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Experimental Investigation of the Effect of Natural Zeolite Pozzolan on the Mechanical Properties and Water Absorption of Ordinary Portland Concrete

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Abstract

This study investigates the influence of natural zeolite as a supplementary cementitious material (SCM) on the mechanical properties and water absorption of ordinary Portland concrete. Zeolite was used as a partial cement replacement at levels of 0%, 2%, 6%, 8%, 12%, and 15% within various mix designs (cement content ranging from 320 to 400 kg/m³). The experimental program focused on evaluating compressive strength at 7 and 28 days, as well as water absorption capacity. The results indicate that while early-age (7-day) compressive strength experienced a slight decrease due to the dilution effect of the zeolite, 28-day strength significantly improved at an 8% replacement level. Furthermore, water absorption tests reveal that the pozzolanic reaction of zeolite refines the interfacial transition zone (ITZ) and reduces capillary porosity. The findings suggest that natural zeolite, when properly proportioned, enhances the long-term durability and structural efficiency of concrete.

Keywords: *Natural Zeolite, Ordinary Portland Concrete, Compressive Strength, Water Absorption, Pozzolanic Reaction.*

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1-Introduction

The rapid expansion of the global construction industry has intensified the environmental impact of cement production, particularly regarding the massive emission of carbon dioxide (CO_2) and the depletion of natural resources. To mitigate these ecological footprints, recent research has pivoted toward the development of sustainable concrete through the reduction of clinker content without compromising mechanical performance or durability [1, 2]. While various strategies—such as optimizing the water-to-cement ratio or implementing advanced curing techniques—have been explored [3, 4], the integration of supplementary cementitious materials (SCMs) remains the most viable and cost-effective approach to enhancing concrete's long-term service life and reducing its environmental footprint [5].

Among various pozzolans, natural zeolite—a crystalline aluminosilicate mineral—has emerged as a promising candidate due to its high reactivity and ability to refine the pore structure of the cementitious matrix [8]. Recent studies indicate that the incorporation of zeolite can improve the interfacial transition zone (ITZ) between cement paste and aggregates, facilitating the formation of secondary calcium silicate hydrate (C-S-H) gels. This process enhances long-term mechanical properties and reduces water permeability. However, while the pozzolanic benefits of zeolite are well-documented, a significant knowledge gap persists regarding the synergistic interaction between diverse cementitious intensities and varying zeolite replacement levels.

Most existing literature focuses on a fixed cement content, which fails to provide a comprehensive understanding of how zeolite dosages influence microstructural densification across different cementitious regimes—ranging from low-strength to high-strength applications. The necessity of investigating a wide spectrum of cement contents (ranging from $320$to 400 kg/m^3) alongside varying zeolite dosages stems from the complex interplay between the "dilution effect" and pozzolanic activity. In low-cementitious intensity mixes, the availability of $Ca(OH)_2$produced during cement hydration may limit the extent of the pozzolanic reaction. Conversely, in high-intensity mixes, the excess of hydration products might alter the pore-refining efficiency of the zeolite.

Furthermore, the durability of concrete in aggressive environments is fundamentally governed by its permeability [9]. While reducing permeability is a proven method to enhance resistance, the optimal balance between pozzolanic activity and the potential reduction in early-age strength due to the dilution effect remains inadequately characterized for varied cement grades.

To address these gaps, this study presents a systematic investigation into the influence of natural zeolite on the mechanical properties and water absorption of ordinary Portland concrete. Unlike conventional studies, this research examines a wide parametric range, including multiple cement contents ($320, 340, 360, 380$, and 400 kg/m^3) and various zeolite replacement levels ($2\%, 6\%, 8\%, 12\%$, and 15%). The objective is to establish a predictive understanding of the optimal zeolite-to-cement ratio required to maximize both strength and durability, thereby providing a robust technical framework for tailoring sustainable and resilient concrete designs for diverse structural requirements.

2. Experimental Program

2.1. Materials

The cement utilized in this research complies with the **ASTM C150** requirements for Type II Portland cement. The chemical composition and physical properties of the constituent materials are summarized in Table 1.

2.1.1. Water

To ensure the integrity of the hydration process and prevent any adverse chemical interactions within the cementitious matrix, potable water was utilized for all concrete mixtures. The water source was the municipal drinking water supply in Tabriz [16]. The water quality was verified to be free of harmful impurities and excessive concentrations of alkali ions (such as $Na^{+}$and K^{+}), thereby minimizing the risk of alkali-aggregate reactions (AAR).

2.1.2. Natural Zeolite

The supplementary cementitious material used in this study was a natural zeolite, characterized by its light green hue. The zeolite was sourced from the Abike Cement Plant mine, located approximately one kilometer northeast of Abike. Geologically, the deposit is situated within the central Alborz region, originating from the volcanic-sedimentary rocks of the Eocene-aged Karaj Formation. These deposits are characterized by layered structures with a gentle slope toward the southwest [9]. The detailed physicochemical properties of the zeolite are summarized in Table 1.

2.2. Specimen Preparation and Testing Procedures

All specimens were prepared in strict accordance with the ASTM C192 standard. The mixing procedure was carefully controlled to ensure a homogeneous distribution of the cementitious matrix and zeolite particles. Zeolite was incorporated as a partial replacement for cement at specified replacement levels (0%, 8%, and 15%).

Following the mixing process, the fresh concrete was cast into standard molds and subjected to mechanical vibration to achieve full compaction and eliminate entrapped air. The specimens were then cured in a controlled environmental chamber at a temperature of $23 \pm 2°C$and a relative humidity of 95%.

The compressive strength of the specimens was evaluated at 7 and 28 days of age using a standard hydraulic compression testing machine. To ensure a uniform stress distribution during testing, a constant loading rate of 0.5 MPa/swas applied.

