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Improvement of Durability of Concrete by Granulated Blast Furnace Slag Sand

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ABSTRACT

Concrete with granulated blast furnace slag sand has high resistance to freezing and thawing attack without AE agent. However, when rapid hardening portland cement is used, long term curing period is necessary to obtain the effect by granulated blast furnace slag sand. In this paper, it will be shown that ground granulated blast furnace slag and thíckening agent is useful in order to get the effect of granulated blast furnace slag sand at early age. Not only resistance to freezing and thawing attack but also resistance to scaling can be improved by granulated blast furnace slag sand. But, steam curing stunts the improvement of resistance to scaling.

INTRODUCTION

Precast factory concrete member manufactured by pre-tensioning method is required high strength at early age for applying prestressed stress. Ordinary, rapid hardening portland cement is used for binder and steam curing is applied. After steam curing, precast concrete member is put on the air. Normally, it is not cured in moisture condition for long time.

It has been clarified that resistance to freezing and thawing of concrete is deteriorated by steam curing. Because the air in fresh concrete is warmed by the heat of steam and expanded. The expanded air joins each other. The size of joined air becomes bigger and the bigger buoyant force is generated. The air with buoyant force floats up and goes outside. The air by AE agent vanishes in the concrete and the effect of AE agent is lost. On the other hand, when granulated blast furnace slag is used as concrete sand, resistance to freezing and thawing can be improved without AE agent [Ayano and Fujii 2014]. So, even if concrete member is cured by stream, the resistance to freezing and thawing of factory products can be gained.

Not only resistance to freezing and thawing attack but also enough resistance to scaling is obtained when most amount of sand is granulated blast furnace slag sand even if AE agent is not used. The effect of granulated blast furnace slag sand depends on the type of cement. When ordinary portland cement or portland blast-furnace cement is used, high resistance to freezing and thawing attack can be obtained at relatively young age. However, high resistance to freezing and thawing attack can not be obtained at early age when rapid hardening portland cement is used. It is shown in this paper that the resistance to freezing and thawing of concrete with rapid hardening portland cement at early age can be improved by ground granulate blast furnace slag or thickening agent.

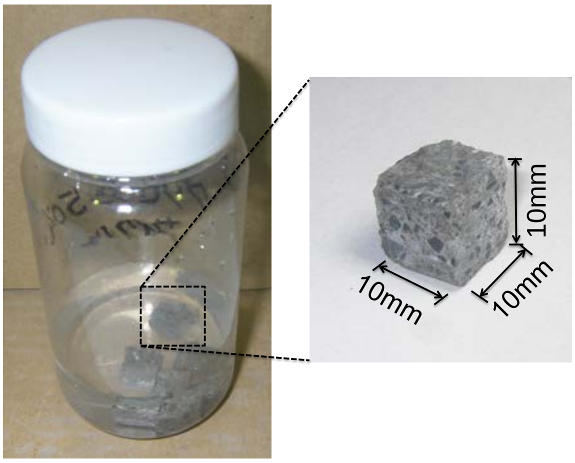


Figure 1. Freezing and thawing test using small size mortar specimen

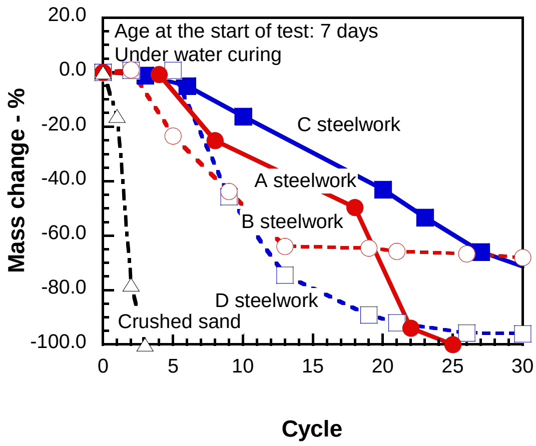


Figure 2. Freeze-thaw resistance of mortal with GBFS sand manufactured in 4 ironworks

EXPERIMENTAL INVESTIGATION

Materials, mix proportions and curing method

Ordinary portland cement (density: 3.15 g/cm^3, Blaine fineness: 3,350 cm^2/g), rapid hardening portland cement (density: 3.13 g/cm^3, Blaine fineness: 4,600 cm^2/g), and ground granulated blast furnace slag (density: 2.89 g/cm^3, Blaine fineness: 4,150 cm^2/g) are used as binder. As a fine aggregate, crushed sandstone sand (density in saturated surface dry condition: 2.64 g/cm^3, water absorption: 2.00 %, finess: 2.93) and granulated blast furnace slag sand (density in saturated surface dry condition: 2.77 g/cm^3, water absorption: 0.69 % finess: 2.32) are used.

