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The impact of sodium silicate coatings on the freeze-thaw resistance of ground granulated blast furnace slag mortar

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Abstract
The study elucidated how sodium silicate coating halts the deterioration of the mortar samples significantly with the addition of ground granulated blast furnace slag (GGBS) into the binder mass (B), the coated samples exhibited a substantial increment in freeze and thaw resistance compared to non-coated samples. The study included implementing freeze and thaw cycles on mortar samples with 4 different GGBS/B ratios: 0%, 30%, 50%, and 70%. The multiple coatings of sodium silicate were also tested against freeze and thaw cycles (3 and 6 coatings). The cumulative scaling was measured for all mortar samples at 7,14,21,28, and 35 freeze-thaw cycles. The freeze-thaw resistance tests indicated that the mortars with the addition of sodium silicate coating were the most resistant to deterioration, moreover, the higher the GGBS/B ratio in the samples the more resilience it shows to the freezing-thawing cycles.

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Keywords: Ground granulated blast furnace slag, Sodium silicate, Freeze-thaw resistance, Deterioration, Coating

Introduction

The freezing and thawing cycle causes concrete structures to deteriorate in snowy and cold locations. The freezing and expansion of water within the concrete is the principal source of freeze-thaw damage. Many chloride-based anti-freeze chemicals are utilized in Japan, which greatly accelerates concrete deterioration due to freeze damage. The paper presents the effect of ground granulated blast furnace slag (GGBS) accompanied by Sodium silicate on the mortar. The study evaluates the performance of the mortar samples with the content of GGBS and sodium silicate coating on selected properties of cement mortars, such as cumulative scaling, freeze-thaw resistance, and mass retention ratio [1, 2].

Researchers have paid close attention in recent years to the alteration of cement composites by other particles. Concrete, the most often used cement composite in practical applications, was also modified by substituting a component of the binder with other elements such as Fe_2O_3, Al_2O_3, and SiO_2. Many researchers were interested in the incorporation of GGBS and silicate coating (Sodium silicate) into concrete not only because of the similarity of its chemical composition to constituents of C-S-H but also because GGBS has the potential to improve cement composite properties through various mechanisms [3].

Ground granulated blast furnace slag (GGBS) is a byproduct of blast furnace pig iron manufacturing. It is primarily composed of silicate and aluminosilicate of melted calcium that must be removed from the blast furnace on a regular basis. The chemical compositions of GGBS are determined by the raw materials used in the production of iron, while the physical properties are determined by the cooling process used to cool down the molten materials. When molten slag is rapidly cooled with water, it transforms into granulated slag, a fine, granular, virtually entirely noncrystalline, glassy form. For almost a century, GGBS has been used as a primary supplemental cementing ingredient. It possesses exceptional cementitious and pozzolanic characteristics that are latent. There have been far too many studies on the influence of GGBS on the strength of various types of concretes and mortars [4, 5].

Sodium Silicate coatings is a highly reactive pozzolan and could consume calcium hydroxide (CH) to form secondary C-S-H, on the other hand, GGBS contains higher amounts of SiO_2 compared to OPC (Ordinary Portland Cement) and higher amounts of CaO. Al_2O_3 is also higher in GGBS compared to OPC [6]. Soluble sodium silicates, popularly known as "waterglass," are used in a variety of applications in the cement industry. They can be used as set accelerators in shotcreting applications, as moisture reducers in mortar and concrete manufacturing, and as cementitious waste forms. One of the most common uses for sodium silicate is as a concrete sealant. In contrast to other sealants that either resist water (e.g., silanes, silicones, stearates) or work as a physical barrier covering (e.g., epoxies, polyesters, vinyls), soluble silicate sinks into the concrete surface and, theoretically, combines with portlandite to produce C-S-H gel:

$$Na_2SiO_3 + H_2O + Ca(OH)_2 + C\text{-}S\text{-}H + 2NaOH$$

Where the acronyms C-S-H are derived from cement chemistry notation, where C = CaO, S = SiO_2, and H = H_2O, hyphens denote the variable composition of C-S-H gel [7].

