Metalworking waste from Canterbury Road, Hawkinge, Kent

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Summary

The metalworking waste includes 1.4kg of iron-smelting slag, and a large nodule of ironstone that would be suitable as an ore, from Early Iron Age contexts. The smelting slag was probably allowed to cool within the furnace. 0.56kg of probable iron smithing debris was identified from a Late Iron Age context. Fragments of a number of small, triangular-plan crucibles and probably one large crucible, also triangular in plan, used for melting copper alloys, were recovered from Late Iron Age, and possibly Early Iron Age, contexts. Alloys of copper and tin (bronze) were melted, often with significant quantities of arsenic present, typical of Iron Age copper alloys. Traces of lead were occasionally detected in the copper alloy.

Keywords

Metalworking ferrous, metalworking non-ferrous, Iron Age, technology, ceramic

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Introduction

South-East Archaeology maintained a watching brief during ground-works associated with a residential development at "Dickson land", an area located off Canterbury Road, Hawkinge, Kent (NGR TR 219398). Traces of Early Iron Age settlement were identified, and a number of pits were located. Some of these contained suspected crucible fragments, slag, semi-vitrified pottery, fired clay, burnt sandstone and charcoal. The remains of Late Iron Age / early Conquest settlement were also identified together with the poorly preserved remains of sixteen or more possible cremation burials / pyre deposits, dating from the EIA to the 1st century AD (Priestly-Bell, 2000). The metal working waste, comprising crucible fragments and slag, has been examined and is described in this report.

Table 1: Contexts and dates

Context	Date
58	Early Iron Age *c*. 550-350BC
81	Early and Late Iron Age material
87	Earlier EIA
113	Probably EIA
117	EIA
125	Probably LIA with residual EIA sherds from 129, which 125 cuts.
129	Probably EIA with intrusive LIA material from 125.
144	EIA
146	EIA
150	Early 1st millennium BC (to 500BC)
154	Early 1st millennium BC (to 500BC)

Analytical Method

An EDAX Eagle II X-ray fluorescence (XRF) system was used to analyse the metalworking waste. The advantage of this technique is that it is rapid and no sampling is required. The object is bombarded with X-rays, which are directed via a fibre optic cable onto an area less than 0.5mm in diameter. The primary X-rays are absorbed causing the atoms in the excited area to emit secondary X-rays whose energies are characteristic of the elements present, and in this way the composition of small, selected areas of the sample can be determined. The disadvantages of the XRF technique are that only the surface of the object is analysed, which is invariably badly corroded or weathered. The analysis obtained is rarely representative of the composition of the uncorroded material beneath. Prior to each set of analyses the machine was calibrated using an aluminium copper alloy. The analysis conditions were 40kV and the current was adjusted so that a deadtime of approximately 30% was obtained.

Copper and its alloys are prone to corrosion. Although XRF analysis provides compositional information on the surface analysed, the composition of a corroded surface can differ greatly from the composition of the original metal beneath. For example, tin-rich corrosion crusts are often formed on high tin bronzes as a result of tin oxide being insoluble, and therefore immobile, relative to copper ions, which are highly mobile (Cronyn, 1990). Therefore analytical data must be interpreted with caution.

Results

The waste from Hawkinge was systematically examined, to identify the different types present, and sorted into categories. The amount of material in each category was then weighed for each context and some examples were subjected to XRF analysis. Descriptions of the metalworking processes, and the different categories of waste produced by these, are given in the appendix of this report.

Copper alloy working debris

CRH99-125

This context contained fragments of small crucibles, 11 of which were rims (mass 96g) and 17 body fragments (mass 76g). The fragments are likely to be sherds from the small triangular-plan crucibles typical of the Iron Age (Wainwright, 1979, 125-149 and Gregory, 1991, 139, type B). Fragments such as that shown in figure 1 are from the vertices of the crucible, which are pouring lips, whereas straight fragments are from the crucible sides (figure 2). The crucibles are likely to have been about 7cm deep and 7cm wide. All of the fragments were heavily vitrified throughout, indicating that the clay had been fired to high temperatures.