The quality of granulated blast furnace slag sand was examined by using 10 by 10 by 10 mm cubic mortar shown in Figure 1[Oyamada et. 2011]. Every specimen exposed to -17 degrees Celsius for 16 hours and 20 degrees Celsius for 8 hours alternately by 30 cycles in salty water. The concentration of salty water is 10 % by mass. Figure 2 shows the results of granulated blast furnace slag manufactured in four different factories. The quality of granulated blast furnace slag is judged to be better when the mass loss is less. In this experiment, granulated blast furnace slag manufactured at Factory-A shown by ● is used.

As a coarse aggregate, crushed sandstone (maximum size: 20 mm, density in saturated surface dry condition: 2.75 g/cm^3, water absorption: 0.56 %) is used. The polycarboxylate type of high range water reducing agent, air entraining agent, de-forming agent and alkyl aryl sulfonate and alkylammonium salt type of thickening agent are used as the additional agent.

The designed slump of concrete is 21 cm, while the unit of water content of concrete is 175 kg/m^3. The water to binder ratios of the concrete is a fixed constant of 35% for every mixture. The mix proportions of concrete are shown in Table 1 and Table 2. Table 1 and Table 2 are for ordinary portland cement and rapid hardening Portland cement. The dosage of AE agent for concrete with granulated blast furnace slag sand is zero.

Two types of specimen were used. One concrete specimen was cured in water at 20 degrees Celsius. The other concrete specimen was cured by steam before de-mold.

Table 1. Mixture proportion of concrete with ordinary portland cement

<table>
<tr><th rowspan="3">Type</th><th rowspan="3">W/B (%)</th><th rowspan="3">GGBF/B (%)</th><th rowspan="3">Air (%)</th><th rowspan="3">s/a (%)</th><th colspan="5">Unit content(kg/m^3)</th><th rowspan="3">HRWRA (B×%)</th><th rowspan="3">DF (B×%)</th><th rowspan="3">TA (B×%)</th></tr>
<tr><th rowspan="2">W</th><th colspan="2">B</th><th rowspan="2">GBFSS</th><th rowspan="2">G</th></tr>
<tr><th>OPC</th><th>GGBFS</th></tr>
<tr><td>N0T</td><td rowspan="10">35</td><td>0</td><td rowspan="10">2.0</td><td>42.2</td><td rowspan="10">175</td><td>500</td><td>0</td><td>755</td><td rowspan="10">1,027</td><td rowspan="10">0.5</td><td rowspan="10">0.01</td><td rowspan="5">0.08</td></tr>
<tr><td>N15T</td><td>15</td><td>42.0</td><td>425</td><td>75</td><td>750</td></tr>
<tr><td>N30T</td><td>30</td><td>41.8</td><td>350</td><td>150</td><td>744</td></tr>
<tr><td>N45T</td><td>45</td><td>41.6</td><td>275</td><td>225</td><td>738</td></tr>
<tr><td>N60T</td><td>60</td><td>41.4</td><td>200</td><td>300</td><td>732</td></tr>
<tr><td>N0</td><td>0</td><td>42.2</td><td>500</td><td>0</td><td>755</td><td rowspan="5">0.00</td></tr>
<tr><td>N10</td><td>10</td><td>42.1</td><td>450</td><td>50</td><td>751</td></tr>
<tr><td>N20</td><td>20</td><td>41.9</td><td>400</td><td>100</td><td>748</td></tr>
<tr><td>N30</td><td>30</td><td>42.2</td><td>350</td><td>150</td><td>744</td></tr>
<tr><td>N40</td><td>40</td><td>41.7</td><td>300</td><td>200</td><td>740</td></tr>
</table>

OPC: Ordinary Portland cement, GGBFS: Ground granulated blast furnace slag, GBFSS: Granulated blast furnace slag sand, HRWRA: High-range water reducing agent, DF: De-forming agent, TA: Thickening agent

