The life of brick linings in tunnel kiln cars at the Bogdanovich Refractories Plant in 1970 was 20-28 cycles. Apart from the well-known causes [1, 2], the low resistance of the lining may be attributed to the extreme overheating of the metal part of the linings (the support angles), because of the operation of the kilns in the firing zones under pressure, and of the poor sealing of the joints of the cars; this overheating leads to compression of the lining at the edges at the level of the support brackets, and to the failure of the corners of the base.

Tests were carried out on linings of kiln cars made from mullite–siliceous concrete blocks with phosphate bonds. The block structure (Fig. 1) was designed in the light of existing experience* [3, 4] to effect the elimination of the causes of low resistance. To avoid forcing out of the lining at the edges, they were made without metal support and face brackets, the insulation of the lining was made in a metal cladding, and the insulating material consisted of chamotte concrete containing aluminous cement together with aggregate made from scrap ultralightweight brick. The blocks around the perimeter of the cars were fitted on metal pins; in the central part they were laid freely on the insulating concrete. Three-face temperature joints 50–70 mm wide at the top were specified for free expansion of the blocks during heating and elimination of the sand which collected in the joints.


<table>
<thead>
<tr>
<th>Material</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>TiO₂</th>
<th>Loss on ignition, %</th>
<th>Refractoriness, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamotte made from Arkatsyansk clay</td>
<td>51,00</td>
<td>44,45</td>
<td>1,99</td>
<td>0,62</td>
<td>0,26</td>
<td>0,13</td>
<td>2,34</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>Poldnevsk clay BG2</td>
<td>32,73</td>
<td>30,82</td>
<td>1,99</td>
<td>0,36</td>
<td>1,40</td>
<td>0,50</td>
<td>1,10</td>
<td>10,73</td>
<td>1710</td>
</tr>
<tr>
<td>Hydrated alumina</td>
<td>--</td>
<td>63,65</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>35,36</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1. Scheme of the block lining for tunnel kiln car.

Fig. 2. Dilatometric curve for mullite–siliceous concrete with aluminophosphate bond.

Fig. 3. Block lining of the kiln car before service.

TABLE 2. Composition of Phosphate Bonds, %

<table>
<thead>
<tr>
<th>Initial material</th>
<th>Bond</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Distilled</td>
</tr>
<tr>
<td></td>
<td>alumino-phosphate</td>
</tr>
<tr>
<td></td>
<td>clay-phosphate</td>
</tr>
<tr>
<td>Hydrated alumina (&lt; 10 μm)</td>
<td>21</td>
</tr>
<tr>
<td>Poldnevsk clay (&lt; 1 mm)</td>
<td>18</td>
</tr>
<tr>
<td>Orthophosphoric acid; 33%</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>84</td>
</tr>
<tr>
<td>50%</td>
<td>79</td>
</tr>
</tbody>
</table>

The hydrated alumina used for preparing the aluminophosphate bond was ground for 2–2.5 h in a vibration mill. Upon reaction with orthophosphoric acid as a result of the separation of heat the bond was warmed up to 70–80°C. The clay-phosphate bond was prepared by heating a mixture of acid and clay to boiling point.

Laboratory cylindrical specimens of diameter 36 and height 50 mm were pressed at 800 kg/cm². The properties of the specimens are presented in Table 3, and in Fig. 2. The specimens with the aluminophosphate bond set in air, and are not damaged after drying, but possess a high strength in a wide temperature range; the shrinkage of the concrete at 1400°C is slight.

The specimens with the clay-phosphate bond containing a third less P₂O₅ had inferior properties, but the body of this composition was more suitable for production purposes since it set much more slowly.

In preparing blocks the coarse chamotte (fractions 10–5 and 5–2 mm) was loaded into the concrete mixer of the forced action type S-724B, the phosphate bond was added, blended for 3–5 min, followed by the clay, and finely milled and fine fractions of chamotte, and the whole blended for another 5–7 min. The blocks were tamped in layers 50–70 mm thick with a pneumatic tamping device TR-1 in metal molds on bases with a compressive air pressure of not less than 5 atm. The surface of each layer was scratched.