Figure 1: Pouring lip rim fragment of small triangular crucible, from context 125 (x 1.8)

Figure 2: Typical longitudinal section of crucible rim, from context 125, thinning towards the rim (x2)

The inner surfaces of the crucible sherds were reduced-fired grey whereas the outside surfaces were often vitrified where the clay had reacted with the ashes from the fuel used for heating, and frequently red-coloured because of the presence of copper. Analysis of the outer surface detected copper, varying levels of tin and very small traces of lead. Analysis of droplets of metal adhering to the inside of one crucible fragment (see figure 3) detected copper and tin with some arsenic and traces of lead.

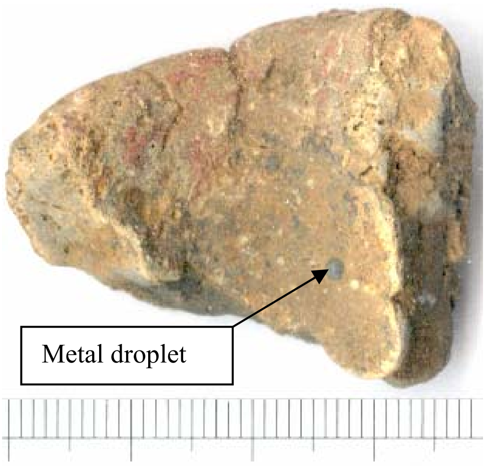

Figure 3: Inner surface of crucible sherd from context 125, with one of the metal droplets indicated (x 1.6)

This context also contained 16 fragments from larger ceramic vessels, 11 of which could be reassembled to form 3 larger sherds, as shown in figure 4. It is likely that all of these sherds derive from a type of large, triangular-plan crucible with a fairly flat base and a capacity of about 1000cc, known from other sites of this period (Wainwright, 1979, 125-149 and Gregory, 1991, 139, type C). These large crucibles are about 18cm across and 11cm deep. The inside surfaces of the sherds were grey and reduce-fired, whereas the outside surfaces were reduced-fired black in some areas and oxidised-fired orange in others. The friable surfaces of the sherds are heavily abraded but on two fragments a vitrified, red layer survived on the inside surface. There also appears to be a small area of rim with a pouring lip on one of the sherds (figure 5), where XRF analysis detected copper and traces of tin, arsenic and lead. The composition of the clay, determined by XRF analysis, was similar to that used for the smaller crucibles.

The large crucible fragments are only vitrified on the surface, rather than throughout their thickness like the small crucibles, indicating that the smaller crucibles were re-used more frequently or heated more strongly. Many more small crucibles than large ones are represented amongst the Hawkinge fragments and at Thetford small crucibles also outnumbered large ones in a ratio of 6:1 (Gregory, 1991, 136-143). This is consistent with Wainwright's comment (1979, 125-149) that few cast objects of this date would require more than a fraction of the large amount of copper alloy that the bigger crucibles could hold.

Figure 4: Outer surfaces of reassembled sherds, possibly from a large crucible, context 125 (x 0.5)

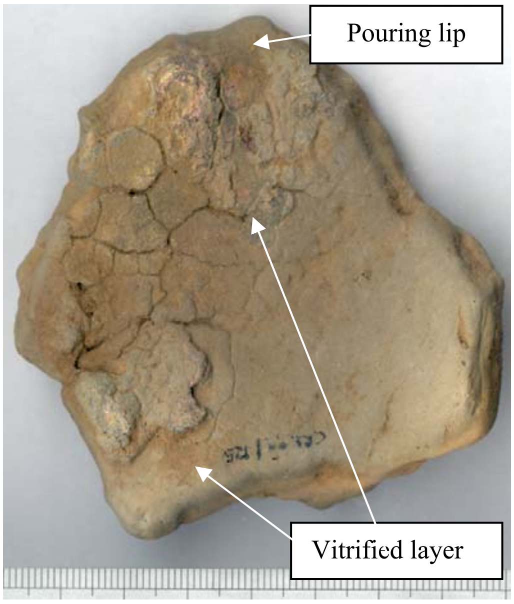

Figure 5: The inner surface of a large crucible fragment, showing the vitrified layer (x 0.8)

