Evaluation of metalworking residues from Jerpoint Abbey, Co. Kilkenny (04 E 1512 ext.)

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12 June 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 situation for the following late medieval period with the few sites interpreted as iron smelting sites showing a-typical furnaces (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 Jerpoint Abbey

The metalworking residues from Jerpoint Abbey, excavated under license 04 E 1512 ext. are small collection (1781 g) and were mostly found inside the chapter house (Neary 2010). The features connected to the metalworking were tentatively dated to the $14^{th}/15^{th}$ century (ibid., appendix 3: 3). Only two small fragments (40 g) were retrieved from features not containing modern material. The collection as a whole, however, seems very homogenous and does probably represent the debris from the same metalworking phase. The horizontal distribution of the metalworking remains (Fig. 1) shows a concentration around the potential metalworking features and burnt layers. A smaller concentration away from these area's, in the SE corner of the building, could represent a dump of material.

Slag

The slag consists of small fragmented pieces which can be roughly divided into two groups, dense iron rich pieces, which are interpreted as fragments of Smithing Hearth Cakes (SHC's) (Fig. 2) and lighter, silica rich fragments resulting from the vitrification of clayey materials. As nearly all tuyere fragments have similar material adhering (see below), it is more than likely that this is the origin of the lighter type of slag. Strikingly, a signicant proportion of the slag has a strong surface shine, rarely seen on slag from other sites (Fig. 3).

Technical ceramics

Twelve fragments consist of heat-affected clay, most of them have silica rich slag adhering on one side. The clay is generally homogenous with occasional inclusions of angular quartz. Fragments like this from metalworking sites can result from the vitrification of clay lining of the hearth itself or clay walls surrounding the hearth (smithing), furnace walls (smelting) or tuyeres. Tuyeres can be used both on smelting or smithing sites, but in Ireland seem to predominantly if not exclusively used on smithing sites (Young 2009:53). One fragment (S# 2011c) has an unvitrified part surviving below some adhering slag pointing outwards (Fig. 4).

Copper

Two droplets of copper, together with smaller pieces (S# 2024) were retrieved from the centre of the chapterhouse. As they were found in one of the disturbed layers it is not possible to say if these were related to the iron working residues.

3. Conclusions

The metalworking remains from the chapterhouse at Jerpoint Abbey probably represent a single phase of metalworking. The location, type of slag and use of tuyeres all argue strongly for the assemblage to be the result of smithing activity.

Ironworking is rather common inside large buildings. Here only the examples of remains of ironworking in Irish Cistercian abbeys is given. At Duiske about 3.6 kg (8 lb) of slag were found in the northern transept, but without context or dating evidence. Also at Mellifont Abbey, Co. Meath 'furnace bottoms' or pieces of 'iron bloom' were found in the crypt and the cloister area (de Paor et al. 1969:40) and at Tintern abbey, Co. Wexford slag was found in a 13th century drain and in pits contemporary with the dismanteling of the building after the Dissolution (Lynch 2010:79-80, 169-171). Another site, as yet unpublished, at Aghmanister, Timoleague, Co. Cork, had substantial metalworking in the nave of the church belonging to a 12th - 13th century Cistercian monastery, but here the building was probably not in use as a monastery any more when the metalworking took place. Small scale smithing within a religious building, as in any large building, will in most cases be connected to a phase of construction or demolition.

Interesting about Jerpoint Abbey is that it is one of a growing number of late medieval Irish sites were the use of tuyeres is attested, showing either the use of native workers or the adoption of local techniques by the monks. Tuyeres would not have been used for centuries in Britain or on mainland Europe.

