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# The application of $CO_2$ in the curing process of cement brick products

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**This study aimed to analyse the effect of applying $CO_2$ gas to the curing of cement products for the reduction of $CO_2$, not only from the general steam curing process but also from cement factories and thermoelectric power plants, which are major causes of global warming. Cement mortar bar test specimens were produced by brick mixing in Korea. The $CO_2$ uptake rate was measured after 1 hr of $CO_2$ curing and the compressive strength and length changes of the specimens were tested by comparing them with air-cured specimens and steam cured specimens for 5 hr. The $CO_2$ uptake rate was measured as approximately 10% using an electronic scale and a thermogravimetric analysis (TGA). The $CO_2$-cured specimens had relatively outstanding strength immediately after curing owing to carbonation. However, the strength at 28 days was the lowest due to reduced inner moisture by early carbonation reaction. In addition, the $CO_2$-cured specimens showed the lowest dry shrinkage rate due to significant production of $CaCO_3$, which has excellent dimensional stability and which reduced the initial moisture by an exothermic reaction.**

**Key words: Cement bricks, $CO_2$ uptake, $CO_2$ curing, Carbonation, Concrete, Compressive strength, Length change.**

## Introduction

$CO_2$ emissions from the growth of the global economy and the increase in energy consumption have reached 34.5 billion tonnes, and $CO_2$ emission from cement clinker production is approximately 9% of total $CO_2$ emissions [1]. Thus, there are numerous ongoing studies on reducing the use of cement through the massive use of compound materials such as fly-ash or slag, developing $CO_2$-absorbing cements, storing $CO_2$ within minerals through carbonation, and applying $CO_2$ curing of cement products to reduce $CO_2$ emission from construction [2-4].

The cement production amount in Korea reached 54 million tonnes and emitted about 51 million tonnes of $CO_2$ during cement production processes in 2013. Of this produced cement, 17.5 million tonnes was used in various cement products such as concrete bricks, concrete blocks, precast concrete, and lightweight concrete panels which undergo steam curing after moulding in order to obtain their initial strength. This steam curing also emitted $CO_2$ due to required fuel consumption. According to previous research [5], the compressive strength of a specimen that used $CO_2$ during the curing process was reported to be similar to that of a steam-cured specimen. If the $CO_2$ emitted from the cement factories and the thermoelectric power plants reused was in this curing process, the $CO_2$ reduction effect would be doubled not only by reducing emitted $CO_2$ during steam curing, but also by storing $CO_2$ emitted from cement factories or thermoelectric power plants.

In this study, trial mixtures accepted by Korean industrial standards for application to cement brick, which is a representative cement product, and elementary experiments using pure $CO_2$ were performed for the analysis of the effect of $CO_2$ in the curing process. But in a future study, low concentrations of $CO_2$ similar to exhaust gas from cement factories or thermoelectric power plants will be used.

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## Experimental Study

### Carbonation of cement by $CO_2$ curing

The carbonation of cement differs in hardened and fresh states. Carbonation by $CO_2$ in hardened cement is as shown below in Eq. 1 and Eq. 2. The produced calcium carbonate has been reported to fill voids, decrease the absorption rate [6], and improve the strength [7].

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (1)$$

$$C\text{-}S\text{-}H + 2CO_2 \rightarrow SiO_2 + 2CaCO_3 + H_2O \quad (2)$$

Carbonation by $CO_2$ in fresh cement is as shown below in Eq. 3 and Eq. 4. In a moist environment, $C_3S$ and $C_2S$ react with $CO_2$ to produce $C_xSH_y$ and calcium carbonate instead of calcium hydroxide, a product of a hydration reaction, and this is characterized by accelerated setting and rapid strength gain [8, 9].

$$C_3S + (3\ x)CO_2 + yH_2O \rightarrow C_xSH_y + (3\ x)CaCO_3 \quad (3)$$

$$C_2S + (2\ x)CO_2 + yH_2O \rightarrow C_xSH_y + (2\ x)CaCO_3 \quad (4)$$

This study applied the carbonation at the initial curing of the non-hardened specimen and followed Eq. 3 and Eq. 4.

### Specimen preparation

The mix proportions of the $CO_2$-cured specimens were set to a water-cement ratio (w/c) of 35% or less, which is standardized by KS F 4004 [10], and the cement and sand contents were set as shown below in Table 1 based on past research [11, 12]. Specimens were produced by pressing prismatic specimens with dimensions of 40 × 40 × 160 mm according to KS L ISO 679 [13].

**Table 1.** Mix proportion.

| Specimen | w/c | Unit weight (kg/m$^3$) | | |
|---|---|---|---|---|
| | | Cement | Water | Sand |
| C30-25 | 0.25 | 300 | 75 | 2097 |
| C30-30 | 0.30 | 300 | 90 | 2058 |
| C21-30 | | 210 | 63 | 2202 |
| C21-35 | 0.35 | 210 | 73 | 2175 |
| C18-35 | | 180 | 63 | 2227 |

### Curing methods

Curing of the produced specimens was carried out in order to compare the characteristics of each type of curing: $CO_2$ curing that used $CO_2$ gas, regular air curing, and steam curing, which is the present method of curing concrete bricks (Fig. 1).

