

Liquid steel in Anglo-Saxon England

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ABSTRACT: Prior to Huntsman's discoveries in Sheffield in the 1740s, steel production in Western Europe, and in England in particular, has been assumed to be by solid-state carburization of malleable iron, a process often referred to as cementation. Here we present archaeometallurgical data that Saxon smiths in 8th-9th century AD England were using decarburization of molten cast iron to produce steel of comparable quality to that produced by Huntsman 1000 years later. The evidence derives from metallurgical analysis of edged tools and stock iron, and crucially the analysis of pieces of ferrous material that lack distinctive artefactual form. The evidence presented here will necessitate a re-assessment of Saxon ironworking technology and the early occurrence of cast iron fragments in the archaeological record, and has far-reaching implications for our (lack of) understanding of the development of iron technology.

Introduction

It has been postulated that in Western European antiquity three methods may have been used to produce steel: one was directly from the smelting process by careful control of fuel-to-ore ratios; another was by solid-state carburization of ferritic iron (heating iron in a carbon-rich atmosphere); and the third, any of a number of processes which produced a liquid steel. Liquid steel processes are well-attested archaeologically in medieval and later contexts in other parts of the world, predominantly in the Near East, Sri Lanka, Turkmenistan, and China (Bronson 1986, Craddock 1995). Documentary sources and recent work indicates their use from the 6th to 7th centuries AD in the Near East (Lang *et al* 1998). It is currently believed that after the introduction of the blast furnace into Europe during the medieval period, steel was produced by the decarburization of cast iron. There have been finds of cast iron from pre-medieval contexts, but due to the absence of securely dated cast iron artefacts or evidence for the refining of cast iron, these have usually been regarded as accidental by-products of metallurgical processing (Rehder 1999). The results presented here will necessitate a re-examination of this material.

Archaeometallurgical studies of iron artefacts from early medieval English urban archaeological sites, including Fishergate in Anglian York (Weimer 1993), Coppergate in Viking York (McDonnell 1992) and

Hamwic in Saxon Southampton (McDonnell 1987a and 1987b, McDonnell *et al* 1991), showed a high degree of sophistication in the use of alloys and manufacturing techniques to produce steeled tools such as knives, axes and punches. In all cases no elements other than carbon and phosphorus were alloyed with the iron, but metallographic analysis of steeled artefacts from Hamwic, recovered from well-sealed contexts of 8th–early 9th centuries AD, revealed significant microstructural differences from other tools of the same period.

Saxon Hamwic lies beneath the modern city of Southampton. This important middle Saxon trading settlement and port flourished between the early 8th and mid 9th centuries AD, and is estimated to have covered an area of 45ha at the height of occupation. There was little or no archaeological activity on the site in preceding periods, and no major subsequent development until the 19th and 20th centuries. Excavations during the last four decades have recovered evidence for an extensive system of planned roads and streets with well established and densely packed tenements, accompanied by evidence for a full range of contemporary craft activities. Among these crafts, iron smithing seems to have been one of the most productive and long lived—over 6500 iron artefacts were recovered from the excavations with iron smithing evidence present in the earliest and latest phases of occupation (Andrews 1997). Though no evidence for smelting was found within the Saxon town, two

smithies were identified, initially through the discovery of large concentrations of smithing slag which amounted to just under 1000kg (McDonnell in prep). Both these smithies were situated at major crossroads on the north-south street and were associated with domestic dwellings, which also fronted the road. Within these small (c6x4m), simply-built extensions to the neighbouring dwellings, several phases of slag- and charcoal-filled pits were found, typically 0.5m in diameter and slightly less in depth, some having a flint cobble lining (Andrews 1997). These pits were associated with more typical clay-lined hearths and a full range of slags and residues—smithing slag lumps, hearth bottoms, tuyeres, hearth lining, hammerscale, stock material and tools (Andrews 1997, Mack 1998). Some knives from Hamwic and stock iron from Hamwic's southernmost smithy have been studied in detail (McDonnell 1987a and 1987b, McDonnell *et al* 1991, Mack 1998).

Methods of examination

The edged tools and bars were photographed, drawn, conserved to remove adhering corrosion and X-radiographed. One or more sections were cut, mounted in conducting Bakelite, ground and polished in the usual manner. The billets/lumps were recorded in the same

manner, but where possible, complete half-sections were removed. Some sections were mounted in cold mounting resin, as they were too large for the hot mounting press. The samples were examined first in the unetched condition and then routinely etched in 4% nital. Specialized etchants, *eg* Stead's reagent, were used to reveal remnant cast microstructures; details are given in the text. Digital micrographs were captured through a Mutech image grabbing board from a CCTV camera attached to a Nikon Optiphot reflected light microscope. Image processing and analysis of the non-metallic slag inclusions was carried out using Scion Image for PC 4.02 beta (Scion Corporation 2000). Images were converted to 256 level grayscale, and automatically thresholded for standardization. The resultant binary images were analysed using original and adapted macros written in Pascal. This generated data on over 31,000 slag inclusions, giving information on size, shape, and contribution to overall slag content.

