# "Freeze" Lining Concepts for Improving Submerged Arc Furnace Lining Life and Performance

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## ABSTRACT

Traditional submerged arc furnace linings consist of a variety of lining types and configurations. Often, these configurations consist of composite linings, comprised of combinations of amorphous carbon blocks, various types of ceramic bricks and carbonaceous ramming pastes of various compositions.

The actual configurations employed, mostly comprise an "insulated" refractory concept. The wall philosophy utilizes a cold face ceramic lining, usually in combination with carbonaceous ramming paste or carbon blocks. Often, additional ceramic inner walls are utilized to contain the pastes or protect the carbon.

In the bottom pad lining, the same concept of a cold face ceramic in combination with carbon paste or block, is utilized, often with air convection cooling to protect the furnace bottom shell.

In 1995, SAMANCOR investigated the incorporation of a water cooled, highly thermally conductive, carbonaceous composite lining system, designed to achieve a true thermal equilibrium. This concept utilizes the efficiency of cooling and low thermal resistance of graphite and hot pressed carbon, to provide wall hot face temperatures that are significantly below solidification temperature of the furnace product, thus forming a frozen protection layer, (skull) on the refractory hot face. This in turn, allows the achievement of a true thermal equilibrium, lowering heat losses and providing protection of the wall from process actions.

In early 1996, SAMANCOR applied this "freeze" lining concept in the repair of a ferromanganese furnace, including the incorporation of a new concept taphole configuration. The repair proved a resounding success and since then, many new and relined ferromanganese, silicomanganese and ferrochrome furnace linings are proving the value of this "freeze" lining concept.

Wall and bottom temperatures are extremely low compared to past practice, furnace productivity and reliability are improved and taphole maintenance is dramatically reduced. Additional furnace relines utilizing this concept are installed or now underway in South Africa, Europe and North America.

"Freeze" lining concepts provide the operators of submerged arc furnaces the opportunity to increase lifetime, improve performance, reduce maintenance, economize energy and resources and thus improve profitability.

The paper reviews the considerations required for configuring "freeze" lining concepts and philosophies for the submerged arc furnace and reviews actual performance data of operating furnaces compared to the previously used "insulating" lining system.

## 1. INTRODUCTION

All too often, SAMANCOR has been forced to endure a variety of lining problems, degradation and wall and bottom breakouts. Productivity losses, high maintenance costs, production interruption and facility damage, seriously hamper profitability and endanger personnel. However, certain concepts and philosophies that combine water cooling, highly thermal efficient carbonaceous refractories and traditional ceramic refractories, into a lining-cooling "system", can be utilized to end these lining failures.

The lining "system" so configured, utilizes low thermal resistance and water cooling, to "super chill" the refractory hot face and thus retain an insulating layer of hot face ceramic refractories and solidify a protective layer of process slag and metal. This enables the lining system to achieve a true thermal equilibrium and thus, minimize heat losses and prevent lining degradation, refractory loss and provide long life.

This is possible because once thermal equilibrium is achieved, refractory temperatures are maintained significantly cool, to prevent chemical attack from occurring. Additionally, the protective accretion or "skull" of process slag and metal, protects the refractory mass from thermal shock, abrasion and erosion. Contrast this situation with the conventional concept of utilizing thick refractory mass to outlast degradation and erosion in a "wear versus time" contest, that all too often resulted in breakouts and high maintenance.

## 2. PHILOSOPHIES

2.1 Successful refractory "system" lifetimes are dependent upon a variety of internal and external factors. How these factors are addressed (or ignored) will determine the ultimate lifetime of the refractory system. These internal factors include the obvious considerations that users must address, such as accommodating thermal expansion and differential thermal movements, accommodating expected thermal stresses, maintaining effective heat transfer and selecting the proper type of refractory, with suitable refractory properties. Ignoring or not properly considering any of these internal factors will result in unsatisfactory refractory system performance.

However, the factors external to the lining system, are often more responsible for refractory life and trouble-free operation. These external factors include operations effects, such as the type of raw materials and their charging method, process reactions and furnace availability. Other external factors that can negatively affect refractory system performance are the physical geometry or shape of the lining, the lining configuration and arrangement, cooling method or lack of cooling and obviously, the wear mechanisms encountered in the process.

SAMANCOR recognized that refractory lifetime is not assured merely by providing the "correct" refractory material or properties. How these many internal and external factors are addressed, will determine the success or failure of every refractory lining. The philosophies utilized in the "freeze" lining "system", address all of these internal and external factors and thus, are the best ways known to optimize lining life.

2.2 Figure 2-1 represents a typical, thick wall, thick bottom, rammed mass lining utilized by SAMANCOR in submerged arc furnaces. The carbon ram utilized in the walls and bottom is typically insulated from the steel and bottom by thick, ceramic refractories. Additionally, ceramic wall hot face linings are often utilized to protect the carbon ram at start-up. In the example shown in Figure 2-1, a total wall thickness of 1290mm and a total hearth pad thickness of 2560mm, are utilized. This happens to be an actual example of a conventional, insulating type, carbonaceous lining.

Additionally, a typical taphole configuration for the rammed mass lining shown in Figure 2-1, utilizes an even thicker wall at the tapholes. In this example, the total wall thickness at the taphole increases to 1590mm, utilizing additional carbon ramming.

The actual furnace that utilized this lining configuration exhibited a history of breakouts, especially through the bottom pad and taphole walls. A finite element, heat transfer computer model analysis of the pad was undertaken, to determine the expected bottom penetration. As was suspected, the thick ceramic subhearth lining prevented achievement of a thermal equilibrium. Consequently, the computer model predicted total penetration of the pad bottom, which actually had historically occurred on this furnace and others in this plant, utilizing the same lining configuration. This total pad penetration is depicted in Figure 2-2, as defined by the 1200°C solidification temperature isotherm location for ferromanganese.

Additionally, a thermal analysis of the walls was conducted, to determine temperatures at the various refractory material interfaces. Two (2) separate analyses were made. The first utilized the full wall lining as depicted in Figure 2-1. The second assumed the loss of the hot face ceramic material due to thermal shock and melting. The results in the first case, depicted in Figure 2-3, show a hot face carbon paste temperature of over 1300°C. The results in the second case, depicted in Figure 2-4, show a cold face carbon temperature of almost 1300°C. This situation means that the entire carbon paste lining temperature is higher than the 1200°C solidification temperature of the process material. This will result in erosion from process material and process actions and chemical attack of the carbon from process gasses. Furthermore, once the carbon paste lining ultimately disappears, the remaining ceramic back-up lining is then exposed to process actions. Thus thermal shock, high heat load and abrasion will result in additional lining loss and subsequent break-out. This is the situation on the subject furnaces, that resulted in major productivity reductions, high maintenance and downtime, which required a change in philosophies to correct. "Freeze" lining concepts were subsequently chosen by SAMANCOR, to improve performance and achieve long life, on three furnaces in this plant.

