APPLICATION OF HIGH INTENSITY REFRACTORY COOLING SYSTEMS IN PYROMETALLURGICAL VESSEL DESIGN

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ABSTRACT

The operating conditions which all pyrometallurgical vessels have to withstand are arduous, resulting in operating campaigns being tailored around maintenance cycles. The refractory lining is generally a process consumable, and the re-lining costs have to include lost production during the maintenance shutdowns. Combinations of certain smelting environments including high hearth power densities, DC plasma open arc and open bath operation and slag that is aggressive to common ceramic lining materials result in a further reduction in campaign life and increased operating costs.

Composite Furnace Module (CFM) refractory cooling system technology has been specifically developed for the high wear areas of pyrometallurgical process containment vessels. The technology has been successful in both extending campaign life and reducing the overall refractory life-cycle operating costs. CFM systems incorporate a matrix of copper cooling pins and refractory materials supported by a copper base panel with integral cast cooling water pipes which are located away from the process to improve safety. CFM technology promotes the structural stability of the lining whilst ensuring that the hot face surface temperature distribution is as uniform as possible to reduce wear associated with thermal stresses. The configuration of the CFM system has been customised to dissipate a wide range of heat fluxes which promotes the wear protection mechanisms in different zones of the furnace.

This paper describes CFM technology applications in high wear areas of various furnaces including the slag bath side walls, freeboard linings, tapholes, offgas ports and furnace roofs. Case studies are presented outlining the pre-existing problems, the design and analytical methodology, and the post installation performance improvements.

1 INTRODUCTION

Composite Furnace Module (CFM) technology was developed in the early 1990's to address the shortcomings of refractory cooling systems. The main aim of the technology is to provide a uniform temperature on the furnace lining hot face, combined with the additional safety aspect of the water passages being moved as far away as possible from the process interface.

CFM technology consists of a backing plate from which a number of copper pins or rods extend towards the hot face. A refractory material is cast between the copper pins. The backing plate is water cooled by means of internal water passages. The distribution of the copper pins in the refractory matrix reduces variations in the hot face surface temperature distribution. The resultant uniform hot face temperature limits the wear of the lining, thereby extending the lining life.

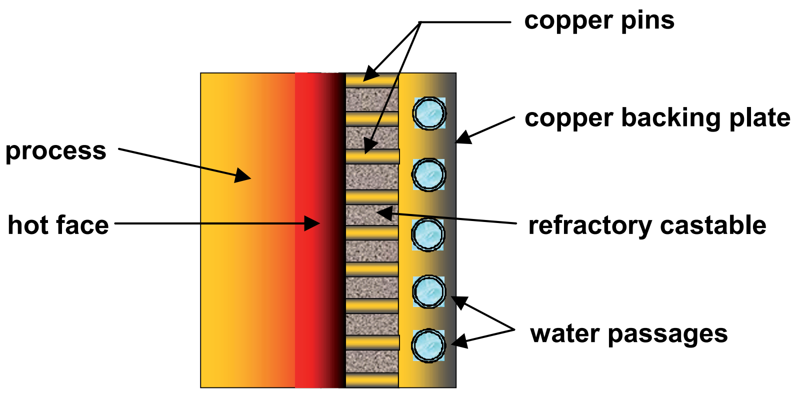

Figure 1: CFM schematic section

Various modeling, laboratory and industrial trials have been carried out to assess the viability of the CFM concept. These trials proved highly successful, leading to the first large scale commercial installation of this technology in the sidewall, tapholes and roof off gas port of an electric arc, slag cleaning furnace in 2003. The capability and flexibility of CFM technology in solving lining wear in different parts of the furnace was clearly established from the success of this installation, facilitating further diversification of the technology.

2 FURNACE BATH SIDEWALL

2.1 Copper Blister Slag Cleaning Furnace

The electric arc slag cleaning furnace at BHP Billiton's Olympic Dam smelter suffered from significant bath sidewall corrosion. The sidewall consisted of a Magnesium oxide refractory lining, cooled by a free falling water curtain external to the furnace shell. The slag cleaning furnace receives slag containing considerable amounts of residual copper from the upstream flash furnace.