All formed specimens were cured in an air-curing chamber at a constant temperature of 20 ºC and a relative humidity (RH) of 60%. The $CO_2$-cured specimens were taken out after 2 hr in the air-curing chamber. For easy penetration of $CO_2$, all parts of the moulds were removed except for the bottom, and the specimens were placed in the $CO_2$-curing chamber, which had an interior size of 30 × 30 × 25 cm; the specimens were cured for 1 hr at a temperature of 20 ºC, a RH of 60%, a $CO_2$ concentration of 95 ± 1%, and pressure below 10 kPa. They were then moved to the air chamber for the continuation of curing. When producing concrete bricks, it is advantageous to reduce the initial curing time, so this study set the $CO_2$ curing time as 1 hr. The steam-cured specimens were removed from the air-curing chamber after 2 hr and placed into the steam-curing chamber at a temperature of 60 ºC and a RH of 100% for 5 hr. Then they were placed back into the air-curing chamber for the continuation of curing.

### Test methods

*Calculation of $CO_2$ uptake rate by observing the change in mass*

The calculation and formula of the real-time $CO_2$ uptake rate by observing the change in mass was suggested [5]. As shown in Fig. 2, the specimens were placed on an electronic scale (GF 6100, AND, Japan) inside the $CO_2$-curing chamber, and the mass was logged every 10 sec for 1 hr of $CO_2$ curing to observe

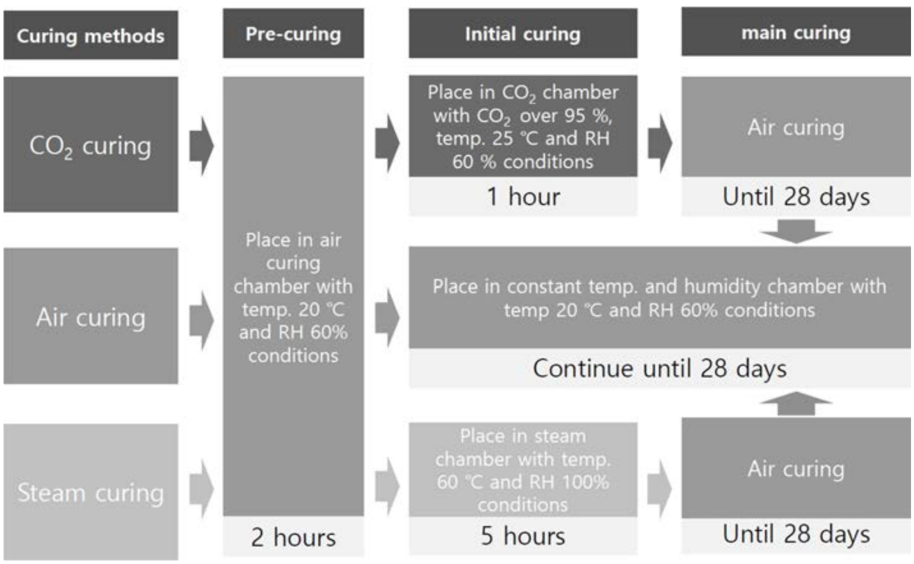



**Fig. 1.** Curing methods of this study.

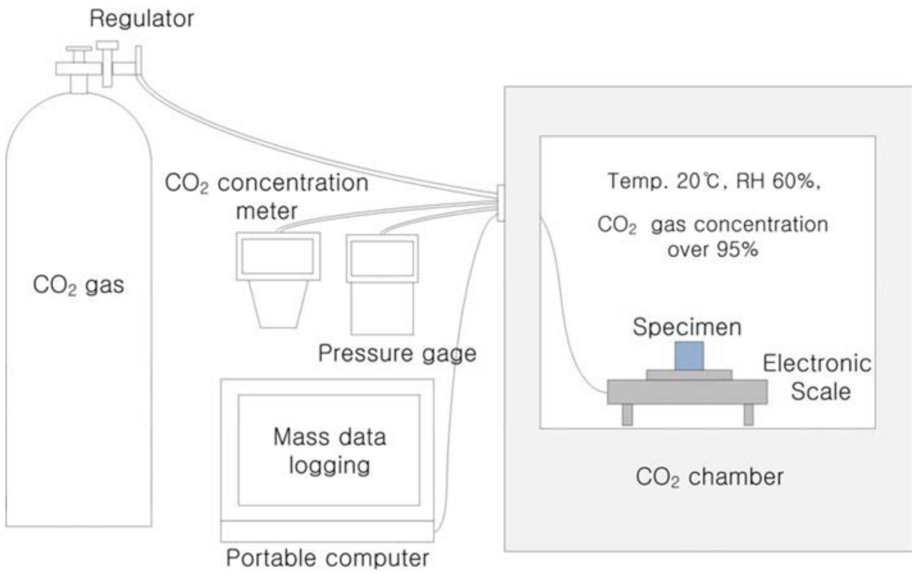



**Fig. 2.** $CO_2$ uptake measurement by mass data logging.

the changes in mass.

