-upon-Trent England, late 1880s. British Aluminium used the process of Paul Héroult about this time.^[7]

The ores of base metals are often sulfides. In recent centuries, reverberatory furnaces have been used. These keep the fuel and the charge being smelted separate. Traditionally these were used for carrying out the first step: formation of two liquids, one an oxide slag containing most of the impurity elements, and the other a sulfide matte containing the valuable metal sulfide and some impurities. Such "reverb" furnaces are today about 40 m long, 3 m high and 10 m wide. Fuel is burned at one end and the heat melts the dry sulfide concentrates (usually after partial roasting), which are fed through the openings in the roof of the furnace. The slag floats on top of the heavier matte, and is removed and discarded or recycled. The sulfide matte is then sent to the converter. The precise details of the process will vary from one furnace to another depending on the mineralogy of the orebody from which the concentrate originates.

While reverberatory furnaces were very good at producing slags containing very little copper, they were relatively energy inefficient and produced a low concentration of sulfur dioxide in their off-gases that made it difficult to capture, and consequently, they have been supplanted by a new generation of copper smelting technologies.^[8] More recent furnaces have been designed based upon bath smelting, top jetting lance smelting, flash smelting and blast furnaces. Some examples of bath smelters include the Noranda furnace, the Isasmelt furnace, the Teniente reactor, the Vunyuikov smelter and the SKS technology to name a few. Top jetting lance smelters include the Mitsubishi smelting reactor. Flash smelters account for over 50% of the world's copper smelters. There are many more varieties of smelting processes, including the Kivset, Ausmelt, Tamano, EAF, and BF.

For other uses, see Bloomery (disambiguation).



A bloomery in operation. The bloom will eventually be drawn out of the bottom hole.

A **bloomery** is a type of furnace once widely used for smelting iron from its oxides. The bloomery was the earliest form of smelter capable of smelting iron. A bloomery's product is a porous mass of iron and slag called a **bloom**. This mix of slag and iron in the bloom is termed sponge iron, which is usually consolidated (shingled) and further forged into wrought iron. The bloomery has now largely been superseded by the blast furnace, which produces pig iron.

Process



An iron bloom just removed from the furnace. Surrounding it are pieces of slag that have been pounded off by the hammer.

A bloomery consists of a pit or chimney with heat-resistant walls made of earth, clay, or stone. Near the bottom, one or more pipes (made of clay or metal) enter through the side walls. These pipes, called tuyères, allow air to enter the

furnace, either by natural draught, or forced with bellows or a trompe. An opening at the bottom of the bloomery may be used to remove the bloom, or the bloomery can be tipped over and the bloom removed from the top.

The first step taken before the bloomery can be used is the preparation of the charcoal and the iron ore. The charcoal is produced by heating wood to produce the nearly pure carbon fuel needed for the smelting process. The ore is broken into small pieces and usually *roasted* in a fire to remove any moisture in the ore. Any large impurities in the ore can be crushed and removed. Since slag from previous blooms may have a high iron content, it can also be broken up and recycled into the bloomery with the new ore.

In operation, the bloomery is preheated by burning charcoal, and once hot, iron ore and additional charcoal are introduced through the top, in a roughly one to one ratio. Inside the furnace, carbon monoxide from the incomplete combustion of the charcoal reduces the iron oxides in the ore to metallic iron, without melting the ore; this allows the bloomery to operate at lower temperatures than the melting temperature of the ore. As the desired product of a bloomery is iron which is easily forgeable, nearly pure, and with a low carbon content, the temperature and ratio of charcoal to iron ore must be carefully controlled to keep the iron from absorbing too much carbon and thus becoming unforgeable. Cast iron occurs when the iron melts and absorbs 2% to 4% carbon. Because the bloomery is self-fluxing the addition of limestone is not required to form a slag.

The small particles of iron produced in this way fall to the bottom of the furnace and become welded together to form a spongy mass referred to as the bloom. The bottom of the furnace also fills with molten slag, often consisting of fayalite, a compound of silicon, oxygen and iron mixed with other impurities from the ore. Because the bloom is highly porous, and its open spaces are full of slag, the bloom must later be reheated and beaten with a hammer to drive the molten slag out of it. Iron treated this way is said to be *wrought*, and the resulting nearly pure iron is called *wrought iron* or bar iron. It is also possible to produce blooms coated in steel by manipulating the charge of and air flow to the bloomery

A **blast furnace** is a type of metallurgical furnace used for smelting to produce industrial metals, generally iron, but also others such as lead or copper.

