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# Study on potential of carbon dioxide absorption in reinforced concrete beams

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# Study on potential of carbon dioxide absorption in reinforced concrete beams

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**Abstract.** The global gas emission is keeping on increasing for which cement industry alone contributes 5%. The enormous water is required for curing of concrete in construction industry which can effectively be used for various purposes. The accelerated carbonation curing shows a way to reduce these emissions in a very effective way by sequestering it in concrete elements. In this research the effect of accelerated carbonation curing was checked on non-reinforced concrete elements (cubes) and reinforced concrete elements (prisms). The 100mm x 100mm x 100 mm cubes and 150mm x 150mm x 1200mm prisms were cast. They were $CO_2$ cured for 4 and 8 hours and were tested for compressive strength and flexural strength test. The $CO_2$ curing results showed 27.7% and 1.8% increase in strength of cubes and prisms, respectively when compared to water cured specimens. This early age strength through waste gas proves beneficial in terms of reducing in atmospheric pollution and saving the water which is a critical resource now-a-days.

## 1. Introduction

Cement industry emits 5% of global gas emissions and $CO_2$ is released during manufacturing of cement. Cement on mixing with water releases heat of hydration [1]. Carbonation is the process by which $CO_2$ is absorbed in the concrete.Uncarbonated concrete units contain the typical cement hydration products of calcium silicate hydrates and calcium hydroxide [2, 3, 6]. As concrete carbonates, calcium hydroxide and calcium silicates are converted to calcium carbonate, as shown in following equations:

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

$$C_3S + 3CO_2 + H_2O \rightarrow C\text{-}S\text{-}H + 3CaCO_3$$
$$C_2S + 2CO_2 + H_2O \rightarrow C\text{-}S\text{-}H + 2CaCO_3$$

Accelerated carbonation curing is the faster rate of curing process which requires specific temperature, relative humidity and pressure.

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### *1.1. Research background*

Cement is the versatile material and it is the backbone of the construction industry from past many years. Water curing is the only process which has been used from past many years to reduce the heat of hydration. Accelerated carbonation curing requires only 4 to 8 hours of curing time under controlled conditions to get the strength which the conventional water cured concrete specimen require 28 days. This early age strength is because of the reaction of $CO_2$ gas with calcium hydroxide (Ca $(OH)_2$) and the bogus compounds named tri-calcium silicate ($C_3S$) and di-calcium silicate ($C_2S$) to form calcium carbonate ($CaCO_3$) and calcium silicate hydrate gel (C – S – H) [3]. The gel imparts strengths to concrete and the latter helps in pore refinement of concrete [5]. The reinforced concrete elements undergo corrosion when placed in the corrosive atmosphere. This corrosion is prevented by placing an appropriate cover or protective coatings on reinforcement. This helps in protecting steel in acidic environment [4, 7, 8, 9]. The literature background on carbonation of reinforced concrete has not published as no research has been done in this area so we were unable to find more literature background on this area. The literature study done for this area was taken from carbonation of non-reinforced concrete elements.

## 2. Experimental Work

### *2.1. Carbonation Chamber*

The metallic carbonation chamber was made of size 1300mm x 600mm x 300mm with an inlet and outlet valve. A pressure meter with a pressure release valve was also fixed to release the excess pressure in the chamber as shown in Figure 1.

**Figure 1.** Carbonation chamber

### *2.2. Material Specifications*

The concrete mix design was done as per IS 10262, aggregates confirming to IS 383 and OPC 53 grade cement confirming to IS 12269 were used.The river sand was used as fine aggregate throughout the experiment. The specific gravity of fine aggregate was 2.62 and fineness modulus was 3.3.The cement used was of type OPC 53 grade. It has a specific gravity value of 3.15. The properties of coarse aggregate is given in Table 1.

**Table 1.** Properties of coarse aggregate

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| S. No. | Properties | 10 mm | 20mm |
|---|---|---|---|
| 1 | Flakiness index (%) | 14.09 | 11.9 |
| 2 | Elongation | 10.77 | 9.26 |
| 3 | Impact value (%) | 11.67 | 9.56 |
| 4 | Crushing value (%) | 12.11 | 11.35 |
| 5 | Fineness modules | 6.07 | 7.04 |

The non-reinforced concrete samples (cubes) and reinforced concrete samples (Prisms) of grade M25 were made of size 100mm x 100mm x 100mm and 150mm x 150mm x 1200mm, respectively. The samples were cured for 4 and 8 hours in the carbonation chamber and were compared with water cured cubes of 28 days curing.

