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Experimental Investigation of Carbon Dioxide Adsorbing Concrete Blocks Incorporating Zeolite and Dunite as Sustainable Mineral Admixtures

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ABSTRACT

The construction sector is facing growing challenges to reduce greenhouse gas emissions by adopting environmentally sustainable construction materials with lower carbon footprints. Among the emerging solutions, carbon dioxide (CO_2)-adsorbing concrete has attracted considerable attention because of its ability to capture atmospheric CO_2 while maintaining the engineering properties required for structural applications. This study experimentally evaluates the potential of developing sustainable concrete blocks with enhanced CO_2 adsorption capacity through the partial replacement of conventional materials with natural zeolite and Dunite. Concrete mixes containing different replacement proportions were prepared and assessed for both fresh and hardened properties. Workability, compressive strength, water absorption, and density were determined in accordance with the relevant Indian Standard specifications. In addition, the CO_2 adsorption capacity of the concrete blocks was evaluated to examine the effect of these mineral additives on carbon sequestration performance. The findings reveal that incorporating zeolite and Dunite improves the CO_2 adsorption capability of concrete while preserving satisfactory mechanical properties when used within optimal replacement limits. However, higher replacement levels reduce workability and compressive strength, primarily due to increased pore volume and weaker cementitious bonding within the concrete matrix. Overall, the results indicate that a balanced combination of zeolite and Dunite can produce sustainable concrete blocks with enhanced carbon capture potential and acceptable structural performance. The outcomes of this research provide valuable insights into the development of eco-friendly construction materials that can contribute to carbon mitigation efforts while supporting the long-term sustainability of the built environment.

Keywords: Sustainable concrete, Carbon sequestration, Zeolite, Dunite

INTRODUCTION

Concrete is increasingly being engineered to perform multiple functions beyond providing structural strength, with growing emphasis on improving its environmental performance. One of the most promising developments in this field is carbon dioxide (CO_2)-adsorbing concrete, which has the ability to capture atmospheric CO_2 through physical adsorption and mineral carbonation while continuing to meet the mechanical requirements of conventional construction applications. By integrating carbon capture into cement-based materials, this approach offers an effective means of reducing the environmental burden associated with the construction industry.

Among the various supplementary materials investigated for sustainable concrete production, natural mineral admixtures have shown considerable potential in enhancing both durability and environmental performance.

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Natural zeolite, in particular, has been extensively studied because of its highly porous alumina silicate framework, large specific surface area, and pozzolanic characteristics. Earlier research has demonstrated that replacing a portion of cement with zeolite can improve long-term compressive strength, refine the internal pore structure, and enhance durability through the formation of additional calcium silicate hydrate (C–S–H) gel. Nevertheless, higher replacement levels often result in reduced workability and lower early-age strength due to the material's greater water absorption capacity. More recently, zeolite has also been recognised as a suitable candidate for improving the CO_2 adsorption behaviour of cementitious materials.

Magnesium-bearing silicate minerals, particularly Dunite, have also attracted attention because of their ability to permanently store carbon dioxide through mineral carbonation reactions. Most published studies have concentrated on the carbonation characteristics of Dunite and its application in carbon capture and storage technologies. In comparison, relatively few investigations have explored its incorporation into concrete as a sustainable constituent. Moreover, the combined use of zeolite and Dunite in cementitious composites has received limited attention, especially in terms of achieving both enhanced mechanical performance and improved CO_2 adsorption under normal curing conditions.

Considering these research gaps, the present study examines the development of carbon dioxide (CO_2)-adsorbing concrete blocks by incorporating zeolite and Dunite as sustainable partial replacement materials. Concrete mixtures with varying replacement levels were prepared and evaluated for workability, density, water absorption, compressive strength, and CO_2 adsorption capacity to determine an optimum mix capable of balancing structural performance with carbon sequestration efficiency. The findings are expected to provide a better understanding of the combined influence of zeolite and Dunite and support the development of environmentally sustainable cementitious materials with enhanced carbon capture capability.

