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The Monitoring and Repair of Furnace Linings at TEMCO

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The Tasmanian Electro Metallurgical Company, TEMCO, carried out an upgrading programme from 1985 to 1988 in which the capacities of three manganese furnaces were increased while still retaining the same furnace hearth, side-wall, and cover geometry. A strategy involving continual monitoring and repair of the lining was implemented owing to increased stressing of the lining.

TEMCO uses a combination of thermocouple monitoring, infrared thermography, and heat-flux monitoring to highlight any areas of concern in the integrity of the lining of each furnace. No single technique of monitoring is used in isolation owing to the limitations of each method. Should a problem area be detected, the furnace lining can be repaired by the use of one of two techniques.

If it is determined that there are voids between the furnace lining and the steel shell resulting in an insulation layer, then cold-face grouting is employed to fill these voids with a carbonaceous material of high heat conductivity. This results in a more efficient removal of heat from the furnace via the lining, and hence helps push the freeze line back into the furnace. If, on the other hand, it is determined that there is damage to the inside of a lining, then the furnace is hot-face grouted. This involves the drilling of a hole through the lining and the pumping of a carbonaceous material to the interior of the lining with the intention of effectively repairing the damaged area.

The monitoring of furnace linings has been effective in detecting areas of concern, which have subsequently been repaired successfully. Successful repairs to furnace linings have included hearth and taphole repairs at Furnace 5, hearth and sidewall repairs at Furnace 1, and a sidewall repair at Furnace 2.

Introduction

The Tasmanian Electro Metallurgical Company, TEMCO, is a wholly owned subsidiary of the Broken Hill Proprietary Company Limited, BHP. The TEMCO operation is located at Bell Bay in northern Tasmania, Australia. TEMCO was established in 1960, and the Bell Bay site was chosen because of the availability of abundant hydro-electric power, the availability of suitable land, and the nearby access to a deepwater port.

In 1962 a 13,2 MVA Elkem furnace was commissioned, and this produced ferromanganese and silicomanganese alternately. In 1966 Furnace 2, a 15 MVA Elkem furnace, was commissioned, and this shared a common raw-material feed system and building with Furnace 1. Together the furnaces had a total annual production of 45 kt of ferromanganese and 21 kt of silicomanganese.

In 1976 a 600 t/d Lurgi sinter machine was commissioned to sinter Groote Eylandt manganese fines, and a 45 MVA Elkem ferrosilicon furnace, Furnace 5, was commissioned to produce 25 kt per year. In 1977 a 29 MVA Elkem furnace, Furnace 3, was commissioned, increasing the yearly plant capacity to 135 kt of ferromanganese equivalent.

During the period from 1985 to 1988, an uprating programme was carried out to increase the capacity for manganese alloy by 40 per cent and to upgrade the equipment. Furnace 1 was uprated to 29 MVA, Furnace 2 to 27 MVA, and Furnace 3 to 36 MVA. Modular electrodes were installed at Furnaces 1 and 2, and casting machines were installed for Furnaces 1 and 2 combined and Furnace 3. A process-control computer was also installed to monitor and control all the furnaces, and an Energy Recovery Unit, ERU, was commissioned to utilize the off-gas from the manganese furnaces to generate 10 to 11 MW of power.

The operating loads for Furnaces 1 and 2 were increased from 12 to 18 MW, and for Furnace 3 from 18 to 24 MW However, all the furnaces retained the same furnace hearth, sidewall, and cover geometry. This resulted in increased stressing of the lining, and therefore a strategy involving the continual monitoring and repair of the lining was developed to ensure maximum lining life at the desired load levels.

Lining Monitoring

TEMCO's experience suggests that no single method is adequate for monitoring the condition of furnace linings, and hence use is made of a combination of three different measuring techniques: thermocouple monitoring, infrared thermography, and heat-flux monitoring. The advantages and disadvantages of the three techniques are listed in Table I.

TABLE I
ADVANTAGES AND DISADVANTAGES OF LINING MONITORING TECHNIQUES

Method	Advantages	Disadvantages
External thermocouples	Continuous data Ease of interpretation Known technology Alarm function Non-intrusive	Electrical insulation Single-point data Good contact essential Vulnerable to mechanical damage Large numbers required Subject to surface effects
Intrusive dual thermocouples	Continuous data Ease of interpretation Known technology Alarm function Heat-flux calculations No surface effects	Electrical insulation Single-point data Vulnerable to mechanical damage Large numbers required Intrusive
Infrared thermography	Fast High resolution Proven record Easy access Covers large area Non-intrusive	Approximation Subject to surface effects Sidewall only Non-continuous data
Heat-flux meter	Good approximation Non-intrusive Simple to use Flexible	Access difficulties Subject to surface effects Assumed k values Single-point data Non-continuous Interpretation of results

Thermocouple Monitoring

Each of the furnaces has thermocouples that are monitored continuously by the process-control computer system. Daily the operators review the graphical displays indicating temperature trends to detect any adverse trends, and the computer initiates alarm messages if the absolute temperature measured reaches a predetermined alarm level.

