Bronze casting experiments

Tristan Bareham

Abstract

This paper describes the bronze casting experiments carried out by the East Sussex Archaeology and Museums Project (ESAMP) during the HMS meeting at Flag Fen on 21st-22nd May 1994. Five castings were made on the 22nd and these are examined. Further reference is made to other casting experiments carried out by ESAMP and the paper also looks at some relevant areas of experimental development.

Introduction

The bronze casting work carried out by ESAMP is part of ongoing experimental programme carried out at the Iron Age Activity Centre at Michelham Priory, East Sussex. The original aim of this work was to replicate a Bronze Age woodworker's toolkit which could then be used in a reconstruction building programme. ESAMP also intend to produce a range of decorative bronzework, in particular small ornaments from the Iron Age, and to use this to explore a range of casting techniques.

The castings carried out at Flag Fen were primarily intended as a demonstration for HMS members and the general public, so detailed recording was not carried out. However by examining details of this work it is possible to discuss some of the major casting variables involved with experimental replication.

The variables

The furnace used for the castings was made specifically for the HMS conference (Fig 1). It was not based on a specific excavated example but nevertheless we hoped it would allow us to explore potential aspects of furnace design. The external dimensions of the furnace were: width 550mm and height 550mm. Access to the crucible was through an entrance opposite the bellows hole; a chimney was created to allow the escape of exhaust gases. The chimney and door of the furnace had temporary covers placed over them during the heating of the metal to facilitate heat retention. The bowl and dome were created as one integral unit. The material used was a Sussex earthenware clay which had sand, chopped straw and charcoal added to it. The clay was fired as the furnace was used; the firing depth and pattern are described below.

The air supply to the furnace was provided by foot bellows of the variety used until recently by travelling blacksmiths. The double diaphragm of these bellows gives a continual airflow into the furnace; two leather bag bellows produce a very similar effect. The fuel used was charcoal which had been commercially produced in steel kilns from native hardwoods. ESAMP has since then produced charcoal in traditional earth clamps from oak, hazel and hornbeam. This clamp-produced charcoal has proved subsequently to be more effective both in terms of temperature qualities and furnace management.

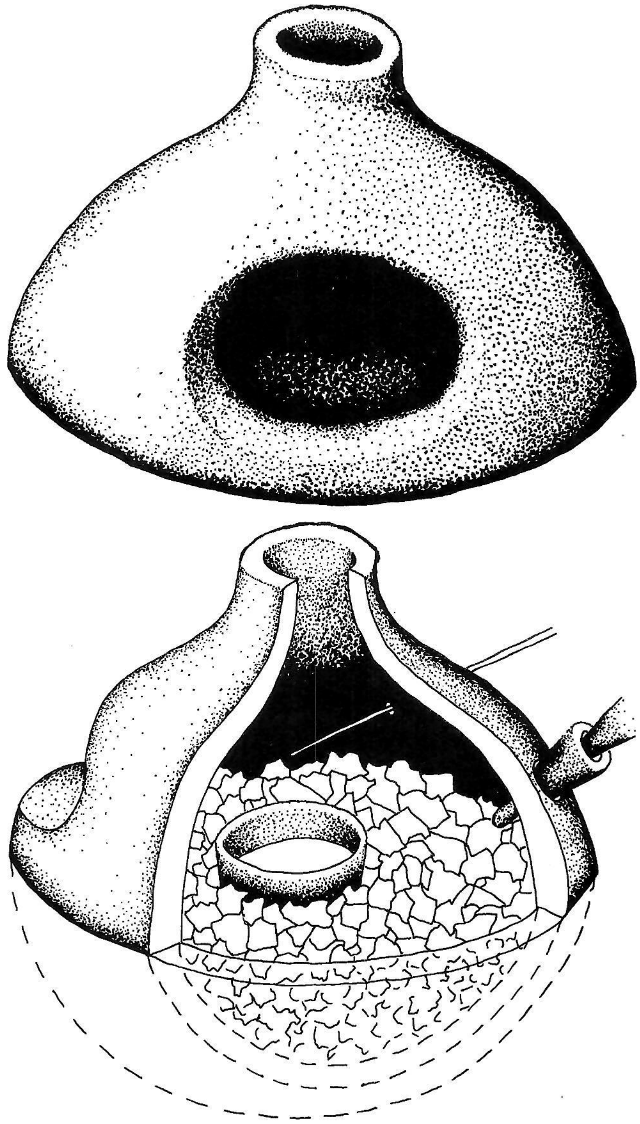

Figure 1: Front view and cutaway side view of furnace showing crucible, probe and tuyere.

