

ENHANCING STRUCTURAL PERFORMANCE AND SUSTAINABILITY WITH CO₂ ABSORBING CONCRETE USING ZEOLITE AND GGBS

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Abstract

Despite being one of the most popular building materials, the manufacture of concrete greatly increases CO₂ emissions. Zeolite and ground granulated blast furnace slag are used in this study to partially replace ordinary Portland cement in order to explore the possibility of CO₂-absorbing concrete. While GGBS promotes durability and mechanical qualities, zeolite's microporous structure aids CO₂ sequestration. The impacts of these materials on carbonation depth, compressive strength, split tensile strength, and CO₂ absorption capacity are the main topics of this study. Mix designs for M30 grade concrete were created by substituting 10%, 20%, and 30% zeolite for OPC in addition to a fixed 30% GGBS. Compressive strength, split tensile strength, carbonation depth, and CO₂ absorption by weight were all evaluated for specimens of hardened concrete. According to the data, compared to normal concrete, a 30% Zeolite and 30% GGBS replacement improves split tensile strength by 7.75% and compressive strength by 11.54%. Furthermore, the depth of carbonation rose fivefold, and the absorption of CO₂ improved considerably. These findings demonstrate how Zeolite and GGBS can improve concrete's performance while lessening its negative effects on the environment, making it a workable option for environmentally friendly building.

Keywords: Carbon Sequestration; CO₂ Absorbing Concrete; Ground Granulated Blast Furnace Slag; Sustainable Construction; Zeolite

Introduction

Because of its cost-effectiveness, durability, and adaptability, concrete is the most widely used building material. However, the manufacturing of Ordinary Portland Cement (OPC) is the main source of its production, which contributes significantly to world CO₂ emissions. The cement business is a major contributor to environmental deterioration and climate change, accounting for roughly 7-8% of worldwide CO₂ emissions. Finding sustainable

substitutes for traditional concrete is crucial to lowering its carbon footprint while preserving structural integrity as the demand for infrastructure rises.

The creation of CO₂ absorbing concrete, which not only lowers emissions but also absorbs and stores atmospheric CO₂, is one promising strategy for reducing CO₂ emissions. By using ingredients that aid in carbon sequestration, this creative

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concrete helps to mitigate the negative environmental effects of cement manufacture. Zeolite has drawn significant attention among the several materials investigated for this purpose because of its exceptional capacity to absorb and store CO₂. Zeolite is a microporous aluminosilicate substance that works very well for CO₂ adsorption because of its high surface area and superior ion exchange capabilities. By enabling long-term CO₂ capture, its incorporation into concrete promotes sustainable building methods.

Zeolite has significant environmental advantages, but there are drawbacks to using it in concrete, especially when it comes to longevity and mechanical strength. Zeolite can change the cement's hydration process, which could have an impact on the concrete's structural performance. Ground Granulated Blast Furnace Slag (GGBS) is a supplementary cementitious material (SCM) that is used to overcome this constraint. A by-product of the production of steel, GGBS is well known for improving the workability, strength, and durability of concrete. It enhances the overall performance of the concrete by reacting with calcium hydroxide (Ca(OH)₂) during cement hydration to generate more calcium silicate hydrate (C-S-H) gel. Additionally, using GGBS lessens dependency on OPC, which lowers CO₂ emissions related to cement production.

The study also explores the importance of bamboo biochar as a CO₂ absorbent by substituting fine aggregate with zeolite and cement with biochar. Superior results in compressive and split tensile strength, impact resistance, water absorption, and CO₂ sequestration were obtained with the ideal mixture of 50% zeolite and 1% bamboo biochar, highlighting the significance of natural materials in lowering carbon emissions (Revathi *et al.*, 2024). The addition of zeolite significantly enhances mechanical properties while providing an effective means of CO₂ absorption. Studies indicate that zeolite-infused concrete can absorb up to 60% more CO₂ than conventional concrete, with compressive strength peaking at 10-20% zeolite content. However, increased zeolite levels reduce workability due to its rough texture and shape. Despite this, zeolite-modified concrete meets structural requirements while serving as an eco-friendly alternative to traditional concrete (Durisetty *et al.*, 2020).

