The Mechanical Performance Experiments of Blast Furnace Hearth Ramming Material and Carbon Brick Refractory Mortar

Xiaogang Ma, Liangyu Chen & Yang Li

School of Mechanical Engineering and Automation, Northeastern University, Shenyang 110819, Liaoning, China

ABSTRACT: In this paper, the mechanical properties experiments of BF hearth ramming material and carbon brick refractory mortar were carried out. The compressive strength experiments of refractory mortar at different curing temperatures and the resin and asphalt combined with ramming material at different molding pressures and curing temperatures were carried out respectively. The conclusions are as follows: (1) In the experiment temperature range, the compressive strength of resin combined with ramming material is significantly higher than that of asphalt under the same conditions. (2) With the increase of temperature, the compressive strength of resin combined with ramming material and refractory mortar first increased and then decreased, while the asphalt combined with ramming material increases gradually.

1. PREFACE

The BF hearth ramming material was made with the high temperature electric forging anthracite, artificial graphite and silicon carbide as main raw material, the phenol resin, coal tar pitch and coal tar as binder by mixing kneading, used for the leveling layer of BF bottom brick lining and gaps between BF hearth carbon brick and cooling wall. In the hearth building, the ramming material has a certain degree of intensity and density after ramming and a certain compressive plastic to absorb the radial thermal expansion of brick lining. The refractory mortar is the joint material, used for BF lining. It will produce the compressive plastic deformation to absorb the circumferential thermal expansion of brick lining in the BF oven. In the thermal expansion of carbon brick, both the ramming material and refractory mortar have a certain degree of absorption in the BF oven, so in general, the thermal stress of hearth masonry can be reduced in the high temperature production of BF, the strength of the hearth masonry can be improved.

In the remanufacturing process of BF and other thermal power equipments in the oven, the mechanical properties parameters of ramming material and refractory mortar for evaluating the thermal stress of brick lining are the necessary basic data in the oven or normal production, especially the compression strength of ramming material and refractory mortar with temperature variation. In this paper, the compressive strength experiments of ramming material under different molding pressures and curing temperatures were carried out, in order to obtain the
correlation between compressive strength and molding pressure and curing temperature. It can also provide the material property data for making the optimal curve of oven and the mechanical properties of BF hearth. The experiment apparatus used as follows: (1) DLY-30 Universal Material Hydraulic Pressure Testing Machine. (2) RGM-3300 Microcomputer Control Universal Material Testing Machine. The raw materials used in this experiment are resin and asphalt combined with ramming material and refractory mortar from a certain factory.

2. THE PREPARATION of SAMPLES

According to the "Ferrous Metallurgy Industry Standards" of industrial information technology, the ramming material can fill every corner and small gap with a certain degree of intensity and density. In order to meet the requirements of no leaking molten iron and gas, the compression ratio or volume density of ramming material must be consistent with the requirements of standards after construction. Based on these standards, the compression strength experiments of ramming material under different molding pressures and curing temperatures were carried out; the various phenomena in the process of the sample preparation were observed.

The sample of asphalt and resin combined with ramming material is prepared by the DLY-30 Universal Material Hydraulic Pressure Testing Machine; with the cylinder mould diameter is 50mm. The asphalt combined with ramming material samples is prepared under 45kN, 70kN, 98kN and 140kN four kinds of pressure, and 70kN, 98kN and 140kN three kinds of pressure to resin; the pressure is maintained for 30 seconds.

<table>
<thead>
<tr>
<th>Pressure (KN)</th>
<th>Temperature (°C)</th>
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<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>75</td>
<td>1.652</td>
<td>1.627</td>
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<tr>
<td>70</td>
<td>95</td>
<td>1.641</td>
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<tr>
<td>98</td>
<td>115</td>
<td>1.628</td>
<td>1.608</td>
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<td>140</td>
<td>135</td>
<td>1.643</td>
<td>1.606</td>
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<tr>
<td></td>
<td>155</td>
<td>1.623</td>
<td>1.602</td>
</tr>
</tbody>
</table>

The cure experiments of ramming material were carried out respectively under 75°C, 95°C, 115°C, 135°C and 155°C five kinds of temperature, and 95°C, 115°C, 135°C and 155°C four kinds of temperature for refractory mortar (The whole heating process is in accordance with the asphalt and resin combined with ramming material curing temperature curves of the industry standard). The curing refractory mortar was processed into the sample with the size is Ø50mmx50mm±1mm on the Lathe. The qualities of ramming material and refractory mortar samples after curing were weighed by balance, the diameter and height of them were measured with 6 points by venire caliper. The volume density of samples can be obtained by the average value of measurement. The volume density of ramming material and refractory mortar under different molding pressures and curing temperatures are shown in table 1.

