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Assessment of archaeometallurgical residues from the Merthyr Learning Quarter

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Abstract

The archaeometallurgical residues from Ynysfach are of international significance as they represent the first materials from the process known as refining to be identified and investigated. They supplement the physical remains of the refineries discovered on the site and further investigation will provide important new evidence for the implementation of the process.

The refinery process residues are of two classes – slag flows (which appear to contain both dense examples with low vesicularity and very high vesicularity) and microresidues. In practice, slag would have been tapped from the furnaces at a level above that preserved on the site, so there is no opportunity to examine any flows left in a primary location. Refinery slags are, however, present as both unstratified/ex-situ material and as primary flows in the unusual circumstance where those flows have broken through into the underlying drain system. The drain systems also contain large quantities of microresidues derived from the process. These resemble spheroidal hammerscale and are tentatively suggested to result from the intense reaction between the cooling water and the molten slag.

To date, only one fragment of cast iron resembling contemporary descriptions of the product of the refineries has been identified in the collection. Certain identification of this piece requires further analysis.

Identifying the residues associated with the primary smelting at Ynysfach is rather more difficult. The excavated area was founded on a deep make-up layer of blast furnace slag that may, or may not, have actually been produced at Ynysfach. Some blast furnace slag was identified from below a blocking wall in the refinery and was associated with fragments of 'failed' pigs. This is more confidently attributable to Ynysfach, but may not be representative of bulk slag compositions. Other fragments of iron pigs similarly have an uncertain provenance.

Materials certainly derived from outside the immediate site include unstratified examples of fragments of tuyères from Bessemer convertors, pieces of puddling slags and possible examples of steel-making slags.

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Methods

The materials assessed here include residues collected as individual finds during excavation, residues collected as bulk samples during excavation, hand-picked items retrieved as unstratified or from unsealed contexts, together with some items collected and processed as part of the metalwork collection.

All materials were examined visually and recorded to a database. The materials are listed in Tables 1 and 2.

The material has not been subjected to any form of instrumental analysis, so all identifications made here must be regarded as provisional.

This project was undertaken for the Glamorgan-Gwent Archaeological Trust.

Results: nature of the resource

The materials assessed here include 53 items collected as individual finds during excavation, 100 bulk samples recovered during excavation, 59 hand-picked items retrieved as unstratified or from unsealed contexts, together with various items initially collected and processed as part of the metalwork collection (including 3 pieces of tuyère from Bessemer convertors, 5 pieces of slag, 1 piece of possible finers metal, 22 fragments of iron pig and 9 fragments of smaller cast iron flows).

Results: summary of materials

Residues and semi-products from iron smelting

The smelting process is represented by both waste (blast furnace slag) and by the semi-product (iron pigs).

Since much of the site was founded on a make-up layer of blast furnace slag, this material occurs almost throughout. In most cases, the occurrence of residual slag from this deposit cannot be distinguished from slag created during the subsequent operation of the works. It is not known whether the slag deposit was created by importing slag from the main Cyfarthfa works, or whether it presents the waste from the initial operations at Ynysfach. There is also a possibility of slag derived from external sources also being brought onto the site late in its history, alongside the puddling and steel-making residues.

Blast furnace slags are mainly greenish to dark glassy slags, but some are pale and crystalline. Many examples were noted as forming flows 200-300mm in width with a central cavity. Blast furnace slags also occur commonly as fills of gutter-like pieces of cast iron, interpreted as representing the slaggy end of an iron tap.

Pigs were variable in shape, but typically approximately 110mm wide and up to 80mm deep. The pigs are often poorly preserved.

Residues and semi-products from refining

Refining slags are not currently represented in the archaeometallurgical literature, so recognition of these slags is through association with the physical evidence for the refineries.

The drains around the refineries contain two suites of material. One suite includes flows (particularly in c236) which appear to have accidentally leaked down into the drains alongside the troughs. These flows are highly vesicular, with bulbous flow lobes, a dull surface and a grey internal colour. Other isolated particles in the drains of the refinery are smaller slag masses that have a lower degree of vesicularity and are therefore denser. These too are interpreted as refining slags.

