

Summary

Copper (Cu) is a soft, reddish metal which has been used for the production of a wide range of artefacts. Since the end of the Bronze Age it has been used primarily in the manufacture of decorative objects. Copper is obtained by smelting suitable ores and is most commonly used in the form of alloys; that is, other pure metals are added to produce new metals with different properties.

Sources of copper ore

Copper ores are found in only a parts of the British Isles. Evidence for the early sources of copper ores is somewhat patchy. During the 18th and 19th centuries large quantities of copper ore were mined in Cornwall but smaller deposits have also been exploited in Devon, Gloucestershire, Cheshire, Cumbria and Yorkshire, as well as Wales and Scotland. At depth, copper ores are usually present as sulphides but at the surface some deposits may have weathered to form oxides and carbonates.

Copper mines

The extent and form of copper mining has varied over time but also reflects the nature of the copper ore deposit. Relatively little is known about copper mining prior to the Industrial Revolution. It is likely that early copper mining started as quarrying at the point where a copper ore outcropped (e.g. Alderley Edge). The excavation of the prehistoric copper mine at the Great Orme, Wales, has demonstrated that prehistoric miners could pursue copper ore deposits deep underground. The discovery of stone hammers in underground Bronze Age contexts has encouraged a re-evaluation of similar stone hammers recovered (mostly in the 19th century) from other copper mines. Archaeological evidence for copper mining from later periods is rare.

The mining of copper became a significant industry in Cornwall from the early 18th century. At its height in the 19th century there were hundreds of mines, some extending hundreds of metres underground. Like most mining landscapes, the areas around historic copper mines tend to be characterised by huge heaps of waste rock.

Copper ores contain copper compounds and a variety of other minerals (gangue). As mined, the copper content may be very low but careful sorting, and where necessary crushing and washing of the ore, can help to remove some gangue and improve the overall copper content (beneficiation).

Copper smelting

Metallic copper is usually extracted from its ores by smelting. The smelting would be carried out at a sufficiently high temperature and with a suitably reducing atmosphere (i.e. rich in carbon monoxide rather than oxygen) to reduce the copper compounds to

metallic copper (typically 1100-1200°C). In most cases it will also have been necessary to heat the ores to a temperature at which the gangue present would form a slag which could separate from the metallic copper. Depending on the nature of the gangue, other materials may have been added to ensure that a fluid slag formed. Analogies with early copper smelting in other countries suggests that the smelters would have used charcoal as a fuel and utilised clay-built bowl or shaft furnaces.

Unfortunately there is little or no direct archaeological evidence for copper smelting in the British Isles before the 18th century; there are no furnaces and no slags heaps. It has been argued that prehistoric copper smelting may have been carried out on such a small scale and at such low temperatures that a fused mixture of slag and copper would be formed. This would then be crushed in order to recover the small prills of copper. The crushing of such slag might explain why some early evidence has been so elusive. This model for early copper smelting is unlikely to be appropriate for the relatively large Roman ingots (12-22kg).

It can also be argued that early copper smelting slags have not been identified because they have been systematically exploited by later smelters. If the early copper smelting technologies were relatively inefficient then later smelters may have used old slags as a source of copper. This practice is known in the post-medieval lead smelting industry but it has not been documented for the copper industry.

Our understanding of copper smelting technology in the medieval and early post-medieval period (i.e. up to the mid 17th century) is based almost entirely on written sources from Germany. From the late 16th century the English copper industry was dominated by Germans who were granted a monopoly for its exploitation. The smelting of copper began to become a significant industry in Britain from the late 17th century. It is likely that this was due at least in part to the development of the reverberatory furnace which kept fuel and ore in separate chambers (firebox and hearth) and so allowed the use of coal as a fuel. The reverberatory furnace was also enabled greater control of the furnace atmosphere. By opening or closing small apertures it was possible to obtain fully reducing or oxidising conditions as required.