### *2.3. Curing of Specimens*

#### *2.3.1 Water Curing*

The prisms and cubes were placed in water for 28 days to facilitate required hydration process.

#### *2.3.2. $CO_2$ Curing*

The $CO_2$ regulator and air preheater was attached to the carbonation chamber. Pure $CO_2$ gas of purity 99% was used for the carbonation. The temperature in the chamber was maintained at 20 to 25$^o$C, relative humidity at 50$^o$C to 60$^o$C and pressure was maintained between 5 to 10MPa as shown in Figure 2 and 3.

**Figure 2.** Carbonation chamber with $CO_2$ cylinder, $CO_2$ regulator and air heater

**Figure 3.** Prisms and cubes placed inside the chamber

### *2.4. Reinforcement details*

Two 10mm diameter bars at the bottom with a clear cover of 25mm and two hanger bars of 8mm diameter at the top were provided as shown in Figure 4. The stirrups of the size of 8mm diameter with a spacing of 150mm was provided.

**Figure 4.** Reinforcement cage inside plywood moulds

## 3. Results and Discussions

### *3.1. Results of Compressive Strength Test*

The concrete cubes of M25 grade were tested by using compression testing machine and results are given in Table 2 and Table 3.

**Table 2.** Compressive strength of $CO_2$ cured concrete specimens

| Time intervals of curing | Compressive strength (MPa) |
|---|---|
| 4 hours | 29.8 |
| 8 hours | 33.2 |

**Table 3.** Compressive strength of water cured concrete specimens

| Curing Period | Compressive strength (MPa) |
|---|---|
| 28 days | 26 |

*3.2. Flexural strength test*

Three prisms cured for the period of 4 and 8 hours by $CO_2$ were tested as shown in Figure 5. The results of flexural strength test are shown in Table 4 and Table 5.

**Figure 5.** Flexural strength test

**Table 4.** Flexural strength of $CO_2$ cured specimens

| Time intervals of curing | Flexural strength (MPa) |
|---|---|
| 4 hours | 25.6 |
| 8 hours | 28.8 |

**Table 5.** Flexural strength of water cured specimens

| Time intervals of curing | Flexural tensile strength (KN) |
|---|---|
| 28 days | 28.3 |

*3.3. Load – Deflection Curve*

The load deflection curve of water cured prisms and $CO_2$ cured prisms for 4 and 8 hours are given in Figure 6, 7 and 8.

