Enhancing Carbon Capture and Utilization in Concrete Through Partial Replacement With Zeolite

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***Abstract*- The construction industry is a significant source of global CO2 emissions, primarily due to cement production. This study investigates the potential of enhancing carbon capture in concrete by partially replacing cement with high-quality industrial zeolite powder, a chemical absorbent known for its superior adsorption properties. Dynamic column breakthrough experiments were conducted to evaluate CO2 uptake in both normal concrete and concrete with 15% zeolite replacement. The results show a substantial increase in CO2 uptake for zeolite-enhanced concrete compared to normal concrete, suggesting that incorporating zeolite can effectively reduce the carbon footprint of construction materials.**

Keywords- carbon capture, zeolite, concrete, CO2 uptake, sustainable construction, dynamic column breakthrough

I. Introduction

Concrete is the most widely used construction material, but its production is responsible for substantial CO2 emissions, mainly from cement manufacturing. Finding ways to reduce these emissions is crucial for sustainability in the construction industry. One promising approach is enhancing the carbon capture capabilities of concrete itself by using materials with high adsorption capacities. High-quality industrial zeolite powder, a chemical absorbent with high surface area and porosity, offers a potential solution. This research explores the effectiveness of partially replacing cement with zeolite to improve the CO2 uptake capacity of concrete. Ease of Use

II. Materials and Methods

The study utilized M20 grade concrete. Zeolite-enhanced concrete was prepared by replacing 15% of the cement content with high-quality industrial zeolite powder. Dynamic column breakthrough experiments were conducted to measure the CO2 uptake over 7, 14, and 28 days.

A Materials

- Cement: Ordinary Portland Cement (OPC) was used.
- Zeolite: High-quality industrial zeolite powder, known for its chemical absorbent properties, replaced 15% of the cement by weight.
- Aggregates: Fine and coarse aggregates conforming to IS standards.
- Water: Potable water was used for mixing.

B. Concrete Mix Design

Two concrete mixes were prepared:

- Normal Concrete: Standard M20 grade mix.
- Zeolite-Enhanced Concrete: 15% replacement of cement with high-quality industrial zeolite powder.

C. Experimental Procedure

Dynamic column breakthrough experiments were conducted to measure the CO2 uptake of both concrete types at different curing periods (7, 14, and 28 days). The CO2 uptake was quantified using gas chromatography.

III. Results and Discussion

A. CO2 Uptake in Normal Concrete

• Normal Concrete 7 days Sample
Initial Flow 250 ml/min
Operational Flow 225 ml/min
Sample Weight 2 gram

$$q_b = \frac{\frac{225}{60} \times \frac{9612.72}{10^6} \times 36}{2} = 0.649 \text{ ml/g} = 1.272 \text{ mg/g}$$

tq = [(78.5 – 39) × 0.9] – 30.4 = 38.25 – 30.4 = 7.85 s

$$q_a = \frac{\frac{225}{60} \times \frac{9612.72}{10^6} \times 7.85}{2} = 0.141 \text{ ml/g} = 0.276 \text{ mg/g}$$

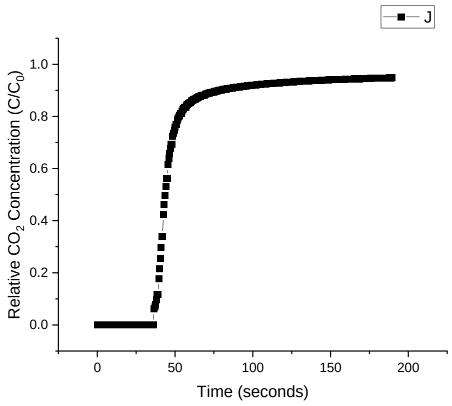

Fig 1 Dynamic CO2 Breakthrough Curve for Normal Concrete 7 days Sample

- Normal Concrete 14 days Sample

Total Uptake = 1.548 mg/g
Initial Flow 250 ml/min
Operational Flow 220 ml/min
Sample Weight 2 gram

$$q_b = \frac{\frac{220}{60} \times \frac{9576.87}{10^6} \times 38.5}{2} = 0.676 \text{ ml/g} = 1.325 \text{ mg/g}$$

t_q = [(107 – 38.5) × 0.9] – = 61.65 – 52.61 = 9.04 s

$$q_a = \frac{\frac{220}{60} \times \frac{9576.87}{10^6} \times 126.05}{2} = 0.159 \text{ ml/g} = 0.311 \text{ mg/g}$$

