Efforts to improve the processing ratio of the BOF type furnace for hot metal dephosphorization at the Kakogawa Works

KAZUMASA ADACHI* YOSHIO SUZUKI*
KOSUKE SAITO* ATSUHIKO YOSHIDA*

* Steelmaking Department, Kakogawa Works, Iron and Steel Business - KOBE STEEL, LTD, JAPAN
1. Process flow of steel making process at Kakogawa Works

2. Change due to new facility operation

3. Issues after starting up the BOF type furnace for hot metal dephosphorization

4. Improvement of adhered metal melting method in furnace
   1) Investigation of metal melting method
   2) Optimization of top-blown oxygen condition
   3) Results of actual application

5. Conclusion
1. Process flow of steel making process at Kakogawa Works

Construction in 2014

No. 2, 3 Blast Furnace

Hot Metal pretreatment

No.1, 2, 3 LD-OTB

No.1, 2, 3 RH

Steel Making Plant

No.3 & 4 Continuous Casting Shop

Blooming Mill

Hot Strip Mill

Plate Mill
2. Change due to new facility operation

Change due to new facility operation

- De-S : 100% of the TP
- De-P : 24% of the TP

After improvement
KR 98%, TP 2%

After improvement
DP 58%, TP 10%
3. Issues after starting up the BOF type furnace for hot metal dephosphorization

In order to improve the processing ratio by shortening the cycle time at the beginning of the operation of the BOF type furnace for hot metal dephosphorization, the processing ratio was improved to 58%.

→ subsequent to October 2014 the BOF type furnace for hot metal dephosphorization processing ratio fell to 48%.

Effort increase of the metal melting time : ▲3%

Effort to improve processing ratio
4. Improvement of adhered metal melting method in furnace

It adheres to the entire circumference from the furnace entrance to the slag line. Adhesion of the metal was promoted by slopping due to the decrease in internal volume of the furnace, and yield reduction occurred.
4. Improvement of adhered metal melting method in furnace

<table>
<thead>
<tr>
<th></th>
<th>Current status</th>
<th>Kobe works) H-furnace</th>
<th>After improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Method</strong></td>
<td>Metal melting lance</td>
<td>Secondary combustion</td>
<td>Secondary combustion</td>
</tr>
<tr>
<td><strong>Conceptual diagram</strong></td>
<td><img src="current_status.png" alt="Diagram" /></td>
<td><img src="after_improvement.png" alt="Diagram" /></td>
<td><img src="after_improvement.png" alt="Diagram" /></td>
</tr>
<tr>
<td><strong>Extended processing time</strong></td>
<td>10min</td>
<td>0min</td>
<td>0min</td>
</tr>
<tr>
<td><strong>De-Si</strong></td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td><strong>De-P</strong></td>
<td>○</td>
<td>×</td>
<td>○</td>
</tr>
</tbody>
</table>
4. Improvement of adhered metal melting method in furnace

1) Investigation of metal melting method

■ Method of dissolving the extensively adhered metal

There is a method of melting the metal using slag which has attained a high temperature. This is done by secondary combustion of CO gas in the forming slag.

< Condition comparison >

- Impact pressure : within a range of somewhat higher
- Oxygen accumulation : equivalent
- \(I/R(\text{melting range })\) : larger than the range of the H-furnace

<table>
<thead>
<tr>
<th>Slag-forming stage</th>
<th>Metal melting stage</th>
<th>De-Si stage</th>
<th>De-P stage</th>
<th>Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kobe works) H-furnace</td>
<td>Kakogawa works) The BOF type furnace for hot metal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact pressure (Pa)</td>
<td>1600〜6500</td>
<td>200〜1200</td>
<td>3500〜4000</td>
<td>800〜1200</td>
</tr>
<tr>
<td>Oxygen accumulation (Nm³/t)</td>
<td>8.3×[Si] + 1.9 〜 8.3×[Si] + 4.1</td>
<td>3.3〜7.1Nm³/t</td>
<td>7.9×[Si] + 2.6</td>
<td>3.6〜6.9Nm³/t</td>
</tr>
<tr>
<td>I/R</td>
<td>0.08〜0.25</td>
<td>0.41〜0.47</td>
<td></td>
<td>Optimization necessary</td>
</tr>
</tbody>
</table>

< Supplement >

\(R=\) Distance from lance center axis to furnace wall (mm)
\(I=\) Distance from the point farthest from the center of the gas jet contact surface on the bath surface to the furnace wall refractory (mm)
4. Improvement of adhered metal melting method in furnace

1) Investigation of metal melting method

■ Formula for calculating “I”

“I” was calculated by the formula (2) using the hard core length \( Z_C \) of the gas jet described in formula (1).