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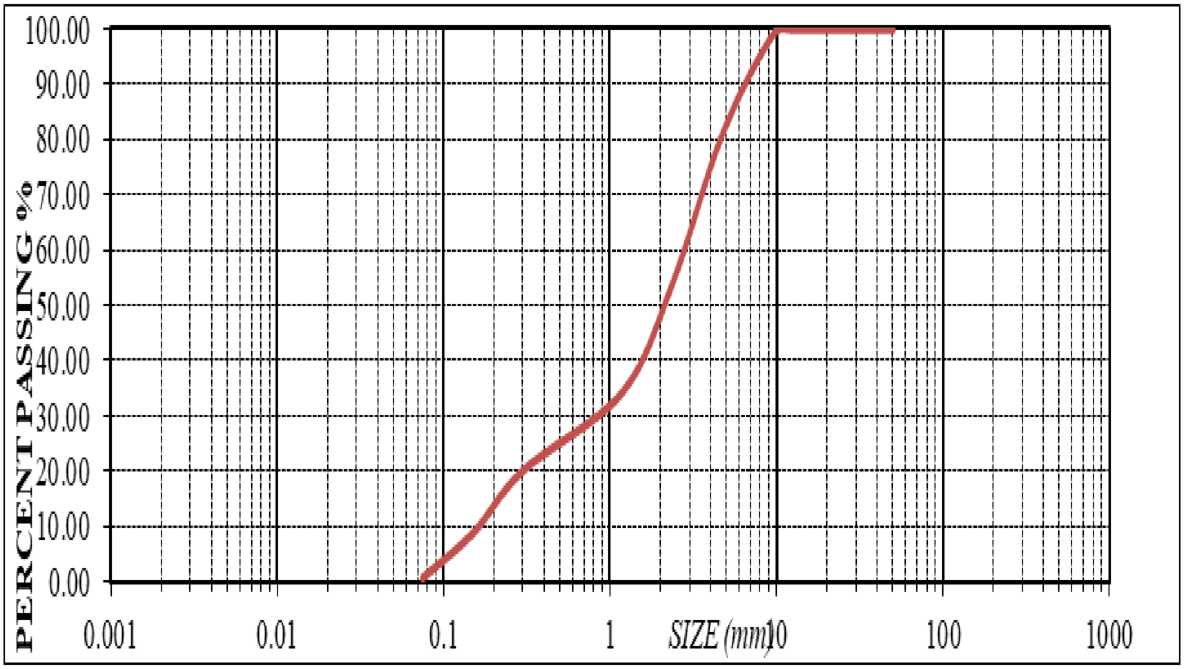

Figure 1: Report of sand grading experiment

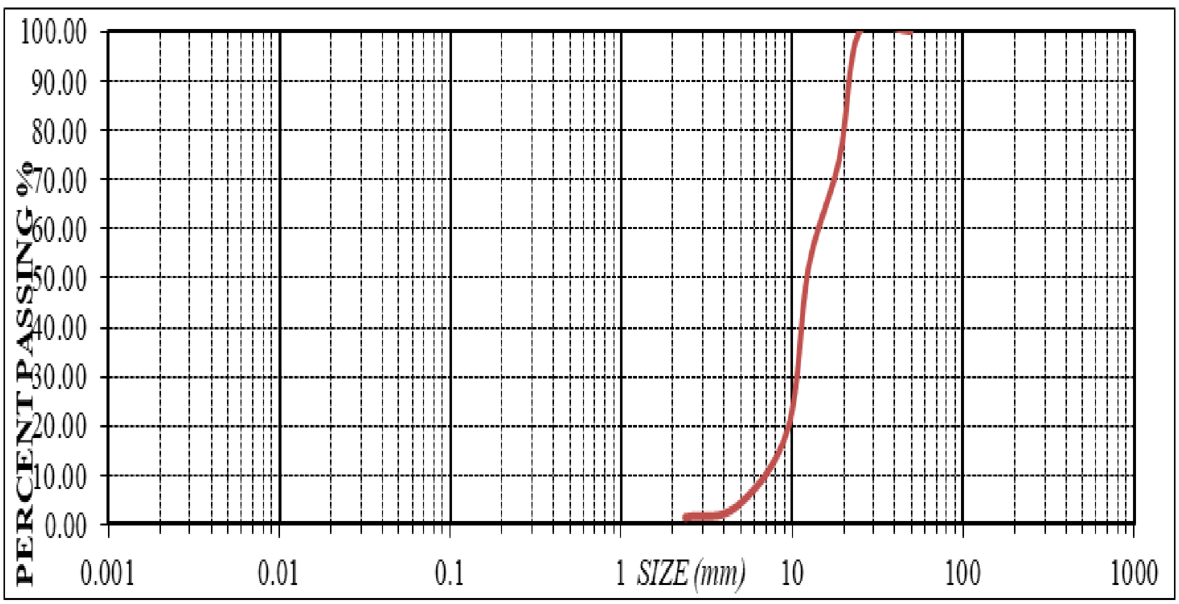

Figure 2: Report of the pea sand aggregation experiment

Table 1: Results of Sufian Type 2 Cement Mechanical Experiments

Specific gravity gr/cm^3	3.11
Specific surface area gr / cm^2	2974
7-day compressive strength with standard sand (237 kg / cm^2)	237
28-day compressive strength with standard sand (kg / cm^2)	462
Initial Reception Time (minutes)	116
Final Reception Time (minutes)	175

Table 2: Chemical composition of cement used

Chemical composition	(%)
CaO	63.13
SiO_2	21.77
Al_2O_3	4.53
Fe_2O_3	3.66
MgO	2.17
SO_3	2.22
Na_2O	0.32
K_2O	0.83

