MONITORING AND CONTROL OF FURNACE 1 FREEZE LINING AT TASMANIAN ELECTRO-METALLURGICAL COMPANY

A. De Kievit[1], S. Ganguly[1], P. Dennis[1] and T. Pieters[2]

[1]Tasmanian Electro Metallurgical Company Pty. Ltd. (TEMCO)
PO Box 164, George Town, Tasmania 7253, Australia. E-mail: Alan.dekievit@BHPBilliton.com
[2]Bateman Metals Ltd, Bartlett Road, Bokesburg, 1462, South Africa. E-mail: tertius.peters@batemanbv.com

ABSTRACT

TEMCO has been producing manganese ferroalloys in submerged arc electric furnaces for over 40 years. The furnace linings all along have been of conventional insulation type until 2001 when a freeze lining of UCAR concept was installed for a 20 MW Furnace.

Continuous improvement of furnace lining performance has been a key component in improving the business competitiveness of TEMCO. The expected minimum campaign life of the freeze lining is fifteen years as compared to the ten years of the conventional linings.

The success of the freeze lining is very critical to the quanta and direction of heat flow through the lining that control the freeze protection. Under freeze protection can lead to reduced lining life and over freeze protection, on the other hand, can lead to operating difficulties and loss of smelting efficiency. It was, therefore, necessary to develop a computer based system to monitor and control the freeze protection.

The computer based monitoring and control system uses the basic principles of heat transfer, activeX object and heat flux from dual thermocouples and that is reviewed.

1. INTRODUCTION

The concept of a carbon crucible encapsulated with alumina refractory bricks placed in a steel shell has been the conventional lining design at TEMCO since 1962. Different carbon materials such as large blocks, hot ramming paste and cold ramming paste and different grades of alumina bricks have been trialled over the years. The average lining life has been increased from 5-6 years to 10 years for the current design (Appendix 1) through temperature/heat flow monitoring using dual tip thermocouples in the hearth and sidewalls of the lining. It is to be noted that the power density i.e., MW/M^2 of the crucible area on the furnaces have increased by two folds over these years.

2. FREEZE LINING

The concept of freeze lining has been under consideration at TEMCO for about ten years and different designs available in the market place have been critically examined for TEMCO application. The principle of freeze lining is very simple and sound. The combination of cooling, super conductive thermally efficient lining materials, and the insulating effects of residual hot face ceramics and accretions/freeze, results in refractory temperatures that are below their "critical reaction temperatures" for all wear mechanisms that can be encountered in operations. This results in a refractory lining that does not deteriorate with time, maintains its integrity and provides longer life. However, the method of application of this principle is different for different pyro-metallurgical furnaces and reactors and the success of this principle on a furnace or reactor is related to the method of application. The issues with freeze lining that TEMCO has envisaged are; minimum lining life of fifteen years for its financial viability, nature and degree of movement of bricks in the lining over its life span and process to address the movements, extent of damage to the lining in case of loss of water cooling for an extended period and proper method for control of the thickness of freeze during normal operation. The issues, therefore, have needed to be addressed with the installation of a freeze lining at TEMCO.

3. UCAR CHILL-KOTE FREEZE LINING

The UCAR® Chill-Kote™ freeze lining is based on the concept of production and maintenance of a protective "freeze" layer of process slag and metal on the hot face of the refractory by transferring heat away from the furnace lining. This is achieved through the combined effect of use of high conductive carbon and graphite refractory in the hearth and sidewall and efficient sidewall cooling with water curtain on the steel shell. This lining design relies on the transfer of heat from the core of the furnace, through the hearth and sidewall out, to the sidewall and achieves a well-distributed and balanced heat flux. This design also has measures for the movement of bricks in the lining during start-up and over its life span.

4. TEMCO FURNACE 1 FREEZE LINING

The UCAR® Chill-Kote™ freeze lining design was modified for Furnace 1 by TEMCO to accommodate three tap holes, thicker wall surrounding the tap holes, with the same heat flux profile as rest of the furnace, to counteract the adversity of physical attack and extend tap hole life and protect the hearth steel shell to a maximum of 150°C by the use of additional ceramic refractory and air-cooling (Appendix 1). The final design was justified through thermal finite element analysis (FEA) carried out by Bateman Titaco[1]. Numerical mesh, temperature contour and vector heat flux distribution of conventional and freeze lining (without freeze formation) are compared in (Appendix 2, Appendix 3, Appendix 4). The FEA results indicated a higher heat loss on the freeze lining . However with the freeze formation the heat losses for both linings would be similar in practice.

