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Durability of Concrete Composites Containing Fly Ash and Blast Furnace Slag for use in for Precast Concrete Products

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ABSTRACT

In the construction industry, fly ash and blast furnace slag are used in a ecological way as cement mixing materials. That the concrete composites containing these materials have different physical properties compared with ordinary concrete has been indicated. In this study, the applicability of using concrete composites containing fly ash and blast furnace slag into precast concrete fabrication process was evaluated. The purpose of this study, then, is to subject concrete composites to the same standards of evaluation for durability as ordinary concrete. There evaluations include drying shrinkage, carbonation, salt attack and Freeze-thaw test. As a result of the tests, it was concluded that the cure condition is very important for durability of concrete containing fly ash and blast furnace slag to be used in standard construction.

Keywords. Fly ash, Blast furnace slag, Precast concrete, Durability, Physical property

INTRODUCTION

By-products of industrial manufacturing, fly ash (FA) and blast furnace slag (BFS) are being used in construction material concrete as part of the effort to tackle global environmental problems. There are many previous studies of composite cement concrete containing these secondary products, as well as many examples of their actual use in construction. Generally, the life span of buildings is said about to be 100 years or more. In this regard, demonstrating the durability of concrete composites containing FA and BFS is indispensable to safely use these construction materials. That the properties of concrete composites containing FA and BFS have different physical properties compared with ordinary concrete has been indicated. For example, premature reinforcement bar corrosion is attributed to a reduction in the resistance to salt damage and carbonation due to a decrease in cement component of the composite. In this study, the applicability of using concrete composites containing FA and BFS into precast concrete fabrication process was evaluated. Ordinarily, precast concrete is fabricated in a factory. And these materials have high quality. Therefore the inherent, disadvantages caused by using FA and BFS in concrete might be reduced by the advantages of the careful and exacting curing process which is possible with precast concrete. The purpose of this study, then, is to subject concrete composites to the same standards of evaluation for durability as ordinary concrete by drying shrinkage, carbonation, Salt Attack and Freeze-thaw test.

CHARACTERISTICS AND DURABILITY TEST

This study especially focused on evaluating the effects of blended FA and BFS durability of precast concrete. Durability related properties determined were: drying shrinkage, carbonation, salt attack and freeze-thaw damage, which are some of the important factors that the design of concrete structures of service life.

Specimen Preparation and Curing. The cementitious materials used in this test were ordinary Portland cement, FA and BFS. In this investigation, four different mixtures were prepared and designated as N, FA10+BFS, FA15+BFS, and BFS as shown in Table 1. Mixture N containing only cement was used as a control concrete. The other mixtures, FA10+BFS, FA15+BFS, and BFS, were proportioned to have cement replacements of FA in the 10 %, 15 % and 0% and BFS in the 40 % , 45 % and BFS in 55 % respectively by weight of cement. These mixtures were proportioned for water-to-binder ratio of 42 %, 36 %, 37 % and 38 %. The coarse aggregate is river stone with a maximum size of 25 mm. The fine aggregate is river sand, and its fineness modulus is 2.7. The influence of curing on the durability was investigated. Two type of curing methods were compared. After demoulding at 24 hour, a first set of specimens was cured under steam condition at 60 °C as precast concrete at 2 hour. A second set of specimens was stored in a room at 20 °C and RH 60 %.

Table 1. Mix Proportion of Concrete Specimen

Mix No.	W/B (%)	W	C*1	FA*2	BFS*3	S*4	G*5	Added
N	42	153	364	-	-	821	973	2.55
FA15	36	150	188	62	167	759	973	3.34
FA10	37	150	182	41	182	774	973	3.24
BFS	38	150	178	-	217	787	973	2.77

Where C, FA, BFS, W, S, and G are the weights of cement, fly ash, blast furnace slag, water, sand, and gravel (kg/m3) And B is C+GA+BFS

*1 Ordinary Portland Cement, *2 Fly ash type II, *3 BFS 4000 cm^2/g, *4 Yoshino river aggregate