2.3 The concept of "freeze" lining philosophies, is successfully utilized in refractory systems worldwide, for ironmaking blast furnaces, direct reduction furnaces, cupolas, electric arc furnaces and other metallurgical process lining applications. The theory is to combine effective cooling, with a thin, thermally efficient, conductive carbonaceous lining, to provide a refractory hot face temperature that is significantly below process metal solidification temperature. This in turn, provides a chilled surface on which, an insulating layer of process slag and metal is easily solidified. Often, a hot face layer of ceramic is also maintained intact below this slag accretion (skull) layer because of the efficient cooling, which also assists with keeping refractory temperatures low.

The combination of cooling and high thermal efficiency lining materials and the insulating effects of residual hot face ceramics and slag accretions (skulls), results in refractory temperatures that are below their "critical reaction temperature", for all encountered process chemical reactions. This is because all chemical attack mechanisms which can affect refractories, are temperature dependent chemical reactions. If you maintain refractory temperatures below their "critical" reaction temperature for each attack mechanism encountered, that chemical reaction cannot occur. Thus, as long as cooling efficiency is maintained, the carbonaceous lining would be too cold for any chemical attack to occur. This eliminates any possible refractory degradation and loss of properties from chemical attack, assuring long life.

Furthermore, as long as cooling efficiency is maintained, the hot face refractory temperature is maintained below process material solidification temperature. Thus, the insulating slag accretion and solidified process metal, provide a protective layer on top of the refractories, which prevents thermal shock damage, abrasion and erosion by process actions.

2.4 One of the key elements of the "freeze" lining philosophy, is to utilize as little refractory materials as possible in the configuration. This minimizes the thermal resistance between the process and the cooling. However, practical considerations often require greater than optimal refractory thickness. In these situations, judicious use of a variety of highly conductive carbonaceous materials such as graphite or semigraphite, can be utilized with high conductivity carbon, to minimize the thermal resistance of a greater than optimal thickness lining. This assures that low hot face wall temperatures can be maintained, encouraging accretion formation and thus allowing true thermal equilibrium to occur. This results in a refractory lining that does not deteriorate versus time, and thus maintains its integrity, providing long life.

2.5 Another positive result of achieving a true, thermal equilibrium, is that heat losses can be minimized over the life of the lining. This is because as refractory linings wear and lose thickness, heat losses intensify until ultimately, break-outs occur from extreme heat fluxes. In a true thermal equilibrium situation, where lining degradation and loss is prevented, heat losses are constant and predictable and are maintained at an optimum, which assures low refractory temperatures and a protective accretion on the refractory hot face, as long as cooling efficiency and thermal resistance are maintained as originally provided.

## 3. MATERIALS

The "freeze" lining concept utilizes high thermal efficiency carbonaceous materials in combination with sidewall water cooling and bottom convection cooling. These carbonaceous materials provide a low thermal resistance, which allows them to be combined with certain ceramic materials, which are then properly cooled by the carbonaceous materials.

In this way, the ceramics can be retained for insulation, electrical isolation and steel shell temperature control, especially in the bottom pad. The cooling effect of the carbonaceous materials allows the survivability of these ceramics, which otherwise would be lost to high heat load and thermal shock.

These carbonaceous materials consist of a variety of materials, including carbon, semigraphite, semigraphitized carbon and graphite. However, the words "carbon" and "graphite" are often misused interchangeably in the literature, but the two are not synonymous. Additionally, the term "semigraphite" is also misunderstood and is often confused with other types of materials. The following briefly describes the major differences and characteristics of the variety of carbonaceous materials, used as refractories, in a "freeze" lining concept for submerged arc furnaces.

3.1 Carbon

The terms, carbon, formed carbon, manufactured carbon, amorphous carbon and baked carbon, refer to products that result from the process of mixing carbonaceous filler materials such as calcined anthracite coal, petroleum coke or carbon black with binder materials such as petroleum pitch or coal tar. These mixtures are formed by molding or extrusion, and the formed pieces conventionally baked in furnaces at temperatures from 800 to 1400°C (1500 to 2550°F) to carbonize the binder. The resulting product contains carbon particles with a carbon binder.

Typically, conventionally baked carbon is manufactured in relatively large blocks. As the binders carbonize and the liquids volatilize, they escape through the block, resulting in porosity. This porosity results in a permeable material that can absorb elements from the furnace environment such as alkalies. These contaminants use the same passages to enter the carbon that the volatilizing binders used to escape the block and and chemically attack the structure.

Conventionally baked carbon can be densified and thus, permeability improved and pore sizes reduced. This can be accomplished by the introduction of additional binders, impregnated into the baked carbon under a vacuum, and the resultant product rebaked to carbonize the impregnation. Multiple impregnations are also possible to double or triple densify the end product. Each densification, however, adds additional cost and results in a higher priced product.

Some manufacturers also add special raw materials to the carbonaceous mix prior to baking to improve the end products' properties. Silicon carbide or silicon metal can be added to improve permeability, reduce pore sizes and improve abrasion resistance. Artificial or natural graphite can also be added to improve thermal conductivity. Some manufacturers also impregnate the baked carbon with silicon carbide to improve thermal conductivity. However, each of these steps also results in a higher priced product.

3.2 Hot-pressed Carbon

An American manufacturer developed a unique proprietary method of manufacturing carbon which is called the BP process or hot pressing. In this method of manufacturing carbon, which as previously described, is a product containing carbon particles with a carbon binder, a special pressing/carbonizing operation is utilized.

In this process, carbon particles and binders are mixed as before, but are then introduced into a special mold. A hydraulic ram then pressurizes the mixture while simultaneously, an electric current passes through the mix, carbonizing the binders. Unlike conventionally baked carbons that take a period of weeks to bake out the binders, this proprietary process carbonizes the binders in minutes. More importantly, as the liquids volatilize, the hydraulic ram squeezes the mixture together, closing off the pores formed by escaping gases. This forms an impermeable carbon compared to conventionally baked carbon, usually at least 100 times less permeable. This impermeability makes it difficult for furnace contaminants, such as alkalies, to enter the hot-pressed brick and makes hot-pressed carbon an ideal wall refractory.

To make this product even more alkali resistant, special silica and quartz additions are also added. These additions are made because sodium or potassium in the furnace react preferentially with silica, forming compounds that do not swell in the carbon. Normally, the reaction of these alkalies with carbon would form lamellar compounds which do swell, causing volume expansion spalling of carbon. Thus, the combination of hot pressing and raw material composition results in a superior alkali-resistant carbon.

Hot pressing also results in a higher thermal conductivity than conventional carbon, which makes this product a desirable wall lining. This is because the higher thermal conductivity promotes the formation of a protective skull of frozen materials on its hot face because of its ability to maintain a hot face temperature that is below the solidification temperature of the slag and metal. The protective skull protects the wall from chemical attack and erosion from moving liquids.

Because of the special manufacturing process required for hot pressing, the product is restricted to sizes not exceeding approximately 500x250x120mm (20x10x5in.)

3.3 Graphite

The term graphite, also called synthetic, artificial or electrographite, refers to a carbon product that has been further heat treated at a temperature between 2400 and 3000°C (4350 and 5400°F). This process of graphitization. changes the crystallographic structure of carbon and also changes the physical and chemical properties.

Graphite is also found in nature in flake form, and, if used in a refractory product, usually forms part of a mixture of ceramic materials for the binder. This ceramic bonded, natural graphite containing refractory is considered a ceramic product. However, natural graphite flake is often used as an additive in various carbon products, to enhance thermal conductivity.

