Heat Effects on Bentonite Bonding

1985 Silver Anniversary Lecture

Differences in thermal decomposition of bentonites used as foundry bonding clays have a strong influence on their consumption in circulating system sands. Bentonite burnout and consumption depend on the sand-to-metal ratio and on the cooling time of the casting in the mold.

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When heated to temperatures greater than 500-600°C, clays lose almost all of the hydrogen and oxygen from their crystal lattice in the ratio of 2 H:1 O (H₂O). This loss of combined water results in a loss of the bonding properties of the clay and is irreversible. It happens when molding sand is heated up to these temperatures or higher, such as in the molding process.

In my earlier paper, "Heat Effects on Bentonite Bonding," the effect of heat on various bentonites was discussed. High swelling U.S. western bentonite was shown to lose its combined water and, hence, its bonding capacity at higher temperatures than low swelling U.S. southern calcium bentonite. For a system sand then, western bentonite is more durable than southern bentonite.

The same difference was found when European bentonites were compared in their natural calcium state and after activation with sodium carbonate, common practice in Europe and other parts of the world. Soda activation was found to improve durability by stabilizing the thermal decomposition of bentonite, but there still remained considerable differences among bentonites of different origins.

The thermal decomposition and durability of bentonites are of interest from both a technological and economic standpoint and considerable progress has been made in the field of bentonite research during the last 25 years. Durability has been investigated and found to be interrelated with many bentonite properties.

Bentonite Durability

Durability curves of bentonites from various deposits are compared in Fig. 1, both in the natural calcium state (designated Ca) and after soda activation (designated Na). Since bonding capacity of different bentonites varies, clay addition to the silica test sand used was chosen individually in order to produce identical green compressive strengths.

The mixtures were subjected to increasing temperatures for three hours; remilled to 45% compactability after each temperature increase; and tested (remill method). The durability curve of a natural western (Wyoming) bentonite (designated WB) serves as a base of reference.

It can be seen that soda activation improves the rate of loss of bonding capacity for all of the bentonites tested, but the final decomposition temperature remains unchanged. It can also be seen that some of the clays react more to soda activation than others and a few
approach the durability of Wyoming bentonite. Even after soda activation however, considerable differences persist between the various bentonites.

This means that soda activation cannot inherently change the mineralogical character of a bentonite. It has no significant influence on the bonding capacity of a bentonite, but it can increase the swelling capacity of a bentonite as well as the resistivity against sand expansion defects, which is possibly more important than its effect on durability.²

Simple moisture/green strength curves of 5% bentonite test mixtures are shown in Fig. 2. Western bentonite again serves as a reference. Durability values are from the remull test curves in Fig. 1 and correspond to the temperature at which the green compressive strength of the test mixture drops to 50% of its initial value.

Sodium bentonite bonded sands are less water sensitive at high moisture levels than calcium bentonite bonded sands.³ The same holds true for soda activation. Water sensitivity can be expressed by the loss in green compressive strength from the 45% compactability value to the value at 6% moisture. (See Fig. 2.)

The following conclusions about bentonite durability can be drawn then:

- in the soda-activated state, high durability bentonites develop high swelling capacities;
- water sensitivity decreases with increasing durability;
- durability appears to be closely related to the Fe₂O₃ + MgO content of the clay, indicating the degree of substitution of Al and Si in the crystal lattice structure.

**Thermal Decomposition**

Thermal degradation of a clay occurs with loss of combined water. Dehydration curves of various bentonites are shown in Fig. 3. High durability bentonites appear to have lower combined water contents.

Carbonate decomposition is another factor to consider. Carbonates decompose at elevated temperatures to lose CO₂. Bentonites may contain lime (calcium carbonate) and additional carbonate is introduced by soda activation.

Many bentonites used in Europe contain up to 10% carbonate and sometimes even more. Carbonates theoretically should not decompose before 900°C (1650°F) but almost all of the carbonate decomposes by 700°C (1290°F). This means that carbonate-silicate reactions take place at comparatively low temperatures in the intimate mixture of clay mineral and carbonates.

Such thermal degradation can result in defects in castings poured. Loss of both CO₂ from carbonate decomposition and combined water may be a source for pinholes.

**Casting Tests**

A realistic evaluation of bentonite durability is possible by pouring test castings. Systematic pouring tests with spherical test castings and with test mixtures using western and southern bentonite and fireclay are reported in the literature.⁴ Test castings with 8.5% western and 8.5% southern bentonite confirmed that western bentonite is more durable than southern bentonite.

The amount of heat introduced into a green sand mold and consequently, bentonite burnout at a given pouring temperature, both depend on the sand-to-metal ratio.⁵ The temperature distribution in a bentonite bonded sand mold after pouring and the influence on bentonite burnout were also measured by researchers.⁶ They found that no bentonite is "burnt dead" beyond a distance of 20 mm into test castings. They also found that a temperature of 300°C
(572°F), the lowest temperature that still affects bentonite thermally, is reached at a distance of about 50 mm into the mold. With increasing wall thickness of the casting, these temperature limits are shifted to increasing distances from the mold/metal interface.

Other test have shown, in addition, that as long as the cooling time of the casting in the mold before shakeout and the sand-to-metal ratio are constant, bentonite burnout does not really depend on the shape of the casting.

