Case study

Failure analysis of Rocker liner used as a charging system of blast furnace

Piyas Palit *, Souvik Das, Suman Mukhopadhy, Nilotpal Dey, Sandip Bhattacharyya

R&D and Scientific Services, Tata Steel Limited, Jamshedpur 831 001, India

A R T I C L E   I N F O

Article history:
Received 1 January 2013
Received in revised form 4 June 2013
Accepted 26 June 2013
Available online 18 July 2013

Keywords:
Rocker liner, Carbide, Heat treatment, Wear

A B S T R A C T

In this study, failure analysis of rocker liners used for charging system of blast furnace was carried out. The failed rocker liner samples shows non-uniform distribution of carbides, resulted in variation of hardness as well as wear properties. In the case of failed sample, the reason for the poor wear resistance of the component was due to the non-uniform carbide in pearlitic matrix. The heat treatment of failed sample was unable to affect the morphology of the primary eutectic carbides, although some dissolution of carbides and re-precipitation of secondary carbides in the matrix material has occurred. After proper heat-treatment and chemistry modification, the Rocker liner obtained high hardness (with uniformity) due to proper distribution of carbide phases in the tempered martensitic matrix. Thus, proper heat treatment is needed to achieve optimum property with changing the material composition to deal with this stringent working condition. Rocker liner with modified microstructure was trailed in the blast furnace and it has given a life of around 20–22 months life.

© 2013 The Authors. Published by Elsevier Ltd. Open access under CC BY-NC-ND license.

1. Introduction

The Rocker liner is a fundamentally important charging unit of blast-furnace operation. In the modern day, blast furnace rocker liner is used as a path-way of charge. In bell-less top charging system of blast furnace, the rocker liner is used for carrying the charge (i.e., raw material, burden etc.) to the related hopper through tilting motion and it acts accordingly. The tilting Rocker liner is situated in the assembly of two hoppers from where the top charging is done. The charge is fed to the hopper with the help of the liner. The liner assembly is tilted and the charge is fed to a hopper and other in course of operation (Fig. 1). The working temperature of the liner generally rises to 20 °C–40 °C above the ambient temperature during the operation. During the operation those liners undergo wear during carrying of charges to the hopper. The components get worn out within 8 months of service, whereas the expected life is 24 months. In-depth investigation of a failed rocker liner has been carried out and the root cause has been identified. Material of the liner should be such that it should be withstand wear and impact during feeding of the material in blast furnace. Frequent failure of the component leads to interruption in production and therefore, it is important to achieve higher life for the component.

* Corresponding author at: Scientific Services, Tata Steel Ltd., Jamshedpur 831 001, India. Tel.: +91 8092084742.
E-mail address: piyas.palit@tatasteel.com (P. Palit).

2213-2902 © 2013 The Authors. Published by Elsevier Ltd. Open access under CC BY-NC-ND license.
http://dx.doi.org/10.1016/j.csefa.2013.06.001
2. Visual inspection of Rocker liner

A photograph of assembly of hopper has been shown in Fig. 2(a). One shaft is connected with the rocker liner frame for tilting purpose. The inner view of the hopper has shown the liner frame containing rocker liners (Fig. 2b). One frame containing 6 liners. Rocker liners are approximately 760 mm × 600 mm in size and thickness is around 36 mm. The liners are getting worn out during operation of feeding and finally liners are failed. The worn out portion of the liner is shown in Fig. 2(c). It is clearly observed that the middle of the liner is more wear out than the side portion. This is indicating that the wear occur in the direction of feeding.
3. Experimental procedure and results

3.1. Compositional analysis

Chemical analyses of the samples collected from the rocker liner were carried out using X-ray fluorescence spectroscopy (XRF); carbon (C) and sulphur (S) content of the samples were determined using combustion infrared technique. The obtained chemical analysis of the sample is provided in Table 1. The chemical composition of the liner sample conforms to the high-chromium white iron as per DIN (mat No: 0.9635) grade: G-X 300CrMo15-3.

