APPLICATION OF UCAR® CHILL KOTE™ LINING TO ILMENITE SMELTING

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ABSTRACT

The UCAR® CHILL-KOTE™ freeze lining concept combines wall cooling with carbon and graphite refractories of higher thermal conductivities to "chill" the refractory lining by transferring heat from the refractory lining. Effective sidewall water cooling, together with the efficiency of the heat dissipating conductive refractories, lowers the temperature of the lining to below that of the molten process materials. This causes a layer of slag and process metal to solidify or "freeze" and form a protective "skull" which completely coats the refractory hot face. Once formed, the slag skull insulates the refractories, reducing heat loss and protect the lining from erosion, chemical attack, thermal shock, and other stresses. The result: extended life and greatly improved refractory performance.

The Ilmenite smelting process depends on the presence of a solidified slag skull to protect sidewall refractory material from chemical attach by molten slag. No known refractory material is able to withstand this corrosive material. To date, UCAR has not applied their Chill Kote ™ technology in the ilmenite smelting industry. This paper revolves around the results obtained from conducting an ilmenite smelting campaign on a 500kW DC open-arc furnace with a UCAR designed refractory system. The purpose of this test was to establish the effects such a lining has on refractory wear and the reduction-smelting process. Proper thermocouple management enabled the authors to monitor lining wear for the duration of the campaign.

Prior to the pilot-scale campaign, modeling work was completed to evaluate the feasibility of applying UCAR® CHILL-KOTE™ technology to ilmenite smelting furnaces. The successful operation of a pilot-scale furnace equipped with the UCAR® CHILL-KOTE™ lining as well as concise modeling suggest that it should be a viable option to consider for an industrial-scale furnace.

1. INTRODUCTION

Ilmenite smelting is conducted in both AC and DC electric furnaces. The ilmenite is reduced with a carbonaceous reductant (typically anthracite) to produce a high titania slag (containing approximately 86% TiO_2) and a low manganese pig iron. The slag is processed further for the production of white pigments, while the pig iron is used mainly as feedstock in the foundry industry.

Large pyrometallurgical furnaces often contain much complexity and uncertainty that make it difficult to reason intuitively about their dynamic behaviour. Ilmenite-smelting furnaces in particular must be operated with a freeze lining to prevent attack of the sidewall refractory material by the corrosive liquid high-titiania slag [5]. Because the freeze lining consists of slag solidified from the slag bath, it interacts both chemically and thermally with the slag bath.

This interaction represents a delicate balance in the process that must be maintained by carefully controlling the relative amounts of the process inputs (ilmenite, reductant and electrical energy). The result is that an ilmenite-smelting process presents a number of interesting process control challenges. A typical ilmenite smelting DC furnace is shown in Figure 1:

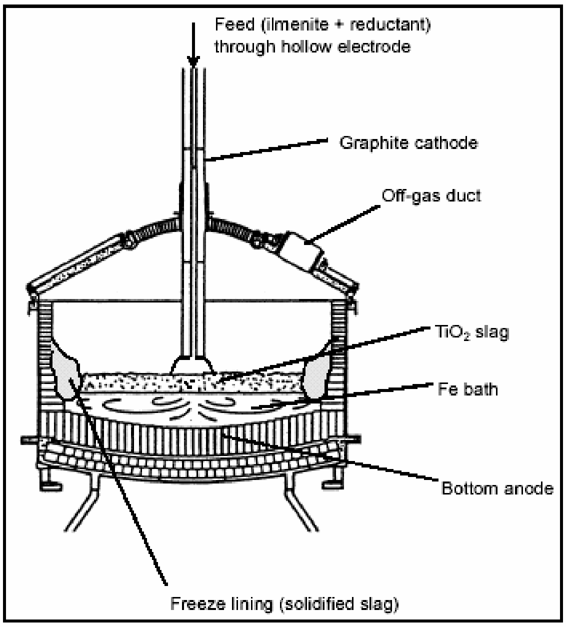

Figure 1: Typical Ilmenite-smelting furnace [4]

The ilmenite smelting process is conducted within a crucible of solidified, high titanium content slags (known as the freeze lining), contained within the furnace refractory walls. This freeze lining protects the magnesia refractory from chemical slag attack [3]. Apart from increasing the MgO content in the slag, and thereby exceeding the maximum impurity specification, chemical attack by the slag on the magnesia bricks reduces the life of the refractory lining, leading to side-wall breakthrough. Protecting the integrity of the freeze lining, through firm control over mass and energy balance within the process, is therefore one of the primary objectives of ilmenite smelting. Another potential problem in ilmenite smelters is hydration damage caused to the magnesia bricks in the lining in the event of any water leaks. Iron penetration in the hearth has also been observed previously as shown in figure 2:

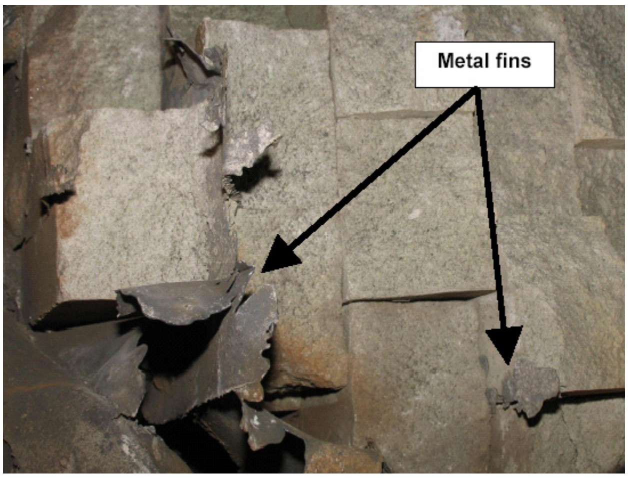

Figure 2: Iron penetration into the hearth found after a refractory break-out on a DC-ilmenite smelter [3]

Taking all of the above mentioned refractory problems into account, UCAR Refractory Systems designed a CHILL-KOTE™ freeze lining configuration that can potentially be used to replace the conventional magnesia refractories. The CHILL-KOTE™ lining contains carbon and graphite which are significantly better conductors of heat when compared to conventional magnesia linings. This article describes the evaluation of such a lining for ilmenite smelting using a combination of modeling and test work in a 500kW DC pilot furnace.

2. THE UCAR® STATE-OF-THE-ART "CHILL-KOTE"™ FREEZE LINING CONCEPT

The UCAR® CHILL-KOTE™ freeze lining concept combines wall cooling and thermally conductive carbon and graphite refractories to "chill" the refractories by transferring heat away from the furnace lining [1]. Effective water sidewall cooling, together with the efficiency of the heat dissipating conductive refractories, lowers the temperature of the lining below that of the molten materials. This causes a layer of slag and process metal to solidify or "freeze" and forms a protective "skull" which completely coats the refractory hot face. Once formed, the slag skull insulates the refractories, reducing heat loss and protect the lining from erosion, chemical attack, thermal shock, and other stresses. The result: extended life and greatly improved refractory performance.

The UCAR® CHILL-KOTE™ freeze lining concept allows significant reductions in lining thickness and mass. As a result, the working volume and capacity of the furnace is increased, installation and commissioning time is shortened, and profit-robbing downtime is reduced. In addition capital costs are lower. CHILL-KOTE™ freeze linings combine low thermal resistant carbon, graphite, and semi-graphite materials with various ceramic refractories especially selected for insulation, electrical insulation, and steel shell temperature control. Within a Chill-Kote lining, each component provides the properties required for its application and which work together in a cohesive system to enhance lining performance. An added advantage is that should the protective skull be lost during upset conditions, self healing and the replacement of the skull will occur quickly due to the low refractory hot face temperature.

UCAR's proprietary "hot-pressing" method of manufacturing produces carbon, semigraphite, and graphite refractories with low permeability, superior resistance to chemical attack, and outstanding thermal conductivity. UCAR's advanced hot-pressed refractories have an unsurpassed track record of reliable service in blast furnaces, direct reduction furnaces, cupolas, electric arc furnaces, and other metallurgical processes around the world.

3. MODELING OF AN ILMENITE-SMELTING DC FURNACE PROCESS

Zietsman and Pistorius (2004) constructed a one-dimensional wall model to describe the dynamic response of the furnace sidewall and freeze lining resulting from interactions with the liquid slag bath and changing conditions in the bath. A schematic representation of the freeze lining and wall region of an ilmenite-smelting DC arc furnace is shown in figure 3.

A furnace model was also constructed to characterize the dynamic behaviour of and interactions between the freeze lining and slag bath in response to changes in furnace operating parameters. A schematic representation is shown in figure 4.

