# IMPROVED FURNACE LINING PERFORMANCE AT YIWANG FERROALLOYS

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## ABSTRACT

*Yiwang Ferroalloys produces manganese metal in a three stage process. The first stage generates high carbon ferromanganese and a High Grade slag from primary raw materials. The second stage produces low carbon silicomanganese from the High Grade slag. In the third stage, some of the High Grade slag from Stage one and the low carbon silicomanganese from stage two are reacted together to manufacture manganese metal. In limiting the manganese recovery in the first stage of the process, the slag will contain a high level of MnO.*

*When molten, this slag composition is very reactive towards standard furnace linings which incorporate regular grades of carbon backed by ceramic refractory materials. The result at Yiwang was lining campaigns of less than six months.*

*Faced with this problem, Yiwang evaluated the advantages of a carbon based lining system in which the generation of a frozen layer between the process and the refractory lining becomes a buffer zone or working lining which can form and reform as process conditions change.*

*In late 2006, a UCAR ChillKote™ lining was installed in the 10.5 MVA high carbon ferromanganese furnace at Yiwang. Since start up in 2007, this lining has provided more than four years of service, a significant advance on what has been achieved using standard refractory lining systems.*

*This paper outlines the challenge faced by Yiwang, the solution supplied by GrafTech and the results achieved by Yiwang.*

***KEYWORDS:*** *high carbon ferromanganese, high grade slag, conductive furnace linings.*

## 1. INTRODUCTION

Yiwang is a privately owned specialty ferroalloy manufacturer located near Taiyuan in Shanxi Province, China. The principal product is metallurgical grade manganese metal, typically 97% Mn. Graftech is a US based company which manufactures and supplies carbon products, including graphite and carbon refractory linings for metallurgical furnaces.

## 2. THE YIWANG PROCESS

A commodity containing between 95 and 98% manganese with low levels of carbon, iron and silicon cannot be produced directly in a single stage operation using pyrometallurgical processes. The raw materials do not exist in a natural state. The process developed by Yiwang Ferroalloys is based on the following three steps:

Stage 1: High carbon ferromanganese and high grade slag: the purpose is to generate a slag high in manganese and low in iron, while also manufacturing a saleable alloy of high carbon ferromanganese.

Stage 2: Low carbon silicomanganese and discard slag: the purpose is to generate a silicon based reductant which is low in carbon and also contains manganese.

Stage 3: Manganese metal and discard slag: this is the principal product, manufactured by reacting the low iron High Grade Slag with the Low Carbon and Low Iron Silicomanganese reductant.

Yiwang's saleable products are High Carbon Ferromanganese from stage 1 and Manganese Metal from stage 3.

## 3. HIGH CARBON FERROMANGANESE OPERATIONS

In a submerged arc furnace, High Carbon Ferromanganese is produced by either a recycle or a discard slag practice. The selected option is based on the quality and cost of raw materials, the product line and required overall plant manganese recovery. It is common practice to integrate High Carbon Ferromanganese and Silicomanganese operations such that a High Grade Slag is transferred from one furnace to the next. In this two stage operation, the High Grade Slag typically analyses between 20% and 35% Mn with less than 0.5% Fe, and a Mn:Fe ratio of greater than 50:1. The High Carbon Ferromanganese operation often imposes a limit on manganese recovery from raw materials to about 70%, while 98% or more of the iron in the raw materials is transferred into the first stage alloy. Careful selection of raw materials is also required to prevent dilution of the manganese in the High Grade Slag. As a result, the slag to alloy ratio is usually about 0.5:1. The alumina content of the slag will also influence both manganese recovery and manganese dilution, and this has a bearing on raw materials selection since the alumina content of manganese ores is a variable.

The production of High Carbon Ferromanganese at Yiwang is an enhanced version of the standard two stage industrial process, made necessary by the fact that a Super High Grade slag needs to be prepared, one which has a Mn to Fe ratio in excess of 150:1. Maximum iron transfer with low manganese transfer necessitates using a low basisity slag, defined by the ratio ($CaO$ + $MgO$ /$SiO_2$), even though the MnO is a basic oxide and, in these circumstances, the $Al_2O_3$ is acidic. The following products are generated by Yiwang in the first stage of their production process:

Metal: HCFeMn alloy containing 65-75% Mn, 7%C, 0.5% Si.

Slag: Super High Grade Slag containing 45-55% MnO, less than 0.3% FeO, less than 0.01% P, less than 8% $Al_2O_3$, and a basisity ($CaO$ + $MgO$ /$SiO_2$) of less than 0.4:1.