Circulating System Sands

In a circulating system sand, the bentonite is subject to all possible states of degradation due to thermal stress. The methylene blue value determined with system sands, therefore, also measures the average activity of this mixture so it should be possible to distinguish newly added from thermally damaged clays.

As long as the bentonite in the sand is not entirely burnt dead, it is still active, swells, develops bonding action and is removable by washing. Dead burnt clay, however, remains baked onto the sand grains and cannot be renewed by washing.

By means of a detailed analysis of the fines fraction of a sand by conventional methods, it is possible to evaluate the state of preservation (retained activity) of a bentonite in system sands with sufficient accuracy.

The fines fraction of a system sand (AFS clay <20 microns; removable by clay wash test) is composed of:
- total live bentonite—a mixture of more or less thermally affected bentonite;
- combustible carbonaceous matter—calculated from the loss on ignition (LOI) portion in the AFS clay, from which the loss on ignition of the live bentonite must be deducted;
- ashes from additives—usually negligible in amount.

The methylene blue bentonite content determined for a given system sand will always be lower than the calculated total live bentonite as defined above. The methylene blue content, expressed in percent of total live bentonite content, reflects the state of preservation of the bentonite in a system sand.

Table 1 contains some values determined with system sands using bentonites of different types and origins. The effect of differences in durability is evident. A low state of preservation of the bentonite in a given system indicates an increased bentonite consumption. It is very important to know, however, that under comparable conditions, the bentonite consumption is also influenced by the bonding power of the bentonite, which is not expressed by the state of preservation value.

Influence of Carbon—Recent statistical evaluation of much system sand data has revealed an effect of carbonaceous additives on bentonite and its burnout rate in sand. Seacoal appears to have a moderate effect only, while certain premixes containing resins and bituminous by-products can influence the state of preservation of the bentonite to a more pronounced extent.

Bentonite Consumption—In circulating system sands, bentonite must be added at each cycle of preparation for two reasons: to bond the shakeout core sand and new sand added to the return sand; and to replace the bentonite burnout in the sand.

Table 2 contains some practical observations on bentonite consumption in five foundries with comparable automated molding and pouring lines and
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Table 1. State of Preservation Ranges of Bentonites in Various System Sands

<table>
<thead>
<tr>
<th>Bentonite Used</th>
<th>State of Preservation of Bentonite %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazilian Calcium</td>
<td>60 to 70</td>
</tr>
<tr>
<td>European Soda Activated</td>
<td>70 to 90</td>
</tr>
<tr>
<td>Wyoming Western</td>
<td>90 to 95</td>
</tr>
<tr>
<td>Wyoming and Southern 1 : 1</td>
<td>80 to 90</td>
</tr>
</tbody>
</table>

Table 2. Bentonite Consumption Data for Five System Sands in Automated Iron Foundries

<table>
<thead>
<tr>
<th>FOUNDARY No.</th>
<th>BENTONITE TYPE</th>
<th>SAND MOIST. CONTENT %</th>
<th>GELS LEVEL (OF 10), PIS</th>
<th>BENTONITE MOIST. COST</th>
<th>CENTER SAND (OF 10) PORTION %</th>
<th>BURN OUT PORTION %</th>
<th>TOTAL (OF 10) PORTION %</th>
<th>BURN OUT FOR 100% IRON</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bavarian Activated</td>
<td>9</td>
<td>4.0</td>
<td>19</td>
<td>9:1</td>
<td>0.4</td>
<td>0.18</td>
<td>0.22</td>
</tr>
<tr>
<td>2</td>
<td>Bavarian Activated</td>
<td>10</td>
<td>3.2</td>
<td>23</td>
<td>5:1</td>
<td>1.2</td>
<td>0.2</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>Bavarian Activated</td>
<td>10</td>
<td>5.7</td>
<td>21</td>
<td>10:1</td>
<td>0.3</td>
<td>0.13</td>
<td>0.17</td>
</tr>
<tr>
<td>4</td>
<td>California</td>
<td>7</td>
<td>4.0</td>
<td>13.5</td>
<td>9:1</td>
<td>0.25</td>
<td>0.1</td>
<td>0.15</td>
</tr>
<tr>
<td>5</td>
<td>Bavarian Activated</td>
<td>10</td>
<td>4.5</td>
<td>33</td>
<td>7:1</td>
<td>0.83</td>
<td>0.31</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Influencing Factors

The data has shown then, that for a given case, bentonite burnout and bentonite consumption are determined by a number of factors. These influencing factors are summarized here.

- Sand-to-metal ratio—is the major factor controlling consumption.
- Cooling time of the casting in the mold—is a second important factor in terms of consumption.
- Pouring temperature—is of secondary influence for typical cast iron pouring temperature ranges.
- Bentonite type—geological origin, petrographical character, bonding capacity, montmorillonite content.
- Degree and manner of activation—in the case of soda-treated bentonites.
- Carbonaceous additives—and respective pyrolysis products and residues.
- Core binder condensation products.
- Moisture requirement of the sand—increased moisture requirement increases the sand-to-metal action of sand and reduces heat transfer.
- Mold density and heat conductivity of compacted sand.

This lecture was originally presented at the 1985 AFS Casting Congress, Pittsburgh, PA.

References