The high wear of the bath sidewall lining was attributed to chemical corrosion of the refractory matrix by the slag constituents. A redundant slag taphole copper panel was converted into a CFM element by attaching copper pins in a specific pattern to its hot face. This panel was also fitted with a number of thermocouples in the copper pins and refractory to monitor the performance of the unit.

The trial CFM unit was installed and the thermocouple data analyzed [1]. The following trends were observed:

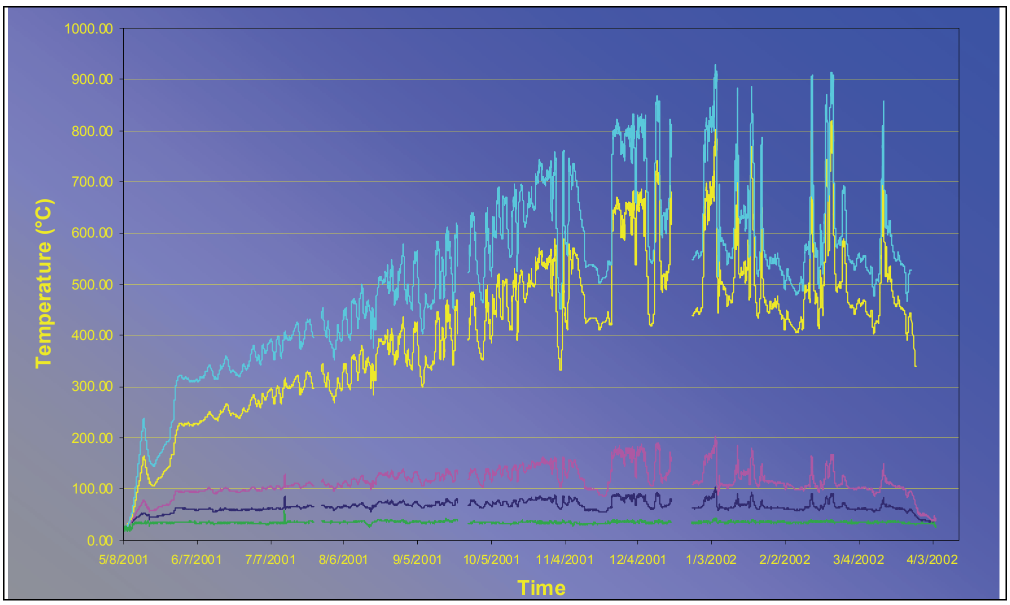

Figure 2: Temperatures measured in trial CFM element (in refractory – top; on copper – bottom)

All the temperature trends indicated an initial increase in both average temperature and temperature fluctuation amplitude, followed by average temperature stabilization for the duration of the test campaign. Large cyclical variations occurred around the stable average temperatures. It was concluded from the data that the refractory in front of the copper pins gradually wore away, causing the temperatures to rise, after which a point was reached where the effect of the copper pins and cooling system was sufficient to freeze slag onto the hot face of the element. Temperature fluctuations occurred when the freeze lining periodically broke away and reformed. This conclusion was supported by the observations made during the excavation of the trail unit and relining of the bath sidewall after operation for one year.