## 4. THE FURNACE LINING

The Yiwang process introduces several challenging aspects when compared with the standard high carbon ferromanganese recycle slag operation. Major variations are that the slag to alloy ratio is greater than 1:1 and the slag liquidus temperature is higher at around 1450°C. When liquid, the MnO present in this slag is very reactive toward any form of carbon such as electrodes and lining materials, according to the following reaction:

$$MnO_{(l)} + C_{(s)} = Mn_{(l)} + CO_{(g)}$$

Traditional furnace linings in China incorporate insulating materials at the cold face with carbon based materials at the hot face. As a result, the process initially practiced at Yiwang resulted in high hot face temperatures and very short lining campaigns, particularly on the sidewalls. Since a process which cannot be contained will not be commercially viable, Yiwang faced a significant challenge to a sustainable operation.

In 2006, Yiwang had started on a plant expansion which included the installation of a new 10.5 MVA High Carbon Ferromanganese furnace, designated F101. Short lining campaigns could not be accepted as downtime would deprive the down-stream furnaces of an essential raw material, namely the Super High Grade slag. Therefore Yiwang approached GrafTech for a solution based on the concept of the process slag being allowed to freeze onto the refractory hot face, thus providing a working lining between the process and the lining materials.

The establishment of a freeze lining can only be achieved if the temperature at the hot face of the lining is lower than the slag liquidus temperature. In addition, efficient carbon lining performance requires a hot face operating temperature of less than 800°C. In order to establish the required thermal profile, the heat presented to the lining must be removed rapidly and uniformly. The high thermal conductivity lining therefore includes the following component parts:

- Water cooling on the shell sidewalls and air cooling under the hearth
- Graphite tiles fitted directly to the inside of the steel shell
- Low permeability and uniform high density carbon bricks fitted directly against the graphite tiles

The lining technology adopted by Yiwang for F101 required several changes to their standard furnace design. Water sprays had to be installed to cool the shell. The furnace shell was also placed on beams and the cavity thus created is now cooled with ambient temperature forced air.

The lining has a low thermal resistance and creates the conditions under which solid process materials are in contact with the refractory hot face, thus presenting an insulating layer to the hot face carbon refractories. This arrangement enables the lining system to achieve thermal equilibrium, thus minimizing heat losses and preventing lining degradation. Once thermal equilibrium has been achieved, refractory temperatures are low and therefore chemical attack cannot occur. The protective layer of solid process material protects the refractory mass from thermal shock, abrasion and erosion.

The general arrangement for the GrafTech ChillKote™ lining installed on F101 is shown in figure 1. The lining includes graphite tiles and HotPressed™ carbon bricks in the side walls. A GrafTech three-part taphole block was installed in each of the two tapholes.

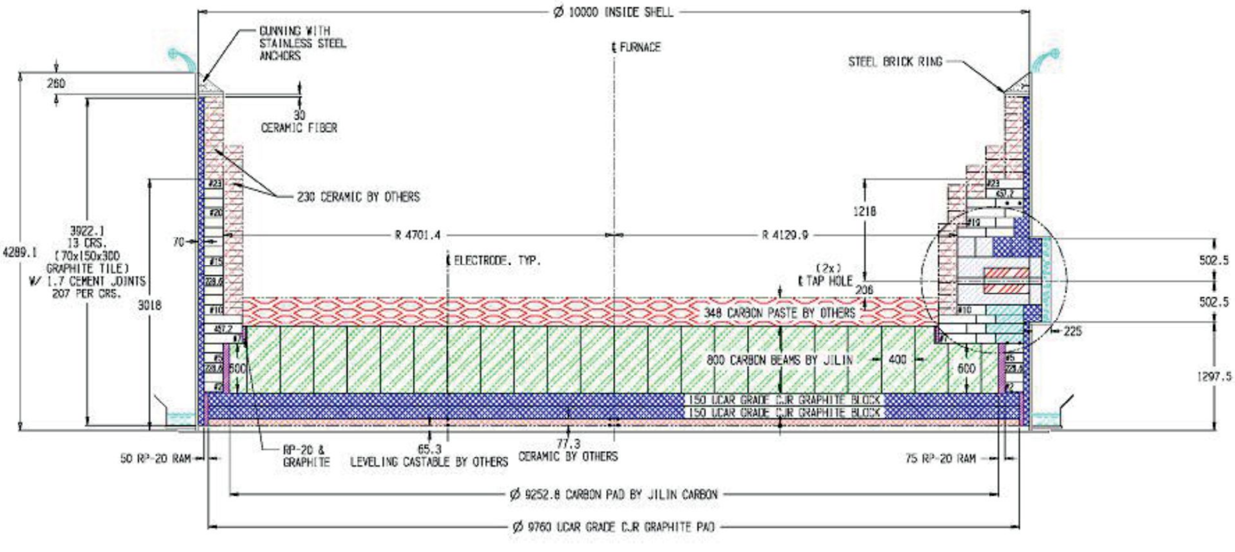


**Figure 1:** F101 Furnace Lining

Since the heat removal rate achieved by water cooling cannot be applied to the hearth, the solution in this section of the lining was to install graphite over an insulating ceramic layer which covers the shell, then to build up with carbon blocks and carbon ramming paste. The purpose of the graphite in the hearth is to distribute the heat evenly over the entire hearth cross section and onto the lower sidewalls where the effects of water cooling come into effect. The wall lining is only 643 mm thick yet the entire lining operates well below a hot face temperature of 600°C.