4. Figures

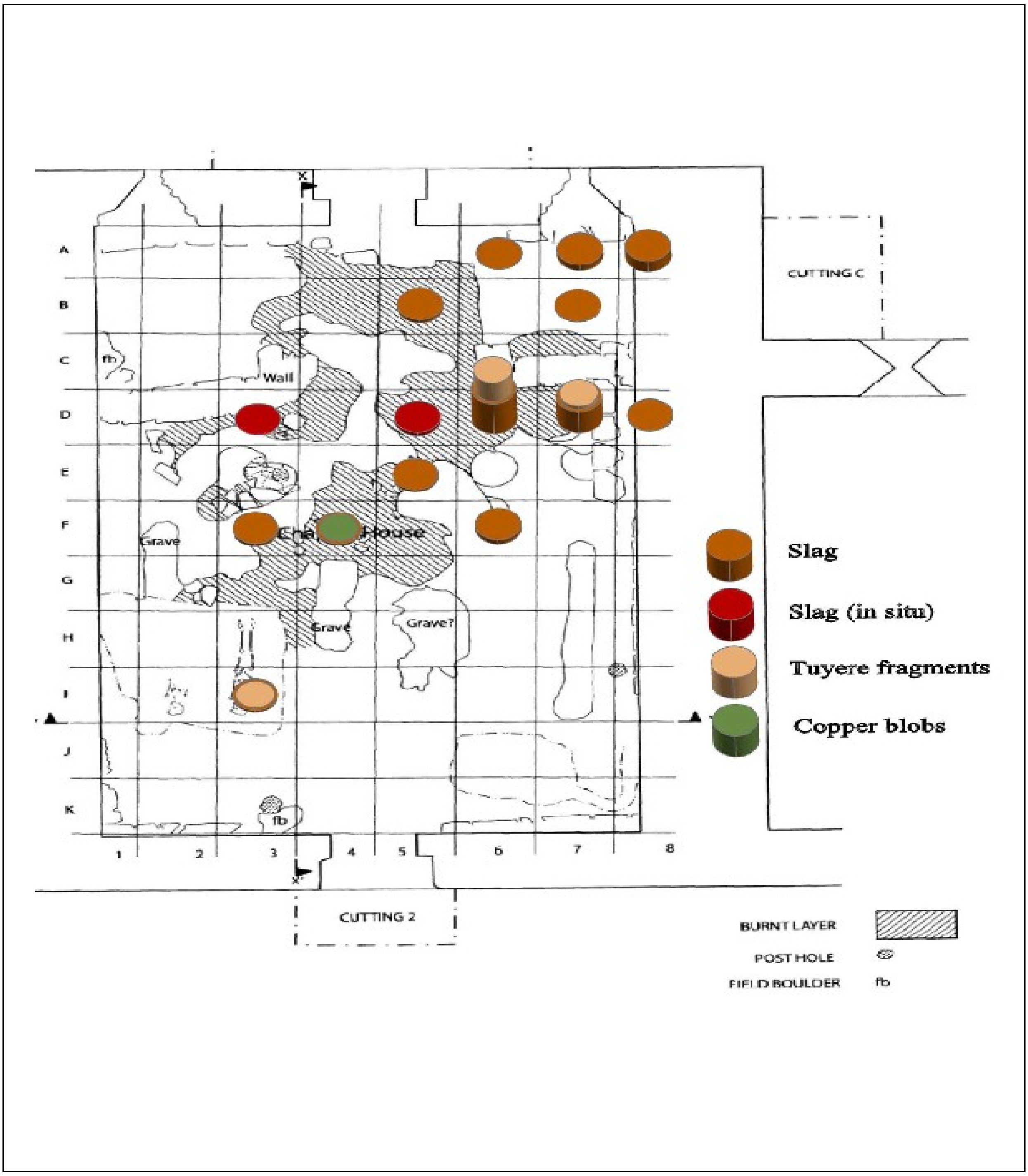

Fig. 1 Horizontal distribution of metalworking residues

Fig. 2 Smithing Hearth Cake

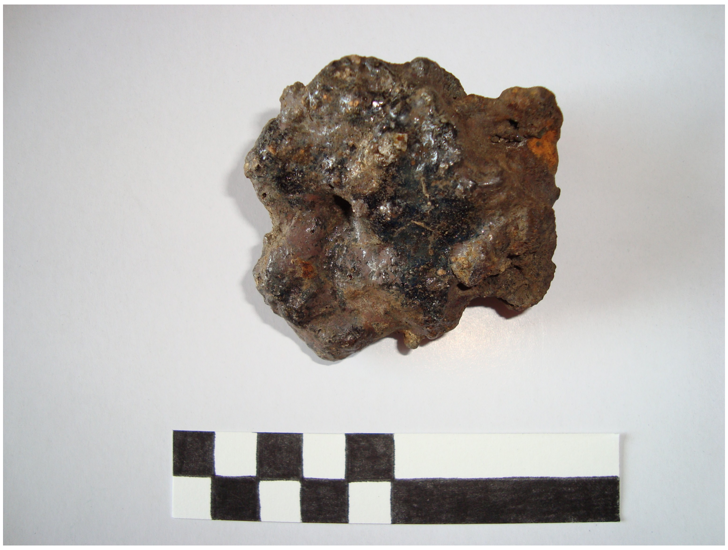

Fig. 3 Smithing Hearth Cake with shiny surface

Fig. 4 Tuyere fragment with slag adhering

5. Descriptive Catalogue

Sample No.	Quadrant	Feature	Weight (g)	Description
2011a	D7	2	209	Two relatively dense smithing hearth cakes, one with a shiny black upper surface
2011b	D7	2	40	Three fragments of reddish to black shiny vitreous material, one containing a flat piece of vitrified stone-like material
2011c	D7	2	39	Four fragments of ceramic material. All have homogeneous orange to red clay without inclusions and are vitrified on the outside. One piece has some unvitrified outer area surviving
2014a	F6	24	10	Two pieces of relatively dense slag, together forming one lobe, brownish black on the upper surface and grey on the base
2014b	F6	24	27	Two fragments of relatively dense slag, both with dull brown to black upper surfaces and shiny black, more vitreous bases
2015	A6	5	20	A fragment of reddish black lobed vitreous slag
2018	F4/F6	7	22	Elongated piece of iron rich slag, rusty on the base
2019	A8	5	122	Four pieces of vitreous material with shiny reddish, black and somewhat metallic patches on the surface
2020	B7	5	13	Lobed piece of black, shiny vitreous material
2021	F3	3	31	Five fragments of iron-rich slag, some with straw-like impressions
2023	E5	1	25	Fragment of relatively dense slag. Dark grey lobes on the upper surface, shiny black vitreous material on the base
2024	B5	4	38	Two pieces of reddish black shiny vitreous material
2025a	D8	2	5	Two small fragmets of brown iron-rich slag
2025b	D8	2	5	Small fragment of brown dull slag with flow structure
2027a	D6	2	230	Nine fragments of relatively dense grey-brown slag with occasional rusty patches. Some pieces possible fragments of SHC's.
