RILEM Week 2023
Vancouver, BC, Canada
September 4-8, 2023

STUDY ON THE CAUSES THAT EFFECT OF CARBONATION ON THE ELASTIC MODULUS OF DIFFERENT CURED CONCRETE AND MORTAR CONTAINING HIGH GGBS CONTENT

Noguchi.Y.[1], Yahiro.R.[2], and Iyoda.T.[2]

[1] Master student, Graduate School of Shibaura Institute of Technology, mh23027@shibaura-it.ac.jp
[2] Master student, Graduate School of Shibaura Institute of Technology, mh22020@shibaura-it.ac.jp
[3] Professor, Shibaura Institute of Technology, iyoda@shibaura-it.ac.jp

ABSTRACT

Concrete using Ground granulated blast-furnace Slag (GGBS) has been widely used for a long time because it is expected to improve long-term compressive strength, high durability, and reduce environmental impact. However, previous studies have shown that GGBS is sensitive to the surrounding environment and easily carbonated, and it is necessary to know its compressive strength and elastic modulus in such an environment. In this study, concrete and mortar with different replacement ratios of GGBS were prepared to compare the compressive strength and elastic modulus of concrete and mortar. The specimens were cured under various environmental conditions, such as in tap water, in air and accelerated carbonation curing. The compressive strength and elastic modulus tests were conducted. As a result, a decrease in the elastic modulus was observed for specimens with a higher replacement ratio of GGBS on carbonated curing. This is thought to be caused by differences in the physical properties of the aggregate and cement paste, shrinkage of the matrix, or microscopic cracking due to hydration, and an investigation is underway to determine the cause.

Keywords: *Concrete, Elastic Modulus, Carbonation, Ground granulated blast-furnace slag.*

Noguchi,Y

3-7-5, Toyosu, Koto-ku, Tokyo, 135-8548

Email: mh23027@shibaura-it.ac.jp| **Tel:** +81 3-5859-8356 | **Web:** www.db.shibaura-it.ac.jp/~iyoda/

1. INTRODUCTION

Japan has declared that the sum of CO_2 emissions and absorption will be virtually zero by 2050. The concrete industry is working to reduce CO_2 emissions from the cement production process. The effort is the development of concrete using large amount of ground granulated furnace slag (GGBS), as a replacement for cement. Furthermore, since GGBS is latent hydraulic, it is expected to enhance long-term strength and durability. However, GGBS is known to be sensitive to its surroundings and to be carbonates easily. It is necessary to understand the effect of environmental difference on the properties of concrete using GGBS. Previous studies on concrete with large amount of GGBS have shown that cement pastes replaced with GGBS have a significant increase in accidental shrinkage compared to ordinary Portland cement (OPC) [1]. Also, since specimens replaced with GGBS are easily carbonated, the effect of carbonation shrinkage should be considered. In addition, carbonation of the specimen is said to cause coarsening of the porosity [2]. There is concern about the effect of carbonation on physical properties, but details are scares. Therefore, in this study, I measured the compressive strength and elastic modulus of concrete under various environments including carbonated environment. The purpose of this study is to investigate the effects of carbonation on the compressive strength and elastic modulus of concrete and determine the causes of such effects.

2. CORRELATION BETWEEN COMPRESSIVE STRENGTH AND ELASTIC MODULUS OF CONCRETE

2.1. Outline of experiments

In this study determine the effect of GGBS replacement rate and environment on the elastic modulus of concrete. Compressive strength and elastic modulus tests were performed on the specimens prepared cylindrical specimens of φ100*200mm. **Table-1** shows the mix proportions of concrete. The amount of GGBS was replaced by cement at 0~80%. Since the porosity around the aggregate may affect the elastic modulus, tests were conducted to compare the elastic modulus for different replacement rates of GGBS while the amount of aggregate was kept constant. Considering the amount of SO_3, SO3 was adjusted to 2% and 4% by replacing gypsum with GGBS.

