The study of relationship between capability of CO₂ absorption and strength and pore structure using blast furnace slag cement

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ABSTRACT

Cement that is main component of concrete is one of the highest CO_2 emission materials, on the other hands, it can react with CO_2 and absorb it after hydration. Therefore, it is one of the carbon neutral methods for concrete to reduce amount of cement, and adsorb more CO_2 than emission from manufacturing process. This study aims at setting CO_2 emission from concrete life cycle as net zero by carbonation and putting into practical application. And thus, we evaluated the relationship between CO_2 balance, compressive strength and pore structure using different blast furnace slag's replacement ratio and fineness powder. The result showed that the compressive strength of mortar which is high content of blast furnace slag was down by carbonation. In addition, maximum capability of CO_2 absorption correlate with CaO content form using material, on the other hand, to use higher content of Portland cement made carbonation depth less. We also examined admixture combination to keep out compressive strength down by carbonation and get CO_2 balance using not only blast furnace slag but also particular admixture based γ -C2S which can react with CO_2 and then it made compressive strength increased. The result showed that using γ -C2S with carbonation didn't occur compressive strength down, whereas carbonation depth is less than without γ -C2S.

KEYWORDS: blast furnace slag, compressive strength, pore structure, CO₂ balance

1. Introduction

In recent years, it is pressing need to reduce emission of CO_2 that is a factor in global warming, and all industries are required to make the transition to decarbonized society. In the Japanese construction industry, concrete using highly substituted cement admixtures such as ECM cement is being developed to reduce the use of clinker, which emits a large amount of CO_2 during production. On the other hand, since the main component of concrete is hydrates with calcium like $Ca(OH)_2$, it is possible to absorb a large amount of CO_2 by carbonation. Therefore, combining those methods is expected to lead to CO_2 balance. However, depending on the mix proportion of admixture, it is difficult to organize the CO_2 balance simply by the substitution ratio because the amount of calcium that absorb CO_2 decreases, and the carbonation rate is different. In addition, there is little knowledge about effects of carbonation on strength and porosity using admixtures.

In this study, we focused on blast furnace slag fine powder (GGBS), which can be replaced with a large amount of cement. we evaluated the relationship between CO_2 absorption, compressive strength and pore structure using different GGBS replacement ratio and fineness powder. We also examined admixture combination to keep out compressive strength down by carbonation and get CO_2 balance using not only GGBS but also particular admixture based γ -C2S which can react with CO_2 and then it made compressive strength increased.

2. Materials and Methods

2.1 Materials and Mix Proportion of Mortar

Table1 shows the mix proportion of mortar. In this study, 3 types of powder were mixed in accordance with each mix proportion. Ordinary Portland cement with 2% SO₃ is replaced by GGBS which is added anhydrous gypsum as 4 % SO₃ contained in GGBS. In addition, mix proportion using γ -C2S were added it 20% as powder substitution. We use LEAF (Denka Co., Japan) as γ -C2S. The mix proportion was set at a constant water-cement ratio of 50% and powder: fine aggregate ratio was set at 1:3. We mixed using mortar mixer, and cast it into specimens of 40×40×160mm.

Symbol	W/P [%]	P:S	GGBS		Binder ratio [weight %]		CO ₂ emission	
			Replacement	fineness	Bilder fatto [weight %]			of binder
			[%]	[cm ² /g]	OPC	GGBS	γ-C2S	[g/kg]
Ν	50	1:3	0	-	100	0	0	764
BA			30	4000	70	30	0	543
BB			50		50	50	0	395
BC			70	3000, 4000, 8000	30	70	0	247
N·γ			0	-	80	-	20	643
BA·γ			30	4000	56	24	20	466
BB·γ			50		40	40	20	348
BC·γ			70	3000, 4000, 8000	24	56	20	230

Table1 Mix Proportion of Mortar

2.2 Curing condition

After casting the mortar, the specimens were demolded at the age of 2 days and were cured in 3 types of environment; carbonation (20°C, 60% RH, CO₂ concentration was 5%), water curing (20°C, 60% RH), air curing (20°C, 60% RH, CO₂ concentration was 0.05%) for 7, 28, and 56 days.