Table 3: Physical and Chemical Properties of (Zeolite)

Chemical Compounds (%)	**Zeolite Abic**
SiO_2	64.45
Al_2O_3	13.39
Fe_2O_3	3.89
CaO	3.59
SO_3	1.83
MgO	1.10
Na_2O	1
K_2O	1.67
LOI	4.06
Specific weight (gr / cm^2)	2.55
Blain (gr / cm^2)	3400

3. Concrete Mix Design and Proportioning

The concrete mix design was formulated in accordance with the Iranian National Standards for concrete aggregates (ISIRI 302) and the Iranian Concrete Code, ensuring that the Portland cement properties complied with the specifications **of** ISIRI 389. The design objective was to establish a robust parametric study…”

3.1. Mix Design Philosophy and Aggregate Grading

To evaluate the influence of zeolite on the cementitious matrix, the cement content was varied across five levels: 320,340,360,380, and 400 kg/m^3. The aggregate skeleton was designed to optimize workability and pumping characteristics. A maximum nominal size of 19 mmwas selected for the aggregate mixture, ensuring that more than 90%of the particles passed the 19 mmsieve. The grading curve was optimized to fall within the range of $A_{19}$and B_{19}(approaching B_{19}), with a fineness modulus (n) targeted between 0.4and 0.5to enhance particle packing density. To achieve an optimal balance between workability and packing density, the sand-to-aggregate ratio was set at 40: 60(sand to coarse aggregate). This specific ratio was selected to mitigate the potential coarseness associated with typical local sand gradings and to ensure a sufficient volume of fine particles for creating a cohesive cement paste.

3.2. Water Content and Superplasticizer Integration

To isolate the influence of zeolite substitution on the concrete’s properties, the water-to-cementitious materials ratio (w/cm) was kept constant at **0.50**. Due to the potential impact of zeolite on the mix rheology, a polycarboxylate-based superplasticizer was incorporated to maintain consistent workability. This dosage optimization ensured that the required free water was minimized, preventing any adverse effects on the mechanical strength and permeability of the specimens.

3.3. Zeolite Replacement Strategy

The replacement levels of natural zeolite were strategically selected (0%, 8%, and 15%) to investigate the threshold at which pozzolanic activity effectively densifies the Interfacial Transition Zone (ITZ) without compromising the rheological properties of the fresh concrete. This parametric approach allows for a comprehensive analysis of the synergistic effects between cementitious intensity and pozzolanic substitution.

Table 4: Component values of 320 kg / m^3 concrete mixes studied

Slump	**Gravel (kg)**	**Sand (kg)**	**Zeolite (g)**	**Zeolite content**	**Cement (kg)**	**Water (kg)**	**W/C**	**Number**
11.5	6.121	9.21	_	_	2.544	1.33	0.5	1
12	6.121	9.21	50	2%	2.446	1.32	0.5	2
11	6.121	9.21	152	6%	2.538	1.26	0.5	3
10.5	6.121	9.21	199	8%	2.484	1.24	0.5	4
12	6.121	9.21	285	12%	2.376	1.18	0.5	5
12.5	6.121	9.21	382	15%	2.295	1.14	0.5	6

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Table 5: Component values of 340 kg / m^3 concrete mixes studied

Slump	**Gravel (kg)**	**Sand (kg)**	**Zeolite (g)**	**Zeolite content**	**Cement (kg)**	**Water (kg)**	**W/C**	**Number**
10.5	6.035	9.053	-	-	2.866	1.43	0.5	1
11	6.035	9.053	57.32	2%	2.808	1.4	0.5	2
12	6.035	9.053	171.96	6%	2.694	1.34	0.5	3
11.5	6.035	9.053	229.28	8%	2.636	1.31	0.5	4
11	6.035	9.053	343.92	12%	2.522	1.26	0.5	5
10.5	6.035	9.053	429.9	15%	2.436	1.21	0.5	6

Table 6: Component values of 360 kg / m^3 concrete mixes studied

Slump	**Gravel (kg)**	**Sand (kg)**	**Zeolite (g)**	**Zeolite content**	**Cement (kg)**	**Water (kg)**	**W/C**	**Number**
10	5.934	8.902	-	-	3.034	1.54	0.5	1
12	5.934	8.902	60	2%	2.974	1.48	0.5	2
10	5.934	8.902	182	6%	2.851	1.42	0.5	3
10.5	5.934	8.902	242	8%	2.791	1.39	0.5	4
10	5.934	8.902	364	12%	2.669	1.33	0.5	5
9.5	5.934	8.902	455	15%	2.578	1.28	0.5	6

Table 7: Component values of 380 kg / m^3 concrete mixes studied

Slump	**Gravel (kg)**	**Sand (kg)**	**Zeolite (g)**	**Zeolite content**	**Cement (kg)**	**Water (kg)**	**W/C**	**Number**
11	5.833	8.750	-	-	3.203	1.60	0.5	1
9	5.833	8.750	64.06	2%	3.138	1.56	0.5	2
10	5.833	8.750	192	6%	3.010	1.50	0.5	3
9.5	5.833	8.750	256.24	8%	2.946	1.47	0.5	4
10	5.833	8.750	384.36	12%	2.818	1.40	0.5	5
11.5	5.833	8.750	480.45	15%	2.722	1.36	0.5	6

Table 8: Component values of 400 kg / m^3 concrete mixes studied

Slump	**Gravel (kg)**	**Sand (kg)**	**Zeolite (g)**	**Zeolite content**	**Cement (kg)**	**Water (kg)**	**W/C**	**Number**
9.5	5.732	8.598	-	-	3.372	1.68	0.5	1
11	5.732	8.598	67	2%	3.30	1.65	0.5	2
10	5.732	8.598	202	6%	3.169	1.58	0.5	3
10.5	5.732	8.598	269	8%	3.102	1.56	0.5	4
9	5.732	8.598	404	12%	2.967	1.48	0.5	5
8.5	5.732	8.598	505	15%	2.866	1.43	0.5	6

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4. Methodology (Condensed & Standardized)

4.1. Specimen Preparation and Curing

Concrete specimens were prepared using Type II Portland cement and natural zeolite as a partial cement replacement. To ensure rheological consistency across varying cementitious intensities and zeolite dosages, a polycarboxylate-based superplasticizer was incorporated into all mixtures. The water-to-cementitious materials ratio (w/cm) was strictly maintained at 0.50.

