Alloys + Metals Review

MAKING IRON THE ROMAN WAY

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INTRODUCTION

To the archaeologist, human history is seen as a series of "Ages", typified by the materials from which tools and weapons were made; we are all familiar with the Stone Age, the Bronze Age, and the Iron Age. This classification was originally worked out by a Danish museum curator, as a method of displaying his collections. However, it was quickly realised that it described a real progression in terms of man's conquest over his environment. The limitations in shape imposed by the intractability of stone gave way to the easier formability of copper and bronze, materials which permitted a considerable evolution in design, although the relative scarcity of copper and tin meant that metal objects were not in everyday use. It was the advent of iron, the ores of which are widely spread beneath the surface of the Earth, that paved the way to a greatly increased pace of technological innovation and laid the foundations of modern society.

In the past, archaeologists tended to accept that the technique of reducing iron from its ores evolved somewhere in the Near East and spread throughout the known world, without giving much thought to the technology involved. Admittedly, a number of general surveys were published before World War II, dealing with the pre-history of the iron industry, but these tended to be archaeological rather than technological in character. It is only in the past two decades that a technological approach has been made to the subject, by scientists such as Tylecote and Coghlan in England, Gilles in Germany, Pleiner in Czechoslovakia, and Radwan and Bielenin in Poland.

Any approach to primitive technology requires first a detailed study of data from the archaeological record. Literature searches of obscure archaeological periodicals have been combined with selective excavations to produce a large corpus of data. Ethnographic studies of modern primitive societies have thrown a great deal of light on the technologies used in antiquity, although these have to be viewed with some caution, since the impact of modern industrial society is often subtly marked and may blur the record.

In addition, it has been found of immense value to reconstruct the furnaces of antiquity and to attempt to reproduce as authentically as possible their operating parameters. This type of study gives a great deal of information about the production capacities and potentialities of early furnaces and also about the manning requirements, which is of value in the social and economic interpretation of early industries. Iron smelting experiments using facsimiles of early furnaces have been carried out in recent years in Austria, Czechoslovakia, Denmark, Germany, Poland, and the UK, using different types of furnace and varied ores and fuels.

THE ANCIENT IRONMAKING PROCESS

Today, iron is made in blast-furnaces, using the indirect process; that is to say, high-temperature operation produces a molten iron-carbon alloy, which has to undergo further refining outside the blast-furnace to convert it into steel or iron.

The process used in antiquity was a direct process, by means of which relatively pure iron was produced in a solid state at much lower temperatures than in the blast furnace, in the form of a sponge. It was possible by suitable heat treatment to convert this into steel. The raw materials for this process were iron ore (usually the more reducible ones, such as the carbonates or limonite) and charcoal as a fuel. There is some indirect evidence for the occasional use of other fuels, such as peat and coal, but charcoal was by far the most favoured material. The use of a flux such as limestone to remove the gangue (stony) portion of the ore was not apparently understood in antiquity, except in China, and so a large part of the iron in the ore had to be sacrificed to remove silica, the major gangue constituent, as fayalite ($2FeO.SiO_2$). It will be seen that the yield of the process was poor by modern standards; however, in Roman economic terms yields were obviously satisfactory.

Furnaces were small and varied greatly in design; however, the more developed types were all basically simple shafts, usually cylindrical or beehive-shaped, standing 1-2m high, with an internal diameter of 25-40 cm. The materials of construction depended to some extent on the local geology; thus, in mountain areas they would be built in stone, lined with clay, whilst in the lowlands they would be built entirely of clay.

The process consisted of charging a mixture of ore and charcoal, usually carefully size-graded, to the furnace and igniting it. Temperatures of 1200°C and above would be maintained in the combustion zone for long periods, more ore and charcoal being added as the stockline dropped. The air blast would be supplied by bellows or, in the case of the taller furnaces, would be a natural draught. Furnaces were sometimes carefully sited so as to take advantage of prevailing winds.

As the ore became reduced, metallic drops would form in a pasty state (pure iron is not molten until well over 1600°C) and would move slowly down the furnace under gravity, coalescing with other globules in the process. In doing so they would take up a certain amount of carbon, both from the hot reducing carbon monoxide gas and from direct contact with charcoal. They would collect in a spongy "bloom" above the tuyere (the nozzle through which the blast entered the furnace), where they would be exposed to oxidizing conditions for long periods, in contact with the air entering the furnace. As a result, they would become decarburized to very pure iron. The final product of smelting was this bloom, which consisted of a sponge composed of discrete iron lumps, only the last reduced material containing a significant proportion of carbon; the interstices of the sponge would be filled with fayalite slag.