Research on the partial replacement of cement with natural zeolite demonstrates improvements in both mechanical and durability properties. Compressive strength increased by 6.7% at 10% zeolite replacement, while split tensile strength peaked at 15%. Additionally, acid resistance was highest at 10% replacement, with lower strength

loss observed. Ultrasonic pulse velocity tests revealed reduced velocities at higher zeolite content, indicating modifications in the internal structure. Overall, a 10% zeolite replacement was found optimal for enhancing concrete performance (Prudhvi and Reddy, 2024).

Zeolites are also recognized as efficient CO₂ capture agents due to their high porosity and structural stability. Experimental studies highlight that zeolite 13X can achieve CO₂ uptake of up to 6.9 mmol/g under optimal conditions. Advances in 3D-printed zeolite monoliths and hybrid composites further improve CO₂ capture efficiency. Continued research is needed to optimize these materials for practical applications in mitigating climate change (Kumar *et al.*, 2020).

Experimental evaluations on cement mortar with varying zeolite content (0%, 10%, 20%, and 30%) show notable improvements in mechanical strength and carbonation resistance. At 10% zeolite content, compressive strength increased by 3.96%, rising further to 9.71% at 20% and 5.85% at 30% after 28 days. Carbonation tests revealed that zeolite concrete sequesters CO₂ effectively, with a carbonation depth of 5 mm every 48 hours. Importantly, carbonated zeolite concrete retained comparable compressive strength to uncarbonated samples, demonstrating its dual function in enhancing strength and reducing atmospheric CO₂ levels (Sudarsono *et al.*, 2022).

In order to improve compressive strength, the study investigates the partial replacement of concrete with ground granulated blast-furnace slag (GGBS). After testing 32 different mixes, it was shown that adding more GGBS increases strength up to an ideal range of 55-59% of the overall binder concentration. Beyond this point, more GGBS can still be used as a filler but does not further increase strength. Additionally, the study explores the chemical reactions that occur during hydration and the beneficial impacts of GGBS on the characteristics of concrete, suggesting that it has the potential to be a long-lasting mineral additive that lowers porosity (Oner and Akyuz, 2007).

The study investigates how the mechanical and durability characteristics of concrete are affected by substitute materials such as zeolite, ground granulated blast-furnace slag (GGBS), and construction and demolition waste (CDW). The ideal mixture, known as Mix Batch M4 (60% Sand, 20% Zeolite, 10% GGBS, 10% CDW), produced better flexural and split tensile strengths in addition to the highest compressive strength of 67.37 MPa. Significant improvements were found in durability characteristics including water absorption, drying shrinkage, and chloride permeability, which were also evaluated in the study. Mix Batch M4 in

particular demonstrated lower drying shrinkage (4.02%) and water absorption (4.00%). Furthermore, machine learning algorithms were incorporated to forecast the characteristics of concrete, proving their usefulness in enhancing mix designs and encouraging environmentally friendly building methods (Anand *et al.*, 2025).

The article highlights the thermal, environmental, and financial advantages of using sustainable insulating materials in building, with a focus on fly ash, lime, and bamboo biochar. Fly ash, a byproduct of burning coal, increases the strength of concrete and lowers thermal conductivity, while bamboo biochar provides efficient insulation because of its low thermal conductivity and carbon sequestration. Lime is celebrated for its moisture-regulating properties and longevity in building applications. The study provides the importance of optimizing these materials for future construction practices to enhance energy efficiency and reduce carbon footprints (Deshmukh and Yadav, 2025).

An investigation assessed the effectiveness of synthesized nano-zeolite for capturing CO₂ via temperature swing adsorption. At 20°C and 1 atm, it showed an adsorption capacity of 4.81 mmol/g and a CO₂/N₂ selectivity of 18.65. After 10 adsorption-desorption cycles, the nano-zeolite's CO₂ removal effectiveness remained above 88%, demonstrating its capacity for renewal. High surface area and pore volume were found during characterization, which improved its applicability as an adsorbent (Pham *et al.*, 2016).

