"FREEZE" LINING ON M12 FURNACE: MOTIVATION, INSTALLATION AND OPERATION

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ABSTRACT

The lining, together with the electrodes, forms the heart of the operation of a submerged arc furnace. Subsequent to a lining failure on M12 furnace during the early 1980s, Metalloys was active in investigating the concept of thermally efficient "freeze" linings for its furnaces. The theory revolved around that, not only would, thermally efficient linings result in significant cost savings, but they would also last longer as a result of being subjected to less harsh operational conditions. After having proved the concept on the "smaller" furnaces, Metalloys decided to implement the concept on its largest submerged arc furnace, M12.

Subsequent to having recovered from an impending failure of a lining installed in 1981 in M12 in the mid 1980s, Metalloys managed, through rigid lining management, to extend the life of this lining to 1999. At the end of 1999 the decision to replace the lining in the furnace with a "freeze" lining was made and planning and design proceeded in earnest. This paper discusses the options considered in making the final decision. The features of the design of the lining are also discussed. Consideration is given to the furnace shell cooling system as a result of its importance in maintaining the thermal equilibrium in the lining.

Note is made of the fact that the purchase of a "freeze" lining is an expensive exercise but that the time savings in the installation of the lining and the efficiency improvements during operation far outweigh the additional capital cost. The experience on M12 has been that the payback period of the marginal capital expenditure is less than three years.

As a result of the opportunity to reline a furnace the size of M12 not presenting itself very often, the learning points from the installation of the lining and the operational advantages and disadvantages are significant.

Finally, the point is made that the project had its pros and cons but overall the success of the project has been evident and, as such, the "freeze" lining is likely to become the norm at Metalloys.

1. INTRODUCTION

This paper will not give consideration to the technical and theoretical operational advantages to be gained from the "freeze" lining. These aspects are adequately dealt with in the paper entitled '"Freeze" Lining Concepts for Improving Submerged Arc Furnace Lining Life and Performance' presented at Infacon 8 [1]. The paper presented at Infacon 8 gave detailed consideration to the technical aspects of the "freeze" lining which was followed by a discussion on the operating philosophy of Metalloys regarding the aspects surrounding the linings of the submerged arc furnaces in operation at the plant. This paper presents the first-hand experience gained by Metalloys in utilizing the concept of the "freeze" lining on the 81MVA submerged arc furnace producing high carbon ferromanganese.

M12 furnace at Metalloys, an 81MVA submerged arc furnace, was commissioned in July 1978 and operated satisfactorily until November 1980 when the furnace broke out opposite number two electrode. During the dig-out of the furnace, in order to prepare the shell for relining, it became evident that the breakout was principally as a result of the thermal degradation of the carbonaceous lining material. This prompted the feeling that a "natural" lining protecting the hot face of the carbonaceous lining would act as a crucible in

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which the reaction could take place and there would theoretically be no degradation of the carbonaceous lining material.

At that point in time the "freeze" lining, as we know it today, was not available and an attempt was made with the normal carbonaceous material to utilize a "freeze" lining concept that would emphasize the maintenance of a thermal equilibrium in the process. The concept and operation of the lining was successful and, after an initial impending failure of the lining four years into the operation, the first signs of significant degradation of the lining became evident early in 1999 after 18 years of operation.

During the early 1990s work was undertaken with Emsa and UCAR to finalize a design for a "freeze" lining that was proven in one of the smaller Metalloy's furnaces. The design and installation of this lining is discussed in the paper presented at Infacon 8 [1]. This paper deals with the decision to reline, the final design, the lining installation, and the subsequent operation of the lining of M12 furnace at Metalloys. The furnace M12 is the largest, both in terms of physical size and in electrical rating, furnace at Metalloys.

2. THE DECISION TO RELINE

The decision to reline a furnace the size of M12 is not made lightly as the reline is not cheap. This decision is normally based on technical manifestations of impending lining failures so it is a binary yes/no type of decision. The decision as to what type of lining is a more complicated one that is based on financial and performance comparisons of the linings available.