Artificial or synthetic graphite refractories begin as a baked carbon material, similar in manufacture to the carbon refractory material described previously. However, after carbonizing of the binder is completed, this baked carbon is then loaded into another furnace to be graphitized at a high temperature. Graphitization changes the structure not only of the carbon particles but also the binder. The resulting product contains graphitized particles as well as a graphitized binder.

There is no industry-wide system for designating the various grades of graphite that are commercially available. Each manufacturer has a method and nomenclature to describe the available grades and varieties which are made for specific purposes or properties. These grades differ with regard to raw materials, grain sizes, purity, density, etc. For denser versions, the porosity of the material can be filled with additional binder materials such as tar or pitch by impregnation under a vacuum. Then, the impregnated material is rebaked prior to graphitization, forming a less porous product. Multiple reimpregnations/rebaking can be performed prior to garphitization to provide additional densification.

Purification can be utilized to reduce the ash levels of graphite for high purity requirements. In addition, proprietary manufacturing methods and techniques can also be used to minimize ash or iron contamination of graphites.

Graphite products are manufactured in large blocks or rounds and must be cut and machined into blocks or shapes for use as a refractory. Close tolerances can be maintained with machined graphite components due to its easy machinability.

3.4 Semigraphite

The term semigraphite is used to describe a product that is composed of artificial graphite particles mixed with carbonaceous binders such as pitch or tar and baked at carbonization temperatures of 800 to 1400°C (1500 to 2550°F). The resulting product is composed of carbon bonded graphite particles in which the graphite particles had previously been manufactured at temperatures close to 3000°C (5400°F) but with binders that have only been baked in the 800 to 1400°C (1500 to 2550°F) range. The resulting product, a true carbon bonded graphite, exhibits higher thermal conductivity than the carbons but, because of the carbon binder, not as high as 100% graphite. Thermal conductivities will vary with baking temperature and can be increased by rebaking at higher temperatures.

This carbon bonded graphite product (semigraphite) should not be confused with carbon products (carbon bonded carbon) which contain additives of graphite to enhance thermal conductivity. These products are not considered as semigraphite, because the majority of their composition is carbon not graphite. A true semigraphite contains no carbon particles except the binder.

These semigraphite products are also conventionally baked (as described for carbon), which results in a relatively porous material. However, these conventionally baked semigraphites can also be densified and rebaked to carbonize the impregnated binder. Thus porosity and consequently permeability, can be reduced. Some conventionally baked semigraphites can also be impregnated with or combined with silicon metal and silicon carbide for greater abrasion resistance and lower permeability.

3.5 Hot-pressed Semigraphite

One American manufacturer also utilizes its proprietary hot-pressing method to make a true semigraphite refractory. The resultant product is considerably less permeable and has a higher thermal conductivity than conventionally baked semigraphites.

Two distinct products are available for a variety of applications. One grade is composed of crushed graphite particles, which were previously processed at graphitization temperatures, with a carbonaceous binder and the addition of silica and quartz materials for alkali resistance (as previously described for hot-pressed carbon).

The other grade is a silicon carbide containing hot-pressed semigraphite refractory. It is composed of the same graphite component as the first product and the same carbonaceous binder. However, silicon carbide is substituted for the silica and quartz. The resultant product is more abrasion resistant and even less permeable than the first product. It has proven especially resistant to thermal shock and cyclic operation.

Because of the special manufacturing process required for hot pressing, the resultant products are restricted to sizes not exceeding approximately 500x250x120mm (20x10x5in.).

3.6 Semigraphitized

The term, semigraphitized material, refers to a baked carbon that has been further heat treated at a temperature between 1600 and 2400°C (2900 and 4350°F). This process only begins to change the crystallographic structure of the carbon and alters its physical and chemical properties. However, because this additional heat treating occurs at temperatures below graphitization temperatures, the product is considered to be semigraphitized. It contains carbon particles with a carbon binder, which are both semigraphitized. (This is different than a semigraphite product which is composed of true graphite particles with a carbon binder.) It has a higher thermal conductivity and resistance to chemical attack (alkali or oxidation) than carbon or semigraphite. This is because the binder is usually attacked first and the semigraphitized binder is more resistant to attack than the carbon binder of a semigraphite.

These semigraphitized products are also manufactured in large blocks or rounds and must be cut and machined into blocks or shapes for use as a refractory. However, because of their semigraphitized bonding, they are more difficult to machine than a true graphite.

3.7 Material Discussion

These groups of carbonaceous material form the basis for a full range of specialized products for use as a refractory in the "freeze" lining concept. As discussed, various additives such as graphite particles, alumina, silicon carbide or other ceramics are included by some manufacturers to improve properties, or multiple impregnations are used to improve permeability or reduce pore sizes. However, the general characteristics of each material classification do not change. For convenience, these classifications are summarized in Table 3-I.

**TABLE 3-I**

**Classifying Carbonaceous Materials**

| | Characteristic | | |
|---|---|---|---|
| Product classification | Baking temperature, °C | Particles | Binder |
| Carbon | 800-1400 | Carbon | Carbon |
| Hot-pressed carbon | ~1000 | Carbon | Carbon |
| Graphite | 2400-3000 | Graphite | Graphite |
| Semigraphite | 800-1400 | Graphite | Carbon |
| Hot-pressed semigraphite | ~1000 | Graphite | Carbon |
| Semigraphitized | 1600-2200 | Semigraphitized carbon | Semigraphitized carbon |

Currently, there is a large variety of carbonaceous refractory material on the market produced by different manufacturing techniques with various properties. It is difficult to provide material properties for these products without referring to specific manufacturer's grade designations, because each manufacturer produces products that are unique to that manufacturer and thus, exhibit unique properties. A representative listing of some of these materials' properties are summarized in Table 3-II.

In general, carbon or semigraphite materials are used for the hot face lining materials that will be in contact with the process. Usually, graphite materials are reserved for a backup lining, to take advantage of their high thermal conductivities and because they are more easily dissolved by iron containing process metals. In addition, many ceramic materials such as high alumina, mullite and chrome corundum are used in the bottom pad as a wearing surface, to minimize exposure of the carbonaceous materials of the pad to molten materials. Some designers also provide a lining of ceramic materials on the face of the sidewalls for wear protection and to minimize heat losses, mainly because of poor historical performance with some large, conventionally baked, carbon block designs. This ceramic hot face lining also provides electrical isolation.

Ceramic materials for the bottom pad can be inexpensive super-duty fireclays of 40 to 50% alumina or a variety of high alumina products in the 60% range. The objective is to provide a lining that will melt and vitrify (or fuse together) on its hot face in the presence of molten metal, effectively sealing the surface to penetration, but is effectively cooled on its cold face by the conductive, carbonaceous refractories.

In another philosophy, refractory materials such as artificial mullites or chrome corundum are chosen which are resistant to melting. These materials however, do require elaborate jointing techniques such as interlocking, tongue and groove or roll-lock interfacing to prevent joint penetration by molten materials and resultant flotation of bricks.

