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Summary

An Iron Age ferrous knife was examined by metallography to determine the metal structure. A sample through the cutting edge of the blade revealed uniform low-carbon iron comprising mainly ferrite and grain-boundary cementite. Hardness was 236 HV. The blade had not been deliberately hardened.

Keywords

Technology
Iron Age
Iron

Author's Address

English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth, PO4 9LD. Telephone: 023 92856787. Email: vanessa.fell@english-heritage.org.uk

Introduction

A ferrous knife blade and tang was recovered from the backfill of a ditch of a Middle Iron Age roundhouse during excavations at Limes Farm, Landbeach, Cambridgeshire (context 15, SF1). The knife is a relatively common form from Iron Age Britain, with a riveted tang and a wide thin blade (Crummy forthcoming).

The knife is accreted with soil and iron corrosion products and there is no visible evidence that the organic handle survives (Fig 1). The overall length is 122mm of which the blade measures c. 70mm. The blade is single edged with a slightly convex cutting edge. The back curves downwards slightly; at mid blade the thickness is c. 0.5mm at the extant cutting edge (although this is now rather corroded and difficult to measure precisely) and thickness at the blade back is c. 1.5mm. The X-radiograph (Fig 2) shows the form of the knife, which seems to be complete as buried apart from some corrosion losses, and deterioration or loss of the organic handle. An X-radiograph taken at 90 degrees to Figure 2 shows two incomplete rivets of lengths c.10mm, which once secured the handle (Fig 3). The radiographs suggest that metal survives in the blade but that the blade does not have a complex structure.

Figure 1. Iron Age knife SF1, length 122mm.

Knives from other Iron Age sites have been examined by metallography to investigate their construction and metal composition, and to determine if structure correlates with function. Of particular interest are any indications that a blade might have been worked or heated to improve its usefulness. Examples of such treatments known to have been used during the Iron Age include the use of steels for hardness and strength, heat treatments to modify those properties, and cold-working to harden blade edges.

Two very similar knives to the Landbeach example have been examined by metallography, both with riveted plate-tangs and from Middle Iron Age contexts. One from Abington Park, Great Abington, Cambridgeshire (sf 104), is made of low-carbon iron (c. 0.1–0.2% C) with occasional higher-carbon areas and hardness range 121–184 HV 0.1 (Gilmour 1999). The carbon is present as partly sheroidised pearlite suggesting that the blade was annealed or otherwise reheated for a short time. The other, a very similar knife but with a more upward curved blade, is from Old Down Farm, Hampshire (Davies 1981, 124, fig 30 no 22). This knife has higher levels of carbon at the area of blade sampled (0.3–0.6% C) and a hardness of 175 HV 5 (Ehrenreich 1985, ODF5a). The microstructure is pearlite and therefore this blade was also not quench-hardened, although it was probably a strong and tough implement in use.

Figure 2. X-radiograph showing the blade to the left and the riveted plate-tang of the handle to the right. The arrow marks the position from where the metallographic sample was removed.

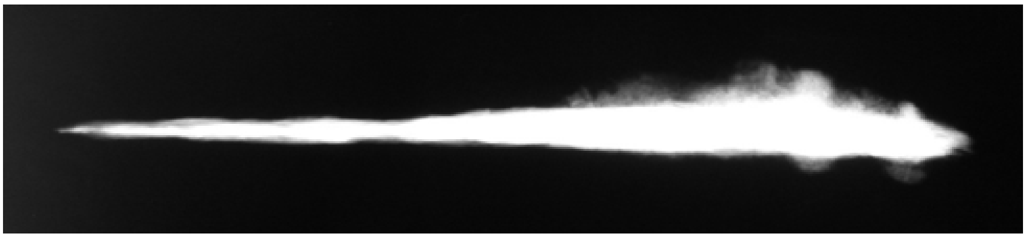

Figure 3. X-radiograph taken at 90 degrees to Fig 2. The two rivets are visible to the right.