5. FREEZE LINING MONITORING

5.1 Monitoring Of TEMCO Conventional Lining

TEMCO has been monitoring the linings of furnaces since 1986 following the temperature trends of thermocouples installed in the hearth as well as in the sidewalls. The temperatures of these thermocouples and their trends have been an integral part of process control and furnace operating strategy. Temperature limit for every thermocouple is calculated based on a half thickness of the carbon lining using the basic principles of heat transfer. This method with reactive approach has deemed to be sufficient and working well for the TEMCO conventional lining.

5.2 Monitoring Of TEMCO Freeze Lining

The most important consideration in any "freeze" lining concept is to provide a proactive method for control of the configuration and thickness of the freeze during normal operation. that is able to achieve a true thermal equilibrium. The success of the freeze lining in real life operation is dependent on achieving a stable freeze at all times. The method of monitoring is needed to be more extensive and reliable. This has been achieved by installation of dual tip thermocouples at three levels in different locations of the hearth as well as the sidewalls, calculation of heat flow/flux through the hearth and sidewalls using the temperature readings from these dual tip thermocouples and principles of heat transfer and development of a 3D on line graphic presentation of the freeze using the heat flow data and a computer program.

5.3 Heat Transfer Algorithm for Freeze Lining

The cross-sectional view of the sidewall and the algorithm for calculation of hot face temperature are as below.

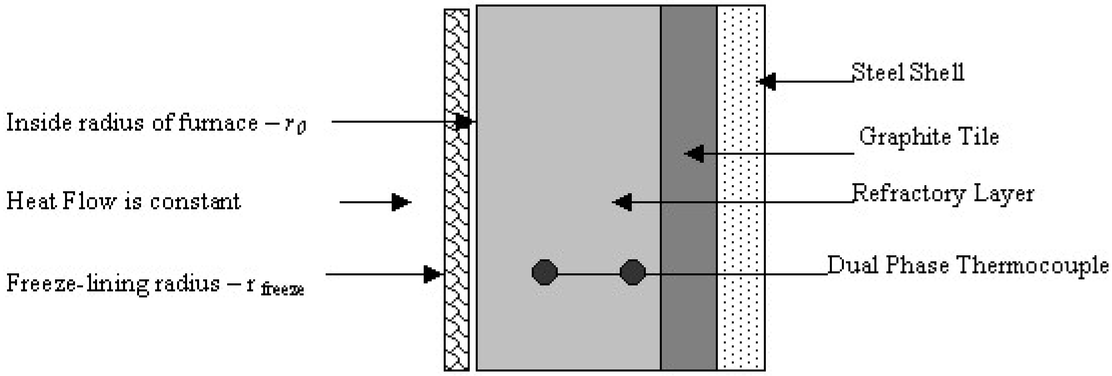

Figure 1. Cross-section of Furnace Sidewall.

$$Q = \frac{2\pi (T_2 - T_1)}{\left(\frac{Ln\left(\frac{r_2}{r_1}\right)}{K_{refractory}} \right)} \tag{1}$$

where: Q is the Heat Flow (W/m) through the sidewall

t_1 = cold face thermocouple temperature (K)

t_2 = hot face thermocouple temperature (K)

r_1 = inside radius (m) of cold face thermocouple

r_2 = inside radius (m) of hot face thermocouple

$k_{refractory}$ = thermal conductivity (W/mK) of refractory

Heat flow between the two thermocouples (Q) is calculated using the above equation and temperature data from dual thermocouples at known radii in the refractory lining. The calculated Q is used in the equation below to solve for the hot face temperature.

$$T_{Hotface} = \frac{QU}{2\pi} + T_{shell} \tag{2}$$

where: $U = \left(\frac{Ln\left(\frac{r_1}{r_0}\right)}{k_{refractory}} \right) + \left(\frac{Ln\left(\frac{r_2}{r_1}\right)}{k_{tile}} \right) + \left(\frac{Ln\left(\frac{r_3}{r_2}\right)}{k_{shell}} \right)$

If $T_{hot\ face}$ is higher than the melting point of the refractory brick the hot face wear can be obtained by equation 3,

The new hot face radius

$$r_0^* = \frac{r_0}{e^y} \tag{3}$$

where: $y = \frac{2\pi (T_{slag/metalliquidus} - T_{hotface}) k_{refractory}}{Q}$

The following equation can be used to calculate the freeze-lining radius when no wear has taken place.

$$r_{freeze-lining} = \frac{r_0}{e^y}$$

where: $$y = \frac{2\pi\left(T_{slag/metalliquidus} - T_{hotface}\right)k_{metal/slag}}{Q}$$

5.4 Computer program

The formulae in section 5.3 are the basis of the computer program. It uses differential thermocouple readings at each point on the furnace lining to calculate the radial heat flow in real time. Heat Flow calculations are made for each of the three levels of the sixteen-thermocouple segments. There are four additional thermocouples at tap hole level.

