The 16th International Congress on the Chemistry of Cement 2023 (ICCC2023)
"Further Reduction of $CO_2$ -Emissions and Circularity in the Cement and Concrete Industry"
September 18–22, 2023, Bangkok, Thailand

# Effect of Mix Proportion as W/C and Amount of GGBS Contents on $CO_2$ Adsorption

**R. Yahiro[1*], M. Kojima[2], and T. Iyoda[3]**

[1] *Shibaura Institute of Technology, Tokyo, Japan*
*Email: mh22020@shibaura-it.ac.jp*
[2] *Takenaka Corp., Chiba, Japan*
*Email: kojima.masarou@takenaka.co.jp*
[3] *Shibaura Institute of Technology, Tokyo, Japan*
*Email: iyoda@shibauta-it.ac.jp*

## ABSTRACT

In recent years, there has been a growing movement in the world toward the realization of a carbon neutral society as a measure against global warming. There are also a number of efforts in the construction industry. Types of cement with a high percentage of admixture replacement are becoming widely used to reduce $CO_2$ emissions during cement production. In addition, technology that uses the carbonation reaction of concrete to adsorb $CO_2$ into concrete is attracting attention. At higher W/C, $CO_2$ penetrates deeper into the concrete because of the larger pores, resulting in a greater depth of carbonation. In this study, we examined the effect of different mix proportions on the amount of $CO_2$ adsorption. Cement pastes with different W/C and blast furnace slag fine powder substitution rates were carbonated in a high concentration $CO_2$ chamber and measured the amount of adsorption, considering the ease of $CO_2$ penetration. As a result, a tendency was observed that the $CO_2$ penetrates more deeply, and the amount of $CO_2$ adsorption is higher in mix proportion with high blast furnace slag fine powder content or high W/C. Also, it shows a trend that the potential to adsorb $CO_2$ is greater as the CaO percentage that the sample has is increased.

**KEYWORDS:** *$CO_2$ adsorption, ground granulated blast furnace slag, carbonation reaction, $CO_2$ penetration*

## 1. Introduction

In recent years, rising seas, droughts, floods, and extreme weather conditions caused by global warming have occurred in the world. Therefore, as a measure against global warming, there is a growing movement toward the realization of a carbon-neutral society, in which the sum of emissions and absorption of the greenhouse gases that cause the problem is substantially zero. There are also a number of initiatives being undertaken in the construction industry. It is a problem of $CO_2$ emissions during cement production. In an effort to reduce $CO_2$ emissions from the cement production process, cement with high replacement of admixtures such as ground granulated blast furnace slag or fly ash is being used. In addition, there has been a growing interest in technologies that use the carbonation reaction of concrete in order to absorb $CO_2$ into the concrete. Considering the carbonation reaction, even if the concrete is carbonated in the same period of time and in the same environmental place, the ease of $CO_2$ penetration is different depending on the types of cement and W/C. Therefore, the carbonation depth is different. $CO_2$ absorption cannot be determined by only the carbonation depth because different types of W/C and cement absorb different amounts of $CO_2$ when carbonated.

In this study, we prepared specimens of cement paste with different types of cement and W/C. Accelerated carbonation was applied. The sample was divided, and the $CO_2$ absorption was calculated for each part of the sample. This allowed us to study the quantification of $CO_2$ absorption considering the ease of $CO_2$ penetration and the $CO_2$ absorption potential of different types of cement.

## 2. Materials and outline of experiments

### 2.1 Materials and mix proportions

In this study, cement paste samples were used to eliminate the influence of aggregate as a fundamental study. The mix proportion is shown in Table 1. The experiment was conducted with four mix proportions, different types of cement and different W/C. As cement, Ordinary Portland Cement (OPC) and Blast Furnace Cement, which is made by replacing ground granulated blast-furnace slag (GGBS) with OPC, were used in the test. The blast furnace slag cement was set as BB with 50% replacement of GGBS and BC with 70% replacement of GGBS. Table 2 also shows the chemical composition of OPC and GGBS. The amount of CaO in the cement was changed by changing the percentage of GGBS.

