

# Investigating the Mechanism of Carbonation on Different Concentration of Carbon Dioxide

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## ABSTRACT

In recent year, powder admixture are used in the cement industry to reduce carbon dioxide emissions. Blast Furnace Slag powder (BFS) can be set at a high replacement rate, and the amount used is large. Cement using BFS has some merits, but it has low resistance to carbonation. Previous studies have reported that the progress of carbonation of concrete using ordinary portland cement and blast furnace cement is not equivalent. In Japan, according to Japanese industrial standards, carbonation is determined through accelerated carbonation test, by making use of 5% of carbon dioxide at 60% humidities and 20°C of temperature. But in reality there are some difference between the natural carbonation and accelerated carbonation. In this study, carbonation would be investigated on the hardened mortar made with slag cement and also clarify the mechanism of carbonation by carrying out different carbon dioxide concentration. We mainly focused on calcium hydroxide (CH) and C-S-H which are key products of hydrations that form carbonation. Considering the mechanism of carbonation between the natural environment and accelerated environment including the chemical characteristics of CH and C-S-H.

**KEYWORDS:** BFS, Accelerated carbonation test, Carbonation rate coefficient, CH, C-S-H

## 1. Introduction

There are various deterioration phenomena which must be considered in durability evaluation of cement hardened. For example, Carbonation, salt damage, ASR and chemical erosion etc. And these deterioration phenomena slowly appear after years of many years. For that reason many studies evaluate deterioration phenomena by accelerated test. Accelerated test are carried out by increasing the concentration of deterioration factors, exposing it to a high temperature environment, or using electric action. That means the hardened cement will be exposed to the very severe conditions as compared with the natural environment. As a result, it is believed to have different reactions for example in acid resistance tests like in acid rain and reactions in sewers. In this research, we focused on accelerated test and differences in the natural environment with carbonation. The mechanism of carbonation is that carbon dioxide in the air enters from the surface of the hardened cement and reacts with the hydrate in the hardened to produce calcium carbonate. The chemical reaction formula at that time is as shown in Formula (1)(2).



This research assumed that the carbonated hydrate is CH and C-S-H which occupy most of the cement hardened. Consideration of the influence on the carbonation rate when the amount of hydrate in cement hardened and C/S of C-S-H are changed using blast furnace slag fine powder (BFS).

## 2. Outline of Experimental

### 2.1 Using Material and Speciment

Table 1. show the chemical composition of the Ordinary Portland Cement (OPC) and BFS. Table 2. show the mix proportion of cement hardened. The size of cement hardened is 40×40×160mm. Water-

Binder ratio (W/B) is 50%, Sand and Cement ratio (S/C) is 3:1. In this study, BFS is used at different mixing ratio of 0% (B0), 20% (B20), 50% (B50), 70% (B70) as binder. The specimens were demolded at the next day from casting. Curing method was non-curing, sealing curing for 7 days, 28 days (and 56 days for compressive strength). In this case non-curing means that carbonation test was carried out immediately after demolding.

**Table 1. Chemical Components of Materials**

Cement	Density [g/cm <sup>3</sup> ]	Specific surface area [cm <sup>2</sup> /g]	Contents (mass%)											
			SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	MnO	Cl
OPC	3.16	3500	21.28	5.09	3.15	65.36	1.01	2.01	0.32	0.41	0.25	0.14	0.1	0.006
BFS	2.91	4290	33.42	13.43	-	43.29	6.02	2.62	0.27	0.3	0.6	0.01	0.18	0.004

**Table 2. Mix Proportion for Binders**

Symbol	W/B (%)	S/C	Ratio of Binder (weight %)	
			OPC	BFS
B0	50	3	100	0
B20			80	20
B50			50	50
B70			30	70

## 2.2 Compressive Strength Test

After sealing curing for 7 days and 28 days, 56days we had a compressive test of cement hardened in reference to JIS R 5201.