Total Uptake = 1.636 mg/g

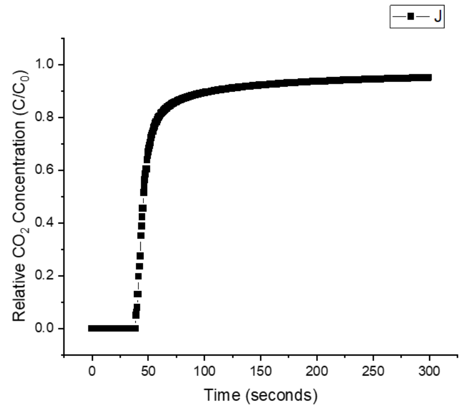

Fig 2 Dynamic CO2 Breakthrough Curve for Normal Concrete 14 days Sample.

- Normal Concrete 28 days Sample

Initial Flow 260 ml/min
Operational Flow 230 ml/min

$$q_b = \frac{\frac{230}{60} \times \frac{9631.73}{10^6} \times 31.5}{2} = 0.582 \text{ ml/g} = 1.14 \text{ mg/g}$$

t_q = [(96.5 – 31.5) × 0.9] – 48.37 = 10.13 s

$$q_a = \frac{\frac{230}{60} \times \frac{9631.73}{10^6} \times 10.13}{2} = 0.187 \text{ ml/g} = 0.37 \text{ mg/g}$$

Total Uptake = 1.14 + 0.37 = 1.51 mg/g

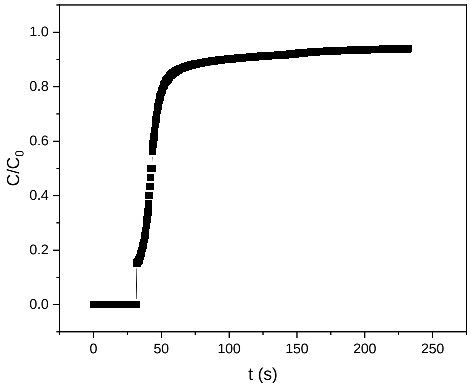

Fig 3 Dynamic CO2 Breakthrough Curve for Normal Concrete 28 days Sample

The CO2 uptake in normal concrete increased from 7 to 14 days, indicating active carbonation processes. The slight decrease at 28 days suggests that the formation of a dense calcium carbonate layer might be limiting further CO2 diffusion and reaction within the concrete matrix.

B. CO2 Uptake in Zeolite-Enhanced Concrete

- 15% Zeolite 7 days curing

Initial Flow 260 ml/min

Operational Flow 230 ml/min

$$q_b = \frac{\frac{230}{60} \times \frac{9629.21}{10^6} \times 33}{2} = 0.609 \text{ ml/g} = 1.194 \text{ mg/g}$$

t_q = [(70 – 33) × 0.9] – 25.85 = 7.45 s

$$q_a = \frac{\frac{230}{60} \times \frac{9629.21}{10^6} \times 7.45}{2} = 0.137 \text{ ml/g} = 0.27 \text{ mg/g}$$

Total Uptake = 1.19 + 0.27 = 1.46 mg/g

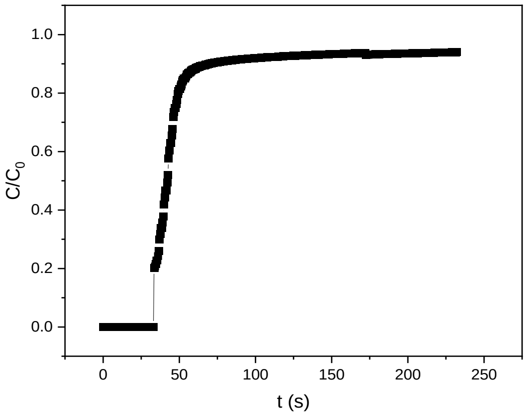

Fig 4 Dynamic CO2 Breakthrough Curve for 15% Zeolite 7-day curing Sample.