As shown in figure 2, the wall is constructed with small Hot-Pressed™ bricks. Segmenting the wall into multiple brick rings greatly reduces internal stress within each brick, thus eliminating the principal cause of cracking. Small component pieces are subjected to less expansion when compared with large carbon blocks. The carbonaceous cement between the bricks provides both stress relief and thermal conduction. The high thermal conductivity graphite tiles installed adjacent to the water cooled shell ensure that cooling is efficient in all parts of the lining. Figure 3 shows the taphole under construction with the graphite lintels having been placed in position.

**Figure 2:** F101 Installation of HotPressed™ carbon bricks

**Figure 3:** F101 Taphole under construction showing lintels in position

## 5. PERFORMANCE OF THE LINING

Following start up in April 2007, F101 has been in regular operation, except for the following three periods:

- 2009: 3 months, when the entire plant was idled due to the World Financial Crisis
- 2010: 2½ months, when the Central Government instructed the ferroalloy industry to lower $CO_2$ emissions in order to meet the commitments of the 2006-2010 Five Year Plan
- 2011: 8 months, when the auxiliary equipment in Melt Shop No.1 was under renovation

During the 2011 shutdown, the furnace lining was inspected. After removing the protective freeze lining which had replaced the sacrificial ceramic layer, as shown in figure 4, the sidewall carbon brick furthest from the tapholes was noted to be in its original condition.

Excavation at the taphole blocks identified wear back to the original adjacent carbon bricks in the sidewalls, as shown in figure 5. The original 870 mm depth of taphole block had been eroded by about 400 mm at both tapholes.

Yiwang's tapping practice involves using a drill to open and a mudgun to close, with minimal use of oxygen lancing. Since only one taphole had been used throughout the 44 months of operation between April 2007 and May 2011, yet the same erosion pattern was noted at both tapholes, it has been concluded that erosion was not due to tapping activities. The hot face taphole erosion pattern indicates that standard furnace conditions do not permit the tapholes to remain at the design thickness. This will be a consideration in any future design.

**Figure 4:** Condition of Sidewalls after four years of Operation

**Figure 5:** Condition of the Tapholes after four years of Operation

## 6. CONCLUSIONS

F101 was restarted in early 2012 after the Meltshop renovation without making any repairs to the lining. At that time, lining life stood at 44 months, more than eight times longer than what had been achieved previously. Regular monitoring of the lining using the thermocouples embedded in the sidewalls and the hearth provides the operators with a means of determining the condition of the lining.

Based on improved lining performance in F101, Yiwang has decided to install the same lining concept and materials in F301 in 2012, the 18 MVA High Carbon Ferromanganese furnace in Meltshop No.3.

## 7. REFERENCES

[1] Coetzee, C., "Application of UCAR® CHILL-KOTE™ Lining to Ilmenite Smelting", 11$^{th}$

International Ferroalloys Congress Proceedings, New Dehli, India, February 17-21, 2007.
[2] Duncanson, P.L. and Toth, J.D., “The Truths and Myths of Freeze lining Technology for Submerged Arc Furnaces”, International Ferroalloys Congress, INFACON X, Cape Town, South Africa, February, 2004.
[3] Hearn, A.M., Dzermejko, A.J. and Lamont, P.H., “”Freeze” Lining Concepts for Improving Submerged Arc Furnace Lining Life and Performance”, 8th International Ferroalloys Congress Proceedings, Beijing, China, June, 1998.
[4] Duncanson, P.L. and Sylvén, P, “A financial model for investment in hearth technology”, Steel plant and equipment manufacturer supplier conference, Ranchi, India, January 2007.
[5] Coetzee, C., Lamont, P.H., Duncanson, P.L. and Sylven, P., “GrafTech Installation of Jindal #2 FeCr Furnace”.INFACON XII, Helsinki, Finland, June 2010.
[6] Olsen, S.E., Tangstad, M. and Lindstad, T., “Production of Manganese Ferroalloys”, Sintef and Tapir Academic Press, Trondheim, 2007.