102g of vitrified clay with an oxidised inner surface (therefore not from a crucible), 19g of fuel ash slag and 13g of vitrified copper alloy working slag were also recovered from this context. A droplet trapped within the slag was analysed and high concentrations of tin and copper, with significant levels of arsenic, were detected.

CRH99-129

10 fragments of small crucibles, 4 with rims (96g) and 6 without (26g) were also recovered from this context. The crucibles had quite pointed bases as indicated by the two adjoining fragments shown side by side in figure 6. Analysis of the red vitreous layer on the crucibles detected copper and a trace of lead. One sherd (15g) from a large crucible, very similar to those described for context 125, was also recovered from this context. Context 125 cuts context 129 and the crucible fragments in context 129 are likely to derive from the later feature. 3g of fired clay and 8g of vitrified clay were also present. Some contexts contained very small, fired clay fragments, which were possibly from moulds. However analysis could not detect significant amounts of metal.

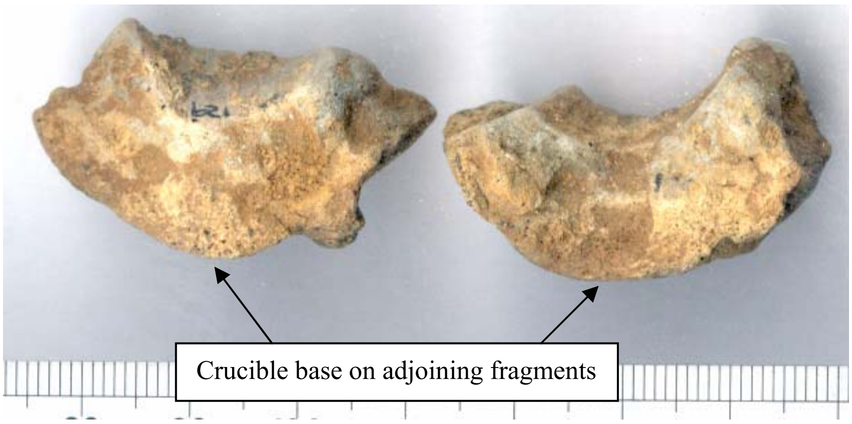

Figure 6: Two adjoining halves of a small crucible base (x 1.4)

Iron working Debris

Several blocks of dense, well-consolidated slag, likely to be the product of smelting activity, were recovered from contexts 58 and 117. Large lumps of charcoal were preserved in outline inside the block from context 58 and fired clay still adhered to some surfaces of the lumps. The slag appears to have solidified in the base of a furnace. Context 117 contained a large module of concretionary hydrous ferric oxides, goethite and lepidocrocite (confirmed by XRD analysis). These are common weathering products of iron bearing minerals (Deer, Howie and Zussman, 1992). XRF analysis of the nodule detected a high iron oxide (FeO) content, on average 85wt%, making the nodule a good ore for smelting. The nodule also contained 0.6wt% manganese oxide, 4wt% alumina and 10wt% silica. XRF analysis of the slag blocks detected between 70 and 75wt% of iron oxide (FeO), 0.5wt% manganese oxide and between 1.7 and 2.4wt% phosphorous pentoxide. This iron content falls within the range detected in Iron Age smelting slags from other sites (Tylecote, 1986, 146). A high iron concentration is necessary in the slag to make it fluid enough to separate from the iron at the temperatures used.