MATERIALS AND EXPERIMENTAL PROGRAM

Materials

Ordinary Portland Cement (OPC) 53 grade conforming to IS 12269 was used as the primary cementitious binder throughout the study. Natural river sand meeting the requirements of Zone II as specified in IS 383 was used as the fine aggregate, while crushed granite coarse aggregate with a nominal maximum size of 20 mm, conforming to IS 383, served as the coarse aggregate. The aggregates were carefully selected to satisfy the grading requirements for conventional concrete and were confirmed to be free from harmful impurities. Potable water was used for both mixing and curing to ensure consistency during the experimental programme.

Natural zeolite and Dunite were incorporated as sustainable mineral admixtures because of their distinct yet complementary roles in carbon sequestration. Zeolite, a naturally occurring crystalline alumina silicate, was chosen for its high specific surface area, porous structure, pozzolanic characteristics, and ability to adsorb atmospheric CO_2. Dunite, a magnesium-rich silicate mineral predominantly composed of olivine, was included because of its potential to chemically sequester CO_2 through mineral carbonation while also contributing to the refinement of the concrete microstructure. The physical characteristics of all constituent materials used in this investigation are presented in Table 1.

Table 1: Physical Properties of Materials

Sl.No	Property	Cement	Fine Aggregate	Coarse aggregate	zeolite	Dunite

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1	Specific gravity	3.06	2.55	2.59	2.30	3.20
2	Standard consistency (%)	32	-	-	-	-
3	Initial setting time (min)	30	-	-	-	-
4	Bulk density (kg/m^3)	-	1750	1600	-	-
5	Water Absorption (%)	-	1.0	0.5	22.5	0.3

Concrete Mix Design

The control concrete mix of M30 grade was designed in accordance with IS 10262:2019. Zeolite was used as a partial replacement for cement at levels of 10%, 15%, and 20%, whereas Dunite was incorporated as a partial replacement for fine aggregate at 10%, 15%, and 20%. Along with the control mix, seven modified mixtures (10Z–10D, 10Z–15D, 15Z–10D, 15Z–15D, 15Z–20D, 20Z–15D, and 20Z–20D) were prepared to examine the combined effect of these mineral admixtures on the fresh, physical, mechanical, and CO_2 adsorption properties of concrete. The replacement percentages were selected based on the optimum ranges reported in earlier studies, while the water-to-binder ratio, aggregate proportions, and mixing procedure were kept identical for all mixes to ensure a uniform basis for comparison.

Specimen Preparation

A total of eight concrete mixtures, including one control mix and seven modified mixes with different zeolite and Dunite replacement levels, were prepared. Three concrete block specimens of dimensions 200 × 150 × 100 mm were cast for each mixture, giving a total of 24 specimens for the experimental programme. The control mix comprised three specimens, while the remaining 21 specimens represented the seven modified mixes. The average value of the three specimens was used to evaluate the engineering properties and CO_2 adsorption performance of each concrete mixture. The mould used for specimen preparation and the concrete block after demoulding are shown in Figure 1.

Figure 1: Mould used for preparation of specimen and specimens after Demoulding

Curing Process

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After Demoulding at 24 hours, the specimens were cured in potable water under laboratory ambient conditions (27 ± 2°C) until the specified testing ages of 7, 14, 21, and 28 days. At the end of the curing period, the specimens were removed from the curing tank, surface moisture was wiped off, and they were allowed to reach a saturated surface-dry (SSD) condition under laboratory ambient conditions before weighing and testing. This procedure was adopted to minimize the effect of free surface water on the measured specimen mass and to ensure consistent comparison among all concrete mixtures.

