

Carbon Curing of Concrete using CO₂ Gas

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Carbon dioxide (CO₂) is one of the major greenhouse gases released because of human industrial activities. A considerable proportion of these emissions originate from industrial point sources, with cement manufacturing being a particularly important contributor. Cement production is estimated to account for nearly 5% of worldwide CO₂ emissions. One potential approach to reducing these emissions is to capture and reuse CO₂ during the production of concrete. During this process, CO₂ reacts with calcium-rich components present in the cementitious material to produce stable calcium carbonate (CaCO₃). This reaction enables a portion of the emitted CO₂ to be permanently stored within the concrete in a thermodynamically stable form.

Since CO₂ and moisture are naturally present in the environment, carbonation can occur in concrete under normal conditions. However, controlled carbonation curing can be used to enhance this process at an early stage of concrete production. In the study discussed, CO₂ obtained from cement-kiln flue gas was investigated for beneficial use in concrete curing. The results indicate that this technique can reduce carbon emissions while accelerating early-age strength development and potentially enhancing the durability of concrete products.

Furthermore, when compared with conventional curing, carbonation treatment for approximately four hours was reported to produce strength comparable to the 28-day strength normally achieved through conventional curing, based on the cement content used.

KEY WORDS: CO₂ utilization, Carbonation Curing, Early Curing

1. INTRODUCTION

The atmosphere plays a vital role in regulating the Earth's climate by trapping part of the heat received from solar energy and maintaining conditions that support life. However, rapid industrial development, extensive fossil-fuel consumption, deforestation, and other human-induced activities have considerably increased the concentration of carbon dioxide (CO₂) in the atmosphere. This alteration of the natural greenhouse-gas balance is considered one of the major factors contributing to contemporary climate change. An increase in atmospheric CO₂ enhances the greenhouse effect, resulting in the retention of more heat within the Earth's climate system. As the planet becomes warmer, the atmosphere can hold greater quantities of water vapour. Because water vapour also contributes to the greenhouse effect, its increased presence can further influence the warming process. The accumulation of greenhouse gases has been associated with a significant rise in global average temperature. Continued warming is expected to produce widespread environmental consequences. Sea levels, for example, may increase because of the loss of land-based ice and the expansion of seawater caused by higher temperatures. Such changes can increase the vulnerability of coastal and low-lying regions to flooding. Climate change can also alter rainfall patterns, soil conditions, and ecosystem stability, particularly in tropical and other environmentally sensitive regions. Increased heat and changes in precipitation may accelerate land degradation and contribute to the expansion of desert-like conditions. Consequently, global warming represents a serious challenge for both natural ecosystems and human societies, with potential impacts on water resources, agriculture, biodiversity, settlements, and overall environmental sustainability. The growing concentration of carbon dioxide (CO₂) in the atmosphere has made the management of this greenhouse gas an important aspect

of efforts to address climate change. Although capturing CO₂ from industrial processes can reduce direct emissions, identifying productive applications for the recovered gas is equally important for developing an effective carbon-utilization strategy. One promising application involves incorporating captured CO₂ into the production of concrete through controlled carbonation treatment. In this method, freshly manufactured concrete products are exposed to CO₂ under regulated curing conditions. The gas penetrates the concrete matrix and reacts with available calcium-containing materials, resulting in the formation of carbonate compounds. This reaction enables a portion of the captured CO₂ to be retained within the concrete in a stable form.

1.1 CARBONATION PROCESS

The curing carbonation process is different from weathering carbonation that naturally occurs in hardened concrete. Weathering carbonation is well known and has been extensively investigated. In weathering carbonation, hydration takes place first when cement is mixed with water and is followed by natural carbonation, a reaction between the hydration products and the atmospheric carbon dioxide. The weathering reactions of major hydration products (calcium hydroxide and calcium-silicate-hydrates) are :



The underlying principal is that the cement compounds C₃S and C₂S are instantaneously carbonized into calcium carbonate and silica gel once cement is mixed with water and exposed to carbon dioxide gas. Curing carbonation is an accelerated curing process that injects CO₂ gas into the curing vessel at room temperature.

