

Refractory Practices in Ferro-alloy Smelting Furnaces

B. Chatterjee & K.K. Singh
National Metallurgical Laboratory
Jamshedpur 831 007.

Introduction

Ferro-alloy furnaces are basically electrothermic furnaces where various iron-alloys viz. Fe-Si, Fe-Mn, Fe-Cr etc., are produced. In the production of these alloys, the furnace inside acts as a receptacle. Lining therefore plays an important role. The choice of refractories for the furnace lining is determined by the technology of smelting, the character of the slag and alloy composition as well. The ferro-alloy furnace lining is distinguished by the considerable thickness of the hearth which ensures greater thermal inertia and stability of temperature in the smelting zone of a furnace during short idling periods. Further, a fact common to all ferro-alloy furnaces is that the actual working layer of the furnace lining is the so called coating i.e., accretion formed by burden, components, lining fragments and smelted alloys.

Development of newer refractories for linings of ferro-alloy furnaces has been slow as compared to steel making vessels and blast furnaces. Most of the ferro-alloy furnaces have much or less similar refractory lining as practised (1) 35-40 years ago. The main reason behind this is that furnace loads are relatively low as compared to the furnace dimensions.

Refractory Practices : Side Lining

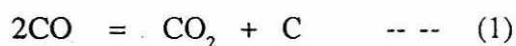
Fireclay bricks are normally used in side lining above carbon hearth. High alumina bricks of 45% Al_2O_3 content and above are used as permanent refractory lining. These refractories are indigenously available and their properties are given in table 1. The high alumina refractories are manufactured from quality raw materials by controlled processing to obtain high resistance to chemical attack, high temperature volume stability, low apparent porosity, high compressive strength, good thermal shock resistance and low creep. The calcination temperature of raw materials and the brick firing temperature are controlled in such a way that more coarsely grained mullite is formed instead of finely dispersed mullite (2) in order to increase the corrosion resistance. Properties of bricks are related to the development of intergranular bond, lowering the glassy phases and increasing the crystalline phases. NML has carried out extensive R & D work on the development of high alumina refractories in the range 60-90% alumina (3) from indigenous raw materials.

The upper part of the side lining deteriorates due to carbon monoxide cracking and alkali attack. Low temperature fired fireclay bricks with high Fe_2O_3 content dis-

integrate quite oftenly during laboratory test at 500°C in CO atmosphere. Hence, this type of brick should not be used in this part of the furnace lining. High temperature fired 'Superduty' fireclay bricks or high alumina andalusite-based bricks (4) are now used in this section with better service performance. Apparent porosity of these bricks is 15% maximum, Fe₂O₃ content 1.5% maximum and they are fired at 1450°C minimum. Whenever, upper part of the side lining fails, andalusite-based bricks are used for repair purposes. Andalusite-based bricks have very good alkali resistance. As alkali attack has been observed in a number of ferro-alloy furnaces, bricks with good resistance towards alkali attack should be used. There is no lifting problem of the side lining with the use of andalusite-based bricks. However, these bricks are not available indigenously due to rare availability of andalusite.

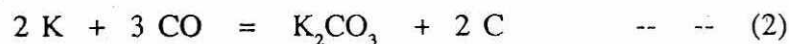
Wear Mechanism of Side Lining

SiO and CO gases ascend through the mix from the furnace crater. Most of the SiO gas reacts with carbon present in the mix forming SiC and CO. In the colder regions of the mix, the furnace gas contains mainly CO. It is unstable at lower temperatures and reacts as follows :



In the side lining, temperature drops from 1300-1400°C at the hot face to 200-300°C at the cold face. CO penetrating into the bricks decomposes as per eqtn. 1 and results in carbon deposits and disintegration of fireclay bricks.

The raw materials used in the production of ferro-silicon and silicon metal contain 10-20 Kg of alkalies (Na₂O + K₂O) per ton of alloy. In the hot zone of the furnace these oxides get reduced to Na and K which ascend with the furnace gas because of their low boiling points. They react with CO at lower temperatures in the upper layers of the mix as follows :



Carbonate is stable upto about 1000°C, above this temperature alkali gas forms.