Testing of Specimen

The experimental programme included slump, density, water absorption, compressive strength, and CO_2 adsorption tests to assess the influence of zeolite and Dunite on the fresh, physical, mechanical, and carbon sequestration performance of concrete. The CO_2 adsorption capacity of the concrete blocks was determined from the increase in specimen mass after curing. The amount of CO_2 adsorbed was calculated by relating the measured mass gain to the molecular weight of carbon dioxide.

RESULT AND DISCUSSION

Properties of concrete in Fresh State

The workability of the concrete mixtures was evaluated using the slump cone test, and the corresponding results are presented in Table 2. A gradual reduction in workability was observed with increasing replacement levels of zeolite and Dunite. The control mixture recorded a true slump of 85 mm, while the slump reduced to 65 mm for the mixture containing 20% zeolite and 20% Dunite. This decrease is mainly attributed to the porous structure and high water absorption capacity of zeolite, which increases the water demand, along with the angular shape of finely ground Dunite particles that increases internal friction within the concrete matrix. Despite the reduction in slump, all mixtures exhibited a true slump, indicating adequate cohesion and workability for concrete block casting.

Table 2: Test Results of Slump Cone Test

Mix ID	Zeolite (%)	Dunite (%)	Slump (mm)
Control mix	0	0	85
10Z–10D	10	10	81
10Z–15D	10	15	79
15Z–10D	15	10	77
15Z–15D	15	15	74
15Z–20D	15	20	71
20Z–15D	20	15	68
20Z–20D	20	20	65

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Compression strength

The compressive strength results are presented in Table 3 and Figure 4. The concrete mixture containing 10% zeolite and 10% Dunite achieved the highest compressive strength, representing a 15.77% increase compared with the control concrete after 28 days of curing. This improvement is attributed to the pozzolanic activity of zeolite, which enhances the formation of additional C–S–H gel, along with the filler effect of Dunite that contributes to a denser concrete matrix. In contrast, increasing the replacement level to 20% zeolite and 20% Dunite resulted in a 16.23% reduction in compressive strength relative to the control mix, mainly due to the dilution of cementitious material and the lower formation of hydration products.

Figure 2: Indication of Compression Test

Table 3: Test Results of compression Test

Mix ID	7th day (N/mm^2)	14th day (N/mm^2)	21st day (N/mm^2)	28th day (N/mm^2)
Control mix	8.310	12.950	14.020	14.200
10Z–10D	15.460	15.620	16.420	16.440
10Z–15D	14.680	15.660	16.220	16.380
15Z–10D	11.145	15.320	15.435	15.575
15Z–15D	11.175	12.085	12.245	12.285
15Z–20D	11.075	11.150	15.320	15.535
20Z–15D	11.030	11.075	11.185	11.188
20Z–20D	11.285	11.395	11.570	11.895

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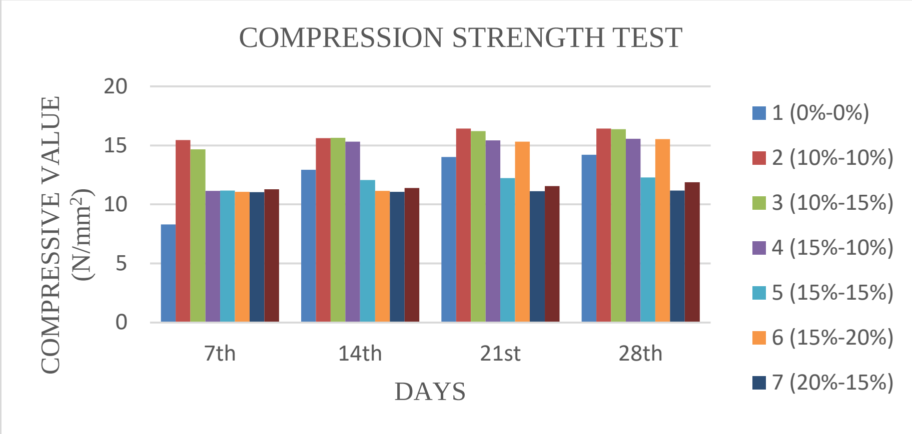

