Evaluation of metalworking residues from Bridgetown Priory, Co. Cork (98E0377)

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Mitchelstown
28^{th} August 2011

Content

1. The archaeology of bloomery iron production

a) The bloomery process

Iron can be extracted from its ores using one of two processes, the direct process where a solid iron bloom is produced or the indirect process where liquid iron is made. This last process is carried out in the blast furnace and does not concern us here.

Iron occurs in various forms in nature, usually combined with other elements to form ores. Some of these ores need to be roasted to removed unwanted chemical elements and excess water. When the ore is ready for smelting, it will still contain a substantial amount of gangue (typically quartz or limestone based) which has to be removed. At the same time the iron oxides have to be reduced to pure iron. Generally, a clay based furnace is filled and replenished with alternating layers of the prepared ore and charcoal and heated to temperatures of 1250-1400º C and higher (Pleiner 2000:133-136). It is assumed that the furnace would have been preheated to reduce the loss of heat through the furnace wall (de Rijk 2003:16). During smelting the carbon from the charcoal will gradually take up the oxygen from the iron oxides. Most of this free iron will form into a bloom under or next to the oxidisation zone inside the furnace. The rest of the iron will combine with the molten gangue to form slag, which percolates through the bloom and solidifies at the base of, next to or in a pit under the furnace. Some of the clay from the furnace wall and/or the tuyeres will also contribute to the chemical make-up of the slag.

After the smelting the bloom is to be removed from the furnace. This bloom, however, will still contain a substantial amount of slag, which needs to be removed. This process, called refining, was undertaken at about 1200º C, the smelting temperature of slag (Tylecote 1987:248-249) and would be accompanied by regular hammering, leading to a consolidated bloom or billet. Refining can take place at the smelting or at the smithing site and will result in the formation of refining slag.

The now consolidated bloom would next be transformed into an object by smithing, which encompasses a wide range of activities involving both cold and hot working. Removing and, especially, adding carbon to iron would have been of major importance: iron with a carbon content higher than 0.2 % (steel) will become harder and stronger, but also more brittle. Gansum (2004) suggests the use of bone as an agent for the uptake of carbon during the smithing process.

b) Material remains

Furnaces

A vast body of iron smelting furnaces has been excavated to date. H. H. Coghlan (1956:86) was one of the first to propose a classification, which he based on morphological, combined with technological, criteria. He distinguished the bowl furnace, the domed furnace and the shaft furnace, with distinctions made between furnaces using natural draught and those using forced draught. Next, H. Cleere (1972) would suggest a typology using the availability of slag tapping facilities as a main criteria, followed by the draught supply. This author included the pit furnace with the bowl furnace as non-slag-tapping, while remarking that in some cases the pit furnace can be seen as a slag-tapping furnace (ibid.:23). R. F. Tylecote (1973) distinguished between bowl and shaft furnaces, based on the ratio difference between height and width; both types could be slag-tapping or not. In the following years several authors would propose variation on these classifications (Martens 1978b, 1978a; Pelet 1976; Pleiner 1978; Serning 1978) with I. Martens and I. Serning arguing for accepting the formation of the slag blocks at the base of the pit furnace as the result of slag tapping, in this case under the furnace as opposed to from the side. The latter view is now