The majority of the slag would have been tapped off the furnace in a molten state at intervals. It was for this purpose that a temperature of over 1200°C was required, since much below this temperature the slag will not run. It built up at the base of the furnace, being kept inside by the use of a weir which was broken down from time to time, the slag running out into a prepared hollow. It seems likely that some types of furnace had a continuously open slag taphole, and that slag ran throughout theprocess, being removed from time to time as the hollow filled up.

The raw bloom was removed from the furnace with tongs and repeatedly heated and hammered, each cycle serving to expel the entrapped slag and consolidate the iron. The resulting product was a compact lump of iron, heterogeneous in nature from the point of view of carbon, but containing very little slag, and that in the form of elongated stringers. This was the semi-finished product of the ironworks, and was probably exported in that form to the users, for further working up into tools and weapons.

ROMAN IRONMAKING IN THE WEALD

The Weald of Sussex and Kent is one of the primary ironmaking areas in Britain. The clays of the area, notably the Wadhurst Clay, contain good carbonate ore that is relatively easily won, and the heavy soils supported a dense forest cover of hardwoods, an unrivalled source of charcoal. Furthermore, the clays themselves are refractory up to the temperature at which the early furnaces operated and are excellent for furnace construction.

Iron was being made in the Weald before the Roman invasion of AD 43; there is a reference in Caesar's Gallic War that clearly relates to the Weald. However, it was by no means a major industry at that time. It was with the imposition of the Pax Romana on the south-east of Britain that ironmaking began on a major scale. In the years following the invasion, large ironmaking settlements were set up in the region around Hastings and Battle; great slagheaps remaining to the present day testify to the production of the area. By the mid IInd century, the reserves of ore and timber had been exhausted, and the centre of the industry moved north, into the High Weald; for the next hundred years the industry continued, in areas such as Maresfield, Wadhurst and East Grinstead, where no trace remains at the present time of the industrial heritage apart from the slag heaps, now merged into the surrounding countryside.

One of the most intriguing questions that hangs over the Roman industry of the Weald is : who owned the ironworks? Ownership of the mineral rights in provinces of the Roman Empire was vested in the Emperor himself. So far as precious metals are concerned, these ores were exploited directly by the Imperial procurators. However, it is clear from inscriptions found on tombstones at Lugdnnum (Lyons) in Gaul that licences were granted to private companies for the exploitation of iron ores. In Britain, however, no such inscriptions have come to light. On certain of the Wealden sites, other types of inscription have been found, in the form of tiles stamped with the CL BR monogram of the Roman Classis Britannica (British Fleet). There is a strong reason for postulating, therefore, that in Roman Britain the major iron industry centre (probably the second largest in the whole Roman Empire) was a nationalised concern. It must be borne in mind in this connexion that the Fleet was not a fighting force, like the modern Royal Navy, but the supply and transportation arm of the Army, andmay well have made iron in the Weald to supply the Legions on the Wall, in Wales, and even on the Rhine frontier.

THE SMELTING TRIALS

The Equipment

The furnace was built on the lines of a IInd - IIIrd century Roman type discovered at Holbeanwood, Wadhurst, Sussex, in October 1968 by the author (Fig. 1). Standing to a height of 1 m, with an internal diameter of 30 cm and walls tapering upwards from 30 cm at the base to about 20 cm at the top (fig. 2), it was constructed of the clayey Ashdown Sand dug from the smelting site at Horam, Sussex. The clay was identical with that of the Holbeanwood furnaces, and was not treated beyond puddling with water and treading with bare feet; no fillet was identified in the Roman furnaces. It was built up in a series of "sausages" which were luted together with moistened clay. A semi-circular opening about 30 cm in diameter was made in one side at the base, leading out into a hollow about 80 cm long by 30 cm wide by 5 cm deep, also lined with clay.

Thermocouples were inserted in the back wall at 20 cm intervals starting from 5 cm below the top. Chromel-alumel was used for the three upper thermocouples and platinum/platinum rhodium for the lowest. An Orsat was used for analysis of the top gas (O_2, CO, CO_2).

Blowing was effected in two ways, using an old vacuum cleaner and an electric blower respectively; the former, which gave only about 150 l/min, did not produce adequate temperatures, and was replaced by the electric blower, which gave about 500 l/min.

This, of course, was hardly authentic; however nothing is known of the type of bellows used in Roman times. Furthermore, the author could not call on the sources of slave labour available to his Roman counterparts !

The blast was introduced into the furnace through the front opening. This was filled with clay lumps into which a clay nozzle was inserted at the top of the arch. The nozzle of the bellows was aligned with this aperture.

The bottom part of the furnace arch was stopped at first with a sandstone lump, to act as a slag plug; however, this fused indissolubly with the clay and proved impossible to withdraw, and so for later experiments an ordinary turf was used.