## 2.3 Carbonation Tests

After sealing curing for 7 days, 28 days and non-curing cement hardened carbonation test was carried out natural carbonation (Outdoor environment without rain) and accelerated carbonation environment (temperature 20°C, relative humidity 60%, CO<sub>2</sub> concentration 5%). The carbonation depth at that time is set to 0mm. The casting surface of the cured and opposite side of size 40×40 mm were both sealed with aluminum tape and the two open surfaces were carbonate. The carbonation depth was measured in compliance with JIS.

## 3. Results and Discussion

### 3.1 Compressive Strength Test

Figure 1. show the result of compressive strength after each curing. Compressive strength was decrease as BFS replacement ratio increase. And focusing on the different age of curing, the compressive strength increases in all mix proportion as the age also increase.

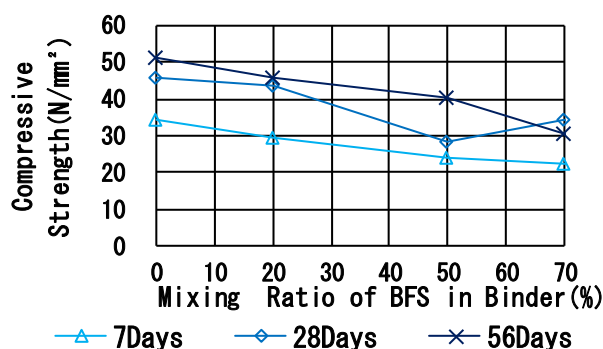


Figure 1. Compressive Strength

### 3.2 Carbonation Tests

Figure 2.-7. show the time course of carbonation depth for each mix proportion by different curing period. Figure 2. 4. 6. were results from natural environment. And the others were results from accelerated environment. Carbonation depth of natural environment and accelerated environment were

increased as BFS replacement ratio increase. Focusing on the difference of curing type, the specimen on long curing period shows the lower carbonation depth.

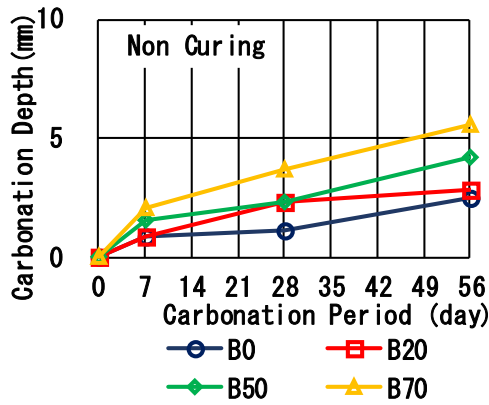


Figure 2. Time course of carbonation depth (natural environment non-curing)

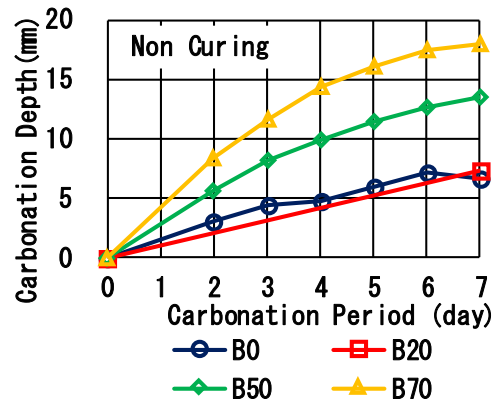


Figure 3. Time course of carbonation depth (accelerated environment non-curing)

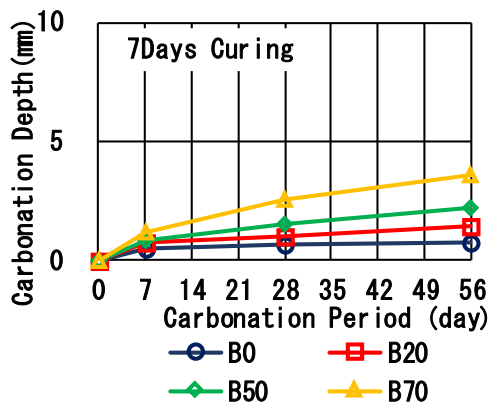


Figure 4. Time course of carbonation depth (natural environment 7days curing)