After completion of the tamping the shuttering was removed. Because of the absence of a drier, the blocks were dried for 10 days in the workshop. Under these conditions the blocks set only at the surface to a depth of up to 50 mm, and thus their strength was low during installations.

Two linings for kiln cars were constructed from Mullite–siliceous blocks: one with the clay-phosphate bond, and the other with the aluminophosphate bond. The sides of the cars were cast with chamotte concrete containing aluminous cement (Fig. 3).

After the first cycles longitudinal cracks extended through the layers of the block and with further working they were enlarged. When the cars were removed from service, transverse cracks and scaling had developed in some blocks mainly those at the corners.

In preparing blocks the coarse chamotte (fractions 10–5 and 5–2 mm) was loaded into the concrete mixer of the forced action type S-724B, the phosphate bond was added, blended for 3–5 min, followed by the clay, and finely milled and fine fractions of chamotte, and the whole blended for another 5–7 min. The blocks were tamped in layers 50–70 mm thick with a pneumatic tamping device TR-1 in metal molds on bases with a compressive air pressure of not less than 5 atm. The surface of each layer was scratched.

The use of chamotte not purified by electromagnets to remove tramp iron led to reaction of the metallic impurities located in it with the phosphate bond, and the liberation of gas. In the presence of 10% bond this led to the formation of longitudinal cracks. With the addition of 6.5% bond, the tight packing of the surface layers rendered them very difficult to scratch.

After completion of the tamping the shuttering was removed. Because of the absence of a drier, the blocks were dried for 10 days in the workshop. Under these conditions the blocks set only at the surface to a depth of up to 50 mm, and thus their strength was low during installations.

Two linings for kiln cars were constructed from Mullite–siliceous blocks: one with the clay-phosphate bond, and the other with the aluminophosphate bond. The sides of the cars were cast with chamotte concrete containing aluminous cement (Fig. 3).

After the first cycles longitudinal cracks extended through the layers of the block and with further working they were enlarged. When the cars were removed from service, transverse cracks and scaling had developed in some blocks mainly those at the corners.

The preparation of the Mullite–siliceous concrete during laboratory and industrial research involved using Arkalyksk chamotte, Poldnevsk clay BG2, and aluminophosphate and clay-phosphate bonds.

The chemical composition and refactoriness of the original materials are given in Table 1 and the compositions of the phosphate bonds in Table 2. The composition of the batch was 25% chamotte fractions 10–5 mm, 15% 5–2 mm, 40% <2 mm, and 10% finely milled (content of fractions <0.088 mm not less than 50%), 10% Poldnevsk clay fractions <2 mm. In addition to the above we added 7–10% aluminophosphate (composition I) or clay-phosphate (composition II) bond.

In preparing blocks the coarse chamotte (fractions 10–5 and 5–2 mm) was loaded into the concrete mixer of the forced action type S-724B, the phosphate bond was added, blended for 3–5 min, followed by the clay, and finely milled and fine fractions of chamotte, and the whole blended for another 5–7 min. The blocks were tamped in layers 50–70 mm thick with a pneumatic tamping device TR-1 in metal molds on bases with a compressive air pressure of not less than 5 atm. The surface of each layer was scratched.

The use of chamotte not purified by electromagnets to remove tramp iron led to reaction of the metallic impurities located in it with the phosphate bond, and the liberation of gas. In the presence of 10% bond this led to the formation of longitudinal cracks. With the addition of 6.5% bond, the tight packing of the surface layers rendered them very difficult to scratch.

After completion of the tamping the shuttering was removed. Because of the absence of a drier, the blocks were dried for 10 days in the workshop. Under these conditions the blocks set only at the surface to a depth of up to 50 mm, and thus their strength was low during installations.

Two linings for kiln cars were constructed from Mullite–siliceous blocks: one with the clay-phosphate bond, and the other with the aluminophosphate bond. The sides of the cars were cast with chamotte concrete containing aluminous cement (Fig. 3).

After the first cycles longitudinal cracks extended through the layers of the block and with further working they were enlarged. When the cars were removed from service, transverse cracks and scaling had developed in some blocks mainly those at the corners.