In a blast furnace, fuel, ore, and flux (limestone) are continuously supplied through the top of the furnace, while a hot blast of air (sometimes with oxygen enrichment) is blown into the lower section of the furnace through a series of pipes called tuyeres, so that the chemical reactions take place throughout the furnace as the material moves downward. The end products are usually molten metal and slag phases tapped from the bottom, and flue gases exiting from the

top of the furnace. The downward flow of the ore and flux in contact with an upflow of hot, carbon monoxide-rich combustion gases is a countercurrent exchange process.

In contrast, air furnaces (such as reverberatory furnaces) are naturally aspirated, usually by the convection of hot gases in a chimney flue. According to this broad definition, bloomeries for iron, blowing houses for tin, and smelt mills for lead would be classified as blast furnaces. However, the term has usually been limited to those used for smelting iron ore to produce pig iron, an intermediate material used in the production of commercial iron and steel, and the shaft furnaces used in combination with sinter plants in base metals smelting

Crucible steel



"Kirk nardeban" pattern of a sword blade made of crucible steel, Zand period: 1750–1794, Iran. (Moshtagh Khorasani, 2006, 506)

The *crucible steel* of the Industrial Revolution is referred to in this article as "English crucible steel." It was developed for making watch springs but was also used in other applications such as scissors, axes and swords. Throughout the 19th century and into the 1920s a large amount of crucible steel was used for the cutting tool of machine tools, where it was called *tool steel*.

Crucible steel is steel made by two different methods, both involving melting the starting materials in a crucible. In the original method Benjamin Huntsman melted *blister steel* (See: Cementation process).^{[11][12]} In the direct method, developed in the United States in the 1880s, an iron source and carbon were placed in the crucible.^[13]

The crucible process continued to be used for specialty steels, but is today obsolete. Similar quality steels are now made with an electric arc furnace. *Tool steel* was largely displaced, first by high speed steel^[13] and later by materials such as tungsten carbide.

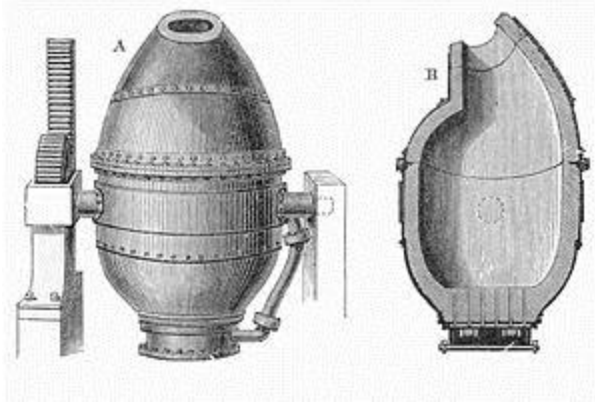
Crucible steel has aroused considerable interest for well over a thousand years and there is a sizeable body of work concerning its nature and production

Origins

The process was described in a treatise published in Prague in 1574. It was again invented by Johann Nussbaum of Magdeburg, who began operations at Nuremberg (with partners) in 1601. The process was patented in England by William Ellyot and Mathias Meysey in 1614.^[11] At that date, the "invention" could consist merely of the introduction of a new industry or product, or even a mere monopoly. They evidently soon transferred the patent to Sir Basil Brooke, but he was forced to surrender it in 1619. A clause in the patent prohibiting the import of steel was found to be undesirable because he could not supply as much good steel as was needed.^[12] Brooke's furnaces were probably in his manor of Madeley at Coalbrookdale (which certainly existed before the English Civil War) where two cementation furnaces have been excavated.^[13] He probably used bar iron from the Forest of Dean, where he was a partner in farming the King's ironworks in two periods.