Table 2. Mixture proportion of concrete with rapid hardening portland cement

<table>
<tr><th rowspan="3">Type</th><th rowspan="3">W/B (%)</th><th rowspan="3">Air (%)</th><th rowspan="3">s/a (%)</th><th colspan="6">Unit content (kg/m^3)</th><th rowspan="3">AE (B×%)</th><th rowspan="3">HRWRA (B×%)</th><th rowspan="3">DF (B×%)</th><th rowspan="3">TA (B×%)</th></tr>
<tr><th rowspan="2">W</th><th colspan="2">B</th><th colspan="2">S</th><th rowspan="2">G</th></tr>
<tr><th>HPC</th><th>GGBFS</th><th>CS</th><th>GBFSS</th></tr>
<tr><td>HN</td><td rowspan="5">35</td><td>4.5</td><td>39.8</td><td rowspan="2">155</td><td rowspan="2">443</td><td rowspan="3">0</td><td>682</td><td>0</td><td rowspan="2">1,086</td><td>0.01</td><td rowspan="2">0.8</td><td>0.00</td><td>0.00</td></tr>
<tr><td>H0T1</td><td rowspan="4">2.0</td><td rowspan="4">42.0</td><td rowspan="4">0</td><td>795</td><td rowspan="4">0.00</td><td>0.01</td><td rowspan="2">0.04</td></tr>
<tr><td>H0T2</td><td rowspan="3">153</td><td>437</td><td>797</td><td>1,056</td><td>0.6</td><td rowspan="3">0.02</td></tr>
<tr><td>H10</td><td>393</td><td>44</td><td>796</td><td>1,055</td><td>0.5</td><td rowspan="2">0.00</td></tr>
<tr><td>H20</td><td>349</td><td>88</td><td>794</td><td>1,053</td><td>0.4</td></tr>
</table>

HPC: Rapid hardening portland cement, GGBFS: Ground granulated blast furnace slag, CS: Crushed sand, GBFSS: Granulated blast furnace slag sand, AE: Air entrained agent, HRWRA: High-range water reducing agent, DF: De-forming agent, TA: Thickening agent

Experiment on the resistance to freezing and thawing action of concrete

100 by 100 by 400 mm prism concrete specimens were used. The experiment on the resistance to freezing and thawing attack of concrete followed the guidelines of JIS A 1148: 2010 (Method A) (Japanese Industrial Standards Committee 2010). However, salt water was used for freezing and thawing test. The specimens were alternately exposed to -18 °C and 5 °C in salt water of 10% concentration to the solution by mass every 5 hours. Resistance to freezing and thawing attack was judged by the relative dynamic modulus of elasticity. Resistance to scaling was judged by the mass loss.

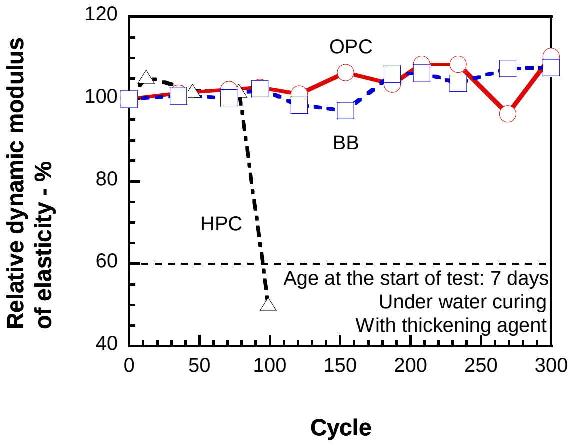


Figure 3. Effect of type of cement on freeze-thaw resistance of concrete with GBFS sand showed by relative dynamic modulus of elasticity (age at the start of test: 7 days)

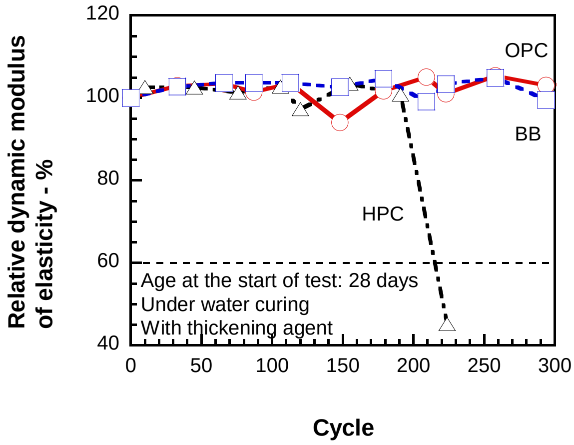


Figure 4. Effect of type of cement on freeze-thaw resistance of concrete with GBFS sand showed by relative dynamic modulus of elasticity (age at the start of test: 28days)