Mechanical property. The compressive strength of concrete was determined in accordance with JIS A 1108 at the age of 1 to 182 days. Each specimen was prepared in 100 φ mm × 200 mm dimensions. The test results represent the average of experimental results from three identical specimens. A graph of the concrete's age-compressive strength with different curing method and mix proportion was shown in Fig. 1. The rate of strength development decreased after a curing time of 28 days in N concrete. With FA10+FFS, FA15+BFS and BFS concrete, the early strength was lower than that of the N concrete, but strength gains continued for a long time. In addition, while the application of steam curing did not increase compressive strength in the short term (1 to 7 days), the compressive strength in FA10+BFS, FA15+BSF and BSF was increased after the 28 day period.

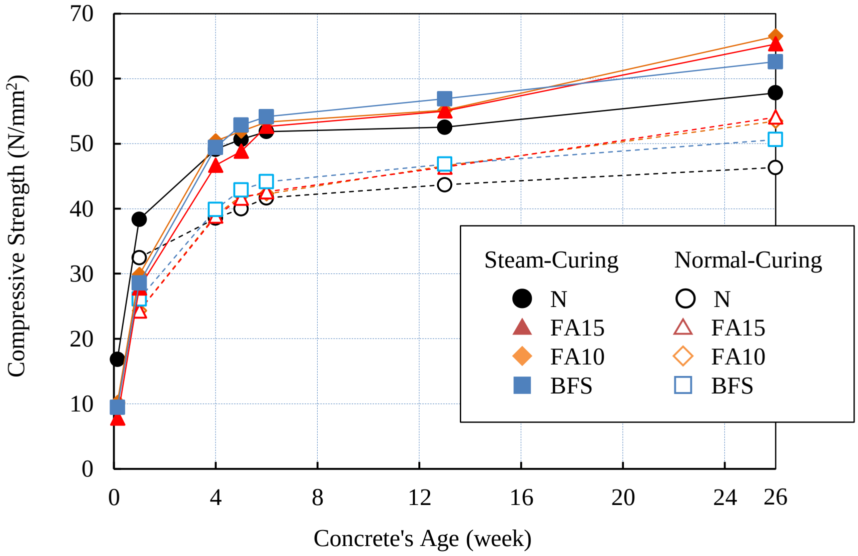

Fig. 1 Compressive Strength of Concrete

Drying Shrinkage Test. The drying shrinkage test of concrete prism specimens (100 × 100 × 400 mm) was determined in accordance with JIS A 1129 (contact gauge method) at the age of 15 to 182 days. The results of drying shrinkage of the concrete are shown in Fig. 2. For each parameter, two specimens were measured, and the average value of was taken as the shrinkage of the concrete. The shrinkage of the FA10+FFS and FA15+BFS concretes was significantly lower than the shrinkage of N concrete at all ages. Moreover, the reduction in the shrinkage obtained in the investigation by the combination of the use of FA and BSF in concrete with steam curing was in the order of 20 % when compared to N concrete.