Whichever ceramic materials are utilized in the pad, the effect is that the process metal remains in contact with the ceramic, which is more resistant to abrasion from moving liquids. The carbonaceous material in the pad thus forms a cooling member instead of a crucible, until late in the campaign when the ceramic may totally wear away by abrasion. The high conductivity of carbonaceous materials, especially if bottom cooling or a graphite cooling course is utilized, enables penetration of the metal into the pad, to be arrested in the ceramic layer. This provides a long-wearing bottom pad design, combining the properties of two or more different refractory materials to optimize the performance of each, in the zone to which they are most suited.

Representative properties of some of these ceramic materials are shown in Table 3-III. They can be combined in various layers such that the more economical materials are located on the hot face, where they will be consumed more easily until thermal equilibrium is reached. The more expensive, hot metal resistant materials can then be located next to the carbonaceous materials where they can be more easily cooled for longevity. The tendency is to utilize specific grades of refractories in each bottom pad zone that can best withstand the attack mechanisms prevalent in that zone. The result is a pad lining composed of not just one grade of refractory but sometimes, even three or four different types of materials, both carbonaceous and ceramic.

TABLE 3-III

**Representative Ceramic Bottom Pad Materials**

| Property | Material: Hard-burned superduty fireclay | 60% Alumina | Artificial mullite | Chrome corundum |
|---|---|---|---|---|
| Density, g/cc | 2.24 | 2.40 | 2.45 | 3.43 |
| Crushing strength, MPa | 31 | 35 | 85 | 78 |
| Porosity, % | 13 | 22 | 19 | 8 |
| Thermal conductivity, W/m°K | | | | |
| at 500°C | 1.9 | 2.0 | 1.9 | 2.5 |
| at 1000°C | 0.9 | 1.7 | 1.8 | 2.3 |

## 4. CONCEPTS

As previously noted, some of the advantages of the "freeze" lining concept, are the ability to reduce lining thickness, increase furnace inner volume, reduce capital costs, reduce installation time and get back on-line faster. This is possible because instead of having to install a thick mass of refractories to withstand "wear versus time", the "freeze" lining concept allows a true thermal equilibrium to be achieved, with protective slag and metal accretions on the lining hot face.

In the case of the lining example previously described in Figures 2-1 and 2-2, significant lining volume savings were realized in the conversion to a "freeze" lining concept. Figure 4-1 depicts the new "freeze" lining outline, on top of the original, thick mass, insulated, carbon paste lining. The cross hatched area shown in Figure 4-1, represents the excess lining material not required with the "freeze" lining concept in this example. The actual furnace in which this concept was installed, has been successfully operating at higher productivity, no maintenance and at significantly lower refractory temperatures. Typically, wall cold face temperatures are in the range of 30-40°C. The bottom pad temperatures below the electrodes, in the lower graphite interface, are in the range of 220-250°C.

The financial justification for converting this furnace lining to a "freeze" lining concept was the shorter installation and commissioning time compared to the original, thick mass lining, which included thick zones of carbon ramming paste. The time and labor required to properly cure the ramming paste in the original design was not required with the new, freeze lining concept. This, combined with the smaller refractory mass of the freeze lining concept, allowed the furnace to be rebuilt and commissioned and to produce product much faster than with the original, thick mass lining.

4.1 Bottom Pad Cooling Layer

The freeze lining concept for the bottom pad utilizes combinations of materials, to take advantage of the best properties and characteristics of each. For best performance, bottom cooling is required, such as fan cooled, convection cooling, typically utilized with exposed steel bottom support grillage. A layer of high conductivity graphite or semigraphite is utilized as the lowest carbonaceous materials layer. This highly conductive layer acts as a cooling device, intercepting penetrating heat and directing it radially to a spray or panel type, water cooled steel sidewall shell. Because of its high thermal conductivity, this cooling layer is able to intercept the intense, localized heat below each electrode, and more evenly distribute the heat load over the entire bottom, before directing it to the sidewall cooling. In the previous example cited, the average temperature at the bottom of its graphite pad, directly below each electrode, averages 220-250°C.

This cooling layer of graphite or semigraphite also helps to cool the other refractories located above it, thus helping to locate the process metal "freeze point" isotherm, as high in the bottom of the pad as possible.

This is best accomplished with graphite, the highest conductivity carbonaceous material. Graphite will provide the optimum cooling capability, especially when furnace lining outside diameters exceed 9m. The cooling layer thickness will also be determined by the furnace diameter, utilizing finite element, heat transfer computer modeling to optimize lining configuration and performance.

It should be noted that sometimes, depending on furnace diameter, it is necessary to insulate the cooling layer from the steel bottom grillage, to control steel temperature. However, the purpose of the graphite cooling layer is to intercept the downward heat flow and direct it radially to the water cooled sidewalls. Consequently, the location of the freeze line isotherm is not radically altered as a result of this thin, insulation layer.

4.2 Bottom Pad Crucible Layer

For the best performance, the bottom pad crucible will be configured to utilize at least one layer of high conductivity block carbon on top of the cooling layer. A sacrificial layer of ceramic or other low cost material, is located on top of the carbon layer. In operations, as heat is generated and penetrates into the pad, the graphite cooling course and the carbon crucible course intercept this heat and radially convey most of it to the water cooled sidewalls. However, until a thermal equilibrium is achieved, the uppermost portion of the bottom pad will be lost to thermal shock, erosion, and chemical attack. This is the reason for the topmost sacrificial layer.

As thermal equilibrium is reached, the process metal solidification temperature isotherm reaches a "fixed" location. The key to configuring a successful bottom pad refractory system is to locate this freeze line isotherm as high in the pad as possible, preferably in the sacrificial material layer.

If this sacrificial layer is an economical ceramic such as fireclay or low alumina, the cooling effect of the carbon crucible layer and the graphite cooling layer below it, will be able to prevent total melting of the ceramic. The uppermost zone of this ceramic will soften and the individual bricks will fuse together in a plastic, impermeable mass. This will prevent process metal-crucible carbon contact and provide electrical isolation. If the bottom pad is configured correctly, sufficient ceramic will also be retained above the carbon crucible, to provide insulation and minimize heat loss as well as provide electrical and process metal isolation.

4.3 Refractory Sidewalls

The most important consideration in any "freeze" lining concept, is to provide a configuration that is able to achieve a true, thermal equilibrium and whose properties and integrity do not deteriorate versus time. These requirements are not merely satisfied with material properties alone. Concept, geometry, configuration, accommodation of differential thermal expansion, thermal and mechanical stresses, all of these internal and external factors must be considered if the lining is to be successful.

Sidewall problems can be traced to a combination of factors: lack of thermal expansion relief, high thermal gradients across the wall block and inability to accommodate differential thermal expansion. All of these factors promote cracks with subsequent metal and chemical attack. Attack of the wall by metal and chemicals most often is a result of the cracking problem.

Proper "freeze" lining wall design requires a high thermal conductivity refractory that will minimize thermal gradients through the wall and consequently, promote the formation of a protective layer of solidified materials on its hot face. Proper wall design also incorporates provisions for radial thermal expansion of the wall but more importantly, incorporates provisions to accommodate differential thermal expansion of the wall thickness.