The mass loss shown in this figure is obtained from the following equation.

$$W_n = \frac{w_0 - w_n}{w_0} \times 100 \quad (1)$$

where, W_n: mass loss at n cycle of freezing and thawing (%), w_0: the initial mass of the specimen before test (kg), w_n the mass of the specimen at n cycle of freezing and thawing (kg)

Durability factor is defined as following equation;

$$DF = \frac{P \times N}{M} \quad (2)$$

where, DF: durability factor, P: the relative dynamic modulus of elasticity at N cycles of freezing and thawing (%), N: the number of cycles at which P reaches the specified minimum value for discontinuing the test (60 percent in this paper) or the specified number of cycles at which the test is to be terminated (usually 300 cycles), whichever is less, M: specified number of cycles at which the exposure is to be terminated (300 in this paper). The concrete is judged to be good when durability factor is over 60.

RESULTS AND DISCUSSIONS

Effect of type of cement and curing period

Figure 3 shows the effect of type of cement on the resistance to freezing and thawing attack of concrete with granulated blast furnace slag sand. OPC and HPC are the result of concrete with ordinary portland cement (shown in N0T of Table 1) and rapid hardening portland cement (shown in H0T1 of Table 2), respectively. BB is the result of concrete with 55 % of ordinary portland cement and 45 % ground granulated blast furnace slag by mass (shown in N45T of Table 1). These concrete are not mixed AE agent. Relative dynamic modulus of elasticity of OPC and BB keeps 100 % till 300 cycles. On the other hand, HPC breaks at 100 cycles. However, the resistance to freezing and thawing attack of HPC can be improved when water curing is longer as shown in Figure 4. Figure 4 shows the result when water curing period is 28 days.

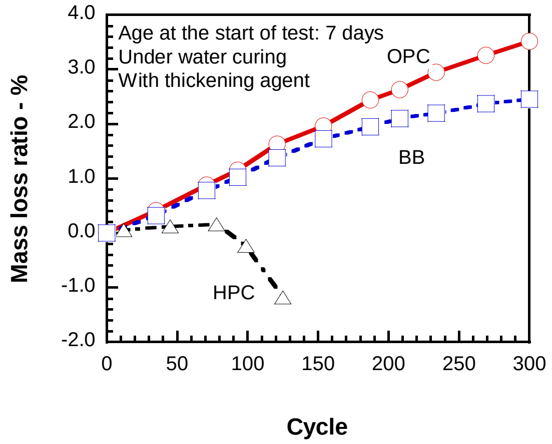


Figure 5. Effect of type of cement on freeze-thaw resistance of concrete with GBFS sand showed by mass loss ratio (age at the start of test: 7 days)

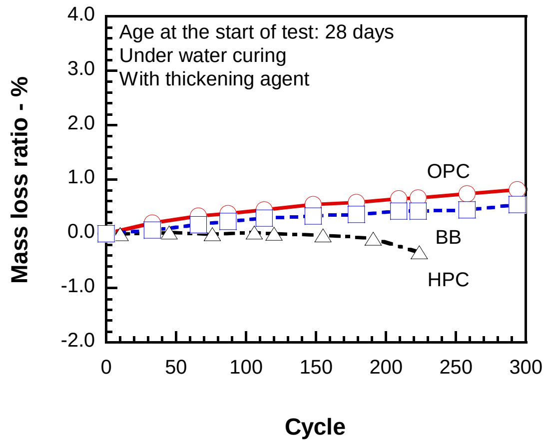


Figure 6. Effect of type of cement on freeze-thaw resistance of concrete with GBFS sand showed by mass loss ratio (age at the start of test: 28 days)

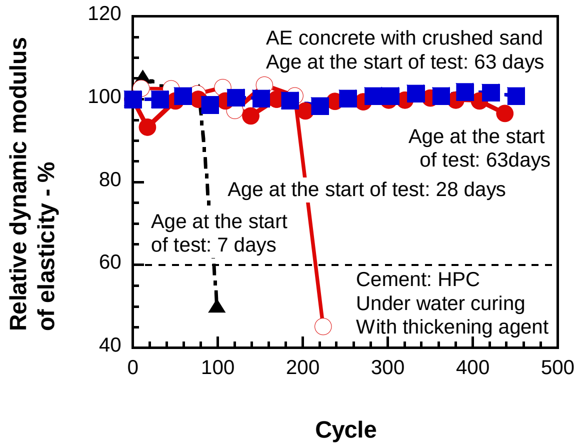


Figure 7. Effect of curing period on freeze-thaw resistance of concrete with HPC and GBFS sand