Experiment Details

Materials

Experiments were conducted using mortar. The mortar was mixed with water, cement, and fine aggregate in the ratio of 1: 2: 4.5 by mass, referring to the formulation given in JIS A 1146. Since this study aims to elucidate the degradation phenomena in mortars subjected to freezing and thawing in presence of silicate coating and GGBS, the experiments were conducted without using chemical admixtures such as Air entraining agents, however, a water-reducing admixture was utilized in the experiments [8]. Ordinary Portland cement (density:3.15g/cm^3, blaine value:3,350cm^2/g) and GGBS (density: 2.89 g/cm^3; blaine fineness: 4150 cm^2/g) were used as cement binder, crushed hard sandstone sand (dry surface density: 2.66 g/cm^3, water absorption: 1.53%, coarse grain ratio: 3.08) as fine aggregate, crushed stone (dry surface density: 2.76 g/cm^3, water absorption: 0.44%, coarse grain ratio: 3.08) as coarse aggregate, and tap water was used as mixing water: After the mortar was mixed, it was cast into a 40 x 40 x 160 mm mold, cured in a room for 18 hours, and then molded. After molding, the specimens were cured in water at a temperature of 20±2℃.

Freeze-Thaw Test

The freezing and thawing test method, prescribed by the Japan Society of Civil Engineers Standard JSCE-C 507, was developed to evaluate the quality of GGBS and Silicate coating. The test was conducted using small mortar specimens soaked in freezing water (5% Sodium Chloride aq) as described in the "Quality Evaluation Test Method for Blast Furnace Slag Fine Aggregate by Freezing and Thawing in Salt Water" [9].

Figure 1 shows an overview of the preparation method for the small specimens. With a wet diamond cutter, small specimens of 10±2 mm per side were prepared from mortar cured in water. To ensure the homogeneity of the material, the 10 mm from the edge of the formwork and the 10 mm from the casting surface were discarded. The 5 mm portion from the side surface in contact with the formwork was also discarded so that all six sides were cut surfaces. Figure 2 shows 3~6 mortar pieces, 10 × 10 × 10 mm in size, were soaked in 50 mL of freezing water and placed in a polypropylene container with a volume of 100 mL. The bottle containing the mortar pieces and the solution was alternately frozen at −20°C for 16 hours and thawed at 20°C for 8 hours. The concentration of the sodium chloride solution was 5% by mass, in accordance with the JSCE-C 507 standard. In the freezing process, a programmed thermostatic chamber, where small specimens were frozen and thawed in 24 hours, consisted of a 16-hour freezing process and an 8-hour thawing process, as shown in Figure 3.

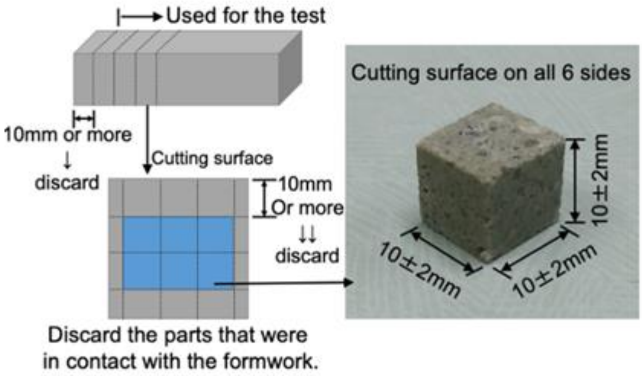

Fig 1: Preparation of small specimens

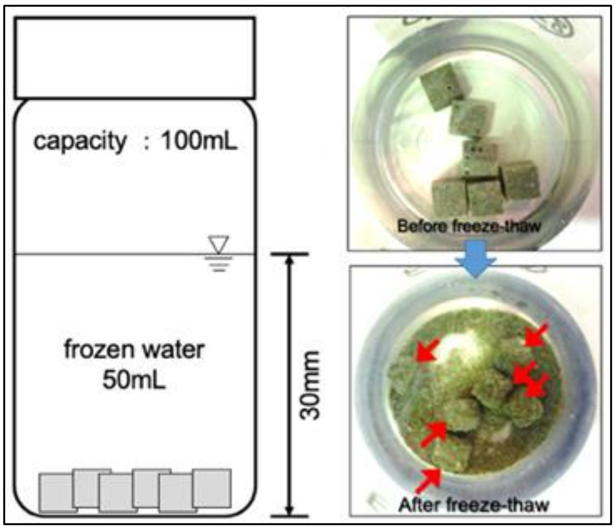

Fig 2: Container used for small piece freeze-thaw test and state of small pieces during the freeze-thaw test