Differential expansion occurs because the wall hot face temperature is higher than the wall cold face temperature. This differential can be as high as 1700°C (3100°F), especially when an accretion of solidified materials is absent. As a result, the hot face of the wall grows at a faster rate than the cold face. The differential induces high stresses in the blocks which are restrained from bending or bowing. Cracks result parallel with the hot face.

Thermal spalling and cracking of the hot face can also be induced by the rigors of start-up, especially when the wall design cannot accommodate radial expansion and the refractory thermal conductivity is low. This type of cracking also occurs parallel to the refractory hot face.

Cracks interrupt the ability of large blocks to convey heat and facilitate cooling, because each crack acts as an air gap which is a barrier to effective heat transfer. Once the ability to convey heat away is lost, the protective accretion can no longer form and therefore, carbon will be attacked by the metal and chemicals. This is because the carbon temperature will be above the critical reaction temperature for attack by these mechanisms.

In addition, the rammed layer required between the shell and the cold face of a large block carbon wall, also insulates the carbon from the cooling system. This is because ramming materials shrink when cured and possess thermal conductivities that are significantly lower than baked carbon. The lower conductivity and shrinkage combine to provide additional barriers to heat transfer and result in high hot-face carbon temperatures above the solidification temperature, so that skulls cannot form on block walls. This makes them unsuitable for a "freeze" lining concept.

Proper "freeze" lining wall design not only accommodates thermal growth and expected differential movements, and utilizes a carbon refractory with high thermal conductivity, but also uses a carbon refractory possessing an extremely low permeability. The low permeability prevents chemical and metal attack by preventing penetration into the refractory.

It has also been demonstrated that a carbon refractory that possesses a low elastic modulus, combined with a low coefficient of thermal expansion, results in low mechanical stress at the important pad/wall interface. American hot pressed carbon, hot pressed semigraphite and big beam blocks as well as graphite, fulfill all of these requirements. Because of the elastic properties of the hot-pressed carbon, expansion stresses are easily accommodated, which prevents cracks from occurring in the wall. The opposite is true for the strong large blocks that typically are used in Europe and Asia in an attempt to increase the life of big block carbon walls. Because of differential expansion and bending, and close fit due to precision machining and the lack of thermal expansion provisions, these stronger blocks are prone to stress cracking, pinch spalling and thermal shock. Thermal shock is particularly size dependent, so that the larger the exposed hot face cross-section, the more thermal shock is likely to occur. Walls composed of smaller cross-section hot pressed pieces are unaffected by thermal shock.

Expansion relief is also a requirement for preventing pinch spalling and stress cracking. This relief is provided by the use of special, heat setting, carbonaceous cements. Ideally, these cements should be installed in a sufficiently thick layer to provide expansion relief before curing. After curing, they should provide a strong carbonaceous bond to seal the joint. Multiple layers and rings provided by small, hot pressed brick also permit differential expansion without cracking.

High thermal conductivity hot-pressed carbon and semigraphite refractories promote the formation of a protective skull of frozen material on the hot face of the walls. This protective skull prevents wear of refractories due to erosion from gases or molten materials. Additionally, rammed layers are not utilized, to maximize heat transfer to the water cooled shell. The result is an ideal "freeze" lining sidewall.

A single, full-thickness, large block cannot accommodate the differential growth experienced and consequently it cracks, thus interrupting heat transfer. The cracks prevent the hot face of the block from being cooled below the solidification temperature so that a protective skull cannot form. Thus, the large block carbon is continually exposed to molten materials at high static pressure. These high pressures tend to force the molten materials into the pores of the big block materials. Slag and metal impregnation results in damage to the carbon and additional cracking and spalling.

In an attempt to prevent metal impregnation of large carbon blocks, some manufacturers have introduced densified or reimpregnated carbon blocks with low porosity and minimal pore size. These "micropore" carbon refractories are designed to limit the amount of molten materials that can enter the structure of the block through its porosity. This solution is contrary to the "freeze" lining concept employed with hot-pressed carbon or semigraphite, which utilizes high thermal conductivity and the prevention of cracking, to promote a hot face temperature that is maintained below solidification temperature. Thus, in the case of the "freeze" lining wall concept, a skull quickly forms on the wall hot face and impregnation by molten materials is prevented. The resulting skull thickens over time to form an insulating layer once thermal equilibrium is achieved. Wall hot-face temperatures in these systems at the back of the skull are typically in the range of 200 to 600°C (400 to 1100°F). Another advantage that this cooler wall provides is that other temperature dependent reactions, such as oxidation or alkali attack, cannot occur as long as the wall temperatures remain below their critical reaction temperatures in carbon. Typically, these critical reaction temperatures are between 870 and 1100°C (1600 and 2000°F). As long as the wall hot face temperature can be maintained below these critical reaction temperatures, attack by these mechanisms cannot occur. However, if stress-induced cracking, deterioration of ram layers or any other disruption of heat transfer occurs, wall temperatures will increase, usually above these critical reaction temperatures. This results in chemical attack of the wall material, but only in the zone of the wall that is in the range of 870 to 1100°C (1600 to 2000°F). Usually, these chemical reactions do not occur above 1100°C (2000°F) in carbon so that consequently, a deteriorated band of material is found within the wall thickness. This brittle zone is usually sandwiched between sound carbon on both the hot and cold faces, which is defined by the location of the 870 and 1100°C isotherms in the sidewall.

As previously mentioned, some operators utilize a ceramic hot face layer on the carbon walls to prevent wall erosion. In addition, because of the low thermal conductivity of these materials, wall heat losses will be reduced. Several furnaces in Europe and South Africa have been lined using this concept. The longevity of the ceramic is dependent upon good thermal contact with the carbon and maintaining uninterrupted heat transfer capability through the carbon for the life of the ceramic. For reasons previously discussed, large block carbon walls are prone to cracking and loss of heat transfer capability. Thus, if cracking does occur, high temperatures in the ceramic result, hastening their demise. Therefore, only hot pressed bricks can be successful with the ceramic hot face lining configuration in a "freeze" lining concept.

Hot-pressed brick are resistant to chemical attack as long as they are properly cooled. However, because all sidewall cooling is dependent upon heat transfer through the entire wall thickness and then to a furnace shell on the wall cold face, it is imperative that contact be maintained with the cooling system at all times. Often, high-conductivity grouting materials must periodically be injected between the shell and wall to reestablish contact with the refractories, thus assuring heat transfer. Otherwise, the small air gap that forms between the shell and wall, may result in high wall temperatures and, consequently, chemical and hot metal attack can occur.

Another consideration when configuring "freeze" lining concept sidewalls, is to utilize a thin layer of graphite tiles, cemented directly to the steel shell. This layer of graphite forms a highly conductive annulus between the water cooled steel shell and the cold face of the carbonaceous sidewall. This super cooled annulus then acts a heat distribution layer, which can evenly distribute heat to the cooling water, especially when water flow is partially stopped to allow for cleaning. Another advantage is that this layer can act as a freeze surface in the event molten materials ever work their way inwards due to abnormal operating events or accidents which might disrupt lining integrity.

In summary, successful "freeze" lining concept sidewalls should be configured to accommodate differential thermal movements, accommodate stresses without cracking, provide low thermal resistance for the life of the lining by preventing deterioration of properties and characteristics and be efficiently cooled for their lifetime. Large block carbon and rammed joints are unsuitable for the application.

