

POTENTIAL OF CARBON DIOXIDE ABSORPTION IN CONCRETE

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Abstract: Cement industry contributes to 5% of global CO₂ emissions. To mitigate pollution, there is a need of CO₂ sequestration into stable forms. Present research focusses on CO₂ being channelized towards an important construction practice. This paper summarizes the potential of CO₂ absorption in concrete. To verify CO₂ absorption in concrete, an artificial CO₂ environment for curing of concrete cubes using dry ice was created. Considering concrete of M20 grade, a comparative experimental study of water cured concrete cubes, CO₂ cured concrete cubes, for penetration (using phenolphthalein indicator), and compressive strength was carried out. The result analysis of the tests indicated that CO₂ cured concrete cubes showed 22.125% higher compressive strength than water cured concrete cubes and CO₂ penetration of 13.5 mm after 2 hours. The rate of CO₂ penetration and strength gain in concrete was found to be rapid in the early hours. It is shown that CO₂ can prove to be a useful resource in the construction scenario, especially in the precast industry.

Index Terms – Cement industry, pollution, CO₂ sequestration, carbonation, CO₂ curing, dry ice, penetration, compressive strength, precast industry

I. INTRODUCTION

The process of curing in the construction sector is an important practice, which helps concrete achieve its strength by lowering of temperature. Water, a critical resource is continuously being used for this purpose. Carbonation, a natural phenomenon, can be applied artificially to sequester carbon dioxide, a harmful pollutant.

A. Carbonation of concrete

Carbonation is known to improve surface hardness, strength, and durability of cement-based products by pore refinement of the cement paste matrix. Carbonation can be helpful in non-reinforced cement-based products. However, for reinforced cement-based products, as the pH of carbonated cement paste reduces due to carbonation, reinforcing steel loses its passivity and becomes vulnerable to corrosion.[1] Carbonation in cement-based products can be defined as a reaction between the CO₂ dissolved in water and the cement hydration product Ca(OH)₂ in the pore water [2]. This reaction produces calcium carbonate (CaCO₃) and water. Calcium silicate hydrates and calcium aluminate hydrates also react with CO₂ in the

presence of moisture to produce calcium carbonate and hydrates of silicates and aluminates and water [3]. It has been explained that the sequence of the carbonation mechanism is as follows:

CO₂ diffusion through the cement paste matrix;

CO₂ dissolution in the pore solution and reaction with calcium hydroxide:



CO₂ diffuses through the pores depending upon the pore structure and the degree of saturation of the pores in the cement paste matrix. CO₂ in gaseous phase does not react with cement hydration products; it has to dissolve in the pore water first to form carbonic acid (H₂CO₃). Out of the hydrates in the cement paste, the one which reacts with CO₂ most readily is Ca(OH)₂. Other hydrates also react with dissolved CO₂, and hydrated silica, alumina, and ferric oxide are produced [4]. When all Ca(OH)₂ becomes carbonated, the pH value of the pore solution is reduced from 12.5 to 8.3 [4]. CaCO₃ produced by the process of carbonation precipitates inside the pores of the cement paste matrix. This results in pore refinement of the carbonated cement paste matrix. Pore refinement leads to increased surface hardness, reduced permeability of the carbonated portion of the cement-paste matrix, and increased compressive strength of the cement-based product. Due to pore refinement, however, it becomes difficult for CO₂ to diffuse further in the cement paste matrix, which results in reduced rate of carbonation of cement-based products. The carbonation curing technology was applied to the treatment of concrete blocks to reduce shrinkage by as much as 50% under subsequent exposure to carbon dioxide or to wet-dry cycles. The water permeability of carbonated concrete can be reduced due to the precipitation of calcium carbonate crystals and efflorescence can be reduced by the deliberate reaction of calcium hydroxide.

B. Factors affecting carbonation

The rate of carbonation is the highest when the relative humidity of the surrounding environment is 50% to 70% [4]. Concrete with high internal moisture shows a much lower rate of carbonation because the diffusion of CO₂ becomes difficult when pores are saturated with water. Carbonation rate also

reduces at a lower internal moisture level due to insufficient water in the pores [5]. The other factors responsible are temperature, pressure, porosity of concrete, water to cement ratio. The temperature and pressure are the main parameters and they are responsible for the changes in the parameters of the concrete [6].

II. METHODOLOGY

A. Experimentation

The concept was to test the penetration of CO₂ and therefore its sequestration into stable components in concrete. For achieving this, there was a need to provide a controlled CO₂ curing environment for allowing the CO₂ to get absorbed in concrete. The material used for creating CO₂ curing environment is dry ice. Dry ice is the purest form of CO₂ with its purity more than 99%. To observe the variation in properties, two different curing setups were created: controlled setup and experimental setup. For the lab experimentation purpose, concrete cubes of M20 grade were casted and placed in the above mentioned two different setup and tested for compressive strength and CO₂ penetration test after 2 hours, 1 day, 7 days, 14 days and 28 days respectively.

B. Material Specifications

To satisfy the mix design as per the IS 10262:2009 code, the materials were selected as coarse aggregate, fine aggregates confirming to IS 383:1970, Ordinary Portland Cement 53 grade cement confirming to IS 12269.

1) Fine aggregates

The sand used for the mix design was artificial crushed sand. The fine aggregate has specific gravity of 2.82 and fineness modulus of 3.218.