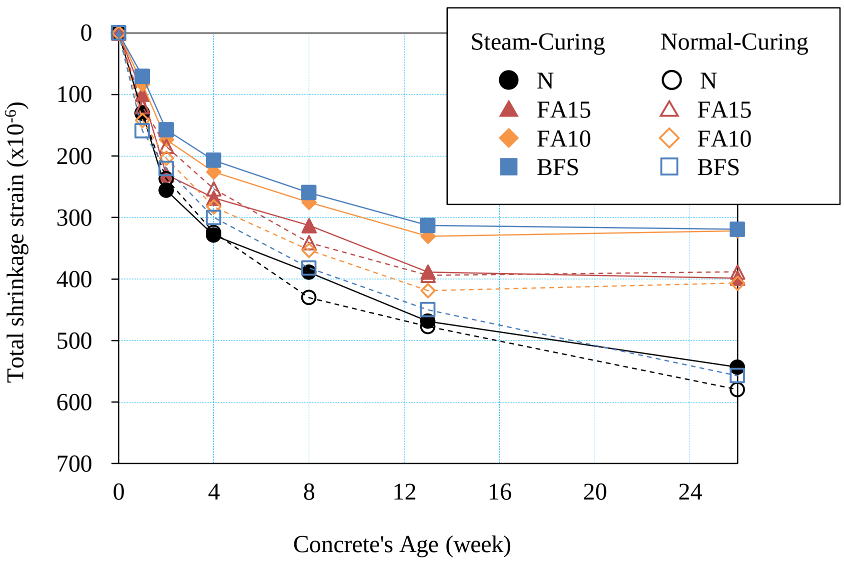

Fig. 2 Time-dependent change in total shrinkage strain

Accelerated Carbonation Test. The accelerated carbonation test of concrete prism specimens (100 × 100 × 400 mm) was conducted in accordance with JIS A 1152-1153. Test pieces were exposed to 5 % of CO_2 (20 °C and RH 60 %) environment at the age of 7 to 182 days. As generally known, the rate of carbonation is considered as proportional to the square root of exposure time. Fig. 3 shows the carbonation rate coefficient of concretes by Eq. (1).

$$X = A\sqrt{t} \tag{1}$$

Where, X : Depth of carbonation (mm) , A : Carbonation rate coefficient (mm/√week), t : time (day)

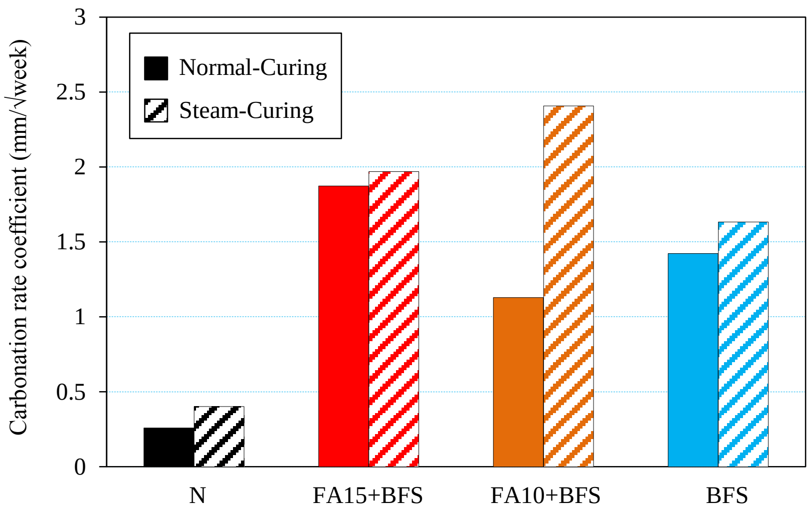

Fig. 3 Carbonation rate coefficient

The rate of carbonation of FA10+BFS, FA15+BFS and BFS concrete is greater than the N concrete. This result was expected since not only was the $Ca(OH)_2$ in the cement paste reduced by its replacement with FA but it was also assumed to be further reduced by its consumption as an effect of the pozzolanic reaction with the FA. On the other hand, it was also found that for all specimens, steam-curing decreases the rate of carbonation. This can be attributed to the steam curing's effect of decreasing the volume of large voids. In fact, the compressive strength of all the different concrete mixes is increased in relation to the N concrete.

Accelerated Chloride Migration Test. Overview of chloride ion diffusion test by electrical migration method is shown in Fig. 4. Initially, cathode side cell is filled with an aqueous solution of NaCl (0.5 mol/l) and anode ide cell is filled with an aqueous solution of NaOH (0.3 mol/l) to simulate the pore solution in concrete. Both sides of the cells were inserted with titanium mesh electrode and 20 V was applied by a direct current stabilized power source device. Anode side cell solutions were collected and chloride ion concentrations were measured by potentiometric titrator. Based on these test results, the apparent permeability of chloride ions through the waterproofing membranes and substrate concrete were calculated using Eq. (2) of Nernst-Planck flux equation.