Table-1. Mix proportions of concrete

No.	W/B (%)	s/a (%)	Unit weight(kg/m^3)					
			W	OPC	GGBS (SO_3 2%)	GGBS (SO_3 4%)	S	G
N	55	50	168	305	-	-	897	932
B55			165	135	165	-		
B70			164	90	-	210		
B80			165	60	239	-		

The curing process is shown in **Figure-1**.After the concrete specimens were cast, they were sealed and cured in a constant temperature and humidity chamber(temperature: 20℃, relative humidity : 60%) for 2 days. The specimens were then removed from the formwork and were cured under various environmental conditions, such as in tap water, in air and accelerated carbonation curing. In addition, to consider the effect of drying of the specimens in the early stages of hydration, some of the specimens which was cured in tap water for 26days moved to air conditions. The specimens were cured in the air until the day of the test was conducted.

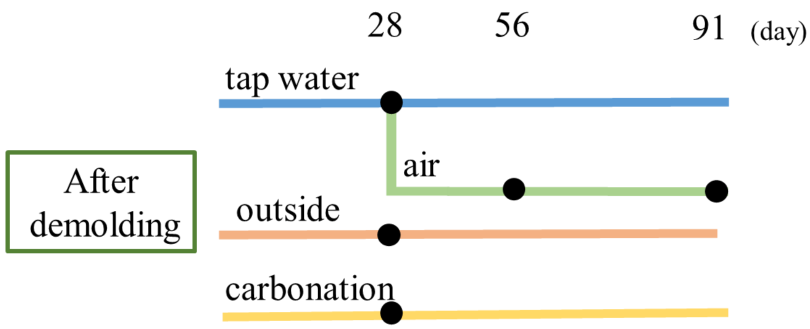

Figure-1. The curing processes.

2.2. Compressive strength and elastic modulus test

The tests were conducted on cylindrical specimens in accordance with JIS A 1108 and JIS A 1149. The tests were conducted at 28, 56, 91days of age.

2.3. Results of compressive strength and elastic modulus test

The results of elastic modulus tests for each concrete age are shown in **Figure-2**. The relationship between compressive strength and elastic modulus is shown in **Figure-3**. The dotted line in the figure shows the estimation equation of the elastic modulus given in the "Standard Specification for Concrete [Design]" edited by JSCE (equation 1) and the "Standard for Calculation of Reinforced Concrete Structures (2018)" edited by AIJ (equation 2).

[JSCE]

$$Elastic\ Modulus\ of\ concrete = 3.35 \times 10^4 \times \left(\frac{\gamma}{2.4}\right)^2 \times \left(\frac{\sigma_B}{60}\right)^{1/3} \quad (1)$$

Where γ means the unit volumetric mass of concrete and σ_B means the compressive strength of concrete.

[AIJ]

$$Elastic\ Modulus\ of\ concrete = 1.0 \times 0.95 \times 3.35 \times 10^4 \times \left(\frac{\gamma}{2.4}\right)^2 \times \left(\frac{\sigma_B}{60}\right)^{1/3} \quad (2)$$

The elastic modulus essentially increases as compressive strength increases, as shown in the estimated equation. In this study, the elastic modulus increased with compressive strength under all curing conditions for N. On the other hand, the compressive strength of the B55 under accelerated carbonation curing and cured in air is only about 80% of the value obtained by applying the estimated equation. In addition, accelerated carbonation cured specimens in B70 and B80 with high GGBS replacement showed a slight increase in compressive strength compared to demolded specimens, but the increase was small compared to N. In addition, the elastic modulus was not accompanied by an increase in compressive strength, stagnation or decrease was observed. A slight decrease in the elastic modulus was also observed in the B55 and B80 specimens cured in air compared to the accelerated carbonation curing. These results suggest that drying or carbonation of the specimens was a common condition that caused the elastic modulus of concrete to stagnate or decrease.