The assessment of how well concrete mixtures containing natural zeolite (NZ) operate in situations that are sulfate hostile shows that natural zeolite enhances durability, compressive strength, and resistance to sodium sulfate attack compared to conventional concrete. Life cycle assessment (LCA) indicates that replacing 20% of Portland cement with natural zeolite can decrease global warming potential by up to 69.7%. Optimal natural zeolite replacement rates improve mechanical properties and extend service life, making concrete more environmentally friendly (Shahmansouri *et al.*, 2021).

Concrete is essential in construction but contributes to CO₂ emissions. Strength and durability are increased by partially substituting industrial waste (such as fly ash, silica fume, metakaolin, and zeolite) for cement. Research indicates that up to a specific replacement level, characteristics get better. There aren't many studies on zeolite mixed with other waste; more research is required. The emphasis is on using industrial waste to produce concrete in a sustainable manner for the benefit of the environment (Iswarya and Beulah, 2021).

Examine how adding 5%, 10%, or 15% silica fume affects the strength and resilience of

geopolymer concrete (GPC) in challenging environments. Ten percent silica fume was used to reach the maximum compressive strength, increasing ability to withstand chemical attacks from sulfuric, hydrochloric, sodium chloride, and sulfate. Increased dosage of silica fume results in better mechanical qualities and decreased water absorption (Paruthi *et al.*, 2024). Compressive strength is increased by 15% when zeolite is substituted for up to 10% of cement. Density is increased and water absorption is decreased by 2.3 times. Resistance to freeze-thaw is improved by more than 3.3 times. The pozzolanic action of zeolite helps to reduce porosity and improve durability (Nagrockiene and Girskas, 2016). Fifteen percent zeolite improves durability and strength, decreases rates of corrosion, and enhances penetration of water and chloride ions, with less drying shrinkage than control samples. In acidic settings, performance was subpar (Najimi *et al.*, 2012).

Investigations also examined how fly ash (FA) and graphene nanoplatelets (GNP) work together to improve calcium aluminate cement (CAC) composites. GNP can improve mechanical qualities by as much as 60%, particularly compressive strength. Fly ash decreases water absorption and increases workability. Strength is greatly increased and porosity is decreased by the 20% fly ash and 0.3% GNP concentration. Together, fly ash and GNP lessen the effects of hydration conversion in CAC (Win *et al.*, 2023b).

The study shows how cement-fly ash characteristics and durability are affected by fly ash fineness and CaO level. Compressive strength, carbonation resistance, and chloride ion penetration are all strongly impacted by fineness. Compressive strength is mostly influenced by CaO concentration. Durability is increased by smaller fly ash particles (Win *et al.*, 2022).

Research has also examined how ASEAN fly ash affects the durability and hydration of cement. Chloride diffusivity is considerably reduced by 70% when 15% fly ash is substituted. Longevity and service life are improved in blended fly ash-cement systems (up to 13% longer). By decreasing porosity and improving microstructure, fly ash increases resistance to chloride penetration (Win *et al.*, 2023c).

Another study assessed how the composition of fly ash affects the performance of calcium aluminate cement (CAC). The addition of fly ash increases reactivity by densifying the CAC microstructure. Compared to fly ash that is high in silica, fly ash that is rich in calcium speeds up hydration by 13%. Increased compressive strength, decreased porosity, and improved workability were noted. Fly ash promotes stability by reducing the

harmful conversion of CAC hydrates (Win *et al.*, 2023a).

The investigation of natural rubber latex-modified concrete with bottom ash as a sustainable alternative for rigid pavements showed that bottom ash reduces compressive strength; however, a 1.0% addition of natural rubber latex enhances both compressive and flexural strengths. The optimal mixes containing 10% bottom ash with 1.0% natural rubber latex and 20% bottom ash with 1.0% natural rubber latex outperform the control mix (Kantatham *et al.*, 2024).