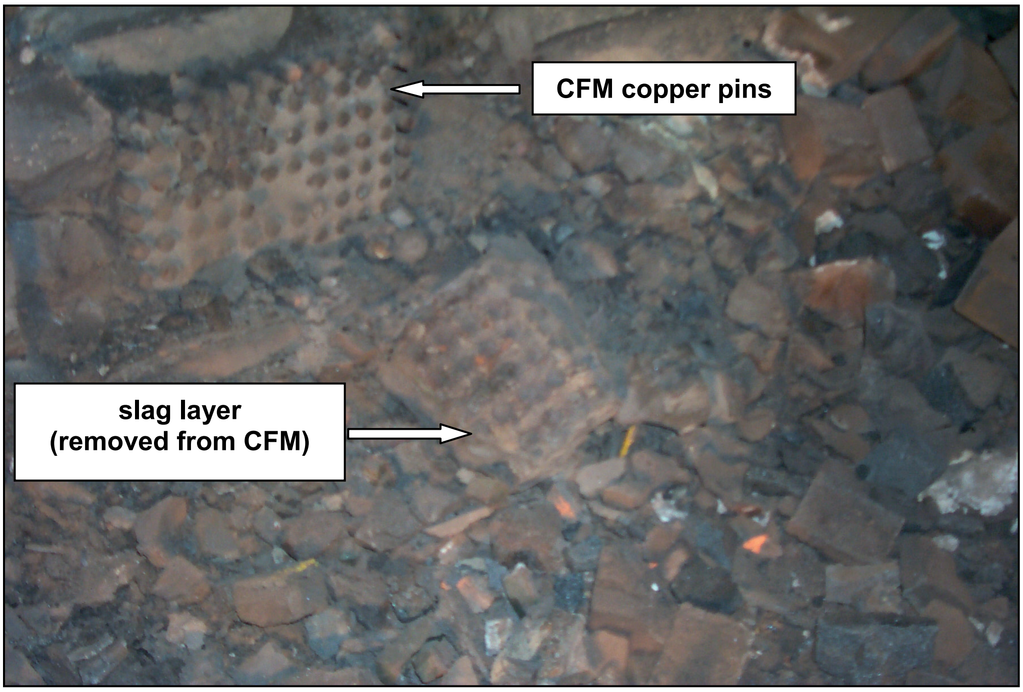

Figure 3: Excavation of trial CFM unit after one year in operation

The trial unit provided sufficient data to facilitate the scale-up to a complete CFM sidewall lining for the slag cleaning furnace. The CFM system consisted of 30 individual elements covering the total periphery of the bath sidewall including three slag taphole elements with CFM tapping inserts and three copper blister tapholes. The CFM installation consisted of approximately 100 tons of copper and 30 tons of refractory for the 12.4m diameter furnace.

The CFMs were installed in 2003 and the data received from the thermocouples imbedded in the CFMs replicated the trial unit performance, confirming operation with a frozen layer of slag on the CFM elements. This CFM system was still in operation at the time of publication of this paper, which implies at least a six fold increase in lining campaign life for this application.

Figure 4: Trial assembly of a CFM bath sidewall system

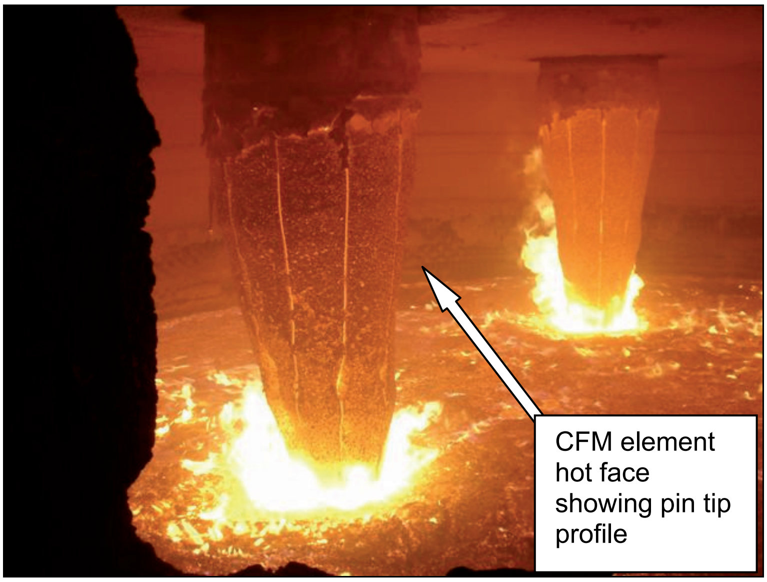

Figure 5: Slag cleaning furnace CFM bath sidewall system in operation (six years in operation)

2.2 Ferronickel Processing DC Furnace

One of the most arduous applications of furnace containment technology is the open bath smelting of lateritic ores. The slag produced by the pyrometallurgical process contains a mixture of MgO, SiO_2, iron oxides, and CaO_2, but is not saturated in MgO at the process operating temperature. Refractory materials containing MgO are readily dissolved into the slag as thermodynamic equilibrium considerations attempt to correct this imbalance. The propensity for corrosion is determined by the slag acidity, quantified in terms of the SiO2 : MgO ratio. Fresh slag is continuously produced, resulting in lining corrosion at a predictable rate. A purely ceramic solution based on refractory material selection has not been found. Intensive sidewall cooling systems capable of maintaining a freeze lining of slag on the refractory hot face are required to provide satisfactory campaign life.

