Effect of Cement Characteristics on the Setting Behavior of Autoclaved Aerated Concrete

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A cement suitable for the Autoclaved aerated concrete (AAC) was developed. The cement in which the CaS, fineness (Blaine), and hemihydrate (H)/gypsum (G) ratio (H/(H+G)) changed was produced experimentally. Using this cement, the effect of the cementitious property on the viscosity of the AAC slurry and the hardening of the AAC green cake was clarified. Though H/(H+G) influences viscosity, CaS and Blaine do not. On hardening, it quickens, as CaS is more abounding as Blaine is higher, and as H/(H+G) is lower. Since the cuttable time shortens on Blaine 4300 cm²/g, and H/(H+G) = 0% is not desirable. The effect of H/(H+G) on slurry viscosity and hardening was regarded as the reactivity of CaA and generation of the ettringite. The hydration temperature of the cement in AAC is higher than ordinary cement paste, and the rapid supply of $SO_4^{2-}$ from hemihydrate of which the solubility is high is required, since the hydration of CaS is extremely active. The characteristic of the cement suitable for AAC consists like as follows: a) HC with many CaS is made as a base. b) The Blaine is desirable at around 3800 cm²/g. c) Hemihydrate and gypsum are coexistence. The adaptability was confirmed by the factory scale test.

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1. Introduction

1.1 Manufacturing process for AAC panels

Autoclaved aerated concrete (AAC) is a building material with light weight, high intensity, excellent fire resistance, thermal insulation, sound insulation and durability. It is manufactured in the following processes:

(a) Silica (quartz sand) and other materials containing silicates are mixed with a calcareous material (cement, quicklime, gypsum, etc.) and water to yield slurry. Generally, for the cement, normal Portland cement (NC) is used.

(b) Metallic aluminum powder, serving as a foaming agent, is added to the slurry, which is then poured into the mold (7 m-length × 1.5 m-width × 0.6 m-height) at 40–50°C. The reinforcing steel for the AAC panel is placed in the mold before pouring.

(c) From the hydrogen gas that arises by chemical reaction between the metallic aluminum powder and alkali, the bubble of the round cellular structure of 0.1–1 mm diameter is formed, and the AAC slurry expands to about double the volume (the foaming process; Fig. 1).

(d) It hardens by the hydration reaction of quicklime and cement, and becomes a hardening body with sufficient hardness at the degree it is taken out from the mould (de-mould) after several hours (hardening process). The hardening body is called “Green Cake”, because it is weak like the cake, and exhibits green colour.

(e) A set of parallel piano wires, arranged at the intervals corresponding to the thickness of the desired AAC panels, are used to cut panels along the major axis of the AAC green cake.

(f) The cut AAC green cakes are autoclaved at 180°C under saturated vapour pressure (1.1 MPa) for about 6 hours. A hydrothermal reaction between the silicate and calcareous materials yields Tobermorite, which adds high strength to the AAC panel.

1.2 Yields and productivity improvement in AAC manufacturing

Thus, the manufacture of AAC panels consists of many different processes. Therefore, the required management items for productivity improvement and yield are very abundant. In particular, the foaming process and the hardening process are the most important with respect to the yield. In the foaming process, when the viscosity of the AAC slurry rises suddenly, the “cavity” (Fig. 2) is formed close to the reinforcing steel, and the bending strength of the AAC panel lowers.

![Fig. 1. Foaming Process of the AAC slurry.](image1)

![Fig. 2. Cavity of the AAC panel caused by the rapid rise of viscosity of the AAC slurry.](image2)
Table 1. The Comparison of Curing Condition and Mixture of AAC and Standard Concrete

<table>
<thead>
<tr>
<th></th>
<th>AAC</th>
<th>general concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>The mixture of main raw material (wt %)</td>
<td>Cement 33, Silicaste 53 Lime 7, Gypsum 7</td>
<td>Cement 16, Fine aggregate 38 Coarse aggregate 46</td>
</tr>
<tr>
<td>The water ratio</td>
<td>Water/Total solid 0.65 Water/Cement 2.0</td>
<td>Water/Total solid 0.09 Water/Cement 0.55</td>
</tr>
<tr>
<td>The curing temperature (°C)</td>
<td>The initial stage 40-50 After several hours 70-80</td>
<td>About 10-30 (influenced by the ambient temperature)</td>
</tr>
</tbody>
</table>

On the green cake, control of the hardness is very important. The green cake decays under handling when the hardness is too low. Inversely, cutting by the piano wire becomes impossible when the hardness is too high. On the other hand, the shortening in hardening time is required for productivity improvement. The hydration reaction of cement and quicklime affects the rise viscosity of the slurry and hardening of the AAC green cake. In particular, the cement that is used most the AAC raw material, and the effect which the characteristic provided is also the greatest.