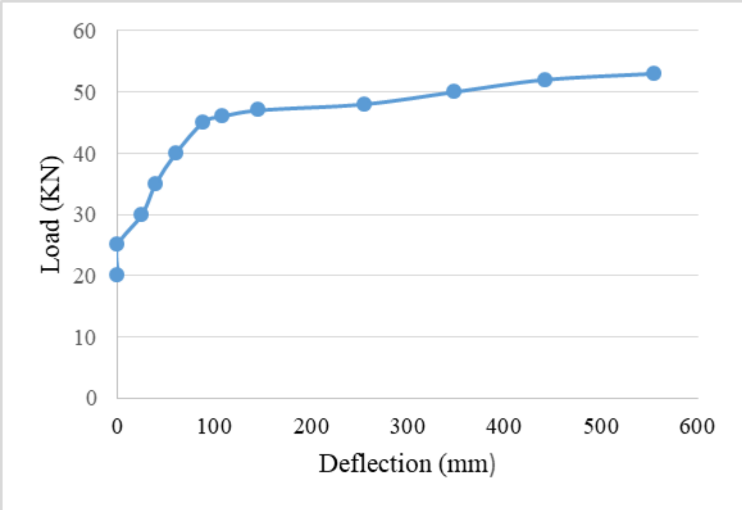


**Figure 6.** Load vs. Deflection curve for 28 days water curing

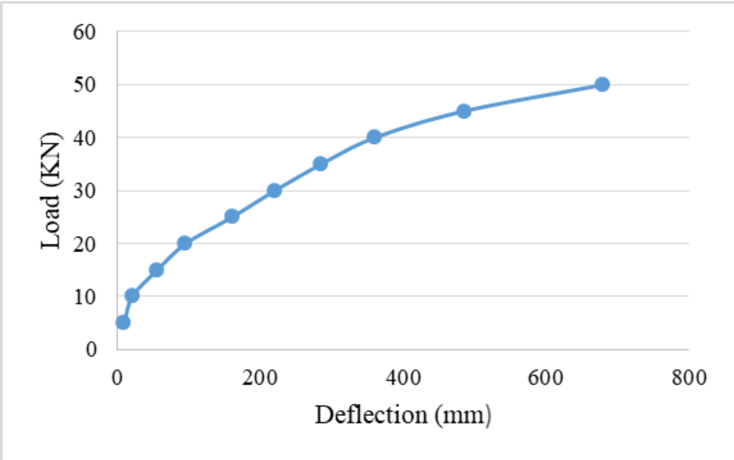


**Figure 7.** Load vs. Deflection curve for 4 hours $CO_2$ curing

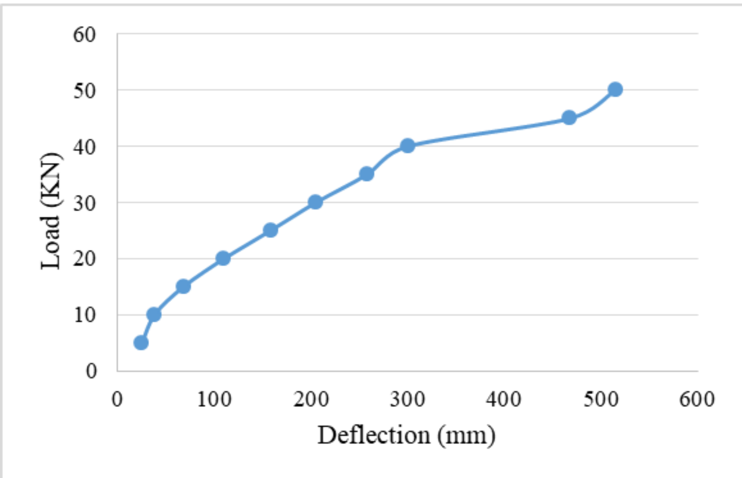


**Figure 8.** Load vs. Deflection curve for 8 hours $CO_2$ curing

From the curves, it is found that the curve for 28 days water curing and 8 hours $CO_2$ curing was comparatively similar which shows that there was lesser deflection for higher loads. This less deflection was caused due to increase in strength due to accelerated curing. The 4 hours $CO_2$ cured prisms showed more deflection than 8 hours cured prisms because of less curing time and the strength was not achieved.

### *3.4. Phenolphthalein test*

The phenolphthalein test was done on the chopped off part of the cube by spraying the phenolphthalein solution. The colourless part depicts the absorption of $CO_2$ as shown in Figure 9.

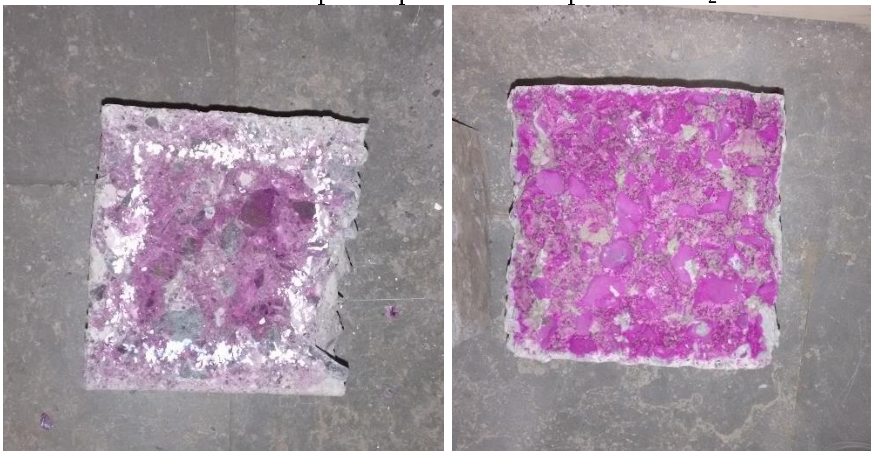

**Figure 9.** $CO_2$ cured and Water cured concrete cubes

The left cube shows the colourless part which shows the $CO_2$ absorbed in the cube. The right cube shows no penetration of $CO_2$ as there is absence of colourless part.

