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EFFECTS OF MINERAL ADMIXTURES ON STRENGTH CHARACTERISTICS OF CONCRETE MIXED WITH SEAWATER

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Abstract

Studies on strength performance of seawater-mixed concrete have been revealed by several researchers. However, it is still unclear whether seawater-mixing improve strength development of concrete. In this study, strength characteristics of seawater mixed or tap water mixed concrete incorporating mineral admixtures such as Fly Ash and Ground Granulated Blast Furnace Slag were investigated. Concrete cylinder specimens with 40%, 50% and 60% of W/B were prepared. At 24 hours after casting, specimens were demolded and then cured in tap water curing, seawater curing or air curing. After 28-days and 91-days curing, concrete specimens were tested. Results showed that seawater-mixed OPC concrete improved compressive strength up to 91-days compared with tap water mixed in all curing conditions. Moreover, effectiveness of seawater-mixing on strength enhancement is larger for OPC concrete than concrete with mineral admixtures, and there is no significant effect of mineral admixtures on strength increment up to 91-days of seawater-mixed concrete in both tap water curing and sea water curing.

Keywords: Seawater-mixing; Strength performance; Curing conditions; Mineral admixtures

1. INTRODUCTION

Seawater is prohibited to use as mixing water for reinforced concrete, because it increases the risk of corrosion of steel bar in concrete. However, in case of unavoidable circumstances, seawater may be used as mixing water, not only for plain concrete but also for reinforced concrete.[1,2] The investigation of concrete mixed with seawater on strength performance has been reported by several studies. Since 1974 to 2011, 68 papers have been published, which are related to concrete mixed with seawater. 42 papers among them revealed strength performance.[3] Nevertheless, the investigation on strength of seawater mixed concrete is not still acquired the agreement, and among researcher whether seawater-mixing improve strength development of concrete is still unclear.[4]

In present study, strength characteristics of seawater or tap water mixed concrete incorporating mineral admixtures such Fly Ash, Ground Granulated Blast Furnace Slag with W/B of 40%, 50% and 60% in tap water curing (TC), seawater curing (SC) and air curing (AC) were evaluated. The effectiveness of seawater mixing, mineral admixtures, curing conditions and water-binder ratio on strength performance is discussed.
Concerning effect of seawater as mixing water on durability of concrete, the authors will present not only strength performance of seawater-mixed concrete but also durability issues related to carbonation in conference presentation. Also, a discussion on both strength characteristics and durability will be included.

2. EXPERIMENTAL PROGRAM

2.1 Materials

Three types of binder were used in this study; Ordinary Portland Cement (OPC), Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS), specified in Japan Industrial Standard (JIS). In this study, two types of GGBFS (B4000 and B6000) with different surface area were used. Table 1 shows the chemical properties of binders, whereas the physical properties of concrete materials such as aggregates and seawater are depicted in Table 2.

Table 1 Chemical properties of binder

<table>
<thead>
<tr>
<th>Constituent</th>
<th>OPC</th>
<th>Fly Ash</th>
<th>B4000</th>
<th>B6000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density g/cm³</td>
<td>3.16</td>
<td>2.26</td>
<td>2.91</td>
<td>2.91</td>
</tr>
<tr>
<td>Finess, cm³/g</td>
<td>3330</td>
<td>3970</td>
<td>4060</td>
<td>5810</td>
</tr>
<tr>
<td>MgO, %</td>
<td>1.31</td>
<td>-</td>
<td>5.32</td>
<td>5.40</td>
</tr>
<tr>
<td>SiO₂, %</td>
<td>-</td>
<td>60.60</td>
<td>34.10</td>
<td>34.06</td>
</tr>
<tr>
<td>SO₃, %</td>
<td>2.14</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>LoI, %</td>
<td>1.97</td>
<td>2.40</td>
<td>0.33</td>
<td>0.36</td>
</tr>
<tr>
<td>Total Alkali, %</td>
<td>0.43</td>
<td>-</td>
<td>0.52</td>
<td>0.70</td>
</tr>
<tr>
<td>Chloride, %</td>
<td>0.016</td>
<td>-</td>
<td>0.006</td>
<td>0.006</td>
</tr>
</tbody>
</table>

Table 2 Physical properties of material

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Aggregate, G (Crushed stone)</td>
<td>Density (SSD) = 2.84 g/cm³, MSA = 20 mm, FM = 6.68, Water absorption = 0.71 %</td>
</tr>
<tr>
<td>Fine Aggregate, Ss (Washed sea sand)</td>
<td>Density (SSD) = 2.56 g/cm³, FM = 2.69, Water absorption = 1.61 %</td>
</tr>
<tr>
<td>Mixing Water, W (Natural seawater)</td>
<td>Density = 1.02 g/cm³, CI = 18.72 g/l, pH = 7.71</td>
</tr>
</tbody>
</table>

2.2 Series of mixture

Fifteen series of concrete mixtures with water-binder ratio of 40%, 50%, and 60% using tap water (T) or natural seawater (S) as mixing water were prepared. Three curing conditions such as tap water curing (TC), seawater curing (SC) and air curing (AC) in 20°C, 60% R.H. controlled room, were selected as curing condition, as described in Table 3.