**Table 1 Mix proportion of cement paste**

| No. | Type of cement | W/C (%) | Unit weight (kg/m$^3$) | | |
|---|---|---|---|---|---|
| | | | W | OPC | GGBS |
| N30 | OPC | 30 | 487 | 1622 | - |
| N50 | OPC | 50 | 612 | 1225 | - |
| BB50 | BB | 50 | 602 | 602 | 602 |
| BC70 | BC | 70 | 675 | 289 | 675 |

**Table 2 Chemical Compositions of OPC and GGBS**

| | Chemical composition (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $SiO_2$ | $Al_2O_3$ | FeO | $Fe_2O_3$ | CaO | MgO | $TiO_2$ | MnO | $SO_3$ | $Na_2O$ | $K_2O$ | $P_2O_5$ |
| OPC | 20.19 | 5.18 | - | 2.78 | 65.01 | 1.18 | 0.25 | 0.15 | 2.10 | 0.31 | 0.36 | 0.16 |
| GGBS | 33.27 | 13.94 | 0.31 | - | 40.00 | 5.47 | 0.57 | 0.15 | 1.99 | 0.26 | 0.26 | 0.02 |

### 2.2 Calculation of $CO_2$ absorption

Figure 1 shows the outline of the experiment. Rectangular specimens of 40×40×160mm were casted, demolded the day after placing, and sealing cured for 7 days. After curing was completed, the sides were sealed with aluminium tape and one 40×40mm surface was released. The specimens were placed in an accelerated carbonation chamber (20°C, 60% RH, 5% $CO_2$ concentration) for 28 days of accelerated carbonation. After carbonation, they were sliced at 10 mm intervals from the release surface and treated with acetone to stop the hydration reaction. The measurement of TG-DTA was performed under $N_2$ flow environment with a temperature increase rate of 20°C/min from room temperature to 1000°C. The $CaCO_3$ content ratio was calculated by using the inflection point of the peak in the DTA curve to estimate the amount of decarbonation. Amount of $CO_2$ absorption was calculated using difference in $CaCO_3$ content ratio between carbonated and uncarbonated. In addition, specimens made under the same conditions were saturated with water under vacuum conditions, and the saturated mass and mass in water were measured. After that, the specimens were placed at 40°C, 30% RH until the mass loss became constant, and then the dry mass was measured. Porosity was calculated by Archimedes' method using saturated mass, mass in water, and dry mass.

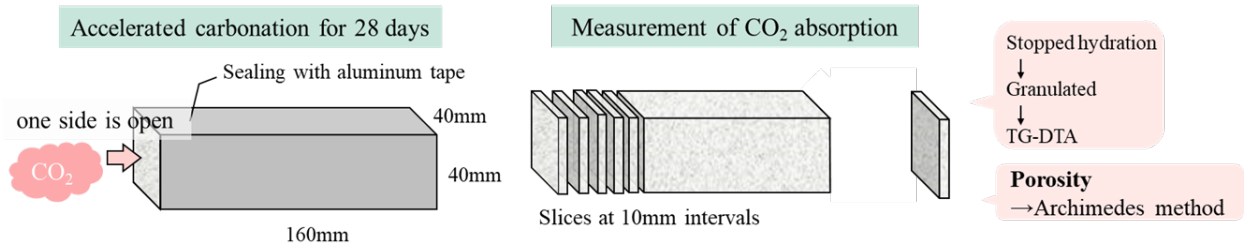


**Figure 1 Outline of the experiment**

The amount of $CO_2$ absorption per sliced 40×40×10mm sample which volume is 16 cm$^3$, with porosity taken into account, was calculated using Equation (1).

$$CO_2 \text{ absorption[g]} = \text{density}\left[\text{g/cm}^3\right] \times \text{Volume}(16\text{cm}^3) \times (1\text{-Porosity}) \times A[\%] \times \frac{44}{100} \quad (1)$$

where, A: difference in $CaCO_3$ content ratio between carbonated and uncarbonated

## 3. Results and discussion

### 3.1 $CO_2$ absorption as hardened cement

Figure 2 shows the amount of $CO_2$ absorption in each mix proportion for each sliced sample. The horizontal shows the distance from the surface in contact with the $CO_2$. N30 and N50 were not completely carbonated even at 10 mm from the surface. On the other hand, carbonation reached 20 mm in BB50 and 40 mm in BC70. It is clear that the depth of $CO_2$ absorption is different depending on the types of cement and W/C as well as the carbonation depth. It was found that in the order of BC70, BB50, N50, and N30, $CO_2$ was absorbed more deeply into the specimen. In BC70, $CO_2$ absorption from 0~10 mm, 10~20 mm, and 20~30 mm was about the same in each layer.

