Study on erosion of large blast furnace hearth and techniques to prolong campaign life of hearth

Wanren Xu
Baosteel Group Corporation, China
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1. Introduction

The hearth lining configurations
Hearth sidewall refractory of 3BF and 4BF: small hot-pressed carbon bricks NMD + NMA
Taphole area refractory of 3BF and 4BF: NMD

3BF: horizontal Iron staves at H1-H4 sections
4BF: vertical copper staves at H2 section and the area of tapholes

<table>
<thead>
<tr>
<th>No. BF</th>
<th>Blow-in</th>
<th>Shut down</th>
<th>Inner Volume</th>
<th>Campaign life</th>
<th>Output per m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>3BF(1ˢᵗ Campaign)</td>
<td>1994.9.20</td>
<td>2013.8.31</td>
<td>4350 m³</td>
<td>18 years and 11 months</td>
<td>15800 t/m³</td>
</tr>
<tr>
<td>4BF(1ˢᵗ Campaign)</td>
<td>2005.4.27</td>
<td>2014.8.31</td>
<td>4747 m³</td>
<td>9 years and 4 months</td>
<td>7358.7 t/m³</td>
</tr>
</tbody>
</table>
The main contents of the presentation

(1) Dissection investigation of hearth- Baosteel No.4 BF
(2) The practice for controlling temperature rising and erosion of hearth sidewall at Baosteel
(3) Discussion about technology philosophy for long campaign life of hearth and configuration of heat transfer system for hearth wall
(4) Summary
2. The dissection investigation of hearth erosion lining at Baosteel No.4 BF
Cross section below 3TH
Erosion profile on the left of 2TH
The bottom ceramic pads

- Iron solidified layer
- Weakened layer
- Powder layer
- Sound layer
- Deadman molten iron
Gap and cracks between carbon brick

Slurry and trace by burning on the surface of brick

Metal iron flowing into the brick (below 3TH)
- The height of taphole centerline is 11.18m for 4BF. The serious erosion areas are located in No. 2 and No. 3 tapholes and the section below the taphole with the height of 9.68-10.18m;
- The most serious erosion area is located at 1.2m just below No. 3 taphole centerline, where the residual thickness of carbon brick is 290mm;
- The lining residual thickness is 560mm at the height of 8.18m below the No.2 taphole;
- The bottom is substantially not eroded and the ceramic pads still exist.

- Much gap and cracks between small size carbon brick were found.
- The clay is not fully filled in the horizontal gap and vertical gap of the carbon brick near and below the No.2 and No.3 taphole. Some areas are absence of clay or the presence of clay has many honeycomb pores.
- The surface of some bricks is with colored stripes just like the traces of gas ablation.
- The presence of iron sheet was found between the H2 and H3 segment at the bottom right direction of No.3 taphole.
It is found in 4BF that large amount of carbon brick have no cement or cement unfilled, large gap exists in lining and un-firmed consolidation. This might be the main cause of large gas fire occurs near the taphole after the blast furnace blows in for one year, high temperature of sidewall at No.3 taphole, iron permeated into the carbon brick and short life of hearth of 4BF.

For Baosteel No.3 BF, the hearth small hot-pressed carbon brick was very closely build with a strong structure, some slurry was not injected between hearth stave and carbon brick, the obvious gas gap was not found. Even after 13 years in operation the hearth sidewall temperatures began increasing more than 200℃ and during the later campaign it was erosion slowly. So that the furnace was keeping higher productivity and high PCI until shut down.
Core sample of H3-17 and the iron penetrated layer

There are solidified iron layer (ring), iron penetrated layer, weakened layer and sound layer on the carbon brick by drill core sampling, and serious iron penetrated phenomenon of carbon brick was found at H3 segment.
The composition of iron solidified layer and iron infiltration layer (H3, height level 10.2-10.7m)