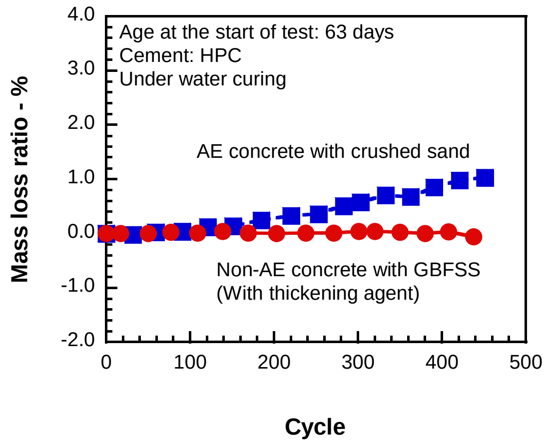
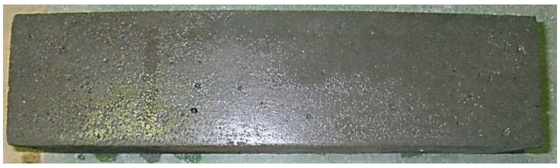


Figure 8. Comparison of mass loss ratio of non-AE concrete with GBFS sand and that of AE concrete with crushed sand

Figure 5 and Figure 6 show the mass loss of concrete shown in Figure 3 and Figure 4, respectively. The mass loss is big when the concrete is damaged by scaling. The mass loss of OPC and BB is about 3 % at 300 cycles when water curing period is 7 days. The mass loss of those concrete is about 1 % at 300 cycles when water curing period is 28 days. Long curing period improves the resistance to scaling. On the other hand, the change of mass of HPC is very small although it breaks earlier than concrete with other binders.

Figure 7 shows the effect of curing period on the resistance to freezing and thawing attack of HPC. For comparison, the result of AE concrete with crushed sand (shown in HN of Table 2) is also shown. When water curing period of HPC is 63 days, the relative dynamic modulus of elasticity keeps 100 % after 300 cycles as well as that of AE concrete with crushed sand. As clear from this figure, long water curing period enhances the resistance to freezing and thawing attack of concrete with rapid hardening portland cement. Figure 8 shows the mass loss of non-AE concrete with granulated blast furnace slag sand and AE concrete with crush sand. The water curing period of both concrete is 63 days and binder is rapid hardening portland cement. The mass loss of non-AE concrete with granulated blast furnace slag sand is



a) GBFS sand (at 468 cycles)

b) Crushed sand (at 451 cycles)

Figure 9. Surface of specimen after freeze-thaw test

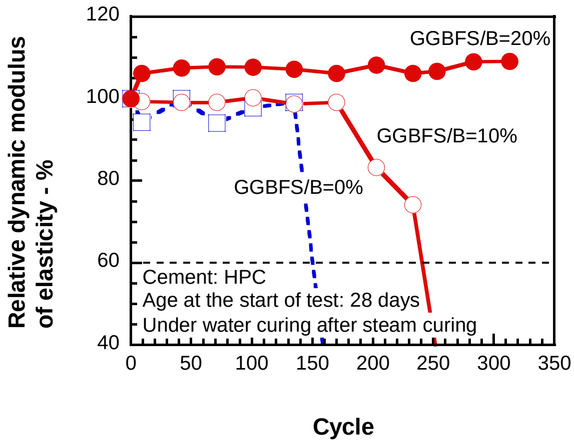


Figure 10. Effect of ground granulated blast furnace slag (GGBFS) on freeze-thaw resistance of concrete shown by relative dynamic modulus of elasticity