The $CO_2$ uptake rate based on the change in mass was determined by Eq. 5, which considered the change in the mass of air in the $CO_2$ chamber by observing the pressure change and the amount of evaporation of the specimen during $CO_2$ curing for 1 hr.

$$CO_2\ uptake(\%) = \frac{M_c - A_m + E_m}{C_m} \times 100 \tag{5}$$

where $M_c$ is the mass change of specimen during $CO_2$ curing, $A_m$ is the mass change of air in chamber during $CO_2$ curing, $E_m$ is the moisture evaporation mass of specimen in $CO_2$ curing chamber without $CO_2$, and $C_m$ is the cement mass of $CO_2$-cured specimen. Also, the quantity of cement in the specimen applied to Eq. 5 was determined by Eq. 6 using the mix proportion in table 1.

$$C_m(g) = MN_c \times \frac{C_c}{C_c + W_c + S_c} \tag{6}$$

where $MNc$ is the mass of specimen before $CO_2$ curing, $Cc$ is the cement unit content in mix proportion, $Wc$ is the water unit content in mix proportion, and $Sc$ is the sand unit content in mix proportion.

*Calculation of $CO_2$ uptake rate by thermogravimetric analysis (TGA)*

The $CO_2$-cured specimen produced $CaCO_3$ by carbonation, but when it was heated at a high temperature, the $CO_2$ decomposed, and so the $CO_2$ uptake mass can be calculated by the change in mass. The heating temperature for $CO_2$ decomposition is known to be 550-1000 °C [8, 14], and the $CO_2$ uptake rate was calculated through TGA using the change in mass at this heating temperature [5].

This study analysed the change in mass by using differential scanning calorimetry thermogravimetric analysis (DSC-TGA, SDT Q600, TA Instrument, USA) of the $CO_2$-cured and non-$CO_2$-cured specimens in order to calculate the $CO_2$ uptake rate from $CO_2$ curing. Then, the $CO_2$ uptake rate was calculated through Eq. 7.

$$CO_2uptake(\%) = \left(\frac{MC_{550} - MC_{1000}}{MC_m} - \frac{MNC_{550} - MNC_{1000}}{MNC_m}\right) \times 100 \tag{7}$$

where, $MC_{550}$ is the mass of $CO_2$-cured specimen at 550 °C, $MC_{1000}$ is the mass of $CO_2$-cured specimen at 1000 °C, $MC_m$ is the cement mass of $CO_2$-cured specimen, $MNC_{550}$ is the mass of non-$CO_2$-cured specimen at 550 °C, $MNC_{1000}$ is the mass of non-$CO_2$-cured specimen at 1000 °C, and $MNC_m$ is the cement mass of non-$CO_2$-cured specimen.

The DSC-TGA specimens were mortar pieces mixed with cement and sand. Hence, the mix proportion in Table 1 was used to estimate the mass of cement ($MC_m$ and $MNC_m$) in Eq. 7. The mass of the specimen inserted into Eq. 7 was over-dried from heating at a temperature above 550 °C, and so it was appropriate to apply the summation of the cement and sand content of the mix proportion, excluding water content. Therefore, unlike in Eq. 6, the water content was excluded, and the sand content was converted to the over-dry condition by applying the water absorption ratio of sand. Then, the mass of cement was calculated as shown in Eq. 8.

$$MC_m(MNC_m)(g) = MC_{550}(MNC_{550}) \times \frac{C_c}{C_c + 0.9822 \times S_c} \tag{8}$$

*Confirmation of carbonation*

In order to confirm the carbonation of the mortar bar specimen by $CO_2$ curing, a 1% phenolphthalein solution was sprayed on the cross sections of the specimens immediately after $CO_2$ curing and at 28 days. The sections that turned red were concluded to be carbonated regions and the sections with no colour change were concluded to be non-carbonated regions, as instructed by KS F 2596 [15].

*Compressive strength and length change*

The most important characteristic for using cement products such as concrete bricks is their compressive strength. The compressive strength of the air-cured, the steam-cured and the $CO_2$-cured specimens was tested immediately after initial curing and at 3, 7, and 28 days by a universal test machine (UTM, AG-582KNIS MS, Shimadzu, Japan), as instructed by KS L ISO 679 [13]. To investigate the dimensional stability of the three different curing methods, the length change was also tested at 3, 7, and 28 days, as instructed by KS F 2424 [16].

## Experimental Results and Discussion

### Calculation of $CO_2$ uptake rate using an electronic scale

Fig. 3 illustrates the $CO_2$ uptake mass as a function of time for each tested specimen. The uptake mass rapidly increased for 20 min and reached a plateau after 30 min. Hence, the average uptake mass from 30 min after to 60 min after was set as the $CO_2$ uptake mass of each tested specimen.

It was confirmed that the $CO_2$ uptake mass increased within the range of 3.21-5.44 g with increasing cement content. The results from the calculation using Equation 5 are presented in Table 2. The $CO_2$ uptake rate was the rate of $CO_2$ uptake mass to cement mass, and so it should have a constant value regardless of the mix proportion. The results of this study showed similar $CO_2$ uptake rates for each tested specimen, between 10.05-11.56%, with an average (AVG) of 10.52% and a standard deviation (STD) of 0.55%.