By 1631, it was recognised that Swedish iron was the best raw material and then or later particularly certain marks (brands) such as *double bullet* (so called from the mark OO) from Österby and *hoop L* from Leufsta (now Lövsta), whose mark consisted of an L in a circle, both belonging to Louis De Geer and his descendants. These were among the first ironworks in Sweden to use the Walloon process of fining iron, producing what was known in England as oregrounds iron. It was so called from the Swedish port of Öregrund, north of Stockholm, in whose hinterland most of the ironworks lay. The ore used came ultimately from the Dannemora mine.^[1]

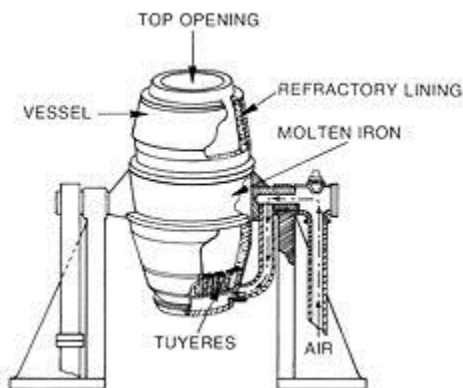
The **Bessemer process** was the first inexpensive industrial process for the mass-production of steel from molten pig iron prior to the open hearth furnace. The process is named after its inventor, Henry Bessemer, who took out a patent on the process in 1855. The process was independently discovered in 1851 by William Kelly.^{[11][12]} Related decarburizing with air processes had also been used outside of Europe for hundreds of years, but not on an industrial scale.^[13] The key principle is removal of impurities from the iron by oxidation with air being blown through the molten iron. The oxidation also raises the temperature of the iron mass and keeps it molten.



Bessemer converter, schematic diagram

The process using a basic refractory lining is known as the *basic Bessemer process* or **Gilchrist-Thomas process** after the discoverer Sidney Gilchrist Thomas.

Details



Bessemer converter components.

Oxidation

The oxidation process removes and skims off impurities such as silicon, manganese, and carbon in the form of oxides. These oxides either escape as gas or form a solid slag. The refractory lining of the converter also plays a role in the conversion—the clay lining is used in the acid Bessemer, in which there is low phosphorus in the raw material. Dolomite is used when the phosphorus content is high in the alkaline Bessemer (limestone or magnesite linings are also sometimes used instead of dolomite)—this is also known as a *Gilchrist-Thomas converter*, named after its inventor, Sidney Gilchrist Thomas. In order to give the steel the desired properties, other substances could be added to the molten

steel when conversion was complete, such as spiegeleisen (a ferromanganese alloy).

Managing the process

When the required steel has been formed, it is poured out into ladles and then transferred into moulds while the lighter slag is left behind. The conversion process, called the "blow", is completed in around twenty minutes. During this period the progress of the oxidation of the impurities is judged by the appearance of the flame issuing from the mouth of the converter: the modern use of photoelectric methods of recording the characteristics of the flame has greatly aided the blower in controlling the final quality of the product. After the blow, the liquid metal is recarburized to the desired point and other alloying materials are added, depending on the desired product.

A Bessemer converter can treat a "heat," the term for a batch of hot metal, of 5 to 30 tonnes at time.^[4] They usually are operated in pairs; one being blown while another being filled or tapped.

Basic oxygen steelmaking



Oxygen converter being charged at ThyssenKrupp steel mill in Duisburg

Basic oxygen steelmaking (BOS, BOP, BOF, and OSM), also known as **Linz-Donawitz-Verfahren steelmaking** or the **oxygen converter process**^[1] is a method of primary steelmaking in which carbon-rich molten pig iron is made into steel. Blowing oxygen through molten pig iron lowers the carbon content of the alloy and changes it into low-carbon steel. The process is known as *basic* because fluxes of burnt lime or dolomite, which are chemical bases, are added to promote the removal of impurities and protect the lining of the converter.^[2]

The process was developed in 1948 by Robert Durrer and commercialized in 1952–1953 by Austrian VOEST and ÖAMG. The LD converter, named after the Austrian towns Linz and Donawitz (a district of Leoben) is a refined version of the Bessemer converter where blowing of air is replaced with blowing oxygen. It reduced capital cost of the plants, time of smelting, and increased labor productivity. Between 1920 and 2000, labor requirements in the industry decreased by a factor of 1,000, from more than 3 worker-hours per tonne to just 0.003.^[3] The vast majority of steel manufactured in the world is produced using the basic oxygen furnace; in 2000, it accounted for 60% of global steel output.^[3] Modern furnaces will take a charge of iron of up to 350 tons and convert it into steel in less than 40 minutes, compared to 10–12 hours in an open hearth furnace.

Electric arc furnace



An electric arc furnace (the large cylinder) being tapped



Rendering of exterior and interior of an electric arc furnace.