## 5. INTRODUCTION OF "FREEZE LINING" CONCEPT AT SAMANCOR LIMITED

### 5.1 First Repair Attempts

Samancor utilised the typical, insulated carbon paste hearth lining concept some time ago and has experienced poor performance with lining longevity and break-outs, as well as poor taphole performance. The main mode of failure was hearth wall failure above or between the tapholes and the loss of process materials through the hearth floor known as the "China Syndrome" failure.

In April 1995, Samancor utilized a new, "in-house" repair design for M3 furnace, based on this insulated concept and requested machining of carbon brick to suit their requirements. The arrangement of this lining repair is shown in Figures 5-1 and 5-2 for discussion purposes.

This design incorporated the use of carbon brick in the bottom sections of the hearth walls in an effort to establish carbon to carbon contact in the lower hearth area and consisted of outer and inner rings, which also support the taphole blocks. The general arrangement, however, is based on the insulated refractory concept, not a freeze lining concept. The sub-hearth consists of a thick ceramic pad with no cooling on both the bottom and outer steel shell. Because of this insulation, wear and degradation of the hearth walls and bottom refractories will be the same as the previously installed insulated paste linings, and that this lining configuration will not reach true thermal equilibrium and establish a protective skull on the hot face as explained earlier in this paper.

Salamander penetration estimates for "insulated", thick lining designs, indicated that it would be impossible for this insulated lining type to reach thermal equilibrium and that a "wear/deterioration" versus time situation would prevail.

Thick carbon paste linings increase thermal resistance and loss of structural integrity during use due to differential baking/curing temperatures of the paste. Paste linings are prone to density loss (volatiles) and cracking due to the high temperature differentials measured from the hot face to cold face early during start-up and operation. If the refractory lining is too thick, with increased thermal resistance, the refractory hot face temperature will be high even if the paste is protected by a ceramic protection lining, preventing slag and metal accretions (skull).

Thick paste or carbon linings are a dangerous practice due to the fact that the excessively thick lining is constantly in contact with the process due to the lack of skull formation. This is aggravated by the fact that the "carbon" portion is insulated from the cooling and the lining is subjected to chemical attack and erosion from process materials and actions. Additionally, the excessively thick lining is subjected to high heat load and extreme temperature differentials in this hostile environment, which can result in heat transfer interrupting cracks and premature failure.

The installation time of paste lining as installed in Furnace M3 are also longer due to the large mass that needs to be heated (melted), transported hot to the furnace and "poured" during installation. Environmentally this type of installation has become unacceptable due to the high volume of pitch volatiles present during heat-up and installation, forcing the installer's crew to wear safety face masks and respirators for protection under these hazardous conditions. The danger of burning employees is also a factor for consideration. The actual installation time to install all the refractory materials during the M3 reline, including the paste, took at least 30 days.

Soderberg paste linings are also subject to prolonged curing times (2 to 3 weeks) before the furnace can be taken up to full production levels.

In the case of installing a "freeze" lining as discussed, long installation times and safety hazards are eliminated. The installation time of all the refractory materials, using a contractor familiar with the "freeze" lining installation procedures, in a furnace similar in size to M3 can be achieved within 7 to 8 days. The "freeze" lining concept using carbon and graphite components as explained in earlier sections of this paper, do not require any special dry-out or curing procedures. The ceramic portion however, needs to be dried and cured as per the procedures laid down by the ceramic manufacturer which may only be a few days.

The "freeze" lining concept therefore eliminates many safety hazards during installation, reduces dry-out or curing times to bring the furnace to full production sooner and has the added advantage of forming a protective skull on the hot face for prolonged trouble free operation.

Unfortunately the reline schedule of M3, at the time of introducing the "freeze" lining concepts, was well progressed and the repair had to proceed as designed, despite the expected performance and installation problems. The rebuild took place from June until August 1995.

5.2 Introduction of first "freeze" lining concepts in a repair

During the period of the M3 reline, Samancor was introduced to "freeze" lining concepts and agreed to do a partial hearth wall and taphole repair on their M2 furnace, to evaluate the "freeze" lining concept.

The M2 furnace experienced the typical symptoms of hearth wall wear and erosion with dangerous wear and break-outs occurring above the taphole blocks. These problems resulted in unexpected shutdowns, dangerous conditions, high maintenance and severe loss of productivity. The repair was intended to provide a way to stabilize wear and form a protective accretion on the repair hot face. This repair consisted of a 100° arc and included both tapholes. The repair concept is illustrated in Figures 5-3, 5-4, 5-5 and is based on the "freeze" lining concept, which utilizes graphite tiles against the steel shell and hot pressed carbon brick on the hot face protected by a ceramic castable for start-up purposes.

The furnace steel shell was removed to expose and remove the residual refractories in the repair area. After removal of the severely damaged ceramic brick and remains of the paste, the bottom half of the steel shell in this area was replaced with new steel. A ceramic levelling layer was placed on top of the existing ceramic floor and the contractor proceeded with the installation of the graphite tiles and pre-cut carbon brick tightly against the new steel shell and refractories in the "old" hearth wall. Ceramic castable material was poured between the hot furnace burden and the carbon brick for protection purposes. The upper half of the graphite tiles, carbon bricks and taphole blocks were installed during phase two of the repair, followed by ceramic castable on the hot face.

A quantity of special graphite grouting material was pumped through nozzles located on the new steel shell, to ensure intimate contact between the steel shell and graphite tiles after all the welding work on this new panel was complete.

It is important to stress that the "freeze" lining concept requires that the shell be water cooled at all times to enhance skull formation and protection of the carbon/graphite lining. Samancor installed shell water cooling on the patch to ensure proper cooling. This repair was done during March 1996 and Samancor, soon after start-up, realized that the repair was performing very well and was superior to the original insulated paste lining.

5.3 Taphole Configuration of M2 Furnace

The repair configuration included carbon and graphite lintels above the taphole to support the hot pressed carbon brick in the upper hearth wall, as well as a replaceable, pre-drilled, graphite taphole insert within a main carbon taphole block. See Figure 5-6 for the taphole repair arrangement. The hot face of the graphite insert is protected by a carbon block with pre-drilled taphole which forms part of the hearth wall and a removable carbon block called a "mickey" on the cold face. The carbon "mickey" can be removed if damaged by the clay gun and has been standard practice at Samancor. During tapping, the graphite absorbs the high temperature of the process materials. The carbon portion of the taphole assembly, due to its lower thermal conductivity compared to the graphite, cannot remove the heat from the graphite. This ensures a hot taphole with improved flow rate through the taphole, with no clogging.

The heat retained in the graphite after tapping, is then used to quickly and thoroughly bake the taphole clay during taphole closure. Samancor drills a 45 mm diameter hole through the baked taphole clay for tapping purposes and the residual clay acts as protection for the graphite during tapping. Obviously the clay can erode over time, and could eventually erode the graphite "core". At this time, the graphite insert could then be bored and a repair core of new graphite installed when deemed necessary. At the time of publishing this paper, no repair to the taphole (graphite portion included) was necessary since installation in March 1996.