2) Cement

The cement was classified under American Society for Testing Materials type 1 and of type Ordinary Portland Cement 53 grade. It has a specific gravity of 3.15.

3) Coarse Aggregates

TABLE I.
PROPERTIES OF COARSE AGGREGATE

| Sr. 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 Modulus | 6.07 | 7.04 |

C. Curing Setups

1) Control Setup

In this setup water of standard properties was used as the curing agent. For lab conditions the cubes were casted and

placed in the water for a time interval of 2 hours, 1 day, 7 days, 14 days and 28 days. This process was conducted at room temperature and at standard atmospheric pressure.



Fig. 1. Control Setup

2) Experimental Setup

In this setup an artificial CO₂ environment was created in which the cubes were placed for the above mentioned time intervals. The artificial environment was created by using dry ice. The curing process took place in a thermocole box insulated with a masking tape for maintaining the environment.



Fig. 2. Experimental Setup

III. RESULTS

A. Compression Testing Machine Results

The compressive strength of cubes at various curing time intervals was found to as follows:

TABLE II.
COMPRESSIVE STRENGTH RESULTS

| Time Intervals | Water Cured (MPa) | Carbon Dioxide Cured (MPa) |
|----------------|-------------------|----------------------------|
| 2 hours | 8.976 | 11.526 |
| 1 day | 13.97 | 14.02 |
| 7 days | 19.34 | 17.96 |
| 14 days | 22.11 | 19.77 |
| 28 days | 24.67 | 20.56 |

Figure 3 shows the results of compressive test of water cured and CO₂ cured concrete cubes:

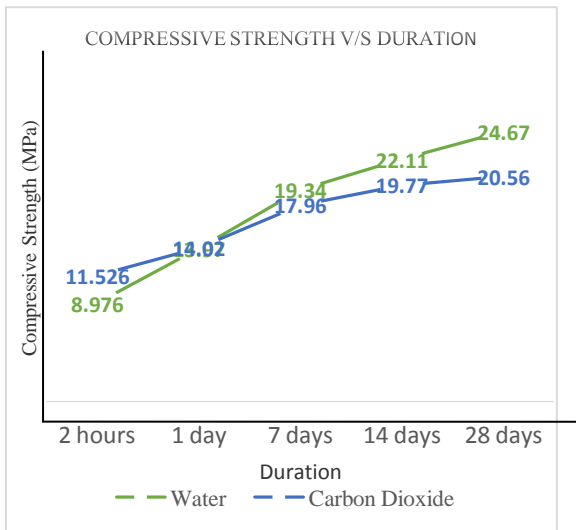


Fig. 3. Compressive Strength v/s Time Duration

After 2 hours, compressive strength of CO₂ concrete cubes was found to be increased by 22.125% more than that of water cured concrete cubes.

B. Phenolphthalein test

Phenolphthalein solution was used as a CO₂ indicator. The property of this solution is that it shows pink colour in presence of base and remains colourless in presence of acid. The concrete cube is basic in nature. On reaction with atmospheric moisture and CO₂ it forms mild carbonic acid (H₂CO₃) which remains colourless on spraying of the indicator solution. The depth measurement is illustrated by the Figure 4:

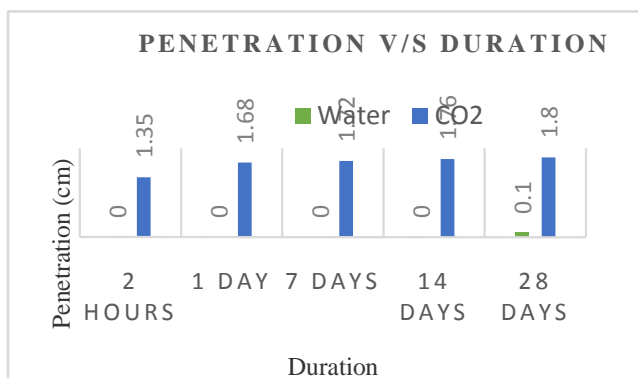


Fig. 4. CO₂ Penetration v/s Time Duration

From Figure 4, it is shown that the average penetration of CO₂ in the cube after 2 hours of curing was 13.5mm and that of water cured cube was 0 mm which was considered negligible as compared to CO₂ cured concrete cubes.

C. Observations and Interpretations

Figure 5 depicts the difference in the penetration depth of water cured and CO₂ cured cubes. After spraying phenolphthalein, the part which turned pink indicated no absorption of CO₂ whereas the colourless part indicated CO₂ absorption in the cube.



Fig. 5. CO₂ Cured and Water Cured Concrete Cubes

IV. CONCLUSIONS

- The increment in compressive strength of CO₂ cured cubes over normal water cured cubes was 22.125% in duration of 2 hours.
- The penetration of CO₂ inside the CO₂ cured cubes and normal water cured cubes was 13.5mm and negligible respectively after 2 hours.
- Precast building products which are cured in a controlled environment are more suitable for CO₂ curing as it would serve as appropriate technology with more efficient service.
- The results would have been better on application of pressurized CO₂ and moist temperature which is more favourable CO₂ curing.
- Channelization of waste CO₂ for curing of concrete in precast plants for its stable sequestration is a way of reducing pollution.
- The outlook of CO₂ as waste and pollutant would change as a resource for progressive construction.

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