Hot face temperatures are calculated by using the heat transfer algorithm and a known reference temperature from a shell contact thermocouple in each segment. An approximate freeze lining width is also calculated by using the hot face temperature and a worst-case estimate of the thermal conductivity of the freeze.

The program also calculates an actual wear isotherm based upon the design wear temperature of the lining refractory. This measure is stored as a radial profile that is used for displaying the estimated unaffected lining level, which is a measure of the wear isotherm into the lining. This measure is calculated for all thermocouple segments at each of the three levels of the furnace and takes into account the different lining brick configurations and wear characteristics.

A facility has also been implemented where thermocouple readings may be taken offline and replaced with a user supplied reading. This allows users to conduct scenario mapping for known and unknown conditions at any segment or level of the furnace. These scenarios are implemented in the real time system and can therefore be based on the real time condition of the lining

The flux model algorithm has been programmed at the Distributed Control System (DCS) control level in order to produce real time model calculations. The program is constructed from typical DCS control and calculation blocks used in programming the Honeywell Plantscape controller. These Calculation blocks run at 1-second calculation cycles and all of their values are available to the SCADA system.

This allows for normal furnace alarms (PVHIGH, PVHIHI) to be generated from any model variable. Alarm action's measures such as furnace reduce load and furnace trip can also be coupled into any process or alarm event trigger from within the controller.

5.4.1 Sensitivity

The sensitivity of the model is determined by: heat transfer principles, integrity of the lining, thermocouple readings, conductivities of lining materials and the assumption of a 100% radial scalar heat flow in the model rather than a multidimensional vector. The sensitivity of the model is mainly affected by the accuracy of the readings from the dual thermocouples and not the reference thermocouple.

5.4.2 Model Validation

The model was validated at start-up by installing sacrificial thermocouples at the hot face of each of the thermocouple locations. Later in the lining campaign, validation will also occur by measuring drilled tap hole length against the theoretical depth determined by the model.

5.4.3 Graphical Representation

The model results are displayed in the SCADA system by exposing all variables to the SCADA data framework. Data is represented as schematic overviews of process mimics, historical trends and an interactive dimensional model (Fig 2-4). Conventional SCADA display abilities are used for process mimics and historical trending on variables such as: Temperatures, radial profiles, lining flux, shell flux, wear profiles.