All specimens were cast in accordance with ASTM C192 standards. Following casting, the specimens were demolded after 24 hours and subsequently transferred to a controlled curing chamber, maintained at 23 ± 2°Cwith a relative humidity (RH) of 95%, to ensure optimal hydration.

4.2. Mechanical and Durability Testing

To investigate the relationship between microstructural densification and mechanical performance, both compressive strength and water absorption tests were performed. Compressive strength was determined using a hydraulic testing machine at a constant monotonic loading rate of 0.5 MPa/s. Concurrently, water absorption was evaluated following BS 1881-Part 122 [10] to characterize the pore network connectivity, providing insight into how zeolite-induced densification influences the overall durability of the concrete matrix.

4.3.Water Absorption Test

The water absorption capacity of the concrete specimens was evaluated in accordance with BS 1881-Part 122 [10]. After a 28-day curing period, the specimens were placed in an incubator at 45 ± 2°Cfor 5 days to ensure complete dehydration. Following this drying process, the dry mass (M_{dry}) of each specimen was recorded. The specimens were then fully submerged in water, with a water head maintained at 25 ± 5 mmabove the surface, for a continuous immersion period of 24 hours. After immersion, the specimens were removed and wiped to achieve a saturated surface-dry (SSD) condition, after which the saturated mass (M_{sat}) was measured. The water absorption percentage (W_{abs}) was subsequently calculated using the following equation:

$$W_{abs}(\%) = \left(\frac{M_{sat} - M_{dry}}{M_{dry}}\right) \times 100$$

5. Results and Discussion

The compressive strength analysis reveals a dual-phase behavior. At 7 days, the dilution effect—caused by the substitution of clinker with lower-reactivity zeolite—resulted in a strength reduction. Conversely, at 28 days, the 8% replacement mix demonstrated superior performance. This is attributed to the secondary hydration process, where the reactive silica in the zeolite reacts with calcium hydroxide ($Ca(OH)_2$) to form stable Calcium-Silicate-Hydrate (C-S-H) gels.

Regarding water absorption, the data indicates that an optimal zeolite dosage (8%) effectively mitigates capillary action by densifying the ITZ. Higher replacement levels, however, show an increase in water absorption, likely due to the higher water demand and the potential for increased interconnected porosity if the pozzolanic reaction is incomplete. Consequently, the study confirms that zeolite acts both as a filler and a chemical agent, provided the dosage is optimized relative to the cement grade.

5.1. Compressive Strength Evolution and Microstructural Implications

The compressive strength evolution for the 7-day and 28-day curing periods is illustrated in Figure [3]. The experimental data reveals a distinct temporal shift in the mechanical performance of the zeolite-incorporated mixes, characterized by a dual-phase response.

During the early-age stage (7 days), the specimens with 15%zeolite replacement exhibited a 9%reduction in compressive strength relative to the control mix. This early-age strength deficit is primarily ascribed to the **dilution effect**; the substitution of highly reactive Portland cement clinker with natural zeolite—which possesses a lower initial reactivity—reduces the early-stage volumetric production of hydration products. Furthermore, the slower kinetics of the pozzolanic reaction compared to the rapid hydration of cement leads to a transient reduction in the structural integrity of the matrix during the first week.

Conversely, a significant performance reversal was observed at 28 days. The 8%replacement level achieved a superior compressive strength compared to both the control and the higher-replacement mixes, identifying this dosage as the **optimal replacement threshold**. This strength enhancement is driven by the secondary pozzolanic activity, wherein the reactive silica within the zeolite matrix reacts with the $Ca(OH)_2$(a byproduct of cement hydration) to synthesize additional calcium-silicate-hydrate (C-S-H) gels. These supplementary gels play a critical role in densifying the capillary pores and refining the **Interfacial Transition Zone (ITZ)**, thereby mitigating the microstructural weaknesses typically found in conventional concrete.

The transition from a strength deficit at 7 days to a pronounced enhancement at 28 days underscores the necessity of considering long-term pozzolanic maturity when evaluating natural zeolite as a partial cementitious replacement.

5-2. Effect of Zeolite Concrete Treatment with 400 grade Cement

In the study of the processing of concrete with Zeolite in 400 grade cement, it is shown in Figure 3 that with increasing of Zeolite percentage at early age (7 days) the amount of compressive strength decreases so that in 15% Zeoloite cement replacement. The control sample decreased the compressive strength by 9%.