Other types of Middle Iron Age knives that have been examined by metallography have narrow tangs and different blade shapes from the Landbeach example. A narrow-bladed curved knife from Abington Park (sf 101) comprises a banded structure of low- and medium-carbon steels that was quench-hardened (Gilmour 1999). Another tanged and narrow-bladed knife, from Winklebury, Hampshire, comprises uniformly distributed medium-carbon steel that was quench-hardened (Tylecote and Gilmour 1986, 22, fig 7). However, these are perhaps unusual examples of Iron Age knives because others investigated do not seem to have had their properties deliberately enhanced. For example, a tanged knife from a Middle Iron Age cremation at White Horse Stone, Kent, is made of plain iron (ferrite) of hardness 115–134 HV 0.1 (Fell 2004; Fell forthcoming). Another is a slender tanged knife from

Gussage All Saints, Dorset (Wainwright 1979) dated to the first century BC (pit 209, layer 10, no 726515 – not listed in site publication) comprising heterogeneous low-carbon iron (0–0.3% C), some of which is spheroidised, with a low hardness of 104 HV 5 (Tylecote 1975, no 131; Spratling et al 1980, 284–5, no 131).

From these results, the knife blades of the Middle Iron Age that have been examined range from carbon-free iron to medium-carbon steels. The levels of homogeneity of carbon and microstructure are very variable, and a few have properties that were deliberately enhanced, for example by quench-hardening of steels.

Because of this variety of compositions in Middle Iron Age knives, it was decided to examine the Landbeach example to investigate the metal structure and composition and to determine if the properties of the blade had been deliberately enhanced. The X-radiographs suggested that the knife was in a suitable condition for sampling. When knife blades are examined by metallography, it is not uncommon that two wedge-shaped sections are removed — one from the cutting edge and one from the blade back. These together would form an overlapping composite pair of sections of the blade, so enabling the investigation of any welded-on components or other features which might enhance the quality of the blade. Iron Age blades and tools, however, are usually of relatively simple construction compared with medieval and later blades and do not normally have welded-on or welded-in components. It was therefore decided to initially remove a single sample from the cutting edge in order to limit any physical damage. Depending on the interpretation of this first sample, a second (overlapped) section could be removed later if justified so that the microstructure at the back of the blade could be closely examined. However, this was not necessary.

Methods

The position for sampling was selected with reference to X-radiographs to determine a location where metal was likely to survive and the condition was relatively robust. Prior to sampling, the selected area was lightly airbraded (using alumina powder 53mμ) to remove loose corrosion layers and to check the dimensions at the cutting edge and the blade back.

A sample was removed from the cutting edge of the knife blade approximately half-way through the depth of the blade. This wedge-shaped sample was cut 10mm into the blade at 37 to 43mm from the tip of the blade. It yielded a section of length 8.5mm, width 1.5–3.0mm including corrosion layers, containing metal of width varying from 0.3mm to 1.1mm (Fig 4). Sampling was aided with a 100mm rubber-bonded silicon carbide disc mounted on a Buehler Isomet low-speed saw rotated slowly to avoid using a coolant. (The section was more angled than was intended owing to difficulty in clamping the blade.)

The sample was mounted in cold setting epoxy resin (Struers 'Epofix') to yield a transverse section of the cutting edge part of the blade. The mounted sample was ground and polished to 0.25μm fineness in diamond slurry according to standard metallographic techniques. It was examined under a metallurgical microscope at magnifications up to x400 in the unetched condition and after etching with 1% nital. The specimen was subsequently examined in the scanning electron microscope for microstructure and for semi-quantitative element analysis in a Leo 4401 Stereoscan electron microscope with a germanium detector, and Isis EDS software at 25kV accelerating voltage and probe current of 1nA. Back-scattered electron images were obtained on a lightly etched and carbon-coated surface. Hardness measurements are microhardness values obtained with a Vickers pyramidal diamond indenter using a 100g load (HV 0.1).

The void in the knife blade due to the sampling process was protected from corrosion with a single coat of Paraloid B72 (acrylic copolymer, resoluble in acetone and other solvents).