Table 1. The volume density of asphalt combined with ramming material.
Table 2. The volume density of resin combined with ramming material.

<table>
<thead>
<tr>
<th>Pressure (KN)</th>
<th>Temperature (°C)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>75</td>
</tr>
<tr>
<td>70</td>
<td>1.685</td>
</tr>
<tr>
<td>98</td>
<td>1.688</td>
</tr>
<tr>
<td>140</td>
<td>1.697</td>
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</tbody>
</table>

Table 3. The volume density of refractory mortar under different curing temperatures.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>95</th>
<th>115</th>
<th>135</th>
<th>155</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume density (g/mm$^3$)</td>
<td>0.878</td>
<td>0.857</td>
<td>0.855</td>
<td>0.796</td>
</tr>
</tbody>
</table>

As can be seen from above tables, under the same molding pressure, the volume density of asphalt combined with ramming material is gradually reduced with the increase of temperature, while the resin is first increased and then decreased; At the same curing temperature, the volume density of resin combined with ramming material is increased with the increase of the molding pressure, while the asphalt is first increased and then decreased; the volume density of refractory mortar gradually decreases with the increase of temperature.

In the experiment temperature, the asphalt combined with ramming material can not be cured completely because of its high completely cured temperature (about 300°C), when the molding pressure is constant, the volume of asphalt combined with ramming material is increased obviously with the increase of temperature, and the internal volatile matter gradually increased, so the volume density is gradually decreased; the resin combined with ramming material can be cured completely because its completely cured temperature is low (about 100~120°C), the volume gradually shrinks during curing, and the volume density first increase and then decrease; the volume density of refractory mortar decreases with the increase of temperature because the internal volatile matter gradually increased.

3. EXPERIMENT RESULTS AND DISCUSSION

The Compression strength experiments of ramming material samples and refractory mortar samples were carried out in turn by RGM-3300 Microcomputer Control Universal Material Testing Machine; with the feed rate is 1.3mm/min. The whole experiment was carried out under the same conditions. The maximum compression strength can be recorded is shown in Table 4, table 5 and table 6.

3.1 The correlation of refractory mortar between compression strength and curing temperature

The maximum load and compression strength of refractory mortar samples which prepared under different curing temperatures are shown in table 4. By the data in table 4, the compression
strength of refractory mortar first increases and then decreases with the increase of curing temperature. In order to show the correlation between compression strength and curing temperature more intuitive, the experiment results are analyzed by using the mathematical model. The fitting curves are shown in figure 1.

Table 4. The maximum load and compression strength of refractory mortar with temperature.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>95</th>
<th>115</th>
<th>135</th>
<th>155</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum load (KN)</td>
<td>39.5</td>
<td>44.7</td>
<td>34.75</td>
<td>27.2</td>
</tr>
<tr>
<td>Compressive strength (MPa)</td>
<td>20.14</td>
<td>22.58</td>
<td>17.56</td>
<td>13.72</td>
</tr>
</tbody>
</table>

Figure 1. The correlation curve. Figure 2. Test block. Figure 3. Destructive test block.

The refractory mortar is mainly consists of refractory material, binder and admixture. The binder is mainly liquid phenol resin or tar, anthracene oil and asphalt; the additives including water reducer, plasticizer and stabilizer, etc, is mainly consists of water-soluble organic polymer. Because of the thermal evaporation of the internal liquid bond, air and water vapor, there will be large and small holes in the heating process, so the shape of refractory mortar after curing like honeycomb.

