EXCAVATION METHOD FOR A 2.4 M DIAMETER PILOT-SCALE FURNACE

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ABSTRACT

An important part of pilot-scale test work, undertaken with the intention to design and build an industrial-scale furnace, is the evaluation of refractory material performance [1]. Information on the wear of the working refractory lining, obtained during excavation of the pilot-scale furnace, can be used to improve designs in future. Therefore, reliable measurement of the wear profile and accurate sampling of refractory materials, are useful methods to apply. The methods described in this paper address these requirements. As furnace excavations (both pilot- and industrial-scale) often produce the opportunity to study process materials in more detail, a method of encapsulating a large sample of process material in resin, is also described.

Keywords: furnace excavation, refractory, 3D scan, core drill, resin encapsulation, sub-merged arc

INTRODUCTION

In 2016 a pilot-scale study was conducted on the production of high carbon ferro-manganese (HCFeMn) using DC-arc furnace technology operating in sub-merged arc furnace (SAF) mode. The furnace containment system was originally designed for ilmenite smelting trials, conducted in the early 1990's, and consisted of magnesia-based ramming material installed in the hearth, and magnesia bricks installed in a water-cooled shell as the sidewall-lining. Magnesia-based refractory is not suitable for HCFeMn production, due to the corrosive nature of the slag, and carbon-based working linings are typically applied on industrial-scale. The design of the containment system was therefore adapted to install [2] carbon-based cold ramming paste as working lining in the hearth and lower sidewalls of the pilot-scale furnace (A in Fig 1). As back-lining, magnesia-based ramming material in the hearth (B in Fig 1), and magnesia-based refractory bricks on the sidewall (C in Fig 1), was retained. Furthermore, the magnesia-based refractory bricks were extended vertically to form the upper sidewall lining as this part of the furnace would not be exposed to slag.

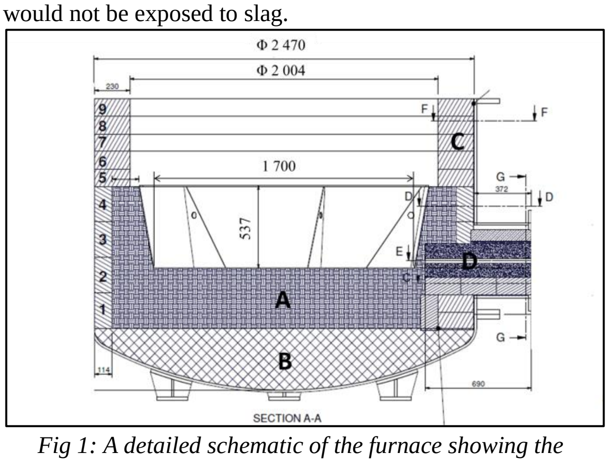

Fig 1: A detailed schematic of the furnace showing the refractory installation and tap-hole detail. A-Carbon-based cold ramming paste, B-Magnesia-based ramming material, C-Magnesia-based bricks, D-Graphite tapblock

The furnace steel shell had an internal diameter of 2 470 mm. After installation, the lower sidewall had a diameter of 1 700 mm in the hearth, and a height of 537 mm. The upper sidewall lining had a height of 570 mm and internal diameter of 2 004 mm. In the past, manual excavation methods, including wear profiling and sampling, were applied. The new methods to excavate and sample the burden, profile refractory wear, and sample the refractory materials developed and implemented after the campaign are described in this paper.

CASTING OF BURDEN

The first step of the excavation was the encapsulation of the tips of the two electrodes inside the burden. The DC-arc furnace operated with two 0.2 m diameter graphite electrodes in sub-merged arc mode. The electrodes had a centre-to-centre spacing of 550 mm and were sub-merged ± 0.3 m (determined by visual inspection) inside the burden. The objective was to encapsulate the sub-merged electrodes inside the burden. Care was taken not to move the electrodes - neither up nor down and neither left nor right - as any movement would adversely affect the study of the burden around the electrode tips. The first step was to secure the electrodes before they were cut off above the burden at a length of 600 mm.