2.1 Do we patch the existing lining or reline?

In the case of M12, it became evident early in 1999 that failure of the lining, after 18 years of operation, was a very strong possibility. The impending failure was indicated by the thermocouple monitoring in the sidewalls of the furnace, the thermographic imaging of the furnace shell, together with the drilling of cores in strategic sections of the lining.

In order to place the monitoring of the lining integrity in perspective, the thermocouple monitoring, although not infallible, was deemed to address the need for continuous monitoring of the high wear rate areas of the lining by means of duplex thermocouples, complimented by a structured program of thermographic imaging of the furnace shell. An important aspect that was evidenced during the core drilling exercise is that the areas that were theoretically determined to be the high wear areas of the lining, and thus had thermocouples, were not exclusively high wear areas and other high wear areas were not continuously monitored using thermocouples. This resulted in the decision to install about six times as many thermocouples in the new lining as there were in the old lining.

The thermographic imaging indicated areas of high temperature around and between the slag tapholes. M12 has two slag tapholes located at a level of 1 meter above the level of the metal tapholes and radially 45 degrees from the furnace centerline. In order to confirm that the lining was in a bad condition in this area of the furnace and to be in a position to compare the state of the lining in different areas, core sampling and core analysis was undertaken on a predefined grid of the sidewalls of the furnace.

Relining a furnace such as M12 is a disruptive activity and as a result of the expense and risks involved very detailed consideration was given to all the possible alternatives.

The alternatives identified were

- Patch the furnace as and when a lining failure occurs.
- Effect a partial repair of the slag taphole areas of the furnace.
- Rebuild the walls of the furnace from the outside.
- A full reline of the furnace.

The option of patching the furnace as and when a lining failure occurred was considered to be a temporary solution and not very conducive to the continued reliability of the furnace as a result of the possibility of untimely disruption to the operation. This was, in any event, the *modus operandi* whilst the reline project was being planned and the lining procured. Effecting a partial repair of the slag taphole area was a very feasible option with the actual repair area being identified by means of core drilling of the existing lining.

The option was, however, discarded as the core drilling indicated that the integrity of the lining adjacent to the repair area was such that no guarantee could be given as to the support of the repaired lining. The option of rebuilding the walls of the furnace from the outside was discarded, although technically feasible, as the integrity of the hearth of the furnace could not be guaranteed.

A full reline of the furnace was then accepted as being the most feasible and least risky operation. Planning the project began in earnest. The existing lining was patched by grouting as and when high lining temperatures were observed or there was a lining failure while the reline project was being planned.

2.2 Type of lining

The decision as too what type of lining to install in M12, i.e. carbon block lining or "freeze" lining, was based on three principle factors.

The three factors can be summarized as

- The technical suitability of the type of lining,
- the final cost of the lining, and
- the flexibility of operation of the relined furnace that includes the monitoring and repair of the lining.

In terms of the technical suitability of the lining it is noted that, although the theoretical modeling of the "freeze" lining indicated successful operation, there was blind faith in that the "freeze" lining concept had not been utilized on a ferromanganese furnace the size of M12 previously. However, the experience on the smaller furnaces at Metalloys with the "freeze" linings, together with the theoretical analysis, mitigated any doubts on the technical success of the "freeze" lining concept on a large manganese alloy furnace such as M12.

There is a very significant cost implication between a "freeze" lining and a standard carbon block lining. Although the capital cost of a "freeze" lining is significantly higher than the equivalent carbon block lining, the life cycle cost of the "freeze" lining should be lower than the carbon block lining..

The third factor is that the "freeze" lining is easier to repair in the case of a localized lining failure. An important parameter that has to be taken into account here is the size of the furnace. The small furnaces, those with transformer ratings of 30MVA and less, are more flexible and the linings can be repaired with less catastrophic influences on the operation than the larger furnaces. Anything that increases the flexibility of the operation of the large furnaces and reduces the risk of a catastrophic failure is an advantage for the operation.

The two issues that directed the final decision in the direction of the "freeze" lining are firstly, the ease with which lining damage or failures can be repaired, and secondly the medium- to long-term financial advantages of the "freeze" lining over the carbon block lining were not trivial and could not be ignored. The decision to reline with a "freeze" lining initiated a project that had a very high profile within the Samancor group and failure was thus not an option.