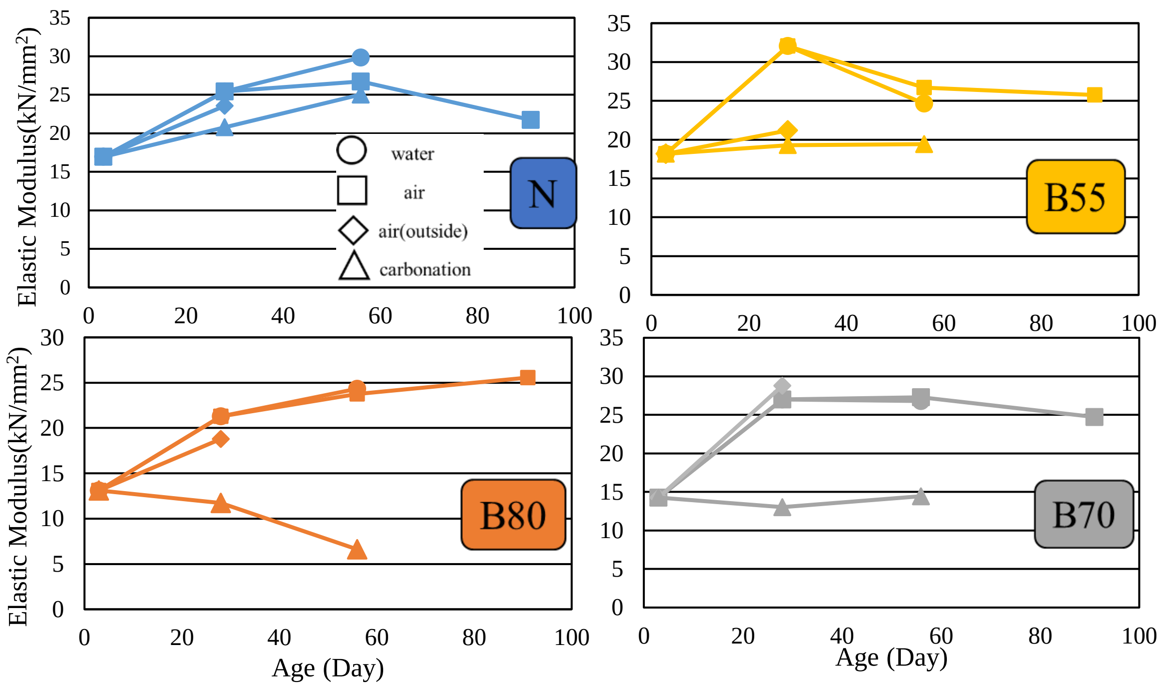

Figure-2. The results of elastic modulus tests for each concrete age

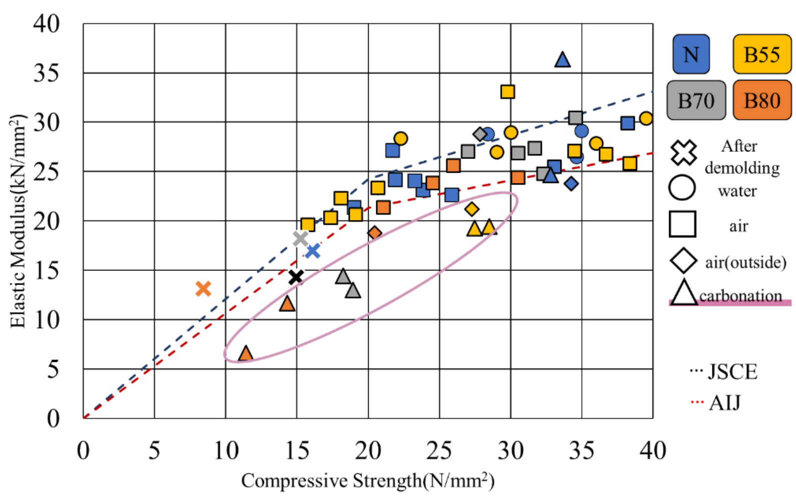

Figure-3. The relationship between compressive strength and elastic modulus

To check for cracks in the surface layer of the specimen, specimens were immersed in acetone and the cracks were visually observed in **Figure-4**. The results by mix proportion and curing environment are shown in **Table-2**. Microcracks were observed on the surface layer of the concrete with reduced the elastic modulus.

