TUNDISH METALLURGICAL PRACTICES FOR SLAB PRODUCTION IN BOKARO STEEL

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Abstract
The usage of basic tundish powder for slab casting of Low Carbon Aluminium Killed (LCAK) steels for deep drawing applications has become the recent trend in tundish metallurgy. CaO-Al₂O₃-SiO₂ system was considered for improving inclusion absorption in tundish. Melting characteristics of the powder were analysed to arrive at an appropriate composition for industrial application. Critical issues pertaining to product quality and caster operation were analysed for cold tundish practices in the Bokaro Steel Limited (BSL) of SAIL. Industrial data showed reduction in the inclusion volume fraction by over 45%. The study revealed considerable reduction in Al fading and silicon pick-up in steel. Operational issues such as thermal losses in tundish were tackled through properly controlling Loss On Ignition (LOI) of the powder in cold tundish practice. The paper describes various aspects relating to the development of tundish metallurgical practices.

1.0 INTRODUCTION
Inclusions have a deleterious effect on the performance of high quality steels, mainly flat products used in deep drawing operation. Due to customer demand and international competition, the thrust for producing cleaner steels free from inclusions is continuously increasing. As tundish provides one of the last opportunities to reduce the number of inclusions in the final product, it is being treated as a metallurgical reaction vessel for improving steel quality. Different types of inclusions mainly oxides, which form during various stages of steel, have a deleterious effect on mechanical properties, e.g. elongation, r bar, bend test etc. Separation of these inclusions is, therefore, very important for improving product quality. Tundish cover powders play an important role in controlling thermal losses and separation of inclusions. Thus, the use of a suitable tundish powder is an essential feature modern tundish metallurgical practice. However, the selection of powder is specific to the grade of steel and product quality requirements. Basic concepts for the development of the basic tundish cover powder are described in the following section.

The presence of reducible compounds viz.: SiO₂ and FeO in tundish powder play an important role on steel cleanliness. Since the silica (SiO₂) content of this powder is well over 92%, it remains in a solid state till 1500°C. and thus the formation of liquid slag in tundish at the interface with the steel is most unlikely. Lack of liquid slag layer hinders hermetic sealing of the steel against atmospheric oxygen, enabling oxygen absorption. Rice husk is conducive to another mechanism of reoxidation because SiO₂ is not stable while casting Al killed steels. Dissolved Al in steel reduces silica present in tundish slag in accordance with the following reaction (1).

\[(SiO₂) + 4/3 [Al] → 2/3 (Al₂O₃) +[Si] \]

---------------- (1)
According to equation-1, silicon pick-up and Al fading will occur causing significant cleanliness deterioration of steel. The reoxidation reaction can be suppressed by lowering the silica or Al activity or by increasing the activity silicon. Figure 1 illustrates the changes in the silicon activity with the variation of SiO2 in tundish covering mass \(^{(1)}\). From the figure it is clear that if SiO2 content is restricted to less than 10%, the activity of SiO2 can be brought down to very low level thereby preventing the chance of reoxidation of steel as per eq.1. For fulfilling quality demands of critical products, low melting slags having potential to absorb alumina inclusions are being increasingly used in modern casting operations. But the extent to which a slag will fulfill the metallurgical functions depends on its physico-chemical properties, which are mainly dependent on chemical and mineralogical composition. The best results achieved, so far, are with calcium aluminate (CaO-Al\(_2\)O\(_3\)-SiO\(_2\)) slag \(^{(2)}\). These powders are having low melting point, liquid at steel making temperature and have very high basicity. As a result, the inclusion absorption capacity of these slags is very high. In addition due to quicker generation of liquid slags air ingress minimised leading to prevention of steel re-oxidation. Since these slags are more dense (>2.5 gm/cc) and more conductive, they pose certain operational difficulties namely thermal insulation and crust formation.

As shown in Figure 2, crusting starts to occur at the top surface of the slag first and grows down because of thermal gradient \(^{(3)}\). In order overcome this problem of thermal insulation sand witch charging or double layer covering practice is followed. This practice enables improved performance these slags in terms of thermal insulation and inclusion absorption. The effectiveness of these basic powders is further enhanced when used in combination with steel flow modifiers e.g. dams, weirs, baffles &, turbulence inhibitor \(^{(4)}\). Laboratory investigations on CaO-Al\(_2\)O\(_3\)-SiO\(_2\) system using Linz high temperature microscope slag were carried out to develop a suitable basic tundish cover material. Suitability of the powder was assessed through Industrial investigations in Bokaro Steel Limited (BSL). The powders were suitably modified to cater their use in cold tundish applications being followed at BSL. The influence of flow control devices on the effectively of the powder was investigated. This paper
describes detailed aspects pertaining to the development of basic tundish cover powder.