Results

The specimen shows that the blade is severely corroded. A core of metal survives to within a few millimetres of the cutting edge, becoming narrower towards the centre of the width of the blade (Fig 4).

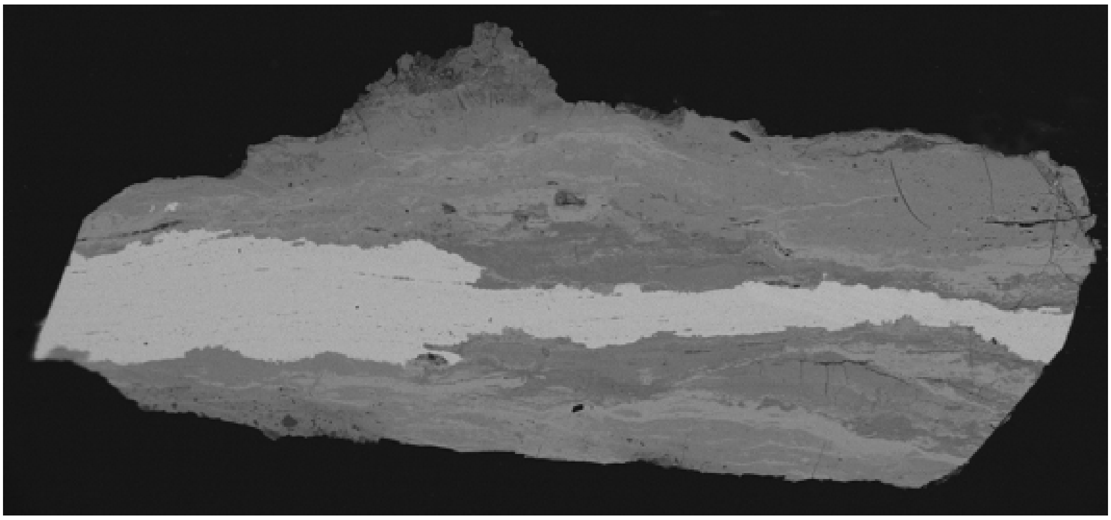

Figure 4. Transverse section through part of the knife blade, as mounted and polished. The cutting edge of the blade is to the left side of the sample shown here (the real cutting edge lies a few millimetres further to the left). The right side of the sample is approximately at the centre of the width of the blade. The surviving core of metal (light) is surrounded by accretions (grey) comprising corrosion products and soil. Length of sample, 8.5mm.

Within the metal there was a very small amount of glassy non-metallic inclusions that were orientated in parallel narrow stringers and broken lines running between the blade edge and blade back (Fig 5). The majority of the inclusions are probably slag from the smelting and bloom preparation events. Other, more broken and rounded particles, may be slag stringers in transverse section or particles of iron scale from forging of the knife.