The reverberatory furnace was well suited to the smelting of sulphide ore which, by the 17th century, formed the bulk of the ores available. Sulphide ores could be smelted by prolonged roasting to remove all sulphur before being smelted; however, it seems that most smelters preferred what is often known as 'matte smelting'. This would comprise a series of relatively quick roasting and smelting cycles. Each roasting cycle required oxidising conditions which would remove a proportion of the sulphur while each smelting stage would remove some iron (and other gangue) as slag. The smelting cycles would yield a slag and a copper-iron

sulphide (matte). Successive smelting cycles would produce mattes with decreasing proportions of iron until the matte was almost pure copper sulphide. This could then be roasted to remove the sulphur and finally smelted to metallic copper. By the early 18th century matte smelting had been further improved by the deliberate mixing of sulphide and oxidised ores in the charge.

Impurities in copper

The chemical analysis of copper and copper alloys usually shows the presence of a range of impurities (such as sulphur, iron, nickel, arsenic, antimony and silver). The range of impurities (as well as their relative abundance) in copper will depend to some extent on the nature of the ore used. While considerable effort has been expended in attempting to relate these impurities to specific ore sources, considerable doubts remain about the provenancing of copper in this way. Most known or suspected prehistoric copper mines in Britain would have yielded fairly pure copper with compositions which would not match the vast majority of contemporary artefacts.

The fate of impurities will also depend on the exact conditions used in copper smelting. Very oxidising roasting will tend to remove impurities and so yield a pure copper. The temperature during smelting and the severity of the reducing conditions will also dictate whether impurities end up in the slag or the metal. Conditions which yield very pure copper will, however, tend to lose some copper in the slag. Most smelting is a compromise between the desire to maximise the yield of copper against the requirements for the purity of the copper.

Copper alloys

Pure copper has some uses but it is a difficult metal to cast and is too soft for most applications. Therefore copper is usually mixed or alloyed with other metals. The alloy elements most commonly encountered in archaeological artefacts are arsenic, tin, zinc and lead. While in modern usage an alloy is made by deliberately adding a second element, this is not always true of early alloys. In some cases, the alloying element was not separately and/or deliberately added; the alloying might result simply from the presence of impurities in the ore. The presence of an alloying element will usually change the properties of copper: in most cases the melting temperature will be lowered, the resulting metal will be harder and the alloy will be a different colour.

Arsenical copper/bronze

Many early Bronze Age copper-based artefacts are made from alloys of copper and arsenic. There is no evidence for the manufacture of metallic arsenic at this time and it is assumed that the arsenic derives from the use of ores

which naturally contained some arsenic. The presence of arsenic in these alloys made them harder than pure copper and this seems to have been deliberately exploited by early Bronze Age copper smiths.

Tin bronze

Tin has been widely used to alloy copper. Tin bronzes made their first appearance in Britain towards the end of the 3rd millennium BC and have continued in use ever since. The levels of tin seen in early bronze artefacts are far in excess of those seen in most copper ores and it is likely that tin bronzes were deliberately produced. While it is possible that copper ores and tin ores could be smelted together, the consistency of prehistoric tin bronzes suggests that the tin was smelted separately and then added to copper. Certainly tin ingots are known from at least the Iron Age (HMS Datasheet 203).

High-tin bronzes (>20% tin) have two specialised applications. In the Roman period a high-tin bronze was used to manufacture mirrors. The high concentration of tin produced a silvery white metal which was capable of reflecting an image. From the medieval period onwards high-tin bronzes have been used to make bells (especially those used in churches). High-tin bronzes tend to be brittle and so when struck will provide a sonorous ring.

Leaded copper alloys

From the middle Bronze Age onwards, tin bronzes often contain at least several percent of lead. Lead appears to be added in particular to those objects which were cast into shape. The association between lead and cast copper alloys (including brasses as well as bronzes) can be seen throughout later periods. In modern foundries lead is used in this way because it makes the molten metal more fluid and so takes the shape of the mould better.

Brass

Brass is an alloy of copper and zinc. There is no evidence for the manufacture of metallic zinc in Britain before the 18th century but there are a number of historical sources which describe how brass was made. Copper (as sheet or fine shot) was mixed with zinc ore and sealed in a crucible. The crucible was then heated until the zinc diffused into the copper to produce brass. This technique (often referred to as brass cementation) developed in the first millennium BC but did not appear in Britain until the first century AD. The nature of the cementation process limited most early brasses to 28% zinc (or less). From the 18th century onwards technologies were adopted in Britain which allowed the manufacture of metallic zinc (HMS datasheet 204) and so the production of brasses with more than 28% zinc.

*David Dungworth
October 2012*