Further work investigated the use of refuse derived fuel fly ash as a sustainable cementitious material in concrete pavements. Refuse derived fuel fly ash enhances compressive and flexural strengths when added, but reduces strength when used as a cement replacement. Microstructural analysis shows improved hydration and denser calcium-silicate-hydrate formation with refuse derived fuel fly ash addition. Leaching tests confirm heavy metal levels in refuse derived fuel fly ash modified concrete are within safe environmental limits. (Hoy *et al.*, 2024c)

A decade of research on sustainable pavement materials using recycled aggregates and industrial by-products has also been investigated. Key innovations include geopolymer stabilization, cement stabilization, and natural rubber latex modification. Findings show superior mechanical properties and environmental suitability of recycled materials compared to virgin aggregates. Practical applications demonstrate potential for reducing the environmental impact of road infrastructure. Future research should focus on long-term performance and standardized mix designs for wider adoption of recycled materials in road construction (Hoy *et al.*, 2024a).

Finally, studies on the mechanical and fatigue properties of hemp fiber-reinforced concrete using natural and recycled concrete aggregates for sustainable pavements revealed that optimal hemp fiber content is 0.5%, enhancing energy absorption and ductility. Increased fiber content improves fatigue life under cyclic loading. Natural aggregate mixes outperform recycled concrete aggregate in compressive strength, but both benefit from hemp reinforcement. Scanning electron microscopy analysis shows improved bond strength between fibres and the cement matrix (Hoy *et al.*, 2024b).

Objectives of the Study

The main objectives of this study include:

- Examining the microporous structure and adsorption capability of zeolite to determine its viability as a CO₂-absorbing material in concrete is one of the study's primary goals.

- Examining how GGBS can improve the durability and strength of CO₂ absorbing concrete and figuring out the ideal replacement amount.

- Assessing the amended concrete's mechanical qualities, such as workability, split tensile strength, and compressive strength.

- Quantifying the CO₂ absorption capacity of the concrete through carbonation depth tests and weight-based absorption measurements.

- To ascertain the Zeolite-GGBS concrete mix's suitability for construction applications, its performance is compared to that of traditional concrete.

- By providing information about the usage of CO₂ absorbing concrete as an eco-friendly substitute for conventional cement-based products, we can support sustainable building practices.

Scope of the Study

This research focuses on developing M30-grade CO₂ absorbing concrete with varying percentages of Zeolite and GGBS. The experimental program involves:

- To ascertain the characteristics of zeolite, GGBS, cement, aggregates, and admixtures, materials are chosen and tested.

- Zeolite and GGBS are used in optimal quantities to partially replace OPC in the design and casting of concrete mixes.

- Compressive strength, split tensile strength, carbonation depth, CO₂ absorption by weight, and hardened concrete testing to determine if modified Zeolite GGBS concrete is feasible for use in practical applications, findings from normal concrete and modified concrete are compared.

Materials and Methods

The experimental study uses a methodical approach to assess how Zeolite and Ground Granulated Blast Furnace Slag (GGBS) affect concrete's strength and its ability to absorb CO₂. Ordinary Portland Cement (OPC), fine and coarse aggregates, Zeolite, GGBS, and potable water are used as key ingredients. A proper mix design is created in compliance with IS 10262:2019 and IS 456:2000 to ensure optimal performance. Mix design is defined as the process of selecting suitable materials and determining their relative quantities to produce concrete with the required strength, durability, and workability in the most economical manner. In this study, M30 grade concrete with a mix ratio of 1:1.48:2.67 (Cement: Fine Aggregate: Coarse Aggregate) and a water-cement ratio of 0.4 was adopted. A control mix was prepared using 100% cement, with no supplementary materials. To evaluate the effect of

partial replacement, three additional mixes were developed: MIX 1 consisted of 10% Zeolite and 30% GGBS replacing cement (60% cement), MIX 2 had 20% Zeolite and 30% GGBS (50% cement), and MIX 3 had 30% Zeolite and 30% GGBS (40% cement). Concrete specimens were cast and cured in water for 7 and 28 days. Cubes of size 150 mm × 150 mm × 150 mm were used for compressive strength testing, and cylinders of 150 mm × 300 mm for split tensile strength. These tests were conducted as per IS 516:1959 and IS 5816:1999 standards. To investigate the long-term performance, carbonation depth and CO₂ absorption by weight were assessed. These tests evaluate the concrete's CO₂ capturing potential, giving insight into its sustainability. The performance of the modified mixes was compared with that of the control mix to determine the effectiveness of Zeolite and GGBS in enhancing strength and eco-efficiency. The below Figure 1 demonstrates the flow of experimental work.