2. LITERATURE REVIEW

The use of carbonation in cementitious materials is an established practice rather than a recent innovation. Its fundamental principles have been recognized for centuries through the use of lime-based binders in traditional construction. In these materials, hardening occurs when calcium-rich compounds react with carbon dioxide from the surrounding air, resulting in the formation of stable carbonate compounds. Under natural conditions, however, the carbonation process proceeds slowly because atmospheric CO₂ is available only in small quantities and at relatively low pressure. The limited penetration of CO₂ into the internal structure of mortar consequently restricts the rate at which strength is developed.

- 1. Carbon curing enhances the compressive strength of concrete. The synthesis of calcium carbonate from cement constituents during carbonation enhances the microstructure and augments the mechanical strength of concrete.**
- 2. CO₂ curing accelerates exothermic processes, resulting in quicker concrete hardening compared to steam curing at 75°C.**
- 3. The 4 hours curing by CO₂ gives the compressive strength nearly equal to the 28 days curing of concrete with water.**

3. METHODOLOGY

Carbon Cured Concrete is a technology that injects wasted CO₂ into concrete to increase its compressive strength. Through chemical reactions, CO₂ introduced to Calcium Oxide ions in a product's cement and subsequently produces a durable and more optimized concrete while at the same instance, it eliminates carbon dioxide. Carbon Dioxide curing is a method that helps reduce greenhouse gas emissions, while at the same time, produces viable concrete products. This is done by placing early-stage cement paste into the CO₂ chamber to accelerate strength development. Chemical reactions between Calcium oxide and CO₂ start to take place to form Calcium Carbonate. This new compound becomes embedded in concrete, which in return makes the concrete application stronger.

The CO₂ embedded in the concrete is permanently trapped, reducing the carbon footprint of the concrete. This process is a sustainable approach to concrete curing, as it captures CO₂ and promotes carbon sequestration, mitigating CO₂ pollution, and global warming.

4. WORKING PROCEDURE

I. Firstly, take all the material, equipment or necessary things i.e. cement, sand, aggregate, water, concrete mould(150mm X 150mm X 150mm), carbon dioxide cylinder, airtight vessel.

II. Cast concrete blocks of mix M25 by inserting the concrete into concrete mould, remove the mould after 24 hours.



Fig.1

III. It's time to construct the airtight vessel (or box) for CO₂ curing.

IV. Place 3 concrete blocks into water curing tank, 3 into CO₂ airtight container.

V. Close the CO₂ curing container with cap and stick tape for no chances of any leakage of CO₂ gas.

VI. Open the valve of CO₂ cylinder to inlet the CO₂ gas (for 2.5 hours).

VII. After 2.5 hours, close the valve and leave the container for 4 hours.

VIII. The curing of concrete cubes is done by absorbing the CO₂ gas.

IX. Compression test is done on concrete cubes to check the compressive strength of CO₂ curing concrete cubes.



Fig.2

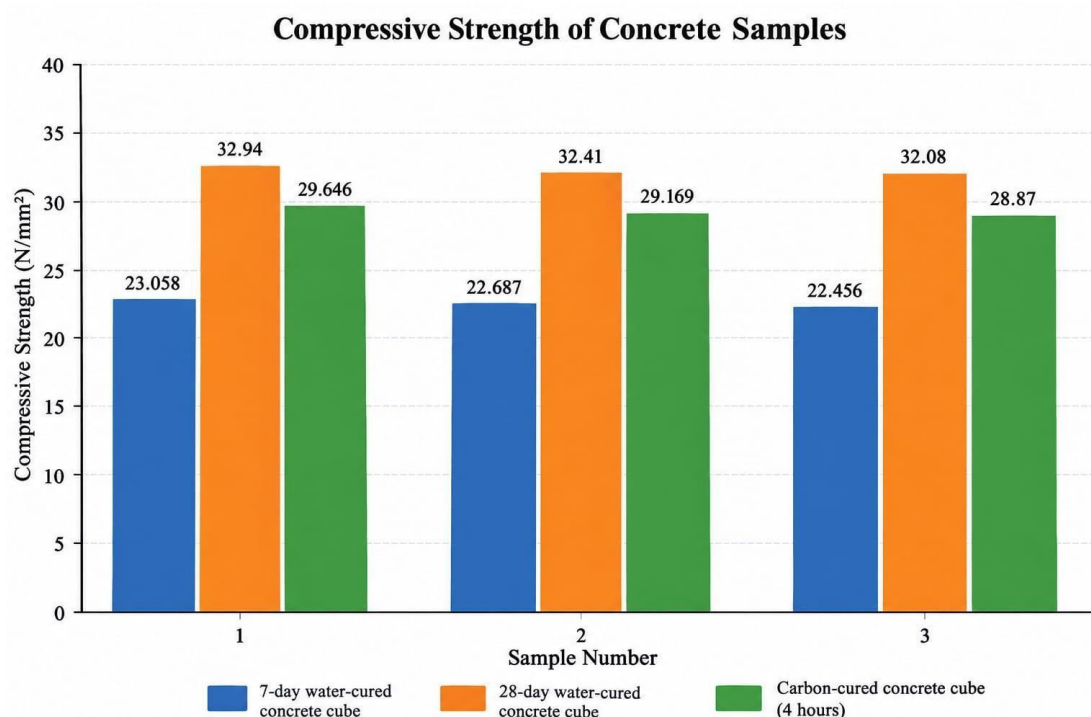
X. After 28 days, we check the compressive strength of water curing and air curing concrete cubes.