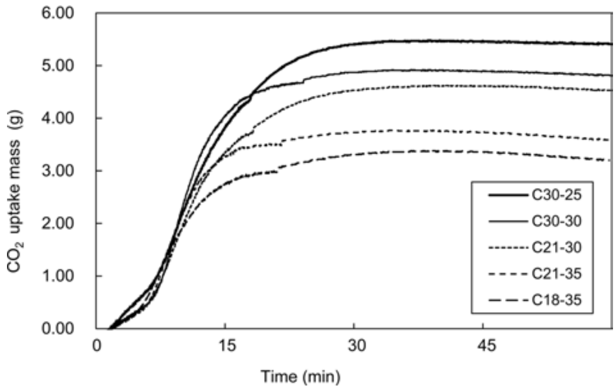



**Fig. 3.** $CO_2$ uptake mass change by electronic scale during 1 hr $CO_2$ curing.

**Table 2.** $CO_2$ uptake results by electronic scale.

| Specimen | Mass of Specimen (g) | Cement mass (g) | $CO_2$ uptake | |
|---|---|---|---|---|
| | | | Mass (g) | Rate (%) |
| C30-25 | 435.57 | 52.85 | 5.44 | 10.30 |
| C30-30 | 445.73 | 46.14 | 4.88 | 10.57 |
| C21-30 | 468.01 | 39.70 | 4.59 | 11.56 |
| C21-35 | 438.57 | 36.69 | 3.71 | 10.12 |
| C18-35 | 437.84 | 31.91 | 3.21 | 10.05 |
| Average | – | – | – | 10.52 |

**Table 3.** DSC-TGA results.

| Condition | Specimen | Initial mass (g) | Mass at 550 (g) | Mass at 1000 (g) | Cement mass (g) |
|---|---|---|---|---|---|
| $CO_2$ curing | C30-25 | 50.81 | 49.18 | 47.83 | 6.15 |
| | C30-30 | 33.12 | 31.84 | 30.95 | 4.05 |
| | C21-30 | 65.70 | 63.86 | 62.59 | 5.56 |
| | C21-35 | 82.33 | 79.80 | 78.36 | 7.03 |
| | C18-35 | 60.02 | 58.22 | 57.16 | 4.35 |
| Non-$CO_2$ curing | C30-25 | 61.89 | 59.58 | 58.64 | 7.46 |
| | C30-30 | 51.02 | 49.12 | 48.54 | 6.25 |
| | C21-30 | 48.01 | 46.32 | 45.71 | 4.03 |
| | C21-35 | 55.00 | 53.14 | 52.47 | 4.68 |
| | C18-35 | 60.90 | 60.33 | 59.99 | 4.51 |

**Table 4.** $CO_2$ uptake results by DSC-TGA.

| Specimen | C30-25 | C30-30 | C21-30 | C21-35 | C18-35 | Average |
|---|---|---|---|---|---|---|
| $CO_2$ uptake rate (%) | 9.24 | 12.73 | 7.74 | 6.35 | 16.73 | 10.56 |

### Analysis of $CO_2$ uptake rate using DSC-TGA

The results of DSC-TGA and the cement mass of the TGA specimens calculated with Equation 8 are shown in Table 3. Using these results, the $CO_2$ uptake rate calculated with Equation 7 is presented in Table 4.

The $CO_2$ uptake rate was 6.35-16.73%, with an AVG of 10.56% and a STD of 3.75%. When compared to the $CO_2$ uptake rate measured using the electronic scale, the DSC-TGA results showed an average value similar to that shown in Fig. 4, but they had a higher standard deviation. This indicated that the DSC-TGA specimens were small, so there was a limitation in the accuracy of the estimated cement amount of each specimen.

### Confirmation of carbonation

First, phenolphthalein indicator was sprayed onto the cross sections of the specimens $CO_2$ cured for 1 hr and the air-cured specimens that were not $CO_2$ cured in order to confirm the carbonation of $CO_2$ curing. As a result, even the internal regions of the $CO_2$-cured specimens had no colour change, as shown in Fig. 5a, but all the non-$CO_2$-cured specimens turned red. This indicated that the $CO_2$-cured specimens were penetrated by $CO_2$. In addition, specimens that were

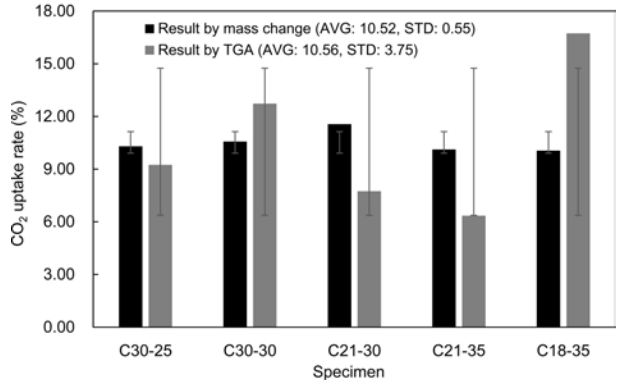
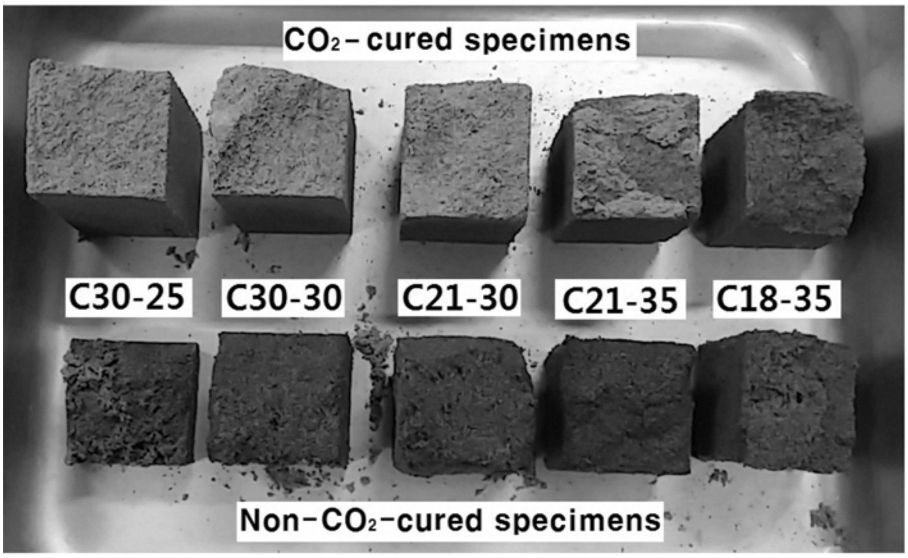