3.2. Microstructural examination of the failed component

Specimens were cut for microscopic examination in the transverse direction from the failed region. The microstructure is shown in Fig. 3(a) and Fig. 3(b) at different magnification. The polished specimens were etched with Vilella’s reagent (95 ml of ethyl alcohol, 5 ml of hydrochloric acid, and 1 g of picric acid). From the microstructure of the samples, massive chromium carbide precipitation was observed in the pearlite matrix. Such kind of structure is generally found in cast condition. The carbides in high-chromium irons are very hard and wear resistance but also brittle [1–3]. In general, wear resistance is related to the shape, size and distribution of carbide formation [5]. From the microstructural analysis, it has been concluded that the material is not heat treated after the casting. The distribution of the carbide was not uniform to sustain stringent working condition of the blast furnace. Thus, proper heat-treatment cycle is necessary for equal dissemination of carbide throughout the structure.

<table>
<thead>
<tr>
<th>Elements</th>
<th>C</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specification: DIN 0.9635 G-X 300CrMo15-3</td>
<td>2.8–3.2</td>
<td>0.60–0.90</td>
<td>0.030 max</td>
<td>0.10 max</td>
<td>0.30–0.80</td>
<td>14–16</td>
<td>1.20 max</td>
<td>2.5–3.0</td>
<td>1.20 max</td>
</tr>
<tr>
<td>Sample #1</td>
<td>3.87</td>
<td>0.87</td>
<td>0.058</td>
<td>0.024</td>
<td>0.73</td>
<td>14.54</td>
<td>0.55</td>
<td>2.55</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Fig. 3. (a) and (b) show the microstructure of the component reveals lumps of carbides in pearlite matrix at different magnification.

Fig. 4. Heat treatment cycle.
3.3. Plant trail

In order to improve material property, proper distributions of carbides are needed in tempered martensite matrix. From the literature review it has been observed that proper heat treatment is needed after solidification to obtain proper distribution of carbide over tempered martensitic matrix. The heat treatment is also needed to reduce retained austenite content and, at the same time, increase hardness and toughness. The heat treatment cycle has been design shown in Fig. 4 [4] to ensure better property of material. In this study, 25 mm × 25 mm sample is taken and carried out heat treatment. From the CCT diagram of such white iron, it has been observed that such material gets austenised above 850 °C [3]. The sample #1 was heated up to 1000 °C hold for 1.30 h and followed by air quenching up to 540 °C and then hold for 30 min and slow air cooled. This slow cooling is necessary to prevention of crack formation. After that tempering done as per the heat treatment cycle (refer Fig. 4) to getting the tough tempered martensite matrix. After the heat treatment of the failed sample, microstructure reveals carbides in tempered martensite matrix (Fig. 6a and b). Although, the structure after heat treatment is quite better than the as cast one. But the carbide distribution was not so uniform after heat treatment.

In order to improve the carbide morphology, chemistry is also required to be change with proper heat treatment. The chemistry of the sample #1 is more prone to formation of primary eutectic carbide. These carbides are quite deleterious to impact toughness and should be avoided in casting. More over the carbon content is increased; more chromium is consumed, forming addition carbide. Thus, carbon content has been lower by maintaining proper ratio with chromium content; so that the cast structure is avoided form primary eutectic carbide formation shown in Fig. 5 [6]. The designed chemistry is given in Table 2 indicating sample#2. In the sample #2 (C = 3.00%) same heat treatment is carried out as in case of sample #1. After

---

**Table 2**

Chemical analysis of failed and modified Rocker liner component.