Furnaces 1 and 3 both have external thermocouples mounted on the sidewall steel shell. These furnaces also have dual thermocouples inserted in the hearth to depths of 75 and 150 mm. The thermocouples at 150 mm are those most commonly monitored.

Furnace 2 has dual-depth thermocouples inserted in both the sidewall shell and the hearth to depths of 75 and 150 mm, which are monitored continually by the process control computer.

Furnace 5 has hearth thermocouples, which are also monitored continually by the process control computer.

The disadvantage of thermocouples in the external shell is that the measurement is subject to surface effects such as ambient air temperature and wind. This disadvantage was overcome in the 1987 relining of Furnace 2, during which dual thermocouples were installed in the brickwork.

Infrared Thermography

Thermographic surveys of each of the furnaces are carried out on a monthly basis by a contractor. The contractor presents a summary of the results to TEMCO personnel on the day of the survey, and issues reports soon after. The survey indicates whether there are any areas of the furnace shell that have become either hotter or cooler since the previous survey, and if there are any areas that require subsequent attention. Surveys have indicated the need for cold-face grouting repair on occasions. The whole sidewall shell is surveyed on each of the furnaces, and photographs are taken of the taphole regions, the regions adjacent to electrodes, and any other areas of concern.

Heat-flux Measurement

Heat-flux measurements are carried out periodically on any one of the four furnaces. Measurements are normally carried out every six months, but are also made by the operators to investigate a suspect area of the lining that has been highlighted by thermocouple readings and/or infrared thermography. These measurements are a guide to determining the position of the alloy–lining interface in the furnace.

Heat flux is measured with a Kyoto Electronics E500 type sensor. This consists of a sensor mounted in a holder with four magnets to enable the sensor to be mounted on the steel shell. The points of interest on the surface of the shell are cleaned by scrubbing with a wire brush before the sensor is mounted to enable good contact between the sensor and the shell. Both the hearth and the sidewall can be monitored subject to ease of access.

Alarm Strategy

The lining philosophy used at the TEMCO furnaces involves the extraction of heat as quickly as possible through the lining, thus keeping the freeze line of the alloy as close to the lining–alloy interface as possible. To suit this purpose, a carbon lining material is used as the major component owing to its high thermal conductivity. A typical lining, that of Furnace 2, which was relined in 1988, is shown in Figure 1.

For the hearth, Carblox AAN cold ramming paste is used as the carbon component. The heat flow depends upon the temperature difference between the shell and the inside face of the lining, and on the thermal conductivity across the lining. It has been found that graphitization occurs to a large extent in the upper regions of the hearth and to a lesser extent in the lower regions, resulting in an increase in the thermal conductivity of the carbon[1]. A thermal conductivity of 22,0 W/m.K is therefore assumed for the carbon layer.

Because of the low thermal gradient through this carbon layer, a layer of Hiamul 60 per cent alumina bricks is used as a thin insulation layer to protect the outside shell from excessive temperatures. These bricks provide a steep thermal gradient in that the thermal conductivity coefficient is 1,68 W/m.K.

Finally, to provide efficient heat flow between the steel shell and the Hiamul bricks, RST-16 cold ramming paste with a thermal conductivity coefficient of 10,0 W/m.K is used.

For the sidewall lining, a paste wall consisting of Elkem type SM (silicon-metal) paste is used in the area exposed to