**Fig. 4.** $CO_2$ uptake rate comparison between mass change by electronic scale and DSC-TGA.

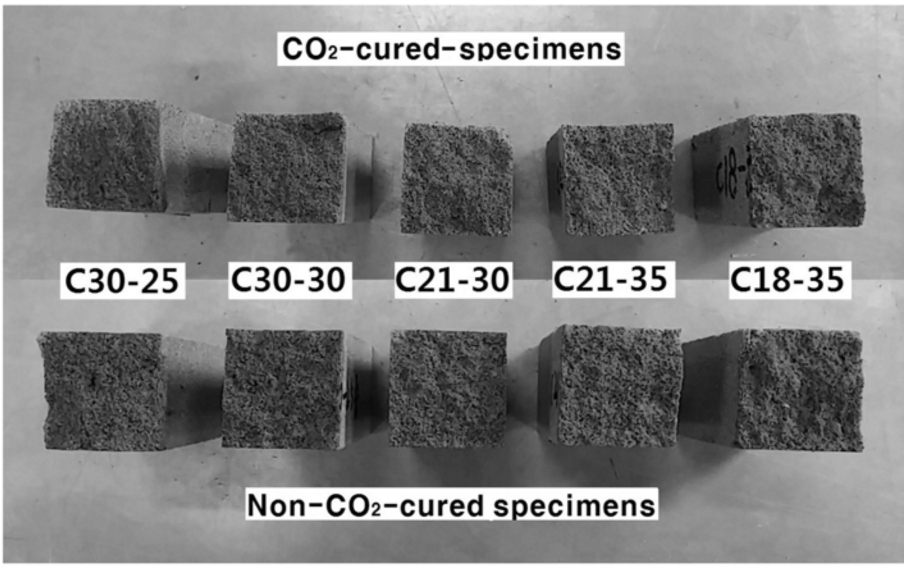
$CO_2$ cured for 1 hr and specimens that were not $CO_2$ cured were placed in the chamber at a temperature of 20 °C and a RH of 60% for 28 days. Afterwards, phenolphthalein indicator was sprayed on the cross sections. As shown in Fig. 5b, both the $CO_2$-cured specimens and the non-$CO_2$-cured specimens turned red, although there were differences in shade.

Steiner suggested a formula to calculate the maximum absorption of $CO_2$ in cement (Eq. 9) [17]. Using this formula, Shi *et al*. [18] determined the uptake to be around 50%.

$$CO_2\ uptake\ (\%) = 0.785 \times CaO - 0.7 \times SO_3 + 1.091 \times MgO + 1.42 \times Na_2O + 0.935 \times K_2O \tag{9}$$




(a) Color change of specimens by phenolphthalein indicator immediately after 1 hr of $CO_2$ curing.




(b) Color change of specimen by phenolphthalein indicator at 28 days.

**Fig. 5.** Confirmation of carbonation using phenolphthalein indicator.

The cement used in this study was analysed with wavelength dispersive X-ray fluorescence (WD-XRF, ZSX 100e, RIGAKU, Japan), and the results were inserted to Eq. 7. This gave a theoretical $CO_2$ uptake rate of 59.2%. The $CO_2$ uptake rate of this study was approximately 10%, and past studies have reported the $CO_2$ uptake rate of cement to be approximately 10-20% [5, 19, 20, 21]. It has been reported in a previous study that there were differences from the actual $CO_2$ uptake rate because a $CaCO_3$ layer formed by carbonation surrounded the reacting surfaces of the cement particles, hence slowing carbonation [22]. So the specimens that were $CO_2$-cured for 1 hr turned red during the 28 days of the air-curing process due to calcium hydroxide, which was produced during the hydration reaction of the cements that were not carbonated during the 1 hr of $CO_2$ curing.

## Compressive strength

To confirm the effect of $CO_2$ curing, the compressive strength of the cement specimens was measured. The results are presented in Table 5.

First, the compressive strength of specimens that were $CO_2$ cured for 1 hr, the compressive strength of air-cured specimens, and the compressive strength of specimens that were steam cured for 5 hr were measured immediately after curing to estimate the initial strength development of $CO_2$ curing. The results are shown in Fig. 6. The compressive strength of the air-cured specimens did not develop, and so it could not be measured. The initial strength of specimens that were $CO_2$ cured for 1 hr was 0.9-1.4 MPa and that of specimens that were steam cured for 5 hr was 2.35-6.41 MPa. The initial strengths of the specimens $CO_2$ cured for 1 hr were about 18-38% of specimens steam cured for 5 hr.