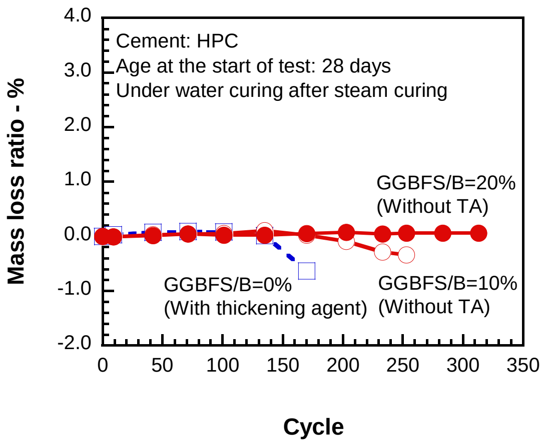


Figure 11. Effect of ground granulated blast furnace slag (GGBFS) on freeze-thaw resistance of concrete shown by mass loss ratio

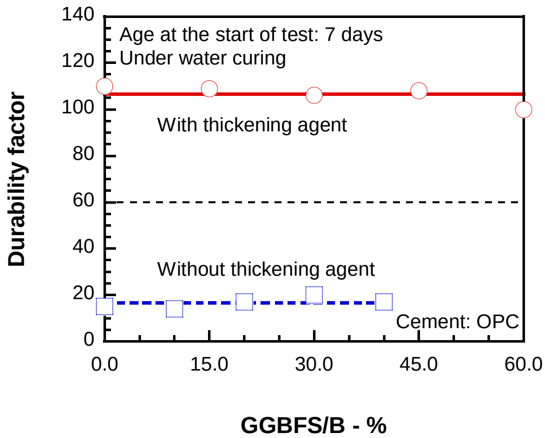


Figure 12. Effect of thickening agent on freeze-thaw resistance expressed by durability factor (age at the start of test: 28 days)

very little. Figure 9 shows the pictures of concrete specimens after test. Apparently, the scaling of AE concrete with crushed sand is much bigger than that of non-AE concrete with granulated blast furnace slag sand.

Effect of ground granulated blast furnace slag and thickening agent

Figure 10 shows the effect of ground granulated blast furnace slag on the resistance to freezing and thawing of concrete with rapid hardening portland cement. These are the result of concrete shown H0T2, H10 and H20 in Table 2. As increasing amount of ground granulated blast furnace slag, the resistance to freezing and thawing attack is improved. When the ratio of ground granulated blast furnace slag to binder is 20 %, the relative dynamic modulus of elasticity keeps 100 % till 300 cycles. Figure 11 shows the mass loss of concrete shown in Figure 10. The mass loss of concrete with rapid hardening portland cement and ground granulated blast furnace slag is very small.

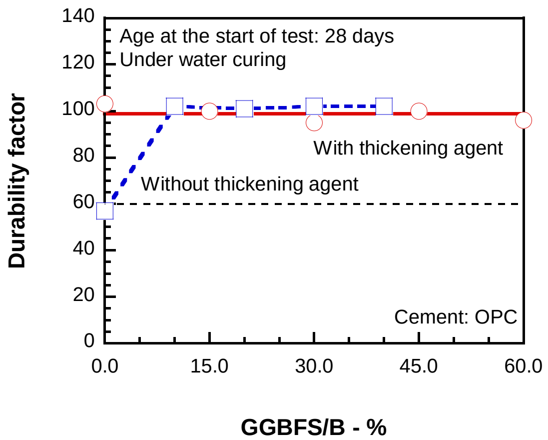


Figure 13. Effect of thickening agent on freeze-thaw resistance shown by durability factor (age at the start of test: 28 days)