Hence, penetration of CO and alkali gas into the side lining results in carbon deposits and formation of alkali carbonate. Carbon deposits disintegrate the bricks and alkali carbonate dissolves partly Al₂O₃ and silica glass present in the fireclay bricks.

Hearth Lining

Ferro-alloy furnaces of all types are almost invariably lined with carbon blocks especially in the hearth bottom and hearth walls. The reasons for using carbon blocks are given below :

1. It has virtually no liquid phase, which means that its resistance to load at high temperature is extremely good.
2. Strength of carbon is quite high at elevated temperatures and in fact it increases with temperature.
3. It has low thermal expansion co-efficient.
4. It can be machined or ground to close tolerances.
5. It does not wet most metals and slags.
6. Thermal conductivity can be varied over a wide range and is high compared with other refractories.

Raw materials needed for making carbon blocks/bricks comprise of dry aggregate and binder. The dry aggregates are usually prepared from coal, coke, calcined anthracite and petroleum coke. The raw materials used in making carbon blocks/bricks play a very important role as shown in table 2. The high % of ash, strength and abrasion resistance of the coal-coke brick and the low porosity of the anthracite brick are worth noting. Bricks made from petroleum coke are weaker and less abrasion resistant than the products of other raw materials. The only outstanding property of petroleum coke is its low ash content. Binders (tar/pitch) are also responsible in contributing variable properties to the carbon blocks/bricks. Although a hard pitch is preferable as binder from the point of view of its high coking residue but the finished blocks are brittle. Hence, a medium hard pitch or a blend of hard pitch and tar are usually used.

The dry aggregate of proper size distribution and the binder in specified quantities are mixed together in a hot mixer at a particular temp. for a specified time. The hot mix is either extruded or pressed in a hydraulic press or formed in a vibratory compactor. The modern practice is to use vibratory compactor for bigger sized blocks as it gives a compact dense product. The blocks thus made are baked in gas/oil fired furnaces at a temp. in the range 1300-1350°C following a certain heating schedule, in reducing atmosphere so as to protect carbon from oxidation. The average properties of carbon blocks/bricks used in ferro-alloy furnaces are given in table 3.

The carbon blocks are very carefully machined and laid up with close joints. In some cases, the machining is done to a minimum and the joints 2 to 5 cm wide are filled with carbon paste (5) and carefully tamped in hot condition. The joints bake in situ during heating. The linings are usually designed with the carbon block manufacturers' standard sizes in mind so that the largest size of blocks can be used with a minimum of machining. The larger the blocks fewer are the joints. It is desirable to use at least two layers of blocks in the hearth and sidewalls and the design should be such that the joints in one layer are covered by the solid block in the other layer. The hearth blocks should always be laid so that the lengths run in one direction only, never with one layer running in one direction and the other layer across it. Figs. 1 & 2 show new lining concepts for Fe-Si/Si-metal and Fe-Mn/Si-Mn furnaces respectively.

The life of a carbon lining is very long. A well installed lining in one type of operation may last for several years and perhaps with patching go through another run equally long. On the other hand, a poorly designed lining under adverse operating conditions may leak or burn out in a few days or weeks. Carbon paste is a cheaper material than formed, baked and machined blocks and probably because it works well when used as a patching material in relatively small quantities, it is also used as the working lining adjacent to the carbon blocks. Tamping of the hot paste is hazardous to health as the fumes from the hot tar/pitch go into the workers eyes, throats and lungs with damaging effects and inspite of the greatest care, large masses of unbaked carbon shrink during baking with consequent cracks throughout the mass although they may not always be continuous and cause trouble.

For laying up the bricks/blocks in the ferro-alloy furnace, various types of carbonaceous cement are used with the bricks. The larger blocks are laid with carbon paste which is similar to the electrode mix containing a tar or pitch bonding material and when heated in the furnace bakes in, to make a material looking like the carbon block itself. The other types of cements are available for use with the blocks, particularly for use when all the surfaces are machined and thin joints are required. Typical pastes and their mode of application are given in table 4.