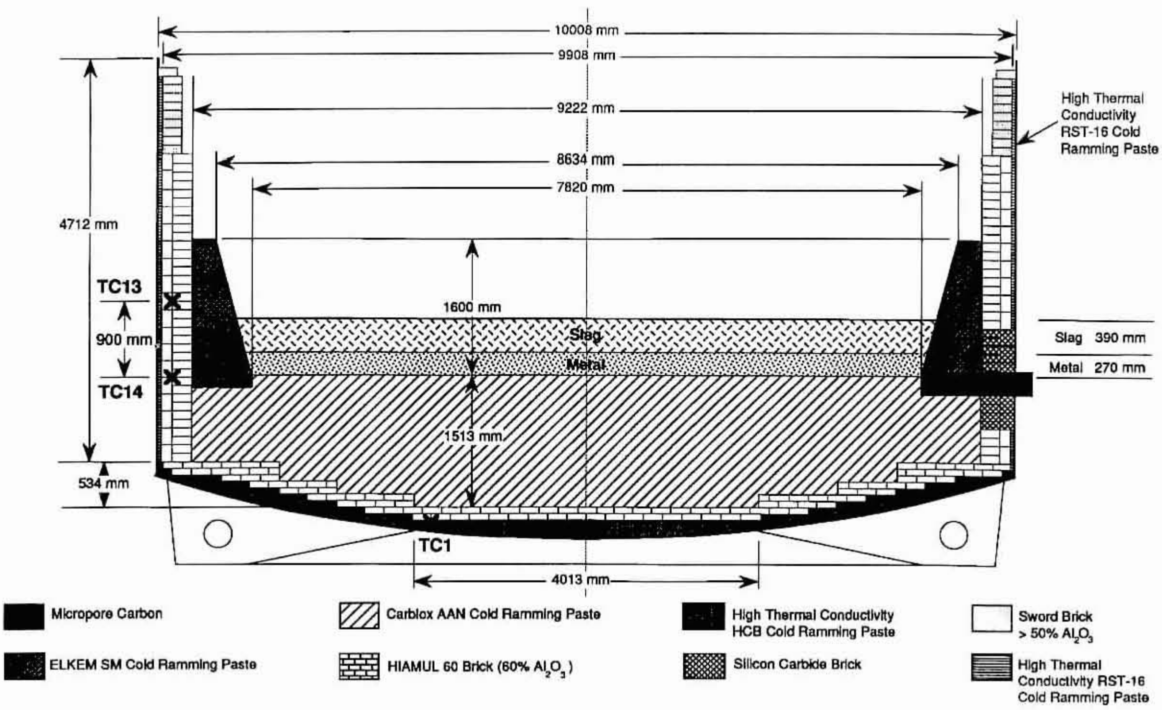

FIGURE 1. Furnace 2 lining, indicating components, theoretical maximum metal and slag levels, and selected thermocouple positions

metal and slag. This type of carbon lining has a thermal conductivity of 7,0 W/m.K. Once again, Hiamul 60 bricks are used for the insulation layer, and HCB cold ramming paste with a thermal conductivity coefficient of 10,0 W/m.K is used between the bricks and the shell to promote efficient heat transfer.

Figure 2 indicates the thermocouple locations on Furnace 2. The thermocouples of interest are located 150 mm into the lining from the steel shell on both the hearth and the sidewall. If the conductive heat flow through the composite lining materials is calculated and equated to the heat loss from the shell by radiation and convection, it can be used as a basis for the determination of alarm setpoints.

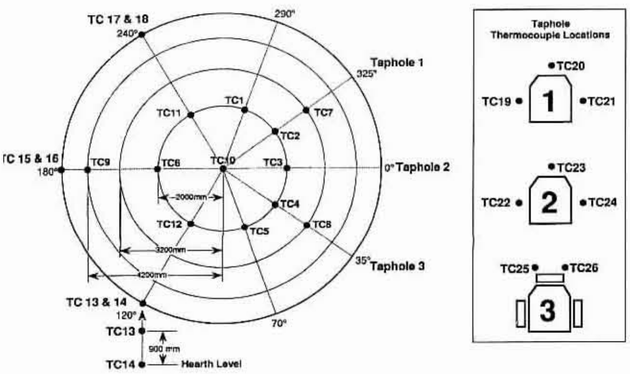

FIGURE 2. Plan view of the thermocouple and taphole positions on Furnace 2

Heat flow by conduction through the lining is given by

$$q = \frac{T_2 - T_1}{r_4\left[\frac{\ln(r_2/r_1)}{k_1} + \frac{\ln(r_3/r_2)}{k_2} + \frac{\ln(r_4/r_3)}{k_3}\right]}, \qquad [1]$$

where

q = heat flow (W/m²)
T_2 = temperature on the inside face of the lining (K)
T_1 = temperature on the outside face of the lining (K)
r_n = radial positions of lining interfaces (m)
k_n = thermal conductivity of lining components (W/m.K)

Equation [1] is derived from the standard form for heat loss by conduction for multi-layer cylindrical walls[2] and enables heat loss to be expressed in terms of heat loss per unit area of lining.

Heat loss per unit area by radiation is given by[3]

$$q = 5{,}669 \times 10^{-8} \times E \times (T_2^4 - T_1^4) \quad \text{W/m}^2. \qquad [2]$$

Heat loss per unit area by convection is given by[4]

$$q = 1{,}97 \times (T_2 - T_1)1{,}25 \quad \text{W/m}^2, \qquad [3]$$

where

E = emissivity
T_1 = temperature of ambient air (K)
T_2 = temperature on the outside face (K).

The heat losses via radiation and convection can be calculated and summed for various temperature intervals. The heat loss can then be approximated by the assumption of linear relationships within each of these intervals. Table II sets out the heat-loss equations for the various temperature ranges.

TABLE II
HEAT LOSS BY RADIATION AND CONVECTION FOR VARIOUS TEMPERATURE RANGES

Temp. range, K	Heat loss per unit area, W/m^2
373–423	17,92T–5 734
423–473	22,98T–7 878
473–523	28,60T–10 536
523–573	36,38T–14 650
573–623	44,28T–19 131
623–673	53,92T–25 137
673–723	65,08T–32 648
723–773	77,86T–41 888

If it is assumed that the temperature of the liquid metal in contact with the inside face of the lining is 1400°C, then the expected temperature of the outside face can be calculated. Similarly, if the inside face of the lining wears for a given distance, the expected temperature of the outside face can be calculated.