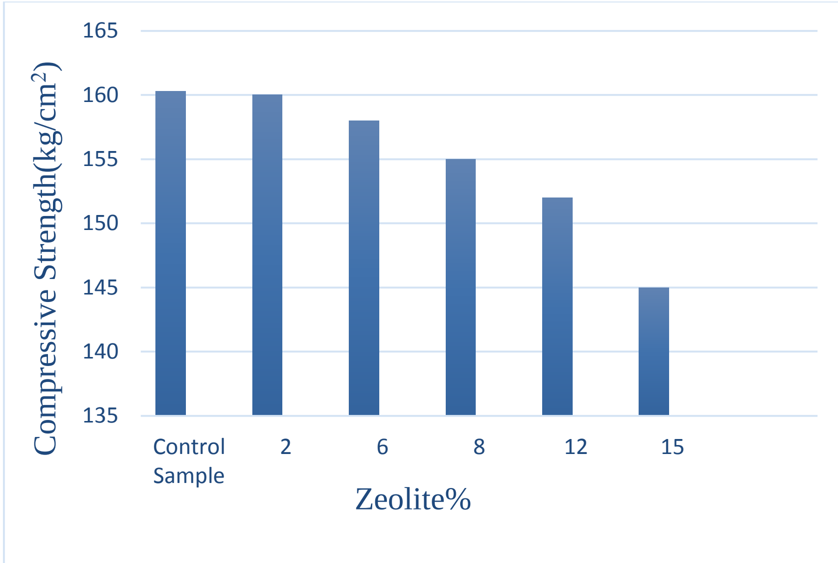

Figure 3: Concrete strength with different percentages of Zeolite with 400 grade cement at 7 days old concrete.

5.2. Compressive Strength Evolution in 400-Grade Cement Matrix

The influence of zeolite replacement levels on the compressive strength of 400-grade cement concrete is illustrated in Figure 3. The experimental results reveal a distinct dependency of mechanical performance on both the substitution dosage and the curing duration.

At the early-age stage (7 days), a progressive decline in compressive strength was observed as the zeolite content increased. Specifically, the 15%replacement level resulted in a 9%reduction in strength compared to the control mix. This initial strength deficit is attributed to the dilution of the highly reactive cementitious phase by the relatively less reactive zeolite particles, which temporarily hinders the early-stage hydration kinetics.

However, the long-term performance (28 days) exhibits a significant reversal of this trend. At this stage, the 8%replacement level demonstrated a strength increase of approximately 2%over the control mix, indicating an optimal balance between the cementitious binder and the pozzolanic filler. Beyond this threshold, specifically at the 12%and 15%replacement levels, the compressive strength began to decline again. This secondary reduction suggests that excessive zeolite substitution leads to an imbalance in the binder-to-aggregate ratio and potentially increases the void ratio due to insufficient pozzolanic activity to compensate for the reduced cement content.

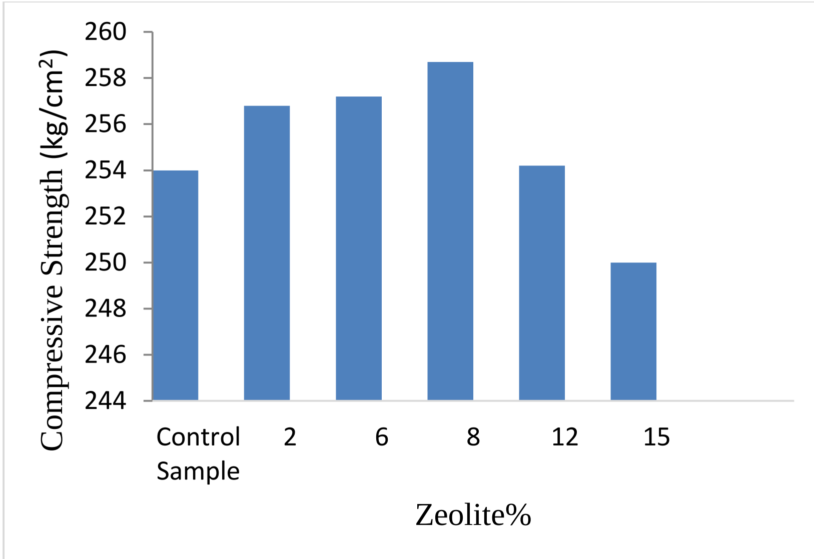

Figure 4: Concrete strength with different percentages of Zeolite with 400 grade cement at 28 days old concrete

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However, the long-term performance (28 days) exhibits a significant reversal of this trend. At this stage, the 8%replacement level demonstrated a strength increase of approximately 2%over the control mix, indicating an optimal balance between the cementitious binder and the pozzolanic filler. Beyond this threshold, specifically at the 12%and 15%replacement levels, the compressive strength began to decline again. This secondary reduction suggests that excessive zeolite substitution leads to an imbalance in the binder-to-aggregate ratio and potentially increases the void ratio due to insufficient pozzolanic activity to compensate for the reduced cement content.

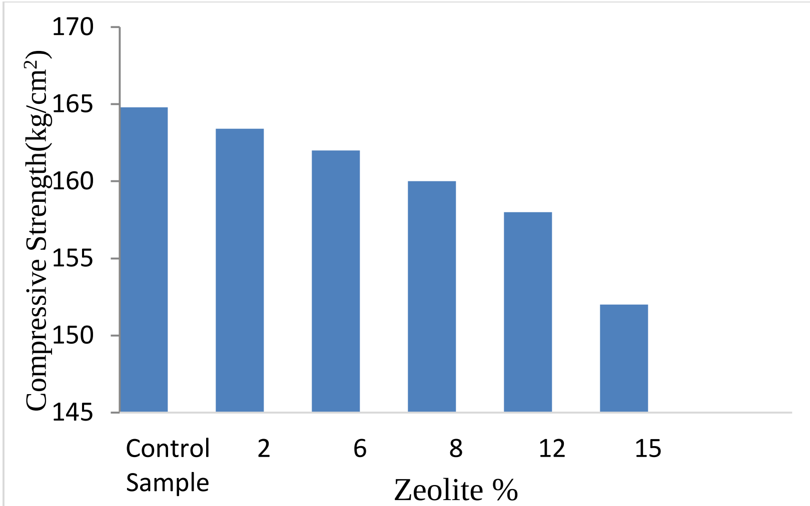

Figure 5: Concrete strength with different percentages of Zeolite with 380 grade cement at 7 days old concrete.