During operation, the electrodes were held in place by large clamps (G in Fig 3) which acted as terminals to apply current to the electrodes. Prior to removal of the clamps, the electrodes were secured by applying an organic composite resin supplied by a South African supplier that typically supplies specialised composite materials to the aerospace, marine, and manufacturing industries. To be suitable, the resin had to be strong enough to contain all process materials (including ore, metal, and slag) but chemically inert to these materials. The resin also had to have a short drying time, colour that contrasted well with the process materials, a low weight-to-strength ratio, be non-toxic, and be durable. To select a suitable resin, laboratory-scale tests were conducted on batches of 30 kg process material to identify a suitable resin.

The brand name of the resin selected was *M1 resin*. The properties of the solid resin are stated in the datasheet [3] as: density of 1500-1800 kg/m^3, compressive strength of 25-30 MPa, bending strength (modulus of rupture) of 50-65 MPa, and a Youngs modulus of 5-6 GPa.

During the planning phase of the project, two options to secure the electrodes were discussed: in the first option, the liquid resin would be pumped around the bottom tips of the electrodes using a system of hoses. The idea was abandoned due to the uncertainty and difficulty of controlling the percolation of liquid resin into the hearth and securing the electrode tips. The second plan, which was eventually implemented, was to first secure the electrodes and then encapsulate the area of interest around the electrodes. This method allowed more control of the flow of liquid resin and ensured that the area of interest was properly encapsulated by the liquid resin.

The resin consists of two individual components, a powder and a liquid binder. The components were mixed at a ratio of 2:1 powder to liquid binder to produce the final liquid resin.

To fix the electrodes, 25 kg of liquid and 50 kg powder were mixed manually using a wooden rod and 50 litre drum. The resin was poured along the base of the electrodes using 5 litre buckets.

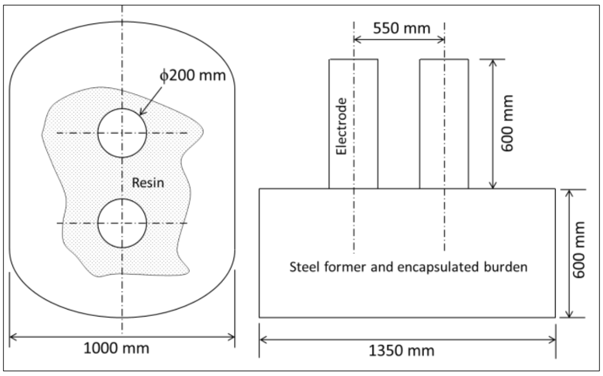

Fig 2: A detailed technical drawing of the electrodes, steel former and the burden removed.

Once the electrodes were secured, the next step of the excavation commenced. A steel former was installed as a containment vessel for the resin and to provide a secure method to remove the encapsulated section from the furnace. The steel former was oval-shaped, 1000 x 1350 mm (see Fig 2), fabricated from mild steel plate, and used to encase the resin while pouring. The steel former had a height of 600 mm and a plate thickness of 10 mm with metal anchors (5 mm in diameter, 200 mm long) welded on the inside to offer support to the resin and burden. Steel flanges with a diameter of 150 mm and 10 mm thick were welded in 4 places to form lifting lugs, used in conjunction with steel chains, to lift and move the former by 5 ton overhead crane (see Fig 4).