Results

Steel in edged tools

The Hamwic edged tools demonstrated levels of quality, in terms of manufacturing techniques and raw materials, practically unmatched until after the Industrial

Table 1: Summary of the metallurgy of edged tools from Hamwic (after McDonnell 1987a and 1987b, McDonnell *et al* 1991).

Reference	Artefact	Back microstructure	Back HV _{0.1}	Edge microstructure	Edge HV _{0.1}
24/22	axe	phosphoric	206	tempered martensite	464
31/92	billhook	ferrite	133	tempered martensite	446
169/1858	chisel	ferrite	135	ferrite + spheroidized carbide	199
169/1045	cold chisel	pearlite + gb cementite	358	corroded	-
30/173	knife	ferrite	154	tempered martensite	743
31/340	knife	martensite + retained austenite	642	tempered martensite	572
31/663	knife	ferrite	192	pearlite	322
99/38	knife	ferrite + some pearlite	186	tempered martensite	772
99/92	knife	ferrite	178	ferrite + pearlite	235
169/417	knife	ferrite + some pearlite	168	tempered martensite	441
169/421	knife	ferrite	198	pearlite	158
169/540	knife	ferrite	180	tempered martensite	612
169/558	knife	ferrite	155	tempered martensite	446
169/610	knife	ferrite	126	tempered martensite	585
169/1617	knife	ferrite	156	tempered martensite	689
169/2407	knife	ferrite + carbide	202	ferrite + spheroidized carbide	185
169/2502	knife	bainite	273	tempered martensite	649
169/2516	knife	ferrite	183	tempered martensite	488

Reference— Site number/finds number

Back microstructure— description of the dominant microstructure of the back

Back HV_{0.1}— typical Vickers microhardness of the back, using 100gf load

Edge microstructure— description of the dominant microstructure of the cutting edge

Edge HV_{0.1}— maximum Vickers microhardness of the cutting edge, using 100gf load

Revolution. Knife blades were mostly constructed by a butt-welded technique, where the cutting edge is a small steel strip hammer-welded to the soft, ferritic iron back, a most economical use of a valuable steel. The majority of the steels had unusually high microhardness values, in the range 500-900 HV (see Table 1), values rare in preceding and later periods (Tylecote and Gilmour 1986), and were exceptional both in homogeneity and cleanness. Carbon was evenly distributed, with an average content estimated from the

metallographic structures and hardness values to be of the order of 1-1.5wt%C (McDonnell 1987a, 1987b; McDonnell *et al* 1991). Quantitative image analysis of polished sections showed that the steel generally had less than 1 vol% slag, in contrast with the ferritic iron backs which had values of up to 4 vol% (Table 2), and estimated values up to 10 vol% in totally corroded samples. How such low slag contents came about in the steel poses an interesting question. Some reduction in volume of oxide-rich slag inclusions can occur during

Table 2: Summary of image analysis data.

Reference	Artefact	metal type	HV _{0.1}	Images	particles	PPI	% slag
<i>Hamwic</i>							
Sou31/92	billhook	steel (tang)	-	30	925	30.8	1.17
		steel	446	24	260	10.8	0.26
Sou31/663	knife	phosphoric	-	30	791	26.4	1.15
		ferritic	-	10	702	70.2	1.96
		steel	322	7	250	35.7	0.93
Sou31/1045	chisel tip	steel	-	30	260	8.7	0.04
Sou31/2261	cast steel bloom	steel	-	30	629	21.0	0.14
		cast iron	-	19	203	10.7	0.09
Sou169/417	knife	ferritic	-	22	671	30.5	2.64
		steel	441	14	843	60.2	1.26
Sou169/421	knife	phosphoric	-	30	1381	46.0	3.89
		ferritic	-	10	682	68.2	0.70
		steel	158	20	739	37.0	0.59
Sou169/540	knife	ferritic	-	30	2089	69.6	1.58
		steel	612	20	1134	56.7	0.97
Sou169/610	knife	phosphoric	-	30	755	25.2	2.03
		steel	585	25	419	16.8	0.86
Sou169/2407	knife	ferritic	-	30	473	15.8	0.73
		steel	185	30	900	30.0	0.88
<i>Coppergate</i>							
2963	knife	ferritic	-	27	1548	57.3	1.95
		steel	252	19	1037	54.6	3.03
2954	knife	ferritic	-	20	2074	103.7	2.27
		steel	169	30	602	20.1	0.57
2829	knife	ferritic	-	30	2125	70.8	1.76
		steel	603	26	491	18.9	0.64
3936	sword	phosphoric	-	20	75	3.8	0.09
2985	knife	ferritic	-	6	193	32.2	0.78
		steel	660	30	851	28.4	0.59
2860	knife	phosphoric	-	30	1539	51.3	0.98
		steel	428	24	1131	47.1	0.71
1765	knife	ferritic	-	29	1046	36.1	3.69
		steel	427	30	328	10.9	0.68
2826	knife	ferritic	-	30	3223	107.4	1.80
		steel	426	15	958	63.9	0.96