\[
Z_C = (4.12 \cdot P_o - 1.86) \cdot d
\]

\[
I = -H \cdot \tan (\theta - \alpha) + Z_c \cdot \cos \theta \cdot \tan (\theta - \alpha) - Z_c \cdot \sin \theta - D - R
\]

\[
\cdots \cdots (1)
\]

\[
\cdots \cdots (2)
\]

< Explanation of symbols >

\( I \) = Distance from the point farthest from the center of the gas jet contact surface on the bath surface to the furnace wall refractory (mm)

\( R \) = Distance from lance center axis to furnace wall (mm)

\( H \) = Distance from the static bath surface to the lower end of the lance (mm)

\( D \) = Distance from lance center axis to nozzle exit outermost periphery (mm)

\( Z_C \) = Gas jet hardcore length (mm)

\( \Theta \) = Nozzle inclination angle (°)

\( \alpha \) = Ejection spread angle after nozzle ejection (°)

Fig. 7 Conceptual diagram of \( I / R \)

\( P_o \) = Nozzle front pressure (kgf/cm²)

\( D \) = Nozzle throat diameter (mm)
4. Improvement of adhered metal melting method in furnace

2) Optimization of top-blown oxygen condition

- I / R and the amount of dissolved metal (yield difference between normal processing)
  - Conditions with a large degree of metal melting are in good agreement with the proper range of H furnace (I / R = 0.08 to 0.25)
  - The lance height increased, the collision pressure was 200 ~ 800 Pa (H-furnace 200 ~ 1200 Pa)

![Graph showing iron yield difference between normal de-P treatment and I/R ratio with error bar (1σ)]
4. Improvement of adhered metal melting method in furnace

2) Optimization of top-blown oxygen condition

【Amount of de-C】
- reduced by +0.09%

【Change in post-treatment temperature】
- post-treatment temperature $\Delta 5^\circ C$

From this result, the of secondary combustion heat was estimated.
4. Improvement of adhered metal melting method in furnace

2) Optimization of top-blown oxygen condition

The secondary heat of combustion is generated by the surplus oxygen generated by the decrease in the reaction amount of de-C and the CO gas in the slag.

→ Calculate the rate at which secondary combustion heat contributed to melting and raising the temperature of the metal from thermal balance.

<Concept of thermal balance>

① Decrease in de-C reaction volume (∆C = -0.09%)

A surplus blowing oxygen of ∆ 0.09% occurs

② Secondary combustion with CO gas by excess oxygen

③ Base metal melting and raising temperature due to secondary combustion

<Heat balance>

1) ① + ③ : Temperature drop (▲)
2) ② : Temperature rise (+)
   → (① + ③) + ② × γ = ▲5°C
2) Optimization of top-blown oxygen condition

【Definition formula】
heat efficiency \( \gamma (\%) \) is given by
\[
\gamma (\%) = \frac{\Delta T \cdot W \cdot m_{Fe} - (Q_{\text{CO}} + Q_{\text{Fe}})}{Q_{\text{CO}_2}} \quad \cdots (3)
\]

< Supplemental formula >

- De-C reaction heat: \( Q_{\text{CO}} = \Delta C \cdot W \cdot q_{\text{CO}} \)
- CO secondary combustion heat: \( Q_{\text{CO}_2} = \Delta C \cdot W \cdot q_{\text{CO2}} \)
- Fe melting and rising heat: \( Q_{\text{Fe}} = (q_{\text{Fe}} + \Delta t \cdot m_{Fe}) \cdot \Delta w \)
- Slight change in hot metal temperature:
  \[
  \Delta T = \frac{(Q_{\text{CO}} + Q_{\text{Fe}} + \gamma \cdot Q_{\text{CO}_2})}{(W \cdot m_{Fe})}
  \]

- Hot iron temperature change

- Metal melting amount

- Amount of hot metal

The heat efficiency is 38% on average
4. Improvement of adhered metal melting method in furnace

3) Results of actual application

■ The frequency of use of the bare metal melting lance
  3.0 times/day → 0.9 times / day

■ The metal melting processing ratio
  0 % → 40 %

< Consistent yield >

■ Iron loss reduction : +0.17%

■ Processing ratio : +0.05%
5. Conclusion

Improvement of metal melting method

- By improving the metal melting process, the metal melting processing ratio was applied up to 40%, and the usage frequency of the metal melting lance was reduced, from 3.0 times / day to 0.9 times / day.
- As a result, in addition to a consistent yield + 0.05% improvement by processing ratio + 4%, integrated yield improved by + 0.22% due to iron loss reduction + 0.17% due to melting of the metal.