EXPERIMENTAL INVESTIGATION ON ZEOLITE POWDER BLENDED CEMENT CONCRETE

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ABSTRACT:
The construction industry contributes significantly to global carbon emissions due to extensive cement production. The utilization of supplementary cementitious materials has gained attention as a sustainable alternative to reduce cement consumption. This study investigates the performance of natural zeolite powder as a partial replacement of cement in M25 grade concrete. Concrete mixes were prepared by replacing cement with natural zeolite powder at proportions of 0%, 10%, 15%, and 20% by weight. Mechanical properties such as compressive strength, split tensile strength, and flexural strength were evaluated at 7 and 28 days of curing. Experimental results revealed that early-age strength slightly decreases with increasing zeolite content due to slower pozzolanic reaction. However, the 28-day strength significantly improved at 15% replacement because of the pozzolanic activity and micro-filling effect of zeolite particles. Beyond 15% replacement, strength reduction was observed due to dilution of cementitious materials. The study concludes that natural zeolite can effectively replace cement up to 15% in M25 concrete without compromising structural performance. The incorporation of zeolite also contributes to environmental sustainability by reducing cement consumption and CO_2 emissions.

Keywords: Natural Zeolite, Supplementary Cementitious Material, M25 Concrete, Compressive Strength, Flexural Strength, split tensile Strength, Sustainable Concrete, Pozzolanic Reaction.

1. INTRODUCTION:

Concrete is the most widely used construction material worldwide. Ordinary Portland cement (OPC), a primary component of concrete, is responsible for approximately 7% of global carbon dioxide emissions. The production of cement requires significant energy and releases large quantities of CO_2 into the atmosphere. Therefore, the development of sustainable construction materials has become essential.

To reduce environmental impact, researchers have explored the use of supplementary cementitious materials such as fly ash, silica fume, slag, metakaolin, and natural zeolite. Natural zeolite is a crystalline aluminosilicate mineral with a porous structure and high silica content, which provides pozzolanic activity. When used in concrete, zeolite reacts with calcium hydroxide released during cement hydration to produce additional calcium silicate hydrate (C-S-H), which enhances strength and durability.

Supplementary cementitious materials (SCMs) such as fly ash, silica fume, slag, metakaolin, and natural zeolite have been widely investigated as partial replacements for cement. Among these materials, natural zeolite has gained attention due to its high silica and alumina content, pozzolanic activity, and porous structure.

Zeolite reacts with calcium hydroxide produced during cement hydration to form additional calcium silicate hydrate (C-S-H) gel, which enhances the strength and durability of concrete. Additionally, zeolite has the ability to absorb CO_2 and improve microstructural properties of concrete.

The present research investigates the mechanical performance of M25 grade concrete incorporating natural zeolite powder as a partial replacement of cement at various replacement levels (10%, 15%, and 20%). The study aims to identify the optimum replacement percentage that provides maximum strength while reducing cement consumption and environmental impact.

2. LITERATURE REVIEW

1. **Dhilshadh P. C. et al. (2026)** carried out an experimental investigation on mechanical and durability properties of zeolite concrete. The results showed that optimum replacement levels of zeolite significantly improve compressive, tensile, and flexural strength of concrete mixes.

2. **Alaa M. Hamad et al. (2025)** conducted a systematic review examining the use of zeolite as a partial cement replacement and reported that zeolite significantly refines the microstructure, improving hydration and pore structure. Optimal replacement levels were highlighted between 10% and 20% for enhanced mechanical and durability outcomes.

3. **Y. Tan et al. (2025)** studied the influence of natural zeolite on ultra-high-performance concrete. Their research indicated that zeolite improves pore structure and hydration reactions, resulting in improved compressive strength and durability.

4. **Canpolat et al. (2023)** investigated concrete mixes where cement was replaced with 5% to 35% natural zeolite powder. They observed that mixes with 20% zeolite produced the highest 28-day compressive strength compared to control specimens, confirming that zeolite enhances later-age strength due to its pozzolanic reaction. Incorporation with 5% fly ash further improved performance, highlighting the benefit of SCM synergies.