Reference— Hamwic artefacts: site number/find number; Coppergate artefacts: catalogue no: Ottoway 1992 (see McDonnell 1992)

HV_{0.1} — measured Vickers microhardness of the cutting edge, using a load of 100gf

PPI— number of particles per image

solid-state carburization, but a slag content as low as 0.04 vol% (in a blacksmiths chisel, Sou 31/1045) raises serious doubts as to whether the steel could possibly have been produced by the same solid-state method as the iron. Indirectly-produced irons typically have slag contents of less than 1 vol%, whilst values of up to 10 vol% or more can be found in directly-produced iron (Rostoker and Dvorak 1990, Piaskowski 1992, Tylecote 1992).

Archaeometallurgists have previously remarked on the high quality of Saxon steel and the disappointing lack of evidence for production processes (Wiemer 1993), and some have proposed a Wootz-type crucible method for Saxon steel production, despite the absence of supporting archaeological evidence (Tylecote 1992: 81). There are other archaeologically-attested processes capable of producing high quality steel, but most utilised crucibles in which carburization and liquation occur, and which leave distinctive residues (Lowe 1989). Such residues have not been recovered from Hamwic (Andrews 1997, Mack 1998, McDonnell in prep). Either the steel was imported from elsewhere, or a different steel-making process was used.

Stock metal and waste

An examination of the stock materials and waste recovered from the Hamwic smithies gave convincing evidence for an alternative production process. Approximately one hundred artefacts from smithing contexts were examined and recorded. Of these 70% could be related to smithing practice—as tools, stock iron, or scrap. Around fifteen artefacts (mostly rods, bars, billets, and bloom fragments) were examined metallographically where metal survived. Many displayed the full range of iron alloys one would expect of a sophisticated Saxon smithy (Table 3). Some however showed microstructures or features wholly unexpected in irons and steels of the period (Mack 1998). The most significant artefacts were a small bar with a rectangular cross-section (Sou 31/1864), a large billet with a square cross-section (Sou 31/2780) and several irregular metallic fragments associated with slag, all from stratigraphically-sealed deposits within the smithies dated to the 8th-9th centuries AD.

Sou 31/1864

The small bar was rectangular-sectioned (20x9mm), was over 50mm long, and weighed 20.3g (Fig 1). The pitted corrosion on the surface of this object was indicative of a steel microstructure prior to sectioning. A small section was removed from one end. Although

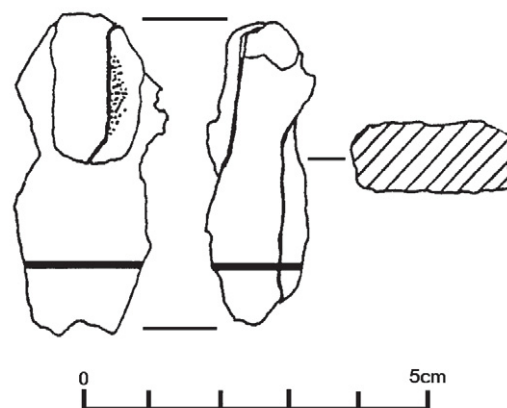


Figure 1: Small rectangular-sectioned bar (Sou 31/1864).

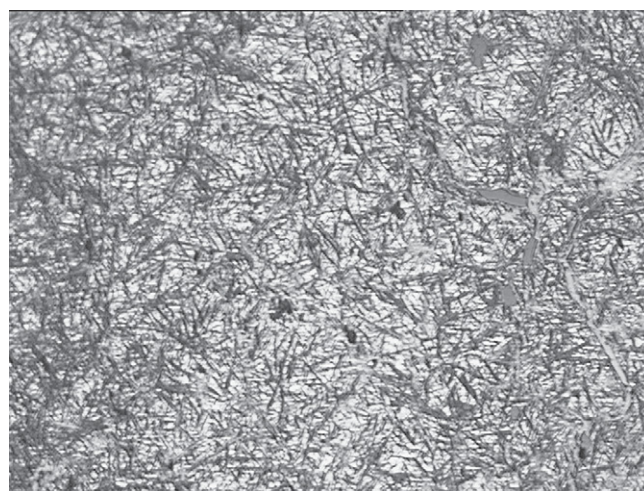


Figure 2: Sou 31/1864. Plate martensite and retained austenite. Width of field 1280µm.

