DESIGN OF HIGH PERFORMING CHEMICALLY BONDED SLIDE GATE PLATES FOR CASTING OF ALLOY STEEL AND MILD STEEL

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Abstract
One of the most important refractory products used during casting of steel is slide gate plate. This material must have the balanced properties in the erosion resistance against molten steel and slag, anti-abrasion with sufficient strength against metal stream, thermal spalling resistance and anti-oxidation to free oxygen in metal or ambient air which can be sucked through the surface of the plates. To meet such requirements Al₂O₃-C material are being broadly applied. Moreover, life of slide plates mainly depends on the selection of refractory materials based on casting conditions and different steel grades to be cast. But now-a-days, for easy removal of non-ferrous inclusions and to control contaminants, addition of Ca, Mn and other alloys are being preferred by steel manufacturers. Fired (Carbon Bonded) Al₂O₃-C materials due to formation of low melting compounds, show high erosion and corrosion, resulting in poor life of the refractory, compared to that of the chemically bonded Al₂O₃-C materials. However, the only demerit with these chemically bonded materials is the poor oxidation resistance. To meet such requirements, scientists are working to develop a reliable chemically bonded slide plates suitable for different type of steel grades.

The present paper deals with the development of silica free Al₂O₃-C plates with the addition of preformed spinel in the range of 5% to 15%. The physical properties like AP, BD and CCS etc. were found to be superior in case of the optimized spinel containing plates than the normal Al₂O₃-C plates. X-ray diffraction and microscopic studies were also conducted to study the different phases and distribution of spinel in the matrix. The optimized product was heat treated at various temperatures in reducing condition followed by measurement of CCS and oxidation strength to standardize the temperature at which it shows better oxidation resistance. Excellent resistance to corrosion with alloy steel, high resistance to abrasion at elevated temperature and high heat strength makes it superior in mild steel and alloy steel teeming. The life potential of these plates were found to be higher than the existing Al₂O₃-C and Al₂O₃-ZrO₂-C slide plates, which leads to higher confidence in operation, resulting in low cost of refractory per ton to liquid metal and make it user friendly.

1. Introduction
Majority of the slide gate plates which are available in the market are generally high alumina or magnesia material. Carbon-bonded[6] plate is normally considered most suitable due to its better abrasion resistance, thermal shock resistance and oxidation resistance properties compared to other bonding systems. Different grades of steel needs to be casted using the same plate depending on requirement and therefore the proper selection of the quality of plate is most important[2-3].

Generally alumina based plates are used but especially in alloy steel containing higher amount of Mn, Cr or high Ca-treated steel (Ca >15-30 ppm) etc Al₂O₃-C plates suffer huge corrosion[1-5] as shown in Fig. 1. Magnesia based plate is suitable for Ca-treated steel because of excellent corrosion resistance but due to its poor thermal shock resistance it has a limitation in bigger plates[1-3]. In this situation Alumina-Carbon plate (with addition of ZrO₂) is considered most popular even though it suffers corrosion and abrasion in various critical steel grades like high manganese, calcia and high oxygen steel. So development of a versatile plate is most important and for this Alumina-Carbon material system is considered as a suitable base. In this paper development of Al₂O₃-C chemically bonded plates and its properties have been discussed in presence of preformed spinel.

2. Experimental Procedure
Al₂O₃-C plate formulations were made with Tabular alumina as the base raw material along with the addition of preformed spinel in the range of 5% to 15% (Tab.1). The plates were pressed in high capacity hydraulic press with a specific pressure of 1.8-2.0 T/cm². Evaluations of plates were carried out after drying and proper heat treatment. The physical, chemical and thermo-mechanical properties were evaluated and compared with that of the normal Al₂O₃-C (both carbon bonded and chemically bonded) plates. Slag corrosion resistant tests were also carried out with synthetic slag H(C/S=2) at 1600°C for 2hrs to optimize the designed product. The optimized product was coked at various temperatures with a soaking time of 6hrs followed by measurement of physical properties like AP, BD, CCS and oxidation strength to standardize the temperature at which it shows better oxidation resistance. X-ray diffraction and microscopic studies were also conducted on coked samples.

Tab. 1: Batch Formulation Error! Not a valid link.

3. Results and Discussions
3.1 Characterization of the Plates
3.1.1 Physical and Thermo-mechanical Properties
The variation of AP and BD of plates are shown in Fig. 2. It is observed that AP is minimal in case of T-2 and T-3 compared to others and maximum in case of ACF. Maximum porosity and minimum BD is obtained in case of ACF because of Carbon bonding. In case of chemically bonded plates (ACC to T3), the density and porosity is better compared to that of Carbon bonded plates. Among the chemically bonded plates, T-2 and T3 showed better properties which may be due to uniform distribution of spinel in the matrix resulting in optimum particle packing and better densification of the product.

Fig. 1: Damage of Al₂O₃-C plate in Ca-alloy treated steel
3.2 Characterization of optimized formulation

After the study of different physical, thermo-mechanical properties of all the formulations, it was found that T-2 was better in all aspects. Hence further characterizations and analysis was carried out after heat treatment of T-2 samples at different temperatures in reducing atmosphere to optimize the coking temperature.