From both these models it was concluded that independent changes in operating parameters as mentioned earlier resulted in changes of the freeze lining thickness. Independent adjustment of operational parameters moves the process away from the current stable point of operation. In some cases it could result in process instabilities such as foaming and crust formation. In other cases it could result in loss of freeze lining and associated damage to sidewall refractory material. The models were constructed for a conventional Ilmenite-Smelting DC furnace lining constituting of a ramming material and mainly Magnesia brick in the sidewall.

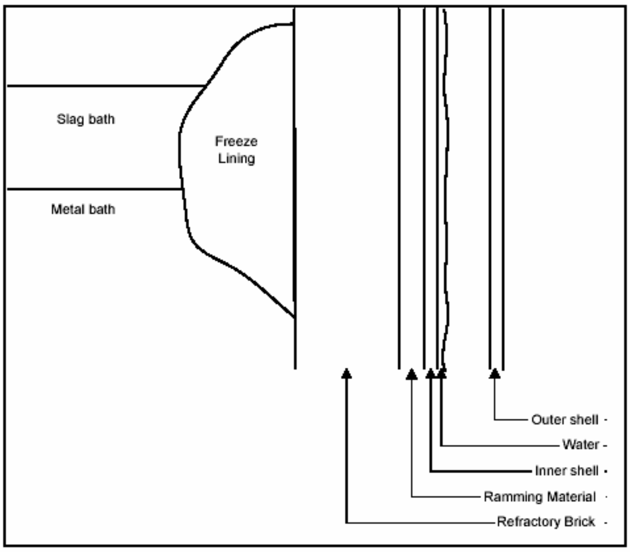

Figure 3: Schematic representation of the "conventional" freeze lining and wall region of an ilmenite-smelting DC arc furnace [5]

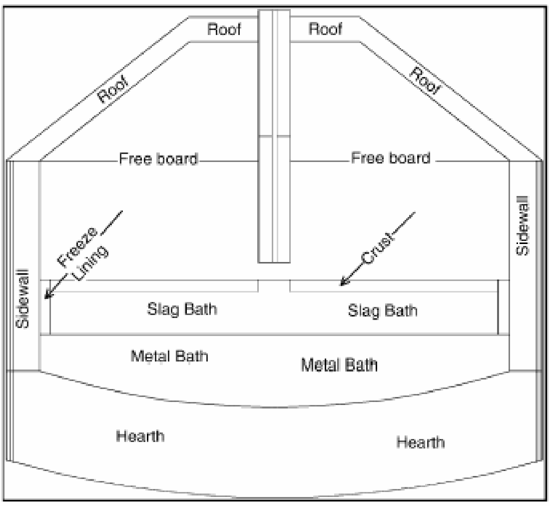

Figure 4: Schematic of the furnace and process as described by the Furnace Model [5]

4. PILOT SMELTING CAMPAIGN ON A 500 KW DC FURNACE

The furnace used in this campaign is a 500kW DC arc plasma furnace as was shown in figure 5. This facility is situated at the Kumba Resources R&D site in Pretoria, South Africa. Due to the size of the pilot scale furnace, the design of the hearth pad refectories was somewhat restricted. For a full scale industrial furnace the hearth pad design would be easier and would look somewhat different to the pilot furnace.

Feed is introduced through a hole in the roof adjacent to the single solid graphite electrode, with metal and slag being tapped from opposing tap holes. Because of the conducting nature of the slag an open arc configuration is used. Ilmenite to power ratio was maintained as close to 0.56kg/kW as possible, with a reductant