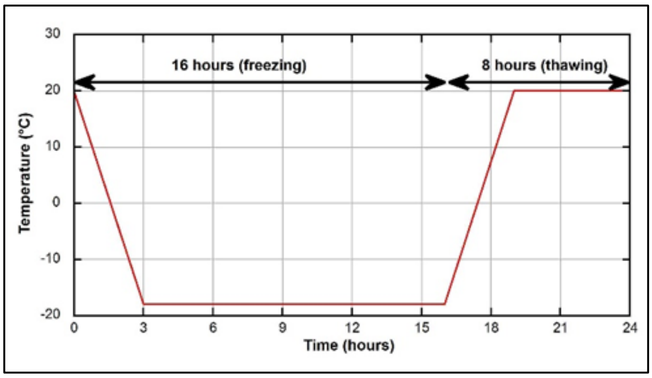

Fig 3: Temperature setting in the freeze-thaw test using a programmed incubator.

Scaling Test

The scaling test was conducted in accordance with the resistance to scaling test of JSCE-K 572 "Testing Methods for Silicate Surface Impregnation Materials" [10].

The specimens were 100 x 100 x 100 mm cubic specimens cut from 100 x 100 x 400 mm prismatic specimens. After the specimens were molded, they were dried in a room for one day, and the two sides in contact with the mold were left, and the other four sides were covered with epoxy resin. After the epoxy resin had cured, the specimens were again cured until the age at which the test began. From the age at which the test was started, the specimens were placed in a test container with the test surface down on a 10-mm-high spacer and filled with a 3% sodium chloride solution so that 5 to 10 mm of the test surface was immersed. The freeze-thaw cycle of the test apparatus consists of a 16-hour freezing process and an 8-hour thawing process. In the freezing process, the temperature of the gas phase in the test apparatus is maintained at -18±2°C for at least 12 hours. In the thawing process, the maximum temperature is 20±2°C as standard, and this temperature is maintained for at least 5 hours. After 7,14, 28, and 35 cycles, the scaling pieces detached from the test surface were collected, dried, and weighed (minimum scale: 0.01 g).

Results

Effect of Sodium Silicate on the Freeze-Thaw Resistance of GGBS Mortar

Figures 4, 5, 6 and 7 show the effect of Sodium Silicate coating on the freeze-thaw resistance of mortar containing different GGBS amounts as a replacement for cement binder (B), a programmed thermostatic chamber was used to subject the mortar to freeze-thaw action at the temperature setting as mentioned previously. The figures indicate the results of cumulative scaling for the mortar samples of age 28 days that had been tested, all samples had been cured under water for 21 days, then coated with sodium silicate and went through water-curing for another 7 days after coating. As shown in Figure 4 represents the cumulative scaling of coated samples and uncoated samples with a 70% replacement rate of GGBS/B used, it can be seen clearly that the coated sample had less cumulative scaling than the uncoated samples all over the freezing-thawing test at 7,14,28, and 35 cycles of the test, the cumulative scaling of the coated sample was nearly the half of the uncoated samples at each measurement of the freeze-thaw test. However, when GGBS replaced the binder by 50% and 30% in Figures 5 and 6 respectively, we can observe that the cumulative scaling difference between the coated and uncoated samples become smaller and smaller. Moreover, when the normal binder was used without GGBS addition, a notable difference can be detected between the coated and uncoated samples in Figure 7.