<table>
<thead>
<tr>
<th>Wt % (Not including Fe and C)</th>
<th>H3-17 (240°, 2TH area)</th>
<th>H3-28 (300°, 3TH area)</th>
<th>H3-8 (180°, Non-taphole area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe₂O₃</td>
<td>8.681</td>
<td>13.02</td>
<td>2.334</td>
</tr>
<tr>
<td>ZnO</td>
<td>1.453</td>
<td>1.352</td>
<td>0.657</td>
</tr>
<tr>
<td>K₂O</td>
<td>0.151</td>
<td>0.352</td>
<td>0.452</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.072</td>
<td>0.089</td>
<td>/</td>
</tr>
<tr>
<td>CaO</td>
<td>0.117</td>
<td>0.209</td>
<td>0.078</td>
</tr>
<tr>
<td>SiO₂</td>
<td>5.89</td>
<td>4.28</td>
<td>1.68</td>
</tr>
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</table>

The SEM morphology of iron solidified layer
The main chemical compositions of the solidified iron layer and iron infiltration layer are Fe, C, Fe$_2$O$_3$, K$_2$O, ZnO.

Fe in the solidified iron layer mainly presents as metal and Fe is mainly as Fe$_2$O$_3$ in the iron infiltration layer.

The contents of Fe, Fe$_2$O$_3$, ZnO and slag phase are relatively high near the area of taphole.
3. The practice for controlling temperature rising and erosion of hearth sidewall at Baosteel
3.1 Maintaining a stable mud and deepening taphole length

Change of No.3 taphole depth and hearth sidewall temp. at 1.0m below 3TH in 4BF

After June 2008, an important measure to control hearth sidewall temp. rising had been adopted in 4BF that is maintaining taphole mud, extending taphole depth from 3.6m to 4.2m. Limiting hot metal output and coal rate had also be carry out. The highest temp. becomes lower and the fluctuation reduces every year. It did not break through 400°C and kept stable until overhaul. Therefore enhancing taphole maintenance and deepening taphole length are very important.

<table>
<thead>
<tr>
<th>The highest Temp. / °C</th>
<th>Thermocouple and date at the highest temp.</th>
<th>Height of thermocouple</th>
<th>Angle of thermocouple</th>
</tr>
</thead>
<tbody>
<tr>
<td>403</td>
<td>TE4749: 2006.10.04</td>
<td>10.58m</td>
<td>305.397°</td>
</tr>
<tr>
<td>513</td>
<td>TE4720: 2007.04.08</td>
<td>10.18m</td>
<td>311.786°</td>
</tr>
<tr>
<td>707</td>
<td>TE4720: 2008.06.22</td>
<td>10.18m</td>
<td>311.786°</td>
</tr>
<tr>
<td>668</td>
<td>TE4685: 2009.05.21</td>
<td>9.68m</td>
<td>244.286°</td>
</tr>
<tr>
<td>469</td>
<td>TE4745: 2010.03.10</td>
<td>10.58m</td>
<td>221.509°</td>
</tr>
<tr>
<td>399</td>
<td>TE4818: 2011.03.01</td>
<td>11.18m</td>
<td>153.99°</td>
</tr>
<tr>
<td>392</td>
<td>TE4656: 2012.11.09</td>
<td>9.18m</td>
<td>311.786°</td>
</tr>
</tbody>
</table>
3.2 Eliminating gas gap near taphole and between staves and carbon bricks

Gas gaps will form between staves and carbon bricks or inside carbon brick due to some reasons, for example, the padding layer is not compacted, the poor slurry quality, un-eliminating the water and gas during oven, un-complete the slurry consolidation, the slurry eroded by the steam and gas after the production.

The gas channel exists between the tuyeres and the tapholes. In the period of tapping the gas will enter the gap inside slurry layer at below the taphole and burn slurry through the gap in the taphole combined brick.
In order to restrain gas fire occurs near the taphole, replacing protection brick, injecting carbon slurry at the front, neck and tunnel of the taphole had taken.
After grouting the gas fire at the tapholes had shrunk and the temp. of carbon brick near tapholes had also dropped.

The gas fire before slurry injection

The gas fire after slurry injection
For a hearth heat transfer system, if the heat flow intensity of stave is lesser than the intensity of heat flow inside carbon brick lining, then there were gas gaps between staves and carbon bricks or inside carbon brick.