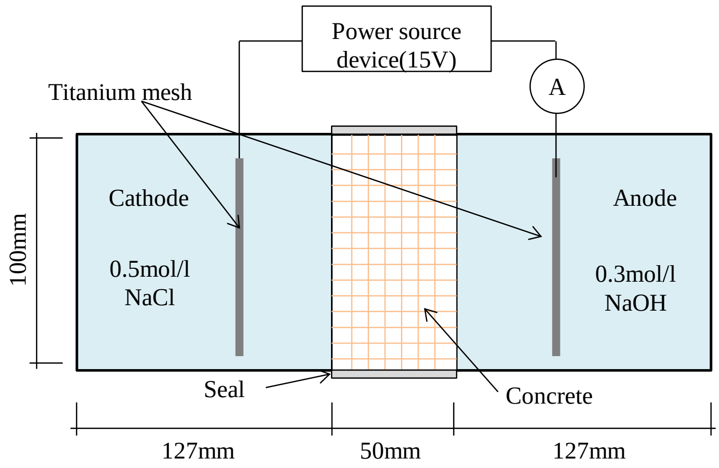

Fig. 4 Electrical migration method

$$J_{cl} = D_{cl}\left(\frac{dC(x)}{dx} - c(x)\frac{zF}{RT}\frac{d\psi(x)}{dx}\right) \quad (2)$$

where, J_{cl} : Flux (mol/cm^2/s), D_{cl} : Diffusion coefficient (cm^2/sec), C : Concentration of Cl$^-$ (mol/cm^3), z : Ionic valency, F : Faraday constant (C/mol), R : Gas constant (J/K/mol), T : Temperature (K), ψ : Electric potential (V)

The calculated results are shown in Fig. 5. Normally, concrete containing FA or BFS has a higher resistance to penetration of Cl$^-$ ions than concrete with ordinary Portland cement. It can be seen also that the concretes containing FA and BFS showed better performance than N concretes in this study. Furthermore, the results showed that FA10+BSF concrete had the lowest Cl$^-$ ions permeability. Moreover, the Cl$^-$ ions permeability resistance increased with steam-curing concrete. These results may be due to the fact that the use of FA and BFS might lead to the densification the pore system in concrete and that steam-curing perhaps assists in furthering this development of a discontinuous pore structure.