Figure-4. Microcracks of concrete

Table-2. The results by mix proportion and curing environment

	water	air	carbonation	outside
N	×	-	-	△
B55	×	-	-	△
B70	×	○	○	△
B80	×	○	○	△

○ observed
△ little
× No cracks

3. EFFECTS OF MICROCRACKS IN THE SPECIMEN ON THE SURFACE LAYER

The microcracks were observed on the surface layer of concrete with a reduced elastic modulus under the conditions where the amount of aggregate was kept constant and the effect of the amount of porosity around the aggregate was eliminated. Shrinkage within the cement matrix in a dry or carbonated environment is considered to have caused microcracks on the surface of the specimens. To verify this, tests were conducted on mortar.

3.1. Mix proportion and Experimental Outline

The mortar mix proportion are shown in **Table-3**. W/B was set to 50%, GGBS ratio of 50~80% and a binder to sand mass ratio of 1:3. As with concrete, GGBS with a 4% replaced gypsum in GGBS was also used I B70 to consider the amount of gypsum. After 2days of sealing and curing after mortar placement, accelerated carbonation curing (CO_2 concentration: 20%) and in-air curing with nitrogen flow (CO_2 concentration: 0%) were performed. Φ50*100mm cylindrical specimens were prepared for B50, B70 and B80 and compressive strength and elastic modulus tests were performed. The tests were conducted by spraying the specimens with phenol phthalein solution when the half of the cracked surface was colored (half carbonated), and when the entire cracked surface was not colored (fully carbonated). The specimens were immersed in acetone as in the case of concrete, and the cracks in the surface layer of the specimens were visually observed.

Table-3. Mix proportions of mortar

No.	W/B (%)	Binder ratio(%)		
		OPC	GGBS (SO_3 2%)	GGBS (SO_3 4%)
B50	50	50	50	-
B70-1		30	70	-
B70-2		30	-	70
B80		20	80	-

3.2. Effects of microcracks in the surface layer

Figure-5 shows the appearance of cracks in the mortar. In the concrete, fine cracks were observed on the surface layer of the specimens that had undergone accelerated carbonation curing and outdoor exposure. However, in the mortar, fine cracks could not be observed in the specimens that were subjected to accelerated carbonation curing.

Figure-5. The appearance of cracks in the mortar

3.3. Effects of microcracks inside of the specimen

The rate of change in compressive strength and elastic modulus of mortar from the base values at demoulding is shown in **Figure-6. Figure-7** shows the elastic modulus of mortars at half and full carbonated for different gypsum contents. The elastic modulus of the specimens cured in air increased as the compressive strength of the specimens increased. On the other hand, in the case of specimens subjected to accelerated carbonation curing, compressive strength increased as in the case of air curing, but the elastic modulus clearly decreased. However, the elastic modulus at half carbonated of B70-2 with doubled gypsum content as smaller than that at after demolding, but larger when fully carbonated.

Therefore, it was suggested that even if no microcracks were observed on the surface of the specimens, changes in the inside of the mortar maybe largely responsible for the decrease in the elastic modulus. The decrease in the elastic modulus is due to the astrain caused by the microcracks within the specimen, which made the specimen more easily deformable. On the other hand, since the cracks are microscopic, the specimen can be deformed along the cracks, thus increasing the compressive strength of the specimen, and allowing force transmission. Moreover, **Figure-7.** shows that the behaviour of the elastic modulus changed significantly depending on the amount of gypsum.

