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Examination on the improvement of crack resistance of the concrete using blast-furnace slag cement

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ABSTRACT

In this research, the crack resistance of concrete using blast-furnace slag cement added sulfate, such as sodium sulfate or anhydrite, was evaluated in order to improve the crack resistance of the concrete using blast-furnace slag cement. When sodium sulfate was added in blast-furnace slag cement, it was clear that the reaction of the blast-furnace slag was accelerated and the strength of concrete using the cement increased at early age. Moreover, it was confirmed that the crack resistance of concrete using the blast-furnace slag cement added sodium sulfate was improved.

Keywords. Blast-furnace slag cement, sodium sulfate, crack resistance

INTRODUCTION

It is said that shrinkage cracking often occurs in the concrete using blast-furnace slag cement, especially, the phenomenon occurs in drying condition. As the reason, it is said that the deformation resistance of the concrete using blast-furnace slag cement lowers compared with the case of other cements in drying condition (Naoya KANBE, 2011).

The crack resistance of concrete using blast-furnace slag cement is improved by appropriate curing such as wet condition keeping. However, it is difficult that wet condition is kept for long term in concrete construction. On the other hand, the crack resistance of concrete using blast-furnace slag cement is improved by increasing SO_3 content in the cement (Shingo MIYAZAWA, 2005).

In this research, the improvement in crack resistance of concrete using blast-furnace slag cement was examined from viewpoint of material design, specifically, the crack resistance of mortar using blast-furnace slag cement added sulfate, such as sodium sulfate or anhydrite, was evaluated.

OUTLINE OF EXAMINATION

Materials. The used cements are shown in Table1, and the mix proportions of mortar are shown in Table2. Three types of blast-furnace slag cement (BFS1, BFS2, BFS3) were used in this research, they were different in their manufacturer. The sodium sulfate or anhydrite was added in BFS1.

In all cases, the water-cement ratio of mortar was 50.0% and the unit weight of fine aggregate was 1300kg/m^3. The fine aggregate used in mortar is quarts sand (density: 2.60g/cm^3).

Table 1. Materials

Types of cement	Slag replacement ratio (%)	Density (g/cm^3)	SO_3 (%)	Notes
BFS1	42	3.04	2.14	---
BFS2	45	3.04	2.08	---
BFS3	44	3.04	2.26	---
BFS1+Na_2SO_4	41	3.03	3.95	Adding Na_2SO_4 at 3.3wt%
BFS1+$CaSO_4$	41	3.04	3.95	Adding $CaSO_4$ at 3.2wt%
Ordinary Portland cement (OPC)	---	3.15	1.95	---

Table 2. Mix proportions of mortar

Symbol	W/C (%)	Unit weight (kg/m^3)			Cement type
		W	C	S	
BB-1	50	302	604	1300	BFS1
BB-2		302	604		BFS2
BB-3		302	604		BFS3
BB-SS		301	602		BFS1+Na_2SO_4
BB-AH		302	604		BFS1+$CaSO_4$
NC		306	612		OPC

Measurement in reaction degree of blast-furnace slag. In this research, reaction degree of blast-furnace slag in cement was measured in order to examine the relation between reaction degree of slag and crack resistance of mortar using the slag. The reaction degree of slag in cement was measured in the case of BFS1, BFS1+Na_2SO_4, BFS1+$CaSO_4$. The cement paste using the above cements respectively was used in the measurement, the water cement ratio of the cement paste was 40%. The reaction degree of slag in cement was measured at the age of 2days, 5days, 7days, 14days and 28days. The cement paste samples were cured with sealing at temperature of 20^{o}C.

The reaction degree of slag was calculated from the difference between initial slag content in the cement and un-reacted slag content in the one. The un-reacted slag content was measured by the selective dissolution method (Shunsuke HANEHARA, 2010).

Measurement of strength. In this research, compressive strength, Young's modulus and splitting tensile strength were measured in order to understand influence of adding sulfate to strength characteristic. Test for compressive strength, Young's modulus and splitting tensile strength conformed JIS A 1108, JIS A 1149 and JIS A 1113. These test proceeded at age of 5days, 7days, 12days, 28days and 56days. The test pieces were placed in the room at temperature of 20°C with sealing until the age of 5days, then those replaced in the room at temperature of 20°C and relative humidity 60% without sealing.