The production of effective crucibles is another area, like mould making, which shows clearly that metallurgists either understood ceramic principles or co-operated with potters (Tylecote and Boydell 1978, 28). Most earthenware clays will melt at around 1100°C. These clays can be made more thermally resistant by the addition of certain inclusions, notably silica and carbon. However, some clays which are low in fluxing agents such as iron and free alkalis have naturally greater refractory properties than ordinary earthenware clays (Bayley 1992, 3). The refractory requirements of the crucibles depend on the method used to heat the metal. Experiments carried out by ESAMP have shown that an effective way of heating lumps of recycled or scrap bronze is by placing them in the charcoal directly above the crucible. When molten, the bronze flows down into the bottom of the crucible. Where the metal is heated primarily through the side wall of the crucible this obviously requires greater refractory capacity in the ceramic than when the heat is concentrated in the area immediately above the crucible. For the Flag Fen casting work we used commercially produced graphite crucibles rather than clay ones. This was done for ease and safety, but from an experimental point of view it should be noted that graphite crucibles are not archaeologically authentic and they have differing thermal properties to ceramic ones.

A variety of moulds were used. The open axe mould was carved in a soft sandstone; it was based on a flat axe (Fig 2) found at Talwrn (Lynch 1970, 214). The surface of the inside of the mould was given a carbon coating by holding it over a candle. This is a practice noted on some Bronze Age stone moulds (Lynch 1970, 222). The purpose of this carbon coating was to facilitate the removal of the cast artefact. Four lost wax moulds were used for the other castings. Two were of tanged chisels and two of boar figurines. The two tanged chisels were based on ones from the British Museum (Fig 3). It is likely, however, that these chisels were originally cast in two-piece moulds. The moulds for the chisels were made so that the hot metal was poured into the same hole that the exhaust gases escaped from. They were angled slightly during pouring to allow the gases to escape. The two bronze boars were based on examples from Sussex (Fig 4). The moulds for the boars were created so that the metal was cast through the back legs, ran through the body and emerged from the front legs. A sprue cup was created over the back legs to facilitate the creation of a reservoir of metal. It was hoped that this would give sufficient pressure to drive the molten bronze throughout the mould. Subsequent lost wax castings carried out by ESAMP have been more successful when the bronze is poured through the snout and allowed to run through all the legs.

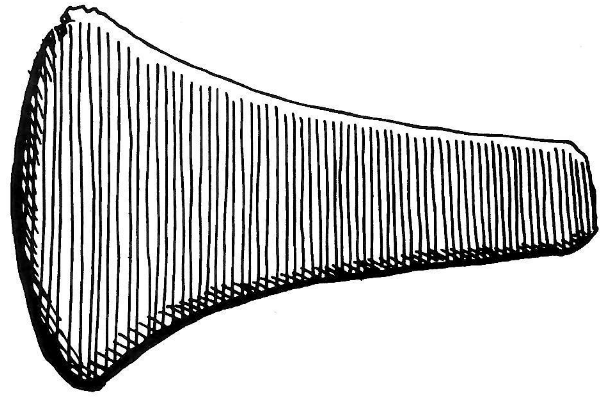

Figure 2: Flat axe from Talwrn (length 160mm).