Fortunately the continued success of the venture, as indicated in the subsequent operation of the furnace, has vindicated any doubts that there were.

3. LINING DESIGN

The design of the "freeze" lining is governed by the principle that the "hot face" of the carbonaceous material must be maintained at a temperature lower than the liquidus temperature of the material being smelted. This allows a thermal equilibrium to be achieved with the refractory temperatures low enough that chemical attack of the refractory material is not feasible thereby rendering the life of the refractory, to all intents and purposes, infinite. The maintaining of the refractory "hot face" at a temperature below the process temperature also results in a buildup of accreted process material adjacent to the lining that acts as a protective layer or a natural lining.

There are two distinct patterns in the lining that is installed in M12. The first is the sidewall lining that is based on the thermal equilibrium concept with the materials of very low thermal resistance. This is the standard "freeze" lining design. The photograph contained in figure 1 illustrates the graphite tiles being installed against the furnace shell.

The layers against the graphite tiles on the inside of the furnace, in the direction of the center, are the hot pressed carbon bricks with a layer of ceramic brick on the hot face of the lining. The function of the ceramic brick is to initiate the formation of the accreted layer and provide protection to the carbon bricks during the furnace start-up after the reline.

The hearth layer of the furnace is where there was a slight deviation from the lining design originally proposed. The furnace had an original sump (salamander) of about 800mm below the level of the metal tapholes. The replacement lining specified originally a single layer of carbon blocks in the hearth but this would have increased the depth of the salamander to 1200mm. It was felt that this was too deep and an additional layer of carbon was included in the hearth of the furnace. The isotherm penetration into the additional carbon was studied via thermal Finite Element Modeling with it being evident that the additional amount of penetration of the isotherm would not compromise the operation. In the installation of the hearth, the bottom layer was leveled using a ceramic brick upon which the carbon was laid. A further layer of ceramic brick then covered the carbon block layers.

Figure 1. M12 lining – graphite tiles installation.

The photograph in figure 2 illustrates the laying of the ceramic brick on the floor of the furnace and figure 3 illustrates the laying of the carbon blocks. Note the theodolite in figure 3. The quality of the installation is extremely important to ensure that the integrity of the "freeze" lining is not compromised.

A critical part of the system is the shell cooling as this ensures that the temperature profiles in the lining are maintained as designed and that the hot face temperature of the lining is kept as low as possible. There are basically two types of shell cooling system that can be instituted and each has its own advantages and disadvantages. The first is spray, or water curtain cooling, and the second is a jacket system. The choice of type of system is one of convenience but the two important issues that the shell cooling system must address are firstly, the cooling must be efficient to ensure that the "freeze" lining operates as designed, and secondly there must be dual redundancy for the water pumping system. This dual redundancy must also cater for standby power supply in case of power failures. The shell cooling is a normal heat exchange operation and it must comply with all the standard requirements to maintain efficient exchange by considering factors such as water treatment, in-and out- temperature monitoring, fouling factors, etc.

A critical function in the monitoring of the shell-cooling effectiveness is the monitoring of the temperature of the lining using thermocouples. As was noted previously, the ineffectiveness of the original lining monitoring system in identifying the high wear areas of the lining resulted in the installation of about six times as many thermocouples as there were in the original lining. Without digressing into too much detail, these thermocouples were positioned on a very carefully predetermined grid that encompassed six levels of the furnace. There are eight thermocouples placed radially at each level in the lining. The temperatures of each of the thermocouples are monitored in the existing distributed control system of the plant.

A final point concerning the design of the lining is that the "freeze" lining is thermally more efficient than the carbon block lining. Without digressing into the thermodynamic motivation of the higher thermal efficiency, the thermal efficiency results in the cost advantages discussed in section 4.2 together with operational advantages in the form of lower off-gas temperatures, and better heat energy distribution in the reaction zone.