1.3 Background of research

Though the characteristic of the cement for AAC is very important, no research has yet been carried out.

The authors aimed at the development of a cement suitable for AAC manufacturing by grasping the effect of the cementation properties in the foaming process and the hardening process of AAC.

The condition of the reaction of the cement in the AAC manufacturing is greatly different from that of ordinary mortar and concrete on temperatures, water/cement ratio, mixture systems, etc., as is shown in Table 1.

Therefore, conventional methods of evaluating the cement setting rate including the cement setting test, the cement strength test, and measurement of the hydration heat from plain cement paste at 20°C are not suitable for the cement used for the AAC. Fig. 3 shows the concept of the reaction profile of the cement required for AAC manufacturing. The required characteristic as based on the following:

(a) The rise in viscosity during the foaming process (by about 1 hour after the pouring) is low.
(b) The hardening time (by about 3-4 hours after pouring) until the piano wire cutting becomes possible is short. The productivity lowers when the hardening time is too long.
(c) The time in which the cutting is possible, the cuttable time, is long (the nominal 60 minute requirement). Cutting by the piano wire becomes impossible when the hardening advances rapidly, and the degree of freedom of production lowers.

1.4 Development of Cement for AAC

For the characteristic of which the above are required, the following was evaluated:

(a) The viscosity of the AAC slurry until the foaming ends from the pouring (about 60 minutes after the pouring).
(b) The curing time to the optimum hardness in the piano wire cutting (about 3-4 hours after pouring).
(c) The time to retain the hardness in which the cutting is possible (for 3-5 hours after pouring).

For the development of the cement for the AAC manufacturing of Fig. 3, the following two plans were considered:

(a) The curing time is shortened by using high-early-strength cement (HC) clinker with many tricalcium silicate (C₃S) quantities, while the viscosity during the foaming process of the AAC slurry is lowered by lowering the fineness. By lowering the fineness, rapid progress of the hydration reaction is suppressed, and the cuttable time is ensured.
(b) The curing time is shortened by increasing the fineness, while the viscosity during the foaming process of the AAC slurry is held low using a medium heat (MC) clinker with small C₃S quantities. By decreasing the C₃S quantity, the progress of the rapid hydration reaction is suppressed, and the cuttable time is ensured.

From an economical viewpoint in the production of the cement, it is disadvantageous with respect to cost increase the fineness in (b). Thus, (a) should be developed.

In the meantime, Uchikawa et al. have reported on the gypsum type in the cement and the effect of hydration temperature on setting time for the cement paste. The setting time was the order of gypsum, hemihydrate, and anhydrite containing cement from the long side. The setting time was shortened with rising curing temperature within 10-30°C. However, the hydration environments of the cement in the AAC manufacturing are a higher temperature, lime and gypsum coexistence, and high water/cement ratio, as is shown in Table 1. Then, the evaluation as for the AAC manufacturing was carried out on the gypsum type in this study.

A factory scale test of the real operation was also carried out after the characteristic of the cement suitable for AAC was ascertained in the laboratory test.

2. Samples

Table 2 shows the type and sample number of the cement used for laboratory testing. The parameters are fineness (Blaine), hemihydrate/gypsum (H/(H+G)), and C₃S content (NC or HC clinker). The C₃S content of NC and HC is 56 % and 64% respectively.
Table 2. Type and Sample Name of Cement for the Laboratory Test

<table>
<thead>
<tr>
<th>Clinker type (C3S %)</th>
<th>NC (56)</th>
<th>HC (64)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H/(H+G) (%)</td>
<td>Blaine(cm²/g)</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3300</td>
<td>3300</td>
</tr>
<tr>
<td>50</td>
<td>6NC 3300-50</td>
<td>11HC 3300-50</td>
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<tr>
<td>100</td>
<td>2HC 3800-50</td>
<td>5HC 3800-100</td>
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</table>