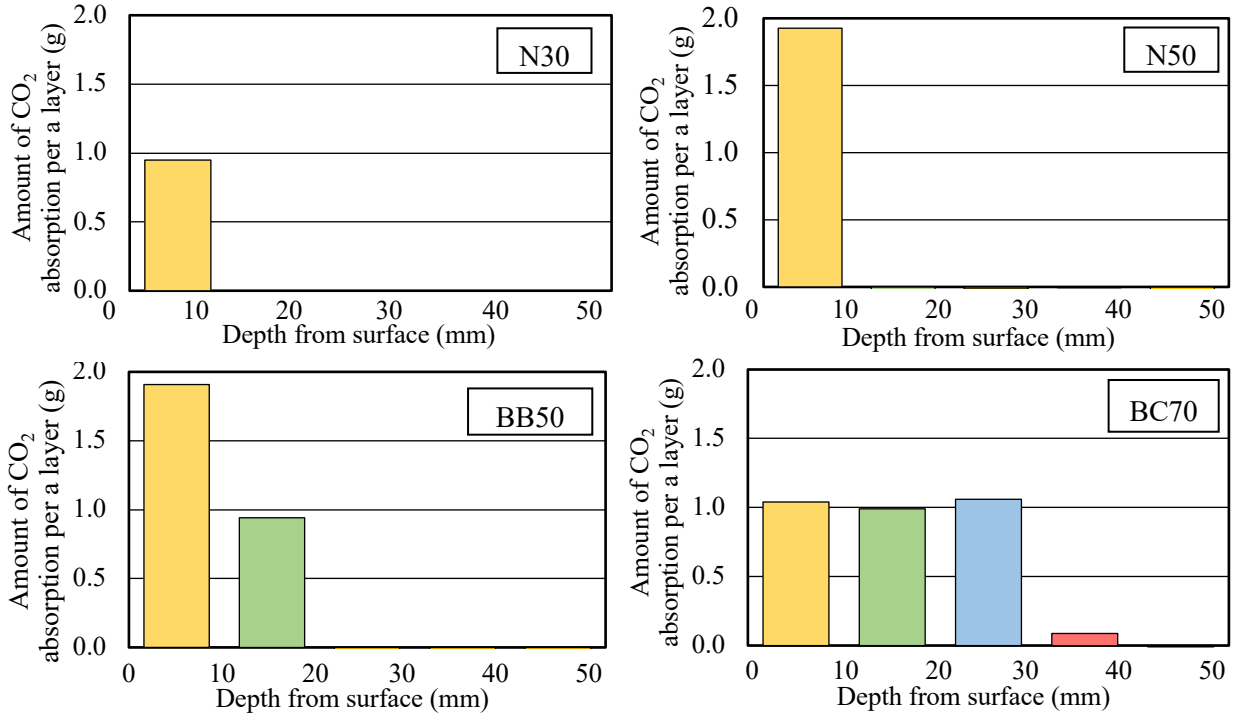


**Figure 2 The amount of $CO_2$ absorption**

Figure 3 shows the amount of $CO_2$ absorption by the total of 40×40×160mm specimen. $CO_2$ absorption was high in the order of BC70, BB50, N50, and N30. It was found that $CO_2$ absorption is greater in total as it absorbs $CO_2$ to a more internal level by carbonating at 5% $CO_2$ concentration for 28 days.