2.0 EXPERIMENTAL:

Development of the tundish powder was done through laboratory investigations to arrive at an appropriate composition. The effectiveness of these powders on product quality was verified through industrial trials. Details of various investigations carried out are presented in the following sections:

2.1 Laboratory investigations:

CaO-Al₂O₃-SiO₂ type slags were selected for laboratory investigations. The minerals viz.: calcite, calcined lime, pure Al₂O₃ and bauxite having chemical composition as shown in Table-1 were selected. These minerals were mixed in different proportions and samples having compositions as shown in Table.2 were made for characterisation of melting properties. The composition of the test samples was made in such a way that the slag has enough potential to absorb alumina inclusions. Care was taken to restrict the content of reducible compounds (SiO₂ & Fe₂O₃) to well below 10% for minimising the reoxidation of steel. During the casting of LCAK steels, generation of alumina takes place and gets absorbed by basic tundish slags. This may reduce the CaO/Al₂O₃ ratio in the slag. In order to counter this, CaO/Al₂O₃ ratio was kept well above unity in base powder so that the powder will remain in molten stage during entire casting operation.

<table>
<thead>
<tr>
<th>Minerals</th>
<th>% CaO</th>
<th>% Al₂O₃</th>
<th>% MgO</th>
<th>% SiO₂</th>
<th>Fe₂O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcite</td>
<td>99</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Pure Al₂O₃</td>
<td>---</td>
<td>&gt;98%</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Calcined lime</td>
<td>88.36</td>
<td>1.20</td>
<td>---</td>
<td>3.55</td>
<td>2.21</td>
</tr>
<tr>
<td>Bauxite</td>
<td>0.81</td>
<td>77.13</td>
<td>---</td>
<td>13.70</td>
<td>2.81</td>
</tr>
</tbody>
</table>

Table 1: Composition of ingredients

<table>
<thead>
<tr>
<th>Sample</th>
<th>Calcite, (%)</th>
<th>Bauxite, (%)</th>
<th>CaO (%)</th>
<th>Al₂O₃ (%)</th>
<th>SiO₂ (%)</th>
<th>Fe₂O₃ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>60</td>
<td>40</td>
<td>60</td>
<td>40</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>B</td>
<td>55</td>
<td>45</td>
<td>56.70</td>
<td>26.80</td>
<td>7.21</td>
<td>2.06</td>
</tr>
<tr>
<td>C</td>
<td>65</td>
<td>35</td>
<td>60.67</td>
<td>24.56</td>
<td>6.28</td>
<td>2.56</td>
</tr>
<tr>
<td>D</td>
<td>70</td>
<td>30</td>
<td>63.39</td>
<td>21.97</td>
<td>6.39</td>
<td>1.75</td>
</tr>
</tbody>
</table>

Melting range of the powder is the most significant property of basic tundish powder since the slag should remain liquid at steel making temperature to prevent re-oxidation and promote Al₂O₃ absorption. Measurement of melting range i.e. start of melting to end of melting of test powders were carried out through Linze high temperature microscope at a heating rate of 10 deg C/min in inert atmosphere (N₂). It was ensured that the test powders should pass 90% below 200 mesh size during melting studies.

2.2 Industrial Trials:

Based on the laboratory investigations, a typical powder composition was selected for industrial trial. The trials were conducted in cold tundish at BSL. In
cold tundish practice the effectiveness of the powder with and without flow control device was investigated. Influence of the powder on various quality issues viz.: Inclusion absorption, Al fading, Silicon pick-up was analysed. Issues related to thermal losses and crust formation in tundish were monitored for its effectiveness.

3.0 RESULTS AND DISCUSSIONS:

3.1 Tundish Powder Composition:

Powder Composition of the basic flux is finalised based on characteristic temperatures, viz.: initial deformation temperature (IDT), Half-Spherical Temperature (DST) and Fusion Temperature (FT). Fusion temperature and the melting range (FT-IDT) of the powder play an important role in identifying melting characteristics of the powder. Melting characteristics of the slag samples is presented in the Table-3.

<table>
<thead>
<tr>
<th>Sample</th>
<th>IDT (°C)</th>
<th>HST (°C)</th>
<th>FT (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1280</td>
<td>1340</td>
<td>1480</td>
</tr>
<tr>
<td>B</td>
<td>1105</td>
<td>1215</td>
<td>1235</td>
</tr>
<tr>
<td>C</td>
<td>1160</td>
<td>1250</td>
<td>1280</td>
</tr>
<tr>
<td>D</td>
<td>1155</td>
<td>1280</td>
<td>1340</td>
</tr>
</tbody>
</table>

IDT: Initial deformation temperature; HST: Half-Spherical Temperature; FT: Fusion Temperature

As per the data shown in Table-3, Silica content and the ratio between CaO and Al₂O₃ play an important role on melt finish temperature of the CaO-Al₂O₃-SiO₂ slags. With the absence of SiO₂ in the sample, the melt finish temperature reaches a maximum at 1480°C, which is undesirable from the point of view of early formation of liquid slag pool in tundish leading to re-oxidation of steel in tundish. The presence of 5-6% SiO₂ in slag (samples B, C & D of Table-3) led to the reduction of melting finish temperature compared to sample A. However higher content of silica and iron oxide in the slag is undesirable, for minimising reoxidation problems in tundish. Increase in CaO/Al₂O₃ ratio in the slag, led to increase the melting finish temperature of the slag.

