Influence of seawater mixing and curing on strength characteristics and porosity of ground granulated blast-furnace slag concrete

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Abstract. Generally, in the concrete industry, several billion tons of fresh water are annually used for mixing water, curing water and cleaning water. Nevertheless, the utilization of seawater in the concrete industry is prohibited, because it increases the risk of corrosion of steel bars in concrete. This study presents strength characteristics and porosity of seawater mixed concrete and tap water mixed concrete incorporating Ground Granulated Blast-Furnace Slag (GGBS) with water-binder ratio (W/B) of 40%, 50% and 60%. The influence of seawater mixing, GGBS and curing conditions such as tap water curing (TC), seawater curing (SC) and air curing (AC) on the strength and porosity of concrete were evaluated. Based on investigation result, it was shown that there is no significant influence of seawater mixing in improving strength of GGBS concrete up to 365 days in TC and SC. Effectiveness of seawater-mixing on strength enhancement of GGBS concrete is larger in air curing than in water curing. Porosity of seawater-mixed concrete is decreased compared to tap water-mixed concrete in all curing conditions.

1. Introduction
Seawater contains about 35,000 ppm dissolved salt and total salinity is approximately 3.5%, of which 78% is sodium chloride [1]. Thus, seawater is avoided to use as mixing water for reinforced concrete, because the risk corrosion of reinforcement bars was induced by chloride in seawater compounds. However, in case of unavoidable circumstances, seawater may be used as mixing water, not only for plain concrete, but also for reinforced concrete [2-4].

Strength is a fundamental characteristic to assess durability of concrete in term quality of concrete. Durability and strength of concrete structure are interrelated, where a strength and durability relationship of concrete may always be estimated. For instance, abrasion resistance increases with increasing the compressive strength, as reported by Nurazuwa [5]. 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 [6]. Nevertheless, the study on the strength of seawater mixed concrete is not still acquired the agreement among researcher, whether seawater-mixing improve the strength development of concrete is still unclear [7].
In this study, strength characteristics of seawater or tap water mixed concrete incorporating Ground Granulated Blast-Furnace Slag (GGBS) in tap water curing, seawater curing and air curing were investigated. The goal of this study is to evaluate the effectiveness of seawater mixing, GGBS and curing conditions on strength performance of concrete. By using GGBS in concrete, expected compressive strength of seawater mixed concrete are enhanced, as well mentioned by other references that mineral admixtures improve compressive strength and durability [8]. This paper also deals with porosity and the relation of compressive strength-porosity, as known that porosity and pore size distribution are one of important factor influencing compressive strength of concrete, as stated by some studies [9-11].

2. Research significance
There are plenty of archipelagic countries such as Indonesia, Japan and others countries, where lots of peoples live in the distant and isolated islands. Transportation of fresh water and others concrete materials for concrete production to distant and isolated islands will raise the cost of concrete work. This research was carried out in order to evaluate utilization of seawater in concrete production. By utilization of seawater in concrete production, it will not only benefit saving fresh water, but also reduce construction cost and CO$_2$ gas emissions in operational transportation, indirectly.

3. Experimental program

3.1. Materials
Two types of binder were used in this study OPC and GGBS (B$_{4000}$), specified in Japan Industrial Standard (JIS). The physical properties of binders and concrete materials such as coarse aggregate (G), fine aggregate (S) and natural seawater as mixing water (W) can be obtained in the previous studies [12].

3.2 Concrete mixtures
Table 1 presents concrete specimen series that were investigated in this research. Eight series of concrete mixtures with water-binder ratio (W/B) of 40%, 50% and 60% using tap water (T) and natural seawater (S) as mixing water were prepared by three type curing conditions such as tap water curing at 20°C (TC), seawater curing at 20°C (SC) and air curing at 20°C, 100% R.H. controlled room (AC) were used as curing conditions. The binder proportions of mixture series were OPC concrete (N) and 50% GGBS$_{4000}$ replacement (B4). Mix proportion of concrete specimen was designed according to Japan Society of Civil Engineering (JSCE). The results of mix proportion of concrete specimen are demonstrated in Table 2.