3.2.1 AP, BD and CCS

The variation of AP and BD at different temperatures is shown in Fig. 6. It was observed that AP increases with increase in temperature. A sudden drop is observed at 600°C and further lowers at 700°C which might be due to initial melting of Al metal present in the matrix. Similar phenomenon is observed in case of bulk density also.

3.2.2 Slag Corrosion

Slag corrosion resistance tests were also carried out with synthetic slag H(C/S=2) at 1600°C for 2hrs. T-2 shows better corrosion resistance property compared to that of ACF and ACC. But the corrosion resistance decreases in case of T-3 compared to T-2, which shows that with excess addition of spinel beyond 10% lowers the corrosion resistance of the plate. The corrosion index and samples after corrosion test are shown in Fig. 4 and Fig. 5 respectively.

3.2.2 Microstructure

The microstructure of the samples coked at 200°C, 500°C and
700°C were shown in Fig. 8 (a), Fig. 8 (b) and Fig. 8 (c) respectively. From the microstructure, it is clearly observed that matrix gets loosened with increase of temperature up to 500°C followed by densification above 600°C. This can be correlated with density, porosity and strength of the samples coked at different temperature.

![Microstructure of T-2 sample coked at 200°C/6hrs](image)

![Microstructure of T-2 sample coked at 500°C/6hrs](image)

![Microstructure of T-2 sample coked at 700°C/6hrs](image)

### 3.2.3 X-Ray Diffraction Analysis

Fig. 9 shows the X-ray diffraction of samples coked at different temperatures. Different peaks show the presence of corundum, spinel and metallic Al phases in different formulations. The peak height of metallic Al decreases with increase in temperature above 600 °C. Above 600°C, Al metal starts melting and formation of different compounds may take place along with the constituents available in the system. Due to conversion of Al metal into different compounds, peak height of metallic Al decreases with increase of coking temperature beyond 600°C.

![X-Ray analysis of samples at different temperature](image)

### 3.2.4 Field trials

For field trial, slide gate plates were manufactured in LS70, LS-50 and 2QC models with this developed material and applied in different steel plants named as Plant-A, Plant-B and Plant-C. The operating parameters and steel chemistry for different plants are shown in the Tab. 2.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Plant-A</th>
<th>Plant-B</th>
<th>Plant-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ladle Capacity (Ton)</td>
<td>100</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>Type of Casting Machine</td>
<td>Billet, Thin Slab</td>
<td>Bloom, ingot</td>
<td>Billet</td>
</tr>
<tr>
<td>Casting Temperature (°C)</td>
<td>1550-1560</td>
<td>1550-1570</td>
<td>1570-1580</td>
</tr>
<tr>
<td>Casting Duration (Minutes)</td>
<td>40-70</td>
<td>55-70</td>
<td>60-65</td>
</tr>
<tr>
<td>Slide Gate Mechanism</td>
<td>LS-70</td>
<td>LS-50</td>
<td>2QC</td>
</tr>
<tr>
<td>Plate Bore Diameter (mm)</td>
<td>55</td>
<td>45</td>
<td>35</td>
</tr>
<tr>
<td>Steel Chemistry:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cabon (%)</td>
<td>0.3-0.45</td>
<td>0.1-0.45</td>
<td>0.17-0.25</td>
</tr>
<tr>
<td>Mn (%)</td>
<td>0.2-0.8</td>
<td>0.5-1.6</td>
<td>0.3-1.2</td>
</tr>
<tr>
<td>Si (%)</td>
<td>0.02-0.2</td>
<td>0.2-0.7</td>
<td>0.15-0.30</td>
</tr>
<tr>
<td>Ca (ppm)</td>
<td>20-40</td>
<td>5-50</td>
<td>-</td>
</tr>
</tbody>
</table>

Plant-A is producing mostly low carbon steel having very high calcium coming from its CaFe alloy addition during treatment for thin slab casting. The plate (LS-70) condition is very good even after 4 heats which is shown in Fig. 10. The average erosion rate is 2.55 mm/heat along the stroke side and 1.6 mm/heat perpendicular to stroke.

![Used Plate after 4 Heats from Plant-A.](image)

Plant-B is producing mainly alloy grade special steels like 20MnCr5, EN-36C, 42CrMo4, 1141, 38MnSiV6. LS-50 plate with the developed material was tried and the condition after 4 heats is shown in Fig. 11. The average erosion rate is 2.78 mm/heat along the stroke side and 1.9 mm/heat perpendicular to stroke.

![Used Plate after 4 Heats from Plant-B.](image)
Plant-C is producing mild steels only. The trial plates were subjected to operating conditions and even after 4 heats, the stroke and bore damage is minimal as shown in Fig. 12.

**Conclusions**

The present study confirmed that the developed material is chemically bonded $\text{Al}_2\text{O}_3$-$\text{MgAl}_2\text{O}_4$-$\text{C}$, having better corrosion and oxidation resistance properties compared to that of $\text{Al}_2\text{O}_3$-$\text{C}$ material. Field trial clearly indicates that the material is capable to withstand multiple number of heats with different steel grades. So the newly developed plate is highly versatile to cater the needs of different grades of alloy steel including high Mn, Ca (up to 35ppm) and mild steel at various steel plants.

**References**