5. **Yılmaz et al. (2023)** demonstrated that although early compressive strengths were lower in zeolite concrete at 1, 2, and 7 days, the 28-day strength increased significantly, with up to 22.3% strength gain at 20% zeolite replacement, reinforcing the effectiveness of zeolite as a cement substitute.

6. **Ameer A. Hilal et al. (2024)** investigated sustainable lightweight geopolymer concrete using waste zeolite. The study demonstrated that zeolite can act as an effective aluminosilicate source and improves the mechanical performance of geopolymer concrete materials.

3. MATERIAL USED

3.1 Cement

Cement is a manufactured material possessing both adhesive and cohesive properties, enabling it to effectively bind other materials. It primarily consists of finely ground limestone, silica, alumina, and iron ore, which undergo high-temperature processing in a rotary kiln at approximately 1600°C to form **clinker**. The clinker is subsequently cooled and ground into a fine powder to produce the final cement product. When mixed with water, cement undergoes hydration, forming a rigid and durable matrix that imparts strength and stability to concrete. Cement plays a crucial role in determining the mechanical and durability characteristics of concrete.

3.2 Coarse Aggregate

Coarse aggregates are particles retained on a 4.75 mm sieve, providing bulk, strength, and durability to concrete. Their properties, including size, shape, texture, and gradation, significantly affect the bonding with cement paste and overall mechanical performance. Angular coarse aggregates are preferred for superior interlocking and load distribution. Coarse aggregates must be clean and free from dust, clay, or organic impurities to ensure optimum concrete performance.

3.3 Fine Aggregate

Fine aggregates are particles passing through a 4.75 mm sieve and retained on a 75 µm sieve. Common examples include natural river sand or manufactured sand. Fine aggregates fill voids between coarse aggregates, improving workability, cohesion, and surface finish of concrete. Critical properties include fineness modulus, specific gravity, cleanliness, and gradation, which directly influence water demand, packing density, and final strength of concrete.

3.4 Water

Water is a key ingredient in concrete, required for the hydration of cement and for ensuring the workability of the mix. Water is essential for cement hydration and mix workability. Its quality and quantity directly affect strength, setting time, and durability. Water should be clean and free of impurities such as chlorides, sulfates, acids, alkalis, oils, or organic matter. The water–cement ratio (w/c) is a critical parameter, influencing compaction, porosity, cracking potential, and overall performance of hardened concrete.

3.4 Natural Zeolite Powder

Natural zeolite is a crystalline hydrated aluminosilicate mineral mainly composed of silicon (Si), aluminum (Al), and oxygen. The most commonly used form in concrete applications is clinoptilolite-type zeolite. Due to its porous structure and high surface area, zeolite exhibits unique physical characteristics beneficial for cementitious systems.

3.3 Natural Zeolite Powder has the following notable characteristics:

- **Colour & Texture:** Fine powder texture, generally white or light grey in colour with uniform molecular-sized channels in dehydrated crystals.

- **Porosity:** Highly porous crystalline structure, Internal pore size: 3–10 Å (Angstroms) helps in Moisture absorption, Internal curing effect and Reduced permeability in concrete.

- **Mechanical Properties:** Low density, moderate compressive strength, thermal stability, ability to absorb gasses and vapors.

- **Sustainability:** Lower cement consumption, enhancing durability, lowering carbon emissions and promoting eco-friendly construction practices.

In this study, Natural Zeolite powder is employed as a partial replacement of cement at 0%, 10%, 15%, and 20% by weight of cement to evaluate its effect on mechanical properties such as compressive, split tensile, and flexural strength.