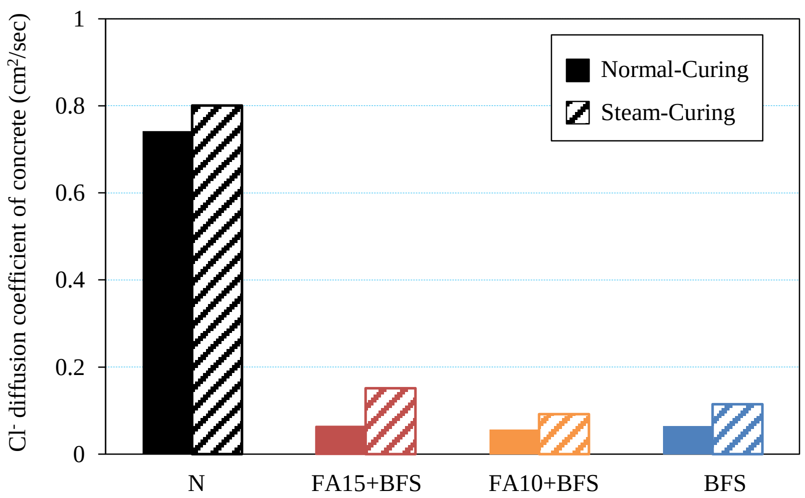

Fig. 5 Cl$^-$ diffusion coefficient of concrete

Freezing-thawing Resistance. The freezing–thawing resistance test of concrete prism specimens (100 × 100 × 400 mm) was conducted in accordance with rapid freezing and thawing test using liquid nitrogen as outlined in previous studies. The specimens were placed in the case and conditioned in liquid nitrogen for 1 min. Then, they were transferred from the case into a hot bath at 40 °C to allow the specimens to thaw for 5 min. The relative dynamic modulus of elasticity was obtained from the results of ultrasonic pulse velocity measurements with the repeated cycles of freezing and thawing. This process was repeated 10 times. Fig. 6 plots the result of the dynamic elastic modulus subjected to freeze–thaw cycles. The results show that, in N concrete, the dynamic elastic modulus decreases with the freeze–thaw cycles and reaches 85 % at 10 cycles. The experimental results showed that the FA and BFS additive mixtures played a significant role on the freezing–thawing properties of concrete. The rate of decrease of the elastic modulus was only less than 10 %. Freeze-thaw resistance of N concrete with steam curing has improved. However, no significant improvement in the FA occurred concrete with steam curing.

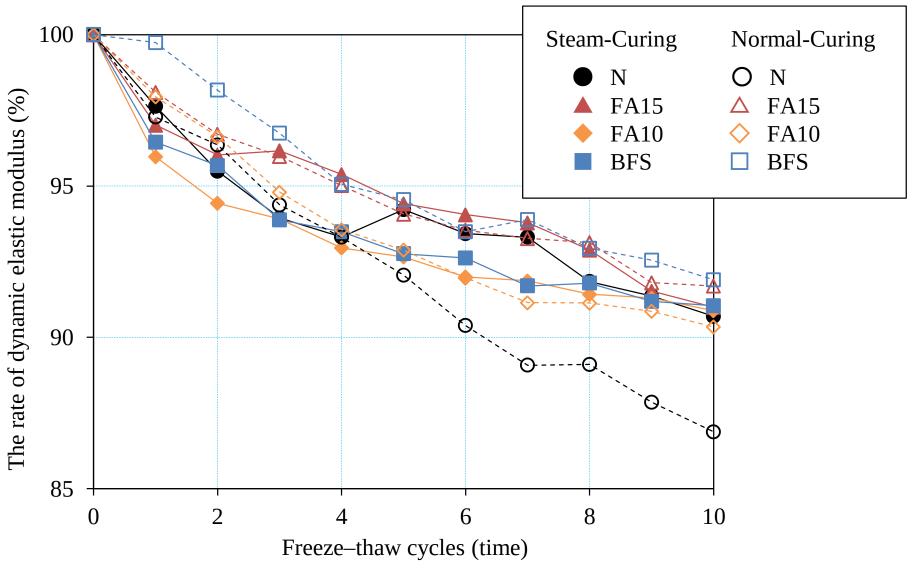

Fig. 6 The dynamic elastic modulus subjected to freeze–thaw cycles

SUMMARY AND CONCLUSIONS

In general, the combination of FA and BFS as partial replacement of cement materials and the subsequent steam-curing are improved the durability properties of concrete.

1) With FA and BFS concrete, the early strength was lower than that of the N concrete, but 28 day strength was higher. In addition, with the application of steam curing, the compressive strength in FA and BSF was increased after the 28 day.

2) The shrinkage and damage of freeze-thawing with the FA10+FFS and FA15+BFS concretes was significantly lower than N concrete. Moreover, the reduction in the shrinkage and damage of freeze-thawing seemed to be further enhanced by the combination of the use of FA and BSF in concrete together with steam curing.

3) The amount of CO_2 and Cl^- penetration is assumed to have decreased by densification of the microstructure with FA and BFS for the accelerated carbonation test and accelerated

chloride migration test. However, rebar protection performance degradation is a concern due to the decrease in the amount of $Ca(OH)_2$ in the cement paste reduced by its replacement with FA and BFS. When considering the durability design of the concrete structure, this effect must be sufficiently taken into consideration.

4) The microstructure in the concrete strongly affects the durability of concrete structure. Further studies are necessary to examine the relationship between the addition of FA or BFS and steam-curing.

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