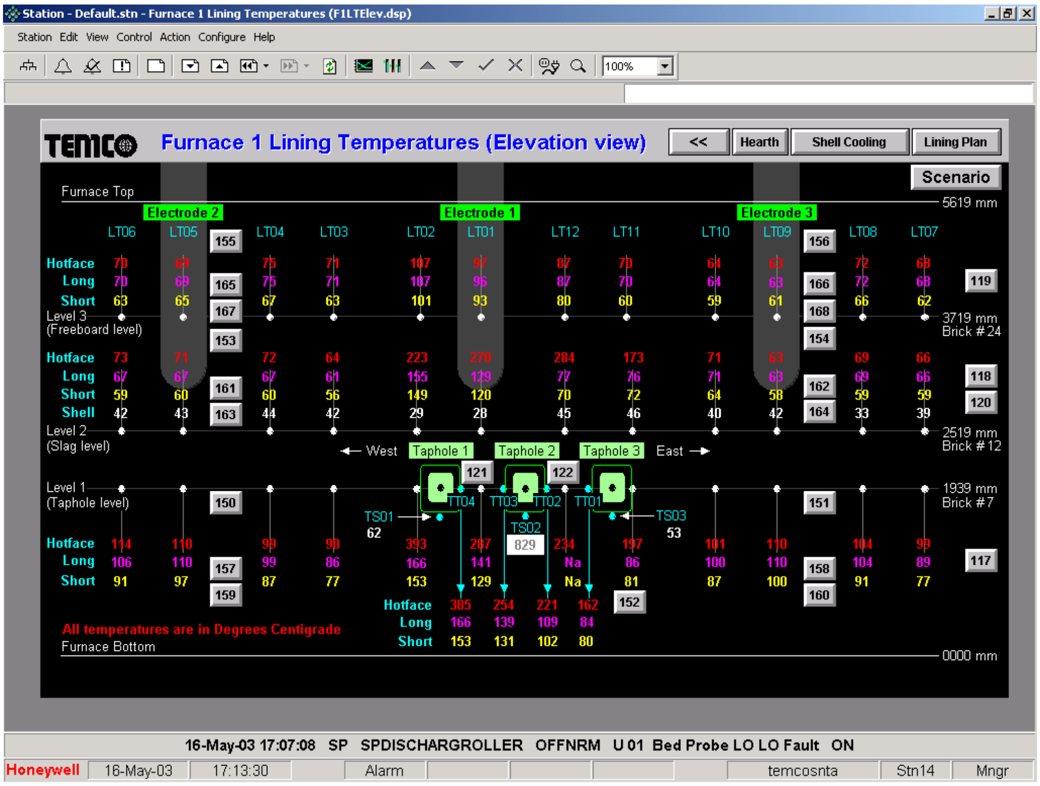

Figure 2. Thermocouples for all shell segments, tap hole, and calculated hot face temperatures.

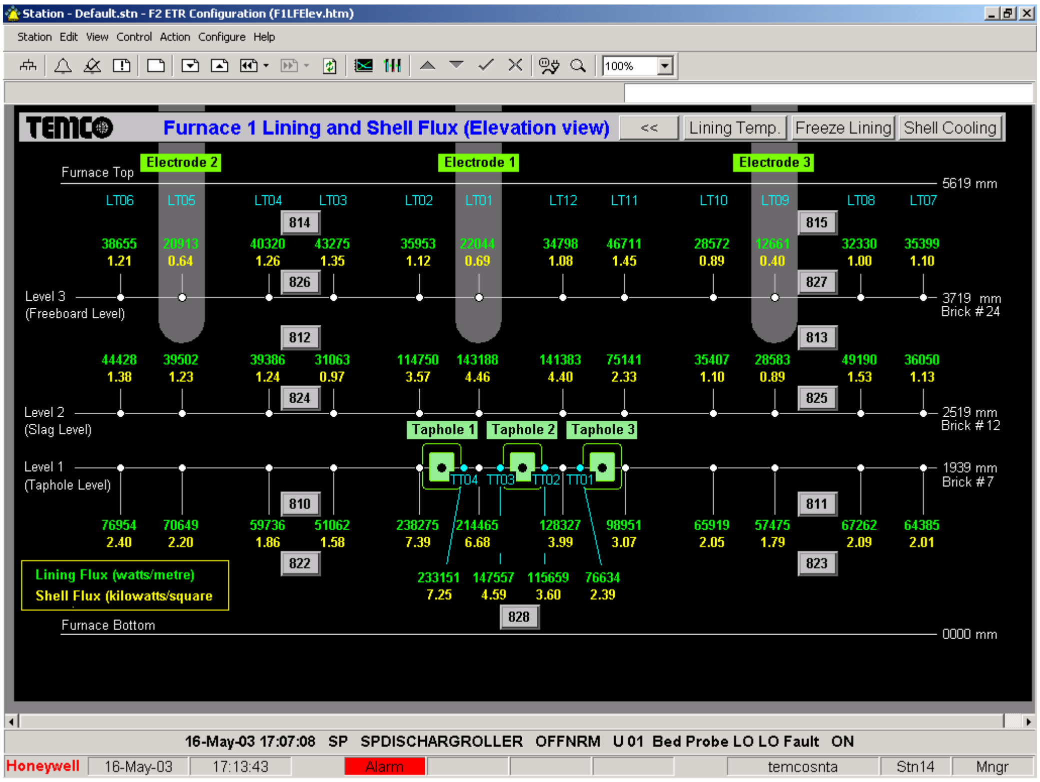

Figure 3. Heat Flux readings for each segment.

