Experimental Studies to Assess the Viability of Zeolite Powder as a Cement Partial Replacement

Abstract:

This study, conducted by This Works, explores the potential of zeolite powder as a substitute for cement in concrete compositions. Zeolite, known for its crystalline structure consisting of silicon, aluminum, and oxygen, demonstrates significant Pozzolanic activity and the ability to absorb carbon dioxide. The research evaluates the effectiveness of incorporating zeolite powder as a partial replacement for cement in M-40 grade concrete, considering proportions of 10%, 20%, 30%, and 40%. The concrete mixture adhered to the specifications outlined in IS 10262-2019. Various mechanical properties including compressive strength, tensile strength, and flexural strength were assessed at curing periods of 7, 14, and 28 days. The findings of these analyses are presented in this paper. Interestingly, concrete mixes containing 20% zeolite powder exhibited the best performance, displaying higher compressive, tensile, and flexural strengths. Additionally, non-destructive tests confirmed that the concrete met industry standards, highlighting the viability of zeolite powder-enhanced concrete.

Keywords: Zeolite Powder, compressive strength, split tensile strength, Flexural strength

Introduction:

The global construction sector, playing a crucial role in economic advancement, has concurrently been identified as a notable contributor to environmental deterioration and depletion of resources[1]. Cement, a fundamental ingredient in concrete formulation, significantly contributes to these issues due to its extensive carbon footprint and energy-intensive production procedures. [2]As apprehensions over climate change and sustainability intensify, both researchers and industries are actively seeking innovative substitutes that can alleviate the environmental impact of construction materials while upholding structural integrity[3]. Among the emerging alternatives, the integration of zeolite powder as a partial or complete substitute for cement in concrete production is gaining substantial attention[4].Zeolites, either naturally occurring or synthetically manufactured, are characterized by their microporous structure and distinctive crystalline arrangement[5]. These minerals have demonstrated promising attributes upon incorporation into cement-based materials. [6]This burgeoning trend presents a transformative route toward construction practices that prioritize sustainability and ecological soundness[7]. This opening section serves as a preliminary exploration of the potential of zeolite powder as a cement replacement in construction.[4] It furnishes an outline of the challenges tied to traditional cement, introduces the concept of zeolites as a cementitious element sets the stage for a deeper examination of this innovative paradigm shift[8]

Materials : In this research, 53 grade Ordinary Portland cement was employed, and its specific gravity and workability were evaluated in accordance with the IS 10262-2019. M-sand was utilized as the fine aggregate, while 20mm coarse aggregate was incorporated. The water content conformed to the guidelines stipulated in IS 456-2000[9]

Table 1: Physical Proportion of Cement, M- Sand, Coarse Aggregate, Zeolite powder, Flyash.

Properties	Cement	M-sand	Coarse Aggregate	Zeolite powder	Fly ash
Colour	Grey colour	Grey-blue	Grey	Off -white	Dark Grey
Specific Gravity	3.15	2.68	2.78	2.6	2.05
Bulk Density (Kg/m^3)	1440	1600	2400	1040	1200
Standard consistency	32%	-	-	-	-
Fineness Modulus	-	2.75	7.69	-	-

Table 2: Chemical Proportion of Cement, M- Sand, Coarse Aggregate, Zeolite powder, Flyash

Chemical Mass in %	Cement	M-Sand	Coarse Aggregate	Zeolite powder	Fly ash
silicon dioxide SiO_2	20-25	18.45	48.78	52.00	55-60
Aluminum oxide Al_2O_3	4-8	8.3	11.2	46.00	25-29
Iron oxide Fe_2O_3	2-4	10.06	9.52	0.60	4.5-4.8
Calcium oxide CaO	60-65	3.68	10.01	0.09	0.5-1.2
Magnesium oxide MgO	0.03	2.45	15.42	0.03	0.3-0.5
Sodium oxide Na_2O	0.10	2.69	2.54	0.10	0.01-0.02
Potassium oxide K_2O	0.03	2.84	0.55	0.03	0.5-0.7