Thermocouple 14 is located in the sidewall of Furnace 2 at the level of the hearth indicated on Figure 1. From Figure 1 the r_n values can be determined for substitution into equation [1]:

$r_1 = 3{,}910$ m $\quad r_2 = 4{,}611$ m

$r_3 = 4{,}954$ m $\quad r_4 = 5{,}004$ m.

The thermal conductivities for each layer are as follows:

k_1 = (Elkem type SM paste) 7,0 W/m.K

k_2 = (Hiamul 60 bricks) 1,68 W/m.K

k_3 = (high-conductivity HCB cold ramming paste) 10,0 W/m.K.

Substitution of these values and T_2 = 1400°C (1673 K) into equation [1] yields

$$q = \frac{1673 - T_1}{5004\left[\frac{\ln(4{,}611/3{,}910)}{7{,}0} + \frac{\ln(4{,}954/4{,}611)}{1{,}68} + \frac{\ln(5{,}004/4{,}954)}{10{,}0}\right]}$$

$= (1673 - T)/0{,}3368$

$= 4967 - 2{,}97T.$ [4]

If T is in the range 473 to 523 K, the heat loss from the shell, as indicated by Table II, will be given by

$q = 28{,}60T - 10536.$ [5]

Equating equations [4] and [5] yields

T_2 = 491K (218°C).

As the temperatures at both extremes of the thermal gradient are known, a linear equation can be constructed that will provide an approximate temperature at a given position of thermal resistance. A simplified expression[5] for heat flow is

$$q = \frac{\Delta T}{RH}.$$ [6]

A comparison of equations [1] and [6] shows that the thermal resistance across the lining, R_H, is 0,3368 m^2.K/W. At the outside face of the lining, the thermal resistance will be zero. Therefore, at 1400°C, R_H = 0,3368 m^2.K/W; at 218°C, R_H = 0,0 m^2.K/W. The combination of these two coordinates into a linear expression yields the result

$T = 3510\,(R_H) + 218$°C. [7]

The R_H value for thermocouple 14 can be calculated from the resistance component of equation [1]. As the thermocouple is located 150 mm into the lining, r_t is 4,854 m. Therefore, for thermocouple 14,

$$R_H = \left[\frac{\ln(4{,}954/4{,}854)}{1{,}68} + \frac{\ln(5{,}004/4{,}954)}{10{,}0}\right]$$

= 0,0680 m^2.K/W.

The temperature at the thermocouple can be calculated from equation [7]:

T = 3510(0,0680) + 218°C

= 457°C.

The temperature expected if the alloy has penetrated halfway through the refractory can be calculated in the same way. In that case, the value for r_1 changes from 3,910 to 4,261 m. By substitution of the new value for r_1 into equation [1], an alarm temperature can be calculated:

$$q = \frac{1673 - T_1}{5004\left[\frac{\ln(4{,}611/4261)}{7{,}0} + \frac{\ln(4{,}954/4{,}611)}{1{,}68} + \frac{\ln(5{,}004/4{,}954)}{10{,}0}\right]}$$

= $(1673 - T)/0{,}2752$

= $6080 - 3{,}63T.$ [8]

Equating equations [8] and [5] yields

T = 526 K (253°C).

At 1400°C, R_H = 0,2752 m^2.K/W and at 253°C R_H = 0,0 m^2.K/W. Therefore, when they are combined into a linear expression,

$T = 4168\,(R_H) + 253$°C. [9]

R_H for thermocouple 14 is 0,0680 m^2.K/W. Therefore, the alarm temperature is calculated from equation [9] as

T = 4168(0,0680) + 253°C

= 536°C.

The predicted heat-flux values for the as-installed and the half-worn paste lining can be calculated from equations [4] and [8] respectively:

As-installed: $q = 4967 - 2{,}97T$
$= 4967 - 2{,}97\,(510)$
$= 3452$ W/m^2.

Half-worn: $q = 6080 - 3{,}63T$
$= 6080 - 3{,}63\,(526)$
$= 4170$ W/m^2.

Similarly, alarm temperatures, expected shell and thermocouple temperatures, and expected heat flux values can be calculated for all the other sidewall and taphole thermocouple positions from the same equations.

For the furnace hearth, equation [10] is used to represent the heat flow through a planar composite lining[6]:

$$q = \frac{T_2 - T_1}{\left(\frac{\Delta x_1}{K_1} + \frac{\Delta x_2}{K_2} + \frac{\Delta x_3}{K_3}\right)}.$$ [10]

The position of thermocouple 1 is shown in Figures 1 and 2. From Figure 1, the lining thicknesses, or x values, can be determined for substitution into equation [10]:

$x_1 = 1{,}513$ m

$x_2 = 0{,}152$ m

$x_3 = 0{,}180$ m.

