ARCHAEOLOGY DATASHEET 302
Steelmaking

Introduction
Although an important aspect of medieval and earlier societies, the manufacture of steel was industrialised during the post-medieval period. Many complementary techniques were developed which often operated at the same time on the same site; there were also close links with other ironworking processes. This datasheet describes pre-20th century steelmaking processes in the UK, their material remains and metallurgical potential.

Carbon steel and other alloys
Until the late 19th century, steel was, like other types of iron, simply an alloy of iron and carbon (HMS datasheet 201). There was considerable variation in the nature of 'steel' and in the properties of individual artefacts. Cast iron, smelted in the blast furnace usually had a carbon content of 5-8%, making it tough but brittle. Wrought iron, the product of the forge, typically contained less than 0.5% carbon, making it flexible but soft. Steel fell somewhere in between, usually with a carbon content of 0.5-1.5%, making it malleable but also capable of taking an edge.

Steel could be made by manipulation of the bloomery (HMS datasheet 301), and worked by hand in the forge. An artefact made of wrought iron could also be case-hardened. This involved packing it in a sealed box containing charcoal and heating, thus increasing the carbon content (HMS datasheet 303).

From the late 19th century, steelmakers experimented with alloys that used other elements in combination with the steel to improve properties such as hardness and corrosion resistance. Tungsten was added in small quantities for high-speed applications such as machine tools. Stainless steel was developed in 1912 as an alloy with chromium (typically 11-20%); modern compositions may also include nickel or manganese for high-grade applications.

Cementation steelmaking
The idea of case hardening individual artefacts was developed further in Europe in the 16th century, and the process of cementation may have originated in Germany during the 1580s. Cementation steelmaking involved heating low-carbon wrought iron bar in a carburizing environment. The cementation furnace consisted of a sandstone chest within a reverberatory chamber, into which bars of wrought iron were placed interleaved with layers of charcoal. The chest was then sealed, either with a lid or using waste products from forging or grinding, and the chest was heated by a coal fire below. The 'heat' lasted for up to 14 days, during which time carbon from the charcoal was absorbed into the iron – thus 'converting' the iron into steel.

The resulting product – known as 'blister steel' because of the surface appearance of the heat-treated metal – was then removed from the furnace and worked in the forge. The composition of the finished steel varied across the section of the solid bar, with more carbon absorbed by the outer layers. As a result the bar was cut, piled and re-worked in the forge, to create a more homogenous product. A single forging produced 'shear steel', a second operation resulted in 'double shear steel' and so-on.

Furnace design changed over time, and also appears to have shown some regional variation. The first English steel furnaces were built at Coalbrookdale (Shropshire) by Sir Basil Brooke in *c*1615 and *c*1630. These were circular in plan with a central flue. They probably contained a single chest and would have had a conical chimney. Other 17th-century cementation furnaces were located in and around Birmingham, Wolverhampton, Stourbridge and Bristol, but none of these have been excavated. The north-east became the main area of cementation steelmaking in the late 17th and early 18th centuries. Ambrose Crowley established several cementation steelworks, and others followed. Of these, the oldest standing structure is at Derwentcote (County Durham), built in 1734. Unlike the West Midlands furnaces this was square in plan (although with a conical chimney), and contained two chests side-by-side. Sheffield became an important centre of steelmaking during the early 18th century, the first documented cementation furnace there being built in 1709 by Samuel Shore. Others quickly followed, supplying the rapidly-growing cutlery and edge-tool trades for which the town had been famous since the middle ages. Cementation was effectively obsolete by the late 19th century (see below), although the last cementation 'heat' took place in 1951.

Cementation furnaces needed good natural draught, and were usually built with deep foundations – flues and firepits being at cellar level. Likely remains include these substantial bases, as well as associated working areas. Fragments of the sandstone chests and the reverberatory chamber above (which may be coated with a greenish 'glaze') may be found in the vicinity. In Sheffield chests were sealed with a mixture including wheelswarf (the residue from edge-tool grinding); during the heat this was transformed into a solid crust which needed to be broken up to remove the steel – the resulting sharp-edged lumps are known as 'crozzle'. Associated buildings included storage for charcoal (the converting medium) and for coal (the fuel). The bars of iron or steel were often stored in the open air.

Crucible steelmaking
A Doncaster clockmaker, Benjamin Huntsman, found the heterogeneous inadequacies of blister steel frustrating, and so in the 1740s developed a high-temperature furnace for melting fragments of blister steel to create a homogenous cast steel. The Huntsman method is commonly known in the UK as 'crucible steelmaking', but this should not be confused with methods developed elsewhere from at least the 8th century AD involving both the carburisation of wrought iron and the removal of carbon from cast iron.