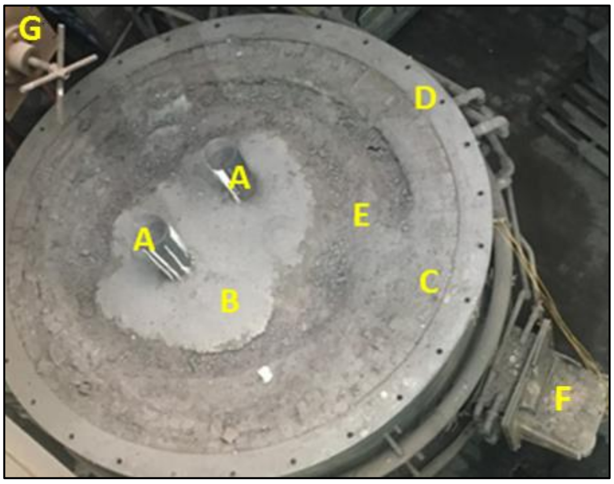

Fig 3: A top view of the furnace showing the cut electrodes and the harden resin which secures the electrode. A-electrodes, B-resin surface, C-refractory lining, D-steel shell, E- burden, F-tapping launder, G-electrode clamp

The next step of the excavation was to install the steel former around the area of interest. As the steel former could only be installed once the process material around the electrodes was dug out, a cavity was dug around the burden which surrounded the electrodes (see Fig 5). This step was carried out using an electric chisel jackhammer and spades to firstly loosen the process material and then remove it. The loosened material was filled into 1 m^3 bags which were removed from the furnace using the overhead crane. The dug out section shown in Fig 5, was the main section of interest i.e. the burden, the electrode tips, and the layers of raw material, slag and metal.

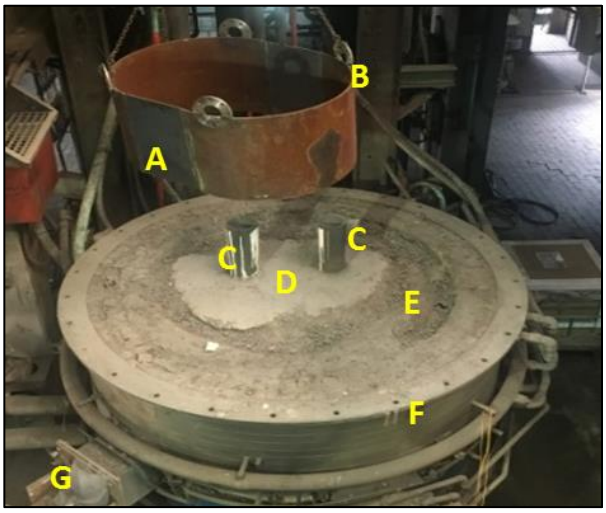

Fig 4: A view showing the steel former was being used to mark the area of interest to be dug around. A-steel former, B-anchor for lifting chains, C-electrodes, D-resin surface, E-burden, F-steel shell, G-tapping launder

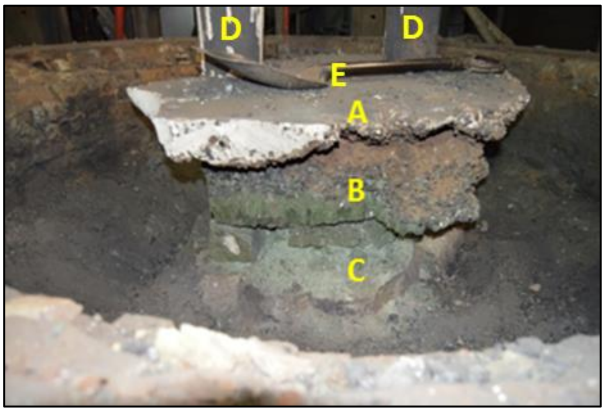

Fig 5: The area of interest which will be encapsulated by the liquid resin. The different layers of solid resin (A), raw material (B), slag and metal are shown (C), electrodes (D) and spade (E).

Once the steel former was installed, the resin could be poured into the steel former. The liquid resin was prepared from 250 kg of powder mixed with liquid in the aforementioned ratio. The liquid resin was poured within 20 minutes of mixing to avoid it from hardening in the mixing container. Therefore, to prepare the resin an electric stirrer rotating at 750 RPM, with 1 m long rod with a mixing blade attached, was used to mix the liquid and powder in a 50 litre drum. Thereafter the liquid resin was poured into the steel former which encapsulated the piece of the burden where the electrodes were sub-merged. As curing of the liquid resin was an exothermic reaction, 3 days were allowed for the resin to cure before any work to remove the encapsulated piece commenced. Once curing was completed, the steel former containing the encapsulated burden and electrodes was removed from the furnace.