<table>
<thead>
<tr>
<th>Elements</th>
<th>C</th>
<th>Mn</th>
<th>S</th>
<th>P</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample #1</td>
<td>3.87</td>
<td>0.87</td>
<td>0.058</td>
<td>0.024</td>
<td>0.73</td>
<td>14.54</td>
<td>0.55</td>
<td>2.55</td>
<td>0.32</td>
</tr>
<tr>
<td>Sample #2</td>
<td>3.00</td>
<td>0.66</td>
<td>0.032</td>
<td>0.033</td>
<td>0.37</td>
<td>14.89</td>
<td>0.45</td>
<td>2.78</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Fig. 5. Relationship between the chromium and carbon contents and the eutectic composition in high-chromium irons.

Fig. 6. (a) and (b) show the microstructure of sample #1 (after heat treatment) at different magnification. The structure reveals non-uniform distribution of carbides in martensitic matrix after heat treatment.
the heat treatment of the sample #2, microstructure reveals carbides in martensite matrix. In this case, the carbide is uniformly distributed in tempered martensitic matrix (Fig. 7a and b).

3.4. Measurement of hardness profile

In case all the samples, hardness profile has been measured with the help of Brinell Hardness Testing Machine (3000 kg load). As we know, the hardness is a representative of wear resistant property so the hardness plays an important role. In case of sample #1 (before heat treatment), the average hardness is quite low around 525–530 HBW. But after heat treatment of sample #1, the hardness value rises to around 550–565 HBW but due to non-uniform distribution of carbide hardness variation was observed throughout the section. In case of sample #2, as the structure comprises uniform distribution of carbide in hardened matrix the hardness value is also increased significantly (630–640 HBW). Moreover, in case of sample #2 uniform hardness was obtained along the section.

3.5. Area fraction of carbides

In case all the three samples, area fraction of the carbide precipitation before and after heat treatment was carried out through Image Analyser. In these study around 20 readings for each sample has been incorporated. In case of Sample #1 (before and after heat treatment), non-uniform distribution of carbide precipitation was observed throughout the section. Such precipitation gives detrimental effect in matrix toughness as well as wear resistance [5]. The non-uniform distribution of carbides affects the hardness variation of the component. This type of variation resulted lowering bulk hardness of the failed component. In case of sample #2, uniform distribution of carbide network has been observed along the section resulting uniform hardness. (Fig. 9)

4. Discussion

From the above analysis, we have concluded that the material property (i.e., wear property) is very much related to the morphology (shape, size and distributions) of carbides. The failed rocker liner samples show non-uniform distribution of
carbides, resulted in variation of hardness as well as wear properties. In the case of failed sample, the reason behind the poor wear resistance of the components was due to non-uniform carbide in pearlitic matrix. The heat treatment of sample #1 was unable to affect the morphology of the primary eutectic carbides, although some dissolution of carbides and re-precipitation of secondary carbides in the matrix material has occurred.

In order to improve the carbide morphology, apart from heat treatment chemistry modification is integrated. The chemistry of the sample #1 is more prone to formation of primary eutectic carbide. These carbides are quite deleterious to impact toughness and should be avoided during casting. Higher carbon resulting more consumption of chromium, forming addition carbide. Thus, carbon content has been lower by maintaining proper ratio with chromium content; so that the cast structure is avoided form primary eutectic carbide formation. But the alloy elements (molybdenum, manganese, nickel and copper) remain constant to avoid pearlite formation upon cooling during heat treatment [6]. In these sample #2 (C = 3.00%), same heat treatment is carried out as in case of sample #1. In these chemistry tempering is required as during casting, martensite is mixed with retained austenite, which lowering the hardness level. Thus, tempering was done to reduce retained austenite content and same time increase hardness and toughness. After the heat treatment of the sample #2, microstructure reveals carbides in tempered martensite matrix. In this case, the carbide is uniformly distributed in tempered martensitic matrix and high hardness was obtained.

5. Conclusion

After proper heat-treatment and chemistry modification, the Rocker liner obtained high hardness (with uniformity) due to proper distribution of carbide phases in the martensitic matrix. Thus, proper heat treatment is needed to achieve optimum property with changing the material composition. Rocker liner with modified microstructure was trailed in the blast furnace and it has given a life of around 20–22 months life.

References