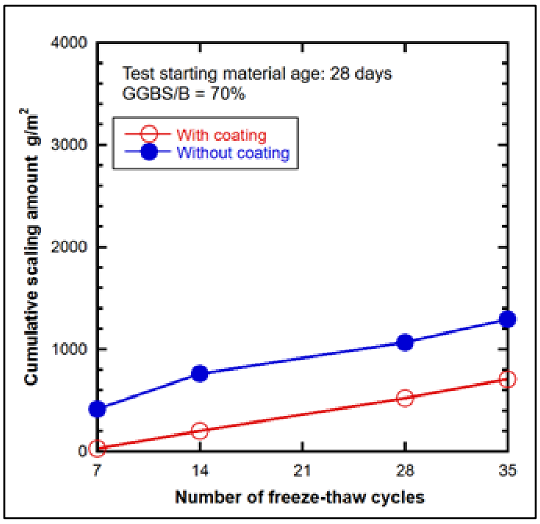

Fig 4: Cumulative scaling of mortar with 70% GGBS/B

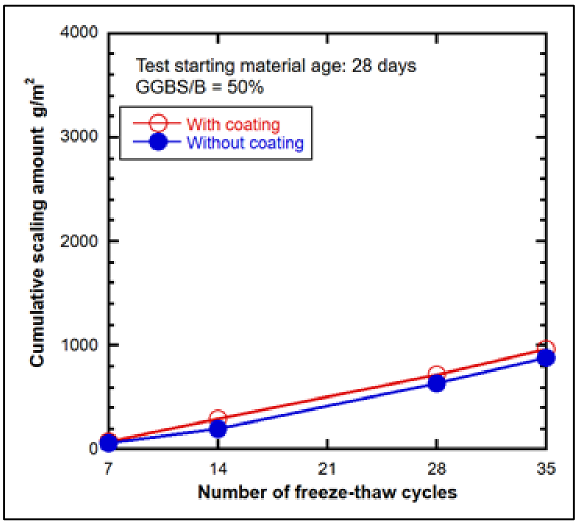

Fig 5: Cumulative scaling of mortar with 50% GGBS/B

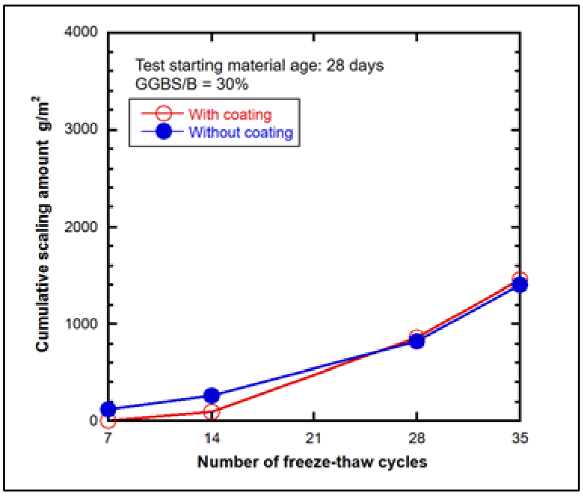

Fig 6: Cumulative scaling of mortar with 30% GGBS/B

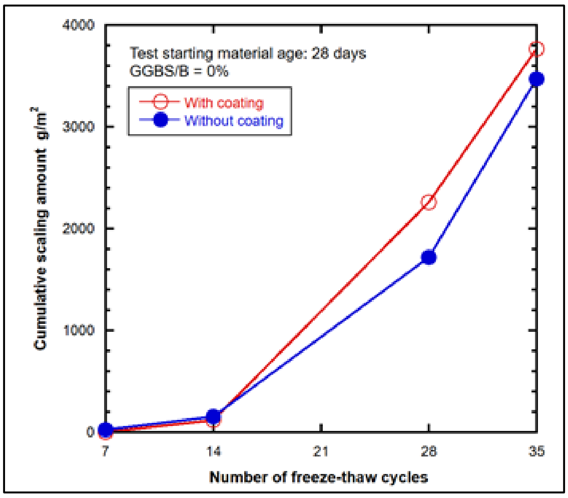

Fig 7: Cumulative scaling of mortar with 0% GGBS/B

Figures 8 and 9 elucidate the substantial decrease in samples' deterioration due to freeze and thaw while using Sodium silicate coating in accordance with the GGBS/B ratio, Hence, the data can be interpreted that the higher the GGBS/B ratio, the more effective the sodium silicate coating against the deterioration of mortar samples because of freeze-thaw cycles.