**Table 5.** Compressive strength results of each curing method.

| Curing method | speci-men | Compressive strength (MPa) | | | | |
|---|---|---|---|---|---|---|
| | | 1 h | 5 h | 3 days | 7 days | 28 days |
| $CO_2$ curing | C30-25 | 1.38 | – | 5.20 | 6.19 | 7.24 |
| | C30-30 | 1.19 | – | 5.75 | 6.33 | 8.60 |
| | C21-30 | 1.10 | – | 1.89 | 2.13 | 2.56 |
| | C21-35 | 1.19 | – | 1.80 | 2.37 | 2.55 |
| | C18-35 | 0.92 | – | 1.05 | 1.12 | 1.61 |
| Air curing | C30-25 | 0 | – | 4.84 | 7.90 | 8.14 |
| | C30-30 | 0 | – | 5.39 | 7.81 | 10.29 |
| | C21-30 | 0 | – | 2.55 | 5.12 | 5.62 |
| | C21-35 | 0 | – | 2.51 | 4.81 | 7.21 |
| | C18-35 | 0 | – | 1.91 | 3.12 | 3.68 |
| steam curing | C30-25 | – | 5.45 | 5.74 | 7.57 | 8.51 |
| | C30-30 | – | 6.41 | 6.74 | 8.00 | 12.59 |
| | C21-30 | – | 3.57 | 3.72 | 4.16 | 6.62 |
| | C21-35 | – | 3.22 | 3.37 | 3.99 | 6.91 |
| | C18-35 | – | 2.35 | 2.47 | 2.49 | 5.16 |

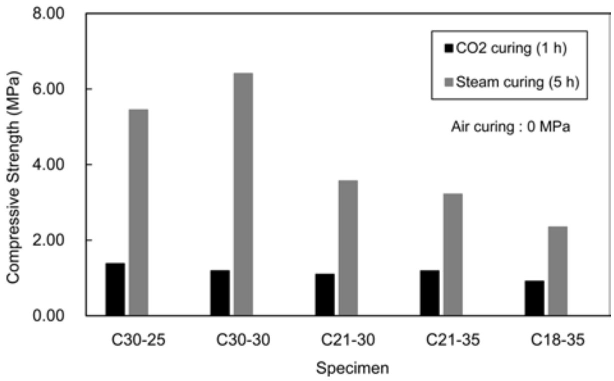



**Fig. 6.** Comparison of initial compressive strengths immediately after $CO_2$ curing.

Fig. 7 illustrates the change in compressive strength as a function of time for each curing method. At 3 days, the compressive strength levels were the highest in the steam-cured specimens with all cement content. Then, in the case of specimens with high cement content, the compressive strength levels of the $CO_2$-cured specimens were higher than those of air-cured specimens. In the case of specimens with low cement content, the compressive strength levels of the air-cured specimens were higher than those of the $CO_2$-cured specimens. At 7 days, the compressive strength levels of the air-cured specimens greatly increased, reaching a level similar to those of the steam-cured specimens. However, the compressive strength levels of the $CO_2$-cured specimens were 36-81% those of air-cured specimens and 45-82% those of steam-cured specimens. At 28 days, the compressive strength levels of the $CO_2$-cured specimens were 30-85% those of the air-cured and steam-cured specimens, and the specimens with a cement content of 300 kg/m$^3$ and a w/c of 0.3 showed the highest compressive strength.

A carbonation reaction consumed the internal moisture and caused evaporation in the non-hardened specimens with its exothermic property. Thus, the moisture content decreased, the hydration reaction was slowed, and the strength was shown to be lower than that found with general wet curing [5, 19]. In addition, Shi and Wu [21] confirmed in their study that the $CO_2$ uptake rate of samples with w/c 0.26-0.46 was similar but the compressive strength was low with low w/c. Low w/c samples had poor strength enhancement because they were hard to mould, and thus there was an optimal moisture amount that caused the $CO_2$ and cement to react to increase compressive strength. In this study, specimens with w/c 0.25-0.35 had similar $CO_2$ uptake rates and compressive strength was low with low w/c, which conformed with the past research mentioned above. Also, the strength enhancement as a function of time was more affected by the hydration reaction than by the initial carbonation from $CO_2$ curing, as displayed in Fig. 5 and Fig. 7.

