# IMPROVEMENT OF LADLE REFRACTORY PERFORMANCE THROUGH OPTIMIZATION OF REFRACTORY QUALITY AND OPERATING PARAMETERS

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## Abstract:

Steel ladle life is one of the key performance indicating factors for steel plant from the operational and refractory performance point of view. Different varieties of Carbon containing refractory are used in the working lining of the steel ladle. To improve the performance of steel ladle life, refractory quality optimisation is done through in depth analysis of the refractory lined. After optimising the quality of magnesia carbon refractory different operating conditions are monitored and suitable change in the ladle design was performed.

The present paper deals with the comparative analysis of different working lining brick properties and performance used in the ladle. Chemical and physical properties are investigated of magnesia carbon bricks supplied by three different suppliers. Oxidation resistance is measured in TG DSC machine along with evolve gas analysis to understand the oxidation reaction in the bricks. Thermal expansion in inert atmosphere, high temperature creep at 1500 deg C temperature and pore size distribution are measured for comparison of the bricks. HMOR and MOE measurement conducted at 1400 degree centigrade on different quality of magnesia carbon bricks. Static slag corrosion in crucible and rotary slag corrosion test was conducted to understand the corrosion behabour of the magnesia carbon materials. Rotating finger test at 1600 degree centigrade was performed in induction melting furnace using plant slag. Detail morphology of the materials was studied by SEM with EDAX. With the continuous improvement in the steel ladle, 20% life improvement achieved in flat product and long product shop in our steel plant.

**Introduction**

Steel ladle refractory is the major consumption in steel making area. Improvement in steel ladle refractory is essentially required since Tata Steel India decided to increase production to 10MTA and above. Important measures are implemented in the ladle management along with improvement in magnesia carbon refractory quality and use of high quality spinel bricks in metal zone (M.Z) of 150 mm compared to 180 mm in slag Zone (SZ). Use of spinel bricks is good options to control refractory consumption, provided the MZ refractory is strong and dependable to target lives exceeding 150 heats. In the flat product segment of the authors` plant it has been a challenge, when targeting a campaign life exceeding 120 heats, to find a 150 mm MZ refractory twice as durable as 180 mm SZ refractory. Analysis of different steel ladle refractory (magnesia-carbon, spinel) has been done to understand limitations. The paper presents relevance role of steelmaking slag and refractory corrosion parameters.
Usage of spinel containing Alumina – spinel bricks is increased to enhance ladle life and production of clean steel. Spinel being a defect structure has a tendency of forming substitution- solid solution by accommodating the $Fe^{2+}$, $Mn^{2+}$ ions from the liquid slag in its defect structure, making the slag more viscous and hence less penetrative. This effect is more enhanced when the spinel is present in nano- range since that gives a considerably higher surface area and higher reactivity. Addition of spinel also increases the hot strength of the brick due to the spinel bond present and has higher thermal shock resistance. It also reduces thermal conductivity, compared to MgO-C bricks, hence improves energy efficiency.

**Experimental**

Eight different types of bricks had been identified for the study, Three (A,E, and H) are MgO-C bricks with varying antioxidant addition and rest five (B,C,D, F and G) are alumina - spinel bricks with varying spinel content. Chemical analysis of those bricks including analysis of LF slag is shown in Table 1.

| **SAMPLE** | **CaO** | **$SiO_2$** | **MgO** | **$Al_2O_3$** | **C** |
|---|---|---|---|---|---|
| Type A | 0.58 | 2.3 | 76.95 | 8.67 | 8 |
| Type B | 0.01 | 0.19 | 2.44 | 94.55 | - |
| Type C | 0.01 | 0.25 | 4.14 | 93.24 | - |
| Type D | 0.01 | 0.38 | 3.36 | 95.53 | - |
| Type E | 0.94 | 2.54 | 77.21 | 4.14 | 10 |
| Type F | 0.01 | 0.34 | 4.48 | 93.25 | - |
| Type G | 0.01 | 0.43 | 5.57 | 91.83 | - |
| Type H | 1.99 | 0.73 | 77.9 | 4.24 | 10 |
| LD slag | 55.2 | 0.29 | 4.02 | 31.66 | - |

Table 1. Chemical Analysis.