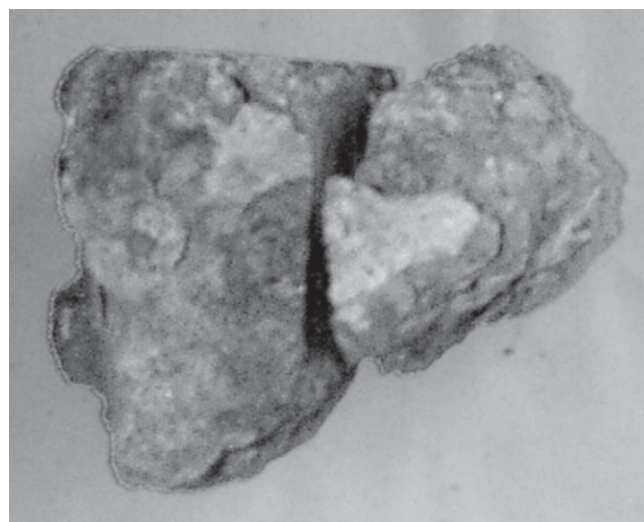


Figure 3: Large billet (Sou 31/2780) with section visible at right side. Width of field 130mm.

Table 3: Stock iron and steel pieces from Hamwic that were metallographically analysed.

Item	SF Number	dimensions (mm)	microstructure
bar	31/1696	19x15x8	piled; ferrite, ferrite+pearlite, phosphoric
bar	31/1864	50x20x9	martensite + retained austenite
strip	31/1869	25x4x1	ferrite with spheroidized carbides
bar	31/2033	62x17x15	no surviving metal
bar	31/2180	80x30x25	phosphoric
plate	31/2032	80x40x1	no surviving metal
bloom	31/2541	50 diam	ferrite and pearlite, <0.3%C
scrap	31/2261	60x15x10	white cast iron + eutectoid steel
billet/ingot	31/2780	100x80x40	pearlite + bainite, solidification features
slag-coated metal, egg-shaped	169/2961	c 50 diam	pearlite + cementite, solidification features
ferritic mass with Fe globules	31/1607	-	FeO-rich slag with oxidized globular Fe inclusions + silicates and glassy phase
slag-coated ferritic lump	31/250	-	highly corroded– no analysis of metal; slag contains much free FeO + iron silicates and glassy matrix – non-diagnostic; silica grains near surface
corroded metal in flat slag plate	31/1929	-	hints of dendritic microstructure surviving in corrosion products; slag– silicate laths in glassy/eutectic groundmass; metallic prills, wustite and silica grains present.
bloom/scrap	31/1795	-	severely corroded
flat slag plate	169/952	-	three sections examined: centre of plate– typical ironworking slag components; upper and basal surfaces– quartz grains degrading to silica-rich slag matrix; no metallic prills
slaggy lump	169/3731	-	surface– coated in fused silica grains, quartz; core – banded Fe corrosion products, small areas of slag as above and patches of surviving metal; no metallography possible
slaggy lump	24/865	-	silicate laths and free FeO (wustite) in glassy matrix; some islands of dendritic metal present, but too small to analyse due to substantial corrosion
slaggy lump	31/251	-	surfaces– fused silica grains in iron corrosion products; core– complex microstructure of varying corrosion products; no metallography possible

Where no dimensions are given, artefacts were fractured prior to analysis

the exterior of the bar had suffered severe corrosion, there was considerable metal surviving towards the centre. The bar was examined using optical microscopy over an entire 8x20mm transverse section. The bar had a total slag content of less than 1 vol% and in the etched condition was revealed as a hardened steel with an *estimated* carbon content in excess of 1% and a structure of plate martensite and retained austenite (Fig 2). The carbon was evenly distributed with no variation in microstructure except a slight tempering near one edge.

The small slag inclusions consisted of a single-phase matrix of glassy slag with very few tiny metallic prills. As with the finished artefacts, the low slag content and structural homogeneity suggested a liquid process, but no obvious solidification features could be seen.

Sou 31/2780

The large billet measured 100x80x40mm and weighed over 600g (Fig 3). The microstructure was examined



Figure 4: Sou 31/2780. Fine pearlite and bainite with grain boundary cementite indicating 0.8-1.2% carbon. Width of field 1280 μ m.

