Post Mortem Study on Al₂O₃-MgO Induction Furnace Linings

Abstract

In steel industry, induction furnace is preferred as a convenient melting unit because of its high efficiency, low energy consumption, easy operational control, and good performance with various kinds of steel scrap. Al₂O₃-MgO type in situ spinel formed neutral linings are the most frequently used refractory materials in induction furnaces due to their high melting point, high strength, high hardness, and high wear resistance. In order to improve various properties of the refractory lining, understanding of high temperature chemistry, slag-refractory and liquid steel-refractory interactions involved in the steel melting process is important. The objective of this research was to examine the wear and corrosion mechanisms taking place in Al₂O₃-MgO linings via post mortem analysis. For this purpose, samples of refractory lining and furnace slag were collected from a 25 ton capacity induction furnace which was shut down for lining repair after numerous heats. Instrumental tools including XRF, XRD, SEM, and EDX were used for the determination of chemical compositions, mineralogy, phase analyses, and microstructural study on slag and lining samples. Density and porosity determinations were made for revealing the internal structure. Result of this study were used to develop new concepts for the production of neutral induction furnace linings having higher durability.

1. Introduction

Induction furnaces are used for melting cast iron, mild steel and various alloy steels in foundries. Normally, the selection of refractory is based on the type of slag generated during melting. If the slag contains high amount of acidic components then a silica lining is used. For slags with a high basicity index magnesite linings are appropriate. Silica lining has good endurance against thermal shock but poor resistance against steelmaking slags. Magnesite lining is more compatible chemically but it is prone to thermal shock and develops vertical cracks during service.

Neutral refractory has become the new trend in steel foundries because of its success in minimizing the lining related problems. Neutral lining has advantage over both silica and basic lining in terms of chemical reaction and thermal shocks [1]. The ramming refractory mass used for neutral lining in the induction furnace consists of a mixture of alumina (Al₂O₃) and sinter magnesite (MgO) blended according to a certain granulometry. Such blends are tested prior to their use for estimating their corrosion resistance and mechanical behavior [2].

Although the preliminary tests are useful, often they fail to predict the behavior of the lining in actual practice. Post mortem study on furnace linings which experienced the real service conditions has become a valuable tool in developing ramming masses with higher performance. The past literature reporting the results of post mortem studies conducted on neutral induction furnace linings is rather too shallow. The present study was undertaken to perform post mortem analyses on the refractory lining of a 25 ton induction melting unit which has been used for melting steel scrap with an overall chemical composition which imposes rather harsh corrosive conditions on the lining.

2. Experimental Procedure

The samples of neutral lining and those of slag were obtained from an induction furnace of Bilecik Demir Çelik Inc. The ramming mass of the lining was provided by KUMAŞ, the specific brand being coded as NH22. With this lining the furnace was used to melt numerous heats of steel until the zone shown in Fig 1 demanded repair due to refractory erosion. The samples of
lining used in the post mortem study were taken from this particular zone where the slag attack, thermal shock effects, and mechanical wear were predominant.

Fig. 1. The zone of the furnace where lining samples were taken

The picture of a representative lining piece used in post mortem work is shown in Fig 2. Several zones could be distinguished visually by the color difference. Samples belonging to each of the zones were cut by a diamond disc as shown in the red insert of the picture. These pieces were prepared for analyses and examination by techniques of XRF, XRD, and SEM.

Thickness of zones was measured to determine slag penetration depth, density of samples were measured by Archimedes method. The SEM analysis of samples were done in Zeiss EVO scanning electron microscope, and phases in samples were identified by Rigaku Rint 2200 X-ray diffractometer. Chemical composition of slag samples was determined in an XRF unit of Rigaku Primus ZSX.

3. Results and Discussion

3.1. Chemical Compositions

Table 1 shows the results of chemical analyses on several samples of slag. The average slag composition is indicated at the bottom of the table. The main components of the slag are SiO₂ and CaO, with considerable presence of Al₂O₃, Fe₂O₃, and MnO. Therefore, instead of using the ratio CaO/SiO₂ as the basicity index we preferred to express it with the ratios B₃ and B₄. Also the optical basicity was evaluated. The results of these calculations are shown in Fig 3.

Table 1. Chemical compositions of slag

<table>
<thead>
<tr>
<th>Sample No</th>
<th>%MnO</th>
<th>%TiO₂</th>
<th>%Cr₂O₃</th>
<th>%CaO</th>
<th>%MgO</th>
<th>%Fe₂O₃</th>
<th>%SiO₂</th>
<th>%Al₂O₃</th>
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<tbody>
<tr>
<td>12</td>
<td>13.45</td>
<td>1.21</td>
<td>3.86</td>
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<td>6.13</td>
<td>5.31</td>
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<td>13</td>
<td>10.98</td>
<td>1.41</td>
<td>3.62</td>
<td>26.62</td>
<td>5.79</td>
<td>10.43</td>
<td>26.02</td>
<td>12.90</td>
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<td>18</td>
<td>10.53</td>
<td>1.33</td>
<td>6.02</td>
<td>23.11</td>
<td>4.56</td>
<td>15.05</td>
<td>25.92</td>
<td>10.95</td>
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<td>21</td>
<td>9.60</td>
<td>1.23</td>
<td>4.61</td>
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<td>0.86</td>
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<td>21.92</td>
<td>4.49</td>
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<td>Average</td>
<td>11.17</td>
<td>1.21</td>
<td>4.82</td>
<td>23.87</td>
<td>5.08</td>
<td>13.43</td>
<td>25.93</td>
<td>12.22</td>
</tr>
</tbody>
</table>

Fig 3. Basicity indices of slag samples

Fig 3 shows that, in terms of the optical basicity index, the chemical characteristics of the slag is slightly on the basic side. This may be due to the high MnO and high CaO content which can make the slag rather detrimental to the lining. The alumina based dry vibrating mixes have neutral characteristics, therefore the furnace slag has a limited but tolerable compatibility with the lining material.