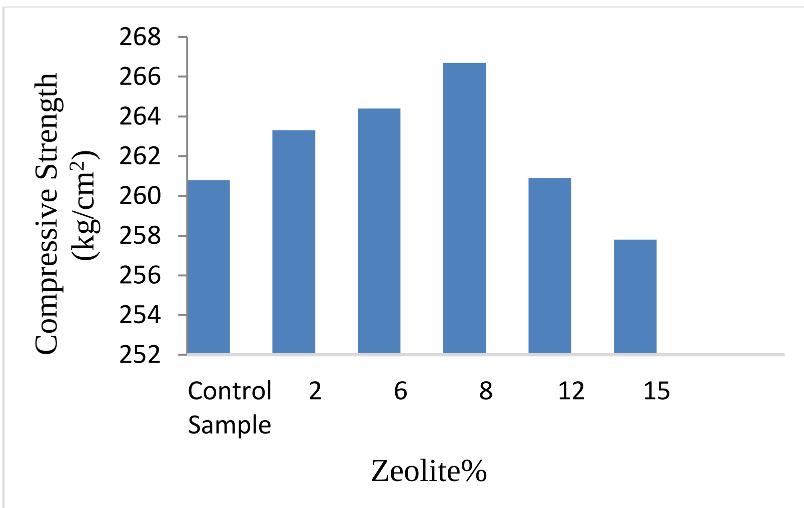

Figure 6: Concrete strength with different percentages of Zeolite with 380 grade cement at 28 days old concrete.

5.4. Compressive Strength Evolution in 360-Grade Cement Matrix

The mechanical response of the 360-grade cement concrete containing varying dosages of zeolite is presented in Figure 7. Similar to the observations in the 400-grade cement matrix, the 360-grade specimens exhibited a dependency on both the replacement level and the curing duration, albeit with slightly different magnitudes of change.

At the 7-day curing stage, an inverse relationship between zeolite content and compressive strength was observed. Specifically, the 15%replacement level resulted in a 6%reduction in strength compared to the control mix. This early-age strength deficit is consistent with the dilution effect and the delayed onset of pozzolanic activity characteristic of natural zeolite.

At 28 days, the long-term mechanical performance showed a significant improvement at the 8%replacement level, where a 3%increase in compressive strength was recorded relative to the control mix. This confirms that even with a lower-grade cement (360-grade), an optimal zeolite dosage can enhance the matrix densification through the formation of supplementary C-S-H gels. However, beyond the 8%threshold, specifically at 12%and 15%replacement levels, the compressive strength declined below the control values. This trend suggests that excessive substitution disrupts the cementitious continuity, likely due to an insufficient amount of reactive clinker to sustain the required hydration and pozzolanic synergy.

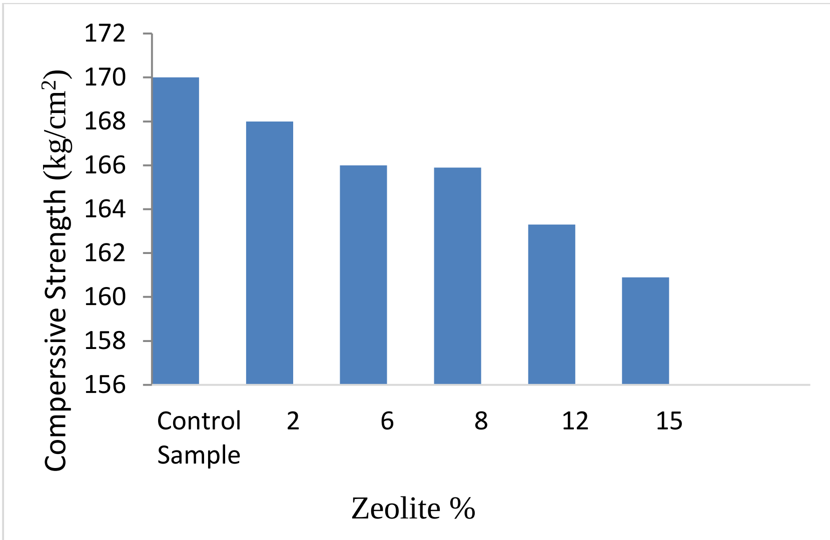

Figure 7: Concrete strength with different percentages of Zeolite with 360 grade cement at the age of 7 days of concrete.

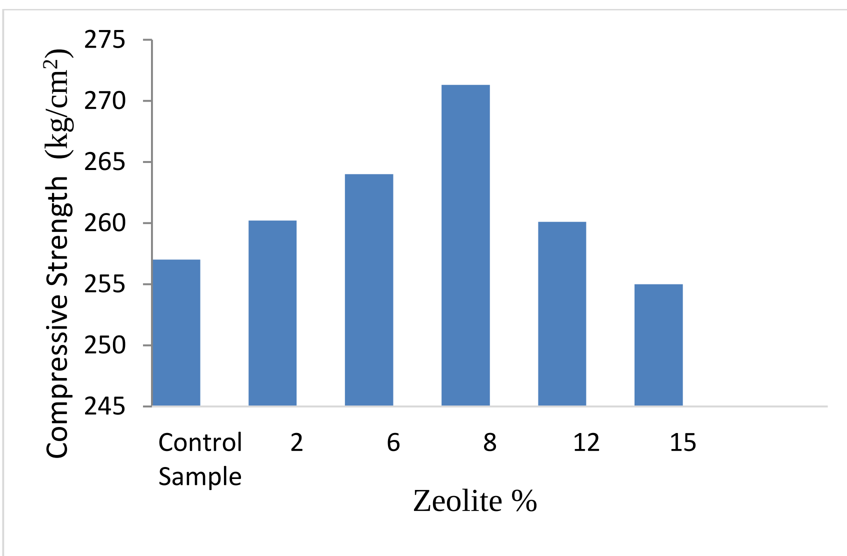

Figure 8: Concrete strength with different percentages of Zeolite with 360 grade cement at 28 days of age

5.5. Compressive Strength Evolution in 340-Grade Cement Matrix

The compressive strength profiles for the 340-grade cement specimens are depicted in Figure 9. The results follow a trend consistent with the previously discussed cement grades, characterized by an initial early-age strength deficit followed by a late-age pozzolanic gain.