### *3.5. SEM Analysis*

The Scanning Electron Microscope (SEM) test was done on $CO_2$ cured and water cured samples. The image shows the formation of $CaCO_3$ inside the concrete samples as shown in Figure 10 and 11. The white part shows the formation of $CaCO_3$ inside the concrete sample. There is a little formation of $CaCO_3$ in the concrete sample cured by water as shown in Figure 11.

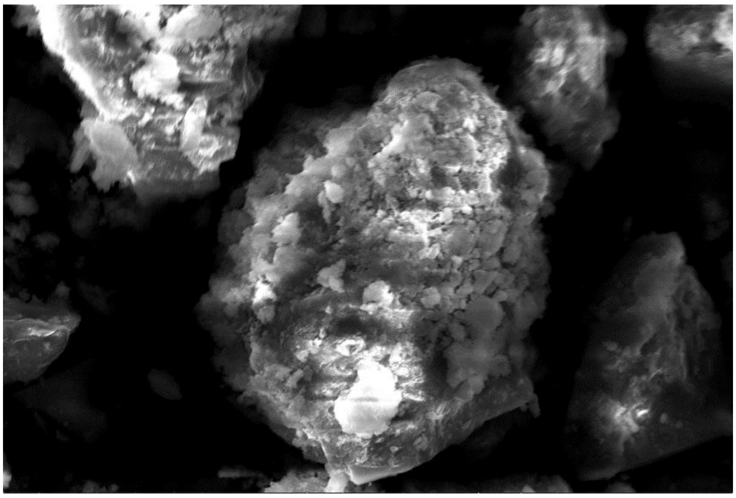

**Figure 10.** SEM image of $CO_2$ cured cube

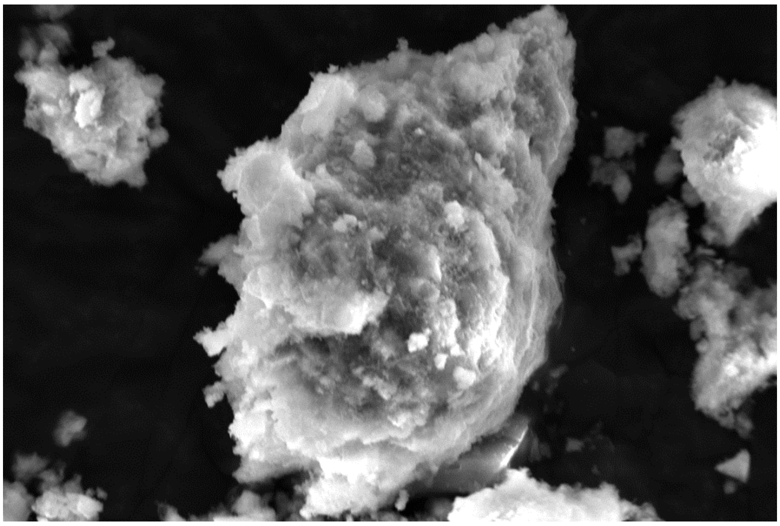

**Figure 11.** SEM image of water cured cube

*3.6. Corrosion of Reinforcement*

Half-cell resistivity test is used to check the corrosion level in the steel bars. To conduct this test, first have to check visually by scrapping the layer off. The top layer of beam was scrapped off after the doing the load test. The image as shown in Figure 12 shows that the reinforcement has not been corroded.

**Figure 12.** Non- corroded reinforced bars after strength test

## 4. Conclusions

The following conclusions are derived from the experimental work.

1. The compressive strength of the concrete specimen at 4 hours and 8 hours carbonation curing showed 12.3% and 27.7% increase in the strength than water cured specimens, respectively.
2. The flexural strength of the prisms for 8 hours $CO_2$ curing showed 1.8% increase in the strength than water cured specimens.

3. The accelerated carbonation curing proves to be an effective resource in the precast industry due to its faster construction.
4. The reinforcement bars were not corroded which means the carbonation level did not crossed the cover level thereby letting the specimen safe from corrosion.
5. The formation of $CaCO_3$ inside the carbonated sample is found from the phenolphthalein test and also from the SEM picture.
6. The carbonation of non-reinforced and reinforced elements showed higher strength increment without corrosion of the bars which proves its suitability in the precast industry.

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