Table 3. Chemical Composition of Cement for the Laboratory Test

<table>
<thead>
<tr>
<th>NO</th>
<th>Clinker (H%)</th>
<th>Blaine (cm²/g)</th>
<th>H/(H+G) (%)</th>
<th>LOI (%)</th>
<th>insol</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>SO₃</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>Total</th>
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<tr>
<td>1</td>
<td>H/C</td>
<td>3320</td>
<td>50</td>
<td>1.2</td>
<td>0.1</td>
<td>20.1</td>
<td>5.1</td>
<td>2.4</td>
<td>64.6</td>
<td>2.0</td>
<td>3.0</td>
<td>0.20</td>
<td>0.49</td>
<td>99.2</td>
</tr>
<tr>
<td>2</td>
<td>H/C</td>
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<td>50</td>
<td>1.2</td>
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<td>20.1</td>
<td>5.1</td>
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<td>64.6</td>
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<td>0.20</td>
<td>0.49</td>
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</tr>
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<td>3</td>
<td>H/C</td>
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<td>50</td>
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<td>0.1</td>
<td>20.1</td>
<td>5.1</td>
<td>2.4</td>
<td>64.6</td>
<td>2.0</td>
<td>3.0</td>
<td>0.20</td>
<td>0.49</td>
<td>99.2</td>
</tr>
<tr>
<td>4</td>
<td>H/C</td>
<td>3910</td>
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<td>1.5</td>
<td>0.1</td>
<td>20.1</td>
<td>5.1</td>
<td>2.4</td>
<td>64.4</td>
<td>1.9</td>
<td>3.0</td>
<td>0.20</td>
<td>0.49</td>
<td>99.2</td>
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<tr>
<td>5</td>
<td>H/C</td>
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<td>100</td>
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<td>0.1</td>
<td>20.2</td>
<td>5.1</td>
<td>2.4</td>
<td>64.9</td>
<td>2.0</td>
<td>3.0</td>
<td>0.20</td>
<td>0.49</td>
<td>99.2</td>
</tr>
<tr>
<td>6</td>
<td>NC</td>
<td>3310</td>
<td>50</td>
<td>1.1</td>
<td>0.2</td>
<td>20.6</td>
<td>5.4</td>
<td>2.7</td>
<td>64.3</td>
<td>1.5</td>
<td>3.0</td>
<td>0.24</td>
<td>0.37</td>
<td>99.4</td>
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</table>


Table 4. Mineralogical Composition of Cement for the Laboratory Test

<table>
<thead>
<tr>
<th>NO</th>
<th>H.M.</th>
<th>S.M.</th>
<th>I.M.</th>
<th>A.I.</th>
<th>L.S.D.</th>
<th>C₃S (%)</th>
<th>C₃S</th>
<th>C₃A</th>
<th>C₆AF</th>
<th>CaSO₄</th>
<th>Total</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>2.27</td>
<td>2.68</td>
<td>2.15</td>
<td>3.93</td>
<td>0.978</td>
<td>64.0</td>
<td>9.4</td>
<td>9.5</td>
<td>7.2</td>
<td>5.1</td>
<td>95.3</td>
</tr>
<tr>
<td>2</td>
<td>2.27</td>
<td>2.68</td>
<td>2.15</td>
<td>3.93</td>
<td>0.978</td>
<td>64.0</td>
<td>9.4</td>
<td>9.5</td>
<td>7.2</td>
<td>5.1</td>
<td>95.3</td>
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<tr>
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<td>64.0</td>
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<td>7.2</td>
<td>5.1</td>
<td>95.3</td>
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<tr>
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<td>2.27</td>
<td>2.68</td>
<td>2.15</td>
<td>3.93</td>
<td>0.978</td>
<td>63.8</td>
<td>9.3</td>
<td>9.5</td>
<td>7.2</td>
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<td>2.68</td>
<td>2.15</td>
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<td>64.2</td>
<td>9.4</td>
<td>9.6</td>
<td>7.3</td>
<td>5.1</td>
<td>95.6</td>
</tr>
<tr>
<td>6</td>
<td>2.16</td>
<td>2.54</td>
<td>1.97</td>
<td>3.83</td>
<td>0.942</td>
<td>56.0</td>
<td>17.0</td>
<td>9.7</td>
<td>8.3</td>
<td>5.1</td>
<td>96.1</td>
</tr>
</tbody>
</table>