| Mixture | W/B (%) | s/a (%) | Mixing Water | Binder Proportion (%) |
|---------|---------|---------|--------------|-----------------------|
|         |         |         |              | OPC | GGBS |
| T40-B4  | 40      |         | Tap water    | 50  | 50   |
| S40-B4  |         |         | Seawater     | 50  | 50   |
| T50-N   |         |         | Tap water    | 100 | --   |
| S50-N   | 50      | 45      | Seawater     | 100 | --   |
| T50-B4  |         |         | Tap water    | 50  | 50   |
| S50-B4  |         |         | Seawater     | 50  | 50   |
| T60-B4  |         |         | Tap water    | 50  | 50   |
| S60-B4  |         |         | Seawater     | 50  | 50   |
### Table 2. Mix proportion of concrete specimen.

| Mixture   | Unit Content ( kg/m³ ) | Fresh Properties |
|-----------|------------------------|------------------|
|           | W  | Binder | S  | G  | WR | AE* (liter) | Sp | Slump (cm) | Air (%) | Temp. (°C) |
| T40-B4    | 160 | 200    | 200| 764| 1010| 2.00       | 0.77| 10.5        | 4.0     | 24.0       |
| S40-B4    | 165 | 206    | 206| 759| 1004| 0.79       | 3.71| 8.0         | 6.2     | 16.0       |
| T50-N     | 160 | 320    | -  | 805| 1087| 1.00       | 2.00| 8.0         | 6.0     | 18.0       |
| S50-N     | 165 | 330    | -  | 802| 1083| 1.03       | 1.27| 8.0         | 6.0     | 18.0       |
| T50-B4    | 160 | 160    | 160| 800| 1081| 1.08       | 1.08| 12.0        | 4.5     | 19.0       |
| S50-B4    | 165 | 165    | 165| 797| 1076| 1.24       | 1.11| 5.0         | 4.0     | 20.0       |
| T60-B4    | 160 | 133    | 133| 814| 1077| 0.83       | 1.41| 6.5         | 5.0     | 23.0       |
| S60-B4    | 165 | 137    | 137| 811| 1073| 0.94       | 1.45| 7.0         | 4.8     | 21.0       |

WR: Water reducer (AE+WR), *100 times dilution

### 3.3. Test methods

After a certain curing period for 28 days and 365 days in TC, SC and AC, concrete cylinder specimens in size of φ100x200 mm were tested in compressive strength. Compressive strength test of concrete specimens was conducted in accordance with JIS A 1108:2006. The average compressive strength and elastic modulus of three specimens were determined for each concrete mixture in three curing conditions.

In regard with total pore volume (porosity) of concrete specimen were tested by Mercury Intrusion Porosimetry (MIP). Concrete cylinder specimens were cut into 5 mm-thick slice samples. Subsequently, the fragments were immersed in acetone for 15 minutes to stop further hydration of cement, and then dried in the vacuum desiccator for 2 days. In the MIP test, complete drying of the samples was required to obtain results without error (3.20). In this study, the maximum applied pressure of MIP test was 33,000 psi (227 MPa), and the surface tension and contact angle of mercury was 485 dynes/cm and 130°, respectively. Porosity of concrete specimens was carried out at 28 days and 365 days period, which was three times measurement in a specimen.

### 4. Result and Discussion

#### 4.1. Strength characteristics

Figure 1 represents the concrete strength development of seawater mixed (S) and tap water mixed (T) OPC concrete and GGBS concrete in TC, SC and AC with a curing period of 28 days and 365 days. It was observed that all concrete specimens were increased in compressive strength up to 365 days from 28 days in three W/B of 40%, 50% and 60%. When concrete specimens were cured in TC, the achieved strength development up to 365 days of OPC concrete is approximately 25% and 24% for tap water mixed and seawater mixed, respectively. It means that strength development up to 365 days of OPC concrete is not influenced by type of mixing water, tap water or seawater. It is also found that strength performance up to 365 days of seawater-mixed OPC concrete is higher than that of tap water-mixed OPC concrete in all curing conditions. This expresses seawater-mixing improves compressive strength up to 91-days compared with tap water-mixing.

In contrast, different trend on strength development up to 365-day from 28-day of GGBS concrete was obtained. When seawater-mixed GGBS concrete was maintained in TC, compressive strength up to 365-day of seawater-mixed GGBS concrete was lower than tap water mixed GGBS concrete. It indicates that strength enhancement up to 365-day from 28 days of tap water mixed GGBS concrete in TC is improved compared to seawater mixed GGBS concrete. However, in case of seawater-mixed GGBS concrete was cured in SC and AC, strength performance up to 365 days seawater-mixed GGBS...
concrete was higher compared to tap water mixed GGBS concrete. It indicates that strength performance of seawater mixed GGBS concrete is improved in SC and AC. Generally, it can be concluded that there is no significant effect of seawater mixing in improving strength of GGBS concrete up to 365 days in water curing, TC and SC.