- 15% Zeolite 14days curing

Initial Flow 260 ml/min
Operational Flow 230 ml/min

$$q_b = \frac{\frac{230}{60} \times \frac{9598.95}{10^6} \times 41}{2} = 0.754 \text{ ml/g} = 1.48 \text{ mg/g}$$

t_q = [(286.5 – 41) × 0.9] – 202.68 = 18.27 s

$$q_a = \frac{\frac{230}{60} \times \frac{9598.95}{10^6} \times 18.27}{2} = 0.336 \text{ ml/g} = 0.66 \text{ mg/g}$$

Total Uptake = 1.48 + 0.66 = 2.14 mg/g

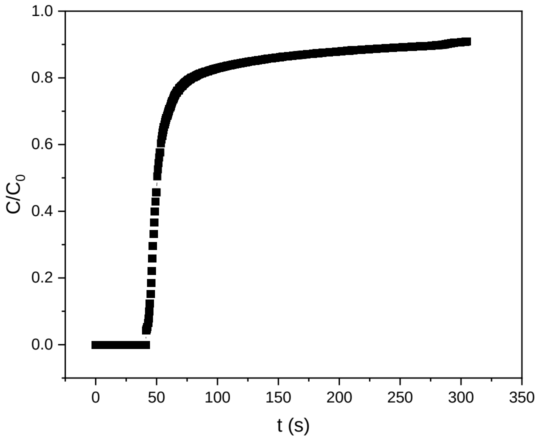

Fig 5 Dynamic CO2 Breakthrough Curve for 15% Zeolite 14 days curing Sample.

- 15% Zeolite 28 days curing

Initial Flow 260 ml/min
Operational Flow 230 ml/min

$$q_b = \frac{\frac{230}{60} \times \frac{9800.62}{10^6} \times 51.5}{2} = 0.967 \text{ ml/g} = 1.9 \text{ mg/g}$$

$$t_q = [(968.5 - 51.5) \times 0.9] - 640.9 = 184.4 \text{ s}$$

$$q_a = \frac{\frac{230}{60} \times \frac{9800.62}{10^6} \times 184.4}{2} = 3.464 \text{ ml/g} = 6.79 \text{ mg/g}$$

Total Uptake = 1.9 + 6.79 = 8.69 mg/g

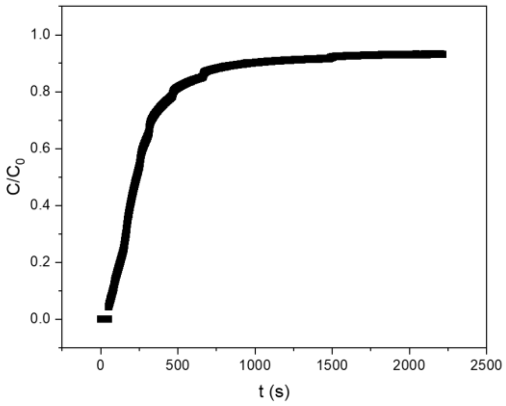

Fig 6 Dynamic CO2 Breakthrough Curve for 15% Zeolite 28 days curing Sample.

The zeolite-enhanced concrete exhibited significantly higher CO2 uptake compared to normal concrete. The higher initial uptake at 7 days can be attributed to the zeolite's superior adsorption capacity. The marked increase at 28 days demonstrates the sustained ability of zeolite to capture CO2, even as the primary hydration reactions slow down, indicating the long-term benefits of using zeolite for carbon capture.

IV. Discussion

A. Using high-quality industrial zeolite powder in concrete

significantly enhances its CO2 uptake capacity. Zeolite's high surface area and microporous structure provide ample sites for CO2 adsorption, leading to continuous and effective carbon capture. These results suggest that incorporating zeolite into concrete can improve immediate CO2 capture and sustain this capacity over a longer period, thus contributing to the reduction of the overall carbon footprint of concrete structures.

B. Compressive Strength

The compressive strength of the zeolite-enhanced concrete was measured to ensure structural integrity. At 28 days, the compressive strength was approximately 24.5 N/mm², achieving the target strength for M20-grade concrete.

V. Conclusion

This study demonstrates that partial replacement of cement with high-quality industrial zeolite powder significantly increases the CO2 uptake capacity of concrete. The zeolite-enhanced concrete shows a pronounced ability to capture and retain CO2 over an extended period, making it a viable option for sustainable construction practices. Future research should focus on optimizing the zeolite content and further examining the long-term durability and mechanical properties of zeolite-enhanced concrete to ensure it meets structural requirements for various construction applications.

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