Figure 1: Natural zeolite powder

Table-1: Chemical Properties of Natural zeolite powder

Sr. No.	Chemical Component	Values (%)
1.	SiO2	63.72
2.	Al2O3	11.40
3.	Fe2O3	2.73
4.	CaO	3.29
5.	MgO	0.05
6.	SO3	0.13
7.	Na2O	1.02
8.	K2O	2.83
9.	TiO2	0.29
10.	P2O5	0.03
11.	L.O.I	14.20
	Total	**99.69**

4. MIX DESIGN AND PROPORTION:

Concrete mix design was carried out for M25 grade concrete in accordance with IS 10262:2019 guidelines by trial mix method for 1 m³ of concrete. In this study, Natural Zeolite Powder was used as a partial replacement of conventional cement in concrete by weight in the proportions of 0% (Control mix), 10%, 15% and 20%.

Table-2: Mix Proportion (Kg/m3) and Mix Ratio for M25

Water (Kg/m^3)	Cement (Kg/m^3)	Fine Aggregate / Sand (Kg/m^3)	Coarse Aggregate (Kg/m^3)
197.16	469.43	628.23	1146.83
0.42	1	1.33	2.44

5. Compressive strength Results and Discussion:

Compressive strength is one of the most important mechanical properties of concrete and represents its ability to resist axial compressive forces that tend to reduce its size. In the present experimental investigation, the compressive strength of concrete was determined in accordance with IS 516:1959 – Method of Tests for Strength of Concrete.

For this test, standard cube specimens of size 150 mm × 150 mm × 150 mm were cast using steel moulds. Fresh concrete was placed into the moulds in three layers, and each layer was compacted properly to ensure uniform density and to eliminate air voids. After 24 hours of casting, the specimens were demoulded and subjected to water curing. The compressive strength test was conducted after 7 days and 28 days of curing to evaluate the early-age and later-age strength development of concrete.

The test was performed using a Universal Testing Machine (UTM). Each cube specimen was placed centrally between the compression platens of the testing machine, and a gradually increasing load was applied uniformly on the specimen until failure occurred. The maximum load carried by the specimen at the time of failure was recorded as the ultimate load. For each mix proportion, a minimum of three cube specimens were tested, and the average value was considered as the representative compressive strength to ensure accuracy and reliability of the results.

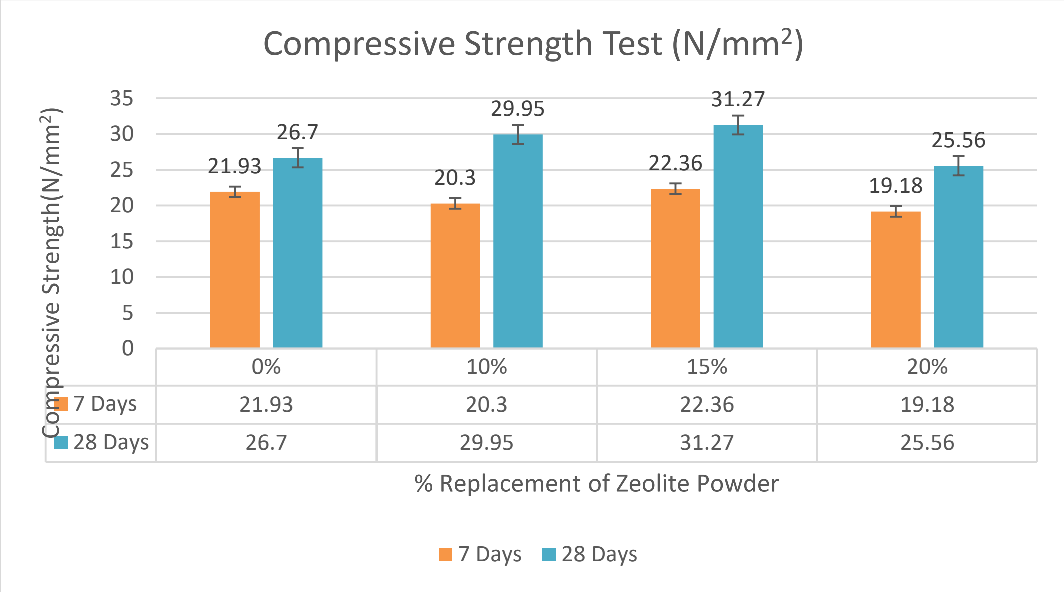
The compressive strength of concrete was calculated using the following expression:

Compressive strength (N/mm^2) = P/A Where, P – Ultimate load (N)

A – Cross-sectional area of specimen (mm^2)

Table-3: Compressive Strength Test Results for 7 and 28 Days in N/mm^2

Sr. No.	Percentage Replacement of Zeolite Powder	Compressive Strength (N/mm^2)	
		7 Days	28 Days
1.	Conventional Concrete (0% Zeolite))	21.93	26.70
2.	Zeolite Concrete (10%)	20.30	29.95
3.	Zeolite Concrete (15%)	22.36	31.27
4.	Zeolite Concrete (20%)	19.18	25.56



Bar Chart-1 compressive strength of Zeolite concrete at 7 and 28-days curing periods

The compressive strength results obtained at 7 days and 28 days are presented in Table-3. The results indicate a significant increase in compressive strength with an increase in curing period, which can be attributed to the continuous hydration process of cement. These results are essential for assessing the structural performance and suitability of concrete for construction applications.

6. Flexural Results and Discussion:

Flexural strength of concrete represents its ability to resist bending stresses and is an important parameter for evaluating the tensile behavior of concrete in structural elements such as beams and slabs. In the present study, the flexural strength test was carried out in accordance with IS 516:1959 – Method of Tests for Strength of Concrete.

Concrete beam specimens of size 150 mm × 150 mm × 700 mm were cast with varying levels of fine aggregate replacement ranging from 0% to 20%. After casting, the specimens were kept under saturated conditions for 24 hours, following which they were demoulded and subjected to water curing. Flexural strength tests were conducted at the curing ages of 7 days and 28 days. Prior to testing, the specimens were air-dried to remove surface moisture.

The maximum load carried by the beam at failure was recorded as the ultimate load.

The flexural strength was calculated using the formula:

$$\textbf{Flexural Strength (N/mm}^2\textbf{) = PL/bd2}$$

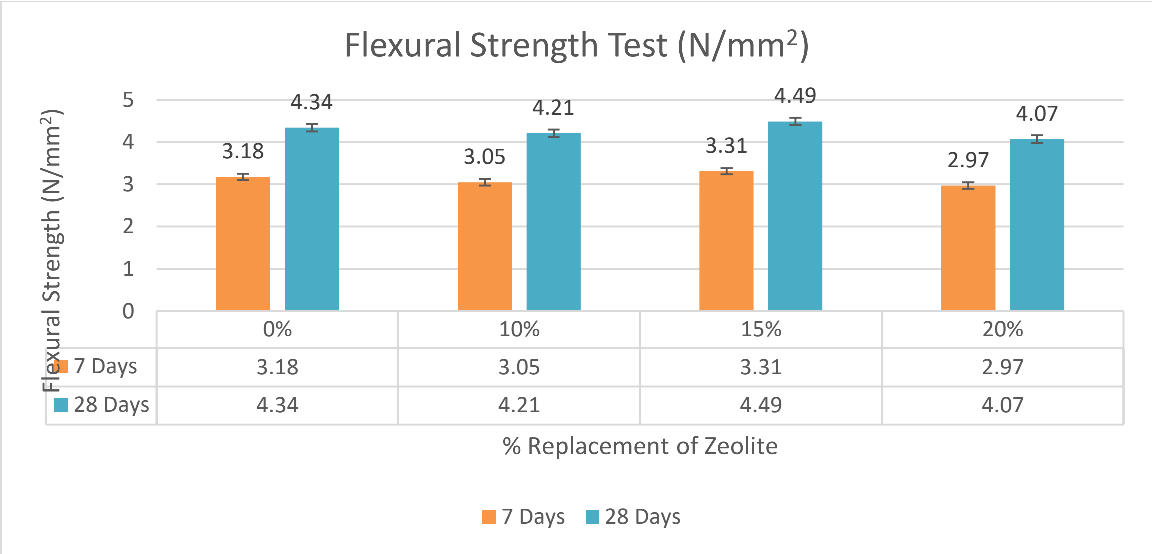
where,

P = Ultimate load applied on the beam (N) L = Effective span of the beam (mm)

b = Average width of the beam specimen (mm) d = Average depth of the beam specimen (mm)