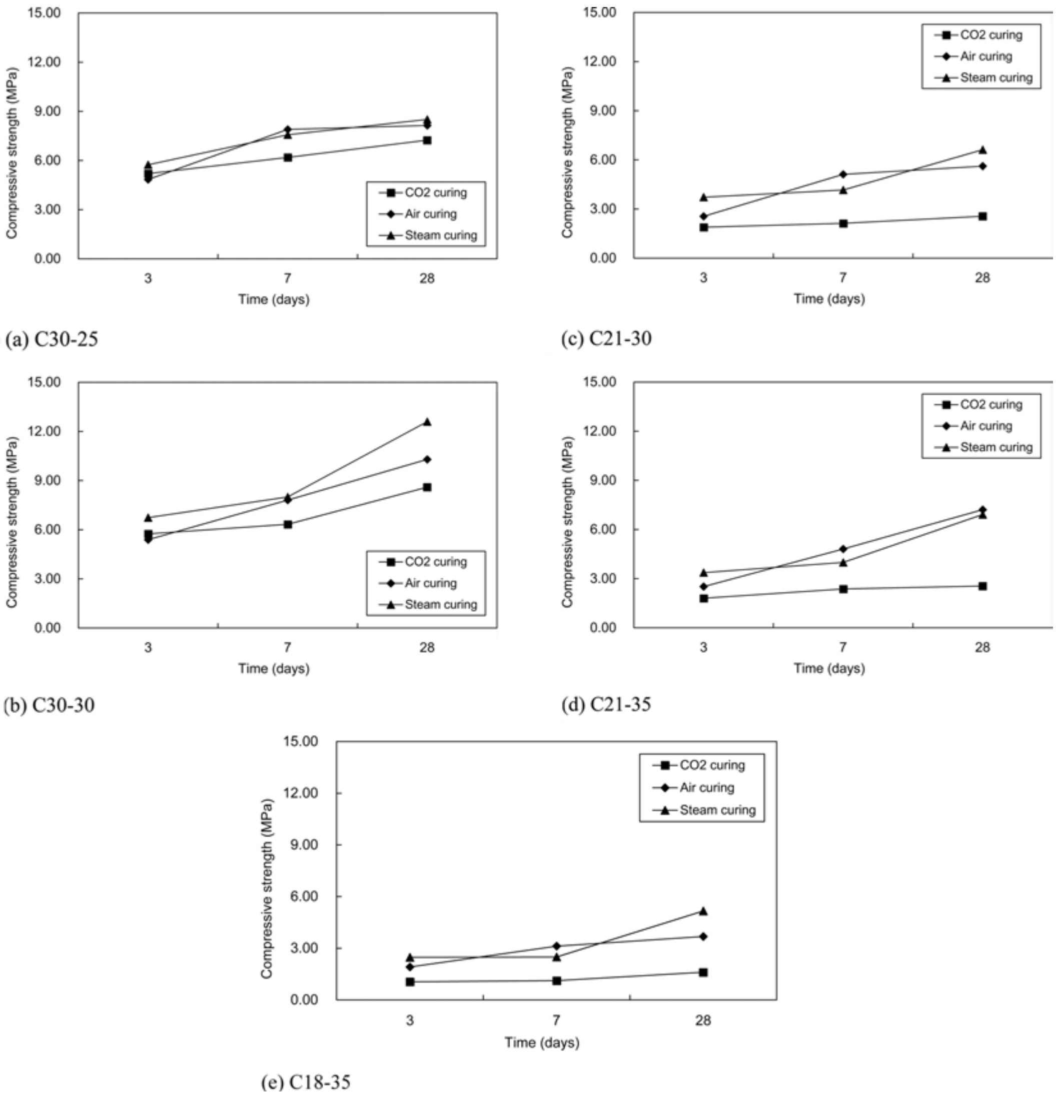



**Fig. 7.** Compressive strength over time.

## Length change

The length change resulting from $CO_2$ curing, air curing, and steam curing is shown in Table 6 and Fig. 8.

The $CO_2$-cured specimens showed the lowest drying shrinkage over time. At 3 days, the level of shrinkage in the $CO_2$-cured specimens was lower than that of the air-cured specimens by an average of 27% and that of the steam-cured specimens by an average of 22%. At 28 days, it was lower than that of the air-cured specimens by an average of 85% and that of the steam-cured specimens by an average of 73%.

The length change in the specimen that was $CO_2$ cured for 1 hr was small for two reasons. The first reason is the excellent dimensional stability of $CaCO_3$. Shi *et al*. [23] confirmed $CO_2$-cured blocks have a lower dry shrinkage ratio than steam-cured blocks by the long exposure experiment, and reported that there are much smaller amounts of silica gel in $CO_2$-cured blocks that are affected by the wetting-drying process, than amounts of $CaCO_3$, which has excellent dimensional stability in reaction to products produced

**Table 6.** Measured length change in specimens of each curing method.

| Curing method | Specimen | Change in length (× $10^{-3}$ %) | | |
|---|---|---|---|---|
| | | 3 days | 7 days | 28 days |
| $CO_2$ curing | C30-25 | −1.25 | −3.44 | −14.69 |
| | C30-30 | −0.62 | −2.50 | −11.13 |
| | C21-30 | 0.00 | −2.50 | −15.00 |
| | C21-35 | 0.00 | −0.63 | −11.88 |
| | C18-35 | −0.44 | −2.50 | −18.13 |
| Air curing | C30-25 | −1.44 | −4.44 | −19.88 |
| | C30-30 | −1.87 | −6.87 | −15.31 |
| | C21-30 | −0.62 | −3.31 | −15.69 |
| | C21-35 | −1.56 | −5.19 | −12.69 |
| | C18-35 | −2.87 | −7.50 | −19.56 |
| Steam curing | C30-25 | −1.44 | −4.50 | −17.56 |
| | C30-30 | −1.50 | −3.87 | −15.75 |
| | C21-30 | −3.75 | −8.69 | −23.13 |
| | C21-35 | −1.25 | −8.31 | −20.81 |
| | C18-35 | −2.62 | −3.06 | −18.94 |