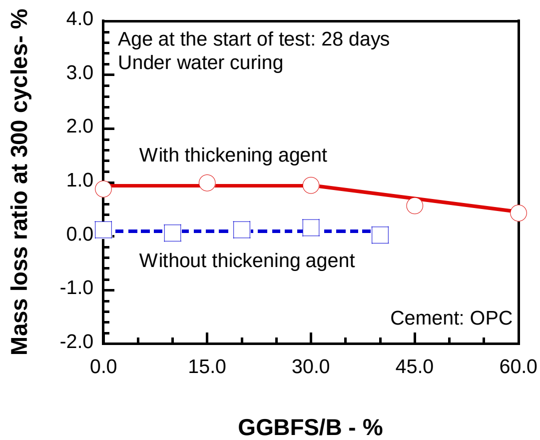


Figure 14. Effect of thickening agent on scaling shown by mass loss ratio

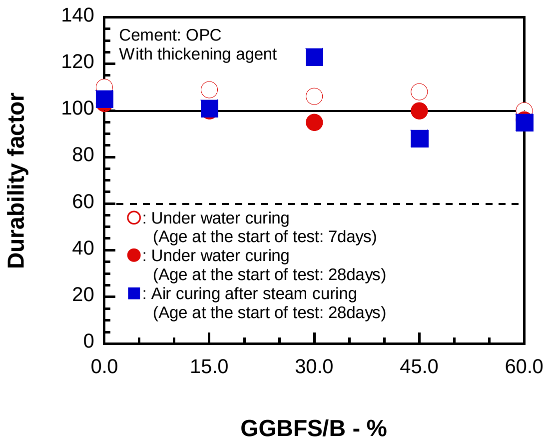


Figure 15. Effect of curing method on freeze-thaw resistance shown by durability factor

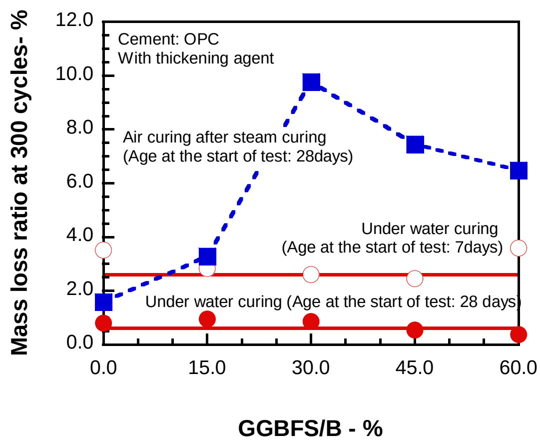


Figure 16. Effect of curing method on resistance to scaling shown by mass loss ratio

Figure 12 shows the effect of thickening agent on the resistance to freezing and thawing of concrete with granulated blast furnace slag sand. These are the result of concrete shown in Table 1. In this result, ordinary portland cement is used for binder. Every concrete is cured in water for 7 days. Durability factor of concrete without thickening agent is low even if ground granulated blast furnace slag is used. However, concrete with thickening agent is improved to be 100 % in Durability factor, irrespective of amount of ground granulated blast furnace slag.

Figure 13 shows the result when concrete is cured in water for 28 days. When water curing period is longer, the effect of thickening agent on resistance to freezing and thawing of concrete seems to be small. However, the mass loss of concrete with thickening agent is bigger as shown in Figure 14. Figure 14 shows the mass loss ratio at 300 cycles. The mass loss of concrete without thickening agent is almost zero, irrespective of amount of ground granulated blast furnace slag. On the other hand, the mass loss of concrete with thickening agent is about 1 %. The thickening agent can improve the resistance to freezing and thawing attack of concrete with young age. However, it deteriorates the scaling of concrete.

Effect of curing method. Figure 15 shows the effect of curing method on resistance to freezing and thawing attack of concrete with granulated blast furnace slag sand. These are the result of concrete shown N0T, N15T, N30T, N45T and N60T in Table 1. In this figure, ○ and ● show the result of concrete cured in water for 7 days and 28 days, respectively. ■ shows the result of concrete cured by steam and in the air till 28 days. Durability factor of all concrete is almost the same. The difference in water curing period, curing method and amount of ground granulated blast furnace slag is very small. However, the mass loss of concrete shown in Figure 16 is dependent on curing method. The mass loss of concrete cured by steam and cured in air till 28 days is biggest. Especially, when concrete cured by steam, the more the amount of ground granulated blast furnace slag, the bigger the mass loss of concrete. The mass loss of concrete cured in water for 28 days is the smallest.

CONCLUSION

The following general conclusions can be drawn from the study provided in the paper:

- When granulated blast furnace slag sand is used, concrete has high resistance to freezing and thawing attack even if AE agent is not used. The scaling of non-AE concrete with granulated blast furnace slag sand is smaller than that of AE concrete with crushed sand.
- The resistance to freezing and thawing attack of concrete with granulated blast furnace slag sand depends on type of cement. Especially, when rapid hardening portland cement is used, resistance to freezing and thawing attack is small at young age.
- The use of ground granulated blast furnace slag and thickening agent is efficient to improve the resistance to freezing and thawing attack of concrete with rapid hardening portland cement at young age.
- Even if concrete with granulated blast furnace slag sand is cured by steam, durability factor is almost 100 %, the scaling of concrete becomes bigger.

ACKNOWLEDGEMENTS

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