Table 5. Chemical Composition of Gypsum and Lime for the Laboratory Test

<table>
<thead>
<tr>
<th>Sample</th>
<th>LOI(%)</th>
<th>insol.</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>SO₃</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime</td>
<td>3.49</td>
<td>0.25</td>
<td>0.66</td>
<td>0.41</td>
<td>0.11</td>
<td>93.72</td>
<td>0.76</td>
<td>0.08</td>
<td>0.01</td>
<td>0.02</td>
<td>99.51</td>
</tr>
<tr>
<td>Gypsum</td>
<td>19.84(H₂O)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>32.53</td>
<td>0.00</td>
<td>46.68</td>
<td>0.00</td>
<td>0.00</td>
<td>99.06</td>
<td></td>
</tr>
</tbody>
</table>

Hemihydrate was prepared by heating and dehydrating natural gypsum used the actual cement manufacturing process. It was confirmed that all gypsum became hemihydrate by powder X-ray diffraction. The gypsum that changed H/(H+G) was added so that the SO₃ quantity in the cement became the clinker with 3.0 weight %, and it was smashed to a fixed fineness using the test mill. Tables 3 and 4 show the chemical and mineralogical composition of cement used for the laboratory test, respectively.

2.2 Other raw materials
Quick lime and gypsum, used in the AAC factory, were used as calcareous materials other than cement. Table 5 shows the results of chemical analysis and fineness measure of the quick lime and gypsum. Gypsum was the industry by-product.

The natural quartz sand (SiO₂ 93%, Blaine 3500 cm²/g), which was ground by the ball mill at the AAC factory, was used.

A recycling material, which crushed AAC after autoclave curing, in addition to carrying out in usual AAC manufacturing process.

3. Methods
3.1 Compositions and preparation of AAC slurry
Table 6 shows the composition of the AAC slurry. Those materials beside metallic aluminum powder were mixed and agitated mechanically for 2 minutes at 45°C. Metallic aluminum powder was added to the mixture, which was further agitated for 30 seconds to yield the AAC slurry.

3.2 Measurement of viscosity of AAC slurry during the foaming process
For measurement of the viscosity during the foaming process, it was necessary that the rotor avoids the buoyancy effect caused by foaming. In addition, it is necessary to lower the rotational frequency as low as possible so that it does not destroy the bubble structure. For the viscometer which satisfied these conditions, Rheocal type HBT + and spindle number SC4-21 of Brookfield Co., LTD., were chosen (Fig. 4). It is possible that this viscometer measures at a very slow rotational frequency of 0.1 rpm. Moreover, the shape of the spindle exhibits very little buoyancy. 400 cm³ of AAC slurry was poured into a stainless beaker (1000 cm³); and the viscosity change during the foaming process for 60 minutes was measured. Simultaneously, the change in foaming height of the AAC slurry for 60 minutes was measured using laser displace-
Table 6. Mixture Proportion of AAC

<table>
<thead>
<tr>
<th>Cement(%)</th>
<th>Silica stone(%)</th>
<th>Lime(%)</th>
<th>Gypsum(%)</th>
<th>Recycled material(%)</th>
<th>Al powder(%)</th>
<th>Water/Total solid</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>40</td>
<td>5</td>
<td>5</td>
<td>25</td>
<td>0.06</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Fig. 4. The viscometer for the measurement of the viscosity during the foaming process of the AAC slurry (Rheocalc type HB3+ and spindle number SC4-21 of Brookfield CO., LTD.).

Fig. 5. The ball test equipment for the measurement of the hardness of the AAC green cake.

ement gauge (KEYENCE LB300). The foaming height was converted into foaming height rate, which made the last foaming height 100%.

3.3 Measurement of the hardness of AAC green cake

The measurement of the hardness of the AAC green cake must be quickly and conveniently carried out in order to ascertain the timing of the de-mold and cutting by the piano wire in continuous manufacturing. This is because the hardness change is much more rapid than standard mortar and concrete.

Next, the ball test, which measures the diameter of the depression as the steel ball (41 mm in diameter and 86 g in weight) is dropped from a height of 50 mm above the upper plane of the AAC green cake, shown in Fig. 5, has been adapted.