3.2. Slag Penetration

The measurements on dimensions and densities of zones shown in Fig 2 are given in Table 2. The results show that the slag penetrate to the first zone and partially to the second zone.

Fig 2. Sample of lining taken from induction furnace
The third zone seems to be densified as well, but this may be due to the development of prilling in the lining rather than slag penetration.

As far as the slag attack is considered, the first zone is highly damaged; the density of this zone seems to be lowered due to carry over by slag, in addition to the chemical wear. The operating temperature of the second zone is lower than the one at the lining surface, therefore some liquid slag that reached this zone by penetration might have solidified there. Such an event may cause eventual partial spalling of the lining during successive heats.

### 3.3. Phase Identification by XRD

The powder XRD pattern of the first zone (PM1) is shown in Fig. 4. It can be seen that, in addition to well crystallized solid phases amorphous slag layer is present due to splashing. Solid phases in the PM1 zone are Magnesium Aluminum Iron Oxide, Calcium Aluminum Silicate and Calcium Aluminum Iron Oxide. These are the result of interactions between the slag and the lining. These phases are prone to decrease the refractoriness.

![XRD pattern of first zone (PM1)](image)

The XRD pattern of second zone (PM2) is shown in Fig. 5. In this zone all solid phases are well crystallized, the main phases are Spinel, Corundum, Periclase and Calcium Aluminum Silicate. With the exception of calcium aluminum silicate, other phases are the phases of the refractory lining. Calcium Aluminum Silicate phase occurs due to interaction of refractory and slag. This phase causes liquid phase at working temperatures and it decreases the refractoriness of lining.

![XRD pattern of the second zone (PM2)](image)

The XRD pattern of PM3 is shown in Fig. 6. The phases in this zone are phases of the refractory lining; the peaks reflecting the minor phases come out from impurities in raw materials, principally the alumina. Thus, we may conclude that the zone PM3 remained unaffected by slag.

![XRD pattern of third zone (PM3)](image)

The XRD patterns recorded for zones PM4 and PM5 were similar to the one shown in Fig 6, except that the...
intensities of peaks were different due to differences in spinel conversion rates. This was due to the lower temperatures existing at the back of the lining.

### 3.4. Microstructural Evaluation by SEM

The SEM image of the first zone obtained by the back scattered electron (BSE) method is shown in Fig. 7. Differences in contrast are due to the presence of different phases. Thus slag has different modes of interaction with the refractory lining. Elemental analysis by EDX were done on the points designated as 1, 2, and 3 on Fig. 5. These analyses show that the particle at point “1” is Al₂O₃ aggregate. Point “2” is the grey phase around Al₂O₃ aggregate which occurs after interaction between slag and Al₂O₃ aggregate. Point “3” is the phase which formed after interaction of the slag with the lining matrix.

These results show that the slag react with the lining matrix and new phases occur upon dissolution of alumina aggregates. Evidently, the presence of Al₂O₃ in the neutral lining allows formation of new solid phases which delay the thermochemical dissolution process of the refractory in the slag.

The SEM (BSE) image of the second zone (PM2) is shown in Fig.8. Similar to the first zone (PM1) there are several solid phases. Elemental analyses by EDX were performed at four different points having differences in contrast. According to elemental analysis the zone at Point 1 is a coarse MgO particle. Zone around Point “2” has Spinel and Calcium Aluminum Silicate phases. Spinel occurs after interaction between MgO and Al₂O₃ at elevated temperatures. The Point 3 is Al₂O₃ aggregate and the Point 4 is Spinel phase. These results show that in this zone slag penetration is less pronounced. Although the matrix is effected chemically by the slag, the aggregates of the original lining, MgO and Al₂O₃, remained intact during slag ingress.

### Conclusion

This report is based on a post mortem study conducted on a neutral type induction furnace lining. The furnace from which the samples of slag ant lining were obtained has been used for melting and refining of steel from scrap. The principal raw materials forming the neutral lining was Al₂O₃ and MgO particulates. The aim of the post mortem study was to investigate the effect of furnace slag on the performance of the lining. The study showed that the slag caused chemical as well as mechanical wear at the immediate lining interface. In the inner zones the refractory aggregates in the lining remained relatively intact from slag attack whereas the matrix reacted partially. This sort of reaction formed new solid phases which hindered the chemical wear.

As a conclusion of practical interest, we can state that, as far as chemical degradation by slag is considered, controlling the chemical characteristics of the matrix in the lining is more important than the purity of aggregates. The spinel phase which forms in the matrix of the lining is functional in improving the structure and the resistance of the lining against thermal shocks and chemical damage. Results of this study may be used as a guide to develop induction furnace linings which have better chemical, thermal and mechanical properties.

### References

[2]: A. Ikose, H. Yamamoto, H. Shikano, K. Hiragushi; “Wearing Test for Slag/Metal Interface and Metal Zone Using High Capacity Induction Furnace”, Taikabutsu Overseas, Vol:10 No:3,