The carbon slurry injecting into such areas as below jumbo or hearth sidewall was in a planned way to implement by blow down opportunity at Baosteel, in order to eliminate the gas gaps.
3.3 Improving deadman liquid permeability and reducing circinate flow of hot metal

Change of hearth sidewall temp. with hearth bottom temp. (2BF, 2nd campaign)
The figures show that the temperature rising at the taphole area and hearth sidewall mostly occurs after a period time of the low hearth bottom temperature. When the hearth bottom temperature rises to a certain level the sidewall temp. begins to fall and be stable.
Relation between circinate flow intensity index and tapping index (2BF, 1st campaign)

It is visible that the change trend of hot metal circinate flow intensity index $Tb / Tw$ is the same and strong correlation with tapping index $Pt$ . The impact of hearth active state to the hot metal circulation and the tapping operation are reflected.
In order to improve active state of the hearth to control the sidewall temperature repeatedly rising, the operation with increasing blast volume and blast energy $E_k$ was adopted in 2BF and 1BF at Baosteel.

With increase of the hearth bottom temperature to a higher level, the sidewall temperatures are converted to decline to the normal range.
2BF, 2nd campaign

The temp. change of hearth bottom with increasing $E_k$.

The lower temp. of sidewall when the bottom temp. was higher.
1BF, 3rd campaign

The temp. change of hearth bottom with increasing $E_k$

The temp. change of hearth sidewall after increasing $E_k$
The operation of center charging with a small amount of coke had adopted from April 2003 when the hearth bottom temperature dropped to a stable level. The hearth bottom temperature had maintained at higher level and the sidewall temperatures had be controlled in the safe range until 2006 that the blast furnace had be shut down.
4. Technology philosophy for long life of hearth and configuration of heat transfer system for hearth wall
We have founded a piece of light material was on the surface of deadman metal in 3BF and a circle belt of Fe- rich material in the middle of residual metal and weakened layer in 4BF.

There are a lot of metallic iron and some C, oxides in the iron solidified layer. The C element is graphite fibers and the iron solidified layer i.e. process concretion on hot face of hearth wall while blast furnace is in production is a mixture of Fe + graphite + coke. That may be a protective layer of hearth carbon brick.
It can be seen that when the temperature of hearth wall carbon brick reached a new higher level, the iron solidified layer disappeared, the carbon brick was erosion and its residual thickness decreased. When a new heat transfer balance of the system was build and stable, the carbon brick temperature was down and iron solidified layer on the hot face of brick has rebuild.
For a hot metal-carbon brick-stave heat transfer system of hearth wall, reducing circinate flow of hot metal and decreasing gas gap between stave and carbon brick, to prevent the iron solidified layer be melted again and again, is the important technology philosophy for prolong campaign life of hearth.
The selection of carbon refractory in the hearth wall should be micro-porous or super micro-porous large carbon bricks with good thermal conductivity, penetration resistance of molten iron and corrosion resistance.

Large carbon brick has few gap between bricks. Using the configuration with large carbon block, it is possible to make sure the brick masonry quality and shorten the construction period.

It must be sure the quality of ramming material and carbon slurry and make the carbon blocks consolidate into a seamless and firm structure at the stage of masonry and oven. It is the basis of long life of hearth.

For hearth design of a larger blast furnace, increasing the depth of salamander cannot float the deadman and relief circinate flow of hot metal. So the hearth diameter should not be too large and depth of salamander could no more than 22% of hearth diameter.
5. Summary

Bad quality of slurry and construction or unbefitting operation during stage of the oven and blow-in would lead to much more gap exists between the carbon brick and make molten iron get into gaps of bricks. It is a main reason of premature higher sidewall temp. and short campaign life of the hearth.

While BF is in production, strong hot metal circinate flow in the hearth is an important reason for the sidewall temperature rising and erosion at 1-2 m below taphole centerline.

The safety work of the carbon brick in the hearth relies on the stable Fe-C-Coke protective layer.
Good coke quality is need for large blast furnace. The measures in advance such as increasing blast energy, improving the liquid permeability of deadman can prevent and control the sidewall temperature rising.

Keeping good condition of taphole channel and mud, ensuring tap clay amount and taphole length are the important measures to maintain stability of the lining temperature at taphole area.

Grouting is a maintenance measure to eliminate gas gaps near taphole and between stave and hearth wall carbon brick. Carbon slurry injection operation at area of sidewall bust be careful and limit the slurry quantity every time.
Thank you for your attention