Figure 4: Variation of Compression strength of various mixes

Density

The density and estimated CO_2 uptake results are presented in Table 4 and Figure 5. The concrete mixture containing 20% zeolite and 20% Dunite recorded the highest density, representing a 13.32% increase compared with the control concrete. The corresponding estimated CO_2 uptake was 0.810 mol, indicating that the addition of zeolite and Dunite improved the carbon sequestration capacity of the concrete. In addition, the strength development of the zeolite-incorporated mixtures was more significant during the early curing period due to the pozzolanic activity of zeolite, with only slight improvements observed beyond 7 days.

Table 4: Test Results of Density Test

Percentage	Initial Density (kg/m^3)	Final Density (kg/m^3)	Difference in Density (kg/m^3)	Mass (kg)	Carbon Adsorbed (moles)
Control mix	2400.00	2272.33	-127.67	-0.3800	-8.63
10Z–10D	2560.00	2563.66	3.66	0.0109	0.247
10Z–15D	2586.66	2592.99	6.33	0.0190	0.431
15Z–10D	2440.00	2449.66	9.66	0.0289	0.658
15Z–15D	2140.00	2149.66	9.66	0.0289	0.658
15Z–20D	2300.00	2310.56	10.56	0.0317	0.722
20Z–15D	2513.33	2524.63	11.30	0.0339	0.772
20Z–20D	2563.33	2575.19	11.86	0.0356	0.810

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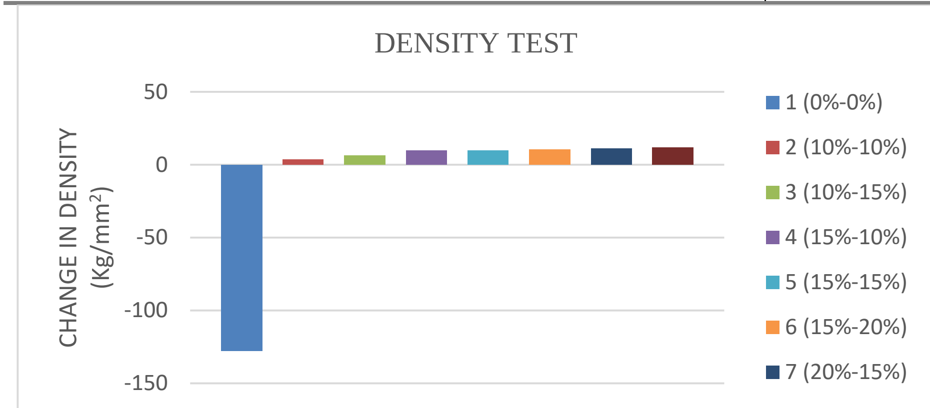

Figure 5: Variation of Density of Various Mixes

Adsorption of Carbon dioxide

The estimated CO_2 uptake of the concrete mixtures after 28 days of curing is presented in Figure 6. An increase in CO_2 uptake was observed with higher replacement levels of zeolite and Dunite, with the 20% zeolite–20% Dunite mixture recording the maximum value of 0.810 mol. This improvement is attributed to the high adsorption capacity of zeolite and the carbonation potential of magnesium-rich Dunite, demonstrating that their combined incorporation enhances the carbon sequestration capability of concrete.