**Physical properties**

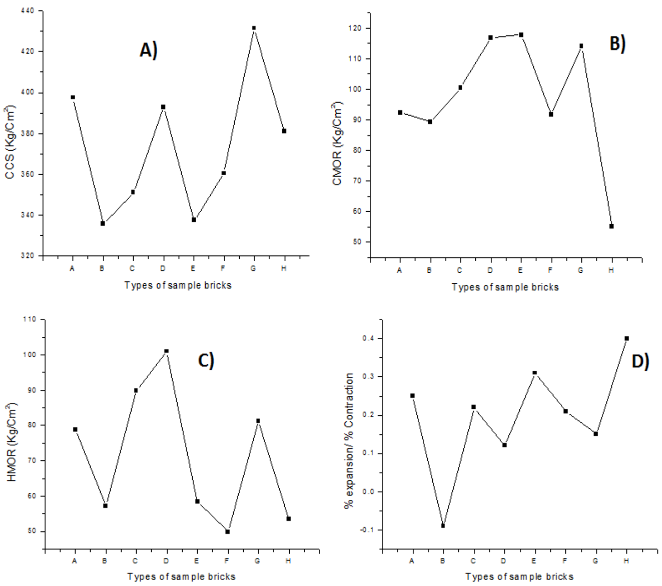


Fig. 1: Different test Curves A) CCS B) CMOR C) HMOR D) PLC

From the CCS graph we can see that type C used in LD # 2 and type F in LD # 3 are showing highest values among them. CMOR values are high in type D, E & F. For HMOR values type C is showing the highest value and in the PLC test type B is showing shrinkage and rest all are showing expansion. Type C is showing less expansion compared to others.

**Optical microscopy, SEM & EDAX**

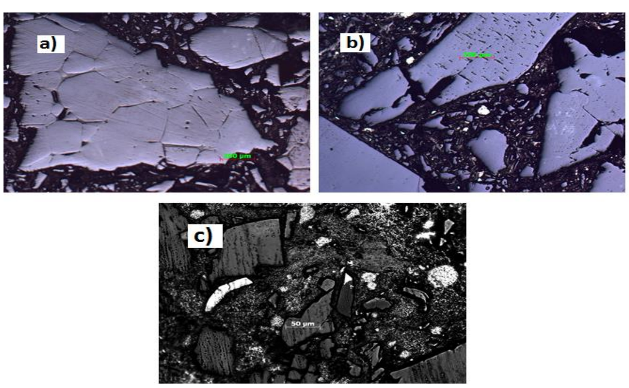


Fig. 2: Optical microscopy of a) Type A, E and H

From the Fig. 2 a) it can be concluded that the Mag-Carbon brick is made up of dead burnt magnesia. When magnesium oxide is calcined at 1500-2000$^o$C it reduces surface area and reactivity is also reduced.