Evaluation of crack resistance. The crack resistance was evaluated by the specimen shown in Figure1. This specimen was placed in the room at temperature 20°C and relative humidity 60% after sealed curing for 5days, and the steel strain (εs) was measured with sealing the two opposite sides of the specimen. Moreover, the shrinkage strain (εm) of unrestrained specimen at the size of 100x100x400mm was measured on the above condition with sealing the two opposite sides of the specimen. In these measurements, the number of specimens were three in each case.

The shrinkage strain (εr) restrained by steel and the restrained stress (σr) are calculated by the following Equation1 and Equation2. In this paper, εr and σr are expressed as the indexes of crack resistance.

$$\varepsilon r = \varepsilon m - \varepsilon s \qquad \text{(Equation1.)}$$

$$\sigma r = \varepsilon s \cdot Es \cdot (As/Am) \qquad \text{(Equation2.)}$$

where Es is Young's modulus of steel(200000N/mm^2), As is cross section area of steel(803.8mm^2), Am is cross section area of the part mortar(9196.2mm^2)

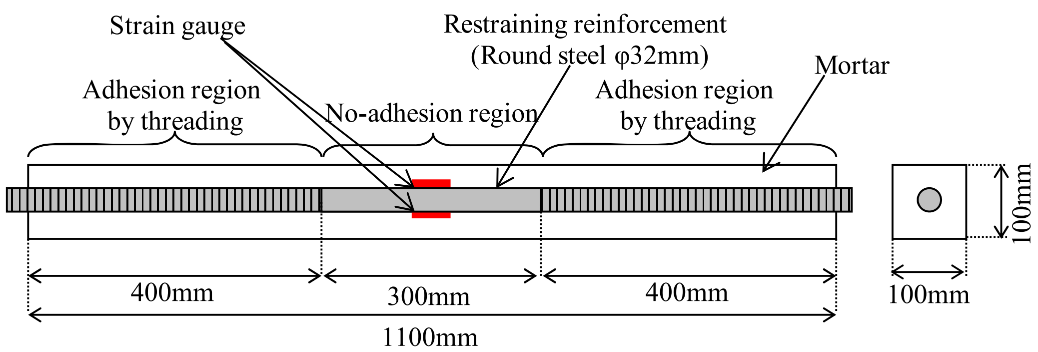

Figure 1. Specimen for evaluating crack resistance

RESULTS AND DISCUSSIONS

Reaction degree of blast-furnace slag. Figure 2 shows reaction degree of the blast-furnace slag in the cement paste samples. In all case, the reaction degree of the blast-furnace slag rapidly rise in 5days, and almost become constant after 5days. The reaction degree of the blast-furnace slag in BFS1+Na_2SO_4 was about 1.5times compared with the reaction degree of the blast-furnace slag in BFS1 and BFS1+$CaSO_4$. Therefore, it is considered that the reaction of blast-furnace slag is accelerated by adding sodium sulfate.