All of the carbon and graphite materials were installed using a special heat setting carbonaceous cement to provide expansion relief during warm-up of these materials. This cement forms a strong bond between the carbon and graphite shapes. Similarly, carbonaceous cement was used between the graphite and steel shell during installation, to ensure intimate contact for uninterrupted heat transfer to the cooling system during operation.

### 5.4 First Complete "Freeze" Lining Reline

The superior performance, low hearth wall temperatures and excellent taphole performance achieved on the "freeze" lining repair zone on furnace M2 compared to insulated, paste type linings previously used, prompted Samancor to convert fully to the "freeze" lining concept for their M4 furnace reline. The actual lining configuration for M4 is shown in Figures 5-7 and 5-8.

In order to convert fully to the "freeze" lining concept Samancor installed the furnace bottom plate on grillage beams with air cooling fans. A water cooling system on the shell was also installed to ensure effective cooling of the graphite and carbon hearth wall refractories.

#### 5.4.1 Hearth Pad Cooling Layer

The hearth pad cooling layer consists of a 300 mm, high conductivity, graphite pad comprised of two, 150 mm thick courses. The graphite hearth pad intercepts the intense heat underneath each electrode and distributes it radially to the water cooled sidewalls. In order to protect the steel plate bottom, a layer of ceramic brick is provided for insulation. A ceramic castable layer is also provided on top of the steel plate to provide a level plane surface for the pad. Both ceramic components also provide required electrical isolation.

The vertical steel shell is lined on its entire hot face with 70 mm thick graphite tiles. These tiles provide heat equalization in "hot spot" areas and allow isolation of shell water spray zones, for shell cleaning.

#### Hearth Pad Crucible Layer

The hearth crucible contains one, 600 mm thick, low elastic modulus, high conductivity carbon block, installed directly on top of the graphite cooling course. A sacrificial layer of reclaimed carbon blocks ± 200 mm thick, were installed on top of the carbon crucible layer. Ceramic material can also be used as a sacrificial layer as was previous described in Section 4.2. Samancor, however, elected to utilize reclaimed carbon in stead of ceramic to save capital.

An annulus of hot pressed carbon bricks is provided between the graphite tiles on the shell wall and the carbon crucible layer. This brick annulus provides a "safety lining" on the block cold face diameter and allows the carbon ram required in the pad to be located closer to process heat. This results in higher ram temperatures and consequently, higher ram conductivity, which is a function of temperature.

All carbonaceous refractories are installed utilizing a special, heat setting graphitic cement, which allows for proper differential expansion of refractories during heat-up. This special cement also carburizes and forms strong carbonaceous bonding after heat up.

All carbonaceous refractories are installed utilizing a special, heat setting graphitic cement, which allows for proper differential expansion of refractories during heat-up. This special cement also carburizes and forms strong carbonaceous bonding after heat up.

5.4.4 Taphole Installation

On the M4 Furnace reline both tapholes installed, duplicated the M2 installation. A recent inspection done on M4 tapholes showed no wear after 14 months of operation. The arrangement is shown in Figure 5-7.

M4 furnace came on-line during June 1996 and showed superior performance early after start-up when compared to the insulated refractory concept used previously. Hearth wall and hearth pad temperatures were found to be extremely low which is proof that a protective skull formed on the hot face. This protective skull is made up of the originally installed ceramic protection lining as well as frozen slag and process materials. The hearth wall and hearth bottom temperatures as measured by Samancor are in line with those predicted prior to start-up. It is believed that the hearth bottom, however, has not yet reached its true equilibrium state based on the fact that the temperatures are still slightly lower than predicted and may be due to the fact that Samancor decided to use two additional courses of re-claimed carbon bricks on the hot face instead of ceramic which may allow for additional cooling by the hearth walls. It is worth mentioning that the thermal conductivity of this layer is estimated to be the 1.5 - 2.5 W/M°K range which prevents heat loss through the highly conductive lining.

Samancor decided, based on the trouble free operation of furnace M4, to convert their M1 and M2 furnaces fully to the freeze lining concept and to re-evaluate their current furnace refractory concepts on their other furnaces. All the carbonaceous refractory materials required for M1 and M2 are on site awaiting installation.

5.4.5 Predicted Hearth Wall Temperature Description :

A one-dimensional heat transfer analysis was performed for Samancor's M4 FeMn furnace. Four cases were considered, as shown in Table IV; all cases used Grade CBY graphite and Grade NMA carbon brick installed against a spray-cooled steel shell. The configurations are shown on the attached sketches. Table V lists the parameters for each material.

Results

The calculated temperatures profiles and the corresponding temperatures at each interface are shown on Figures 5-9 to 5-12. The temperatures and heat flux are also tabulated in Table VI below.

| Table IV | | |
|---|---|---|
| | **Hot Face Material** | **Process Temperature** |
| Case 1A | Ceramic Blow-in Protection | 1450°C |
| Case 1B | Process Skull | 1450°C |
| Case 2A | Ceramic Blow-in Protection | 1700°C |
| Case 2B | Process Skull | 1700°C |

| Table V | | |
|---|---|---|
| **Material** | **Thickness** | **Thermal conductivity k/ Convection Coefficient h** |
| Spray Cooling | | 3958 W/m°·K, T = 35°C |
| Steel Shell | 50 mm | 52 W/m°K |
| Grade CBY Graphite | 70 mm | 120 W/m°K |
| Grade NMA Carbon Brick | 230 mm | 12 W/m°K |
| Ceramic Blow-in Protection (Cases 1A and 2A) | 230 mm | 1.5 W/m°K |
| Process Skull (Cases 1. B and 2B) | 400 mm | 1.5 W/m°K |
| Internal Process | | |
| Case 1A and 1B | | 1883 W/m°K, T = 1450°C |
| Case 2A and 2B | | 1883 W/m°K, T = 1700°C |

| Table VI | | | | |
|---|---|---|---|---|
| | **Case 1A** | **Case 1B** | **Case 2A** | **Case 2B** |
| Shell cold Face | 37.0°C | 36.2°C | 37.4°C | 36.5°C |
| Shell Hot Face | 44.8°C | 41.0°C | 46.6°C | 42.0°C |
| CBY Hot Face | 49.6°C | 43.8°C | 52.1°C | 45.4°C |
| NMA Hot Face | 204.7°C | 137.9°C | 234.7°C | 156.1°C |
| Ceramic Hot Face | 1445.7°C | | 1694.9°C | |
| Skull Hot Face | | 1447.4°C | | 1696.9°C |
| Heat Flux | 8094 $W/m^2$ | 4910 $W/m^2$ | 9524 $W/m^2$ | 5778 $W/m^2$ |

As can be seen, this wall configuration provides very low temperatures (below 235°C) at the hot face of the carbon under both blow-in and operating conditions.

Actual temperature measurements as measured by Samancor shown on Table VII.

Furnace Hearth Pad
The temperature measurements taken directly below the electrodes at an elevation between the ceramic brick and bottom course of graphite interface is well below 250°C when compared to the predicted 405°C. A conservative approach was taken for pad temperature prediction by assuming that the hottest zone would be at the furnace centerline, which is the farthest point effected by wall cooling. The actual temperature measurements indicate that the pad penetration at this time would be less than the original model estimate of 475 mm.