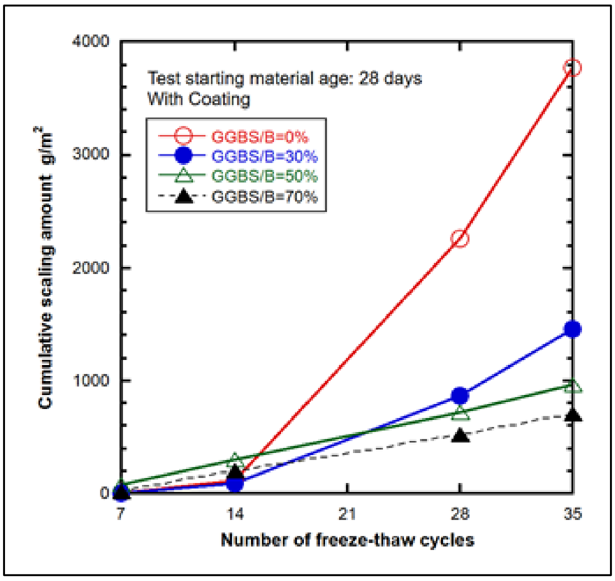

Fig 8: Comparison of cumulative scaling of coated mortar samples at 28 days

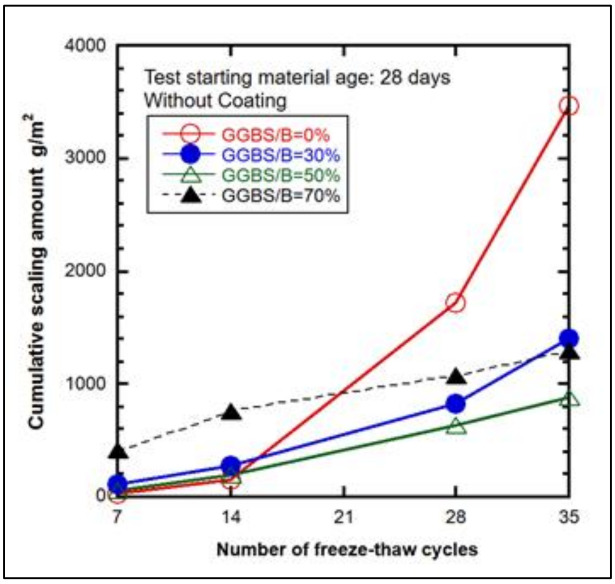

Fig 9: Comparison of cumulative scaling of non-coated mortar samples at 28 days

Effect of Multiple Application of Sodium Silicate on the Freeze-Thaw Resistance of GGBS Mortar

In this section, the results of cumulative scaling of mortar samples at age of 91 days will be discussed after implementing the freeze-thaw test on the samples, a programmed thermostatic chamber was used to subject the mortar to freeze-thaw action at the temperature setting as mentioned previously.

The figures indicate the results of cumulative scaling for the mortar samples of age 91 days that had been tested, all samples had been cured under water for 77 days, then coated with sodium silicate three and six times, and went through water-curing for another 7 days after coating.

As shown in Figures 10, 11,12, and 13 represent the cumulative scaling of 3 times coated,6 times coated and uncoated samples respectively at four different GGBS/B ratios, it can be perceived obviously that the 6 times coated sample had less cumulative scaling than 3 times coated sample, and the uncoated sample along freezing-thawing test for all ratios of GGBS/B, however, the difference becomes less notable when notable as GGBS/B is higher, the difference of cumulative scaling was at its peak when no GGBS was used as shown in Figure 13 as the cumulative scaling of the 6 times coated sample was nearly 30% less than the 3 times coated samples at 35 cycles of the freeze-thaw test.