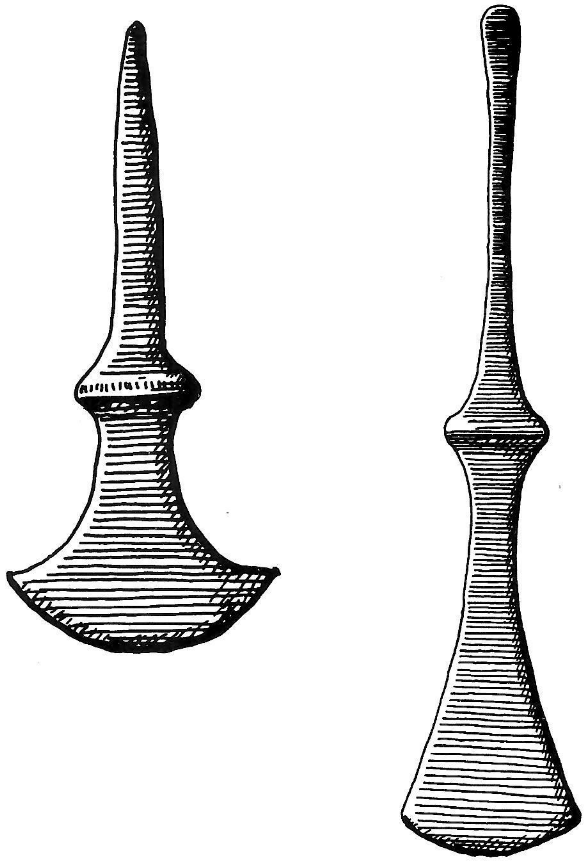

Figure 3: Tanged chisels, no 1 to left (85mm long) and no 2 to right (113.5mm long).

We used beeswax to create the blanks of the desired forms. In the Iron Age it is likely that much of the finished detail on lost wax castings was put on blanks and not created as part of post-casting working (Foster 1991, 185). Beeswax, even when gently heated, can be difficult to work. However some ethnographic studies of lost wax casting have revealed that vegetable oils are sometimes added to the beeswax; this can increase the plasticity and consequently the finished detail which can be achieved. If fine detail has been put onto the surface of the wax blanks it is important that the clay is carefully applied to the surfaces so that this detail is respected. Some moulds show a finer layer of clay on their innermost surface; this was possibly achieved by dipping the wax blank in a slip of clay before a coarser overcoat was applied. The method used by ESAMP involved the repeated application of small pellets of clay in such a way that no pockets of air became trapped in the clay sheath. As it dries the clay shrinks, and since the wax blank remains constant in size some cracking in the clay will inevitably occur. The effect of this cracking can be minimized in several ways. The clay should be well prepared, it should contain a high level of inclusions and the finished mould should be dried slowly. The effects of small cracks can be easily cleaned off the finished item. All the moulds were left to dry for a period of ten days. Prior to casting, the wax was gently melted out of the moulds which were then fired in the furnace. They were then preheated prior to the copper alloys being cast into them, this was designed to prevent the metal freezing in narrow sections of the moulds.

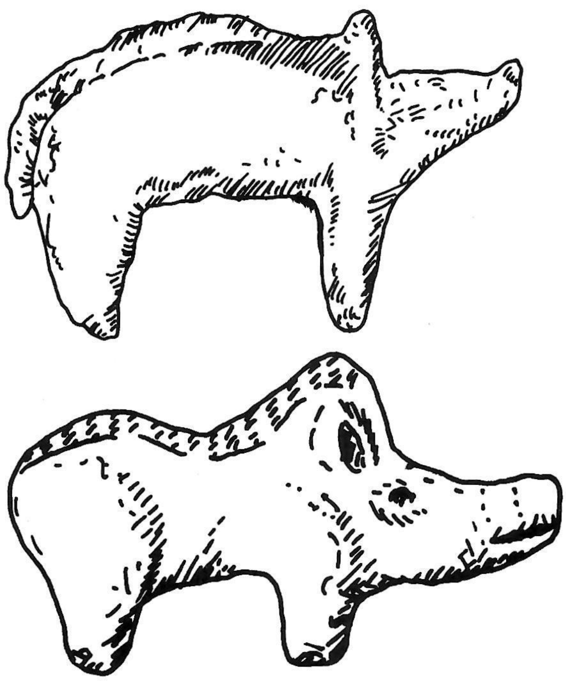

Figure 4: Boars figurines, no 1 above (35mm long) and no 2 below (38mm long).

The copper alloys were derived from a number of metal sources. The copper was obtained from a buzz bar and the tin from old gas piping. The copper-lead mix was from pre-alloyed pellets. The percentage compositions of the alloys used in the castings was achieved through weighing and estimation by eye.

The temperature in the hottest part of the furnace was recorded using a type R thermocouple with a ceramic probe, the temperature inside the moulds and the crucible was measured using a type N thermocouple and nicrosil probe.

The castings

The furnace was heated up gradually for a period of an hour and a half before the castings were attempted. This was designed to ensure that a stable thermal environment was created.

Casting 1 was of boar 1. The alloy was a mixture comprising roughly 90% Cu + 8% Pb + 2% Sn. The metal appeared viscous during the pouring indicating that a sufficient temperature had not been reached. The mould had been preheated to around 600°C prior to the casting, however no metal was seen to emerge through the risers in the front legs. The mould was opened after eight minutes. The back, ears and spinal crest of the boar had been read quite well by the metal even though its surface appeared grainy (Fig 5). The front legs had not been cast and the metal which had been poured down the back legs had separated from the body and was still located in the pouring jets.

