International Journal of Multidisciplinary Academic Studies and Research (IJMASR)
Registered with MSME, Govt. of India: UDYAM-MH-20-0329275
Available at www.ijmasr.org Volume-1, Issue-3, March 2026, Page- 159-162.

To Cite This Article
Ms. Sameena Ansari, Mr. Mohammad Rafiullah, Ms. Vrushalili Paraye, Mr. Nikhil Gahukar, Mr. Swapnil Kurve, Mr. Shubham Mankar, & Mr. Adesh Tenbhurne. (2026). An Experimental Study on the Partial Substitution of Cement by Zeolite Powder in Concrete. International Journal of Multidisciplinary Academic Studies and Research (IJMASR), 1(3), 159–162. https://doi.org/10.5281/zenodo.19682735

Article Info
Received: 23rd March 2026, Accepted: 25th March 2026, Published: 26th March 2026.

An Experimental Study on the Partial Substitution of Cement by Zeolite Powder in Concrete

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Abstract: Concrete is one of the most widely used construction materials, but its production is associated with significant carbon dioxide emissions due to the high energy consumption and greenhouse gas emissions from cement manufacturing. To address this issue, this project aims to investigate the feasibility of using zeolite as a partial replacement for cement in concrete mixtures. Zeolite is a naturally occurring mineral with pozzolanic properties that can potentially reduce the environmental impact of concrete production. The project involves a series of experimental tests to assess the effects of varying zeolite content on the mechanical and durability properties of concrete. These tests include compressive strength, split tensile strength, water absorption, and chloride ion penetration resistance. By substituting a portion of cement with zeolite, the project seeks to determine if this substitution can lead to concrete with improved sustainability and reduced carbon emissions. The probable outcomes of this study will provide valuable insights into the potential benefits and drawbacks of using zeolite as a cement replacement in concrete. The results will be useful for the construction industry and researchers looking for more environmentally friendly alternatives in concrete production.

Keywords: Zeolite, Partial Replacement of cement, strength, concrete.

INTRODUCTION

Cement is a fundamental ingredient in the construction industry, serving as the primary binding agent in the production of concrete. However, the production of cement is associated with significant environmental and economic challenges. These challenges include the release of large quantities of greenhouse gases, high energy consumption, and the depletion of natural resources. As a result, there is a growing need to explore sustainable alternatives and innovations in the construction sector. One such innovation is the partial replacement of cement with alternative materials, and in this experimental study, we \ focus on the use of zeolite as a partial substitute for cement. Zeolite is a naturally occurring mineral with unique properties that make it a promising candidate for sustainable construction practices. Zeolites are micro porous, crystalline minerals composed of silicon, aluminum, and oxygen, which form a three dimensional framework structure. Their porous nature allows them to absorb and release water and other substances making them ideal for various applications, including as a cement replacement. Zeolites are available in various types, and each type offers distinct properties, such as high surface area, cation exchange capacity, and pozzolanic reactivity. These properties can enhance the performance of concrete when used as a partial cement replacement. The use of zeolite in concrete has several potential benefits. Firstly, it can help reduce the carbon footprint of concrete production. By substituting cement with zeolite, we can decrease the demand for clinker, a primary component of cement production that is responsible for a substantial portion of carbon dioxide emissions practices. Secondly, zeolite can improve the durability and strength of concrete. Its pozzolanic reactivity enhances the chemical composition of the material, resulting in a denser and more impermeable concrete structure.

This, in turn, can extend the lifespan of structures and reduce maintenance costs, making it an attractive option for infrastructure projects. Thirdly, the utilization of zeolite as a cement replacement can contribute to the efficient use of natural resources. As we seek to conserve traditional construction materials, the integration of alternative materials like zeolite helps in reducing the environmental impact of the construction industry.

In this experimental study, we aim to investigate the effects of varying levels of zeolite as a partial replacement for cement in concrete mixes. We will assess the mechanical properties, durability, and environmental impact of these mixes to gain a comprehensive understanding of the potential benefits and limitations of using zeolite in construction. Through this research, we aspire to provide valuable insights that can guide the construction industry toward more sustainable and environmentally responsible practices, aligning with the global push for a greener future.

LITERATURE REVIEW

Several researchers have investigated the use of supplementary cementitious materials to reduce the environmental impact of concrete and enhance its performance. Among these materials, zeolite has gained attention due to its pozzolanic properties and eco-friendly nature.

B. Uzal et al. (2009) studied the pozzolanic activity of clinoptilolite, a natural zeolite, and compared it with silica fume and fly ash. The study revealed that zeolite exhibited high pozzolanic reactivity, comparable to silica fume and higher than fly ash. However, the strength contribution was slightly lower due to its pore structure characteristics.

B. Uzal and Turan (2011) investigated the hydration characteristics and microstructure of blended cement containing high volumes of zeolite. The results showed reduced calcium hydroxide content and improved pore structure, indicating enhanced durability of concrete.

G. Vinoth Kanna and P. Ranjith Kumar (2018) examined the properties of M40 concrete with partial replacement of cement by zeolite. Their findings indicated that zeolite improved durability and provided satisfactory strength at optimum replacement levels.