CFM technology was selected to construct the lower furnace sidewalls of a pilot scale 2MW DC furnace to demonstrate the pyrometallurgical process of smelting lateritic ore in an open bath DC furnace operation [3][4]. The trial campaign aimed not only to verify all process parameters, but also to demonstrate the geometric configuration and cooling parameters of CFMs required for the commercial scale vessel.

It was planned to process approximately 260t of ore during the trial campaign, targeting nickel recoveries in excess of 90%, while verifying the process energy requirements and obtaining data for scale up to an 80MW operation.

CFM elements were designed and installed in the bath sidewall. The installation consisted of a ring of 6 CFM elements with an internal hot face diameter of 2 m and a height of 500 mm. The CFMs were installed from the hearth level upwards and additional refractory materials were placed in front of the elements, covering the metal bath depth in order to protect the CFM elements from direct contact with the metal. The CFM elements were extensively fitted with thermocouples to monitor their performance.

During the start-up of the campaign, stable operation was delayed by problems with the operation of the feed system, which resulted in the furnace being held at heat loss conditions followed by manual feed for a period of time. Once the feed system was operational, a total of 193 tons of calcine was fed in 161 batches during the smelting campaign which lasted for 19 days after initial start-up. Continuous smelting was achieved for 15 of the 19 days during which 34 metal taps and 160 slag taps were obtained. 12 tons of FeNi with an average Ni content of 18% were produced during this campaign, thereby demonstrating that FeNi can be successfully produced with this process.

The temperatures and heat fluxes recorded in the slag bath level during the early stages of the trial campaign were as expected and designed, but the lower areas of the elements exhibited much higher temperatures and heat loads than anticipated. Analysis of the data indicated that the bottom of the CFM elements were periodically in direct contact with the molten metal bath, resulting in heat loads of the order of 2MW/m². Never-the-less, all campaign objectives were achieved by managing the alloy inventory level, and exploiting the capability of the CFMs to 'self cure' by rebuilding the freeze lining. After completion of the trial campaign, a dig-out of the furnace lining was performed in order to assess the performance of the lining. The post mortem confirmed that the metal bath had periodically been in direct contact with the CFM copper. Extensive wear of the refractory materials installed to protect the CFM elements in the metal bath occurred during the prolonged heat-up and idling of the furnace due to slag contact. This refractory wear further emphasizes the need for intensive cooling systems in this process to specifically contain the slag. The trial campaign provided significant corroborating data for the commercial application of CFM technology

Figure 6: Left – Post-mortem inspection of CFM slag layer break-out prepared for direct comparison of freeze lining and castable refractory
Right – Post-mortem inspection of frozen metal on bottom of CFM element

The successful implementation of the CFM technology during the trial campaign described above provided the basis for the design of CFM elements in a scaled-up 12 MW demonstration DC furnace for the same process. The detailed design of the demonstration furnace specifically focused on addressing the following issues based on the experience gained during the trial campaign.

- The bottom of the CFM elements must not be installed below the bottom of the metal taphole in order to avoid continuous metal contact.
- Special attention was given to the refractory composite on the CFM hot face exposed to the movement of the slag-metal interface
- Additional heat transfer capacity was provided at the bottom of the CFM panel to cope with possible contact with molten metal. However, no water passages are installed below the maximum metal level to prevent a steam explosion in the extreme case of burn through in the metal bath zone.
- A high level of instrumentation was installed at the bottom of the CFMs to provide early warning of an incipient failure.
- The CFMs were designed for ease of replacement from the outside if required to ensure short shutdowns and significant extension of overall campaign life.
- Special attention was given to the level tolerances of the hearth skew back bricks to ensure that the CFMs are evenly immersed in the bath
- Furnace inventory management and control of the slag-metal interface movement will be monitored as it plays a key role in determining refractory campaign life.