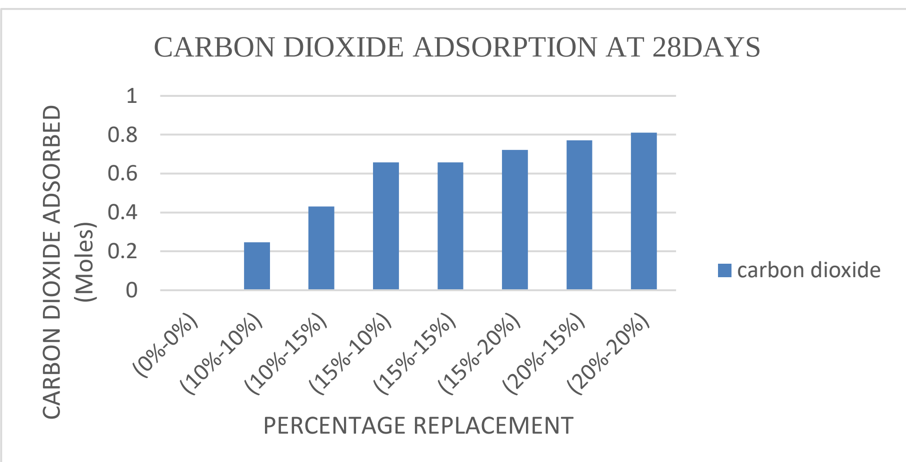

Figure 6: Carbon dioxide Adsorption of Various Mixes

CONCLUSION

1. This study examined the feasibility of producing CO_2-adsorbing concrete blocks by incorporating zeolite as a partial replacement for cement and Dunite as a partial replacement for fine aggregate.
2. The concrete mixture containing 10% zeolite and 10% Dunite exhibited the best mechanical performance, with a 15.77% increase in 28-day compressive strength compared with the control concrete, while further increases in replacement levels led to a gradual decline in strength.
3. The estimated CO_2 uptake increased with increasing zeolite and Dunite content, and the 20% zeolite–20% Dunite mixture recorded the highest uptake of 0.810 mol, confirming the positive contribution of both mineral admixtures to the carbon sequestration capacity of concrete.

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4. The experimental results suggest that the combined incorporation of zeolite and Dunite is an effective approach for producing sustainable concrete with enhanced environmental performance while retaining satisfactory engineering properties.
5. Overall, the findings indicate that the mixture containing 10% zeolite and 10% Dunite offers the most suitable balance between compressive strength and CO_2 uptake, demonstrating the potential of these naturally occurring minerals in the development of environmentally sustainable concrete.