The local carbonate ore benefits from roasting before smelting, so as to remove water and to convert the carbonate to oxide. For this purpose, a facsimile of an ore roasting furnace from the IInd century site at Bardown, Wadhurst (Fig.3) was constructed. This was a trench, 2.5 m long by 40 cm wide by 30 cm deep, dug into the natural soil and lined with puddled clay (Fig. 4). Ore that had been crushed with hammers and screened to +2-5 cm was charged to this, mixed with 2 cm grade charcoal, and ignited. Blast was applied using the vacuum cleaner, and temperatures of 350^{o}C and above were attained, sufficient to change the grey colour of the ore as mined to dark crimson, betokening the conversion to oxides. When too much heat was applied, a further colour change to back took place, indicating that the magnetic oxide Fe_3O_4 had been formed and reduction commenced. The roasting process was a violent one, and considerable fragmentation resulted. The ore was therefore screened again to remove the -2 cm fraction, the fines being discarded.

The Raw Materials

The ore was mined by hand from a brick pit near West Hoathly. It occurs at the base of the Wadhurst Clay as nodules, varying in size from 5 to 40 cm; the carbonate is encase in a skin of limonite, hence the name "boxstone" that is often applied to it.

The charcoal was bought from a Sussex supplier, and was mostly of local hardwood (oak, hornbeam, etc), although the presence of some unquestionable pieces of plywood jigsaw puzzle caused some surprise !

The Trials

Four trial smelts were carried out, the conditions being varied each time. The variations included changes in charging sequence, duration of blowing, frequency and method of slagging, etc. Of the four, the longest was the most successful, in which 80 kg of ore and 100 kg of charcoal were charged. Preheating with charcoal began at 08.30 (a fire having been kept in the furnace overnight) and the first addition of 1 kg of ore was made at 09.20. Ore and charcoal were charged alternately, 1 kg of ore to 1.5 kg of charcoal, at approximately 10 min intervals until 10.58, when the ore:fuel ratio was changed to 1 : 1. The last charge was at 18.21, slag being tapped in small quantities throughout the day. A final charge of charcoal was made, and the furnace was closed up at the top and tuyere for the night. On the following morning it was opened and the resulting bloom was removed by levering it away from the side wall and removing it through the front opening with tongs. A total of 10 kg of iron resulted.

This yield, although modest, was the best achieved, In later experiments it was found that the reduced metal tended to be reoxidized by the blast because the blower used was delivering too large a volume of air. However, sufficient iron was made to encourage further experiments, with a variable blower, since it is clear that the experiments were proceeding on the right lines.

One of the successes of the experiments was the furnace itself. After four heats and considerable stress, resulting from inexpert and indiscriminate use of a crowbar, it was still standing, and only required minor repairs to the innder wall. Large cracks had developed during the initial heating up, but these had been fettled with wet clay to prevent the escape of gas (or the ingress of air). It was found that the slagging up of the interior had the effect of sealing these cracks on the inside, and no gas could be detected escaping through quite large cracks (5-10 mm wide) during later heats. There is no doubt that a considerable number of heats could be made in furnaces of this kind before deterioration became serious.

RESULTS OF THE TRIALS

Agreat deal was learnt in the experiments about the practical operating conditions of Roman furnaces. From an archaeological point of view, much valuable information was gained about the conditions around the furnace itself and the amount of ground surface needed. The life of the furnace structure gives some clue as to the likely production to be expected from groups of excavated furnaces.

The chemistry of the process is, of course, well established. The correct charging sequences and ore/charcoal ratios have been estimated in the past, but it became clear that some of these estimates were wildly wrong. An ore/charcoal ratio of 1 : 1 seems to be the most efficient, and additions should certainly not exceed about 1 kg at a time.

The trials also give some clues as to the likely manning of furnaces. It was estimated that, if roasting was carried out simultaneously, a minimum four people would be required around the furnace complex, not including those people whm would have been needed to operate the bellows that would have been used in antiquity.

The method of stopping up the front of the furnace and of slagging off was also studied, since there is no archaeological evidence of how this was done. Previously it had been thought that the whole front filling would have to be broken down to release the slag. However, it was found that a plug could be inserted in the base of the front arch, which could be withdrawn for the slag to flow. Even better, however, was the use of a turf; this burnt away slowly as the molten slag built up, and the latter began to flow of its own accord. It was found efficacious to operate with a running slag notch, the slag being kept molten by the flame in front of the tuyere being recycled downwards.

CONCLUSIONS

The trials indicated very clearly that a great deal of practical value may be learnt in this way about the early industry. Many deductions and guesses have been made in the past, based on observations of archaeological remains; however, it is possible, by properly designed experiments, to obtain results in concrete terms - slags, furnace structures, and metal - that are directly comparable with archaeological remains. The interpretation of metallurgical remains from antiquity is rendered in this way much more precise than it has been in the past.

It is intended to carry out further experiments in the future, in order to obtain more precise data and achieve a degree of expertise in "making iron the Roman way".