Figure 1. Strength development of concrete specimens.

Figure 2. Strength in TC vs. Strength in SC.

The effect of curing water, TC and SC on strength performance of seawater mixed concrete and tap water mixed concrete is pointed out in figure 2. At 28-day curing period, compressive strength of GGBS concrete in SC were slightly higher than that in TC. Up to 365 days curing, compressive strength of concrete cured in TC slightly increased compared with SC. However, curing water (TC or
SC) does not have significant effect on compressive strength up to 365 days in all concrete mixture, in which the difference in compressive strength was less than 10 percent. It reveals that compressive strength of concrete mixed with tap water and mixed with seawater is not affected by type of curing water, tap water curing or seawater curing.

4.1.1. Porosity. Figure 3 shows the total volume of pores conducted by Mercury Intrusion Porosity (MIP) tests of concrete specimens at 28 days and 365 days. At 28 days, seawater mixed OPC concrete reduced in porosity of concrete compared with tap water mixed in all curing conditions, in TC, SC and AC. In contrast, 28-day porosity of tap water mixed GGBS concrete was lowered comparing to seawater mixed in water curing (TC and SC). When GGBS concrete specimens were cured in air, the porosity of concrete mixed with tap water was higher than that of concrete mixed with seawater. This phenomenon expresses that the porosity of concrete at 28 days is decreased by seawater mixing in AC. It is possibly inferred by accelerating the hydration of seawater mixed concrete, which densify the pore structure and reduces pore volume of concrete.

At 365-day curing period, the impact of GGBS on the porosity of seawater mixed and tap water mixed concrete could clearly be found. Porosity of seawater mixed GGBS concrete was lower than tap water mixed GGBS concrete. It suggests that porosity of seawater-mixed GGBS concrete up to 365 days is reduced in TC, SC and AC. The lowest concrete porosity in water curing, TC and SC were obtained for GGBS concrete in both seawater mixed and tap water mixed.

![Figure 3. Total pore volume (porosity) of concrete specimens.](image)

4.2. Pore size distribution

The typical pore size distribution at curing period of 28 days and 365 days of seawater mixed GGBS concrete and tap water mixed GGBS concrete in all curing conditions is shown in Figure 4. It was found that the pore distribution of tap water and seawater mixed are shown GGBS concrete in TC and SC is not significantly different. This indicates that pore size distribution of concrete is not affected by curing water, TC and SC. The maximum porosity and the large pore size of concrete specimen were
achieved by specimens cured in air. This phenomenon is to be logical as hydration of cement paste in air curing, AC is not perfectly hydrated. No significantly distinct in pore size distribution of tap water mixing and seawater mixing was obtained. The trend of pore distribution of seawater mixed and tap water-mixed concrete were nearly similar. Nevertheless, the difference of various curing age (28 days and 365 days), the pore size distribution of concrete was altered for both seawater mixing and tap water mixing.

4.3. Strength-porosity relationship

Figure 5 demonstrates the relationship between compressive strength and total pore volume (porosity) of tap water mixed and seawater mixed GGBS concrete at 28 days and 365 days curing time in curing water. From this figure, it can be seen that, compressive strength was increased with a decreasing the porosity of concrete in logarithmic relation. A strong correlation is acquired in TC and SC, in which coefficient of correlation, $R^2$ value in TC and SC were more than 0.87 ad 0.83, respectively. It expresses that compressive strength of seawater mixed GGBS concrete and tap water mixed GGBS may be evaluated by its porosity. The higher compressive strength is, the lower porosity of concrete is, which is not influenced by mixing water, binder type and mix proportion of concrete. No significant difference of correlation coefficient, $R^2$ in TC and SC was obtained.
5. Conclusions
Based on the results of experimental study, some conclusion can be drawn:
1. There is no significant influence of seawater mixing in improving strength of GGBS concrete up to 365 days in water curing, TC and SC.
2. Compressive strength up to 365 days of seawater-mixed and tap water-mixed GGBS concrete is not affected by type of curing water, tap water or seawater.
3. Porosity up to 365 days of seawater mixed GGBS concrete is decreased compared to tap water mixed in TC, SC and AC.
4. Pore size distribution up to 365 days of seawater mixed concrete and tap water mixed GGBS concrete is not affected by type of curing water, TC or SC.

6. References
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