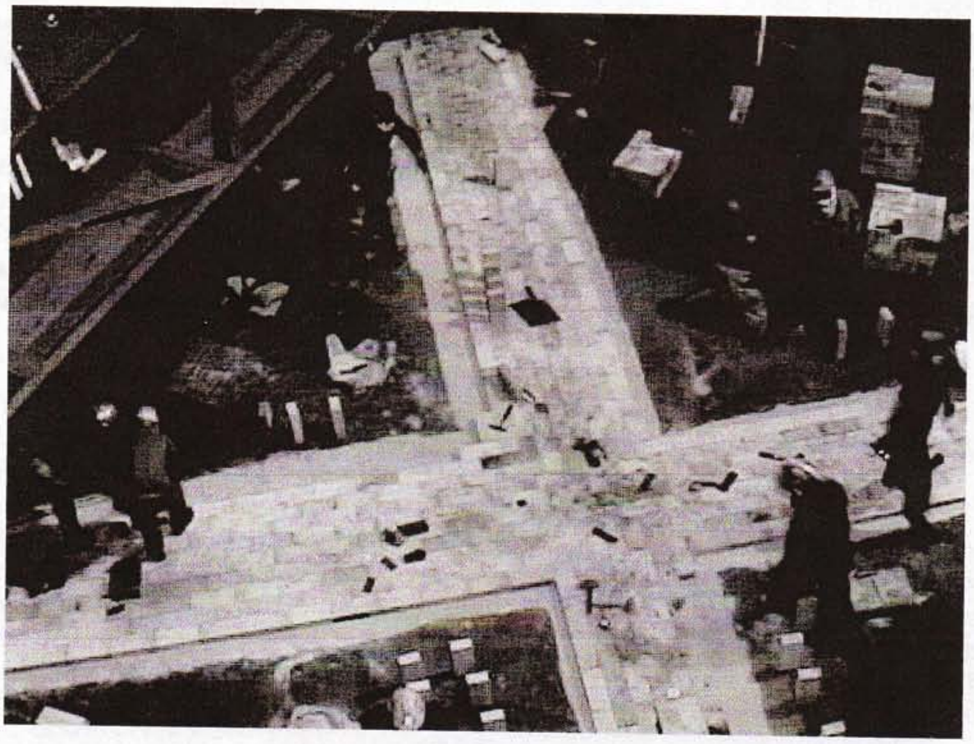

Figure 2. Laying of the ceramic brick in the floor of the furnace.

4. FINANCIAL ADVANTAGES

The financial advantages that are evident in the installation of the "freeze" lining at M12 are two-fold. The first lies in the reduced reline time required for the installation of the lining and the second is the long-term operational efficiency that is increased.

4.1 Installation time

The installation of a carbon block lining in a furnace the size of M12 is a major construction project with all the inherent timing, safety and financial risks. In the past a reline such as the one undertaken on M12 in July 2000 was scheduled to take not less than 90 days, which amounted to a significant loss in production with the associated marketing and financial ramifications.

The reline for the installation of the "freeze" lining was scheduled to take 30 days with maintenance being scheduled to occur simultaneously. The reline was, however, on the critical path.

The final furnace outage was 33 days with the slippage being as a result of repairs to the furnace sand-seal being necessary. In terms of the reduced installation time, the "freeze" lining made an additional 57 days of production available. In a production constrained environment this increased product availability is not insignificant.