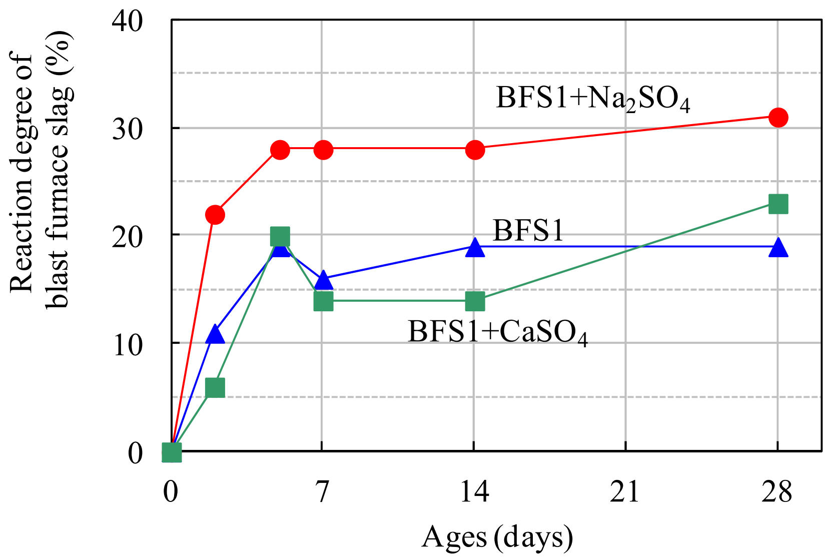

Figure 2. Reaction degree of blast-furnace slag

Strength characteristics. The results of compressive strength are shown in Figure3. The compressive strength in the case of BB-SS increased about 22% compared with that in the case of BB-1 at the age of 5days. However, the compressive strength in the case of BB-SS was equal to that in the case of BB-1 at the age of 7days, and that in the case of BB-SS after the age of 12days lowered than that in the case of BB-1. Moreover, the above tendency was seen in the case of BB-AH. This is because sodium sulfate or anhydrite accelerates reaction of blast-furnace slag at early ages.

The results of Young's modulus are shown in Figure4, and the relations between compressive strength and Young's modulus are shown in Figure6. The Young's modulus in the cases of BB-1, BB-2, BB-3 and BB-AH had increased as compressive strength increasing. On the other hand, the Young's modulus in the cases of BB-SS and NC had not increased as compressive strength increasing, they were constant about 20kN/mm^2 at the all ages.

The results of splitting tensile strength are shown in Figure5. The splitting tensile strength in the case of adding sulfate became larger than that in the cases of BB-1, BB-2 and BB-3 at the many ages. Especially, the splitting tensile strength in the case of BB-SS was raised compared with the cases of BB-1, BB-2 and BB-3. Therefore, adding sulfate to blast-furnace slag cement is assumed to be effective on improvement of crack resistance, because crack resistance is improved by raising tensile strength.