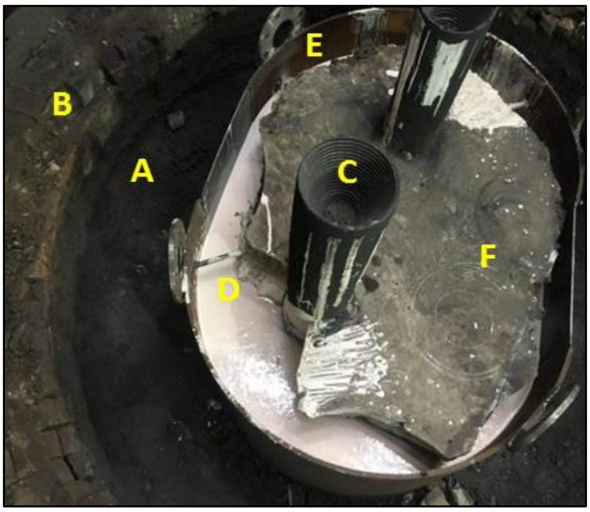

Fig 6: Top view of the encapsulated block showing of A-carbon refractory, B-refractory brick, C-electrodes in position, D-liquid resin contained by the E-steel former, F-resin cast earlier to hold the electrodes

The encapsulated block was dug-out at the bottom of the steel former using electric chisel jackhammer, removed by overhead crane, and stored outside the furnace (see Fig 7).

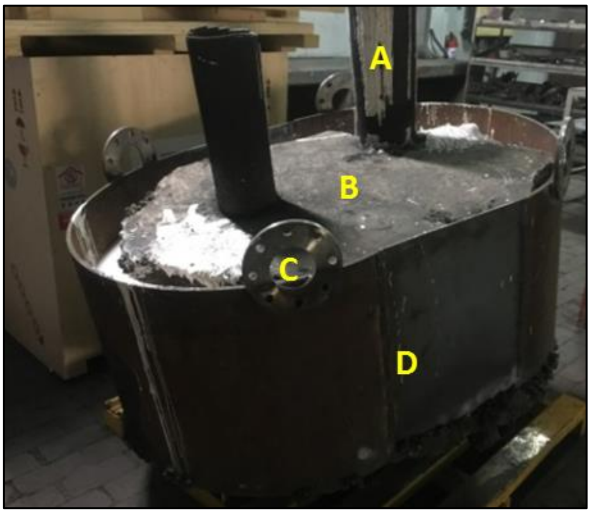

Fig 7: The complete encapsulated block removed from the furnace in a single piece. A-electrodes, B-resin, C-lifting lugs and D-steel former

REMOVAL OF THE BURDEN

In order to reveal the hot face of the carbon-based ramming paste, the remainder of the burden – consisting of slag, metal and un-smelted raw material – was removed. Initially, in order to profile and sample the layers of material in the furnace, only half of the burden was removed – see Fig 8. After profiling and sampling, the remainder of the burden was dug-out, again using the electric chisel jackhammer. Fig 9 shows the last pieces of process material being removed. The hot face of the carbon refractory lining was now exposed in the hearth and on the side walls and the refractory wear could be profiled.

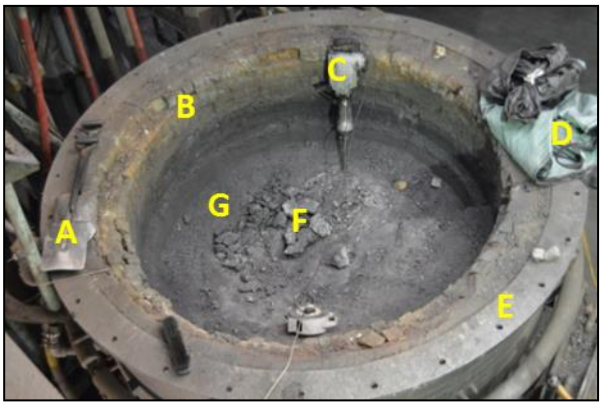

Fig 8: A-spade. B-magnesia bricks, C-electric chisel jack hammer, D-1 m^3 bag for removing material, E-steel shell, F-process material to be removed, G-carbon-based ramming material