The thermal conductivities for each layer are

k_1 = (Carblox AAN cold ramming paste) 22,0 W/m.K

k_2 = (Hiamul 60 bricks) 1,68 W/m.K
k_3 = (high-thermal-conductivity HCB cold ramming paste) 10 W/m.K.

Substitution of these values into equation [10] yields

$$q = \frac{1673 - T_1}{\left(\frac{1,513}{22} + \frac{0,512}{1,68} + \frac{0,180}{10}\right)}$$

$= (1673 - T_1)/0,1772$

$= 9441 - 5,643T.$ [11]

The expected temperatures and heat flux for the as-installed and half-worn conditions of the hearth can be found by the same method as was used for thermocouple 14:

As-installed:

Thermocouple temperature	392°C
Shell temperature	299°C
Heat flux	6213 W/m^2

Half-worn condition:

Thermocouple temperature	441°C
Shell temperature	328°C
Heat flux	7502 W/m^2.

The expected values for the other thermocouple locations in the hearth can be calculated in a similar way.

The method for determining this alarm strategy does not purport to be based on a highly accurate knowledge of thermal gradients, but it does give a reasonable approximation, which has proved successful at TEMCO.

Grouting

TEMCO uses two different methods to grout the furnaces, depending on the lining-repair requirements: cold-face grouting or hot-face grouting.

Cold-face Grouting

All the furnaces are cold-face grouted regularly by one of two environmental crews. These crews are responsible for the furnace off-gas equipment, the water-treatment plant, and the grouting. Each crew is responsible for grouting two furnaces, and at least once a week will attempt to grout either the sidewall or the hearth of one of the furnaces for which it is responsible. If the monitoring techniques detect a lining concern, the crews are flexible enough to respond immediately and grout that area. The grout material used is fine-grained anthracite in a resin binder.

The 25 kg drums of grout are heated on a burner system until the grout has a workable fluidity. The grout is then pumped to each individual grouting point on the sidewall shell or the hearth until the flow ceases.The grouting pump is of a positive-displacement type, and was designed by TEMCO and manufactured in Tasmania.

Grouting points are typically located 1 m apart both horizontally and vertically, with three horizontal rows starting at the taphole level. Additional grouting points are located around the tapholes.

Cold-face grouting is carried out to fill any voids between the furnace lining and the steel shell. Such voids will result in an insulation layer and therefore reduce the extraction of heat from the furnace interior. If there is an insulating effect, the freeze line will penetrate further into the lining, resulting in wear to the face of the inner lining. Cold-face grouting reduces the risk of such damage.

Hot-face Grouting

Hot-face grouting is carried out to repair the inside of the furnace lining. If there is severe damage to the working face of the lining, it may be detected from very high thermocouple temperatures or very high heat-flux measurements, or from hot spots distinguished by infrared thermography visually, or (in the worst case) a metal breakout.

Hot-face grouting is carried out as follows. A hole is drilled through the full thickness of the lining, and the grout is pumped through this newly created channel. The grout effectively replenishes the carbon lining that has been consumed. The hot-face grouting material contains coarser particles of anthracite than the cold-face grouting material and less resin binder. The pump used for hot-face grouting is an Ingersollrand PDA 300 air-operated diaphragm pump.

Case Histories

There are several notable examples of the successful repair of linings by hot-face grouting.

Repair of Furnace 1 Sidewall

At the completion of a tap of Furnace 1 on 4th March, 1990, a hot spot was observed visually on the eastern side of the taphole in use. The furnace was subsequently switched off, and preparations were made for hot-face grouting of this area of the lining.

A hole was cut in the shell 70 cm above the horizontal centre line of the taphole and vertically above the hot spot. A grouting point, consisting of a steel pipe fitted with a quick-release coupling, was welded to the shell around the hole. A hole was then drilled through the lining with a rock drill. Thirty-five drums (875 kg) of grout were pumped into the furnace.

The grouting of the lining proved to be successful, and no more lining problems were encountered in that area.

Repair of Furnace 1 Hearth

On 1st August, 1990, Furnace 1 changed over from silicomanganese to ferromanganese production. The hearth temperatures increased continually following the changeover, and on 6th August the hearth was cold-face grouted. On 7th August the temperatures on two of the hearth thermocouples rose by 150 and 200°C respectively over a twelve-hour period. The temperatures exceeded the alarm limits, and the furnace was switched off, a sand wall was built around the furnace, and the furnace was drained. Heat-flux measurements indicated that the 1400°C isotherm was very low in one region of the hearth.