From context 125, shallow fragments of slag were recovered with convex lower surfaces and flat top surfaces, several of which were porous, and these are probably iron smithing slags. Others pieces of slag were very well-consolidated and full of large crystals, which are indicative of slow cooling. These characteristics are typical of smelting slag, but the distinctive shape of the fragments raises the possibility that they may be well-consolidated smithing slags. In the absence of conclusive evidence of LIA smelting, these fragments have been allocated to the smithing hearth bottom category (table 2). This context also contains 0.6kg of undiagnostic slag, amongst which are rusty agglomerates of charcoal and slag with rare hammerscale flakes (a by-product of smithing activity) and probably some metallic iron. Many small, heat-fractured quartz pebbles were incorporated into the undiagnostic slag in this context.

Table 2: Identification of iron-working waste from Hawkinge

Ctxt	Vitrified Clay	Dense Slag Block	Smithing	Undiagnostic	Fuel Ash	Stone (incl. possible ore)	Fired clay
125	53g		556g total. Includes 332g dense crystalline, but also shallow and bowl shaped; 87g porous slag; 119g in 2 pieces, dense but porous top and bottom, shallow, bowl-shaped, standstone incorporated; 18g shallow, bowl-shaped.	606g total. Includes fragments with a high fuel ash proportion and a fragment containing ore plus 170g of vesicular slag with lots of small, heat-fractured quartz pebble inclusions. 117g (includes rusty agglomerates, containing hammerscale, pebbles, charcoal and small iron fragment)	48g	171g including fragments of coarse ferruginous sandstone	44g
58		804g (large dense slag block in 3 pieces, clay adhered, reddish in areas, large voids inside, crystalline, contains charcoal.		10g			
113				15g			
154	14g					Pebble	
150	28g						
81				6g			
144	29g			66g			
87					20g + sherd with fuel ash adhered		10g
146						121g stone	
117	221g	606g (includes 534g large crystalline slag, with adhered clay)		86g		351g nodule of concretionary hydrous ferric oxides	

Conclusions

Iron smelting took place at the site at an Early Iron Age date. The types of furnace in use were non-tapping furnaces, producing blocks of well-consolidated slag, which probably accumulated in the base of the furnace. Since small discreet areas of this site were excavated and no furnace remains were found it is not possible to estimate the scale or precise location of the iron working activity. A nodule of concretionary hydrous ferric oxide recovered with the smelting slag would be a rich ore and was probably available locally to the site. The Late Iron Age iron-working slag is likely to be waste from iron smithing. Two types of triangular plan crucible were also found, one small and one large. The crucibles are of a form typical of the late Iron Age and were used for melting bronze. A small amount of arsenic and traces of lead were also present in the bronze, which is typical of Iron Age copper alloys.

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Appendix: Background information on Iron Age metalworking

Copper alloy working

Copper is soft ductile metal, which is often alloyed with other metals such as tin, zinc or lead in order to produce an alloy with a particular colour, hardness, malleability or casting fluidity. The terms used in this report for different alloys are based on the following definitions (Bayley and Butcher, 1991). Bronze is an alloy of mainly copper and tin with tin levels usually in the range 5-12wt%. Brass is an alloy mainly or exclusively of copper and zinc, normally with between 10wt% to around 25% zinc. Lead can be added to either of these alloys in which case the alloy is then described as leaded.

There are considerable differences between the types of copper alloys used in Britain before the Late Iron Age compared to those used in Late Iron Age and Roman Britain. In the early and mid Iron Age bronze was the main alloy used. The earliest date for the regular production of brass is 25BC (Dungworth, 1996, 399-421) and objects made from brass do not appear in southern Britain until the early 1st century AD (Bayley, 1988, 193-207). The lead content of Iron Age alloys is generally low although larger more intricate castings occasionally contain moderate amounts of lead. In contrast in the Roman period, although low levels of lead are found in many objects, some contain large amounts of up to 40wt% (Dungworth, 1996, 399-421 and Northover, 1989). Relatively high levels of the impurity arsenic are also found in Iron Age copper alloys, whereas Roman alloys rarely contain more than 0.1wt% arsenic.