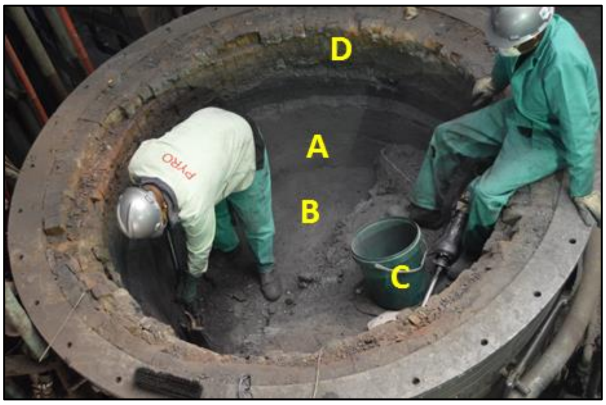

Fig 9: Removal of the burden. A-carbon-based sidewall refractory, B-carbon-based hearth lining, C-bucket for removal of material, D-magnesia bricks

3D SCAN OF THE REFRACTORY WEAR PROFILE

To profile the hot face of the working lining, a 3D scan was carried out by an external company using a Leica HDS6100 ultra-high speed laser scanner [4]. The scanner had to be placed in multiple locations inside the furnace to obtain a complete scanned picture as noted in Figure 10. The 3D scan is converted into 2-D drawings of 12 sections through the wear profile to study areas of highest and least wear in detail. The section that is shown in Fig 11 is the cross section through the taphole. These 2-D drawings of the wear profile were superimposed onto the initial refractory design - see Fig 11 – to identify areas of high wear and of build-up, or lifting, of refractory material.

The high wear areas were the centre of the furnace hearth and the upper parts of the furnace sidewalls (see Fig 11). The centre of the furnace hearth is the most active part of the furnace and the area where the refractory was rammed between steel pins forming part of the electrical system [2]. Due to the nature in which the furnace was operated in submerged arc mode, the upper sidewall refractory was exposed to severe fluctuations in temperature which could have attributed to the wear observed.

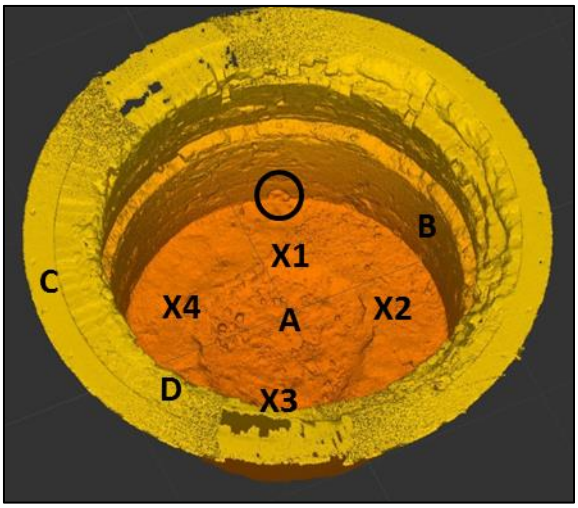

Fig 11: A 3D scan of the furnace after the excavation was completed. The scan shows the wear profile of the furnace in very high detail. A-carbon-based ramming material in the hearth, B-carbon-based ramming material in the sidewall, C-steel shell, D-magnesia bricks, O-the location of the tap-hole, X1-X4 location of core drilled samples.