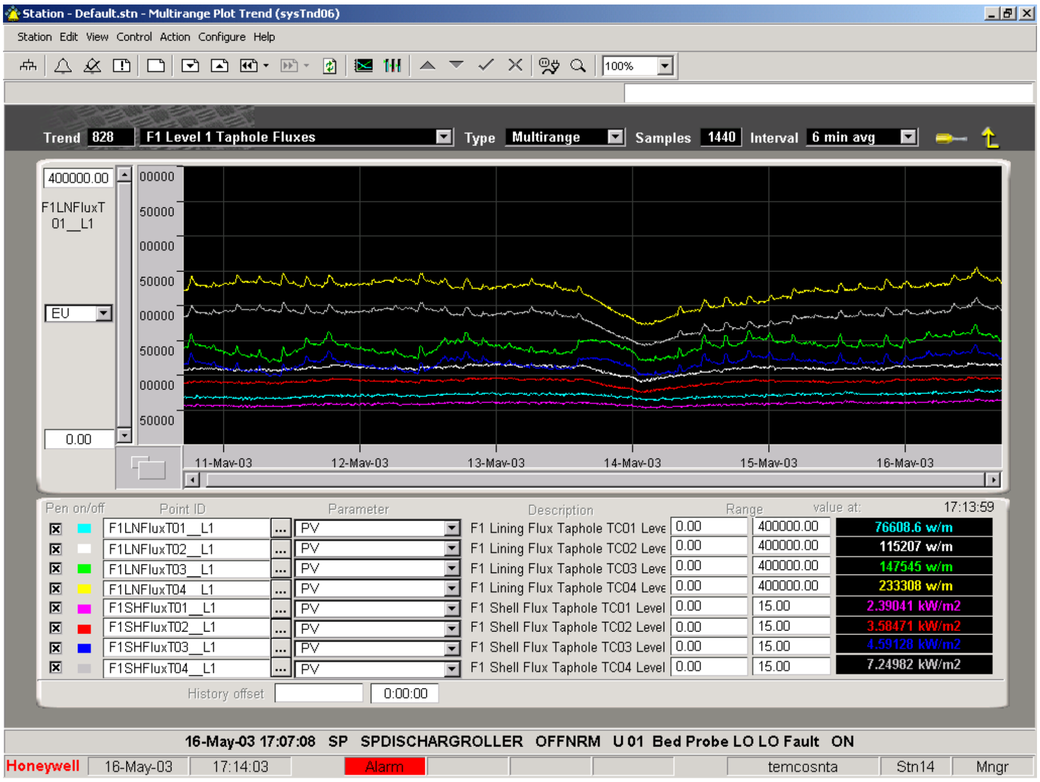

Figure 4. Heat flux trends for tapholes.

5.4.4 Interactive Freeze line Model

The interactive dimensional model is constructed as an ActiveX control that is embedded within the SCADA screen and supplied with data by the SCADA system. The control provides a plan view of the furnace lining and displays each of the lining components: Shell, Refractory (inferred wear radius) and freeze lining (Figure 5,6). Component object model and OLE (Object, Linking and Embedding) automation allow the graphical control to be embedded inside any OLE compliant application such as Excel or Word. Windows control objects such as sliders allow the control to be configured to view a radial cross section of the furnace at any angle.

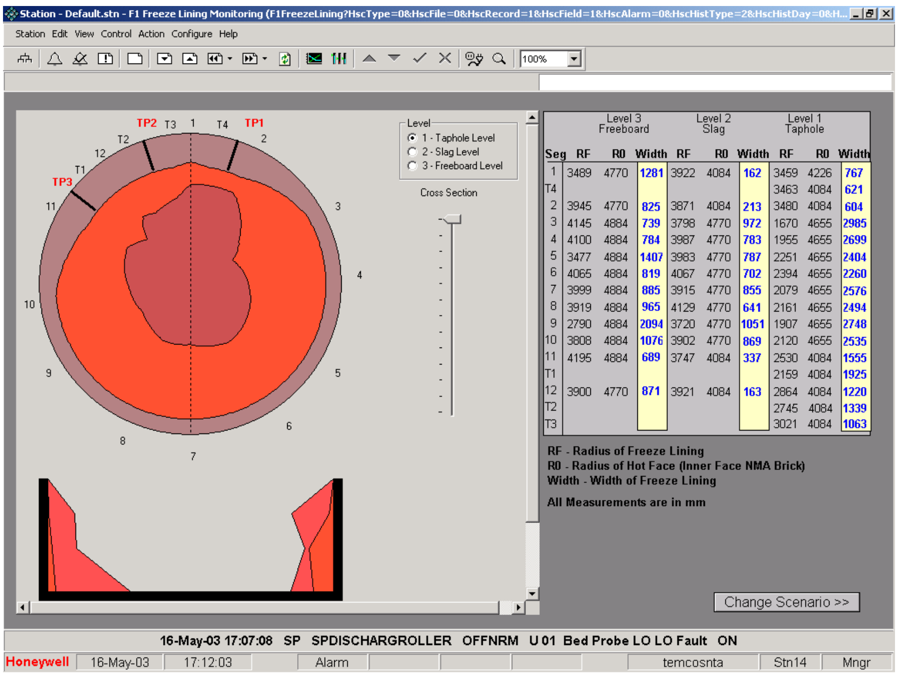

Figure 5. Interaction Freeze Line Model at tap hole level.