At the time of publication of this paper, the CFMs for the 12MW DC demonstration furnace have been delivered and the furnace is to be constructed by mid 2010.

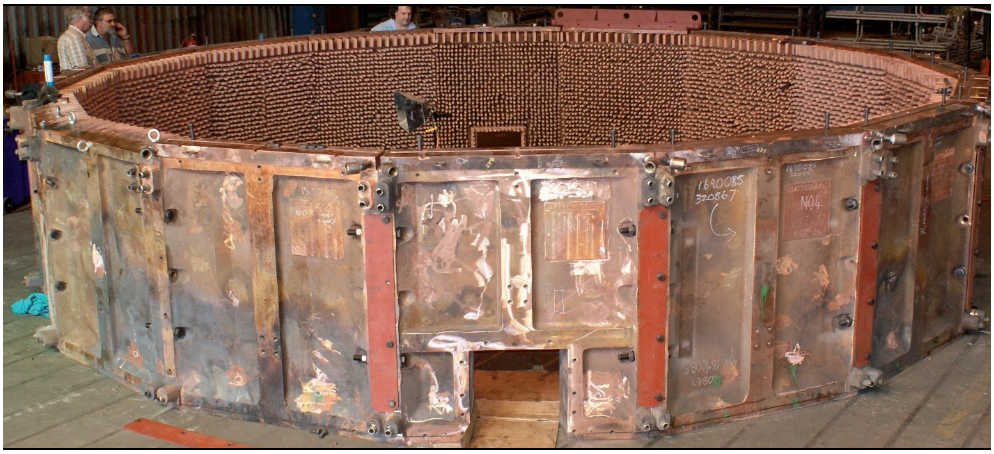

Figure 7: Trial assembly of the 12 MW DC Furnace side wall CFM elements.

3 FURNACE FREEBOARD GAS SPACES AND ROOFS

3.1 Copper Blister Slag Cleaning Furnace Off Gas Port

Another area where high refractory wear rates are prevalent is in the roof port openings, specifically off-gas ports in 'Detric' furnace roof designs. This was the case with the off gas port of the slag cleaning furnace roof described in section 2.1 of this paper. This high wear rate necessitated frequent re-bricking of the 'bull's-eye' refractory ring around the roof off gas port.

The wear in this instance was attributed to the acceleration of the hot furnace process gases through the roof port which increases the heat transfer, combined with poor sealing which led to the combustion of furnace off gas in the presence of ingress air in this area, resulting in the overheating and erosion of the refractories around the opening. A CFM system was designed to replace the refractory ring around the roof off gas port opening, consisting of a number of CFM element segments combined to form a doughnut shape around the port. The hot face pin design on these CFMs was profiled to allow for a smooth geometrical transition between the roof and off gas port inlet. This assisted in reducing turbulence generated by the acceleration of the furnace gases through the port. The inherent structure of the CFM system also provided a gas tight seal, preventing any air ingress that might support combustion in this area. The CFM system was suspended from the overhead 'Detric' roof support structure.

The roof off gas port CFM system was installed in 2003 during the installation of the side wall and is still in operation at the time of publication of this paper.

Figure 8: Two of the CFM element segments of the roof off gas. Note the profiled hot face shape of the pins (refractory still to be cast over the pins)