These materials allow the recognition amongst the unstratified material of what was probably the more normal appearance of refining slag – that of the thin sheet that would have been formed across the surface of the tapped iron.

Alongside these macro-residues, there is a much larger quantity of microresidues. Most of the drains of the refinery area contain fills rich in spheroidal particles of a grain size of up to about 2mm, but usually much less. Where examined so far, these have proved to be hollow. These resemble a fragile form of spheroidal hammerscale, but the context allows their attribution to the refining process. They may result from spatter from the strong air blast, but are probably more likely to be evolved during the vigorous reaction between the molten slag and cooling water after tapping.

The product of the refinery process was a white cast iron slab that would be broken for transport to the puddling furnaces at Cyfarthfa. Just one single unstratified find resembles the contemporary descriptions of the material, but give the number of broken castings present amongst the unstratified material, further analysis is needed to confirm this identification.

Residues from puddling

The collections include a suite of blocks, hand-picked from the site overburden, illustrating a range of morphologies and textures normally attributed to puddling slags.

Residues from steel-making

The most important residues from steel making are three substantial fragments of the multi-bore tuyères employed in Bessemer convertors.

Some macroscopic slag samples resemble the highly vesicular materials derived from steel-making, but given that some of the refinery slags are also extremely vesicular, further work is needed to determine the origin of these pieces.

Results: distribution of residues

The problem at Ynysfach, as at many industrial sites, is that the nature of the industrial processes does not lend itself to a close association between originating metallurgical structure and its residues. It is fortunate the accidental leakage of the refinery slags into the drains did occur – and this will provide the key to unlocking the remainder of the material.

The distribution of the microresidues from refining is driven by the high volumes of water required – for cooling the furnace, for chilling the casting trough and for spraying onto the top of the tapped materials. Contemporary accounts describe how dirty this made the refinery process and its facilities. Here, we can see evidence for the production of hammerscale-like particles during the chilling operation – and their percolation into the drains along with the run-off.

There is not such close association between the smelting process at Ynysfach and trapping of its waste products. The casting house produced tantalisingly little direct evidence for product or waste. The closest to a connection may be provided by the poor quality pig fragments sealed by an altered wall in the refinery (c179).

Many of the materials (most of the pigs, the puddling slag, the convertor tuyères) are present in unstratified or other later deposits. These may indicate materials dumped on the site late in its history, perhaps during alterations or demolition at Cyfarthfa. These materials are not therefore directly associated with the Ynysfach works, but are important indicators of materials

produced/used at Cyfarthfa, for which little direct information is available.

Assessment of potential & further work

The process of refining developed during the late 18th century, through some very poorly understood stages. The turning point came with the realisation that Cort's dry puddling process, licensed by Crawshay for use at Cyfarthfa in the mid-1780s, could not provide a good quality product from the standard feed of grey cast iron from the blast furnaces (as opposed to the recycled materials it was originally developed for).

The refinery developed out of earlier hearths, with perhaps the key developments being made either by Crawshay at Cyfarthfa, or more likely by Homfray at Penydarren Ironworks, also in Merthyr, in the early 1790s. This development allowed the Merthyr ironworks to adopt the puddling process on a large scale, paving the way for the town to become the leading iron-making centre in the World in the early 19th century. Without refining, this would not have been possible.

The site at Ynysfach and its residues are of international importance and provide the first archaeological account of the refinery process. The site is fortunately preserved by being abandoned at the dawn of the steel-making age in Merthyr, unlike the larger works at Cyfarthfa and Dowlais. Accordingly the residues are deserving of detailed investigation and characterisation.

Contemporary accounts by Percy (1864) and Truran (1865), amongst others, provide a vivid picture of refining as undertaken in the early 19th century, but it is clear they did not fully understand the process. Modern investigation may be able to shed new light on the conversion process.