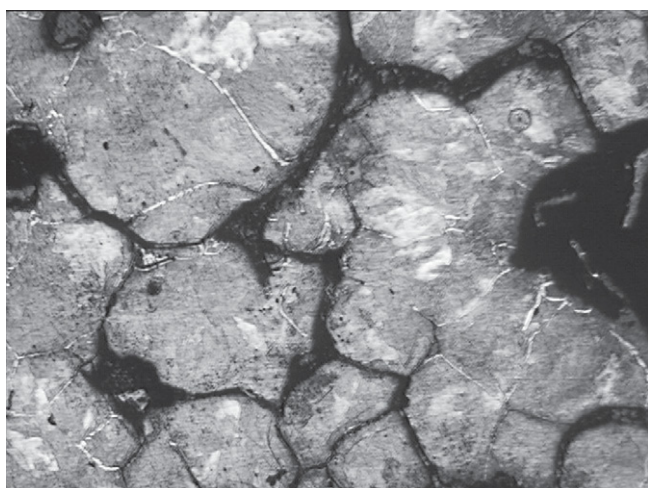


Figure 5: Sou 31/2780. Rounded former austenite grains, interpreted as localized grain boundary melting. Width of field 1280 μ m.

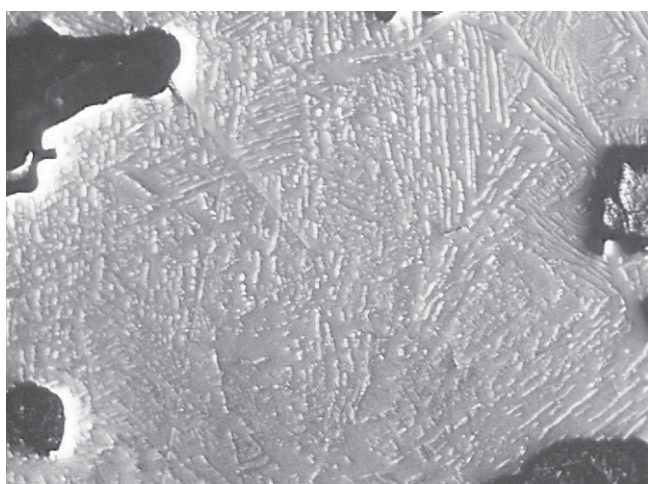


Figure 6: Sou 31/2780. Dendritic structure revealed by etching in Stead's reagent. Width of field 1280 μ m.

by optical microscopy over a complete transverse section. When etched in nital it was shown to be an air-cooled steel, almost the whole cross-section having a uniform large-grained structure of fine pearlite and bainite, with grain boundary cementite indicating 0.8-1.2%C (Fig 4). At the surfaces decarburization to a depth of a few millimetres had reduced the carbon content to under 0.2%. There were no visible slag inclusions in the metal matrix and no weld lines, but numerous sub-spherical voids scattered randomly throughout the metal were interpreted as solidification shrinkage voids. The absence of slag in these voids, and elsewhere, confirms that these voids were not those seen in iron blooms, where they result from incomplete consolidation. Furthermore it seems unlikely that a carbon content in excess of 1% at the centre of this large unwelded billet could have been achieved by the solid state process of pack carburisation. There were rounded former austenite grains in some high-carbon areas, which could be interpreted as localized grain boundary melting due to overheating (Fig 5). The surface decarburization shows that the billet had been exposed to an oxidizing atmosphere for some considerable time at a high temperature, but whether this heat-treatment was part of the original steel-making process or a distinct secondary process cannot be determined.

The absence of any flattening of the shrinkage voids indicates that no substantial hot working had been attempted, however pancake-shaped ferrite grains at the surface proved that it had been hammered when cold. Re-polishing and etching in Stead's reagent revealed a dendritic structure in some areas (Fig 6). Although not visible across the entire section, when taken in conjunction with the probable shrinkage voids and high level of carbon throughout, it provided supporting evidence that the billet was a piece of high-carbon steel made from a melt.

Sou 169/2961

Other material from the Hamwic smithies was in the form of small irregular slag-coated fragments of metallic waste, ranging in size from 20-100mm. Ten of these were sectioned for examination by optical microscopy. Most were severely corroded and contained no surviving metal, however two of these fragments were largely intact.

Sou 169/2961 was an egg-shaped fragment, around 50mm in diameter normal to the long axis (Fig 7). A half-section, cut through that plane, showed a homogeneous steel microstructure in the form of fine

pearlite with grain boundary and needle cementite, indicating around 1.5%C (Fig 8). No slag was visible within the metal matrix, and an apparent slag 'coating' on the surface was an oxidised layer. The numerous voids were identical to those seen in the large billet. At some grain boundaries were patches of a light-etching eutectic structure. Although similar to steadite, the phosphide eutectic, SEM-EDS analysis did not detect phosphorus or other possible alloying elements (for $Z > 11$).