REFERENCE

1. British Cement Association. (2013). *Properties of Portland pozzolana cement*. British Cement Association.
2. Indian Standards Institution. (1963). *IS 2386 (Part 3): Methods of test for aggregates for concrete—Specific gravity, density, voids, absorption and bulking*. Bureau of Indian Standards.
3. Indian Standards Institution. (1991). *IS 1489 (Part 1): Portland pozzolana cement—Specification*. Bureau of Indian Standards.
4. Lee, Y. L., Koh, H. B., Alona, C. L., Ahmad Karim, A. T., Wimala, M., & Ng, C. (2018). CO_2 uptake model of biomass silica foamed concrete. *IOP Conference Series: Materials Science and Engineering, 431*(8), 082008. https://doi.org/10.1088/1757-899X/431/8/082008
5. Madandoust, R., Sobhani, J., Ashoori, P., & Fakoor, M. (2014). The mechanical properties and durability assessment of concrete containing natural zeolite as a highly reactive supplementary cementitious material. *Construction and Building Materials, 51*, 329–337. https://doi.org/10.1016/j.conbuildmat.2013.10.054
6. Meyer, C. (2009). The greening of the concrete industry. *Cement and Concrete Composites, 31*(8), 601–605. https://doi.org/10.1016/j.cemconcomp.2008.12.010
7. Monkman, S., & Shao, Y. (2010). Assessing the carbon uptake of concrete during its service life. *Cement and Concrete Composites, 32*(10), 817–823. https://doi.org/10.1016/j.cemconcomp.2010.09.004
8. Najimi, M., Sobhani, J., Ahmadi, B., & Shekarchi, M. (2012). An experimental study on durability properties of concrete containing zeolite as a highly reactive natural pozzolan. *Construction and Building Materials, 35*, 1023–1033. https://doi.org/10.1016/j.conbuildmat.2012.04.038
9. Papadakis, V. G. (2000). Effect of supplementary cementing materials on concrete resistance against carbonation. *Cement and Concrete Research, 30*(2), 291–299. https://doi.org/10.1016/S0008-8846(99)00249-5
10. Scrivener, K. L., John, V. M., & Gartner, E. M. (2018). Eco-efficient cements: Potential economically viable solutions for a low-CO_2 cement-based materials industry. *Cement and Concrete Research, 114*, 2–26. https://doi.org/10.1016/j.cemconres.2018.03.015
11. Snellings, R., Mertens, G., & Elsen, J. (2012). Supplementary cementitious materials. *Reviews in Mineralogy and Geochemistry, 74*(1), 211–278. https://doi.org/10.2138/rmg.2012.74.6
12. Subramani, T., & Sumathi, C. (2015). Experimental investigation of partial replacement of cement with fly ash and sand with bottom ash and glass used in concrete. *International Journal of Application or Innovation in Engineering & Management, 4*(5), 245–253.
13. Wang, M., Lawal, A., Stephenson, P., Sidders, J., Ramshaw, C., & Yeung, H. (2011). Post-combustion CO_2 capture with chemical absorption: A state-of-the-art review. *Chemical Engineering Research and Design, 89*(9), 1609–1624. https://doi.org/10.1016/j.cherd.2010.11.005
14. Yilmaz, B., & Uçar, A. (2011). Properties of zeolitic concrete containing natural zeolite as a supplementary cementitious material. *Construction and Building Materials, 25*(11), 4270–4275. https://doi.org/10.1016/j.conbuildmat.2011.04.026
15. Zhang, D., Shao, Y., & Ling, T. C. (2017). Carbonation curing of cement-based materials: A review. *Journal of CO_2 Utilization, 21*, 119–131. https://doi.org/10.1016/j.jcou.2017.07.003

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VI, June 2026

16. Zhang, T., Castel, A., & François, R. (2009). Carbonation of concrete with supplementary cementitious materials. *Cement and Concrete Research*, *39*(12), 1180–1188. https://doi.org/10.1016/j.cemconres.2009.07.01
17. Habert, G., Miller, S. A., John, V. M., Provis, J. L., Favier, A., Horvath, A., & Scrivener, K. L. (2020). Environmental impacts and decarbonization strategies in the cement and concrete industries. *Nature Reviews Earth & Environment*, *1*(11), 559–573. https://doi.org/10.1038/s43017-020-0093-3
18. Lothenbach, B., Scrivener, K., & Hooton, R. D. (2011). Supplementary cementitious materials. *Cement and Concrete Research*, *41*(12), 1244–1256. https://doi.org/10.1016/j.cemconres.2010.12.001
19. Pade, C., & Guimaraes, M. (2007). The CO_2 uptake of concrete in a 100-year perspective. *Cement and Concrete Research*, *37*(9), 1348–1356. https://doi.org/10.1016/j.cemconres.2007.06.009
20. Sanjuán, M. Á., Andrade, C., Mora, P., & Zaragoza, A. (2020). Carbon dioxide uptake by cement-based materials: A Spanish case study. *Applied Sciences*, *10*(1), 339. https://doi.org/10.3390/app10010339
21. Shi, C., Jiménez, A. F., & Palomo, A. (2011). New cements for the 21st century: The pursuit of an alternative to Portland cement. *Cement and Concrete Research*, *41*(7), 750–763. https://doi.org/10.1016/j.cemconres.2011.03.016
22. Van den Heede, P., & De Belie, N. (2012). Environmental impact and life cycle assessment (LCA) of traditional and "green" concretes: Literature review and theoretical calculations. *Cement and Concrete Composites*, *34*(4), 431–442. https://doi.org/10.1016/j.cemconcomp.2012.01.004