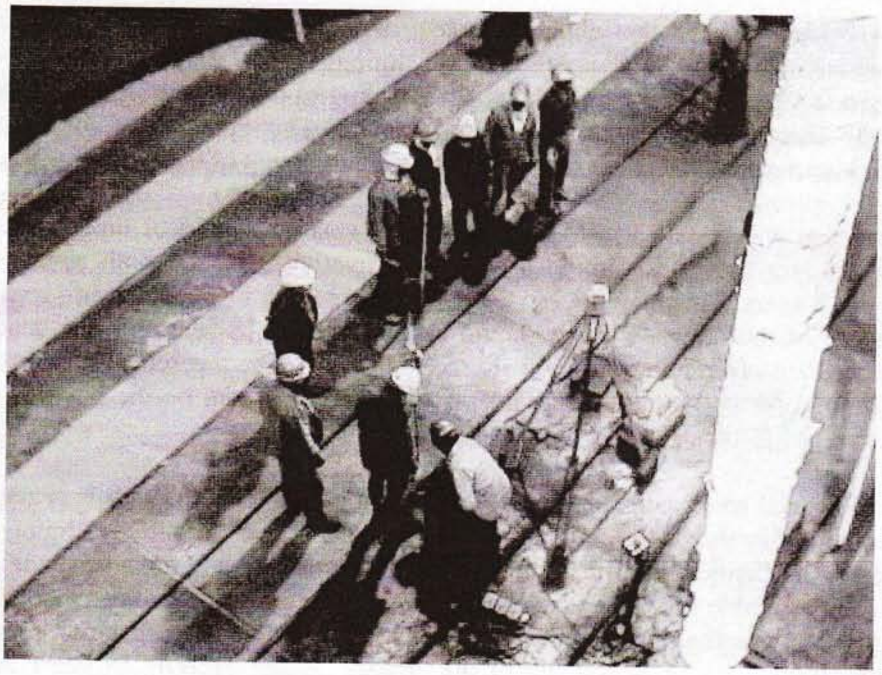

Figure 3. Laying of the carbon blocks in the floor of the furnace.

4.2 Efficiency Improvements

The principle financial gain with respect to lining of M12 has manifested itself in a reduction of specific energy consumption. The furnace reline started at the end of July 2000 and the furnace was out of operation for a period of 33 days. In the subsequent analysis the production during the start-up period has not been taken into account in the energy consumption averages. Figure 4 illustrates the monthly specific energy consumption in the production of high carbon ferromanganese on M12 furnace for the period May 1997 to present. The spike in the data indicates the operational perturbation as a result of the reline.

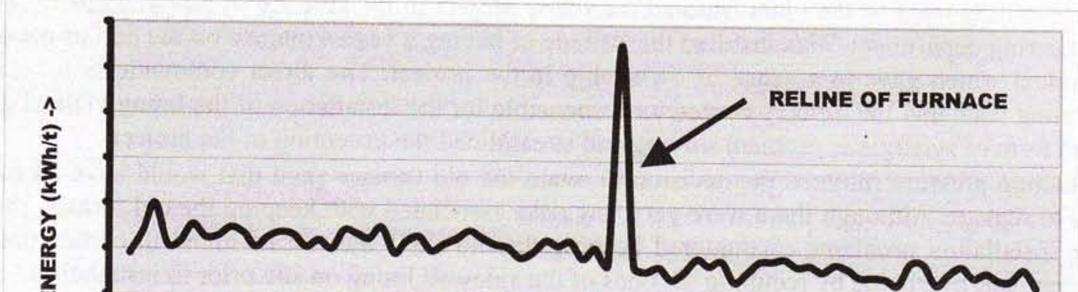

Figure 4. Specific energy consumption for the production of HCFeMn on M12.

Analysis of the data contained in figure 4 indicates an 18 percent improvement in the specific energy consumption, as measured in terms of kWh/t, between the period prior to August 2000 and the period subsequent to August 2000. In the period straddling September 2000 Metalloys undertook a number of initiatives that would have increased the efficiency of the operation by an estimated 10 percent. Assuming the additive nature of the efficiency improvements, with M12 partaking in these efficiency-improving initiatives, the efficiency improvement as a result of the "freeze" lining could conceivably not be more than about 8 percent. The following financial hypotheses are based on a saving of 8 percent and are based on South African 2003 costs.

Experience on M12 has indicated that about 1 percent of the saving is required to cover the additional operating costs that are incurred with having the "freeze" lining. These costs are typically associated with the stricter requirements in terms of shell cooling, regular descaling of the furnace shell, and the maintenance of the integrity of the thermocouple lining monitoring system. The integrity of the thermocouple lining monitoring system is expensive as a result of the inductive environment of the furnace.