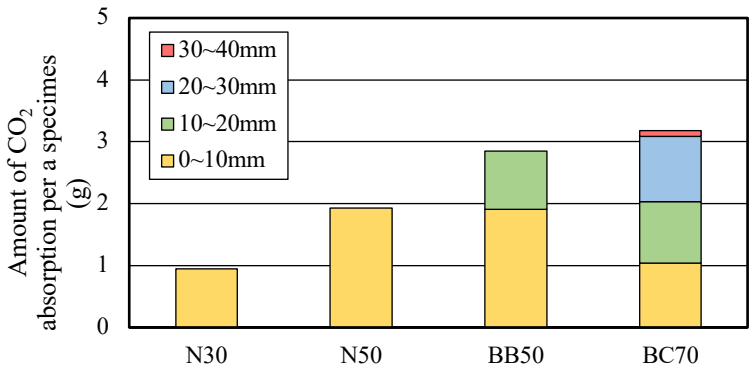


**Figure 3 Amount of $CO_2$ absorption by the total of 40×40×160mm specimen**

### 3.2 $CO_2$ absorption potential of each mix proportion

We focused on the amount of $CO_2$ absorbed per layer shown in Figure 3. It can be seen that the amount of $CO_2$ absorption in one layer is different depending on the mix proportion. Though the largest total absorption was BC70, amount of $CO_2$ absorption of the first layer was smaller in BC70 than in BB50.In addition, the $CO_2$ absorption of N30 and N50 did not reach the second layer, and the first layer is not considered to be fully carbonated either, but the $CO_2$ absorption of the first layer was equal to or higher than that of B70. Therefore, we considered there was potential for the amount of $CO_2$ that could be absorbed by each mix proportion.
$CO_2$ absorption was measured using powder samples in which the effect of porosity was eliminated so that carbonation proceeds in the same regardless of mix proportion. Samples of 48×40×2 mm were made and sealing cured for 7 days. And hydration was stopped and the specimens were granulated. Based on previous studies, accelerated carbonation was performed for 7 days after adding 70% water to the sample mass to eliminate the effect of sample drying. After carbonation, $CO_2$ absorption was measured by TG-DTA.
The results of the $CO_2$ absorption per $1m^3$ of cement paste are shown in Figure 4 Amount of $CO_2$ absorption was high in the order of N30, N50, BB50, and BC70 and smaller for higher GGBS content. Figure 5 shows the relationship between the amount of CaO content per $1m^3$ of cement and the amount of $CO_2$ absorption. The larger the CaO content, the greater the $CO_2$ absorption potential. BC70, which has a smaller $CO_2$ absorption potential, has a smaller CaO content, indicating that the potential for $CO_2$ absorption is affected by the CaO content. It is thought that this difference in potential affected the amount of $CO_2$ absorption in each layer.

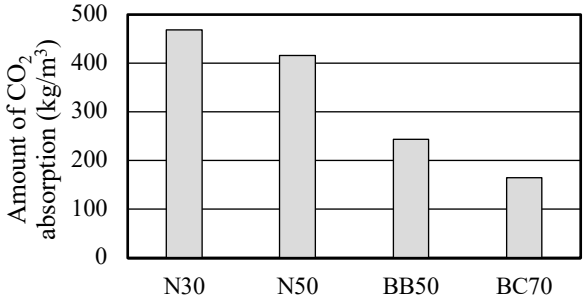


**Figure 4 Amount of $CO_2$ absorption**

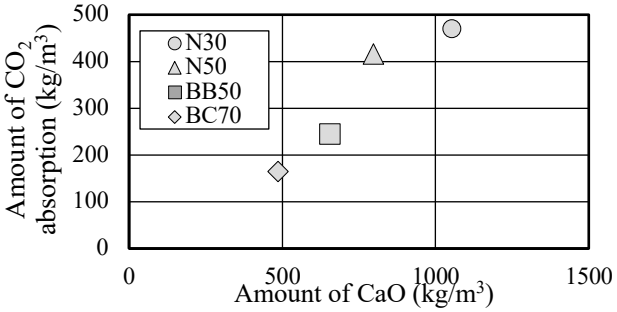


**Figure 5 Relationship between the amount of CaO**

## 4. Conclusions

1) By carbonating the hardened cement pastes and measuring the amount of $CO_2$ absorbed by separating it at each distance from the surface, it was found that the deeper the $CO_2$ absorption, the more $CO_2$ was absorbed.
2) Carbonation with powder samples without considering the ease of $CO_2$ absorption, such as porosity, is thought to provide the potential for $CO_2$ absorption of cement paste, and the higher the amount of CaO in the mix proportion, the greater the potential for $CO_2$ absorption.


## Acknowledgements

This paper is based on results of "Development of Materials, Manufacturing Methods and Quality Control System on Innovative Carbon Negative Concrete", JPNP21014, commissioned by the New Energy and Industrial Technology Development Organization (NEDO).


## References


Iyoda, T., Ishikawa, E.and Ikeo, Y. (2023) "Experimental study on quantification of carbon dioxide adsorption by different cement types and mix proportions", *Eighth International Symposium on Life-Cycle Civil Engineering (IALCCE 2023)* (Printing)

Kuroda, Y. and Kikuchi, T. (2009) "Uptake of Carbon Dioxide in the Demolished and Crushed Concrete", *Concrete Research and Technology*, Vol.20, No.1, :15-22