The hardness of the AAC green cake was measured by the ball test at 15-minute intervals from 2 to 5 hours after the pouring.

4. Results and discussion

4.1 Viscosity of AAC slurry in forming process

Since the water ratio (the volume ratio) of the AAC slurry decreases by foaming, the viscosity of the AAC slurry during the foaming process rises. Simultaneously, the viscosity of the AAC slurry rises by the hydration of cement and quicklime. It is necessary to lower the viscosity change of the AAC slurry during the foaming process in order to avoid the generation cavities (Fig. 2). Here, the characteristic effect of the cement on the viscosity of the AAC slurry, namely C2S content (NC and HC), Blaine and H/ (H + G), is ascertained.

Figure 6 shows the viscosity change during the foaming process of the AAC slurry using 6NC (C2S 56%) and 1HC (C2S 64%) in which the C2S content differs. The change in the viscosity of 6NC and 1HC is almost equal. From this, it can be observed that the C2S content does not influence the viscosity of AAC slurry during the foaming process.

Figure 7 shows the viscosity change during the foaming process of the AAC slurry using 1HC, 2HC, and 3HC in which Blaine differs. These viscosity changes are almost equal, and the Blaine does not influence the viscosity of the AAC slurry in the foaming process either.
Figure 8 shows the viscosity change during the foaming process of the AAC slurry using 4HC, 2HC, and 5HC in which \(H/(H+G)\) differs. The viscosity change of 5HC (\(H/(H+G)=100\%\)) and 2HC (\(H/(H+G)=50\%\)) is almost equal, and 4HC (\(H/(H+G)=0\%\)) is even higher than these values.

4.2 Hardness (ball test) of AAC green cake

The range of the hardness (the ball test value) in which cutting by the piano wire is possible is within 26-21 mm. In addition, the optimum ball test value is 24 mm. The characteristic effect of the cement, C₅S content (56% of NC and 64% of HC), fineness (Blaine) and \(H/(H+G)\) on the hardening time for the ball test value of 24 mm and the cuttable time within the ball test value 26-21 mm of the AAC green cake.

Figure 9 shows the change in the ball test value with time of 6NC and 1HC. The hardening of the AAC green cake of 1HC is more rapid than that of 6NC. Figure 10 shows the relationship between the C₅S content and hardening time for 24 mm of the ball test value. Hardening of the AAC green cake is more rapid, when the Blaine is same, as the C₅S content is higher.

Figure 11 shows the change of the ball test value with time of 1HC, 2HC, and 3HC. Hardening is 3HC, 2HC and 1HC in the quickest order. Figure 12 shows the relationship between Blaine and hardening time to 24 mm of the ball test value. Hardening of the AAC green cake is more rapid when the C₅S content is same, as the Blaine is higher.

Figure 13 shows the change of the ball test value with time of 4HC, 2HC, and 5HC. Hardening is 4HC, 2HC and 5HC in the quickest order. Figure 14 shows the relationship between \(H/(H+G)\) and hardening time for 24 mm of the ball test value. Hardening of the AAC green cake is more rapid in HC than in HC.
when the Blaine and C₃S content are same, as the H/(H + G) is lower.

4.3 Ideal cement for AAC manufacturing

**Figure 15** shows the comparison of hardening time (for the ball test value 24 mm) and cuttable time (within 26–21 mm) of each type of cement. With regards to the hardening process of AAC, 2HC is the most ideal as cement for AAC, when curing time within 3 hours and cuttable time over 60 minutes are set as conditions. In the meantime, it is desirable that H/(H + G) is over 50% with regards to AAC slurry viscosity during the foaming process. Since cuttable time shortens on Blaine 4300 cm²/g and H/(H + G) = 0% these values are not desirable. From this, the ideal characteristic of cement for AAC manufacturing is summarized as follows:

(a) HC with many C₃S (64%) used for a base.

(b) The Blaine is desirable around 3800 cm²/g, which is lower than 4300 cm²/g for general high-early-strength cement. Though this condition is suitable for our present plant, it can be adapted by changing only the Blaine, when the demands in hardening time are different.

(c) Hemihydrate and gypsum are coexistent. In addition, hemihydrate is more desirable, as it is more abundant. We called this cement for AAC “the TBS cement” (TBS). TBS is an abbreviation of “Tei Blaine Soukyou” in Japanese. Tei and Soukyou mean low and high-early-strength, respectively. Full scale factory testing was carried out, and the adaptability of TBS discerned.