The main binder in concrete is OPC 43 grade cement. It reacts with water to generate calcium silicate hydrate (C-S-H) gel, which is crucial for strength enhancement, while also offering the required durability and strength. Table 1 lists the characteristics of the OPC 43 grade.

Table 1. Properties of Cement

Properties	Type	OPC 43 grade
Physical	Specific gravity	3.14
	Initial setting time	47 min
	Final setting time	257 min
chemical	CaO	63.24%
	SiO ₂	21.07%
	Al ₂ O ₃	5.65%
	Fe ₂ O ₃	4.05%
	MgO	1.16%
	Na ₂ O	0.20%
	K ₂ O	0.45%
	SO ₃	2.15%

Ordinary Portland Cement

Fine Aggregate (M-Sand)

A dense and compact concrete construction is ensured by filling in the spaces between coarse particles with fine aggregate. Additionally, it enhances concrete's workability and finishing qualities. An ideal water-to-cement ratio is guaranteed by proper grading, which also stops bleeding or segregation. Table 2 lists the fine aggregates' characteristics.

Table 2. Properties of Fine Aggregate

Type	M Sand
Specific gravity	2.6
Fineness modulus	2.68
Grading Zone	II

Coarse Aggregate

Table 3 lists the characteristics of the coarse aggregates. Concrete gains bulk and strength from coarse particles. The 20 mm aggregate size preserves workability and durability while guaranteeing a strong bond with the cement mixtures.

Table 3. Properties of Coarse Aggregate

Type	M Sand
Specific gravity	2.73
Fineness modulus	7.58
Size	20mm (max)

Zeolite

Zeolite is a microporous substance that has a high capacity to absorb CO₂. It improves concrete's carbonation, which results in the long-term sequestration of CO₂. Additionally, it increases durability by lowering concrete's permeability and promoting the development of stable calcium

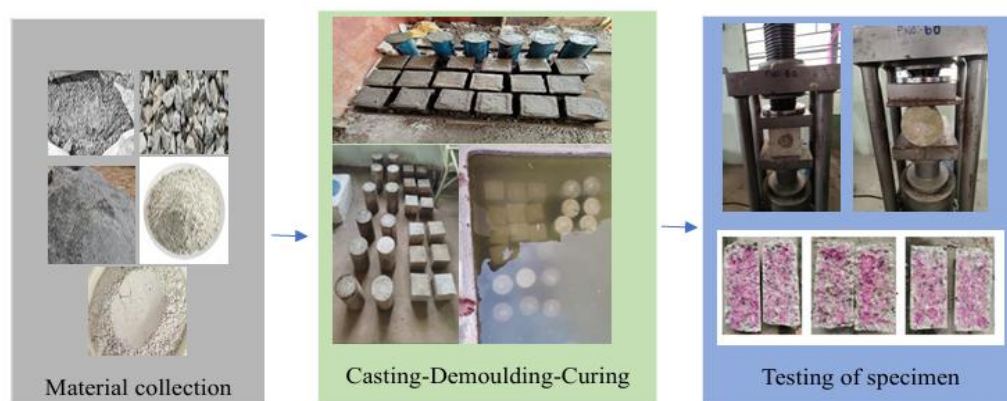


Figure 1. Flow of work

carbonate (CaCO_3). Table 4 lists the characteristics and chemical makeup of the zeolite.

Table 4. Properties of Zeolite

Properties	Parameter	Value
Physical	PH	7 to 8
	Moisture	6 to 8 (%)
	Particle size	200 (%)
chemical	CaO (%)	11.32
	Fe_2O_3 (%)	8.97
	SiO_2 (%)	45.64
	Al_2O_3 (%)	19.69
	MgO (%)	3.16
	Na (%)	2.16
	K (%)	6.41

Ground Granulated Blast Furnace Slag

A supplementary cementitious material (SCM) called GGBS improves the durability and mechanical strength of concrete. It improves resistance to sulfate and chloride assaults, decreases heat of hydration, and makes materials more workable. Additional C-S-H gel is formed as a result of its pozzolanic reaction with calcium hydroxide (Ca(OH)_2), strengthening the concrete matrix. Table 5 lists the characteristics and chemical makeup of the GGBS.