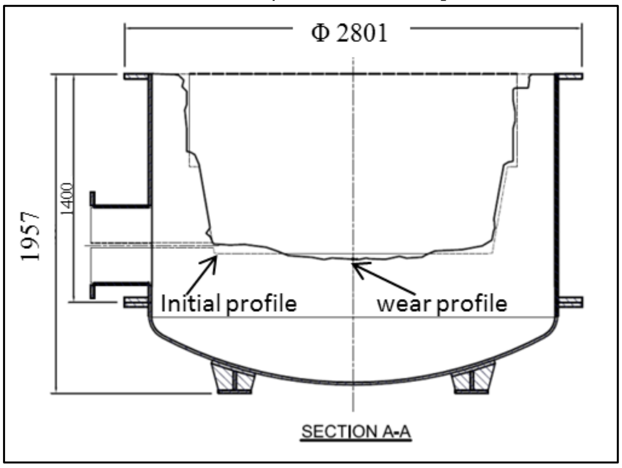

Fig 12: A cross-section of the furnace through the tap-hole. The wear profile is also superimposed on the original refractory design.

The build-up of the refractory to the sidewalls in the hearth is attributed to the way in which the refractory was installed and rammed rather than due to lifting of the hearth by metal infiltration or hydration of the magnesia rammable. As the refractory lining was retained for future experimental work, this assumption could not yet be confirmed.

CORE DRILLING OF REFRACTORY WORK LINING IN THE HEARTH

The core drilled samples were drilled from the carbon refractory in the hearth at 4 specific locations indicated in Fig 10. From Fig 10 it is noted that the core samples were taken in a cross pattern from the tap-hole. The core samples were drilled using a Husqvarna DMS 160 core drill machine and drilled t with a diameter of 20 mm and height of 100 mm. In order to determine whether the carbon refractory was infiltrated by metal or slag a study of the phase chemistry was undertaken using a Zeiss EVO MA15 scanning electron microscope (SEM). Backscattered electron (BSE) images were captured to identify phases present in the refractory based on differences in chemical composition determined by energy-dispersive spectrometry (EDS). Samples were cut

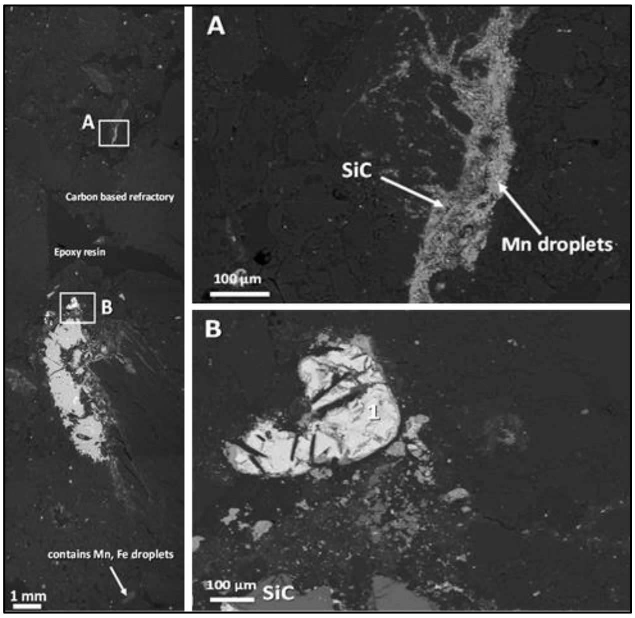

Fig 10: Backscattered scanning electron micrographs (20 kV) of hard build-up where A and B are larger magnifications of the micrograph on the left – scale bars indicating 100 µm and 1 mm respectively. A-SiC and Mn droplets. B- SiC phase and (1) Area of Mn and Fe phases

from the top, bottom and middle of all four cores. The study revealed that manganese and iron were present in the carbon based refractory up to 60 mm from the hot face, and is attributed to the infiltration of the alloy. Silicon carbide (SiC) was noted throughout the sample core and attributed to additives made to the refractory by the supplier.

CONCLUSION

The methods presented here will allow researchers, designers, and operators of submerged arc furnaces to carefully study the burden profile and refractory wear during pilot-scale investigations. The methods have the potential to be scaled-up and applied in investigations of industrial-scale furnaces.

ACKNOWLEDGEMENTS

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