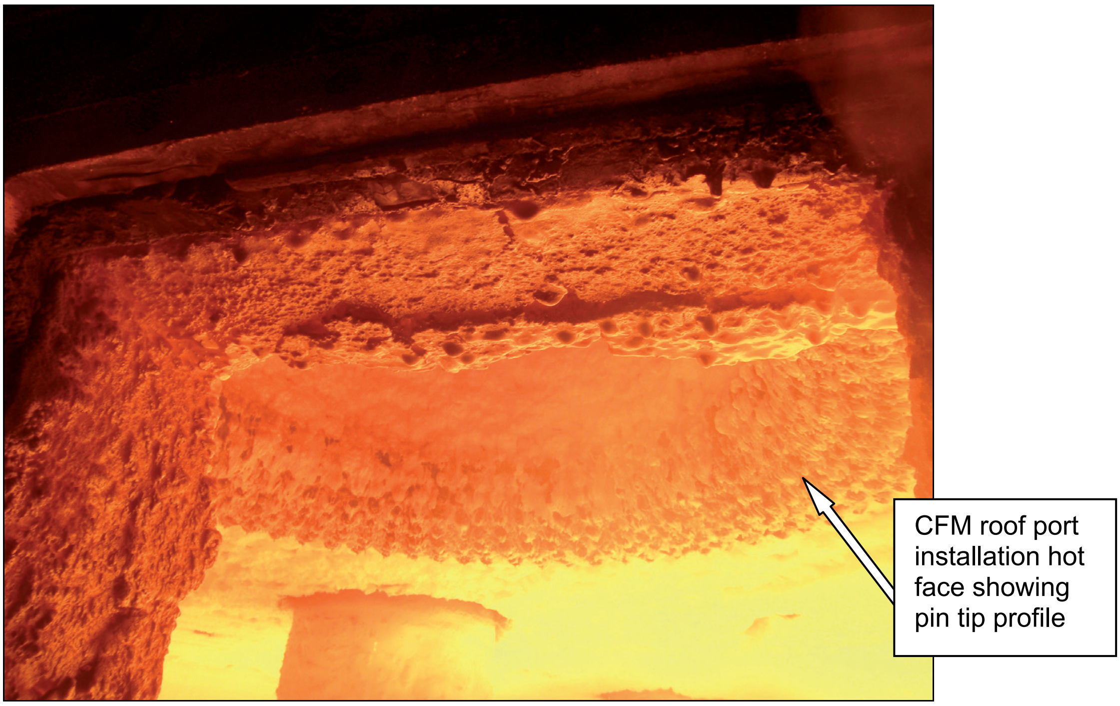

Figure 9: Slag cleaning furnace CFM roof off gas port system in operation (six years in operation)

3.2 Flash Furnaces

The standard flash furnace lining design in the gas space areas consists of water cooled copper beams or ledges alternating with rows of refractory brick courses. Over long periods of operation, the refractories between the water cooled copper beams or ledges show significant wear, up to the point where relining is required. Although the period between relining is typically a few years, the campaign life of such lining could be improved further with a cooling system based on CFM technology. The water cooled copper beams or ledges induce discrete cold areas in the furnace, with hot spots in the refractory areas midway between adjacent copper coolers. This results in wear in the hotter areas between the copper beams, since the refractories next to these beams actually insulate the refractories further away from the cooling effect of the copper beams.

The CFM hot face design distributes the cooling effect of the copper more uniformly through the lining, leading to a uniform hot face temperature and eliminating the hot spot areas where high wear occurs.