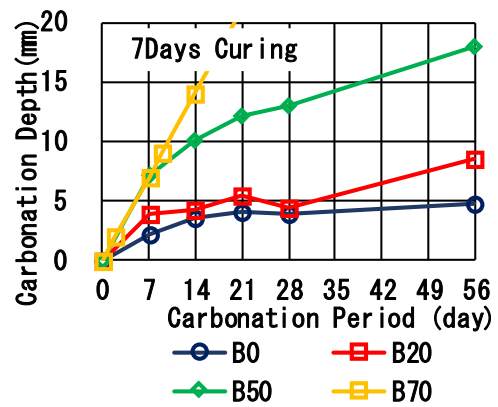


Figure 5. Time course of carbonation depth (accelerated environment 7days curing)

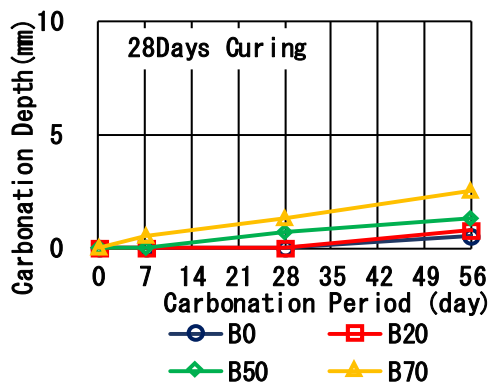


Figure 6. Time course of carbonation depth (natural environment 28days curing)

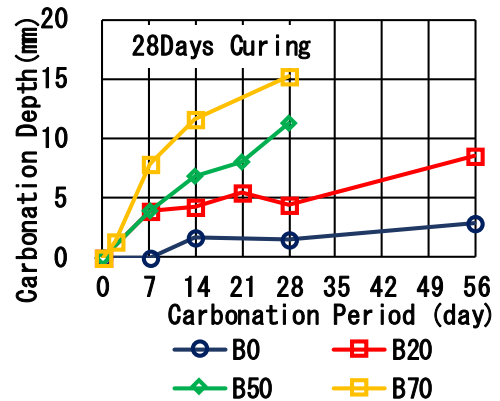


Figure 7. Time course of carbonation depth (accelerated environment 28days curing)

### 3.3 Carbonation Coefficient Rate

Since carbonation is generally organized based on the carbonation coefficient rate, the horizontal axis of Fig. 2-7 is set to square and the slope corresponding to the carbonation coefficient rate. The carbonation coefficient rate increases as the replacement rate increases. By curing the value of carbonation coefficient rate can be greatly reduced. And the carbonation coefficient rate in the natural environment and accelerated environment shows nearly the same behavior, its value is about 10 times.

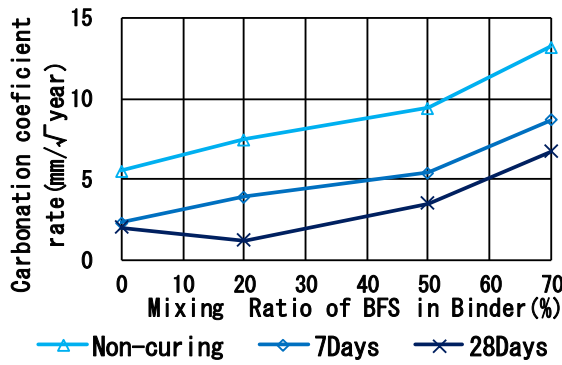


Figure 8. Carbonation Coefficient Rate (natural environment)

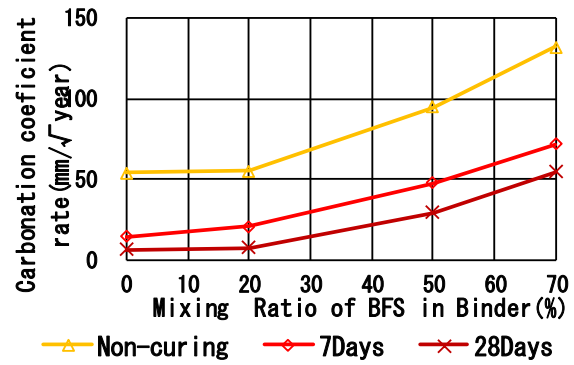


Figure 9. Carbonation Coefficient Rate (accelerated environment)

#### 4.1 Experimental Observation

Pictures of carbonation tests were shown in the Figure 10. In this picture the upper row shows the results of carbonation test at the same age. The lower row was at the same carbonation depth at different carbonation periods. Focus on each difference, it was confirmed the gradation of the phenolphthalein solution in B0 and B20 of promotion tests. And we were trying to examine why such a thing happened on the next chapter.