Fig 1: **Representation of zeolite Powder**

3.1 Mix Proportion

. The study utilized M 40 Grade concrete, prepared following the guidelines outlined in IS 10262-2019.[10] A water-cement ratio of 0.327 was established, and for enhanced workability, Superplasticizers were incorporated at a dosage equivalent to 0.5% of the binder content. Five distinct concrete mixtures were formulated, each associated with a specific zeolite powder replacement percentage (0%, 10%, 20%, 30%, and 40%). For each of these concrete compositions, a total of 27 specimens were created and subsequently subjected to testing. This set included 9 cubes with dimensions of 150x150x150 mm, 9 cylinders measuring 150x300 mm, and 9 prisms measuring 150x150x700 mm. The curing process extended over periods of seven days, fourteen days, and twenty-eight days before the specimens underwent testing.

Table 3 Specifying the Composition of Various Mixtures Utilizing Varied Zeolite Powder Ratios

Mix ID	Substitution of cement (%)	Cement kg/m^3	Zeolite powder Kg/m^3	M-Sand Kg/m^3	Coarse Aggregate Kg/m^3	Water Kg/m^3	Super Plasticizer Kg/m^3
ZP0	0	332	0	720	1069	105	4.74
ZP1	10	298.8	33.2	720	720	105	4.74
ZP2	20	265.6	66.4	720	720	105	4.74
ZP3	30	232.4	99.6	720	720	105	4.74
ZP4	40	199.2	132.8	720	720	105	4.74

Slump Cone Test:

The workability of the concrete was evaluated through the implementation of the slump cone test, conducted in alignment with IS 1199-1959.

Properties of concrete

Compression tests were conducted on concrete cubes measuring 150 x 150 x 150 mm, following the guidelines of IS 516-1959. These evaluations were carried out at 7, 14, and 28 days, employing a loading rate of 140 $kg/cm^2/min$. Similarly, cylindrical concrete samples sized at 150 x 300 mm underwent split tensile tests after 7, 14, and 28 days. A Compression Testing Machine (CTM) with a capacity of 2000 kN was employed, and load application rates ranged from 1.2 $N/(mm^2/min)$ to 2.4 $N/(mm^2/min)$.For assessing the concrete's flexural strength at 7, 14, and 28 days, flexural tests were executed in accordance with the specifications outlined in IS 516-1959. [11]The Flexure Testing Machine (FTM) used for these assessments had a capacity of 100 kN. The specimens utilized in the flexural tests were prisms with dimensions of 150 x 150 x 700 mm

Non Destructive Test:

The utilization of ultrasonic pulse velocity (UPV) testing serves as a non-destructive approach to evaluate the structural soundness of concrete components and their overall integrity. This technique involves gauging the velocity of ultrasonic waves as they traverse through the concrete material. The UPV assessments were carried out on all concrete blends following 28 days of the curing process. Correspondingly, rebound hammer testing was conducted on all concrete mixtures after the same 28-day period. In each mix, nine measurements were collected from different positions using a rebound hammer, and the resulting means were documented and consolidated.

4 Results & Discussions

4.1 Fresh concrete Test :

Workability assessment is conducted using the slump cone test. As the proportion of zeolite powder in the concrete mix increases, there is a noticeable reduction in the slump value.

Specifically, the slump value experiences a decline from ZP0 to ZP4. This reduction in slump is attributed to the presence of multiple pores, an increased surface area, and the cubic nature of the particles (Figure 2)These findings are consistent with previous observations when incorporating zeolites as a substitute for cement.