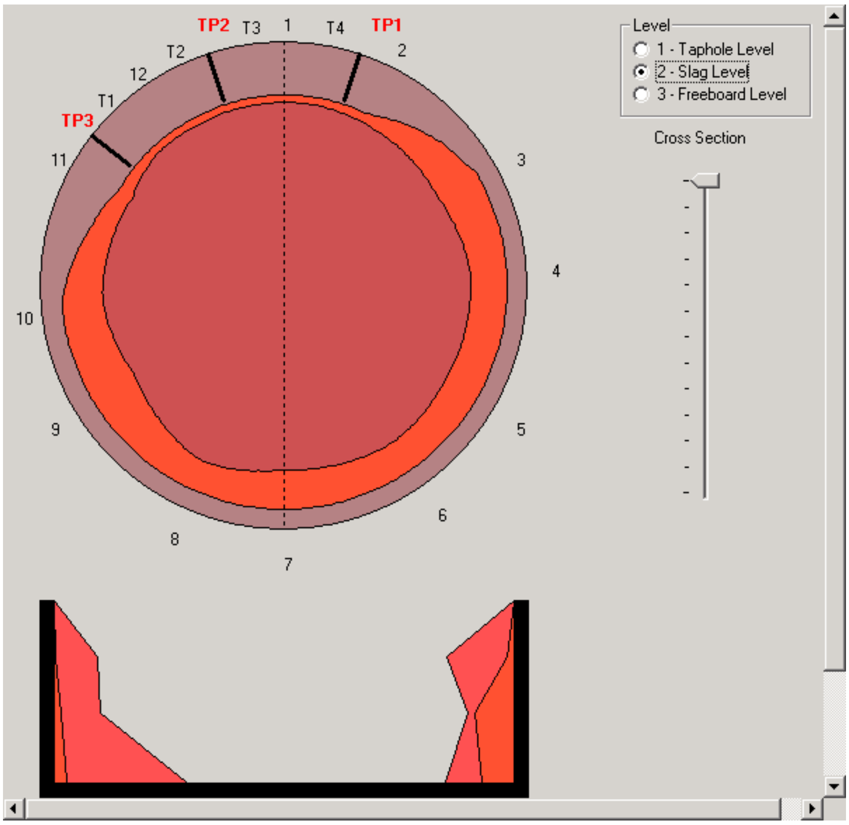

Figure 6. Interaction Freeze Line Model at slag level.

6. APPLICATION OF THE MODEL

Technical and Operating staff use these tools in a wide range of tasks that include: normal operations, exceptional condition handling, alarming, alerting, technical investigations and scenario planning. The model has been useful in looking at the extent of tap hole wear. We have seen large movements in smelting zone during product changeovers from Ferro-manganese to Silico-manganese and vice versa. The model has an advantage over thermocouple reading in monitoring the shape and movement of smelting zone in association with process parameter changes, such as furnace power, electrode resistance, and raw material mix.

7. CONCLUSIONS

This model is the first of its kind developed by Temco and Bateman Titaco. Initial objectives to study the movement of freeze line and wear pattern have been achieved. The model needs more development to realise its full potential. The model can be used in designing future furnace linings.

8. REFERENCES

[1] Marx G.F. & Henning B.J. *Thermal Finite Analysis of the Temco Bell Bay High Carbon FeMn/SiMn FurnaceApplied Heat*, Bateman Titaco, 2000