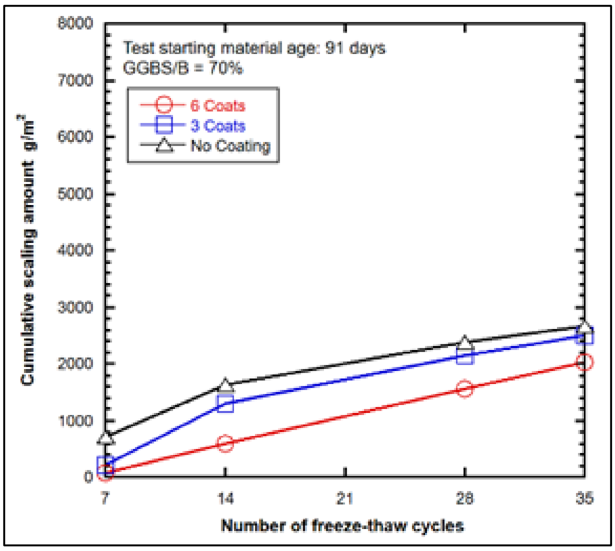

Fig 10: Cumulative scaling of multiple-coating mortar samples with 70% GGBS/B.

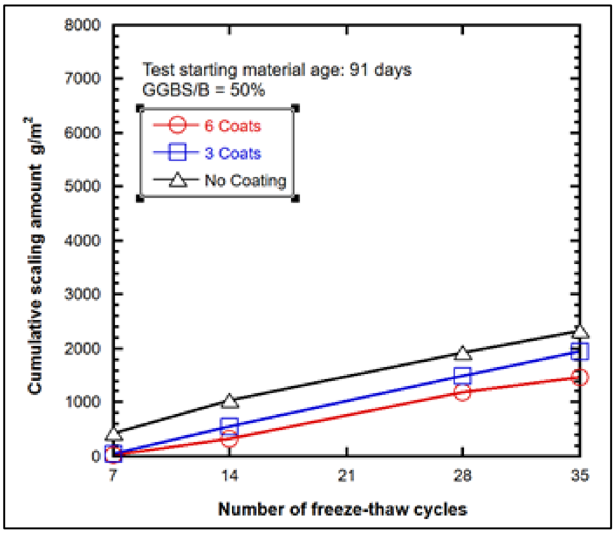

Fig 11: Cumulative scaling of multiple-coating mortar samples with 50% GGBS/B

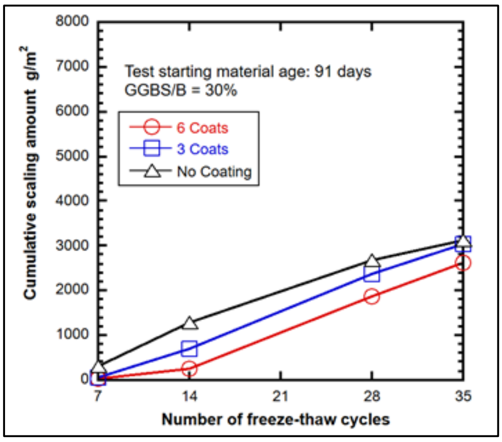

Fig 12: Cumulative scaling of multiple-coating mortar samples with 30% GGBS/B.

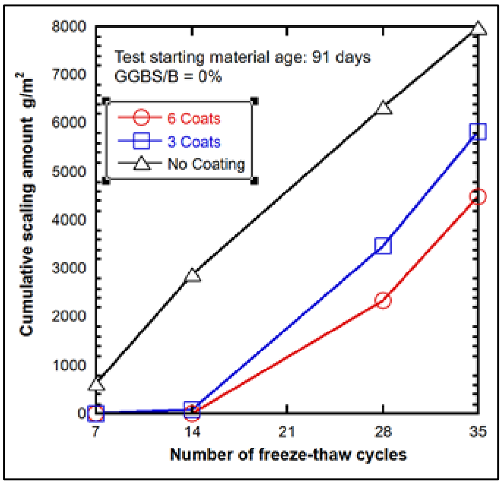

Fig 13: Cumulative scaling of multiple-coating mortar samples with 0% GGBS/B

Figures 14, 15, and 16 elucidate the substantial decrease in samples' deterioration due to freeze and thaw cycles while using multiple Sodium silicate coatings in accordance with the GGBS/B ratio, Hence, the data can be interpreted that the higher the GGBS/B ratio, the less notably the difference of freeze-thaw resistance between 6 or 3 coatings of sodium silicate, even though it can be said that more coatings of sodium silicate will guarantee more resistance of the mortar against the deterioration of freeze-thaw.