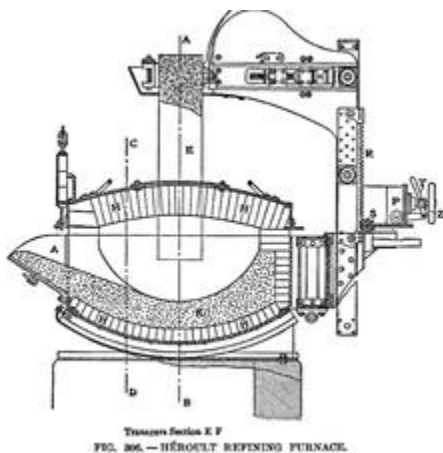
An **electric arc furnace (EAF)** is a furnace that heats charged material by means of an electric arc.

Arc furnaces range in size from small units of approximately one ton capacity (used in foundries for producing cast iron products) up to about 400 ton units used for secondary steelmaking. Arc furnaces used in research laboratories and by dentists may have a capacity of only a few dozen grams. Industrial electric arc furnace temperatures can be up to 1,800 °C (3,272 °F), while laboratory units can exceed 3,000 °C (5,432 °F). Arc furnaces differ from induction furnaces in that the charge material is directly exposed to an electric arc, and the current in the furnace terminals passes through the charged material.

History

In the 19th century, a number of men had employed an electric arc to melt iron. Sir Humphry Davy conducted an experimental demonstration in 1810; welding was investigated by Pepys in 1815; Pinchon attempted to create an electrothermic furnace in 1853; and, in 1878–79, Sir William Siemens took out patents for electric furnaces of the arc type.

The first electric arc furnaces were developed by Paul Héroult, of France, with a commercial plant established in the United States in 1907. The Sanderson brothers formed The Sanderson Brothers steel Co. in Syracuse, New York, installing the first electric arc furnace in the U.S. This furnace is now on display at Station Square, Pittsburgh, Pennsylvania.^[1]



A schematic cross section through a Heroult arc furnace. E is an electrode (only one shown), raised and lowered by the rack and pinion drive R and S. The interior is lined with refractory brick H, and K denotes the bottom lining. A door at A allows access to the interior. The furnace shell rests on rockers to allow it to be tilted for tapping.

Initially "electric steel" was a specialty product for such uses as machine tools and spring steel. Arc furnaces were also used to prepare calcium carbide for use in carbide lamps. The *Stassano electric furnace* is an arc type furnace that usually rotates to mix the bath. The *Girod furnace* is similar to the *Hérault furnace*.

While EAFs were widely used in World War II for production of alloy steels, it was only later that electric steelmaking began to expand. The low capital cost for a mini-mill—around US\$140–200 per ton of annual installed capacity, compared with US\$1,000 per ton of annual installed capacity for an integrated steel mill—allowed mills to be quickly established in war-ravaged Europe, and also allowed them to successfully compete with the big United States steelmakers, such as Bethlehem Steel and U.S. Steel, for low-cost, carbon steel "long products" (structural steel, rod and bar, wire, and fasteners) in the U.S. market.

When Nucor—now one of the largest steel producers in the U.S.^[21]—decided to enter the long products market in 1969, they chose to start up a mini-mill, with an EAF as its steelmaking furnace, soon followed by other manufacturers. Whilst Nucor expanded rapidly in the Eastern US, the companies that followed them into mini-mill operations concentrated on local markets for long products, where the use of an EAF allowed the plants to vary production according to local demand. This pattern was also followed globally, with EAF steel production primarily used for long products, while integrated mills, using blast furnaces and basic oxygen furnaces, cornered the markets for "flat products"—sheet steel and heavier steel plate. In 1987, Nucor made the decision to expand into the flat products market, still using the EAF production method

Original Alphabetical

Study all 7 terms Study 0 term/terms only

alloy

a mixture containing two or more metallic elements or metallic and nonmetallic elements usually fused together or dissolving into each other when molten.

steel

an alloy of iron with small amounts of carbon

□□□

carbon steels

Mild structural steel, widely used, over 90% steel manufactured; concern is with fabrication and erection

□□□

low-alloy steels

made for making bridges, bikes chains and military armour plating.

□□□

high-alloy steels

they contain a higher percentage of other metals

□□□

stainless steels

corrosion-resistant alloys that usually contain iron, carbon, chromium, nickel and some other elements

□□□

pig iron

a low grade, brittle metal; converted to higher quality bar iron in charcoal-powered forges that burned off some of its impurities