Table-3: Flexural Strength Test Results for 7 and 28 Days in N/mm^2

Sr. No.	Percentage Replacement of Zeolite Powder	Flexural Strength (N/mm^2)	
		7 Days	28 Days
1.	Conventional Concrete (0% Zeolite))	3.18	4.34
2.	Zeolite Concrete (10%)	3.05	4.21
3.	Zeolite Concrete (15%)	3.31	4.49
4.	Zeolite Concrete (20%)	2.97	4.07



Bar Chart-2: Flexural Strength of Concrete at 7 and 28 Days

The flexural strength results obtained at 7 days and 28 days are presented in Table-4. The results indicate that flexural strength increases with curing age due to improved bond strength and continued hydration of cement. The study highlights the influence of fine aggregate replacement on the flexural performance of concrete, which is crucial for structural applications where bending stresses are predominant.

7. Carbon dioxide Absorption Results and Discussion:

Carbon dioxide absorption from the zeolite used concrete is compared with the conventional concrete. In this test weighing balance is used. Conventional concrete and zeolite used concrete are kept in water for 7 and 28 days to curing. After 7 days weight of the cubes was taken. Similarly, readings were taken on 28th day. And for co_2 absorption of blocks for 7 days curing is done and after 7^{th} day to the 28^{th} it is taken for open to the atmosphere for finding the CO_2 absorption of concrete blocks. And CO_2 absorption will be found out by taking difference between final and initial weight and dividing it by molecular weight of carbon dioxide which is 44. Then carbon dioxide absorption from the cubes was calculated. Along this the carbon dioxide test was carried out for these cubes were casted.

Table no. 21: CO_2 absorption of concrete blocks in moles and grams.

Percentage of zeolite	Initial weight (7 days)	Final weight (28 days)	CO_2 absorption of blocks(moles)	CO_2 absorption of blocks(gms)
0%	8.497	8.66	0.0037	0.044
10%	8.729	8.782	0.0012	0.0144
15%	8.511	9.111	0.013	0.164
20%	8.511	8.998	0.011	0.133

From above results 15% of zeolite replacement block gives maximum CO_2 absorption i.e. it gives 0.013 moles which is 0.164 gms of CO_2 absorption in 28 days.

8. CONCLUSION

1. Compressive strength of concrete decreases gradually with an increase in the percentage replacement of cement with Natural Zeolite Powder at both 7 and 28 days of curing.

2. Zeolite concrete (15% Zeolite) exhibited the highest compressive strength, while concrete with 20% Zeolite showed comparatively lower strength due to the hydration process and its porous crystalline structure of Zeolite.

3. Concrete mixes containing up to 15% Zeolite replacement achieved compressive strength values within acceptable limits for structural lightweight concrete applications.

4. Tensile strength results showed a similar decreasing trend with an increase in Zeolite content, indicating reduced resistance to

cracking under tensile stresses.

5. The reduction in tensile strength is mainly because of Zeolites have porous crystalline aluminosilicates content have Low density and large void volume when hydrated and Catalytic properties as compared to cement.

6. Flexural strength values showed only marginal variation with the incorporation of Zeolite, indicating that bending performance of concrete is not significantly affected.

7. Zeolite concrete demonstrated adequate flexural strength even at higher replacement levels, making it suitable for elements subjected to bending stresses.

8. Carbon dioxide absorption results found to be higher at the 15% of zeolite replacement concrete for 28 days.

9. Overall, partial replacement of Zeolite concrete with Zeolite up to **15%** can be effectively adopted to reducing carbon for eco-friendly atmosphere also enhancing durability and sustainable concrete without significantly compromising mechanical properties.

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