Iswarya Gowram (2021) studied the effectiveness of natural zeolite and metakaolin as partial replacements for cement in high-strength concrete. The research highlighted that zeolite enhances both fresh and hardened properties of concrete, making it a viable alternative material.

Qing Wang, Jun Zhang, and J.C.M. Ho (2020) explored the effect of zeolite on engineered cementitious composites. The study concluded that zeolite improves shrinkage performance and enhances the overall strength of high-performance concrete.

From the above studies, it is evident that zeolite has significant potential as a partial replacement for cement. However, the optimum replacement percentage and its effect on M25 grade concrete require further investigation, which forms the basis of the present study.

MATERIALS AND METHODOLOGY

Materials:

The materials used in this experimental study include cement, fine aggregate, coarse aggregate, water, and zeolite powder.

Cement: Ordinary Portland Cement (OPC) of 43 grade conforming to IS 269 was used. Cement acts as the primary binding material in concrete.

Fine Aggregate: Natural river sand was used as fine aggregate. The sand was clean, well-graded, and free from impurities. Sieve analysis was carried out to determine its grading.

Coarse Aggregate: Crushed angular aggregates of maximum size 20 mm were used. Aggregates were clean, strong, and free from dust and organic matter.

Water: Potable water free from harmful substances such as salts, acids, and organic matter was used for mixing and curing of concrete.

Zeolite: Natural zeolite powder was used as a partial replacement for cement. Zeolite is a crystalline hydrated aluminosilicate mineral with pozzolanic properties that improve the performance and sustainability of concrete.

Mix Design:

Concrete of M25 grade was designed as per IS 10262:2019 guidelines. The water-cement ratio was maintained at 0.45. Cement was partially replaced with zeolite powder at different proportions of 0%, 5%, 10%, and 15% by weight.

Methodology:

The experimental procedure adopted in this study consists of the following steps:

1. Collection of materials such as cement, aggregates, water, and zeolite.
2. Determination of physical properties of materials including sieve analysis of aggregates.
3. Preparation of concrete mix as per the design proportions.
4. Mixing of concrete with different percentages of zeolite replacement (0%, 5%, 10%, and 15%).
5. Casting of concrete cubes of size 150 mm × 150 mm × 150 mm.
6. Compaction of concrete using hand tamping or vibration.
7. Curing of specimens in water for 7, 14, and 28 days.
8. Testing of specimens to evaluate workability and strength properties.

Experimental Program:

The experimental program includes preparation and testing of concrete specimens with varying percentages of zeolite. The following tests were conducted:

1. Sieve Analysis Test
2. Slump Test
3. Compressive Strength Test
4. Split Tensile Strength Test

These tests were carried out to study the workability and mechanical properties of concrete with partial replacement of cement by zeolite powder.

RESULTS AND DISCUSSION

Sieve Analysis:

Sieve analysis of fine aggregate was carried out to determine its particle size distribution. The fineness modulus of sand was found to be approximately 2.6, which indicates that the sand used was suitable for concrete production and falls within the acceptable range for good workability and strength.

Slump Test:

The slump test was conducted to evaluate the workability of fresh concrete with varying percentages of zeolite replacement.

Zeolite (%)	Slump (mm)
0%	64
5%	68
10%	74
15%	80

It was observed that the slump value increased with the increase in zeolite content. This indicates that the workability of concrete improved due to the finer particle size and water absorption characteristics of zeolite. However, excessive increase in workability may affect the stability of the mix.

Compressive Strength Test:
The compressive strength of concrete was tested at 7, 14, and 28 days of curing. The results indicate that the strength of concrete increases with curing time for all mixes. The maximum compressive strength was observed at 5% replacement of cement with zeolite, reaching approximately 42.12 N/mm² at 28 days. This improvement in strength can be attributed to the pozzolanic reaction of zeolite, which enhances the bonding and densifies the concrete matrix. However, further increase in zeolite content (10% and 15%) resulted in a reduction in compressive strength. This may be due to the reduction in cement content beyond the optimum level, which affects the binding properties of concrete.

Split Tensile Strength Test:
The split tensile strength test was conducted to evaluate the tensile properties of concrete. The results followed a similar trend as compressive strength. The tensile strength increased up to 5% replacement of cement with zeolite and decreased for higher percentages. This indicates that a small percentage of zeolite contributes positively to the tensile behavior of concrete, while excessive replacement reduces its effectiveness.

CONCLUSION

From the experimental results, it is evident that the incorporation of zeolite significantly influences both the fresh and hardened properties of concrete. The optimum replacement level was found to be 5%, which provided the best balance between strength and workability. The improvement in strength at lower percentages is due to the pozzolanic activity of zeolite, which enhances the microstructure of concrete. However, higher replacement levels reduce the cement content, leading to a decrease in strength. Therefore, it can be concluded that zeolite can be effectively used as a partial replacement for cement in concrete, provided that the replacement percentage is optimized.

FUTURE SCOPE

1. Further research can be carried out by using zeolite in higher grades of concrete such as M40 and M50.
2. Long-term durability studies such as resistance to chloride attack, sulphate attack, and permeability can be performed.
3. The effect of zeolite on reinforced concrete structures can be studied.
4. Optimization of mix design with different water-cement ratios and curing conditions can be explored.
5. Cost analysis and large-scale application of zeolite-based concrete can be evaluated for practical implementation.

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