The key potential for the Ynysfach assemblage is therefore to permit documentation and interpretation of the refining process. Other material present on the site have the potential to assist in this, in a supporting role. The blast furnace slags and iron pigs will assist with understanding the feed for the refinery and the puddling slags will assist with documenting the subsequent use of the refined metal. The various conversion process employed in the 18th and 19th centuries have left a complex range of residues that are poorly understood at present and this assemblage may provide a key to unlocking at least some of them.

Specific recommendations

The key investigations that should be undertaken on the Ynysfach assemblage will be the detailed analysis of the macro- and microscopic residues of the refinery process. A suitably broad range of materials should be analysed to evaluate the full range of the materials.

Analysis of the potential semi-product sample, the possible finers metal, is important to investigate the result of the conversion process. Analysis of the pig iron samples will be necessary to understand the feed material for the refinery. Understanding pig composition would be aided by analysis of the accompanying blast furnace slags.

In addition to the material from the processes undertaken at Ynysfach, the transported puddling slags also provide an opportunity for investigation of the residues from puddling at Cyfarthfa, which, despite Cyfarthfa's importance as one of the earliest and largest puddling operations, have not been previously investigated.

All of these materials will require both elemental analysis (WD-XRF and ICP-MS) as well as microstructural and microanalytical investigations (BSEM and EDS). Although the assemblage is limited in size the full range of morphology of refining slags should be investigated (micro-residues, small dense flows, large vesicular flows, platy flows), with some replicate material. A suite of the accompanying materials (blast furnace slags, pig iron, finers metal, puddling slag) , again with similar techniques and with a degree of replication to establish variability.

As a further component of the analysis phase, full documentation of the early Bessemer convertor tuyères should also be undertaken, through illustration and description. If the detailed analysis of the vesicular slags proves that they were from steel-making, then these should be documented alongside the tuyères.

All the analytical work will require publication in full, to complement the site description.

References

Percy, J., 1864. *Metallurgy: Volume 2, Iron and Steel*. London.

Truran, W. 1865. *The Iron Manufacture of Great Britain Theoretically and Practically considered* , 2nd edition. New York.

Table 1. Summary list of archaeometallurgical residues as finds, by context.

context	description	retention
126	pig fragment with bulbous end, 37kg, 61.5 x 12 x 8cm	retained
126	2kg pig piece, 51.5x11.3 widex 9.2cm deep	retained
126	pig frag 25kg, 61x11.4x7.8cm deep	retained
126	pig fragment 38kg, 74.5x16x8.5cm	retained
126	pig fragment 42kg, 80x11x8cm	retained
126	flowed iron with hollow core, 24.4x 11.7x 1.7cm, possible failed pig fragment	retained
126	five fragments of gutter-like cast iron - probaby casting waste - very heavily mineralised	retained
126	iron corroded with slag mass - small spill?	x
126	slag piece	retained
126	curved slag fragment	x
126	very dense lump of iron with curved base - possibly the end of a pig	retained
126	curved sheet of green glassy BF slag	retained
126	1 small prill of dark glassy slag	retained
126	1 block of granular dark slag with non-wetted surface showing flow lobes	retained
126	3 pieces of grey vesicular slag	retained
159	curved sheet of BF slag , pale green with iron externally, dark glass on concave surface	retained
179	shallow pig fragment 22.1l x 8.3w x 2.6d cm	retained
179	possible small pig fragment, 12.9lx 7.7wx1.8cm, 1kg	retained
179	15.9x6.4x1.9cm, possible pig fragment	retained
179	small fractured poor pig tip, 4kg, 6.3x27.2x 2.1 deep	retained
179	shallow pig fragment 15.8lx9.21wx2.4d	retained
182	sheet or flow of iron in concretion	retained
184	2 pieces of concretion formed almost entirely by spheroids	retained
187	dense dark fine slag prill	retained
190	3 pieces of dark to pale green BF slag	retained
190	1 large block of breccia formed of multitudes of thin slag sheet fragments	retained
191	pig fragment, 19kg, 56x11.5x9cm	x
191	pig fragment, not filled, meniscate top, 11kg, 62x11.5x4.5cm	retained
191	probable BF slag on iron flow	retained
191	brown glassy BF slag	retained
191	dark glassy BF slag	retained
194	fragment of convertor tuyère	retained
194	tapering pig fragment, 12kg, 53.5, maximum x-section 10.5 x 4.5cm	retained
194	shallow pig fragment 3kg, 38cm long, 8cm wide, 2.9cm thick	retained
198	mass of irregular wispy clinker-like slag	retained
198	small flow of clinker-like dark slag	retained
198	2 concretions on possible iron	retained
198	exploded fragment - probably of iron rich BF slag	retained
198	fragment of dense stony slag sheet with large central pore	retained
198	3 pieces of glassy BF slag, one with large central cavity	retained
198	1 piece of coal	retained
237	large block of highly vesicular (frothy) slag	retained
237	dense glassy chilled margin of BF slag block	retained
251	small cast iron runner	retained
251	pale blue/green BF or FAS	retained
252	tip of large pig, 5kg. 8.6cm deep and 11cm width	retained
287	c12 pieces of concretion, most rich in spheroids, one with basal contact on gravel	retained
287	1 piece of concretion with very dense (iron?) clast with curious white coralline surface	retained
287	1 piece of stony pale slag	retained
287	2 pieces of sheet concretion, one heavily haematised	retained
287	1 piece of coal shale	retained
305	sheet of dark vesicular slag 10-15mm thick, not quite planar, dark surface	retained
323	dense piece of concreted sediment formed mostly of spheroids	retained
349	2 small concretionary masses, one rich in coarse hammerscale-like materials	retained