Sou 31/2261

The other fragment was a small elliptical flake of metal about 60mm long, 10mm across, and weighing 39g, which appeared to have been broken from a larger piece (Fig 9). The surface had traces of a slag coating. A complete cross-section was examined, on which the



Figure 7: Egg-shaped fragment (Sou 169/2961).

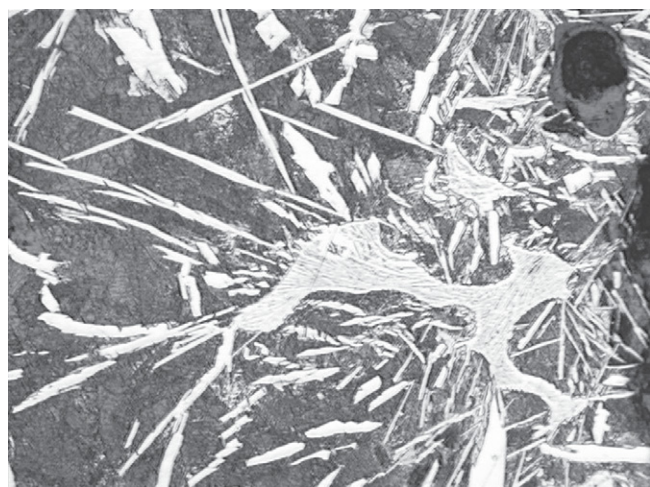


Figure 8: Sou 169/2961. Fine pearlite with grain boundary and needle cementite indicating around 1.5% carbon. Width of field 640 μ m.

fracture surface and two of the original edges could be seen. This was examined under optical and scanning electron microscopy with EDS analysis. Between the external corrosion layers and the original surface of the object was a thin band of predominantly glassy slag (Fig 10). When analysed it was found to have about 60% SiO_2 and 8-18% FeO , with the remainder mostly K_2O . Typically, the glass phase in slags deriving from bloomery smelting has approximately 40% SiO_2 and 25% FeO (McDonnell 1986). The blast furnace produces a glassy slag which has about 50-55% SiO_2 and 5-10% FeO (McDonnell 1997) similar to the slag on this fragment. This slag was identical in microstructural appearance to that seen in the steel bars

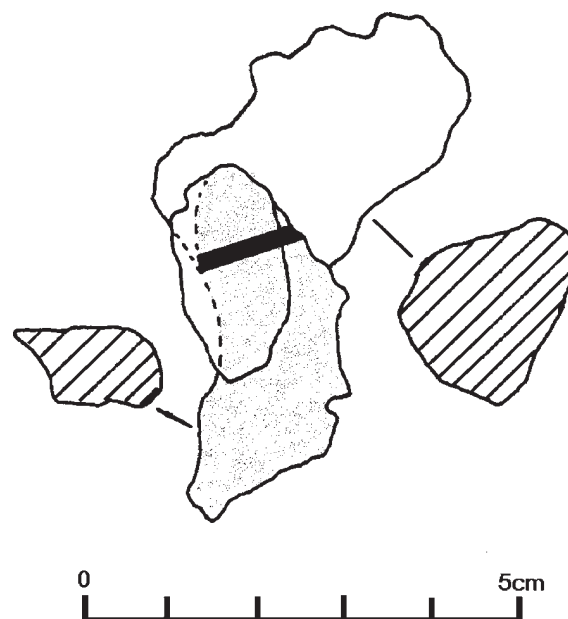


Figure 9: Fragment (Sou 31/2261) showing elliptical flake of metal (shaded).

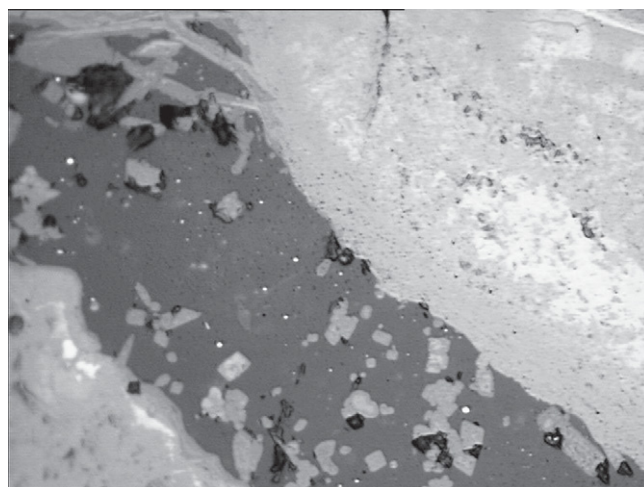


Figure 10: Sou 31/2261. Band of glassy slag between external corrosion (to the left) and the original surface of the metal (to the right). Width of field 320 μ m.