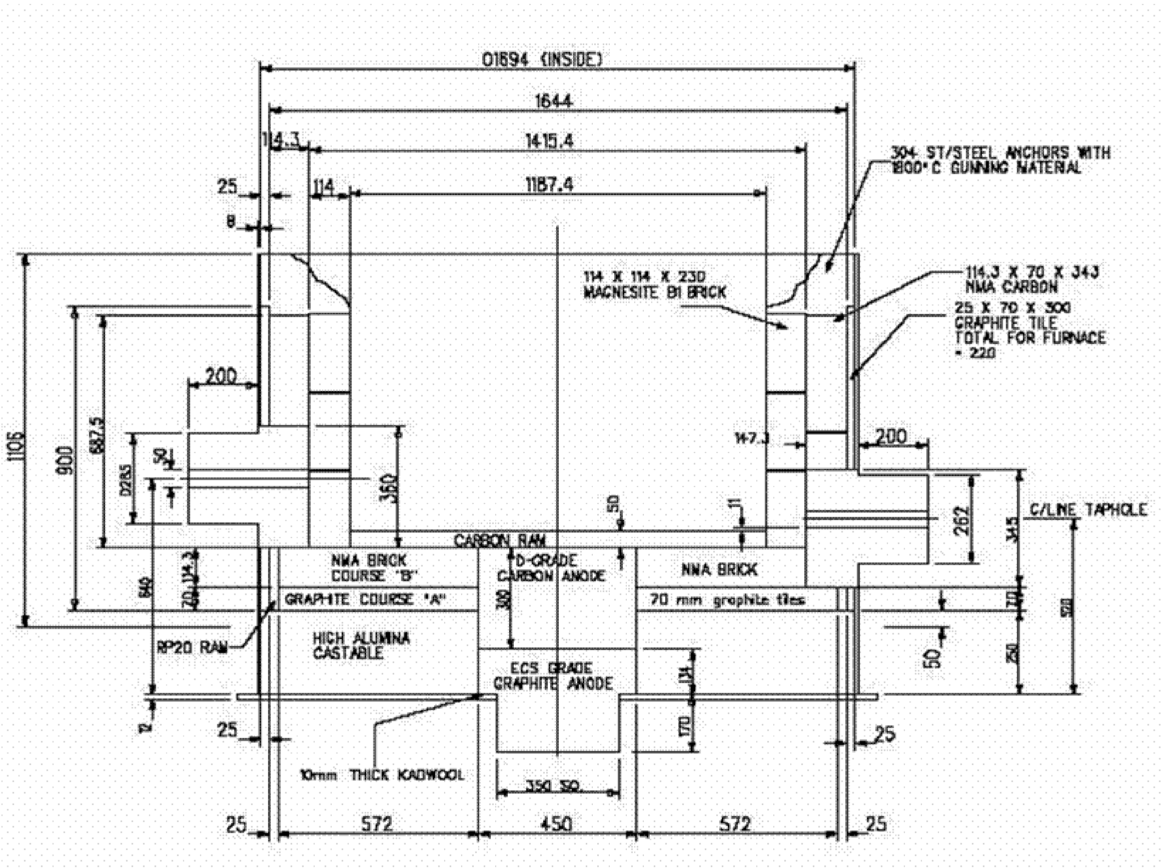

Figure 5: Drawing of the 500kW pilot scale furnace showing the UCAR® CHILL-KOTE™ Lining

to ilmenite ratio of 12%. The furnace was operated using standard feedstock within the operating envelope as established on previous ilmenite smelting campaigns to enable direct comparison between the UCAR and conventional linings. The TiO_2 grade aimed for was 86%-88%.

The furnace was started up by heating scrap to create a molten pool of metal by using a gas burner and arcing. After the required temperature was reached, feeding commenced, with the initial taps through the lower metal tap hole. The initial low TiO_2 slag was tapped as soon as possible, with new slag changing the slag composition to the target TiO_2 grade. A photo of the 500 kW furnace is shown in Figure 6.

Wear of the sacrificial MgO lining was used as primary indicator that a protective freeze lining was present at all times during the campaign. Possible wear of this sacrificial lining was investigated by performing a mass balance on the MgO.

This balance is based on the following assumptions:

- MgO grade in Ilmenite feedstock constant at 0.5% as analysed at the beginning of the campaign
- MgO contributed by the ash in the anthracite is negligible
- Based on previous ilmenite smelting campaigns on this furnace, 7% of the ilmenite feed is lost to the off-gas through dusting
- No metal is tapped with the slag and
- No slag is tapped with the metal