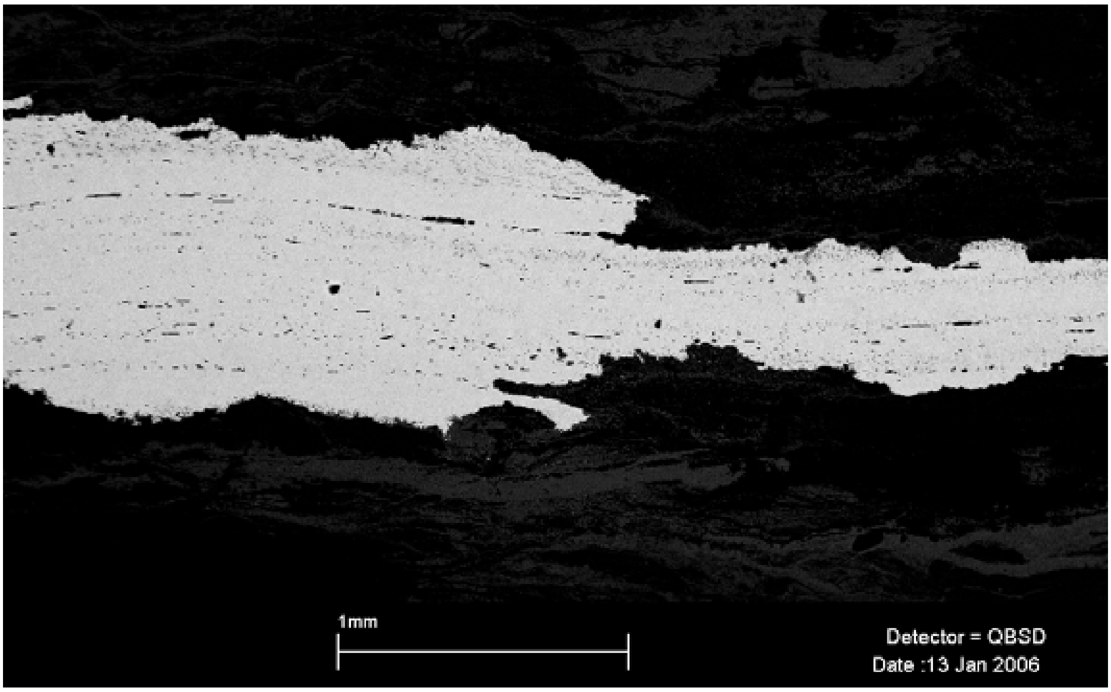

Figure 5. Central part of the mounted specimen showing metal core (pale) with lines of non-metallic inclusions running across the image (between the cutting edge and the blade back). Lightly etched with nital.

Etching of the specimen revealed ferrite (plain iron) with films of grain boundary cementite and occasional coarse pearlite (Figs 6 and 7). There was some slight banding of the microstructure aligned with the inclusions. The carbon composition was estimated visually to be c. 0.1–0.2%, which for this particular microstructure cannot be estimated more accurately. The grains were equi-axed and very small in size (grain size ASTM 8). Vickers microhardness measured with a 100g load within the ferrite near to the cutting edge was 236 HV (0.1) averaged from three indentations (244, 225, 240 HV).

Severe mottling in the grains, suggesting the presence of phosphorus, resulted in difficulty to focus optically and photographically on the etched surface. Therefore the sample was examined in the scanning electron microscope both to examine the microstructure and to determine the phosphorus composition. Element analysis determined only two trace elements of possible significance — phosphorus measuring up to 0.3 wt% and arsenic up to 0.46 wt% (Table 1).

The very slight banding in the microstructure appeared to be due mainly to small variations in grain size, inclusion concentrations and mottling in the grains. Nevertheless, the variations are very minor across the metal sample and seemed not to have affected the carbon composition or distribution. There were no indications of welding, or of element segregations that might suggest a complex metallurgical construction.