XI. Compare both types of curing concrete cubes.

5. TEST AND RESULTS

S. NO OF SAMPLE	7DAYS COMPRESSIVE STRENGTHOF WATER CURED CONCRETE CUBE (N/MM2)	28DAYS COMPRESSIVE STRENGTHOF WATER CURED CONCRETE CUBE (N/MM2)	COMPRESSIVE STRENGTH OF CARBON CURED CONCRETE CUBE IN FOUR HOURS (N/MM2)
1	23.058	32.94	29.646
2	22.687	32.41	29.169
3	22.456	32.08	28.87

Table 1



Graphical representation 1

The results show that the 4 hours curing by CO₂ of concrete block gives nearly the same 28 days compressive strength of concrete which is cured with water only.

6. ADVANTAGES

THE USE OF CO₂ FOR CURING CONCRETE CUBES OFFERS SEVERAL ADVANTAGES, INCLUDING:

- CO₂ curing accelerates the strength development of concrete cubes, enabling faster production cycles and improved concrete quality.
- CO₂ curing helps reduce the carbon footprint of concrete production by sequestering carbon dioxide within the concrete matrix, contributing to environmental sustainability.
- CO₂ curing can reduce production costs by lowering cement requirements and shortening curing and production times.
- The formation of calcium carbonate crystals during CO₂ curing can improve the durability and structural integrity of concrete cubes, supporting long-term performance.
- CO₂ curing is a promising method for reducing carbon emissions while producing high-quality concrete products.

7. APPLICATIONS OF CO₂ CURED CONCRETE

- CO₂ curing could be integrated into the construction industry to reduce carbon emissions and improve the environmental profile of concrete. This could lead to more sustainable building practices and contribute to a circular carbon economy.
- The integration of CO₂ curing could be a collaborative effort involving environmental science, engineering, and material science. This could lead to advancements in concrete technology and contribute to a sustainable future.
- CO₂ cured concrete could be used in infrastructure development projects, reflecting a shift towards environmentally responsible approaches.

- Utilizing CO₂ cured concrete in residential buildings could contribute to more sustainable construction practices.

CONCLUSION

An experimental study carried out on concrete with carbon dioxide gas focused on evaluating the changes in the duration of early strength gain. From the observations and test results, the following conclusions were obtained:

1. CaO-based cementitious materials can undergo carbonation within approximately four hours, facilitating the rapid manufacture of concrete products with adequate mechanical strength and a certain capacity for CO₂ sequestration.
2. The performance of these products can be improved by increasing the CO₂ concentration, extending the carbonation period, and raising the carbonation pressure, which may enhance both strength development and CO₂ uptake.
3. The continuous introduction of carbon dioxide (CO₂) during carbonation curing has shown considerable potential for large-scale concrete production. This approach continuously replaces the CO₂ consumed during the curing process, thereby maintaining an adequate supply and maximizing the amount of CO₂ captured within the concrete matrix.
4. The availability of moisture is essential for effective carbonation. Introducing water-enriched CO₂ may provide a promising strategy for improving the carbonation process, but its potential requires further investigation.
5. Among the binders investigated, Portland cement exhibited the greatest potential for CO₂ uptake, while also providing excellent strength development and mass increase.

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