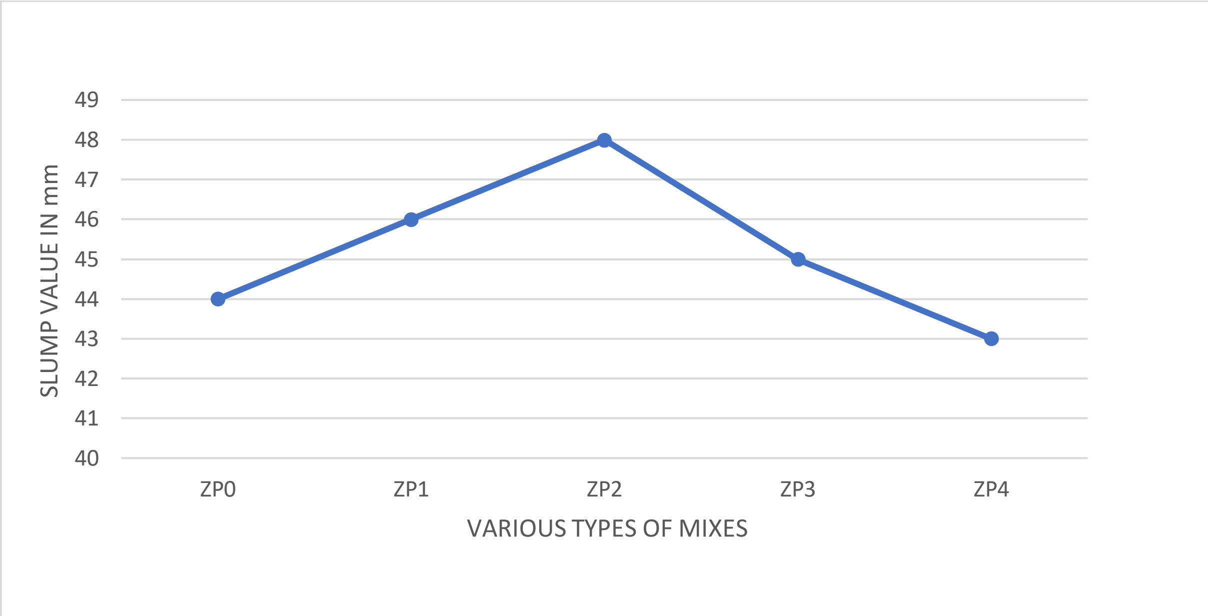

Fig 2: **Various types of slump value by replacing cement with Zeolite Powder**

4.2 Properties of concrete

4.2.1.Compressive strength Test: The study's results demonstrated that all concrete samples incorporating zeolite powder displayed notably higher compressive strength compared to conventional concrete throughout various curing periods. Initially, as the zeolite content gradually increased, the compressive strength consistently rose until reaching its peak with the ZP2 mixture. However, surpassing this threshold, further increments in zeolite proportion led to a decline in compressive strength.In contrast to the baseline strength of conventional concrete, the ZP2 mix achieved peak compressive strength values that were 23.07% higher at 7 days, 21.62% higher at 14 days, and 14.28% higher at 28 days. This observed pattern suggests that the optimal content of zeolite powder for enhancing compressive strength resides within the ZP2 mixture, where the zeolite powder constitutes 20% of the cement's weight.The initial strength increase can be attributed to the improved hydration processes facilitated by the combination of replacement materials and cement. Subsequently, the decrease in compressive strength signifies that a higher concentration of filler materials obstructs the formation of hydrate gel and elevates the concrete's porosity.