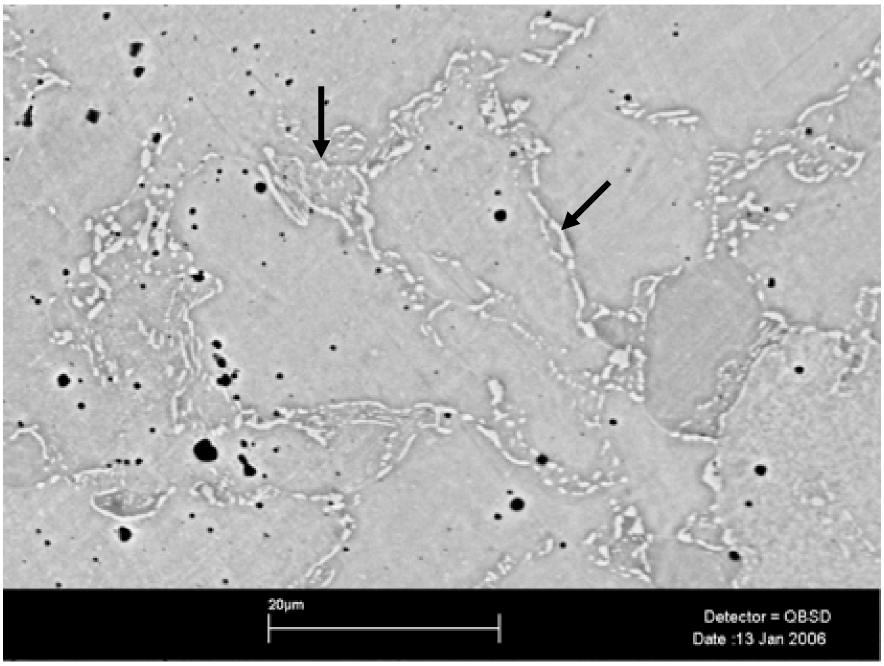

Figure 6. Electron micrograph showing detail of metal comprising ferrite (grey matrix), cementite at grain boundaries (light, eg arrow at right) and as coarse pearlite (arrow at top), and non-metallic inclusions (dark).

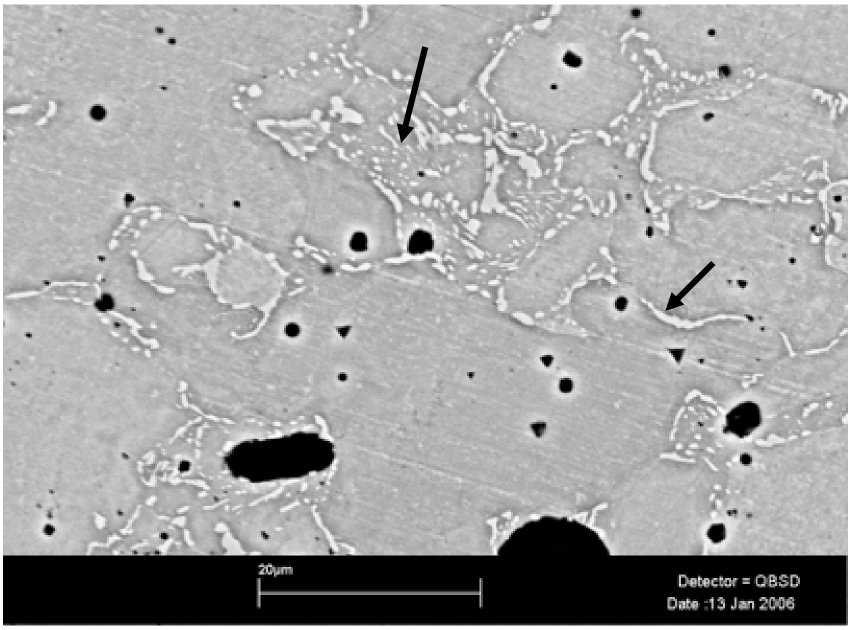

Figure 7. *Electron micrograph showing detail of metal comprising ferrite (grey matrix), cementite at grain boundaries (light, eg arrow at right) and as coarse pearlite (arrow at top), and non-metallic inclusions (dark).*

Table 1. Trace element composition, normalised.

Element	Element wt %				
	Area 1	Area 2	Area 3	Area 4	Area 5
P	0.24	0.26	0.16	0.3	0.11
Cr	0	< 0.1	< 0.1	0	0
Mn	0	0	< 0.1	< 0.1	< 0.1
Co	< 0.1	0	0	0	< 0.1
Ni	0	< 0.1	0	0	0.21
Cu	0	0	< 0.1	–	–
As	< 0.1	0.45	0.46	0.23	< 0.1

–, not sought
Elements not detected (below detection limits): Mg, K, Ti, V, Ca, S

Discussion

Early smelting furnaces commonly produced blooms that contained portions that were carburised in the smelting furnace (primary carburisation) if the smelting conditions were sufficiently reducing and temperatures sufficiently high to allow the iron to absorb carbon from the carbon monoxide atmosphere (Clough 1987; Scott 1990, 16). Sometimes the carbon in the blooms was very localised and it is probable that the smiths selected these steely portions for the manufacture of certain types of tools and implements. In other cases, the carbon in the bloom was distributed more evenly throughout the bloom, or it became so when the bloom was hammered to expel the smelting slag. However, when phosphorus is present, this reduces the high-temperature diffusion of carbon resulting in localised regions of either carbon or phosphorus. The hammering processes also redistribute impurities in the newly smelted iron, some of which segregate or become surface enriched due to oxidation (Tylecote and Thomsen 1973).

