



# Iron working processes

Unlike all the other metals used in the past, iron was produced and worked only in the solid state. This technology is called the 'Direct Process' of iron manufacture, *ie* the production of malleable iron direct from the ore. By contrast, in the later 'Indirect Process', the blast furnace produced liquid pig iron which had to be refined into malleable iron. This datasheet only deals with the direct process.

The direct or bloomery process comprised several stages. Metal was extracted from ore by smelting; raw iron was refined by primary smithing and was then manufactured into artefacts by (secondary) smithing. All these processes generated slags and residues as by-products.

## Iron Ores and Ore Processing

Iron (Fe) is the fourth most abundant element in the earth's crust and many geological processes concentrated iron compounds to form ore bodies. The commonest ores are limonites, carbonates and hematites. They occur as bedded or vein deposits and as nodules within other deposits *eg* clays. However, a major ore source in antiquity was bog iron ore, which formed by the precipitation of iron compounds in lakes and bogs. Iron smelting sites are therefore not restricted to specific geological regions; early (pre-16th century) sites have been found in most counties in Britain.

Bog ores could easily be worked by digging, but for other ores deeper open cast pits, bell pits and deep mining were used. There is no chronology of iron ore mining, as there are few dated examples to

establish the chronology.

All iron ores benefit from processing, which may include washing, roasting and crushing. Roasting was most important since it broke down compounds and caused micro-cracking in the ore lumps. This facilitated reduction in the furnace, by allowing the reducing gases to penetrate the ore lumps. It was essential that the ore charged to the furnace was as rich as possible, over 70% iron oxide. Too much gangue (the non-metallic component of the ore, *eg* silica) would cause large quantities of slag to form at the expense of metal.

## Furnace Structure

The basic furnace was a cylindrical clay shaft between 1 and 2 metres in height with an internal diameter of between 0.3m and 1m. The walls of the furnace were normally over 0.2m thick, to reduce heat loss from the furnace. The air inlets, called *tuyeres* or blowing holes, were positioned about 0.3-0.5m from the base. In the majority of furnaces an arch through the wall of the furnace enabled slag to be removed, either cold or as tapped slag.

## Fuel

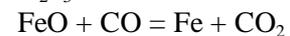
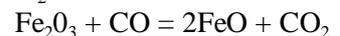
The commonest form of fuel was charcoal. Its availability was probably the most important factor in determining the location of furnaces, since large quantities were needed and it could not easily be transported great distances.

## Smelting

The furnace was charged with fuel and preheated. When hot, mixtures of ore and charcoal would then be fed into the furnace, and bellows

used to pump air into it. There is no single furnace temperature as different reactions occur at different places. These range from initial reduction of the iron ore at about 800°C high up in the furnace to slag liquation at over 1000°C near the base of the furnace.

Two important reactions occur during smelting; the reduction of iron oxide to metallic iron, and the formation of a liquid slag. Carbon monoxide (CO) is formed by reaction between oxygen in the air and carbon present in the fuel. This gas reacts with the oxygen atoms in the iron ore, reducing it to metallic iron:



The second reaction in the furnace is the formation of a slag from some of the iron oxide (FeO) and the gangue oxides (silica, alumina etc) in the ore. Separation of the metal from the slag was achieved by the slag liquating, dropping to the base of the furnace and ultimately being removed. It was necessary for the furnace temperature to be sufficiently high for the slag to be liquid (see Datasheet No 5). Separation was not complete, and the lump of metal or bloom was a mass of metallic iron mixed with slag.

Different technologies use different methods of slag removal. With very rich ores, little slag was produced and it could remain within the furnace. For leaner ores the slag needed to be removed from the furnace. The commonest method was by slag tapping, opening the arch

and allowing the slag to run out of the furnace.

It should be stressed that at no time during the process was the metal liquid. The bloom of metal produced would often be heterogeneous, varying in composition ranging from ferritic iron (no alloying elements), phosphoric iron (containing up to 1% phosphorus) to carbon steels (containing up to 0.8% carbon). The bloom grew until it started to interfere with the air blast, at which stage it had to be removed. There is no evidence that the furnace had to be destroyed to remove the bloom.

### **Bloom Smithing**

The bloom from the furnace had to be refined to remove excess slag, to consolidate the iron and to either homogenise the bloom or separate the different alloys.

The product of bloom smithing was a billet of iron and some smithing slags. These slags may have been very rich in iron and could have been recycled. The billet could be worked up into artefacts or traded off site to another smith.

### **Secondary Smithing**

Secondary smithing was the manufacture and repair of artefacts. Iron smiths had a number of different alloys available, including ferritic iron, (pure iron, relatively soft), phosphoric iron (harder but more brittle) and steels (varying carbon contents, enabling very hard and tough edges to be produced). There were four main techniques used by the smith, cold working, hot working, welding and heat treatments.

In cold working the metal is worked at a low temperature, which distorts the crystal structure of the metal and (slightly) hardens the iron. Hot working (at over 600°C) enables the smith to easily shape the metal.

Welding joins two pieces of iron together by heating them to high temperatures and hammering them together. Heat treatments improve the metal's properties. Steel can be made very hard by heating to about 880-900°C and then quenching by immersing the metal in cold water. Slight reheating (tempering) releases the stresses in the metal, slightly reducing the hardness but considerably improving the toughness.

### **The hearth**

Smithing can be done anywhere; it does not need a purpose built structure, but could use a domestic hearth. Modern forges are waist high, and there is documentary and artistic evidence for them back to the Roman period. Archaeological evidence for such hearths is very poor, due to their above ground position. The smith required fuel and an air blast to obtain high temperatures. Charcoal was the main fuel but from the Roman period onwards there is growing evidence for the use of coal.

By heating the metal the smith increased the chances of the metal oxidising and becoming useless. This could be avoided by careful control of the fire and also by fluxing the metal surface with sand. This formed a thin slag layer which cleaned the metal surface and stopped oxidation of the metal. The smithing process produced slags (see datasheet No 6); the most characteristic are piano-convex hearth bottoms. The hammering of the metal also scattered 'scale', the oxidised film of metal from the surface, around the working area.

### **Conclusion**

Early ironworking was a sophisticated technological process. There are a number of different methods of iron smelting, characterised by different slag

morphologies.

Smithing could either operate at a simple level, producing (relatively) poor products or to a very high standard, manufacturing composite artefacts with superb cutting edges, such as knives. There is not yet enough evidence to draw any firm conclusions about the development, occurrence and usage of the different iron alloys in Britain.

Although the broad picture of ironworking is understood, most detail is absent. Therefore the recovery, identification and analysis of iron working evidence and artifacts is essential for this vital material to be understood.

### **References**

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