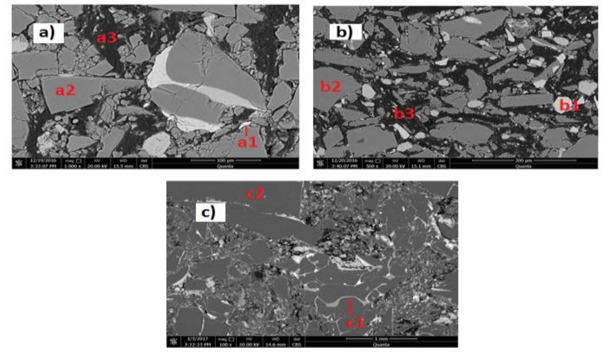


Fig. 3: SEM and EDAX of a) Type A, E and H

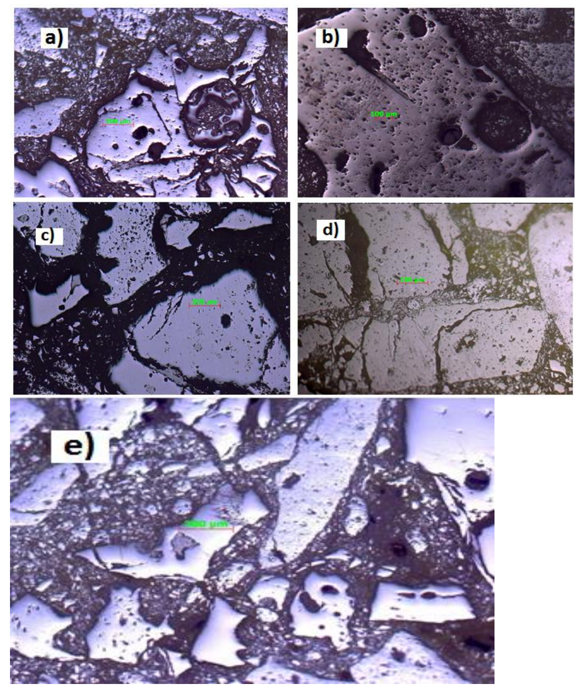


Fig. 4 : Optical microscopy of a) Type B, b) Type C, c) Type D, d) Type F, e) Type G

The type B, C, D F and G contains tabular alumina and electro fused alumina both as raw materials.

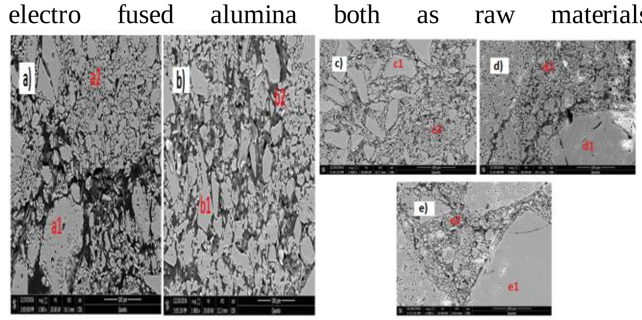


Fig. 5: SEM and EDAX of a) Type B, b) Type C, c) Type D, d) Type F, e) Type G

**Thermal Spalling**

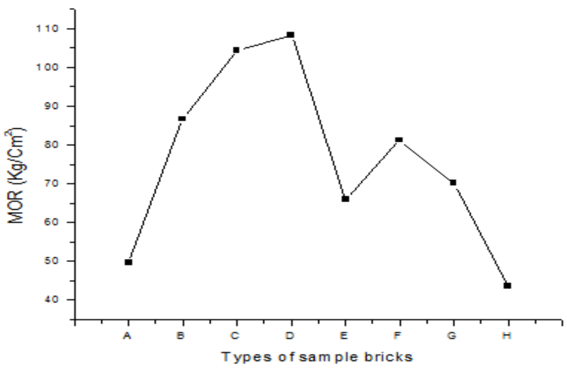


Fig. 6: Thermal spalling curve

After 5 cycles of heating up to 1000 °C and cooling in water MOR is done and based upon the result the above curve is found out. Observing the curve we can predict that Type D and Type C is showing improved results compared to others.