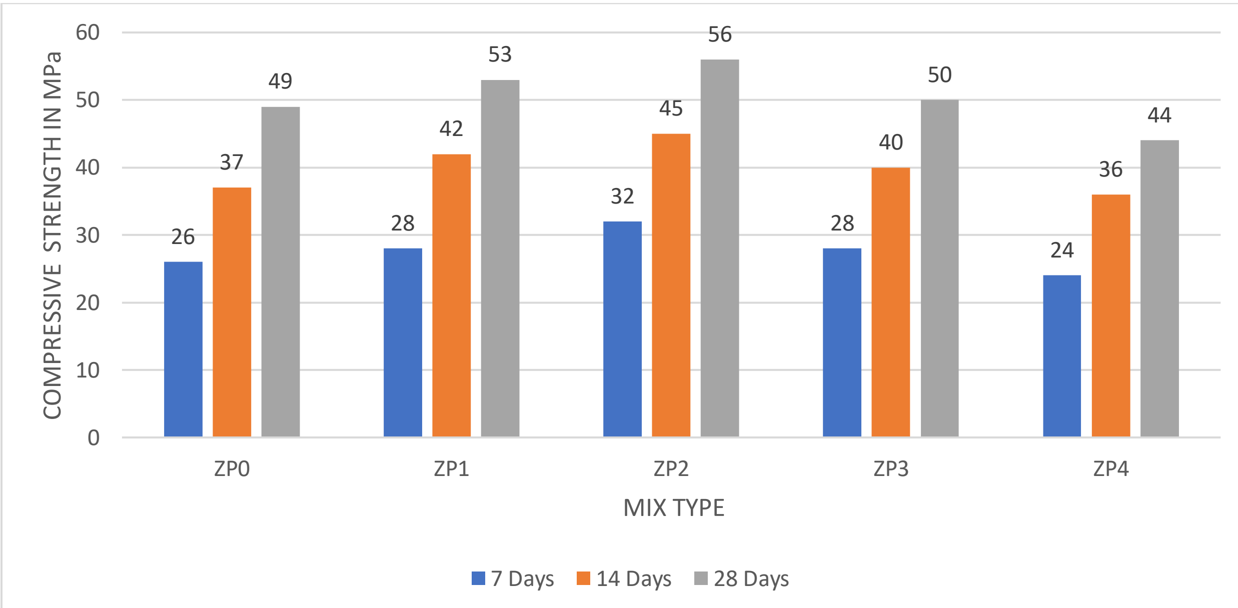

Fig 3: **Compressive strength for the various Percentage of replacement of Zeolite powder**

4.2.2.Split Tensile strength Test:

The split tensile strength of concrete with zeolite powder exhibits a progressive pattern from ZP0 to ZP4. The utmost split tensile strength is evident in the ZP2 Mixture, achieving 4.2 MPa after 28 days. The ZP2 Mix displays a notable surge of 13.33% at 7 days and 20% at 28 days. The subsequent decline in strength can be attributed to insufficient bonding and compatibility concerns between the zeolite powder and the cement paste present within the concrete.

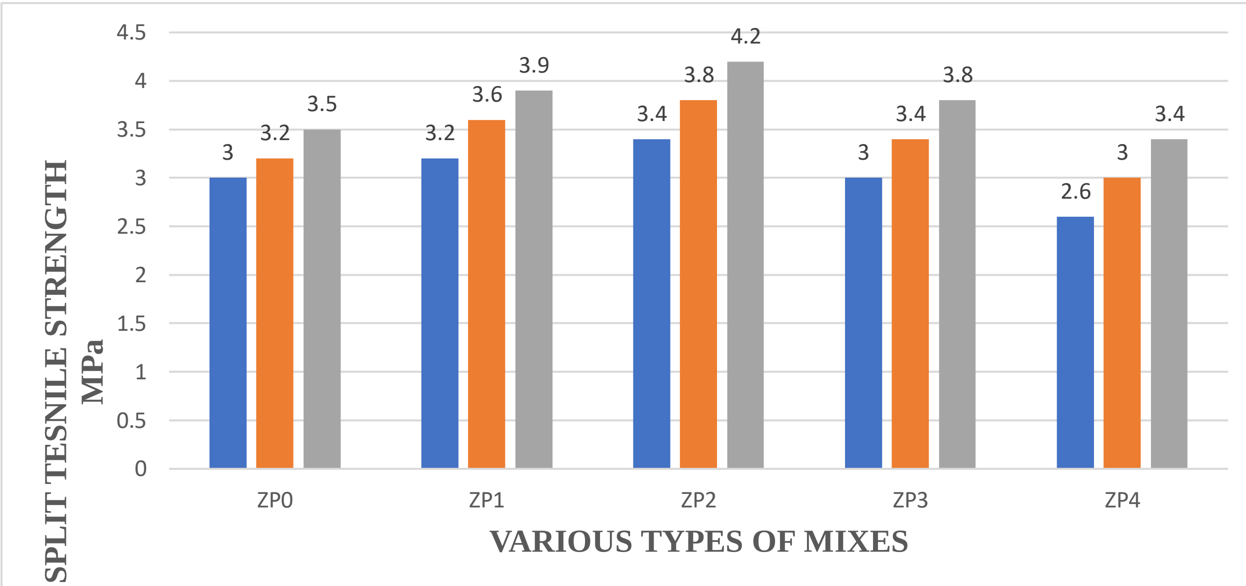

Fig 4: **Split tensile strength for the various Percentage of replacement of Zeolite powder**