2.3 Test methods

Concrete cylinder specimens in size of φ100x200 mm were demolded at 24 hours after casting then cured in tap water, in seawater and in air. After 28 days and 91 days curing, compressive strength and modulus of elasticity was measured in accordance with JIS A 1108 and JIS A 1149, respectively.

Table 3 Mixture series of specimen

<table>
<thead>
<tr>
<th>Mix types</th>
<th>W/B Mixing water</th>
<th>Replacement (%)</th>
<th>Curing conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>T40-N</td>
<td>T 100 - - -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>S40-N</td>
<td>S 100 - - -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>T40-B4</td>
<td>T 50 - 50 -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>S40-B4</td>
<td>S 50 - 50 -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>T50-N</td>
<td>T 100 - - -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>S50-N</td>
<td>S 100 - - -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>S50-F</td>
<td>S 80 20 - -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>S50-F3</td>
<td>S 70 30 - -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>T50-B4</td>
<td>T 50 - 50 -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>S50-B4</td>
<td>S 50 - 50 -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>S50-B6</td>
<td>S 50 - 50 50</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>T60-N</td>
<td>T 100 - - -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>S60-N</td>
<td>S 100 - - -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>S60-F</td>
<td>S 80 20 - -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>T60-B4</td>
<td>T 50 - 50 -</td>
<td>O</td>
<td>SC AC</td>
</tr>
<tr>
<td>S60-B4</td>
<td>S 50 - 50 -</td>
<td>O</td>
<td>SC AC</td>
</tr>
</tbody>
</table>

Table 4 Mix proportion of concrete

<table>
<thead>
<tr>
<th>Mix types</th>
<th>Unit content (kg/m3)</th>
<th>Slump (cm)</th>
<th>Air (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T40-N</td>
<td>160 400</td>
<td>776 1044</td>
<td>1.63</td>
</tr>
<tr>
<td>S40-N</td>
<td>165 412</td>
<td>712 1038</td>
<td>5.15</td>
</tr>
<tr>
<td>T40-B4</td>
<td>160 200</td>
<td>200 764</td>
<td>10.5</td>
</tr>
<tr>
<td>S40-B4</td>
<td>165 206</td>
<td>206 759</td>
<td>3.71*</td>
</tr>
<tr>
<td>T50-N</td>
<td>160 120</td>
<td>805 1087</td>
<td>8.0</td>
</tr>
<tr>
<td>S50-N</td>
<td>165 330</td>
<td>802 1083</td>
<td>8.0</td>
</tr>
<tr>
<td>S50-F</td>
<td>165 264 66</td>
<td>791 1068</td>
<td>10.0</td>
</tr>
<tr>
<td>S50-F3</td>
<td>165 231 99</td>
<td>786 1061</td>
<td>8.5</td>
</tr>
<tr>
<td>T50-B4</td>
<td>160 160</td>
<td>160 800</td>
<td>12.0</td>
</tr>
<tr>
<td>S50-B4</td>
<td>165 165</td>
<td>165 797</td>
<td>5.0</td>
</tr>
<tr>
<td>S50-B6</td>
<td>165 165</td>
<td>165 797</td>
<td>7.5</td>
</tr>
<tr>
<td>T60-N</td>
<td>160 267</td>
<td>819 1110</td>
<td>5.5</td>
</tr>
<tr>
<td>S60-N</td>
<td>165 275</td>
<td>816 1106</td>
<td>5.84</td>
</tr>
<tr>
<td>T60-B4</td>
<td>160 133</td>
<td>133 814</td>
<td>6.5</td>
</tr>
<tr>
<td>S60-B4</td>
<td>165 137</td>
<td>137 811</td>
<td>7.0</td>
</tr>
</tbody>
</table>

WR = Water reducer (AE+WR); * Different
3. RESULT AND DISCUSSION

3.1 Strength development

Fig. 1 shows concrete strength development of seawater-mixed and tap water-mixed OPC concrete, FA concrete and GGBFS concrete in TC, SC and AC. It is observed that all concrete specimens are above line of equality. This indicates that the compressive strength of seawater-mixed and tap water-mixed concrete with and without mineral admixtures were increased up to 91 days from 28 days. Nevertheless, concrete specimens in AC are nearly similar as equality line which means that strength increment of concrete in AC is smaller than both TC and SC.