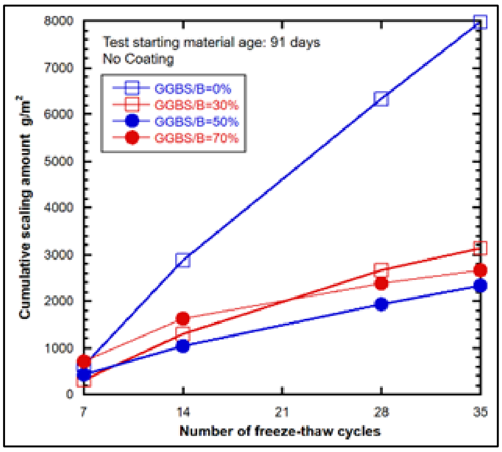

Fig 14: Comparison of cumulative scaling of non-coated mortar samples at 91 days

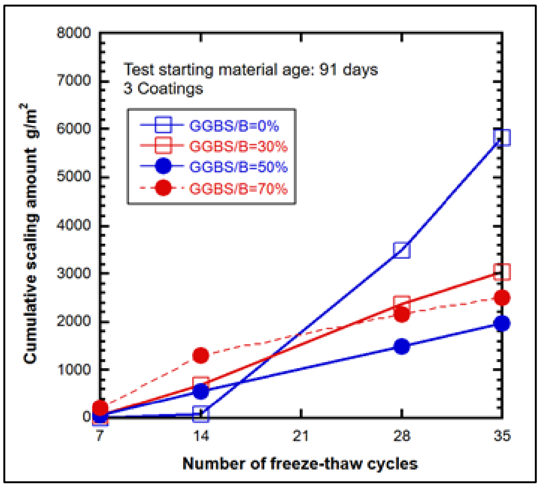

Fig 15: Comparison of cumulative scaling of 3 times coated mortar samples at 91 days

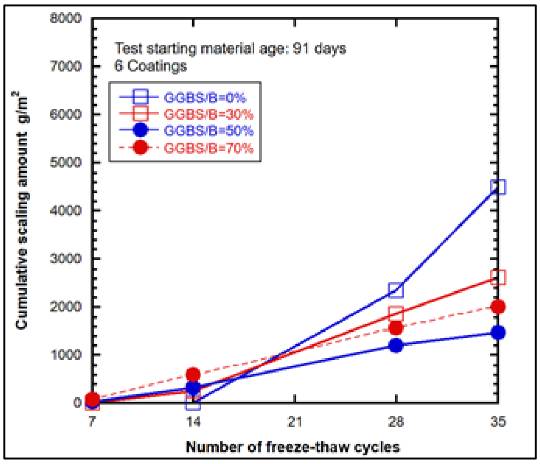

Fig 16: Comparison of cumulative scaling of 6 times coated mortar samples at 91 days

Conclusions

Concrete deterioration can be caused by a variety of factors, including freeze-thaw cycles. The Study discussed how sodium silicate coating affects the resistance of freeze-thaw of mortar samples against deterioration with the incorporation of ground granulated blast furnace slag (GGBS) into the binder, different conditions of the coating had been deliberated thoroughly such as using single or multiple coatings of Sodium silicate, the effect of adding $Ca(OH)_2$ coating besides the sodium silicate, as well as the effect of using paraffin emulsion as a curing agent, comparisons of the cumulative scaling as well as mass retention of the samples, were demonstrated to shed the light on the effect of other factors such as GGBS ratio, curing period, and curing method. The following main conclusions can be drawn from the results of the tests.

1. The higher the GGBS/B ratio, the more effective the sodium silicate coating against the deterioration of mortar samples because of freeze-thaw cycles. The difference between freeze-thaw resistance of coated and uncoated samples is more notable as a higher amount of GGBS is used in the mortar samples.
2. The higher the GGBS/B ratio, the less notably the difference in freeze-thaw resistance of the multiple coatings of sodium silicate compared to a smaller number of coatings, even though it can be said that more

applications of sodium silicate coating will guarantee more resistance of the mortar against the deterioration of freeze-thaw.

3. Curing duration can increase the freeze-thaw resistance of sodium silicate-coated samples.

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