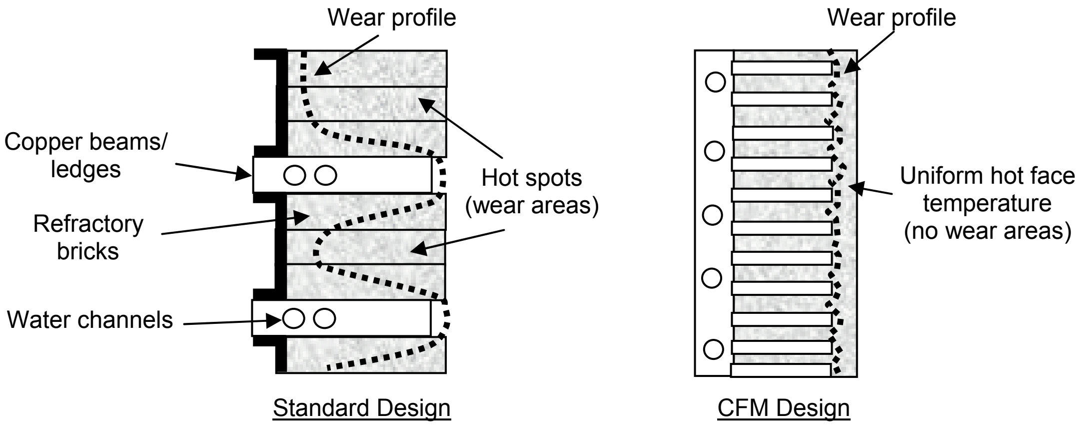

Figure 10: Schematic sections through a typical flash furnace lining indicating typical wear profiles for the standard versus CFM designs

CFMs have been extensively installed in the flash furnace vessels of BHP Billiton's Olympic Dam Copper Smelter and the Kalgoorlie Nickel Smelter in order to further extend the lining campaign life. Bateman designed the CFMs in the upper sidewall and roof of the Olympic Dam Flash Furnace Settler which were installed in 2003. The areas fitted with CFM have shown no significant signs of refractory wear at the time of publication of this paper, in comparison to severe wear in the conventional design. In 2007, Bateman provided a CFM design for the reaction shaft roof of the Kalgoorlie flash furnace, due to significant wear of the original refractory roof. This installation is also currently operating without any signs of wear. Current indications are that the CFM technology will significantly increase the current campaign lives of both these furnaces.

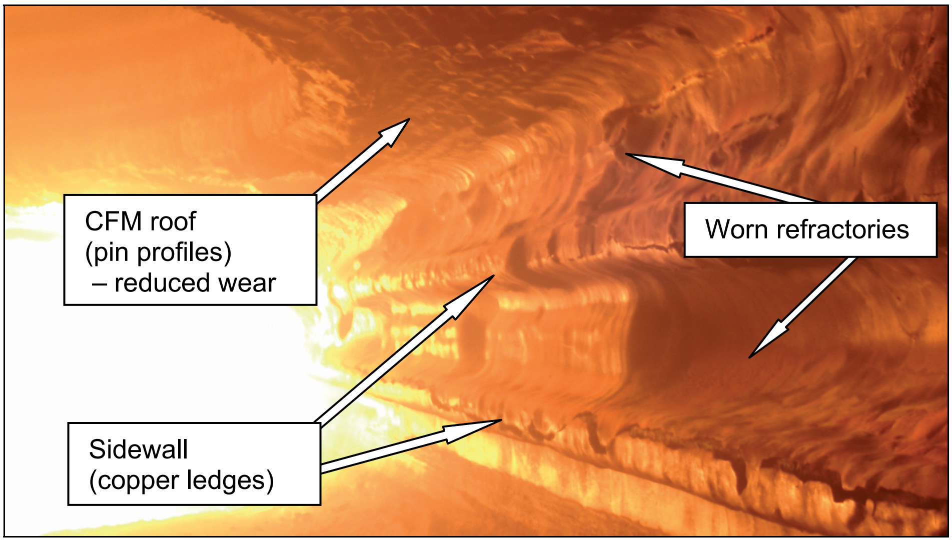

Figure 11: Internal view of a flash furnace freeboard and roof lining, showing high wear in the sidewall with the standard design and virtually no wear in the CFM roof lining