4.4 Factory scale test

TBS with characteristics shown in **Tables 7 and 8** was produced at Sumitomo Osaka Cement Co., LTD. Using this TBS, the AAC manufacturing test was carried out at Sumitomo Metal Mining Siporex Co., LTD. The characteristics of conventional NC in the comparison is also shown in Tables 7 and 8. Other raw materials, pouring temperatures, and evaluation items were the same as in the case of the laboratory test.

**Figure 16** shows the viscosity change during the foaming process of the AAC slurry using TBS and NC. The viscosity of TBS and NC was almost equivalent, and the result of the laboratory test were reproduced.

**Figure 17** shows the change of the ball test value with time for TBS and NC. On the time of arrival for the ball test value of 24 mm, NC was 3 h–45 m, and TBS was 2 h–45 m. In short, the hardening time to the ball test value of 24 mm was short-

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**Table 7. Chemical Composition of Cement for the Factory Scale Testing**

<table>
<thead>
<tr>
<th>NO.</th>
<th>Clinker</th>
<th>Blaine (cm²/g)</th>
<th>H/(H+G) (%)</th>
<th>ig. loss (%)</th>
<th>insol.</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>SO₃</th>
<th>Na₂O</th>
<th>K₂O</th>
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<tbody>
<tr>
<td>TBS</td>
<td>HC</td>
<td>3880</td>
<td>50</td>
<td>0.9</td>
<td>0.1</td>
<td>19.9</td>
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<td>64.6</td>
<td>1.6</td>
<td>2.9</td>
<td>0.16</td>
<td>0.63</td>
<td>99.2</td>
</tr>
<tr>
<td>NC</td>
<td>NC</td>
<td>3220</td>
<td>75</td>
<td>0.6</td>
<td>0.1</td>
<td>21.6</td>
<td>5.6</td>
<td>2.9</td>
<td>64.4</td>
<td>1.4</td>
<td>2.3</td>
<td>0.28</td>
<td>0.56</td>
<td>99.7</td>
</tr>
</tbody>
</table>

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**Table 8. Mineralogical Composition of Cement for the Factory Full Scale Testing**

<table>
<thead>
<tr>
<th>NO.</th>
<th>H.M.</th>
<th>S.M</th>
<th>I.M.</th>
<th>L.S.D</th>
<th>C₃S</th>
<th>C₂S</th>
<th>C₃A</th>
<th>C₂AF</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TBS</td>
<td>2.21</td>
<td>2.37</td>
<td>1.90</td>
<td>0.97</td>
<td>62.3</td>
<td>10.1</td>
<td>9.7</td>
<td>8.8</td>
<td>90.1</td>
</tr>
<tr>
<td>NC</td>
<td>2.09</td>
<td>2.54</td>
<td>1.93</td>
<td>0.91</td>
<td>49.6</td>
<td>24.6</td>
<td>9.9</td>
<td>8.8</td>
<td>92.9</td>
</tr>
</tbody>
</table>
ened by TBS in 1 hour (27%) for NC. For the cuttable time, NC and TBS were 1 h–30 m and 1 h–10 m, respectively. Though it shortened in TBS in 20 minutes, there are no problems during operation, since over 1 hour has been ensured.

4.5 Discussion

C₃S content (between 50% to 64%) and Blaine do not influence the viscosity of the foaming process, however H/(H + G) does (Figs. 6, 7 and 8). The viscosity of the AAC slurry rose when H/(H + G) was 0% (namely, only gypsum). Ordinary cement paste tends to be different in that the setting time is retarded by gypsum. With regards to this, C₃A reactivity and SO₄²⁻ concentration in the solution seem to be related [2]. The solubility of hemihydrate in water at ordinary temperatures is higher than that of gypsum. This setting time for standard cement paste shortens in the case of hemihydrate because it reprecipitates as gypsum by hemihydrate dissolving. In the meantime, C₃A reactivity in the AAC slurry is higher than that for standard cement paste, since the temperature is higher as is shown in Table 1. Therefore, in the AAC slurry, C₃A early hydration is active, and the calcium aluminate hydrate is easily formed. The precipitation of the ettringite on the C₃A particle surface is insufficient when only gypsum, for which the solubility is low in the cement, is included, and the AAC slurry viscosity appears to rise. Though the gypsum is also used as a raw material in AAC (shown Table 4), it does not seem to contribute to the generation of the ettringite on the C₃A surface. The grain size of gypsum for the raw material of AAC is comparatively large (50–150 μm), since it is used without grinding. The viscosity change of the foaming process of AAC slurry is mainly related to the hydration of C₃A, and C₃S and Blaine are related to subsequent hardening process.