**Corrosion cup test**

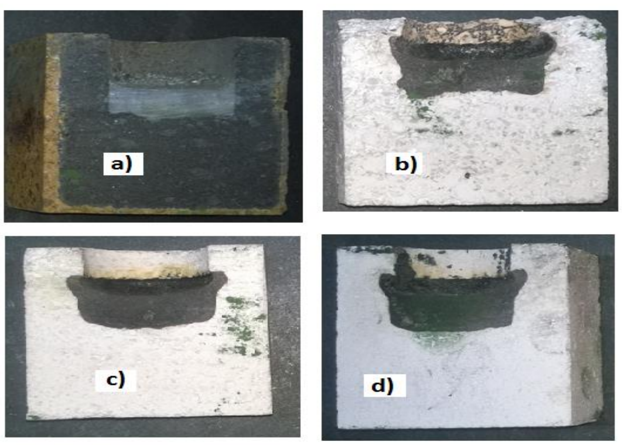


Fig. 7: Cross-sectional view of bricks after corrosion test (LD # 2)
a) Type 'A', b)Type 'B', c)Type 'C', d)Type 'D'

This slag corrosion Cup test had been done with LD # 2 slag at 1600 °C with a soaking time of 2 hours. From the above figures we can visualize that the MgO-C brick is getting oxidized from the outer surface. That means carbon in the bricks is getting released to slag which is detrimental in the steel making. To get purity in steel we need to reduce the carbon percentage. So we are implementing spinel bricks in the steel making ladle for improved performance. Corrosion test results had been shown in Fig.8.

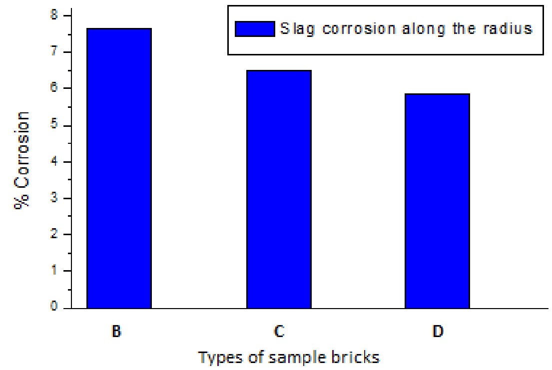


Fig. 8: % Corrosion in the bricks along the radius (LD#2)

For brick A the corrosion along the radius is very less due to the non-wetting property of carbon refractories. But the MgO-C brick is having the disadvantage of getting oxidized. In case of spinel brick there is corrosion along the radius due to slag, air & refractories interaction. According to Lee and Zhang the motion of the slag film caused by surface tension phenomena (Wettability) between the refractory and slag essentially causes the local corrosion of the refractories at the slag surface.

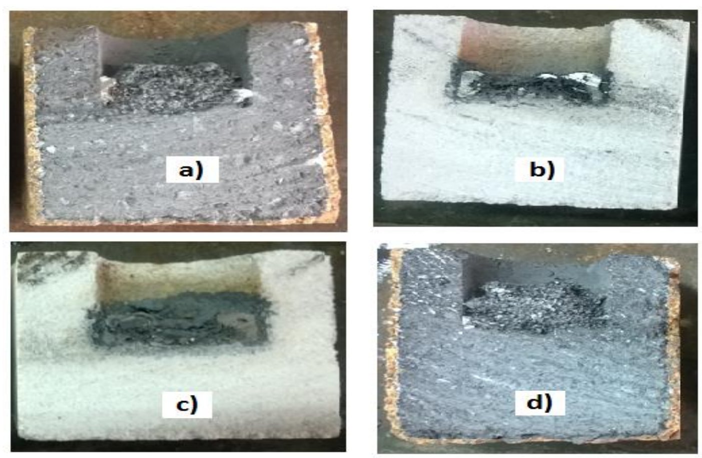


Fig. 9: Cross-sectional view of bricks after corrosion test (LD # 3)
a) Type 'E', b)Type 'F', c)Type 'G', d)Type 'H'

The slag resistance of alumina-rich spinels is one of the most important properties, and the primary reason for the use of spinel in steel-making refractories. Alumina rich spinels, incorporate into the spinel crystal structure (either at vacant lattice sizes or in substitution for MgO) low-melting, low-viscosity components like MnO and FeO in the infiltrated slag. As the slag composition becomes deficient in FeO and MnO the slag viscosity increases, and has a much lower tendency for penetration