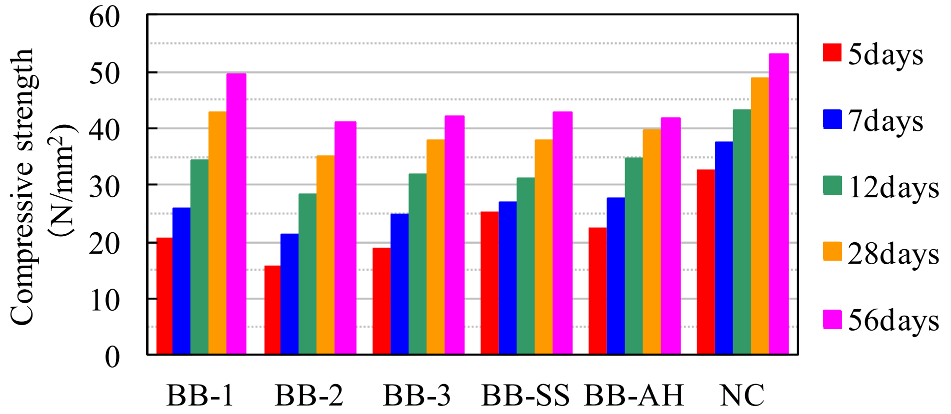

Figure 3. Results of compressive strength

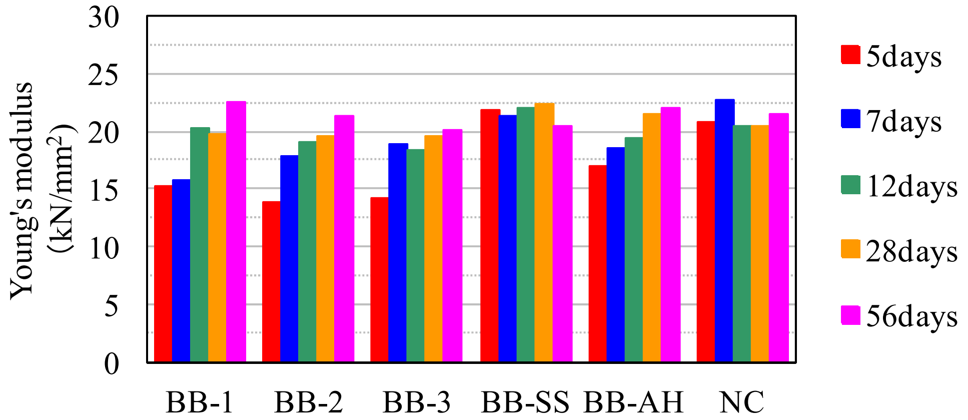

Figure 4. Results of Young's modulus

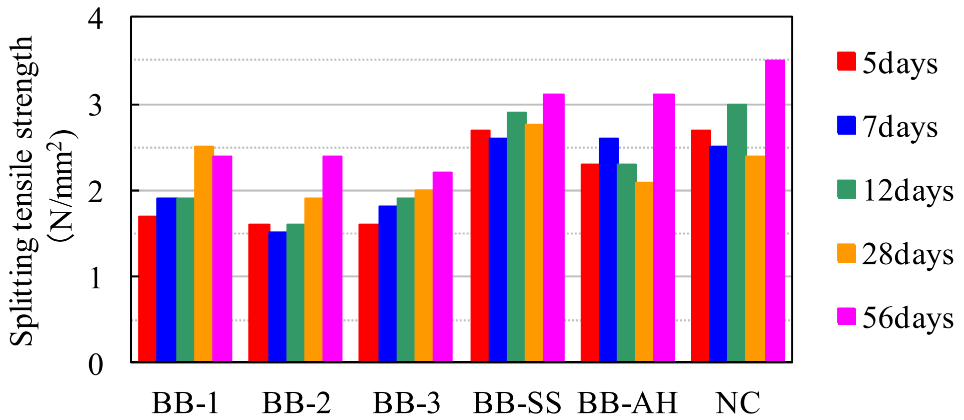

Figure 5. Results of splitting tensile strength

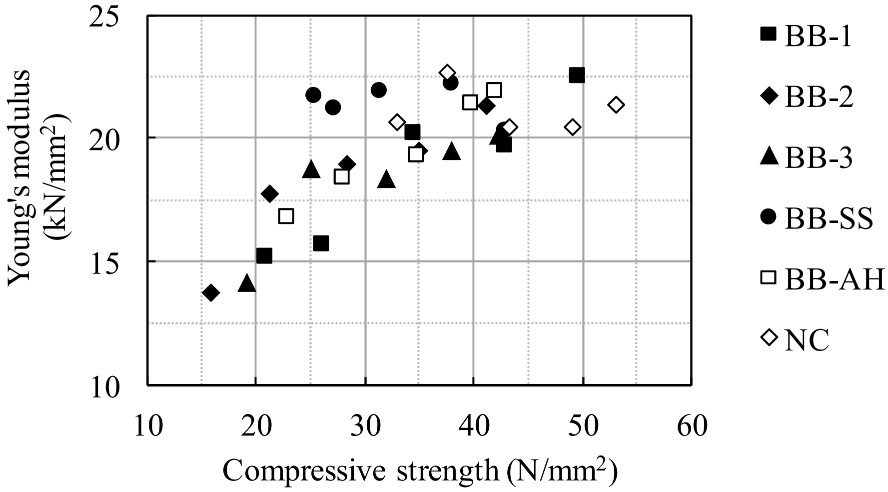

Figure 6. Relations between compressive strength and Young's modulus

Evaluation of unrestrained strain. The results of unrestrained strain (εm) are shown in Figure7. The unrestrained shrinkage strain in the cases of BB-1, BB-2 and BB-3 rapidly decreased after sealed curing for 5 days. On the other hand, the unrestrained shrinkage strain in the case of BB-SS slowly decreased after curing for 5 days. Moreover, the unrestrained shrinkage strain in the case of BB-AH was small because the expansion strain in the case of BB-AH is the largest for 5 days.

Evaluation of crack resistance. The relations between restrained strain (εr) and restrained stress (σr) are shown in Figure8. These curves in Figure8 are expressed by the values of εr and σr from occurrence of tensile stress to cracking. Moreover, the age of cracking and the values of εr and σr at cracking are shown in Table3.

The cracking age in the case of BB-SS were longer than the cracking age in other cases. Furthermore, the restrained strain and the restrained stress when the crack occurred were the largest in the case of BB-SS. Especially, the restraint strain when the crack occurred in the case of BB-SS was twice compared with that of in the case of BB-1 and NC. This is because the reaction of the blast-furnace slag was accelerated by adding the sodium sulfate, and tensile strength in the case of BB-SS increased, and unrestrained strain in the case of BB-SS is the smallest. On the other hand, the improvement of the crack resistance was not seen in the case of BB-AH though tensile strength increased by adding anhydrite. It is considered that a reaction degree of the blast-furnace slag was not enough to improve the crack resistance by adding anhydrite.