During the early curing stage (7 days), the incorporation of zeolite led to a reduction in compressive strength across all replacement levels. Specifically, the 15%zeolite replacement resulted in a 5.8%decrease in strength compared to the control mix. This phenomenon is again ascribed to the dilution of the primary cementitious binder, which limits the initial hydration rate.

At 28 days, the 340-grade cement exhibited a notable response to zeolite addition. An optimal replacement level was identified, where the compressive strength increased by approximately 8%relative to the control mix (at the 8%replacement level). This significant improvement underscores the high pozzolanic efficiency of the zeolite in this specific cement matrix, facilitating the densification of the microstructure. However, as observed in the 400 and 360-grade cements, increasing the zeolite content beyond this threshold—specifically at 12%and 15%—resulted in a decline in strength below the control values. This decline is likely due to the disruption of the paste-aggregate matrix caused by excessive fine particles and the imbalance in the binder's hydration capacity.

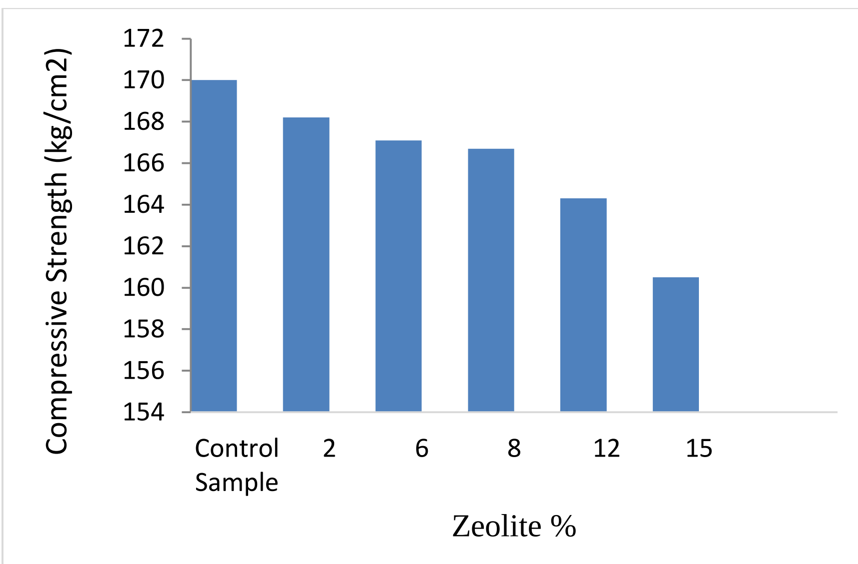

Figure 9: Concrete strength with different percentages of Zeolite with 340 grade cement at 7 days old concrete.

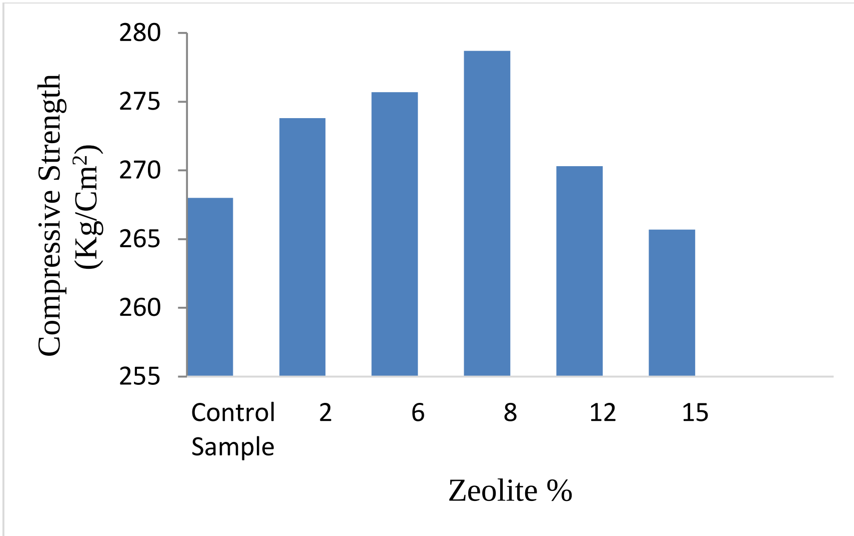

Figure 10: Concrete strength with different percentages of Zeolite with 340 grade cement at 28 days old concrete.

5.6. Compressive Strength Evolution in 320-Grade Cement Matrix

The compressive strength development for the 320-grade cement concrete, incorporating various zeolite replacement levels, is illustrated in Figure 11. As with the higher-grade cement matrices, the mechanical behavior of the 320-grade specimens is characterized by a dual-phase response.

At the 7-day curing stage, the incorporation of zeolite resulted in a reduction of compressive strength. Specifically, at a 15%replacement level, a 5.7%decrease in strength was observed relative to the control mix. This early-age strength deficit is consistent with the dilution of the primary clinker content and the slower hydration kinetics of the pozzolanic material.