A schematic diagram of the furnace lining is shown in Figure 3. The thermal resistance of each layer can be calculated from the resistance component of equation [9]:

$$R_H = \frac{(\Delta x)}{k} \text{ m}^2\text{.K/W}. \quad [12]$$

At a position on the hearth near thermocouple 5, beneath number 1 electrode, the thermal resistance, as calculated by summing of the thermal resistances of each layer, was as follows:

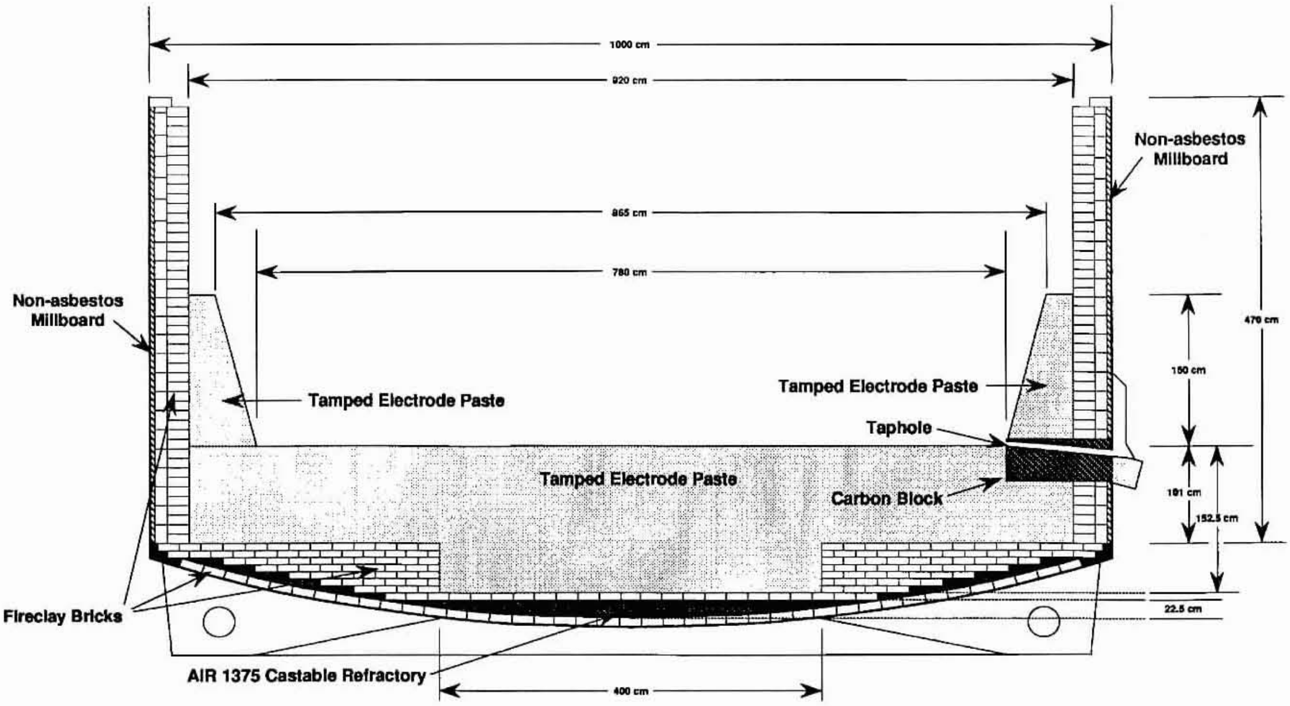

FIGURE 3. Furnace 1 lining, indicating the lining components

			R_H	Sum
Fireclay bricks	$\frac{0,075}{1,15}$	=	0,065	0,065
AIR 1375 cast	$\frac{0,075}{0,76}$	=	0,099	0,164
Fireclay bricks	$\frac{0,075}{1,15}$	=	0,065	0,229
Ramming paste	$\frac{1,525}{22,0}$	=	0,069	0,298.

If 1400°C is the temperature of the melt at the lining–melt interface and 204°C is the surface temperature, a theoretical heat flux can be calculated from

$$q = (T_1 - T_2)/R_H$$
$$= (400 - 204)/0,298$$
$$= 4013 \text{ W/m}^2.$$

A diagram of the lining indicating the thermal resistance of each layer and the theoretical heat flux can be constructed. Such a diagram is shown in Figure 4.