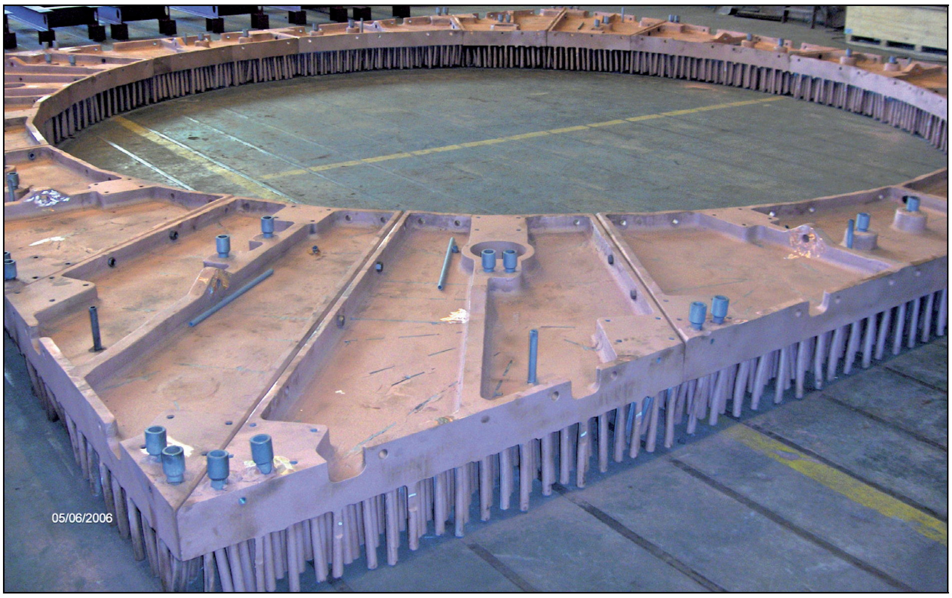

Figure 12: Shop assembly of a CFM system installed in the settler roof of a flash furnace around the reaction shaft interface.

4 TAP HOLES

CFM technology has been incorporated into the designs of tap holes and specifically those used for the removal of slag. The pin length and spacing is carefully adjusted to follow the isotherms which develop under running and closed conditions. This ensures that the taphole wears back to the classical trumpet shape which stabilizes at a particular geometry to provide consistent tap flow rates. The isotherms prevailing at the time of clay injection ensure that the clay cures to achieve the necessary mechanical properties, thereby preventing spontaneous (self) tapping. The isotherms which stabilize after the clay has cured ensure that the taphole can be easily opened and that the slag flows without freezing in the tap channel.

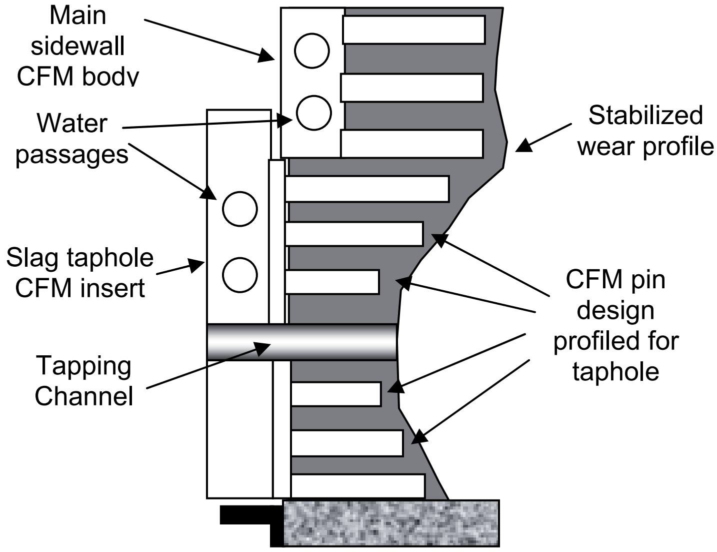

Figure 13: Schematic of a section through a typical CFM slag taphole application

These taphole designs have been implemented in all CFM bath sidewall applications to-date including the furnaces referred to in sections 2.1 and 2.2. The CFM slag taphole inserts for the copper blister slag cleaning furnace described in section 2.1 have been replaced after a campaign life in excess of three years.

5 CONCLUSIONS

The ability of the CFM concept to reduce lining wear in different furnace vessel areas as well as different process has been demonstrated in commercially operating applications and trial campaigns. CFM technology has successfully increased lining campaign lives significantly in slag cleaning furnace sidewalls and flash furnace gas space areas. The applicability of this technology to intensive processes which require high capacity cooling systems to contain corrosive smelting products over prolonged periods has also been clearly established.

Further development of the technology to address damage to the CFM element metallic components by corrosive condensable byproducts is currently being carried out, which will broaden the range of pyrometallurgical processes to which CFM technology can be applied.

6 REFERENCES

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