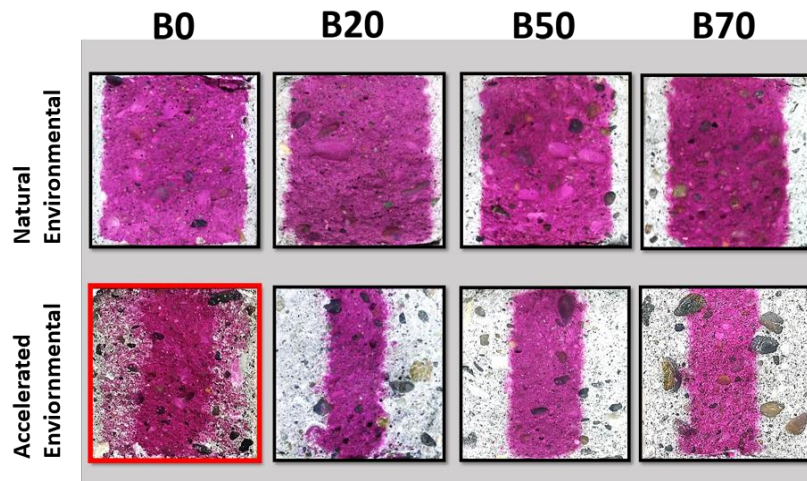


Figure 10. Picture of Carbonation Test

#### 4.2 Carbonation Mechanism

Here, it is assumed that the hydrates to be carbonated are CH and C-S-H. Consider the characteristics of each hydrate. Since CH has a large particle diameter of about 10 $\mu$ m and a small specific surface area, the progress of carbonation is not large. However, carbonation proceeds even if the concentration of carbonate ion in the pore solution is low. On the other hand, since C-S-H has one size of the structure about 10nm and the specific surface area is large, the progress of carbonation is large. However, the reaction does not proceed unless the concentration of carbonate ion in the pore solution is high. From this theory, when the supplied amount of carbon dioxide gas is small like the real environment, if carbonation of CH progresses and consumption is completed due to low concentration of carbonate ion. At that time, in the portion where CH has been consumed, concentration of carbonate ion increases and carbonation of C-S-H proceeds. On the other hand, when the supplied amount of carbon dioxide is extremely large like the accelerated environment, the concentration of carbonate ion instantaneously increases. Therefore, carbonation of C-S-H and CH proceeds. Since the carbon dioxide gas concentration is high, the penetration from the surface to the depth progresses and the carbonation depth progresses, but all the large CH particles are not carbonated and carbonation progresses while remaining. We believe this is the cause of the gradation at the carbonation depth judged by the

phenolphthalein solution, and we are planning to analysis the chemical composition in the future.

## 5. Conclusions

The following was found after carrying out the Carbonation test when cement hardened replaced with BFS was used.

[1] Compressive strength showed higher values with lower replacement rate of BFS and longer curing period.

[2] The carbonation depth is also the same as the compressive strength, the value becomes smaller.

[3] The value of the carbonation coefficient rate was found to be about 10 times more different between the natural environment and the accelerated environment.

[4] In the natural environment, the supplied amount of carbon dioxide gas is small like the real environment, if carbonation of CH progresses and consumption is completed due to low concentration of carbonate ion. At that time, in the portion where CH has been consumed, concentration of carbonate ion increases and carbonation of C-S-H proceeds.

[5] In the accelerated environment, the concentration of carbonate ion instantaneously increases. Therefore, carbonation of C-S-H and CH proceeds. the penetration from the surface to the depth progresses and the carbonation depth progresses, but all the large CH particles are not carbonated.

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