2027b	D6	2	127	Twelve fragments of reddish, black shiny, sometimes metallic, vitreous material
2027c	D6	2	220	Seven pieces of ceramic material, all with adhering vitreous slag. Some pieces consist of oxidised (orange) clay, others of reduced (grey) clay, with one piece showing both (oxidised on the inside). The clay is homogeneous with very occasional inclusions of angular quartz.
2034	D5	32	38	Fragment of rusty iron-rich slag, probable part of an SHC
2035	D3	32	2	Small piece of vitreous material
2037a	Spoil	0	48	Possible fragment of small SHC, with charcoal impressions at the base and rusty patches throughout
2037b	Spoil	0	34	Two pieces of black shiny vitreous material, one a complete 'drip'
2037c	Spoil	0	1	Two small pieces of probable oxidised iron
2040	ESBtrench	0	24	Three fragments of reddish black shiny vitreous material, one containing a flat piece of vitrified stone-like material
2041	A7	4	69	
2042	F4	4	8	Several fragments of copperoxides
2045	Dcent	0	146	Rather dense probable fragment of a SHC, charcoal impressions on the base and relatively smooth upper surface
2051	Dr	0	9	Fragment of shiny black vitreous slag with an inclusion of vitrified stone fragment
2053	C6	0	111	Large fragment of dense slag. Heavily rusted upper part and grey tongue shaped lower part protruding on one side

5. Descriptive Catalogue

2059a	I3	4	21	Piece of relatively dense slag with impressions of organic material (charcoal?, but also longer straw-like ones)
2059b	I3	4	2	Small piece of homogeneous orange clay without inclusions, with vitrified outer side
2060a	ESBmanh	0	70	Piece of relatively dense iron-rich slag with some protruding shiny black lobes
2060b	ESBmanh	0	15	Two pieces of probable iron

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