On 7th August, 1990, the heat flux measured at thermocouple 5 was 8794 W/m^2 and the surface temperature was 260°C. The thermal resistance between the 1400°C isotherm and the outside surface can be calculated by a re-arrangement of equation [6]:

$$R_H = (T_1 - T_2)/q \qquad [13]$$
$$= (1400 - 260)/8794$$
$$= 0,130 \text{ m}^2\text{.K/W}.$$

The heat flux can then be plotted on the lining diagram to give the position of the 1400°C isotherm. Figure 4 shows that the 1400°C isotherm was calculated to be in the

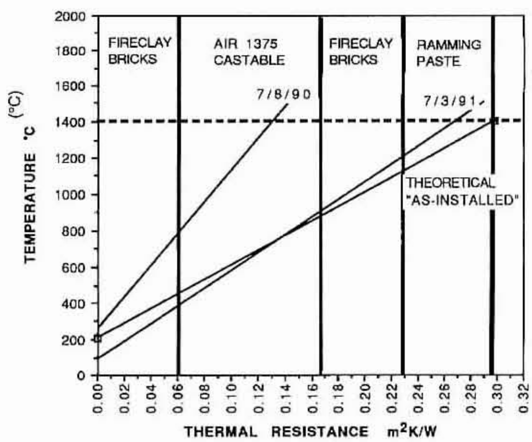

FIGURE 4. Theoretical and measured thermal gradients for suspect area in the hearth of Furnace 1

AIR1375 cast layer. Other heat-flux measurements indicated that the hearth was damaged in the surrounding area. A schematic diagram of the hearth indicating the damaged area is shown in Figure 5. It was assumed that the very high heat flux at thermocouple 5 was due to a metal run between the bricks and the rammed paste. This, too, is indicated in Figure 5.

It was decided that the hearth should be repaired by the setting up of an emergency launder and the drilling of a hole approximately horizontal to the calculated wear region. The furnace would be drained via this hole, and then hot-face grouted through the same hole.

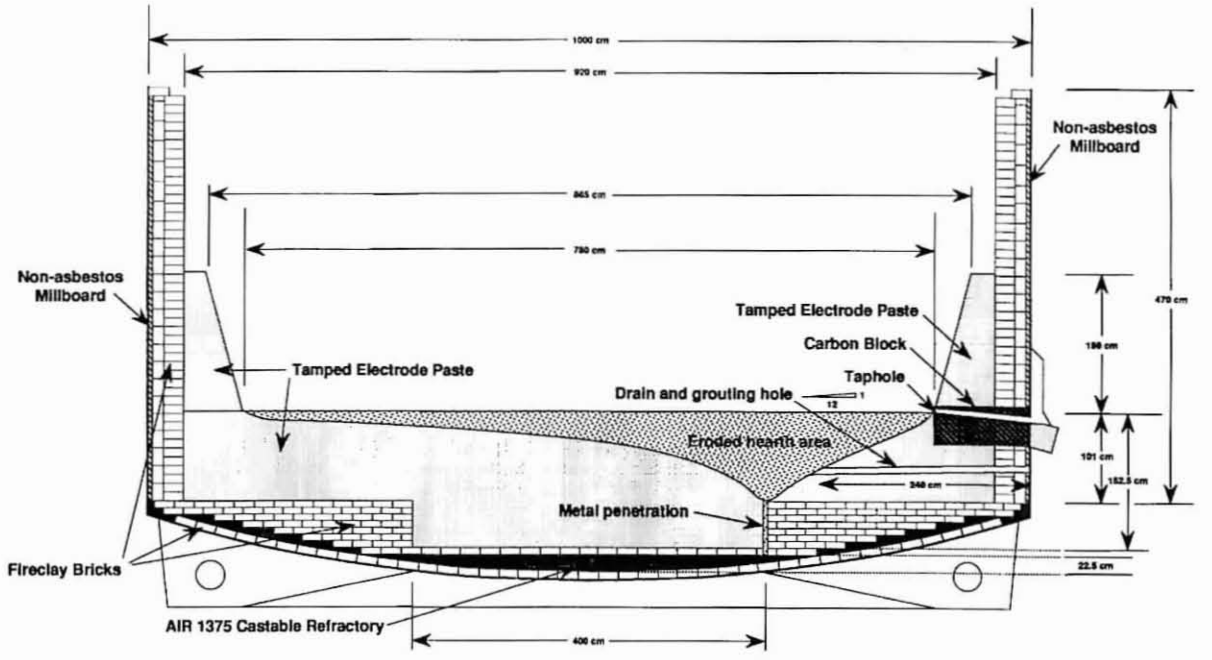

FIGURE 5. Furnace 1 lining, indicating the calculated lining damage to the hearth, and the position and penetration of the drilled grouting hole

From a point 0,5 m below and 1,0 m to the right of number 1 taphole, a hole was drilled with a 56 mm bit 210 cm into the hearth with a drop of 20 cm over that distance. A further 30 cm depth was achieved by oxygen lancing. Figure 5 shows the approximate penetration and direction of the drilled hole. Metal and slag ran for 3,5 hours before the flow ceased. A plate was welded to the shell, and a pipe fitted with a quick-release coupling was attached. The hole was redrilled with a 75 mm bit, and 230 drums (5750 kg) of grout were pumped into the hearth. The furnace was left off for 22 hours after grouting was complete to enable the paste to bake out. The furnace was subsequently turned on and, after the recovery period, operated successfully at full load.