context	description	retention
350	pig fragment, broken both ends 29kg, 60x11x8cm	retained
350	narrow pig fragment with burst out, 73x5x10.5cm	retained
350	20kg pig fragment, 58x11.4x8.2cm, tapering down to rounded end	retained
350	small pig or runner (just possibly sill fragment), 3kg, 26.3x7.5x3.3cm	retained
350	small iron flow	retained
409	2 pieces curved iron in bog ore like matrix - corroded failed pig?	retained
409	thin iron sheet, curved, failed pig?	retained
409	thin iron sheet on base of runner with pale green slag	retained
409	concretion with possible bolt	retained
488	pig section, 33kg, 630mm x 110mm x 80m deep	retained
488	21 kg pig end, strongly tapering	retained
126?	pig fragment	x
refinery area	10cm thick fragment of cast iron in triangular shape, possible finers metal	retained
u/s	lower part of convertor tuyère	in NMW store
u/s	fragment of convertor tuyère	retained
u/s	3 pieces of dark glassy slag	retained
u/s	prill of grey slag broken in two	retained
u/s	fines collection	retained
u/s	21 pieces of vesicular slag, probably refining	retained
u/s	1 large pillow of refining slag	retained
u/s	9 pieces of dense 'puddling' slag	retained
u/s	7 varied BF slags	retained
u/s	1 slaggy pig fragment	retained
u/s	3 vesicular slags - steel/refining	retained
u/s	10 sheet like vesicular slags, possibly refining	retained
u/s	1 stony BF slag	retained
u/s	1 large lobed block	retained
u/s	1 dense, lobed slag flown onto surface of fragmented BF slag and coke	retained

Table 2. Brief summary description of archaeometallurgical bulk samples.
BF = blast furnace, FAS = fuel ash slag, FHS =flake hammerscale