Wear Mechanism of Hearth Lining

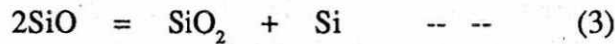
The wear is mainly related with furnace operation. It varies from 300-500 mm but in the central part of the furnace only traces of the carbon hearth are left in tact. Thus, maximum wear takes place in the central part of the furnace. In some furnaces, where mix is fed through charging tube, the central part of the hearth is entirely lost within 0.5 to 1 metre outside the electrode periphery. Actually segregation in the mix fed from the tubes results in underclosed mix in the central part of the furnace which leads to heavy wear of the carbon hearth. Also, sometimes there is a SiC build-up on the hearth and to remove this, furnaces are melted down to flush out the build-up by lime/iron ore or quartzite. This causes high wear inside the furnace.

Carbon blocks and carbon rammings are usually based on gas-calcined anthracite. Graphitization of anthracite starts at above 2200°C. But samples taken from carbon hearth during dig-out show typical graphitic appearance with considerable increase of thermal conductivity. There is also certain partial alkali gas pressure build-up in the Fe-Si/Si-metal furnace. Penetration of alkali gas into the carbon hearth is perhaps the reason for the graphitization. Hearth temperature indicates that graphitization takes place within six to eight months of operation.

Refractory Sub-hearth and Its Wear Mechanism

With the increased thermal conductivity of the carbon hearth, temperature at the interface between carbon and the upper layer of refractory bricks (laid below) is in the range 1750-1800°C. This is above the lowest liquidus temperature (1590°C) for the system $\text{Al}_2\text{O}_3\text{-SiO}_2$ containing about 73% Al_2O_3 and results in melting of the

bricks. Simultaneously, SiO from the furnace crater penetrates through the carbon hearth into the bricks and gets condensed as follows :



This results in reduction of porosity of the bricks and increase of thermal conductivity. The porosity is reduced from 15-20% to 0-2% level and thermal conductivity goes upto 4 times that of the original bricks. This is because the bricks contain Si metal and higher content of SiO₂. Thickness of the bricks has been found in the range 72-74 mm compared to the original thickness of 75 mm.

At temperature above 1650-1700°C, SiO gas penetrating down through the carbon hearth reduces Al₂O₃ in the bricks to AlO (gas). It escapes upwards and a cavity is formed below the carbon hearth. This cavity is filled with liquid metal from above. Thermal conductivity of liquid Si metal at 1400°C is 67 w/mk. It is higher than the graphitised carbon hearth. Due to these transformations, the freeze-line for metal gradually goes down towards the furnace shell. Cooling of the furnace bottom can only stop metal penetration downwards.

Tap hole : Ferro-alloy furnaces are usually provided with two tap holes; one for slag and the other for the alloy. However, some furnaces are equipped with two tap holes for alloy only. The eye of the alloy taphole is about 150-200 mm above the hearth level. The level of slag hole is determined by the maximum alloy level prior to tapping, usually the slag hole is 150 mm above the alloy tap hole. The tap hole is usually lined with a carbon block, approximately 2 m. long which is inserted into the upper course of the bottom lining; its external end reaches out into the taphole opening of the furnace shell. The remaining cavities between the fillings, blocks and lining are filled with anode paste. The furnace shell is cut above the tap-hole block and the arch is tamped with carbon paste. The tamping is periodically renovated approximately every five to seven days by means of a special iron flap behind which the finely ground mixture is tamped. The mixture is baked and made solid with the heat of the furnace.

Runner : Liquid metal runs from the taphole along the block into a ladle or the receiving end i.e., the trough and the runner made either of sheet metal or sections of iron castings. At the first instance, the runner is lined with carbon blocks and in the second with fire bricks. In both cases the lining is covered with tamping carbon paste.

Plug : Moulded carbon plugs are now a days used in place of ceramic plugs. Carbon plugs don't spall and are attacked by the molten steel much less than the one made from clay, so that they are often re-used two and three times. They have another advantage that they do not disintegrate and form inclusions in the steel, but rather burn up and disappear.