Furnace Hearth Wall

Thermocouples were installed at an elevation below the taphole level to monitor hearth wall temperatures approximately 50 to 75 mm deep in the hot pressed carbon brick. These thermocouples encountered reliability problems early after start-up which prompted the use of infra-red scanning of the furnace shell temperatures. Table VII list the shell temperatures which are well below the predicted levels indicating that skull formation has been achieved and maintained.

## 6.0 SAMANCOR EXPERIENCE

### 6.1 Introduction to Meyerton Works

The Meyerton Works of Samancor Limited consists of three manganese alloy producing plants situated on a site of 680 ha,60 kilometres south of Johannesburg, South Africa. In the early 1950's production, of ferroalloys started with No.2 furnace and capacity was expanded during this decade into the early 1960's, eventually culminating in seven alloy furnaces at what became known as the South Plant.

In the early 1970's, the first of the new generation furnaces were installed and commissioned. These furnaces, known as North Plant, were originally installed as 48 MVA Elkem furnaces, which were subsequently uprated to 75 MVA each.

The last capacity expansion took place at West Plant, with the installation and commissioning of an 81 MVA Tanabe furnace in 1978. During the late 1980's, the furnaces at the South Plant were upgraded and modified to comply with increased pollution control requirements.

The Works now consists of ten manganese alloy production furnaces, with individual capacities ranging from 6 MVA to 81 MVA. The total installed capacity of the Works is 340 MVA, translating to a ferromanganese equivalent of 550 000 tonnes per annum. A mix of ferromanganese and silicomanganese is produced, with the bulk of the ferromanganese being produced on the larger furnaces and the silicomanganese being produced on the smaller furnaces. Within the structure of the Meyerton Works, furnaces with a transformer rating of less than 30 MVA are considered small and the rest are considered as large furnaces.

The Manganese Division, of which the Meyerton Works is the only alloy producer, holds the rights to a large proportion of the approximately 12 billion tonnes of manganese ore reserves in the northern Cape in the Republic of South Africa. About 40% of the ore produced by the Manganese Division is converted into alloy at the Meyerton Works.

### 6.2 Principles of Furnace Lining Operations Philosophy

The linings of furnaces have, in the opinion of the author, been neglected as an important part of furnace operating philosophy. The discussion that follows gives an outline of the change in philosophy on furnace linings that has taken place in the operations at the Meyerton Works.

6.2.1 Historical Perspective

In the past, the linings of the small furnaces were considered to be consumable and provision was made for regular replacement. The lining of the furnace was taken to be a receptacle whose only purpose was to contain the molten materials in the crucible. The reline of a small furnace could be performed reasonably quickly and all the material required could be sourced locally. The use of paste linings evolved out of the need for quick and relatively inexpensive replacement.

The linings of the larger furnaces were considered differently. The carbon linings were acknowledged to be expensive commodities and could only be imported, so in the case of a lining failure, the lost production and financial ramifications were significant. Reality thus resulted in a fundamental reconsideration of the factors that were important in maintaining the integrity of the carbon linings of the large furnaces.

6.2.2 Furnace M12

The reconsideration of the factors of importance in maintaining the integrity of the lining of the large furnaces, was given impetus by the break-out of the 81MVA Tanabe furnace M12, in November 1980. This was about two and a half years after commissioning. It was realized at the time, that the degradation of the carbon blocks was thermally initiated and once the molten material had started to attack the carbon, there was very little that could be done to remedy the situation and that failure of the lining was inevitable.

The feeling at the time that if a "natural" lining could be instituted on the hot face of the carbon lining there would be, in theory, no wear on the carbon. This resulted in investigations of the heat transfer characteristics of the lining and methods of utilizing the increased theat transfer to form a "natural" hot face lining, or "skull" of frozen process materials.

To this end, the combination of lining materials and the physical layout thereof were chosen so as to increase the heat transfer through the lining. The steel furnace shell was also water cooled, so as to decrease the hot face temperature of the carbon. Decreasing the hot face temperature of the carbon to a point significantly below the liquidus temperature of the material contained in the crucible, facilitated the formation of the "natural" lining in the furnace. It is important that the temperatures in the lining at critical and potential high wear areas, are monitored and trended so that deviations from a theoretical temperature at the determined positions in the lining, can be reacted upon.

On M12 furnace, there are duplex thermocouples placed in the lining opposite each of the electrodes at the level of the slag taphole. In addition, thermocouples to monitor the taphole temperatures are installed on either side of the tapholes. This particular lining has now been in operation since February 1981 and is currently showing no signs of deterioration and the life of this lining is considered to be indefinite.

The success achieved with this lining prompted a process of reorientation as far as the management of furnace linings is concerned.

6.2.3 Furnace M10

Furnace M10 is one of the 75 MVA Elkem furnaces at the Meyerton Works. During the late 1980's, it was becoming evident that the manifestation of serious lining problems, particularly on the hearth, was inevitable. Planning for a reline of the furnace was initiated and the reline was undertaken in 1990. When the furnace was broken out, metal penetration between the carbon blocks was found in the hearth of the furnace. There was also significant wear of the carbon blocks on the walls of the furnace.

The reline was planned and instituted based on the lessons learned with the lining of M12 during the previous number of years. At this time, the lining in M10 furnace is showing no signs of deterioration and the life is also considered to be indefinite.

A problem that has been experienced with this lining is the maintenance of the integrity of the thermocouples that are important for monitoring the temperature of the lining. In order to overcome the shortcomings, a program of infra-red scanning is related to the temperatures within the lining and the results are used to achieve the same level of temperature monitoring and control as was achieved with the thermocouples in the lining.

6.2.4 South Plant Furnace Lining Repairs and M4 Reline

As a result of the success achieved with a quasi "freeze" line concept in the linings of the large furnaces, it was decided that, in order to achieve a step change in the lining performance of the smaller furnaces, the concept would be extended to the linings of these furnaces.

The process on M2, M3 and M4 furnaces has been discussed previously and will not be considered further. A major breakthrough that has been made in this process is the taphole configuration. This area deserves further attention.

The furnace taphole is a notoriously high wear area of the lining as it is the point that the lining is subjected to the highest thermal stress. In order to maintain the taphole as cool as possible, water cooled taphole arches have very often been used. There is no need for any further explanation as to the undesirability of water in the taphole area or in the lining for that matter. As has been mentioned previously the performance of the "freeze" lining taphole configuration has been exemplary thus far.

6.3 Conclusion

There is no doubt that in terms of improving the performance of furnace linings for the production of manganese alloys, the "freeze" lining concept is the way to go. The success of the linings on the smaller furnaces has resulted in a different way of considering the linings of the furnaces and will consequently manifest itself in significant cost and production loss savings.

## SUMMARY

"Freeze" lining concepts can provide improved life and performance in submerged arc furnace applications. Lining thickness and composition can be configured to optimize performance potential, reduce capital expenditures, reduce reline downtime, eliminate lining maintenance and improve safety and profitability. "Freeze" linings have been proven to perform far superior to conventional, insulated carbon linings, in ferromanganese, silicomanganese and ferrochrome applications in Europe, South Africa and North America. They result in low refractory temperatures, minimal heat losses and improved productivity, which have a positive impact on profitability.

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