The metal preparation processes also break up the slag and other non-metallic inclusions, which tend to align in directions that indicate forging direction. In some circumstances, particularly when elements such as phosphorus or arsenic have segregated into narrow bands that are closely associated with inclusions, these can suggest that welding has occurred. Sometimes this may be due to the folding over and welding (pile-forging) of the metal during preparation; in other cases this may be a consequence of deliberately inserting steel components, such as the cutting edge of a blade. However, there is very little evidence to date that welding in steel components was normal practice during the Iron Age, although there is some evidence from sword blades to suggest complex constructions including possible proto pattern-welding (Lang 2006).

In the Landbeach blade, the orientation of the slag and forging inclusions is consistent with the folding over and welding of iron during bloom preparation and the subsequent forging of the iron billet to eventually form a blade. The metal has a relatively low quantity of inclusions and this is frequently observed in Iron Age ferrous artefacts, in particular blades, which in general have low inclusion densities (Ehrenreich 1985, 60). There was no clear evidence of welding, such as segregation lines, which suggests that the metal was well homogenised and that the carbon originated from the bloom.

The carbon in the blade, visible as cementite, is in a form that suggests that the metal was heated finally to a moderate temperature, for example around 900°C. This would have been only for a short time, such that films of cementite developed at grain boundaries but there was insufficient time for grain growth or recrystallisation (cf Samuels 1980). When phosphorus is present in iron, it is more usual that the metal grains are large, unlike those seen in the Landbeach knife. Possibly this was because heating cycles were rapid and the phosphorus concentration was only moderate. The blade was finally cooled slowly, and may even have been forged to shape during this time. However, because only the core of metal survives (through corrosion effects), there is no surviving evidence for the deformation of grains at the surface of the metal artefact.

The properties sought in a knife today, depending on its intended purpose, include hardness and strength during cutting, as well as toughness to ensure that it does not break during use. In the Landbeach knife, the relatively high hardness of the ferrite will be due in part at least to the presence of phosphorus and arsenic — both elements which originate in iron ores and which are known to increase the hardness due to their solid solubility in ferrite (Tylecote and Gilmour 1986, 9). Nevertheless, phosphorus is unlikely to be deliberately selected for forging thin knife blades for its hardening qualities due to the brittleness that it confers at high temperatures (cf Hopkins and Tipler 1958).

Other types of Iron Age tools and implements have properties that were deliberately enhanced, for example by selection of steely portions of blooms and subsequent heat treatment. The requirement for quenching in particular depended often on the precise purpose for which the individual tool would be used, rather than the broad category of tool (Fell 1995, 7). Although the techniques of hardening steels by quenching were known, at least to some blacksmiths, the very specialised technique of tempering did not seem to be appreciated and therefore although tools and implements could be hardened, they were also rather brittle. Nevertheless, not all artefacts required to be hardened, including the Landbeach knife, which would have been perfectly serviceable for many domestic and craft purposes. The well homogenised structure of the blade, combined with some phosphorus and arsenic content, had resulted in a moderately hard and serviceable implement.

Conclusions

The knife was made from low-carbon steel, which at the area examined, was relatively uniform in composition and microstructure. Carbon was visible as cementite at grain boundaries and as coarse pearlite. The hardness of 236 HV is fairly high and is most probably due to the presence of phosphorus and arsenic. The small grain size and the presence of cementite suggest that the knife blade was finally heated to a moderately high temperature, perhaps in the final forging cycle. It was finally cooled slowly, for example in air. The blade was not deliberately hardened by heat treatment.

Acknowledgements

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