Table 5. Properties of GGBS

Properties	Parameter	Value (%)
Physical	Colour	Off white
	Specific gravity	2.85
	Bulk density	1200 kg/m^3
	Fineness	390 m^2/kg
chemical	Calcium oxide	40%
	Silica	35%
	Alumina	13%
	Magnesia	8%

Water

For the cement to hydrate and produce C-S-H gel, which gives concrete its strength, water is necessary. Unwanted chemical reactions that could erode the concrete structure are avoided by using clean, impurity-free water.

Testing Methods

Compressive strength

An essential test for determining concrete's load-bearing capacity is the compressive strength test. It gives information about the structural integrity of concrete and gauges its resistance to axial loads. A Compression Testing Machine (CTM) with a 2000 kN capacity is used to perform this test in compliance with IS 516:1959. After the cubes were put in the CTM, a constant compressive force was applied until failure. The specimen's

compressive strength was computed and the maximum force at which it failed was noted. Table 6 makes reference to it.

Table 6. Compressive strength of concrete

Sl.No	Type of concrete	Compressive strength results (N/mm^2)	
		7 Days	28 Days
1	CC	22.67	36.4
2	MIX 1	24.4	39.11
3	MIX 2	24.89	39.5
4	MIX 3	25.3	40.6

Tensile strength

Concrete's tensile resistance is assessed by the split tensile strength test mentioned in Table 7, which is essential for determining how well it can tolerate indirect tensile pressures. Because concrete is weak in tension but powerful in compression, this test is crucial for evaluating Concrete's tensile resistance is assessed by the split tensile strength test, which is essential for determining how well it can tolerate indirect tensile pressures. Because concrete is weak in tension but powerful in compression, this test is crucial for evaluating.

Table 7. Properties of GGBS

Sl.No	Type of concrete	Split tensile strength results (N/mm^2)	
		7 Days	28 Days
1	CC	2.68	3.74
2	MIX 1	3.18	3.89
3	MIX 2	3.32	3.92
4	MIX 3	3.46	4.03

Carbonation depth test

The carbonation depth test measures the penetration of CO_2 into concrete and its reaction with hydration products to form calcium carbonate (CaCO_3). The test was performed as per IS 516:1959, where concrete specimens were cured for 28 days and then broken to expose a fresh surface. A 1% phenolphthalein solution was sprayed onto the surface, turning non-carbonated areas pink ($\text{pH} > 9$) while carbonated areas remained colourless ($\text{pH} < 9$). The carbonation vales has been mentioned in Table 8.

Table 8. Carbonation Test Results

Sl.No	Type of concrete	Distance (cm)
1	CC	0.7
2	MIX 1	2
3	MIX 2	2.7
4	MIX 3	3.5

CO_2 absorption test by weight

The CO_2 absorption by weight test quantifies the amount of CO_2 absorbed by concrete over time. After oven-drying, the initial weight of specimens

was recorded. The exposure environment: CO₂ concentration was maintained at 5%, temperature at 25±2°C, and relative humidity at 65±5%. They were then exposed to a CO₂-rich chamber for one hour, followed by weighing again to determine the increase in mass. Molecular weight acts as a conversion factor to translate the mass of absorbed CO₂ into its molar equivalent. Without this, the weight gain measured would not accurately represent the number of CO₂ molecules absorbed, making the data less meaningful for analyzing the material's capacity for CO₂ sequestration. The weight test results were mentioned in Table 9.