widely accepted (see for example Serneels et al. 2000:105; de Rijk 2003:17; Leroy and Merluzzo 2004:64-65; Bayley et al. 2001:11), although some authors still regard the pit furnace as a developed bowl furnace, i.e. non-slag tapping (Pleiner 2000:149,152). The bowl furnace proper (non-slag tapping, with or without a superstructure) has silently, if not completely, disappeared from the recent archaeological record. Older examples of features describes as bowl furnaces have since then been described as bases of shaft furnaces (Clough 1992:183; Buchwald 2008:43) or as basal pits of pit furnaces (Young 2005:2). Recently, only furnaces from Kenya using exceptionally rich magnetite sands as ore have been described as bowl furnaces (Iles and Martinón-Torres 2009), but even here, due to the limited amount of slag produced, the bowl can be seen as a small slag collecting pit. The shaft furnace, i.e. a bloomery with lateral slag removal, can take many forms from low-shaft furnaces (shaft is less than 1.2 m) to domed furnaces. Some shaft furnaces are built in a natural slope or at the side of man-made hollow. The use of furnaces using a pit as a receptacle for the slag, seem to be very closely, but not completely, related to the occurrence of bog ores (de Rijk 2003:61). Some pit furnaces had thin-walled, mobile shafts which could be used several times, such as the near complete example from Scharmbeck in Northern Germany (Pleiner 2000:159).
In Ireland, both during the Iron Age and Early Medieval times, the pit furnace seems to have been the dominant type of furnace used (Young 2003). Evidence for the following Hiberno-Scandinavian period shows the occurrence of shaft furnaces with slag tapping (Young 2006; Dowd and Fairburn 2005). The late medieval period, then, is represented by only a few sites interpreted as connected to iron smelting, mostly showing a-typical furnace types (See for example Addyman 1965; Kiely and O'Callaghan 2003).

Smithing installations

As the colour of the flame inside a smithing hearth is a good indication of the temperature, smithing areas are often covered as to provide shade. Early smithing was carried out at ground level and is characterised by pits of varying sizes and shapes and burnt surfaces. Ground level smithing hearths can be (partially) lined with a clay or stone wall to control the internal environment. This way of smithing survived until late medieval times, as shown by illustrations in manuscripts (Tylecote 1981:44). From Roman times at least, smithing was also carried out at waist level (ibid. 1986:163). This became the norm during the later middle ages in northern Europe.

Slag

Slag is the vitreous substance that forms during heat-related metallurgical processes. It will nearly always contain some of the metal involved, together with other elements derived from the gangue, clay structures or implements, the fuel and substances added during the process. Some vitrification can occur during roasting but the temperatures used (200 – 800º C) will normally not lead to the formation of actual slag (Maréchal 1992:38).
In the bloomery furnace, the material that does not become part of the bloom will form as slag (Crew 1995). The slag which leaves the furnace will show, after cooling down and solidifying, a flow pattern, which sometimes indicates the direction of the slag flow: from vertical (pit furnace) to horizontal (slag raked out of a shaft furnace). A portion of the bloomery furnace slag, which is generally lighter and sometimes called 'fuel ash slag', will form in the hottest, oxidising zones of the furnace, i.e. under the air inlets. The clay on inside of the furnace wall and/or the tuyeres can also become heavily vitrified. There is still no consensus as to the amount of slag resulting from a single smelting operation. It is generally thought that the slag produced is in the region of three to five times the amount of (unconsolidated) bloom, but ratio's possibly as high as 20:1 have been put forward (Crew and Crew 1996:48-50). Slag from pit furnaces which are used multiple times can accumulate into large (up to 400 kg) slag blocks, which are often preserved in situ. As the pit below the furnace is filled with organic material, the slag blocks can retain impressions of the filling material (Henriksen 2002; Mikkelsen 2003). In shaft furnaces the slag leaving the furnace at the

side solidifies showing a ropey lava-like structure on the upper face. If the base of the hearth in a lateral tapping furnace is lower than the base of the tapping hole, slag can cool at the base of the furnace and form so-called 'furnace bottoms'. After smelting the slag remaining in the bloom is removed and cleaned by hot hammering, leading to the formation of refining slag (see above). This type of slag has proven difficult to characterize because of the closeness of its chemistry to that of smelting slag and its shape to that of furnace bottoms and SHC's (see below)(Fluzin et al. 2004:163; Pleiner 2000:255).
Smithing slag forms during the heat related smithing processes such as object manufacture and repair, welding, carburization, etc. It is made up of iron lost from the object/bloom, clay from smithing hearth walls and tuyeres and materials added (fluxes). The typical slag formed in the smithing (charcoal fired) hearth is the Smithing Hearth Cake (SHC): a bun-shaped lump of slag of varying density and appearance. It is this material, especially the larger examples, which were often labelled 'furnace bottoms' and, in combination with shallow pits connected with metalworking, interpreted as resulting from iron smelting in a bowl furnace.
The waste produced in a (bloom)smithy also includes hammerscale, small magnetic globules or flakes of magnetic slag-like material which forms as a result of welding or the striking of hot iron/ bloom (Dungworth and Wilkes 2009).