sample	context	notes
13	152	fine fuel residues
16	169	plastic fuel debris with abundant spheroids
17	174	coke and clinker
18	175	brownish sediment with moderately abundant spheroids and concretions
19	177	well sorted, rich in spheroids
24	232	fuel residues? Rusty fragments (slag?), rare spheroids?
25	187	well sorted, rich in spheroids
26	184	almost entirely spheroids and blebs
27	237	dark sediment with abundant spheroids
29	240	grey sediment with white films and lumps, fairly abundant spheroids
30	187	black well sorted residue rich in spheroids
31	243	fine sandy sediment of fuel residues with spheroids
32	247	abundant spheroids and slag fragments
33	239	well sorted spheroids and slag chips
34	244	dark clay with abundant spheroids
35	256	fuel residues
36	258	fuel residues rich in spheroids
37	267	sticky dark clay with spheroids
38	294	fine fuel residues
39	297	fuel residues with spheroids. Bears large concretions
41	298	dark gritty sediment, probably mainly fuel residues, but some spheroids
42	122	large sample dominantly spheroids
43	119/120	dark, slightly concreted sediment with spheroids
46	173	large coke fragments
82	192	sheets of ferricreted dark sediment with some spheroids
95	324	mainly fuel residues, some spheroids
133	348	mainly clay with shale fragments
134	349	laminated sandy sediment
135	361	dark, slightly concreted sediment with spheroids
137	369, 396, 398	fuel residues
145	307	large flow sheet of grey highly vesicular slag
146	307	vesicular pale brown slag fragment
154	377	abundant large spheroids
155	378	grey clay
161	400, 401	fine laminated carbonaceous sediment, sand laminae, rare spheroids
162	402	rich in spheroids
163	400	grey clayey sediment with pale films and some spheroids
165	394	coke in spheroid-rich matrix
178	272	dark grey sediment with dense slag and shale chips
179	409	very rich in spheroids
181	396, 369	mainly fuel residues
187	417	dominantly spheroids
188	343, 418	clayey but rich in spheroids
194	421	dense iron pan concretion - intense mineralisation
235	433	grey sticky gravelly sediment with ?dense slag clasts
243	448	mainly fuel residues
244	448	ferricrete of slag and/or coke
245	444	orange clay and sand bearing grey degraded shale clasts
246	441	fuel residues with rare spheroids
247	443	mainly coarse coke
252	451	mainly fuel residues
253	409, 416	ferricrete of slag - at least some of which is green and glassy
255	452	ashy sediment with some large spheroids
261	489	cemented pale red-brown gritty material - some of grit may be slag
262	490	brown rusty-looking sediment with some spheroids
263	492	concretionary material with iron, sand coal some spheroids and probably some FHS

sample	context	notes
264	493	dark sediment with ?mica , some organics, probably mainly fuel debris?
265	494	mineral sand in dark matrix with fuel residues and possibly some FHS
267	496	iron-rich hard concretions
275	517, 527	concretionary ash-rich material
276	532	reddish brown ashy sediment?
279	528	abundant large spheroids, some dense slag blebs and prills too
281	526	pale brown/buff clay with lumps of coal
282	529	concreted sediment with slag and coke - some of slag has strange siliceous films
283	561	pale grey clay with ash and fuel with apparent stone chips
287	543	fuel residues with slag fragments and some spheroids
289	560	dark glassy slag in fine fuel rich matrix
292	553	small dark gritty sample
293	559	concreted sediments with dark sediment matrix and clinker clasts
294	538	ferricrete possibly on vesicular slag fragment
295	556	brown clay lumps coated in spheroid-rich dark sediment
299	565	mainly fuel residues, some spheroids
303	567	plastic material formed of ash, and fuel particles
304	542	fuel residues
305	515	fuel residues, slag fragments, rare spheroids
307	515	sandy/ashy sediment with rare spheroids
315	581	fragmented dense lobate slag flow - possibly onto iron plate or other planar surface and with spheroids attached
316	577	5 pieces of dense flow lobed rusty slags, locally highly vesicular, often with tubular vesicles
317	579	coarse coke fragments, rare spheroids
318	578	abundant large spheroids
323	582	grey BF slag, one stony, one glassy
none	287	concreted dark sediment with abundant spheroids
none	415	partially concreted sediment- dark- fuel residues?
none	drain trough 5	almost entirely spheroids
none	117	almost entirely spheroids and blebs
none	189	small chip of green glassy BF slag

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