Heat-flux measurements carried out in March 1991 indicated that the 1400°C isotherm had been pushed back to the upper region of the hearth, and thermocouple readings supported this conclusion. The heat flux at thermocouple 5 was measured at 4788 W/m^2 with a surface temperature of 95°C. From equation [13], a new thermal conductivity between the 1400°C isotherm and the outside surface can be calculated and the heat flux can be plotted as in Figure 4:

$$R_H = (T_1 - T_2)/q$$
$$= (1400 - 94)/4788$$
$$= 0{,}2728.$$

Similar results were achieved with the measurement of heat flux in several other positions. The results indicated that the hearth had been repaired satisfactorily.

Repair of Furnace 2 Sidewall

On 18th August, 1991, the reading from thermocouple 14 on Furnace 2 was observed to be trending upwards to the alarm level of 536°C. The furnace shell was subsequently cold-face grouted in the area of concern, and the temperature began to decline. Ten hours later the temperature rose dramatically and exceeded the alarm level. The furnace load was decreased by the computer-control system and, when the temperature reached 600°C, the furnace was turned off. A heat-flux survey was carried out in the region of thermocouple 14, which is at the hearth level directly adjacent to number 2 electrode in a position indicated in Figures 1 and 2. Heat-flux values of 7200 W/m^2 were measured at shell temperatures of 290°C.

The thermal resistance for each layer in that area can be calculated from the resistance component of equation [1]:

$$R_H = r_4\left[\frac{\ln r_2/r_1}{k_1}\right].$$

	R_H (m^2.K/W)	Sum (m^2.K/W)
HCB ramming	0,005	0,005
Hiamul 60 bricks	0,214	0,219
Elkem SM paste	0,118	0,337.

The 'as-installed' heat flux was calculated to be 3452 W/m^2, and the 'half-worn' heat flux to be 4710 W/m^2. These heat-flux values can be plotted together with the actual heat-flux measurement as in Figure 6, which indicates the thermal resistance of each layer. Figure 6 shows that the 1400°C isotherm of the alloy is located in the Hiamul brick layer.

A hole was cut in the shell, and a grout point was attached 50 cm above the hearth level vertically above the hot region. A hole was drilled through the lining, and 1800 kg of grout was pumped into the lining. After 18 hours, the thermocouple temperature had dropped to 400°C, and heat-flux measurements taken 48 hours after grouting were, on average, 4300 W/m^2 at shell temperatures of 160°C. This heat-flux value is plotted on Figure 6, and indicates that the 1400°C isotherm was pushed back into the furnace.

Repair of Furnace 5 Sidewall and Hearth

Several hot-face grouting repairs to Furnace 5 (ferrosilicon furnace) have also been successful. These were carried out on an area of the hearth that was subject to very high measured heat-flux values, a breakout above a taphole, and a cavity that extended from a taphole block into the hearth and was discovered during a shutdown.

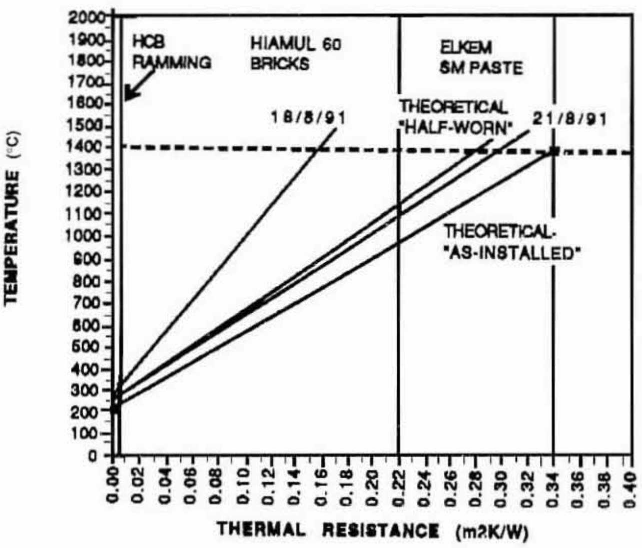

FIGURE 6. Theoretical and measured thermal gradients on Furnace 2 in the region of thermocouple 14

Conclusions

Monitoring of furnace linings by thermocouples, infrared thermography, and heat-flux measurements has helped TEMCO to increase and maintain loads that are 40 per cent higher than in previous operations on the manganese furnaces without changing the hearth or sidewall geometries.

The continual programme of cold-face grouting has ensured the efficient removal of heat through the lining, and hence the prevention of an increase in the penetration of the freeze line of the alloy into the lining.

Hot-face grouting has effectively repaired damage to the linings of Furnaces 1, 2, and 5 and, as such, has prevented the need for relining or partial relining of these furnaces.

The combination of monitoring and repair techniques used has not only prevented the necessity for relining in several instances, but is also expected to increase the lining life of each of the furnaces at operating loads that cause critical stress in the lining.

References

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