### Thermal Expansion

Comparative analysis of thermal expansion conducted of MgO-C, alumina- spinel and corundum bricks, as shown in Fig 10 and thermal expansion of spinel bricks with varying spinel content is shown in Fig. 10(a)

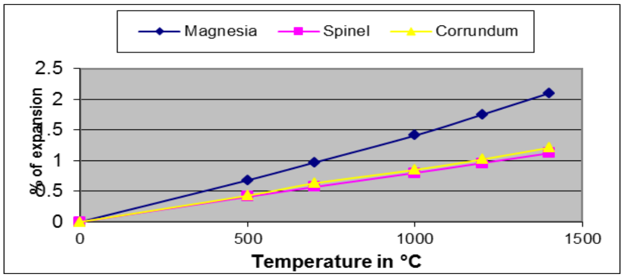


Fig. 10 : Comparative thermal expansion of MgO-C, Spinel and corundum bricks.

The thermal expansion of spinel is least compared to magnesia and corundum. Thus spinel helps in improving the spalling resistance of the brick.

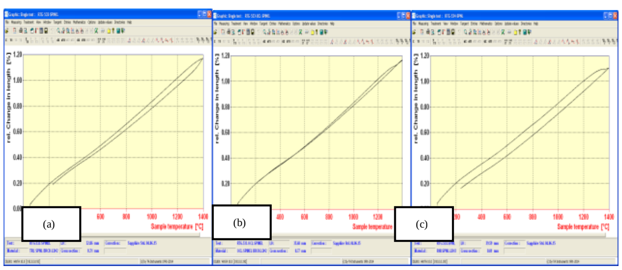


Fig. 10(a): RTE curve for Type 'B', 'C' and 'D' sample

From the above three figures we can see that in Fig. (a) i.e. for type B, the relative change in length is approximately 1.15% at 1400 $^{o}$C whereas in Fig. (b) i.e. for type C it is 1.14% and for type D in Fig. (c), it is 1.1%. All the curves are having almost same slope i.e. they are following same expansion curve. While cooling we can see that the sample C is almost following the same route and reaching the initial state. So it can be confirmed that there is no in situ spinel. So from RTE curves, this can be concluded that the sample C and D are showing improve results compared to type B.

**Plant Performance :**

Both MgO-C and Spinel refractory are being used in the metal zone of steel ladles at. However more focus is being given to Spinel refractory lining rather than MgO-C refractory lining. Currently three different suppliers are giving high Alumina-spinel bricks for metal zone lining**.** More focus is given on trial with spinel bricks is due to its high strengrh, good corrosion and oxidation resistance. Lower thermal conductivity improves energy efficiency.

**Findings of ladle observations**:

- Steel ladles with spinel bricks in the metal zone achieved avg life of 98 heats in LD#3.
- Steel ladles with MgO-C bricks in the metal zone achieved avg life of 88 heats.
- Spinel based ladles shows potential to take more nos. of heat
- The erosion was high in the intermediate layer of Slag zone and Metal zone.

The condition of ladle after 55 heats and after 102 heats is shown in Fig. 11. It shows that the spinel lining has higher potential to prolong higher life.

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Fig. 11. After 55 heats After 102 heats.

**Summary and conclusion:**

In this present investigation, sample bricks from various suppliers which are used in LD # 2 and LD # 3 are taken. Their chemical and physical characteristics were done.

From the SEM diagram it can be concluded that metal is added in preparing bricks which helps in liquid phase sintering.

1. In the corrosion cup test it was found out that the type C (6.48 %) & D (6.12 %) bricks are showing less corrosion compared to A (7.63%) when measured along the diameter.
2. Usage of Spinel bricks has the advantages of high strength, lower conductivity than MgO-C, prevents heat loss and suitable to produce clean steel.
3. In plant performance ladles with spinel refractory lining shows superior performance and it has higher potential to prolong ladle life.

**References:**

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