Copper alloy working waste categories

Copper melts at 1084ºC, and its alloys at lower temperatures still, and so the metal and its alloys can be melted in ceramic vessels, known as crucibles, and cast to shape in clay moulds. In the Iron Age, crucibles typically have a triangular plan and are quite shallow with wide mouths (Wainwright, 1979, 125-149 and Gregory, 1991, 136-143). Both small and large sizes of Iron Age crucible have been identified with bases ranging from fairly flat to quite pointed. Three types were identified at Thetford, Fison Way: two with a smaller capacity of about 22cc and one with a larger capacity of about 1000cc. Traces of copper, lead and tin were detected in all of the crucibles (Gregory, 1991, 136-143). The smaller form was more common than the larger ones, by 6 to 1. The larger crucible was found in the same deposits as the other two types identified and so are probably contemporary. When crucibles are heated, some of the metal they contain is absorbed by, and reacts with, the crucible surface. Analysis of the crucible surface can therefore detect these elements and the type of alloy being cast can be deduced. However the relative ratios of elements remaining in the ceramic is unlikely to reflect the ratios of elements in the original alloy, since the former might be affected by their relative volatility, ease of oxidation and reactivity. Commonly, plant ashes from the fuel used to heat the crucible react with the crucible surface to form a glassy layer. If copper is also incorporated into this layer, it acquires a bright red colour, similar in appearance to red enamels, which is diagnostic.

In this period investment (lost-wax) moulds were used, which were made by first modelling an object in wax and coating it in fine-grained clay. The assembly was then fired and the wax melted out to leave the fired clay mould. Molten metal was poured into the mould, where it solidified, and the mould was then broken to remove the casting. Therefore investment moulds could only be used once. Moulds are fragile and rarely found in large fragments.

However the pieces can sometimes be identified by their smooth casting surfaces and fine-grained fabric. The internal surfaces of moulds are grey in colour, as the surface has been heated in contact with the metal and therefore in a reducing (oxygen depleted) atmosphere. In contrast the outer surfaces are usually oxidised-fired red (Bayley et al, 2001). Analysis of the inner surfaces of moulds can sometimes detect traces of the metals cast in them.

Iron working

Smelting is the process of reducing iron ore to produce iron metal. Little evidence of Iron Age smelting furnaces has been found, and only the bases survive, which are typically fairly small and rounded with an inside diameter of less than half a metre. Although the superstructure of these furnaces does not survive, they may have been clay-built shaft furnaces although domed furnaces have also been proposed (McDonnell, 1986; Cleere and Crossley, 1985: Crew, 1998). Charcoal was the fuel used.

The ore was probably roasted prior to use, to convert it to an oxide and to facilitate crushing. For the Roman period there is evidence that bellows were used to blow air into smelting furnaces, through an inlet near the base known as a blowhole. A similar practice may also have been used in Iron Age furnaces in order to reach the high temperatures required. The area near the blowhole would be the hottest region of the furnace and it is here that the ore would react to form iron. As iron has a very high melting temperature it would not get hot enough to melt, but the particles of iron would accumulate to form a spongy mass, known as a bloom. The iron bloom produced must then be consolidated by smithing, which is described in the next paragraph, into a billet or bar for subsequent trading. The gangue (non-iron minerals) in the ore, and the fuel and the furnace structure, would react together with some of the iron to form a liquid slag. This molten slag could be removed in a number of ways. Slag can be raked out through an aperture at the bottom, tapped out as a flow through a tapping arch, or allowed to collect in dense lumps within the bottom of the furnace or in a pit dug for this purpose beneath the furnace superstructure. The shape of the slag produced generally indicates the method used for its removal (Salter, pers. comm).