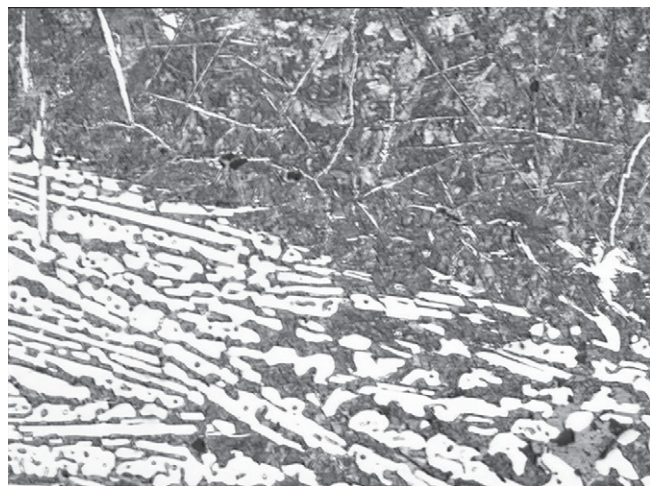


Figure 11: Sou 31/2261. Interface between white cast iron (below left) and eutectoid steel (upper right). Width of field 1280μm.

and some finished steel edges where the inclusions were too small to accurately analyse.

The surface of the fragment, up to a depth of around 5mm, was composed of partially dendritic but predominantly cellular white cast iron, with an apparent carbon equivalent of approximately 3.5-4.0% (Fig 11). This region had a classic cast structure of primary austenitic dendrites and interdendritic and cellular ledeburite, which had decomposed on cooling into pearlite and lamellar cementite. No graphite was present. Microhardness measurements in this region gave values of over 1000HV. The underlying core of the fragment, as far as the fractured surface, was a pore-free steel ($c0.9\%C$) in the form of large grains containing pearlite and bainite, with some small films of intergranular cementite. The interface between the surface and core zones was marked, with numerous needles of cementite protruding from the cast iron into the pearlite/bainite grains. The manganese and silicon contents of the cast iron were at or below detectable limits (SEM-EDS).

Discussion

These high-carbon steels and fragments of cast iron, if recovered from a smelting site, could be regarded as accidental, but such material at a smithy site suggests a deliberate utilization of these materials and thus evidence for steel production at Hamwic, possibly in the small pits which were excavated there. The metallurgical features show that white cast iron was involved in the production of the steel: the elliptical flake (Sou 31/2261) was undoubtedly a piece of near-eutectoid steel attached to white cast iron, and its slags

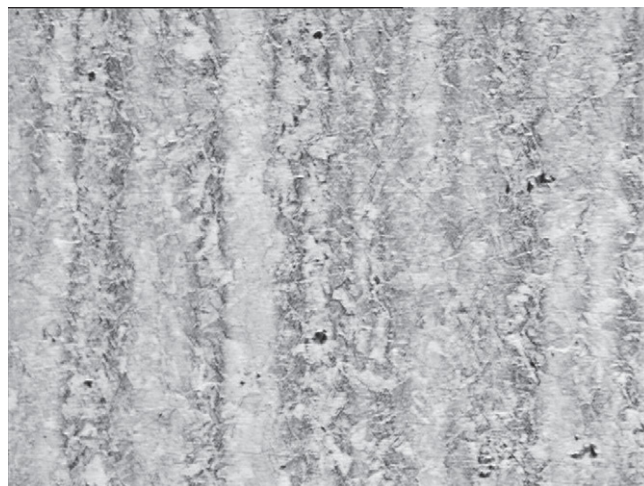


Figure 12: Sou 31/1045. Distorted dendritic structure revealed by etching in Steads' reagent. Width of field 640μm.

were not typical of bloomery material. In view of this association the anomalous solidification structures in the egg-shaped fragment (Sou 169/2961) may be interpreted as interdendritic pools of white cast iron with near-eutectic composition (4.3% C).

A possible interpretation of these findings is that the cast iron was an imported feedstock for a steel-making process, and that a liquid-state decarburization process made high-carbon steel from it. To do this the white cast iron would have to be melted by heating to over 1150°C, a temperature readily attainable in the open hearth, then decarburized at more or less constant temperature either by mixing in low-carbon bloomery iron or by exposure to an oxidizing medium. The first, the co-fusion process, was a quick and effective carburizing process for low carbon iron (Rehder 1989). The resulting microstructures are very similar to those seen in the elliptical flake (Sou31/2261), with the white cast iron representing solidified liquid and the steel the carburized stock. However, unless the resulting steel were melted it would have retained its high slag content, and since all the materials studied were very clean it is possible to rule out this process.