APPENDIX 1 - CONVENTIONAL VS FREEZE LINING

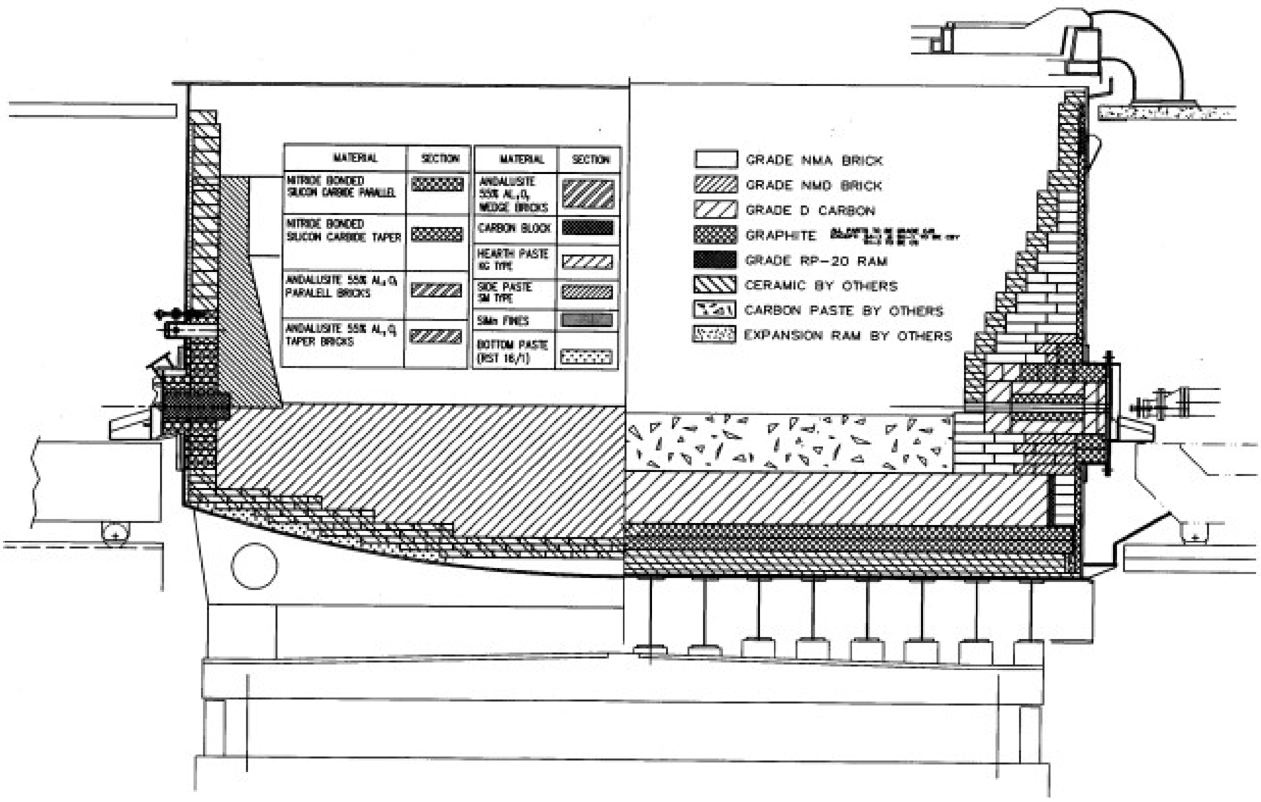

Figure 7. Conventional vs Freeze lining crossection.

APPENDIX 2 – FEA OF TEMCO CONVENTIONAL LINING

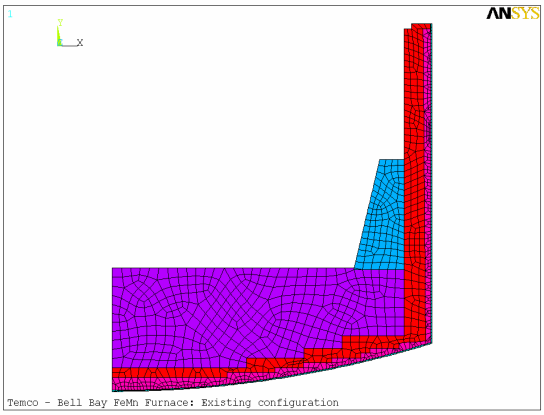

Figure 8. Numerical mesh for TEMCO conventional lining.

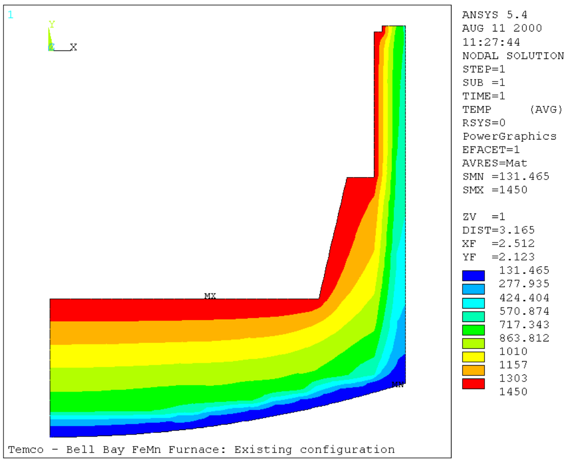

Figure 9. Temperature contour distribution of the TEMCO conventional lining.