The Huntsman process involved a lidded crucible (initially made of south Yorkshire fireclay, but later of graphite) which contained approximately 15kg of blister steel, broken up into fragments. This was melted in a coke-fired 'crucible furnace', also known as a 'melting furnace'. This consisted of a deep cellar from which the fire was stoked and ash raked. The crucible sat on firebars above the fire, and below the working level of the ground floor in a refractory-lined chamber. The furnace reached a temperature of *c*1600°C; after a 'melt' of about 3 hours the crucibles were lifted from the furnace and the molten contents 'teemed' into ingots.

Technically, the term 'crucible furnace' refers to the individual chamber described above, but the term was (and is) often used for a 'melting shop' which would typically consist of several such furnaces or 'holes'. The classic Sheffield configuration was to have rows of furnaces ('holes') down either side of a 'melting shop'; sometimes containing as few as six, sometimes more than 100. Traditional Sheffield practice was to undertake 3 'melts' during each working day. Each melt re-used the same crucible (and the same workforce, refreshed with beer whilst the furnace reheated), but the 'charge' in the crucible was reduced on successive melts. At the end of the day the crucible was discarded.

Largely (but not exclusively) confined to south Yorkshire, crucible steelmaking was entirely reliant on 'blister' steel and so did not replace cementation steelmaking; the two methods were often found in close proximity on many steel- and tool-making sites of the 18th, 19th and early 20th centuries. Some very large castings were made by the crucible method, involving careful choreography of hundreds of small crucibles in massive melting shops; however the development of Bessemer steel had rendered mass-production crucible steelmaking obsolete by the 1870s. Nevertheless the crucible technique remained in use for special steels and experimental work, and the last commercial crucible furnace 'melt' took place (in Sheffield) in 1971.

Crucible furnaces relied on natural draught, requiring deep cellars – a typical melting shop comprising a central tunnel with furnaces running down either side. Above-ground remains are less common, but 'melting shop' floors were usually stone-flagged with a central pit for casting into ingots. Crucibles (used at the rate of one per day per 'hole') were discarded in large quantities: they may be found as material in walls, as hardcore, or simply dumped some distance from site. Tools may include a variety of tongs. Associated buildings included storage for coke fuel, a room for weighing the 'charges' for the crucibles, as well as areas for the manufacture of crucibles. The clay for these was trodden out and moulded on site, and then dried against the back wall of the furnace chimney.

Bessemer steel

Smelting iron, reducing the carbon content of cast iron, increasing the carbon content of small quantities of wrought iron and then remelting even smaller quantities in a high-temperature crucible, was – chemically and economically – a roundabout way of achieving steel. Henry Bessemer (inventor, among other things, of the perforated postage stamp) saw that it might be simpler to remove carbon and other impurities from iron by oxidising: blowing air through molten iron. Bessemer's experiments in the 1850s used low-phosphorous iron and were successful, but commercial adoption of the process was hindered by lower-quality iron grades, and so it did not take off until the 1860s – having been refined by the metallurgist Robert Mushet.

The successful development of the Bessemer process enabled mass-production of high-quality low-carbon steel. This permitted the development of a wide range of items including mild steel rails for railways, massive guns and armour plate for imperial expansion, rolled steel joists and other materials for the construction of steel-framed buildings. The Bessemer converter was a large free-standing cauldron containing 15-40 tonnes of iron; it stood on a concrete base in a large steel-framed shed. Archaeologically these have been under-investigated; however there is potential on certain sites for early experiments to reveal important metallurgical detail about the development of the process.

Open-hearth steelmaking

The Bessemer process was characterised by an extremely rapid conversion of iron to steel. A chemically similar but slower and more easily controlled process was developed in the 1860s by the French metallurgist Pierre-Émile Martin using the energy-efficient Siemens regenerative furnace developed in the previous decade. The resulting Siemens-Martin or open-hearth process became the mainstay of quality steelmaking from the 1880s, gradually replacing the cementation/crucible method. The open-hearth process was also able to deal with lower quality grades of iron (including scrap metal) than the Bessemer process. The open-hearth method was largely superseded in the mid-20th century by basic oxygen steelmaking (itself a refinement of the Bessemer process), and this in turn has been replaced by electric-arc steelmaking.

As with the Bessemer process, below-ground archaeological remains will principally comprise concrete platforms and associated pits – most of the process occurred above ground.

Important research issues

- Cementation steelmaking between *c*1630 and *c*1730 and *c*1750 and *c*1840; also its early development in the W Midlands, SW and NE.
- Crucible steelmaking outside S Yorkshire, especially London, the W Midlands and S Wales.
- Experiments in alloy steels in the late 19th century.
- Early experiments in open-hearth steelmaking and related methods.
- Stratigraphically-secure early steelmaking residues.

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