On hardening, it was proven that C₃S, Blaine, and gypsum type influenced all factors (Figs. 10, 12 and 14). The contribution of C₃S seems have large influence on hardening, because the hardening of the AAC green cake quickens as the C₃S content rate is rises. The effect of C₃S and Blaine on hardening can be easily understood from the viewpoint of the cement chemistry. With regards to the gypsum type, the generation of the ettringite seems to be related, as well as the effect on the AAC slurry viscosity. With regards to the gypsum type, the hardening quickens as H/(H + G) lowers. As well as the effect on the AAC slurry viscosity, the generation of the ettringite seems to be related to this. Interstitial material (C₃A, C₄AF) adheres to each mineral (C₃S, C₃S) without separating in simple substances in ground cement particles. It is supposed that the precipitation of the ettringite on the C₃S surface also becomes inadequate and that the induction period shortens. Figure 18 shows the relationship between hardening time of the AAC green cake and cumulative heat of hydration of the cement measured using a twin conduction calorimeter using the method developed by the authors. These are almost linear in relationship. In 4HC, 2H, and 5HC in which H/(H + G) differs, the heat quantity increases, as H/(H + G) is lower. It has been proved that the hydration of the cement is accelerated in gypsum.

5. Conclusion

The following results were obtained when the adaptability as cement for AAC was studied by the change of C₃S content rate, Blaine, and H/(H + G).

5.1 Effect of characteristics of cement in the manufacturing process of AAC

The effect of the characteristics of the cement on the viscosity of the AAC slurry and the hardness of the AAC green cake are as follows.

(a) C₃S content and Blaine do not influence the viscosity during the foaming process, however hemihydrate/gypsum does.

(b) The viscosity of the AAC slurry rose, in the case where H/(H + G) was 0%.

(c) The hardening quickens when C₃S is more abundant.

(d) The hardening quickens when the Blaine is higher. On the other hand, the cuttable time shortens when the Blaine is higher.

(e) The hardening quickens when H/(H + G) is lower.

5.2 Effect of type of gypsum on viscosity and hardening

The effect of the type of gypsum on viscosity and hardening was considered as follows.

(a) Since the temperature is higher than standard cement paste, C₃A reactivity in the AAC slurry is high. Therefore, in the AAC slurry, early C₃A hydration is very active, and the calcium aluminate hydrate is easily being formed.

(b) In the gypsum of which low solubility, the ettringite deposited on the cement particles (C₃A, C₃S) is insufficient. Therefore, the viscosity of the AAC slurry rises, the induction period of the cement shortens, and the hardening of the AAC green cake quickens.

5.3 Characteristics of cement for manufacturing of AAC

Characteristics of the cement suitable for the manufacturing of AAC are as follows.

(a) HC with much C₃S is made as a base for acceleration of the hardening process.

(b) The Blaine is desirable around 3800 cm²/g which is low-
er than 4300 cm$^2$/g for general high-early-strength cement. The cuttable time is lengthened, as the Blaine is lower, and the degree of freedom of production is ensured.

(c) Hemihydrate and gypsum are coexistent. In addition, hemihydrate is more desirable, as it is more abundant. The generation of cavity damage is suppressed by lowering the viscosity change during the foaming process.

We called the cement for AAC the “TBS” cement. By conducting a factory test of TBS, the adaptability for AAC was confirmed. Table 9 shows a representative example of the characteristics of TBS.

<table>
<thead>
<tr>
<th>Item</th>
<th>TBS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinker type (C:S %)</td>
<td>64%</td>
</tr>
<tr>
<td>H/(H+G) (%)</td>
<td>50%&lt;</td>
</tr>
<tr>
<td>Blaine (cm$^2$/g)</td>
<td>3800</td>
</tr>
</tbody>
</table>

References