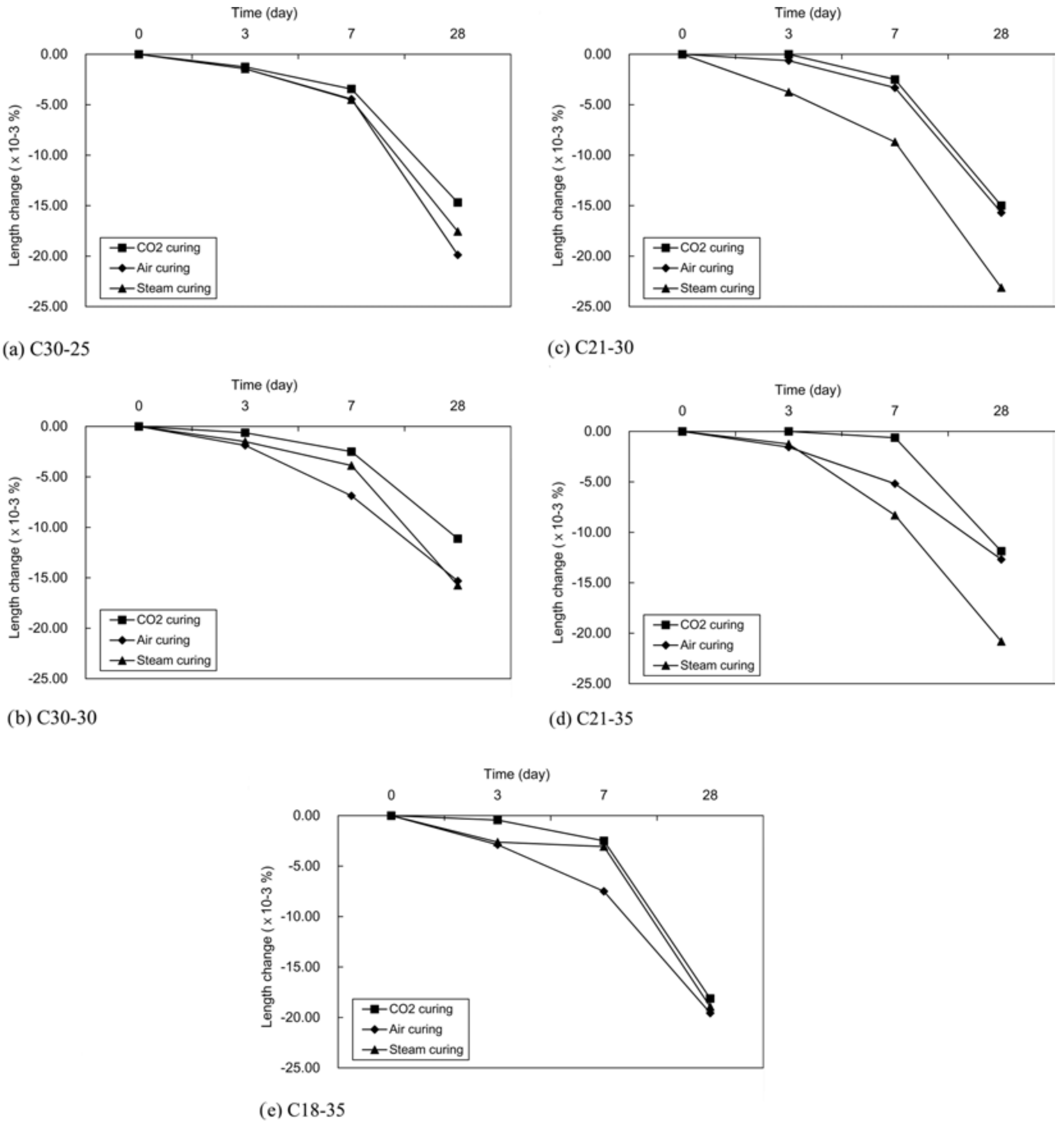



**Fig. 8. Length change over time.**

from the carbonation curing process. The second reason is that moisture reduction existed inside of the $CO_2$-cured specimens. As mentioned above, a carbonation reaction consumed the internal moisture and caused evaporation in the non-hardened specimens with its exothermic property, thus slowing the hydration reaction. Thus, only a small amount of moisture remained inside the hardened $CO_2$-cured specimens for the outflow of moisture, so only a small amount of drying shrinkage occurred.

In summary, application of $CO_2$ as a curing method of cement brick products would be possible if compressive strength was increased. As such, the brick mixture for the application of $CO_2$ curing should involve a cement content of 300 kg/m$^3$ with a w/c of 0.3-0.35. According to the results of El-hassan and Shao [19], if the $CO_2$ curing time was increased and moisture was added to the curing process, the compressive strength would increase. Hence, in future studies, the $CO_2$ curing time and the addition of moisture during the curing process will be increased. In addition, recycled materials like fly ash and blast furnace slag and recycled aggregate will be used as binders and aggregates in cement bricks.

## Conclusions

In researching the application of $CO_2$ in the curing process of cement materials, the $CO_2$ uptake and compressive strength and length change of $CO_2$-cured specimens with a concrete brick mixture was tested in comparison with air-cured and steam-cured specimens. As results, the $CO_2$ uptake rate of the $CO_2$-cured specimens measured by an electronic scale was average of 10.52% regardless of the mixture. The $CO_2$ uptake rate measured by DSC-TGA was similar average of 10.56%, but the measurement by DSC-TGA showed large standard deviations due to the limitations of small-sized specimens. The $CO_2$-cured specimens had relatively outstanding strength immediately after curing owing to carbonation. However, the strength at 28 days was the lowest due to reduced inner moisture by early carbonation reaction. In addition, the $CO_2$-cured specimens showed the lowest dry shrinkage rate due to significant production of $CaCO_3$, which has excellent dimensional stability and which reduced the initial moisture by an exothermic reaction.

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