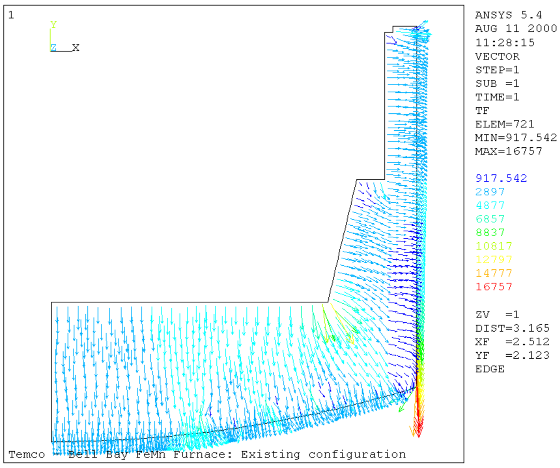

Figure 10. Vector heat flux distribution of the TEMCO conventional lining

APPENDIX 3 – FEA OF TEMCO FREEZE LINING

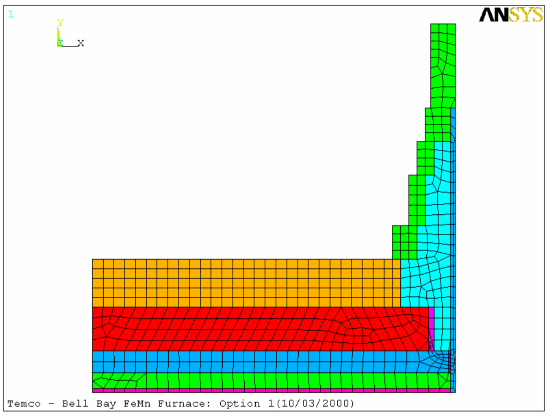

Figure 11. Numerical mesh

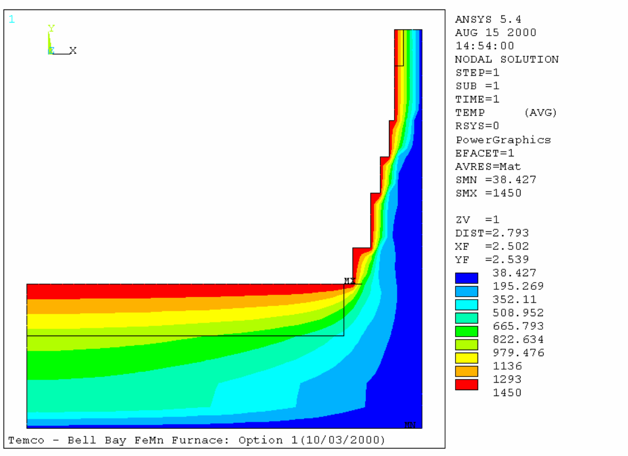

Figure 12. Temperature contour distribution

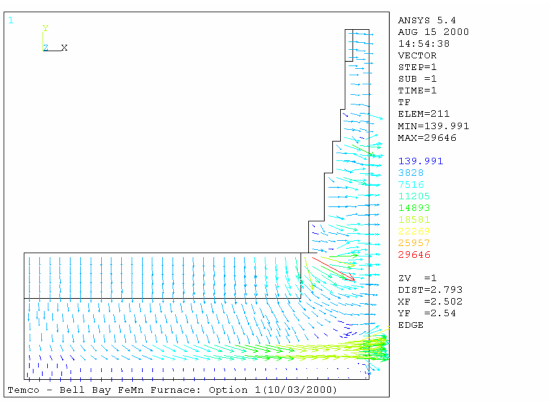

Figure 13. Vector heat flux distribution

APPENDIX 4 – FEA OF TEMCO FREEZE LINING

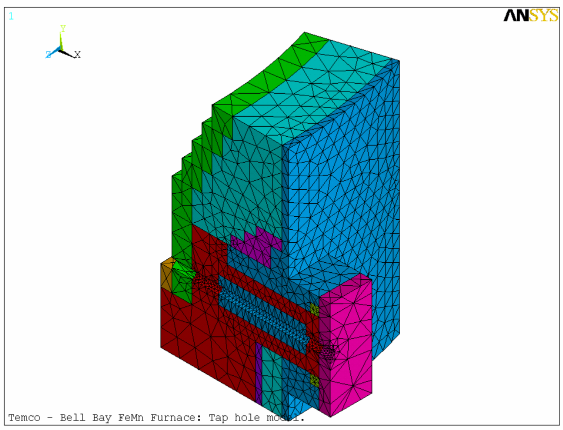

Figure 14. Numerical mesh for TEMCO freeze line tap hole

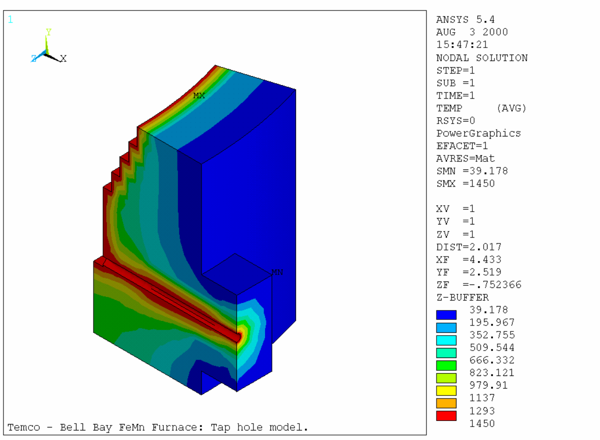

Figure 15. Temperature contour distribution of the Temco freeze line taphole.