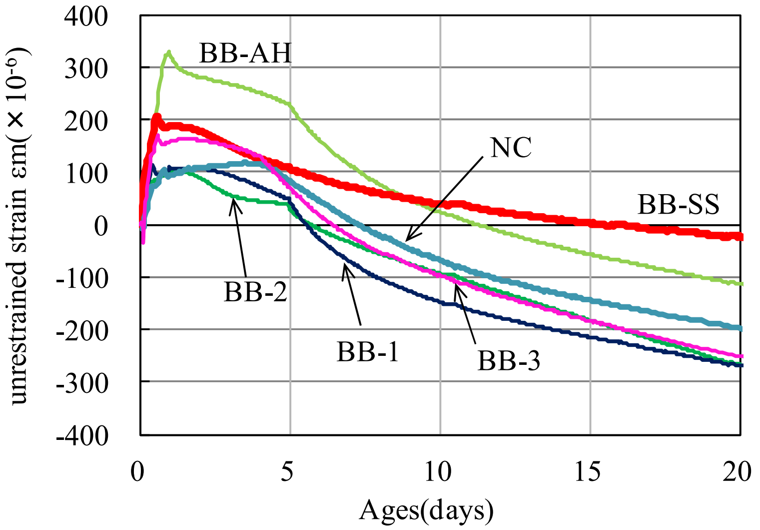

Figure 7. Results of unrestrained strain εm

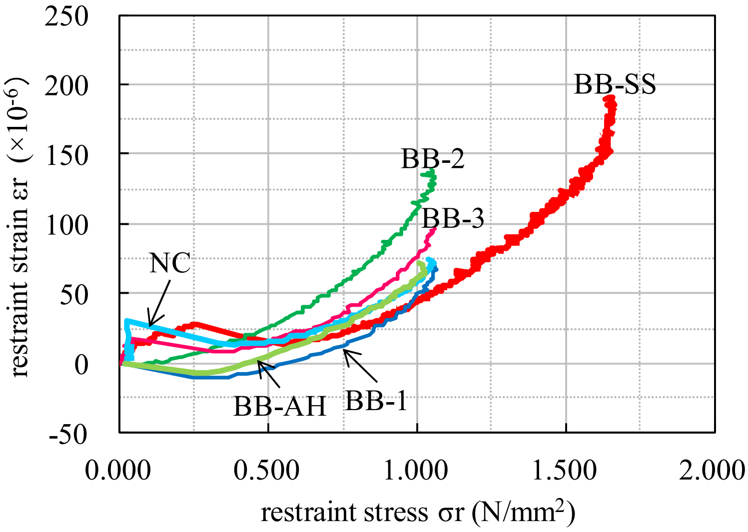

Figure 8. Relations between restrained strain εr and restrained stress σr

Table 3. Cracking ages and Values of εr and σr at cracking

	Cracking age (days)	Restrained stress σr at cracking (N/mm^2)	Restrained strain εr at cracking ($x10^{-6}$)
BB-1	8	1.06	70
BB-2	11	1.05	139
BB-3	7	1.06	97
BB-SS	46	1.63	190
BB-AH	8	1.01	72
NC	9	1.04	75

CONCLUTION

In this research, the improvement in crack resistance of concrete using blast-furnace slag cement was examined from viewpoint of material design, specifically, the crack resistance of mortar using blast-furnace slag cement added sulfate, such as sodium sulfate or anhydrite, was evaluated. The main result is shown as follows.

1) The reaction of blast-furnace slag is accelerated by adding sodium sulfate.

2) The early age compressive strength in the case of adding sulfate became larger than that in the cases of non-adding sulfate.

3) The splitting tensile strength in the case of adding sulfate became larger than that in the cases of non-adding sulfate at the many ages. Especially, the splitting tensile strength in the case of adding sodium sulfate was raised compared with the cases of non-adding sulfate.

4) The crack resistance of concrete using blast-furnace slag cement is greatly improved by adding sodium sulfate.

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