The correlation formula between compression strength \( \sigma_n \) and temperature \( T \) under different curing temperatures can be obtained with the regression analysis method.

\[
\sigma_n = -7.14 \times 10^{-2} T^2 + 9.15 T - 358.8 \quad \text{(MPa)}
\]  

(1)

3.2 The correlation of ramming material between compressive strength and molding pressure and curing temperature

The maximum compression strength of asphalt and resin combined with ramming material samples prepared under different curing temperatures as shown in table 5 and table 6.
Table 5. The correlation of asphalt combined with ramming material.

<table>
<thead>
<tr>
<th>Pressure (kN)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>75</td>
</tr>
<tr>
<td>45</td>
<td>0.19</td>
</tr>
<tr>
<td>70</td>
<td>0.19</td>
</tr>
<tr>
<td>98</td>
<td>0.16</td>
</tr>
<tr>
<td>140</td>
<td>0.18</td>
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</tbody>
</table>

Table 6. The correlation of resin combined with ramming material.

<table>
<thead>
<tr>
<th>Pressure (kN)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>75</td>
</tr>
<tr>
<td>70</td>
<td>6.81</td>
</tr>
<tr>
<td>98</td>
<td>5.67</td>
</tr>
<tr>
<td>140</td>
<td>4.10</td>
</tr>
</tbody>
</table>

As above, under the same curing temperature, the compression strength of resin combined with ramming material is significantly higher than that of asphalt. The compression strength of asphalt and resin combined with ramming material fluctuates in a certain range, but the overall trend is not big. Under the same molding pressure, the compression strength of asphalt combined with ramming material is gradually decreased with the increase of curing temperature, while the resin is first increased and then decreased. The correlation curves between the compression strength of ramming material and curing temperature under different molding pressures are obtained by interpolation method, as shown in figure 4 and figure 5.

As can be seen from above, the compression strength of ramming material is related to both molding pressure and curing temperature. The correlation between compression strength of
According to the "Ministry of black metallurgy industry standards", the ramming material has a certain degree of intensity and density after ramming in the hearth building. In the oven and production process, the influence of compression ratio or volume density on the compression strength is relatively small, so it's generally ignored, in this case, the influence of temperature on the compression strength is mainly considered. The correlation formulas between compression strength of asphalt and resin combined with ramming material and curing temperature are obtained with regression analysis method.

\[ \sigma_L = 1.10 \times 10^{-2} T^2 - 0.71 T + 17.13 \]  
\[ \sigma_S = -0.14 T^2 + 11.47 T - 340.20 \]

4. CONCLUSIONS AND DISCUSSION

The correlation between compression strength of refractory mortar and curing temperature is obtained by the mechanical performance experiments of ramming material and refractory mortar, meanwhile, the correlation formulas are given. It can provide the theoretical basis for thermal
stress calculation of BF hearth lining and improve the accuracy. Through these experiments, the conclusions are as follows:

(1) In the early stage of compression, the asphalt combined with ramming material will produce a large displacement with a very small force. The compression ratio increase is very small under 98kN force, the phenomenon of extruding material will appear when the pressure exceeds 140kN; compared with the asphalt combined with ramming material, the resin is more resistant to compression. The compression ratio of resin combined with ramming material can reach 40% under 98kN force and the compression ratio is very small when the pressure exceeds 120kN, but no extruding material. The compression strength of resin combined with ramming material is significantly higher than that of asphalt after baking in the range of less than 140°C.

(2) The loading speed has almost no effect on the compression ratio within the limits of standards. Under the same molding pressure, the volume density of resin combined with ramming material is greater than that of asphalt. In the experiment temperature range, the molding pressure of ramming material has no significant effect on the compression strength; it is mainly influenced by curing temperature.

(3) In the experiment temperature range, the compression strength of refractory mortar first increases and then decreases with the increase of the curing temperature, the shape of refractory mortar after curing like honeycomb. Under the same molding pressure, the compression strength of asphalt combined with ramming material is gradually decreased with the increase of curing temperature, while the resin is first increased and then decreased. In the experimental temperature range, the asphalt combined with ramming material has not yet achieved the complete cured state, and has good softness; it is not easy to deformation after curing, so the strength of resisting compression increased. When the temperature increases, the internal structure is softened, and the compression strength decreases gradually.

REFERENCES