The difference in weight was used to calculate CO₂ absorption using the formula:

$$CO_2 \text{ absorption by weight} = \frac{(W_2 - W_1)}{44}$$

where;

W_1 = Initial weight of dried specimen

W_2 = Weight after kept CO₂ chamber for 1 hour

Molecular weight of CO₂ = 44

Table 9. Weight Test Result

Sl.No	Type of concrete	W ₁ (g)	W ₂ (g)	Weight (moles)
1	CC	8260	8260	0
2	MIX 1	8340	8390	0.11
3	MIX 2	8030	8100	0.16
4	MIX 3	8130	8310	0.41

Results and Discussion

Compressive Strength

The compressive strength test results showed a gradual improvement in strength with the inclusion of Zeolite and GGBS in Figure 2. At 7 days, conventional concrete achieved 22.67 N/mm², while the 30% Zeolite and 30% GGBS mix (MIX 3) reached 25.3 N/mm², indicating faster strength development. At 28 days, conventional concrete had a compressive strength of 36.4 N/mm², whereas MIX 3 reached 40.6 N/mm², reflecting an 11.54% increase. This enhancement is attributed to the pozzolanic reaction of GGBS, which forms additional calcium silicate hydrate (C-S-H) gel, strengthening the concrete matrix (Oner and Akyuz, 2007; Paruthi *et al.*, 2024). Additionally, Zeolite improves carbonation, which further contributes to strength gain by densifying the matrix (Nagrockiene and Girskas, 2016). The improved 7-day strength observed with Zeolite and GGBS can be attributed primarily to the filler effect rather than the

pozzolanic reaction of GGBS. At early stages, GGBS reacts slowly and contributes minimally to strength gain. Instead, Zeolite, with its fine particle size, acts as a micro-filler, refining the pore structure and enhancing early strength. Additionally, the presence of GGBS improves packing density, reducing voids and increasing early-age strength through a physical densification effect. While the pozzolanic reaction of GGBS significantly contributes to later-age strength (28-56 days), the early improvement is primarily driven by the filler effect of Zeolite and the optimized particle packing of GGBS. The results confirm that Zeolite and GGBS not only enhance strength but also reduce reliance on OPC, making concrete more sustainable. These findings support the use of CO₂ absorbing concrete as an environmentally friendly alternative to conventional concrete without compromising structural performance.

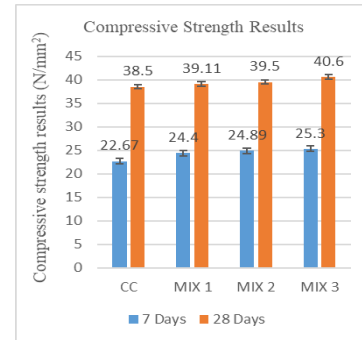


Figure 2. Compressive Strength Results

Split Tensile Strength

The split tensile strength test results in Figure 3 show that incorporating Zeolite and GGBS improved the tensile resistance of concrete. At 7 days, conventional concrete had a tensile strength of 2.68 N/mm², while MIX 3 reached 3.46 N/mm². At 28 days, conventional concrete achieved 3.74 N/mm², whereas MIX 3 exhibited 4.03 N/mm², reflecting a 7.75% increase. This improvement is due to Zeolite's microporous structure, which enhances carbonation and densifies the concrete matrix, making it more resistant to cracking (Najimi *et al.*, 2012; Sudarsono *et al.*, 2022). GGBS contributes by improving the bond between aggregates and the cement paste through pozzolanic activity and better microstructure development (Paruthi *et al.*, 2024). The results indicate that CO₂ absorbing concrete enhances both compressive and tensile strength, reducing the likelihood of cracking and making it suitable for durable and sustainable applications.

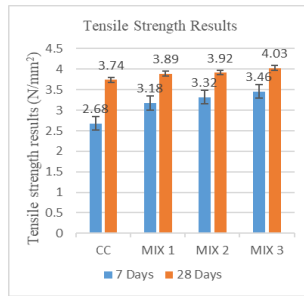


Figure 3. Split Strength Results

Carbonation Depth Test

The carbonation depth test results revealed that Zeolite significantly enhanced CO₂ absorption capacity in Figure 4. Conventional concrete showed a carbonation depth of 0.7 cm, while MIX 3 exhibited a depth of 3.5 cm a fivefold increase. This substantial improvement is attributed to Zeolite's high surface area and microporous structure, which facilitate CO₂ diffusion and reaction with hydration products (Revathi *et al.*, 2024). As CO₂ reacts with calcium hydroxide, it forms stable calcium carbonate (CaCO₃), which increases durability by filling pores and refining microstructure (Nagrockiene and Girska, 2016; Najimi *et al.*, 2012). The results confirm Zeolite's effectiveness in enhancing CO₂ sequestration within the concrete, supporting its role as a promising material in carbon reduction strategies for the construction industry.