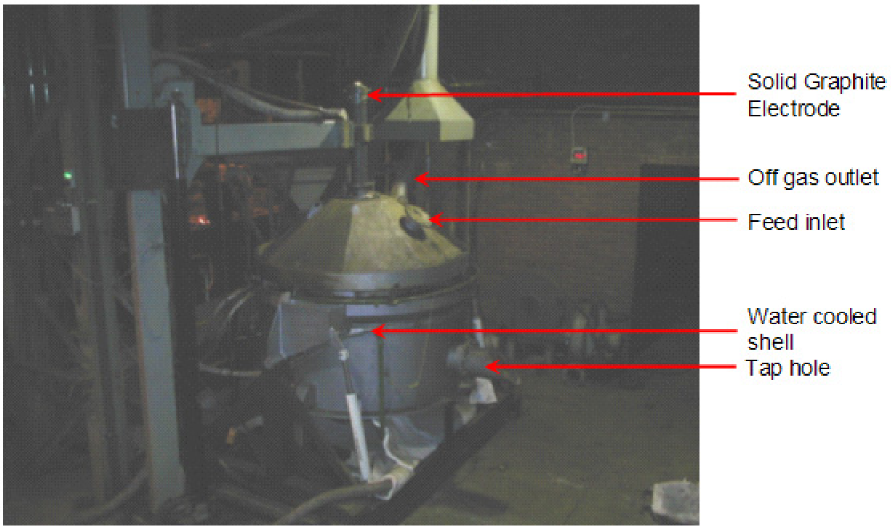

Figure 6: A photo of the 500 kW furnace set-up

Based on the assumptions as listed above, 97% of MgO fed into the furnace can be accounted for. Due to the tapping practices it is known that small amounts of slag are tapped with the metal. Assuming that 3% of the mass metal tapped is slag, all MgO can be accounted for.

It was therefore concluded that little no war of the sacrificial lining occurred during the campaign. These findings are backed up by visual inspection of the lining after completion of the campaign. The photos shown in Figure 7 and Figure 8 indicate no noticeable wear of the sacrificial lining, even in the high-wear zone at the metal-slag interface. In this zone, just below the slag tap hole, the metal layer's rising level will remove any protective skull and when the metal is subsequently tapped; hot slag comes directly into contact with the

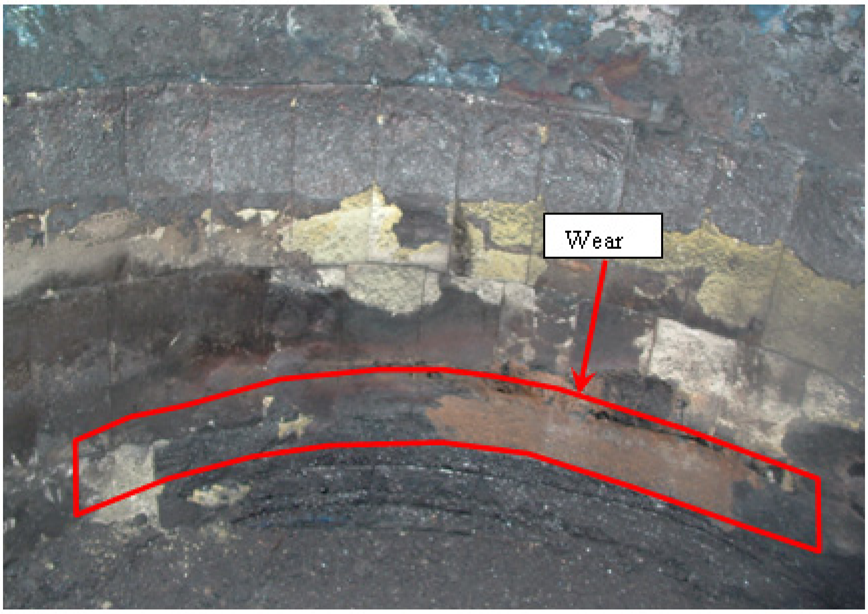

Figure 7: View of the refractory lining after the furnace was cleaned out

Figure 8: Viewed from the top it is clear that no significant wear of the lining has occurred

unprotected refractory lining. This slag will freeze again as a result of the lower hot face temperature of the lining compared to the liquidus temperature of the slag.

5. MODELLING OF A 500 KW DC ARC ILMENITE-SMELTING FURNACE INSTALLED WITH A UCAR® CHILL KOTE™ LINING

A simple one-dimensional static heat transfer model was created for the lower sidewalls and hearth of the furnace [2]. The purpose of this heat transfer model was to use the thermocouple data from the furnace operation to analyse the heat flow in the radial (sidewalls) and axial (hearth) dimensions for the campaign. Figure 9 shows the thermocouple arrangement on the furnace.