Casting 2 was of chisel 1. The mould was glowing red when the metal was poured in. This indicated a temperature of around 850-900°C. An alloy of 90% Cu + 10% Pb was used. The metal poured quickly and evenly into the mould. The mould was left for eighteen minutes before being opened. The chisel itself cracked apart as the clay sheath was broken off. The two broken ends revealed a large crystalline structure in the metal.

Casting 3 was of chisel 2. The mould was preheated to about 400°C and the metal appeared very fluid as it was being poured. The temperature in the furnace was recorded as being over 1300°C just before the casting. The metal was an alloy consisting of 88% Cu + 12% Sn. The mould was opened four minutes after casting. This time the shaft of the chisel broke in two places on opening (Fig 6). Once again a large crystalline structure was observed in the broken ends.

Casting 4 was of the axe. Before casting the open stone mould was preheated for twenty minutes by having a small fire placed on it. The metal ran easily into the mould. A stone slab was pulled over the surface of the cast metal. A 90% Cu + 10% Sn alloy was used. Despite the application of a carbon coat to the mould it was difficult to remove the casting. The mould was slightly damaged upon removal. It was observed that a distinctive purple colouration was noticeable where the hot bronze touched the surface of the stone. This effect has been noted in other experimental castings into stone moulds (Voce 1975, 138). After extraction the axe was broken open and a finer grain than the previous castings was observed.

Casting 5 was of boar 2. A 90% Cu + 10% Pb alloy was used. The metal was viscous and did not pour well into the mould which was at about 400°C. The mould was broken open after thirty minutes. The front legs had separated from the body and only half of the rear right leg was joined to the body (Fig 5).

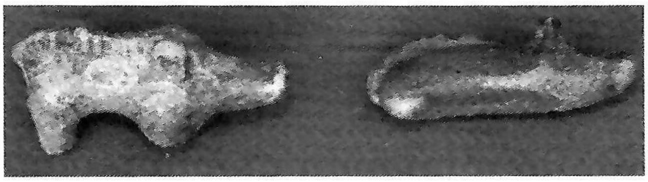

Figure 5: Experimental castings, no 5 to the left and no 1 to the right (both just over 40mm long).

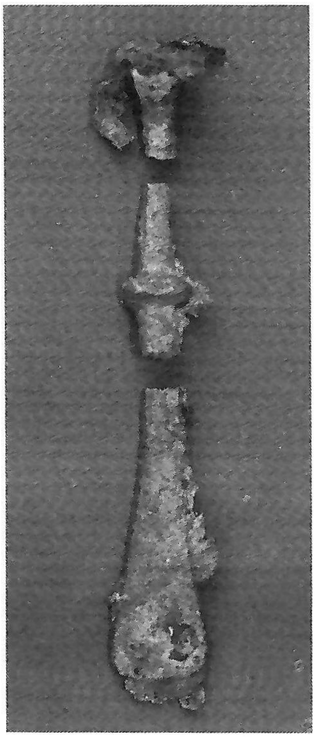

Figure 6: Experimental casting no 3 with sprue at top (about 120mm long).

Discussion

After the HMS weekend the furnace which had been used for a total of around fifteen hours was dismantled. The inside of the base was heavily vitrified and the base lining was well fired. The walls ranged in width from 45mm at the chimney to 70mm the base; only half this depth was fired at the base and a third at the chimney level. The inner first centimetre was well fired, the remaining fired section contained carbonized organic material which had not been burnt out and the matrix was easily broken apart by hand. The outer half of the clay was unfired. There are obvious implications from the excavators point of view of the potentially ephemeral nature of domes on furnaces used for short periods.

None of the castings has been subject to metallographic analysis and therefore any conclusions drawn will tend to be anecdotal in nature. The general quality of the castings was poor. The metal seemed very brittle to the point where it fell apart when the moulds were opened. Further, the observable crystalline structure in the metal seemed larger than had been encountered in previous castings carried out by ESAMP.