The alternative process, decarburization of liquid cast iron, can be done in two ways. In one an oxidizing slag bath is used, as in the medieval fining process, but this possibility can also be discarded as it would have produced distinctive finery slags (which have not been recovered from Hamwic), and would have introduced large amounts of slag into the metal.

In the other process, an oxidizing air blast is directed at the liquid cast iron to burn away some carbon as

carbon dioxide, and if carried out at near-constant temperature this steel-making process has some distinctive features due to the effect of carbon content on the solidification temperatures. Consideration of the Fe-C phase diagram shows that when molten eutectic cast iron is decarburized at a temperature just above the eutectic temperature, solidification starts almost immediately with the formation of austenite, and proceeds to completion when the overall composition of the alloy reaches about 2.0%C. Unlike the normal solidification of a casting, freezing takes place at constant temperature and a solid phase with a uniform carbon content is formed. The advantage of this process is that it ends at a certain carbon level determined by the chosen temperature, for example 1200°C would produce a steel with 1.5%C and 1340°C about 1%C. This makes the carbon level in the finished steel controllable, though the higher temperatures might be difficult to achieve in practice.

In a real process, the solids would form at the liquid surface where the oxygen potential was highest, and either sink to the bottom or be suspended in the melt. A rough calculation of the density of austenite at 1200°C gives a value of 7310kg/m³, compared with the measured value of 7200kg/m³ for liquid cast iron at the same temperature (Angus 1976: 112). The small difference in density is not significant in relation to the uncertainties in the calculation, so it is not certain that the solids would sink. Whether suspended or sunk, agglomeration of the austenitic solids would take place to form pieces of steel of usable size, and could be removed from the melt or oxidation continued to near completion of solidification. In either case some small pools of remnant eutectic liquid could be retained in interdendritic spaces, and gas porosity and shrinkage voids would also be expected in the final product. Porosity in the product could be closed by subsequent forging, and the resulting steel should have a homogeneous carbon content in the range of 1-1.5%C, and be virtually free of slag—properties seen in the stock steel bars described above and the edged tools from Hamwic. Although ideal for producing hard quenchable cutting edges, working this material would have required a considerable degree of smithing skill.

The source of the cast iron was probably the ordinary bloomery furnace, for cast iron can be produced in such a furnace in varying quantities dependant upon operating conditions (Pleiner 1968, Tylecote 1987 and 1992, Rehder 1999). Cast iron has been recovered from several pre-medieval contexts, and has been assumed to be accidentally-produced waste (Pleiner 1968,

Tylecote 1971), but we consider that these fragments reported here represent several stages in a liquid decarburization procedure, from white cast iron to hyper-eutectoid steel bar.

Some of the edged tools were re-examined in the light of this interpretation. When etched in Stead's reagent, the blacksmith's chisel mentioned above (Sou 31/1045) displayed a distorted dendritic structure typical of solidification and subsequent forging, the first evidence for cast microstructures in finished artefacts of this period (Fig 12).

Recent work in northern Italy has provided evidence that deliberate decarburization of bloomery-derived cast iron into high carbon steels may have occurred from the late Roman/early medieval period (Cuccini Tizzoni 1999, Fluzin 1999). Thus, the process inferred here may represent a technology that was used at a low level throughout history in many localities, until the evolution of the blast furnace in the later medieval period enabled this technology to be turned to bulk iron production.

Conclusions

A metallographic study of Hamwic artefacts revealed the presence of homogenous, slag-free, steels amongst smithy debris. These are identified as stock materials, which represent stages in the production of high-quality high-carbon steel for subsequent smithing operations. Some showed remnant as-cast microstructures and microstructures derived from as-cast structures following subsequent heat treatments. It is argued that the steels had been produced by refining of cast irons, and were used in making edged artefacts in Saxon Southampton in the 8th-9th centuries AD.

Traditional understanding views the introduction of the blast furnace into medieval Britain from a diffusionist standpoint, relying on hypothetical transmission of the technology from China to Western Europe. The evidence presented here would support the regional evolution of a technology utilizing cast iron from a low (possibly undetectable) level prior to the medieval period, into the major method of producing iron in the last half millennium. Small quantities of cast iron are known to have been produced in the bloomery furnace. With the gradual evolution of the smelting furnace from bloomery to high bloomery to blast furnace, the decarburization of cast iron became a more economical method of producing iron and steel in increasing quantities.

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