Thus based on the criteria of melt finish temperature (<1300°C) and the melting range (<120-130°C) the basic slag composition pertaining to either sample- B, or sample-C was selected for industrial trials. A typical composition of the tundish powder selected for industrial trials is shown in Figure-3.

Figure-3: CaO-Al₂O₃-SiO₂ system showing identified slag composition

3.2 Steel cleanliness:

The influence of the basic covering compound on steel cleanliness was estimated in different casting conditions, with and without baffles (FCD). In all these cases the basic lined tundishes were used. During the investigation, the inclusion volume fraction of the rolled samples was considered. The details of the inclusion analysis are shown in Table-4. The analysis on inclusion volume fraction for various tundish cover practices is shown in Table-4 and Figure-4. Tundish sizes at BSL is 50t and the higher tundish size facilitated enhanced inclusion flotation
with the consequent reduction in inclusion volume fraction. This has resulted in increasing the cold reducibility of hot rolled coils to over 91%.

![Figure-4: Influence of tundish practice on steel cleanliness](image)

**Table 4: Influence of basic tundish powder on steel cleanliness.**

<table>
<thead>
<tr>
<th>Tundish cover practices</th>
<th>Inclusion volume fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average, %</td>
</tr>
<tr>
<td>Cold tundish practices with no baffle</td>
<td>Silica 0.25</td>
</tr>
<tr>
<td></td>
<td>Basic 0.14</td>
</tr>
<tr>
<td>Cold &amp; basic tundish practices with baffle</td>
<td>Silica 0.18</td>
</tr>
<tr>
<td></td>
<td>Basic 0.12</td>
</tr>
</tbody>
</table>

3.3 **Al fading & Si-pick-up in tundish:**
The influence of basic tundish cover powder on Al fading and silicon pick-up of steel in tundish play an important role for improving deformation characteristics of hot rolled LCAK steel coils. Industrial data pertaining to Al fading and silicon pick-up is presented in **Table-5**. The data showed that the usage of calcium aluminate tundish flux reduced the extent of Al fading and silicon pick-up, in comparison to carburised rice husk. Al fading and silicon pick-up is mainly due to the reoxidation of tundish metal when comes in contact with the reducible oxides present in tundish slag. This has a direct influence on deformation properties of steels.

**Table 5: Al fading & Si pick-up with different tundish fluxes**

<table>
<thead>
<tr>
<th>Tundish cover powder type</th>
<th>Aluminium Loss, %</th>
<th>Silicon pick-up,%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Range</td>
</tr>
<tr>
<td>Rice husk</td>
<td>0.018</td>
<td>0.002-0.037</td>
</tr>
<tr>
<td>Calcium-aluminate</td>
<td>0.011</td>
<td>0.001-0.029</td>
</tr>
</tbody>
</table>

3.4 **Operational aspects with basic tundish slag:**
Since basic powder has low thermal insulation property due to its higher thermal conductivity in comparison to carburised rice husk, an optimum tundish powder is to be obtained by combining the advantages of basic powders and insulation powders. A double layer practice was therefore followed, wherein the addition of
calcium aluminate flux was followed by carburised rice husk at the initial stages of
tundish filling.
The loss on ignition (LOI) of the powder plays an important role in controlling
thermal losses in tundish. Most importantly, the importance of LOI on thermal
losses gets aggravated when cold tundish practices are followed. The cold
tundish practices resulted in excessive thermal losses in tundish to the tune of 15°C
in the initial stages of casting when the basic powder with higher LOI of 10%
was added. To overcome this problem of metal freezing in the initial stages of
casting, the calcined raw materials were pre-fused at 1400°C before grinding and
packing. The usage of these powders with LOI of <2% enabled to minimise initial
metal freezing problems. The visual observation of the tundish slags showed that
the basic powders used has good flowability. In addition it was observed that the
usage of these powders resulted in no crust formation.

4.0 CONCLUSIONS:
Modern tundish metallurgical practices incorporate basic tundish cover powders
for casting steels having stringent product quality requirements on steel
cleanliness. Basic calcium aluminate cover powder with appropriate physico-
chemical properties was developed through laboratory investigations. Influence of
SiO₂ and CaO/Al₂O₃ ratio in powder on melting characteristics was found to play a
key role in identifying for appropriate powder composition. Industrial trials with
these powders showed improvement in steel cleanliness for to over 45% for hot
as well as cold tundish practices. In addition, it enabled to reduce Al fading and Si
pick-up in casting of LCAK steels. This has improved cold reducibility of hot rolled
coils. Adoption of sand-witch addition practice i.e. addition of basic powders at
start of tundish filling followed by carburised rice husk enabled to contain thermal
losses. Crust formation could not be observed while using these low melting
powders and hence no operational difficulties were encountered.

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225