4.2.3.Flexural strength Test:. The assessment of flexural strength demonstrates a similar pattern to the compressive and split tensile strength assessments. The most remarkable measurements of flexural strength were attained, reaching 5.5 MPa after 7 days and 6.5 MPa after 28 days. The highest strength values were consistently observed when 20% of the zeolite powder was employed as a substitute, maintaining consistency across all curing intervals of 7, 14, and 28 days.

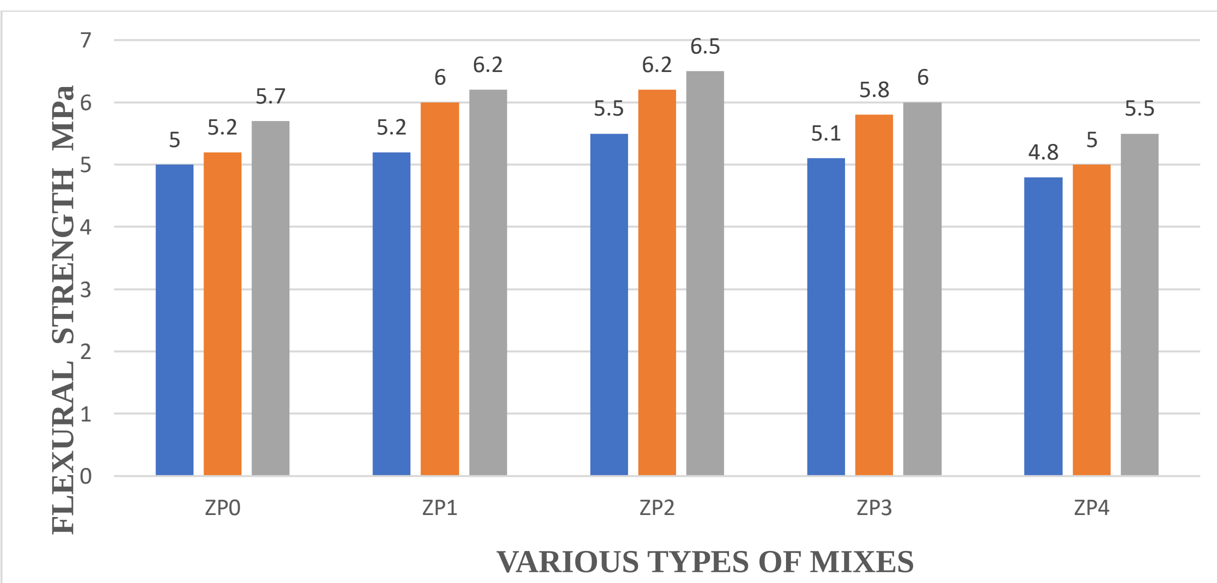

Fig 5: **Flexural strength for the various Percentage of replacement of Zeolite powder**

4.3 Non Destructive Testing Test

Results from both the Rebound Hammer Test and Ultrasound Pulse Velocity Test are recorded for ZP0 through ZP4, yielding the subsequent values.

Table 4. shows the Values of Rebound Value and Mean velocity

Mix Type	Average Mean Rebound Value (MPa)	Mean velocity(UPV) (min/sec)	Quality of concrete
ZP0	30	4.2	Good
ZP1	35	4.6	Excellent
ZP2	41	4.7	Excellent
ZP3	38	4.4	Good
ZP4	35	4.25	Good

Conclusions

This study investigates the effectiveness of integrating zeolite powder into M-40 grade concrete. Alongside evaluating workability, the mechanical characteristics of concrete specimens created with varying levels of zeolite powder substitution (0%, 10%, 20%, 30%, and 40%) were assessed and juxtaposed against conventional concrete.