Some possible explanations for the poor quality of the castings were proposed by HMS members and ESAMP staff shortly after the work was carried out; several areas were discussed. The slow cooling rates could be giving rise to the growth of large crystals in the metal, an excessively reducing atmosphere in the crucibles could be contributing to poor quality metal, the constituent metals of the alloys could be separating and the design of the moulds could be causing problems. It is possible that none, or a number, of the above applied.

The attempts made to alter the temperature and cooling rates of the moulds did not seem to make much difference to apparent quality of the castings. Better quality castings have subsequently been achieved by ESAMP with rapid cooling of moulds which have not been heated prior to casting.

The atmosphere in the furnace can influence the quality of the cast metal. Budd and Ottaway (1991, 134) quote Northover as pointing out that low oxygen contents can lead to the embrittlement of copper. Conversely blow holes and porosity can result from the presence of reducing gases in the casting (Voce 1975, 138). The atmosphere in the crucible in the Flag Fen furnace was probably highly reducing.

The purpose of placing a temporary lid on the crucible was to help prevent the intrusion of small fragments of charcoal into the molten metal. These can be difficult to remove during casting and can become trapped in the mould. In recent experiments ESAMP staff have removed these small fragments of charcoal from the surface of the molten bronze with a small brush made from birch. Although there is no archaeological evidence for such brushes, this type of device was used recently by copper workers to remove the oxide skin which formed on the surface of the molten metal.

The possible segregation of the constituent metals could only be effectively considered if a detailed analysis of the castings was made.

In both the castings of the boars and the chisels, the areas where the castings came apart was where there was a marked difference in volume within the moulds. The points where the legs joined the bodies of the boars, and where the tangs of the chisels ran into the blades, manifested the greatest casting faults. In subsequent castings of similar objects this problem of separation at narrow points has been avoided by allowing the metal to flow more evenly through the moulds. This suggests that elements of the design of the moulds might have been, in part, to blame.

The 'human' variable must also be considered. While ethnographic parallels cannot tell us about specific British prehistoric practices, they can greatly enrich our understanding of the possible processes and techniques used. There are many skills involved in the whole casting process from manual dexterity in manipulating crucibles through to the judgement of the temperature of the metal by its colour. These skills are essential to the production of quality artefacts and, although they are difficult to quantify, they should be noted and incorporated into any experimental design. Certainly the ESAMP staff involved in the casting experiments have produced better quality castings as a result of the development of practical skills gained through practice.

Despite the problems of multiple variables and the 'human' element it is important that experimental metallurgical researchers attempt to fully recreate the original conditions they are examining as it is through the effective management of these inter-related variables that prehistoric bronze casters were able to create the rich range of artefacts which we find and study.

Acknowledgements

The ESAMP staff involved with the HMS experimental castings were Tristan Bareham, Cliff Camp, Adrian Wilkins and Pete Scutt. All illustrations are by Louise Brown.

References

Bayley J 1992, 'Metalworking Ceramics', *Medieval Ceramics* 16, 3-10.

Budd P and Ottaway B S 1991, 'The properties of arsenical copper alloys: implications for the development of eneolithic metallurgy', in P Budd *et al* (eds) *Archaeological Sciences 1989* (Oxford: Oxbow Monograph 9), 132-142.

Foster J 1991, 'Metalworking at Gussage All Saints: A review of recent work', in W A Oddy (ed), *Aspects of Early Metallurgy* (London: British Museum Occasional Paper 17), 185-187.

Lynch F 1970, *Prehistoric Anglesey* (Llangefni).

Tylecote R F and Boydell P J 1978, 'Experiments on copper smelting based on early furnaces found at Timna', in B Rothenberg (ed), *Chalcolithic copper smelting: excavations and experiments* (London: IAMS Monograph No 1), 27-49.

Voce E 1975, 'Bronze Casting in Ancient Moulds', in H H Coghlan, *Notes on the Prehistoric Metallurgy of Copper and Bronze in the Old World* (Oxford: Pitt Rivers Museum Occasional Paper 4), 136-140.

The author

Tristan Bareham is one of the managers of the East Sussex Archaeology and Museums Project (ESAMP) which provides vocational training and experience for individuals who wish to work in the fields of archaeology and museums. The Project runs a wide ranging educational programme for schools, universities and the general public, including classroom presentations, courses in experimental archaeology, and the design and construction of interactive museum displays. ESAMP is supported by the Sussex Archaeological Society and East Sussex County Council Planning Department.

Address: ESAMP, Anne of Cleeves House, Southover High Street, Lewes, E Sussex BN7 1JA.