Fig. 1 Strength development of concrete

3.2 Effect of mixing and curing water

Fig. 2 illustrates strength performance of OPC concrete cured in tap water or seawater. It is found that strength performance up to 91 days of seawater-mixed concrete is higher than that of tap water-mixed concrete. This suggests seawater-mixing improves compressive strength up to 91-days compared with tap water-mixing. Strength performance of GGBFS concrete is represented in Fig. 3. It is obtained that the 28-days compressive strength of seawater-mixed concrete is higher than tap water-mixed. However, the compressive strength at 91 days of seawater-mixed concrete is larger than that of tap water-mixed. This reveals that there is no significant effect of sea water mixing on strength increment up to 91days of GGBFS concrete.

Fig. 2 Strength performance of OPC concrete

The effect of curing water on strength performance is also found. The 28-days compressive strength of OPC and GGBFS concrete in SC are slightly higher than that in TC. While, up to 91 days, strength cured in tap water fairly increases compared with that in SC. However, curing water (seawater or tap water) does not have significant effectiveness on compressive strength both at 28 days and 91
days of OPC and GGBFS concrete in all mixture types. This result is also stated by previous research.\textsuperscript{[4,5]}

### 3.3 Effect of mineral admixtures

Fig. 4 represents 91-days strength ratio of seawater-mixed to tap water-mixed of OPC and GGBFS concrete. It is observed that the strength ratio of OPC concrete is higher than GGBFS concrete in water curing, both sea water and tap water. However, strength ratio of GGBFS concrete in AC is increased compared with OPC concrete. This reveals that effectiveness of seawater-mixing on strength enhancement is larger for OPC concrete than GGBFS concrete in water curing. This phenomenon is obtained by previous study in which strength ratio of OPC concrete was higher than FA concrete, not GGBFS.\textsuperscript{[5]}

**Fig. 3 Strength performance of GGBFS concrete**

Furthermore, effect of curing conditions on strength increment up to 91 days of seawater-mixed OPC and GGBFS concrete is also acquired, where the largest strength ratio are in AC followed by SC and TC. In addition, 91-days strength ratio of seawater-mixed OPC concrete are largest in 50% of W/B followed by 60% and 40%.

Effect of FA replacement in seawater-mixed concrete is shown in Fig. 5. The compressive strength of seawater-mixed FA concrete, both 20% replacement and 30% replacement is increased up to 91 days in water curing. From this, it can be said that effect of 30% replacement by FA on strength enhancement is not significant.

**Fig. 4 Strength ratio of seawater-mixed concrete to tap water-mixed concrete (S/T)**

**Fig. 5 Effect of FA replacement on strength**

Fig. 6 depicts the effect of GGBFS fineness on strength. It is obtained that compressive strength of seawater-mixed \( B_{4000} \) concrete is significantly higher than \( B_{6000} \) concrete in TC, SC and AC. This reveals that fineness of GGBFS affects strength performance of seawater-mixed concrete, the finer GGBFS is the higher compressive strength is.

### 3.4 Strength vs. Elastic modulus

The relationship between compressive strength and modulus of elasticity up to 91 days of seawater-mixed and tap water-mixed concrete in TC, SC, and AC is presented in Fig. 7. It is acquired that correlation between compressive strength and elastic modulus for all concrete
specimens is achieved, as recommended by Japan Society of Civil Engineering (JSCE).[6]

![Fig. 6 Effect of GGBFS fineness on strength](image)

Fig. 6 Effect of GGBFS fineness on strength

![Fig. 7 Compressive strength vs. Elastic modulus](image)

Fig. 7 Compressive strength vs. Elastic modulus

4. CONCLUSIONS

Based on the results of this experimental study, the following conclusions can be drawn:

1. Seawater-mixed concrete and tap water-mixed concrete with and without mineral admixtures were increased in compressive strength up to 91 days from 28 days.
2. Seawater-mixed OPC concrete was improved in compressive strength up to 91 days compared with tap water-mixed concrete in all curing condition, TC, SC and AC.
3. Compressive strength up to 91 days of seawater-mixed concrete with and without mineral admixtures was not affected by type of curing water, tap water or sea water.
4. Effectiveness of seawater-mixing on strength enhancement is larger for OPC concrete than concrete with mineral admixtures.
5. The largest strength ratio (seawater-mixed to tap water-mixed) of OPC concrete and GGBFS concrete was obtained in AC followed by SC and TC.
6. The strength ratio (seawater-mixed to tap water-mixed) of OPC concrete is the largest for 50% of W/B followed by 60% and 40%.
7. There was no significant effect of mineral admixtures on strength enhancement up to 91 days of seawater-mixed concrete in water curing (tap water and sea water). However, the effect of GGBFS fineness on strength of seawater-mixed concrete in water curing, both tap water and sea water was significant.

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REFERENCES


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