• The most notable enhancement in compressive strength in zeolite concrete was observed at a 20% replacement level in the ZP2 mixture. With the progression of the curing period, a decline in compressive strength disparity between zeolite concrete and conventional concrete became apparent. This implies that the inclusion of zeolite powder assists concrete in attaining its peak strength during the initial curing phases.

• Zeolite concrete demonstrated superior split tensile strength in comparison to conventional concrete across various curing periods. Particularly noteworthy, the ZP2 Mix displayed a remarkable 13.33% surge in split tensile strength at seven days. Furthermore, both at 14 and 28 days, the ZP2 Mix outperformed conventional concrete.

• Throughout the flexural test, zeolite concrete consistently exhibited higher values than its conventional counterpart. As a result, the ZP2 Mix achieved the highest flexural strength throughout all curing durations.

• The optimal proportion for substituting cement with zeolite powder was identified as 20%. Non-destructive tests affirmed the commendable quality of zeolite powder-infused concrete.

References:

[1] J. Tanijaya and D. Hardjito, "EXPERIMENTAL STUDY ON THE USE OF NATURAL ZEOLITES AS PARTIAL REPLACEMENT FOR CEMENT IN CONCRETE."

[2] H. Durisety*, K. Palcham, and *K. Prasad Babu, "The Concrete Incorporated With Zeolite for Reducing Atmospheric Carbon Dioxide," *International Journal of Recent Technology and Engineering (IJRTE)*, vol. 8, no. 6, pp. 2117–2121, Mar. 2020, doi: 10.35940/ijrte.F8083.038620.

[3] Z. Xuan and Z. Jun, "Influence of zeolite addition on mechanical performance and shrinkage of high strength Engineered Cementitious Composites," *Journal of Building Engineering*, vol. 36, Apr. 2021, doi: 10.1016/j.jobe.2020.102124.

[4] Ž. Rudžionis *et al.*, "Natural zeolite powder in cementitious composites and its application as heavy metal absorbents," *Journal of Building Engineering*, vol. 43, Nov. 2021, doi: 10.1016/j.jobe.2021.103085.

[5] N. Q. Feng and G. F. Peng, "Applications of natural zeolite to construction and building materials in China," *Constr Build Mater*, vol. 19, no. 8, pp. 579–584, Oct. 2005, doi: 10.1016/j.conbuildmat.2005.01.013.

[6] M. Najimi, J. Sobhani, B. Ahmadi, and M. Shekarchi, "An experimental study on durability properties of concrete containing zeolite as a highly reactive natural pozzolan," *Constr Build Mater*, vol. 35, pp. 1023–1033, 2012, doi: 10.1016/j.conbuildmat.2012.04.038.

[7] B. Ahmadi and M. Shekarchi, "Use of natural zeolite as a supplementary cementitious material," *Cem Concr Compos*, vol. 32, no. 2, pp. 134–141, Feb. 2010, doi: 10.1016/j.cemconcomp.2009.10.006.

[8] P. V. Madhuri, B. Kameswara Rao, and A. Chaitanya, "Improved performance of concrete incorporated with natural zeolite powder as supplementary cementitious material," in *Materials Today: Proceedings*, Elsevier Ltd, Jan. 2021, pp. 5369–5378. doi: 10.1016/j.matpr.2021.06.089.

[9] B. of Indian Standards, “IS 456 (2000): Plain and Reinforced Concrete - Code of Practice.”

[10] IS 2019, “Concrete Mix Proportioning- Guidelines,” *Bureau of Indian Standards (BIS)*, vol. Second Rev, no. January, pp. 1–40, 2019.

[11] B. of Indian Standards, “IS 5816 (1999): Method of Test Splitting Tensile Strength of Concrete.”