In preparing blocks the coarse chamotte (fractions 10–5 and 5–2 mm) was loaded into the concrete mixer of the forced action type S-724B, the phosphate bond was added, blended for 3–5 min, followed by the clay, and finely milled and fine fractions of chamotte, and the whole blended for another 5–7 min. The blocks were tamped in layers 50–70 mm thick with a pneumatic tamping device TR-1 in metal molds on bases with a compressive air pressure of not less than 5 atm. The surface of each layer was scratched.

The use of chamotte not purified by electromagnets to remove tramp iron led to reaction of the metallic impurities located in it with the phosphate bond, and the liberation of gas. In the presence of 10% bond this led to the formation of longitudinal cracks. With the addition of 6.5% bond, the tight packing of the surface layers rendered them very difficult to scratch.

After completion of the tamping the shuttering was removed. Because of the absence of a drier, the blocks were dried for 10 days in the workshop. Under these conditions the blocks set only at the surface to a depth of up to 50 mm, and thus their strength was low during installations.

Two linings for kiln cars were constructed from Mullite–siliceous blocks: one with the clay-phosphate bond, and the other with the aluminophosphate bond. The sides of the cars were cast with chamotte concrete containing aluminous cement (Fig. 3).

After the first cycles longitudinal cracks extended through the layers of the block and with further working they were enlarged. When the cars were removed from service, transverse cracks and scaling had developed in some blocks mainly those at the corners.

In preparing blocks the coarse chamotte (fractions 10–5 and 5–2 mm) was loaded into the concrete mixer of the forced action type S-724B, the phosphate bond was added, blended for 3–5 min, followed by the clay, and finely milled and fine fractions of chamotte, and the whole blended for another 5–7 min. The blocks were tamped in layers 50–70 mm thick with a pneumatic tamping device TR-1 in metal molds on bases with a compressive air pressure of not less than 5 atm. The surface of each layer was scratched.

The use of chamotte not purified by electromagnets to remove tramp iron led to reaction of the metallic impurities located in it with the phosphate bond, and the liberation of gas. In the presence of 10% bond this led to the formation of longitudinal cracks. With the addition of 6.5% bond, the tight packing of the surface layers rendered them very difficult to scratch.

After completion of the tamping the shuttering was removed. Because of the absence of a drier, the blocks were dried for 10 days in the workshop. Under these conditions the blocks set only at the surface to a depth of up to 50 mm, and thus their strength was low during installations.

Two linings for kiln cars were constructed from Mullite–siliceous blocks: one with the clay-phosphate bond, and the other with the aluminophosphate bond. The sides of the cars were cast with chamotte concrete containing aluminous cement (Fig. 3).

After the first cycles longitudinal cracks extended through the layers of the block and with further working they were enlarged. When the cars were removed from service, transverse cracks and scaling had developed in some blocks mainly those at the corners.

In preparing blocks the coarse chamotte (fractions 10–5 and 5–2 mm) was loaded into the concrete mixer of the forced action type S-724B, the phosphate bond was added, blended for 3–5 min, followed by the clay, and finely milled and fine fractions of chamotte, and the whole blended for another 5–7 min. The blocks were tamped in layers 50–70 mm thick with a pneumatic tamping device TR-1 in metal molds on bases with a compressive air pressure of not less than 5 atm. The surface of each layer was scratched.

The use of chamotte not purified by electromagnets to remove tramp iron led to reaction of the metallic impurities located in it with the phosphate bond, and the liberation of gas. In the presence of 10% bond this led to the formation of longitudinal cracks. With the addition of 6.5% bond, the tight packing of the surface layers rendered them very difficult to scratch.

After completion of the tamping the shuttering was removed. Because of the absence of a drier, the blocks were dried for 10 days in the workshop. Under these conditions the blocks set only at the surface to a depth of up to 50 mm, and thus their strength was low during installations.

Two linings for kiln cars were constructed from Mullite–siliceous blocks: one with the clay-phosphate bond, and the other with the aluminophosphate bond. The sides of the cars were cast with chamotte concrete containing aluminous cement (Fig. 3).

After the first cycles longitudinal cracks extended through the layers of the block and with further working they were enlarged. When the cars were removed from service, transverse cracks and scaling had developed in some blocks mainly those at the corners.