Iron is shaped by a process of heating and hammering known as smithing. Smithing uses a charcoal-fuelled hearth, which is likely to have been a shallow, walled structure, constructed from clay or stone, either on the floor or at waist height. Again, air was probably blown into the hearth by bellows through a hole in the hearth wall. During smithing, the surface of the iron being heated becomes oxidised and Small flakes and spheres of oxidised iron and slag, known as hammerscale, detach from the surface and react with other components in the hearth, such as the fuel and hearth lining to form a lump of slag known as a smithing hearth bottom, which accumulates near the blowing hole in the fuel bed. The hot metal is hammered into shape and again slag and scale is detached and collects on the floor. Since hammerscale is magnetic it can be detected in archaeological occupation surfaces with a magnet (Bayley et al, 2001; Crew, 1996).

The processes of smelting an iron ore to form the metal and then smithing the bloom into a form of workable iron are together known as ***Primary Iron-working***. The iron billet or bar produced by primary iron-working will then supply smiths, maybe at other sites, where it will be used to produce iron objects in a process known as ***Secondary iron-working***. In secondary iron-working, bars or billets of iron, or recycled iron, are smithed into useable objects. As this also involves the repeated heating of iron in a hearth and hammering the hot metal into shape, hammerscale and smithing hearth bottoms are again produced. This smithing activity is not associated with smelting and so can be distinguished from the smithing that takes place in primary iron-working.

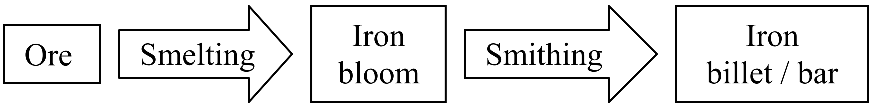

Figure 7a: Primary iron-working processes

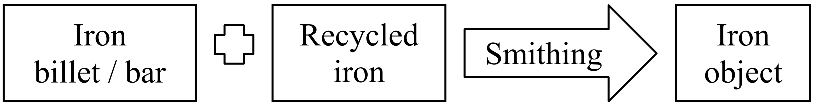

Figure 7b: Secondary iron-working processes

Iron-working Waste Categories

The iron-working debris from Hawkinge has been categorised according to the characteristics in table 3 (Bayley et al, 2001). The final two columns of table 3 indicate whether this type of waste would be produced by primary iron-working, secondary iron-working or both.

Table 3: Description of iron working waste

Waste Category	**Description**	**Primary**	**Secondary**
Dense slag block (smelting):	Large lumps of dense slag, with only a few larger bubbles, and with no particular shape.	√	X
Slag-lined clay (smelting and smithing):	Clay that formed part of a furnace or hearth lining, with a surface that has reacted with the slag or the ash from the fuel at high temperatures and has developed a dark-coloured, slag-like or glassy surface. The furnace or hearth is hottest near the blowing hole, and pieces of vitrified clay from a furnace or hearth wall with the outline of the blowing hole are sometimes found.	√	√
Fired clay (smelting, smithing and other high temperature processes):	Clay that has reached sufficiently high temperatures to be fired, but that has no diagnostic vitrified or slaggy surface.	√	√
Ore (smelting):	When roasted it commonly has a bright red colour, where it has become oxidised.	√	X
Hammerscale (smithing):	Small flakes or spheres of slag and iron oxide expelled or detached from the bloom during consolidation.	√	√
Smithing hearth bottom slag or SHB (smithing):	Spongy lumps of slag, with many small pores, characteristic convex bottom surfaces and concave upper surfaces, produced in the smiths hearth when the bloom is consolidated or when an object is being produced.	√	√
Undiagnostic slag:	Iron-rich slag that does not possess enough diagnostic features for it to be categorised.	√	√
Iron offcuts (smithing):	Small off-cuts from iron rods or bars, often with cut ends, where the smith has used the bulk of the object and discarded the remainder.	X	√
Fuel ash slag (smelting, smithing and other high temperature processes):	Produced predominantly by reaction of ash from charcoal fuel with clay. It is spongy, lighter coloured and less dense than the other slags, as it contains less iron. It is produced when a mixture of plant ashes and clay reach high temperatures, and so alone is not diagnostic of iron-working.	√	√