2.3 Testing methods

After curing, flexural strength and compressive strength test was carried out according to JIS R 5201. Also, carbonation depth was measured by spraying with a 1% solution of phenolphthalein at the broken cross-section between flexural strength test and compressive strength test. In addition, we measured pore amount on BA, BB, and BC which age was 56 days, because they weren't coloured all area by phenolphthalein sprayed. As a sample, we used one of the pieces after measuring carbonation depth, which were cut parallel to the cross section by wet cutter. CO_2 absorption was also measured in some sample.

2.3.1 Measuring amount of CO2 absorption

The CO₂ absorption was measured by differential thermos-gravimetric analysis (TG-DTA) date using carbonation area that didn't colored by phenolphthalein. The age of all sample were 56 days. All of samples were granulated by hammer and preserved in acetone for 4 hours and after that dry by a vacuum desiccator to stop hydration. TG-DTA was performed from room temperature to 1000°C at a heating rate of 20°C/min. under nitrogen. Figure1 shows how to calculate the amount of CO₂ absorption. The decarbonation ratio was determined from the weight loss at 550 to 850°C because the inflection point of the DTA curve wasn't clear. And all so, the amount of CO₂ absorption was calculated from the difference in the decarbonation ratio between before and after of carbonation.



Figure 1 method of calculated amount of CO2 absorption

2.3.2 Porosity test

The samples were saturated with water by a vacuum desiccator. After measuring the saturated weight and the weight in water, the samples were left to dry at 40°C until their weights became constant, and the weight in an absolutely dry state was then measured. Porosity was calculated by Archimedes method.

3. Results and discussion

3.1 Carbonation depth and amount of CO₂ absorption

Figure 2 shows the carbonation depth. Regardless of using γ -C2S or not, BB and BC weren't colored all area by phenolphthalein sprayed at 28days. Also, BA weren't colored all area at 56 days. Focusing on the effect of using γ -C2S when the all area were not carbonated, low GGBS replacement rates show that carbonation depth of using γ -C2S resulted deeper than without γ -C2S. On the other hand, high GGBS replacement rates show that carbonation depth of using γ -C2S resulted smaller than without γ -C2S. Figure 3 shows the relationship between the percentage of CaO in the binder and the amount of CO₂ absorption in carbonation area. The red dotted line is maximum capability of CO₂ absorption that caluculated from the amount of CaO. The case of using GGBS show correlation, and the lower GGBS replacement rates is closer to the maximum. But N was out of line regardless of using γ -C2S or not. Therefor, the using well combination of admixtures not only reduce CO₂ emissions, but also be able to made the high potential of CO₂ absorption. Eventually, it will be expected to lead the CO₂ balance.



3.2 Carbonation and compressive strength

Figure 4 shows the relationship between GGBS replacement ratio and compressive strength of GGBS with Blaine's fineness of 4000 cm²/g at 56 days of age. The result without γ -C2S, the strength of N, BA, and BB increased in the order of water curing, carbonation, and air curing. But for BC with high GGBS replacement

ratio, carbonation resulted in lower strength development than the other curing conditions. On the other hand, the results of using γ -C2S, N, BA, and BB showed the highest strength development in carbonation, and the strength of BC was comparable to that in water curing. Figure 5 shows the results of BC using different fineness of GGBS. Using higher fineness GGBS resulted higher strength, but similar trends were observed in the difference of curing methods.



3.3 Carbonation and pore structure

Figure 6 shows the porosity of BC at 56 days. The case of without γ -C2S, the total porosity with carbonation was larger than with water curing. But using γ -C2S, it was had the opposite result.

Figure 7 shows the moisture deviation rate in pore from water discharge condition to absolutely dry at 40°C. Regardless of using γ -C2S or not, the samples with carbonation showed faster rate of water deviation than water curing in the early time of drying. Mizuno et al. reported that concrete with GGBS has a complex pore structure, but carbonation of C-S-H caused pore coarsening and changing to continuous pore structure. We assume that BC with carbonation increased the speed of water deviation by changing to continuous pore structure. However, CaCO₃ which produced by carbonation of γ -C2S filled in some of pore and also increased strength.



4. Conclusions

Mortars with high GGBS replacement with carbonation showed an increase in total porosity and also tendency for compressive strength to be less pronounced than water curing. However, the combination of the addition of γ -C2S and carbonation showed a trend toward improvement in both of them.

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