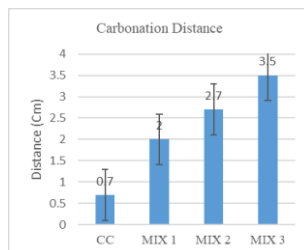


Figure 4. Carbonation Depth Results

CO₂ Absorption by Weight

The CO₂ absorption by weight test results in Figure 5 quantified the amount of CO₂ captured by the concrete. Conventional concrete showed no measurable CO₂ absorption, while MIX 3 absorbed 0.41 moles of CO₂, the highest among all mixes. This increase is attributed to Zeolite's high surface area and selective adsorption properties, enabling it to trap CO₂ molecules effectively (Pham *et al.*, 2016). Additionally, GGBS modifies the pore structure and enhances carbonation reactions, improving long-term CO₂ retention in the concrete (Shahmansouri *et al.*, 2021). These findings suggest that CO₂ absorbing concrete, particularly with high Zeolite content, can serve as an active carbon sink,

offering an eco-friendly and structurally sound solution for sustainable construction. The weight gain due to CO₂ absorption in concrete is primarily influenced by its porosity and microstructural changes. Zeolite and GGBS-modified concrete typically exhibit higher CO₂ uptake due to its refined pore structure and increased surface area. The mechanism involves the diffusion of CO₂ into the concrete pores, where it reacts with Calcium Hydroxide (Ca(OH)₂) to form Calcium Carbonate (CaCO₃) in a process known as carbonation. This reaction leads to a slight weight gain as CaCO₃ is denser than Ca(OH)₂, reducing porosity and enhancing durability. The extent of CO₂ absorption depends on factors such as pore size distribution, permeability, and the availability of Ca(OH)₂, which is lower in GGBS-rich mixes due to reduced cement content. This aligns with research indicating that denser, well-cured concrete absorbs CO₂ more efficiently, contributing to enhanced durability and sustainability.

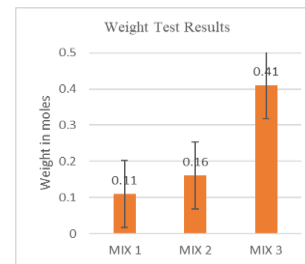


Figure 5. Weight Test Results

Conclusions

The creation and optimization of CO₂-absorbing concrete using ground granulated blast furnace slag (GGBS) and zeolite as partial substitutes for ordinary Portland cement (OPC) were examined in this study. The goal was to increase mechanical strength and durability while also increasing carbon sequestration capacity. According to the experimental findings, adding zeolite and GGBS to concrete greatly enhanced its performance, making it a practical substitute for sustainable building.

- The compressive strength test showed that replacing 30% OPC with Zeolite and 30% with GGBS increased strength by 11.54% compared to conventional concrete, confirming that Zeolite and GGBS effectively contribute to strength development.

- The split tensile strength test also indicated a 7.75% improvement, highlighting better resistance to cracking and structural failure.

- Furthermore, the carbonation depth test revealed that the CO₂ absorption capacity increased

fivefold, demonstrating Zeolite's high efficiency in carbon sequestration.

- The CO₂ absorption by weight test confirmed that Zeolite-based concrete can act as an active carbon sink, significantly reducing the environmental impact of concrete production.

Overall, the study confirms that Zeolite and GGBS-based CO₂ absorbing concrete is an eco-friendly and high-performance material that can reduce cement consumption, lower CO₂ emissions, and enhance durability. These findings support the use of CO₂ absorbing concrete as a sustainable solution for the construction industry, contributing to greener infrastructure and environmental conservation.

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