Lightweight Refractories of Self-Compacting Mixtures

SPECIAL FEATURES OF FORCED HEAT TREATMENT OF SELF-COMPACTING MIXTURES

V. N. Sokov

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The mechanism of self-compaction of mineral-polystyrene mixtures in a closed perforated volume treated by different heating agents, namely, hot gas, live steam, and electricity, is considered. It is established that heat treatment of the foaming mixtures should be started at high temperatures, by a thermal shock, without stepped increase of the temperature, as is commonly done with conventional mixtures.

Forced heat treatment of a material can be carried out using hot gases, live steam, or electric heating. The compaction mechanism of a self-compacting mixture depends on the method of heat treatment and the type of heating agent. We apply the term "forced heat treatment" to self-compacting mixtures, because the mineral component and the water in the closed volume experience the action of the force field arising due to foaming of polystyrene at temperatures above 80°C. Under this effect the internal water can move inside the volume and the mixture can undergo plastic deformation.

The excess pressure arising in the closed volume is defined by the degree of polystyrene foaming and its fractional composition.

In the drying of porous mixtures, especially foamed ones, the solid particles move closer during evaporation of the moisture and this results in high air shrinkage (up to 50%). In the drying of a mineral-polystyrene mixture the polystyrene granules expand at the moment when the mixture is in the plastic state. The forces that develop move the particles closer and compact the particles of the mineral component without breaking the continuity of the interpore contacts. This phenomenon prevents shrinkage of the green.

In further drying of the unmolded green the elasticity of the foamed polystyrene granules eliminates stresses caused by dried mineral particles. After drying, a dense shell of ceramic component forms around the foamed polystyrene granules.

The self-compacting mixture with polystyrene is insensitive to extreme drying regimes and starts to be active at 80°C.

Therefore, we can assume that the drying should be started from high temperatures, i.e., by a thermal shock, without a step-like increase in the temperature, as is commonly done with conventional mixtures. This will prevent the mixture from drying before it starts to be disturbed.

Our experiments show that an extreme drying regime for self-compacting mixtures in a closed perforated volume results in a very important effect, namely, formation of a crust on the surface of parts, which raises their strength and resistance to different factors.

Hot air drying of mixtures with polystyrene allows us to intensify the process without worsening the physicomechanical properties of the green and ready parts. The drying time is reduced 3 - 4-fold. Thus, the drying of foamed mixtures based on kyanite-sillimanite concentrate at AO Podolskogneupor lasts 60 - 72 h. The drying of similar mixtures with polystyrene in producing parts with the same mean porosity lasts 16 - 18 h. When the mixture is heated, the evaporating moisture creates a vapor medium inside the closed mold. The vapor ensures relatively uniform self-heating of the green over its thickness [1], which accelerates polystyrene foaming and hence the moisture removal, which causes shrinkage.

Subsequently, after the moisture has been mechanically squeezed out, drying in the closed volume becomes difficult, because the evaporation surface in the volume is much smaller than the geometric surface of the green, and the material is virtually not covered by the heating agent.

In the drying of self-compacting mixtures we not only remove the moisture but also form a good-quality structure for obtaining the required strength and mean density. As the clay particles move closer, the interaction forces between them grow, but the repulsive forces also become more active. The
overcoming of the energy barrier in the compression of clay particles is accompanied by the compression of polystyrene grains, i.e., by the accumulation in them of internal potential energy that is proportional to the pressure of these grains. If the mold (outer pressure) is removed immediately after the foaming, the residual volume deformation will decrease after some time due to the elastic aftereffect, and the structure of the ceramic component will become less dense. If the foaming of the burning-off addition has been incomplete, the specimen may be destroyed.

This means that demolding should be done only when the volume stress of the compacted green does not exceed the ultimate tensile strength of the interpore contacts. This condition can be fulfilled if only the foaming of polystyrene in the ceramic mixture leads to values of $K_f$ lying to the right of the extremum point on the foaming curve (Fig. 1). Then the inner pressure in the foamed polystyrene is below atmospheric pressure, which causes deformation (shrinkage) of the granules [2] and hence eases the stressed state of the green. Since the ceramic mixture has already acquired some strength due to compaction and loss of most part of its moisture, we should not expect that the green will change its volume.

In order to simplify the experiment verifying these assumptions we prepared specimens from clay-polystyrene mixtures. The drying was done at 90°C for a time known to be sufficient for the polystyrene to foam and partially shrink. In each batch of specimens we determined the ultimate compressive strength after demolding and final drying on the mold plate.

As is clear from Table 1, holding of the green for 4 h in closed perforated molds does not change its strength noticeably. A 0.5 - 1-h hold of the mixture is clearly too short, because the loss of strength compared 5-h hold is 70 - 80%. In this case after demolding we observe an elastic aftereffect, i.e., repeated foaming of the green during its drying on the mold plate, which lowers its strength due to the formation of microcracks that develop during firing in the interpore bridges.

Analysis of the data in Table 1 shows that the optimum holding time in closed perforated molds during drying is 4 h. In this case the strength of the green was 97% of the strength of specimens held in molds for 5 h.

![Fig. 1. Foaming coefficient $K_f$ (1) and mean density $\rho$ (2) of polystyrene as functions of the duration of heat treatment $\tau$ in boiling water.](image)

![Fig. 2. Ultimate compressive strength $\sigma_{comp}$ of the green as a function for the drying time $\tau$ of self-compacting mixtures in a closed perforated volume.](image)

In the drying of self-compacting mixtures in closed molds the strength of the specimens naturally grows to the maximum value at the stage of the complete foaming of the polystyrene. The kinetics of the growth of the strength can be followed from the experimental curve in Fig. 2, where we see that the most intense gain in strength occurs between 1 and 3 h.

After the physically bound water is completely squeezed out of the mixture and the mold is removed, the structure of the green still contains some mixing water, but it is located between particles of the mixture touching one another and constituting a skeleton that is not compressed during drying. Therefore, despite the remaining moisture, such a green exhibits low shrinkage, which means that it can be subjected to intensive regimes.

We should also allow for the fact that the elastic polystyrene granules in the green cause some shrinkage in drying and hence some cracking.

For all these reasons we dried the green on mold plates by a heating agent heated to 120 - 130°C to a residual moisture content of 3 - 4%. The drying time was 1.5 - 2 h.

The complex effect of the heating agent exerted on the mixture for 4 h (90°C) and on the formed green on the mold plate for 1.5 - 2 h (120 - 130°C) reduced the duration of the heat treatment from 16 - 18 h to 5.5 - 6 h, i.e., by a factor of 3, and by a factor of 12 compared to the foam method.

Hot air has a rather low thermal conductivity [5 - 12 W/(m² · K)], and the thermal conductivity of partially foamed polystyrene is also not high. This increases the tem-

<table>
<thead>
<tr>
<th>Holding time, h</th>
<th>Ultimate compressive strength, MPa</th>
<th>Appearance of specimens</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.15</td>
<td>Visible cracks</td>
</tr>
<tr>
<td>1.0</td>
<td>0.2</td>
<td>Small cracks</td>
</tr>
<tr>
<td>2.0</td>
<td>0.5</td>
<td>Cuts</td>
</tr>
<tr>
<td>3.0</td>
<td>0.6</td>
<td>No defects</td>
</tr>
<tr>
<td>4.0</td>
<td>0.68</td>
<td>No defects</td>
</tr>
<tr>
<td>5.0</td>
<td>0.7</td>
<td>No defects</td>
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