Technical ceramics

Tuyeres are ceramic or metal implements to protect the wooden bellow ends against the heat from the furnace or the smithy (Pleiner 2000:196-212). The shape of tuyeres can vary widely: conical, cylindrical or rectangular.
The use of multiple tuyeres in smelting furnaces is often encountered and some block tuyeres are constructed to channel the air of two tuyeres. Furnaces operating without tuyeres will have small openings ('blow-holes') for inserting the bellow ends. From at least the late medieval period onwards, iron tuyeres were used in bloomery iron smelting furnaces (Overbeck et al. 2007:38), these would become common with the development of the blast furnace and are still in use today.
Next to various types of tuyeres connected with smithing, there are also known, especially if not exclusively, in Scandinavia and Northern Germany, clay or stone heat shields (*Essestein*) with holes for air supply into the hearth (de Rijk 2003:76, 79).

2. Metalworking residues at Bridgetown Priory

Excavations of a trench on the western side of the north-west corner of Bridgetown Priory revealed a layer rich in iron slag (Cotter 1998). This layer (F17) was situated on top of a wall (F24) which was part of an annex built against the priory wall and interpreted as post-dating the Dissolution of the priory in the 16th century, although the western part of F24, above which the metalworking remains were found, could have been part of the original building (ibid.:6). In total 683 g of metalworking residues were retrieved (See Catalogue). The collection consist of two types of slag (dense rusty brown (Fig. 1) and frothy with various colours (Fig. 2)) and several pieces of vitrified ceramic material (Fig.3). The two types of slag are consistent with smithing residue assemblages from other sites, with the denser material interpreted as forming under the metal ('Smithing Hearth Cakes') and the lighter material closer to the source of oxygen ('Fuel Ash Slag') (Young 2010; Rondelez 2011). Also at Bridgetown, the slag adhering to the vitrified material resembles much closer the less dense slag material. This ceramic material reminds of fragments of vitrified tuyeres, and the probable indication of a blowhole on one of the pieces would also point in this direction. The fuel used was charcoal.

3. Conclusions

The assemblage found at Bridgetown represents fairly typical remains connected with blacksmithing using charcoal. The material was not found in association to any features connected with metalworking or any iron finds which could give some indications of the technology used or the products made. The smithing activities could be connected to a phase of construction, renovation or dismantling, when iron was needed or recuperated. Alternatively, one of the buildings belonging to the owner of the complex after the Dissolution could have functioned as a forge supplying iron for agricultural or other uses.

4. Figures

Fig. 1 Dense slag

Fig. 2 Frothy slag

Fig. 3 Probable tuyere fragments

5. Descriptive catalogue (all pieces belong to find 8, F17)

Amount	Weight (g)	Dimensions (mm)	Description
1	119	94 x 59 x 27	Elongated Smithing Hearth Cake, rusty brown al round with crystallisation (presumably fayalite) on the upper surface and some flow structure on the lower part. Relatively dense material with imprints of charcoal on both sides.
8	166	(max) 53 x 40 x 39	Relatively dense pieces of slag ranging from brown-grey to rusty brown in colour. Five fractured pieces shown shiny, near metallic internal material. Frequent imprints of charcoal and occasional inclusions of rounded quartz fragments.
14	312	(max) 81 x 55 x 33	Markedly lighter material, ranging from reddish black to mid-grey in colour which is both dull and shiny. Frequent inclusions of rounded quartz fragments and occasionally larger stones/pebbles. This material has a distinctive frothy appearance and in the rare cases where fractures are visible, the internal material is dull mid-grey. Occasional imprints of charcoal.
4	86	(max) 70 x 42 x 27	Fragments of vitrified clay material. The clay has a high sand content and contains frequent smaller and larger pieces of rounded quartz. The colour ranges from reddish brown to dark grey/ black, from the interior towards the exterior. The externally adhering slag ranges from mid-brown to black and is both shiny and dull in appearance. The larger piece shows the vitrification continuing towards the interior in one place, a probable indication of a blowhole.

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