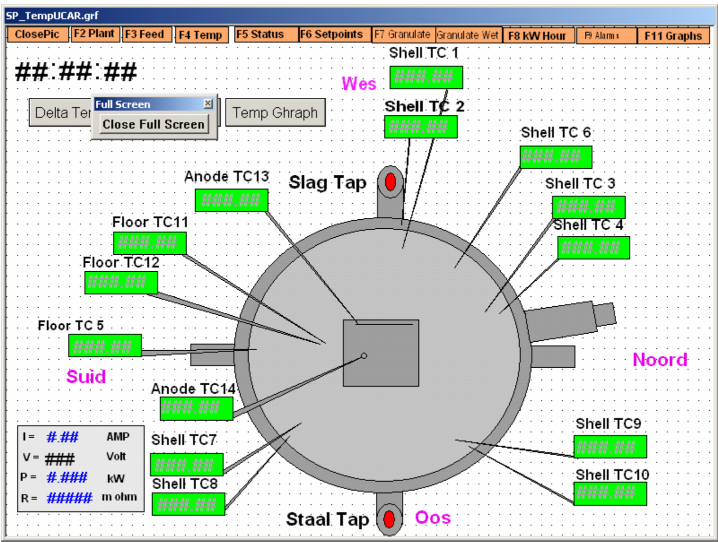

Figure 9: Thermocouple arrangement on a pilot scale furnace

Prior to the pilot-scale campaign, modeling work was completed to evaluate the feasibility of UCAR's Chill Kote™ technology to ilmenite smelting furnaces [4]. The purpose of this modeling work was to demonstrate that the side-wall refractory lining would build a protective skull and eliminate refractory wear.

For the modeling study on the pilot-scale furnace, three operational disturbances were being considered. The three scenarios for which the model was executed were:

1. Scenario 1: Loss of all material feed while maintaining full power
2. Scenario 2:Loss of ilmenite feed while maintaining full power
3. Scenario 3:Loss of reductant feed while maintaining full power

Results for these three scenarios are shown in figures 10-12. In all three instances the simulation was run for 70 minutes before termination of the feed. This was done to ensure that the model was stable.

The following comments can be made regarding thse three scenarios:

- Scenario 1:

  From Figure 10 it is predicted that the initial skull of 86mm would meld away in 19 minutes. During this time it is predicted that the bath temperature will increase by approximately 15 °C. After melting of the