Supervision and Monitoring of Linings : Thermocouples are generally used in the lining or welded to the furnace shell for monitoring the lining conditions. The main

problem with this is that unless a large number of thermocouples are installed, breakout may occur in between thermocouples. Another problem is that thermocouples installed with steel protection tubes show erratic readings. For example, thermocouples installed in the bottom lining of a ferro-silicon furnace with air-cooled bottom recorded temperatures in the range 250-290°C where as calculations based on heat flux measurements showed actual temperatures in the range 600-700°C. The use of thermophotography and heat-flux measurements are quite convincing for control of lining conditions.

External heat-flux measurements help in determining the metal freeze-line in the bottom of the furnace. Such measurements are very useful to check bottom lining conditions and to decide whether relining of the furnace is required or not. Thermocamera is used now a days for checking the side linings. This camera does not give shell temperature but shows relative temperature distribution and hot spot areas. Hot/cold face grouting is used for the lining maintenance and prolonging the lining life. Graphite and silicon carbide based resin bonded grouts are used to restore worn out tap-hole area with improved performance.

Conclusion : Use of newer refractories with improved properties gives increased lining life as compared with conventional refractories. The increased lining cost is outweighed by the extended lining life. Improved lining design, better refractory practices, use of thermophotography and heat-flux measurements to monitor lining conditions and hot/cold face grouting to restore lining conditions could contribute significantly in prolonging the life of furnace linings.

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Table - 1
Properties of High Alumina Refractories (2)

Properties	HA-45	HA-54	HA-60	HA-70	HA-80
Al ₂ O ₃ %	min. 45	54	60	70	80
Fe ₂ O ₃ %	max. 2	1.5	1.4	-	-
A.P. %	max. 18	22	23	25	25
B.D. g/cc	min. 2.10	2.25	2.5	2.70	2.75
CCS, Kg/ cm ²	min. 400	450	350	450	400
RUL, 2kg/ cm ² , ta°C	min. 1480	1480	1450	1470	1470
Spalling cycles (BRRA)	min. 30	30	30	30	30

Table - 2
Influence of Raw Materials on the
Properties of Carbon Blocks/Bricks (6)

Properties	Coal- Coke	Calcined anthracite	Petroleum Coke	
App. porosity, %	13	10	13	
B.D., g/cm ³	1.61	1.53	1.68	
App. Sp. gravity	1.90	1.71	1.95	
Abradability index (Morgan-Marshall Scale)	50	70	90	
% P.L.C., 2 hr. at 1500°C	0.6	0.2	0.2	
C.C.S., Kg/cm ²	1,130	1,050	770	
Oxidation Resistance :				
Air @ 5000°C-1 lit/min	9	15	20	
CO ₂ @1000°C-1/2 lit/min	26	30	45	
Thermal conductivity :				
K.Cal/m ² /°C				
Mean Temp°C	200	4	3.5	4.3
	400	4.5	4.0	4.8
	600	5.0	4.5	5.1
	800	5.1	4.7	5.3
Ash, %	6.5	5.5	0.5	

Table - 3
Average Properties of Carbon Blocks/Bricks (7)

Properties	Carbon Block (600 mm x 750 mm)	Carbon Brick
Bulk density g/cc	1.57	1.65
Apparent porosity, %	21.0	17.0
Cold crushing strength, kg/cm ²	145	260
Modulus of rupture, kg/cm ²	40	90
Electrical resistivity x 10 ⁻⁶ Ohm.cm	50	70
Thermal conductivity 8tu/ hr/Sq.ft/°F/Pt.	9	16
Coeff. of thermal expansion (x10 ⁻⁶ /°C)	2.3	3.2

Table - 4
Application of Carbon Pastes & Cements (8)

Designation	Base Materials	Maximum particle size	Use	Condition when slipped	Mode of application
Carbon paste	Anthracite	1.5-12 mm	Ramming paste, lining hearth, Tapholes, runner & patching	Solid lumps	Heating 30- 110°C & tamping. 100-140°C
Soderberg paste	Carbon	12 mm	Soderberg electrodes	Solid lumps	20-80°C &
Carbon-anceous cement	Graphite/Carbon	15-10 um	Thermic / chemical joints (Thin)	Plastic/ thick cream	trowel