The "freeze" lining that was installed in M12 had a capital cost of about four times the equivalent carbon block lining cost and, for the lack of more accurate information, they are both assumed to have useful operational lives of 15 years. This may not be the case as the carbon block lining life could be shorter than 15 years and the life of the "freeze" lining should be longer than 15 years but the dearth of experience precludes a more accurate assumption for purposes of comparison. The theoretical life of the "freeze" lining is infinite if the lining operates as designed with a scull of raw material on the hot face at all times. The assumption of a 15-year lifespan is thus conservative.

In performing the financial analysis a reasonable assumption is that if the furnace is to remain a productive asset, the only capital outlay that is discretionary is the marginal cost of the "freeze" lining over and above a carbon block lining. The financial ramifications then lie in firstly, the additional revenue as a result of the additional alloy being available for sale and secondly, the cost saving as a result of the lower specific energy consumption. In the first case the saving in the case of M12 is slightly greater than twice the premium on the capital cost of the "freeze" lining. If the life of the "freeze" lining exceeds 15 years the saving will be greater. In line with current corporate requirements of the return on capital expenditure being as short as possible, and an efficiency increase of about 8 percent with a contribution per unit of alloy sold of approximately half of the current value the return on the "freeze" lining is less than three years.

5. LESSONS LEARNED

The opportunity of a reline of a furnace the size of M12 does not present itself very often and thus the maximum learning must be obtained when presented with such an opportunity.

The following points summarize the major learning points that emanated from the reline of M12 furnace.

- The operating team of the plant handled the reline project in the absence of an in-company projects or engineering department. This instilled the attitude of having a vested interest on the part of the operating personnel which gave to a sense of ownership in the project. The direct communication between the operating team and the turnkey contractor responsible for the installation of the lining yielded dividends in the form of synergistic problem solving and streamlined the execution of the project.
- Production pressure initiated the decision to retain the old furnace shell that would have taken about 7 days to replace. Although there were very few risks associated with keeping the old furnace shell, there were installation problems encountered because the old shell was out of round in certain places. The problem was overcome by recutting sections of the sidewall lining on site prior to installation.
- The original installation method of the thermocouples was not user-friendly and the replacement of failed thermocouples during operation is a nightmare.
- As a result of the plant being subjected to windy conditions, the spray cooling of the shell is a messy operation and in hindsight a jacket cooling system would have been the better installation.

6. CONCLUSIONS

The carbon block lining that was installed in M12 furnace in 1981 performed satisfactorily although it was not ideal in terms of furnace efficiency and ease of repair. The lining first started showing signs of premature failure during the mid 1980s with final failure in 1999. During the operation of this carbon block lining there were significant advances made in the design of a "freeze" lining and, subsequent to the concept being successfully implemented on one of the smaller furnaces at Metalloys, a "freeze" lining was installed on M12, the largest of the furnaces at Metalloys.

This paper relates the experience of the M12 operating team, in what was then a pioneering concept and project at Metalloys, in installing and operating the "freeze" lining on M12. The results obtained, both in terms of project execution and subsequent operation, have vindicated the original decision to implement the "freeze" lining concept on a "big" furnace.

In line with business principles, the final concept that is overriding is the one of cost effectiveness and it has been proven by the performance of M12 that the "freeze" lining, although more capital intensive than a carbon block lining, is financially more cost effective. The cost savings are brought about by a shorter reline period together with higher thermal efficiency of the operation of the lining. The shorter reline period and the more efficient electricity consumption have allowed the M12 lining to repay the additional capital cost in about three years of operation.

The final consideration consisted of learning points emanating from the execution of the project. The reline of a furnace, such as M12, does not take place very often and it is thus of importance that as much as possible is learned from such an opportunity.

Although there are pros and cons in this project, in general the utilization of the "freeze" lining concept on a large furnace has proved successful and is very likely to become the norm at Metalloys.

7. ACKNOWLEDGEMENT

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The contribution of the late Nic van der Walt to the establishment of the lining operation philosophy is acknowledged.

8. REFERENCE

[1] Anthony M. Hearn, Albert J. Dzermejko and Pieter H. Lamont., " Freeze Lining Concepts for Improving Submerged Arc Furnace Lining Life and Performance", *Proceedings of Infacon 8*, Beijing, 1998, p401-426.