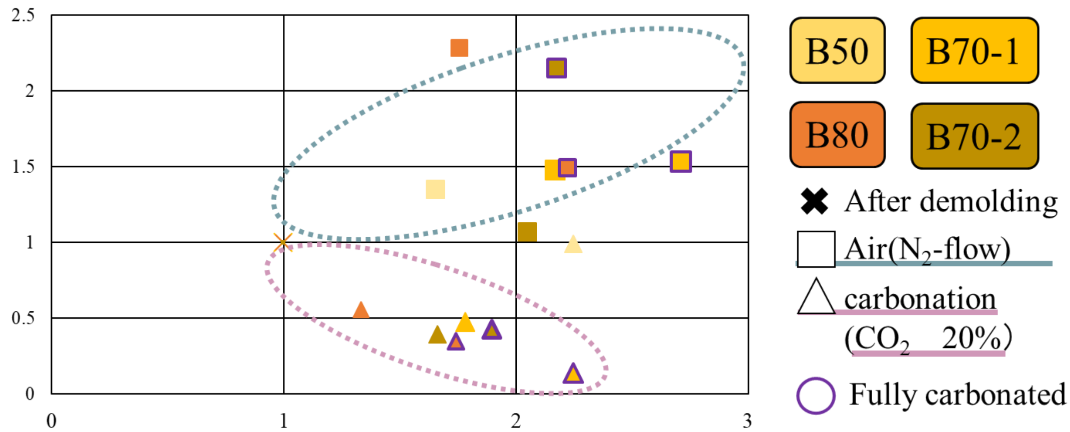

Figure-6. The rate of change in compressive strength and elastic modulus of mortar as compares to demolding.

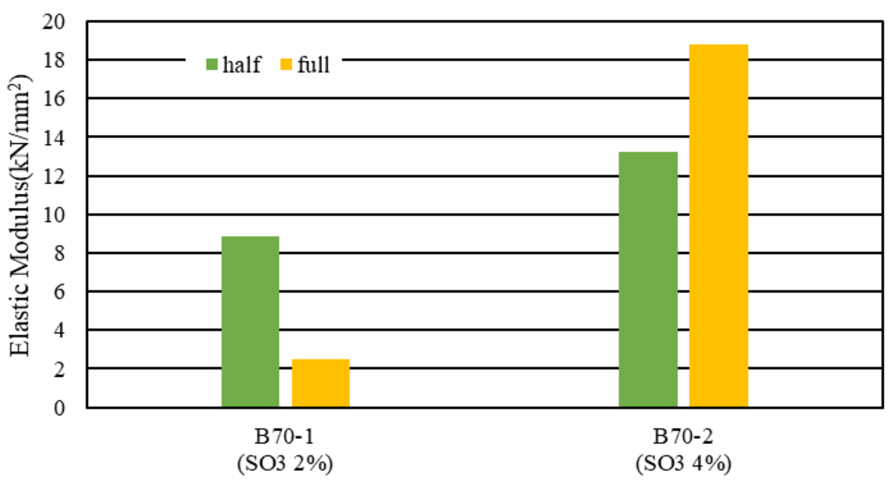

Figure-7. The elastic modulus of elastic modulus at half and full carbonated for different gypsum contents

In the future, we will be conducting a study to confirm that microcracks are present at the aggregate interface or in the cement matrix. We are planning to conduct further investigations by means of permeability and porosity tests to confirm that fine cracks are formed at the aggregate interface or in the cement matrix. Therefore, permeability, and porosity tests to confirm that fine cracking occurs at the aggregate interface or in the cement matrix. Equally it is necessary to consider the amount of gypsum. **Figure-7** suggests that the amount of gypsum has a significant effect on the change in the elastic modulus under carbonation curing. I would like to study a mix proportion which the amount of gypsum in the GGBS is varied so that elastic modulus does not decrease even if the GGBS is highly replaced.

4. CONCLUSIONS

1) Carbonation curing significantly reduces the elastic modulus of concrete and mortar with high GGBS content. Microcracks in the surface layer of the specimen occurred in the concrete but not in mortar. This suggests that the microcracks in the surface layer of the specimens were not the direct cause of the reduction in the elastic modulus.
2) Considering that carbonation causes cracks inside the test specimen will be distorted along the cracks. However, the movement of the aggregate along the cracks allowed force transmission and did not significantly affect the compressive strength.
3) When a high percentage of GGBS was replaced, the elastic modulus at full carbonated was found to be larger than that at half carbonated by doubling the amount of gypsum. It is inferred that the amount of gypsum greatly contributed to the elastic modulus under carbonation environment.

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