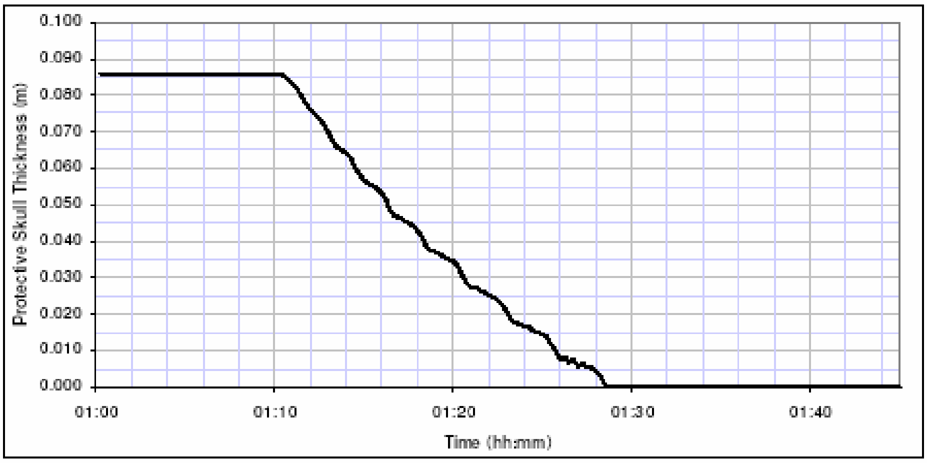

Figure 10: Skull thickness for scenario 1

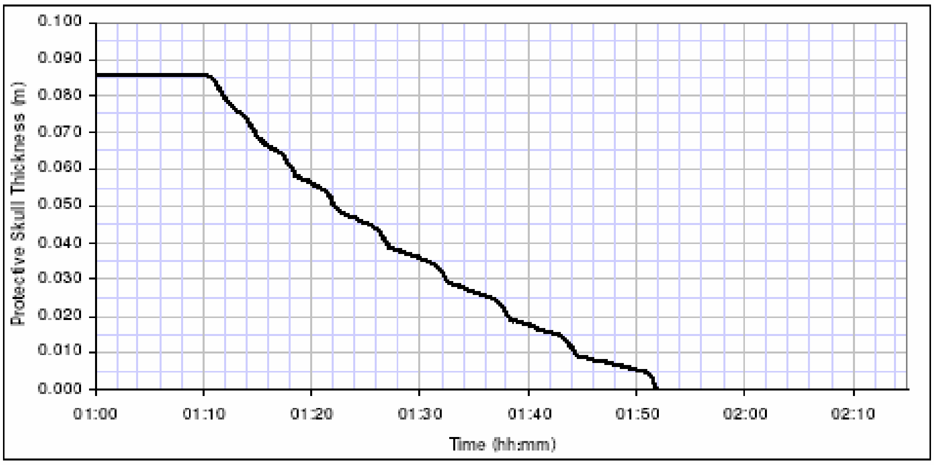

Figure 11: Skull thickness for scenario 2

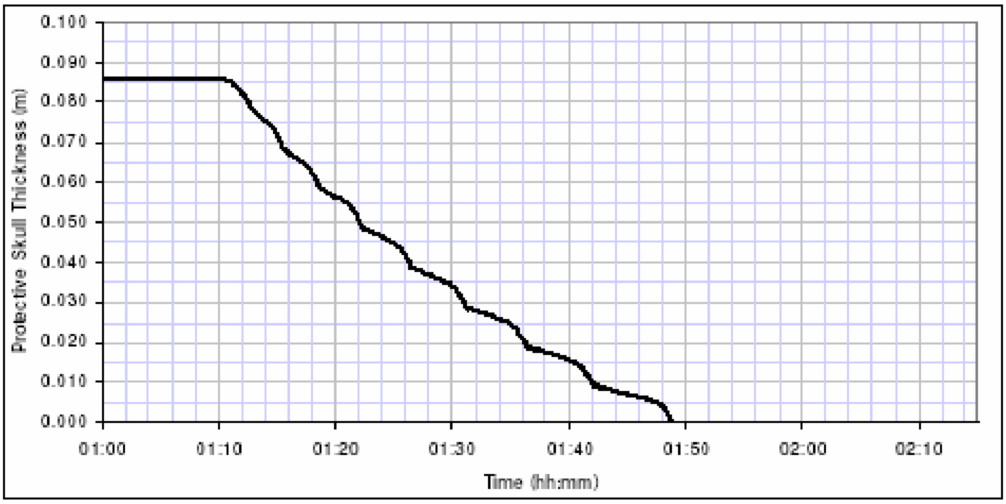

Figure 12: Skull thickness for scenario 3

skull, all the electrical energy will heat the bath, with the result that the bath temperature will increase rapidly. If continued this will lead to catastrophic failure of the lining.

- Scenario 2:

  For this scenario it is predicted that the skull of 86mm will be melted away in 43 minutes.

- Scenario 3:

  For the scenario it is predicted that the skull will melt away in 40 minutes

  The results produced by the model are only relevant to the point where the skull has been completely melted. Beyond this point the liquid slag would react with the refractory brick. This was however not modeled.

  These model results were also used to evaluate the response of the thermocouples installed in the furnace lining. This was done by calculating the precicted temperatures for each of the fixed thermocouples as a function of time. It was found that the skull was melted away before any increase in the fixed thermocouple temperatures was calculated. Using actual thermocouple data obtained for the test campaign the following conclusions were made on the basis of the heat transfer model calculations:

  - **Sidewalls**

    For the entire campaign period there was always some solidified material on the refractory brick.

  - **Hearth**

    Unlike the sidewalls, the hearth had only one set of thermocouples, which made it difficult to verify the measurements. It could not have been estimated how much (if any) of the sacrificial layer had remained, nor how much (if any) metal solidified in the hearth. It was however calculated with reasonable certainty that there must have been a reasonable amount of some protective material between the metal bath and the NMA carbon brick layer in the hearth.

6. CONCLUSIONS AND RECOMMENDATIONS

The successful operation of a pilot-scale furnace equipped with the UCAR® CHILL-KOTE™ lining suggests that it should be a viable option to consider for an industrial-scale furnace. As required, the lining caused heat flow responses necessary to result in slag solidification on the refractory brick. Analysing the measured results from operating the furnace and comparing it with that predicted by the model, suggest that the model is useful in providing qualitative predictions on the lining performance.

With the UCAR Refractory technology there is less emphasis on operational control than with previous conventional type "freeze linings". As the hot face of the UCAR lining is easily maintained below the solidification temperature of the slag there will always be skull formation as was also shown by both modeling and test work results.

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