In the long-term stage (28 days), the 320-grade cement exhibited a notable improvement in mechanical performance at the 8%replacement level, with a 4%increase in compressive strength compared to the control specimen. This indicates that the pozzolanic reaction of the zeolite effectively contributes to the strength development even in lower-grade cementitious environments. However, exceeding the optimal dosage (at 12%and 15%replacement levels) led to a decline in strength below the control values. This reduction suggests that high replacement levels of zeolite may lead to an excess of unreacted fine particles, which can increase the porosity and disrupt the continuity of the hardened cement paste.

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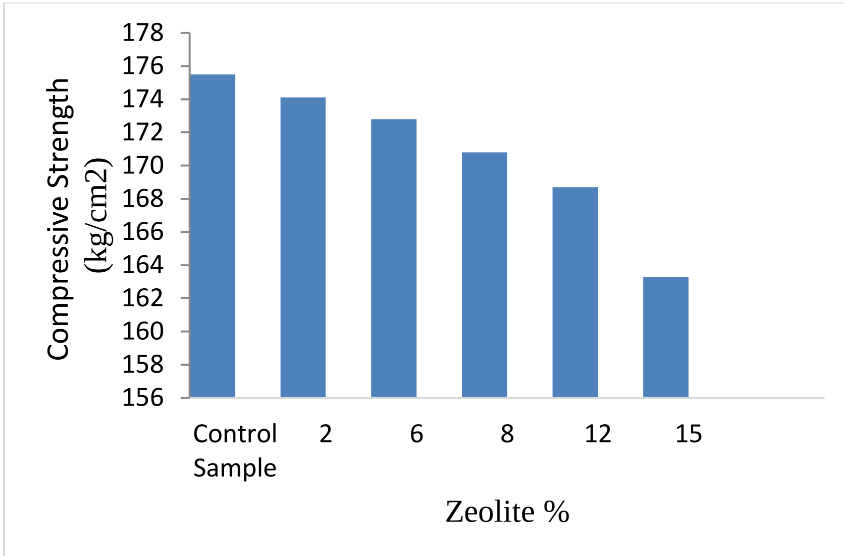

Figure 11: Concrete strength with different percentages of Zeolite with 320 grade cement at the age of 7 days of concrete.

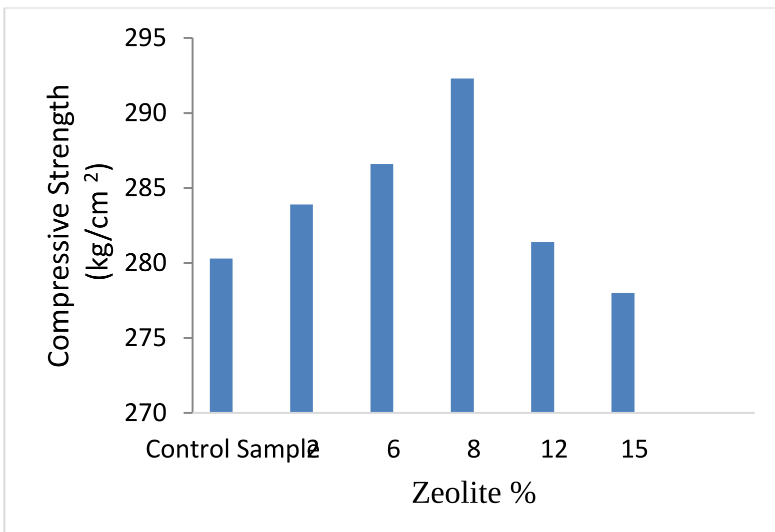

Figure 12: Concrete strength with different percentages of Zeolite with 320 grade cement at 28 days of concrete

5-7.Water Absorption Characteristics

The results of the water absorption tests are presented in [Figure 13]. A clear correlation was observed between the cement grade and the water absorption capacity; specifically, an increase in the cement grade was associated with a higher water absorption rate. Interestingly, the results indicated an increase in water absorption with higher zeolite replacement levels. This phenomenon may be attributed to the increased presence of unreacted zeolite particles and the potential creation of micro-voids at higher substitution dosages, which enhances the capillary suction within the concrete matrix

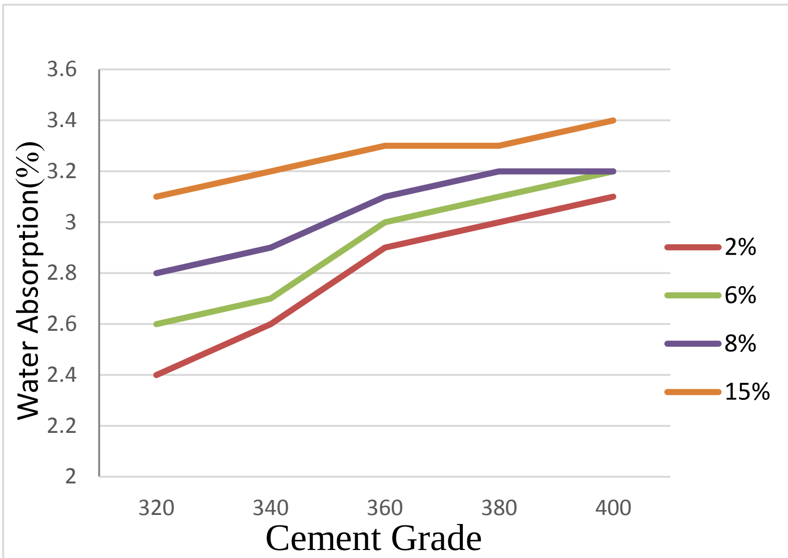

Figure 13: Diagram of water absorption percentage of concrete containing abiotic Zeolite to cement grade

6. Conclusions

This study systematically investigated the influence of zeolite pozzolanic replacement on the mechanical performance and durability of self-compacting concrete across various cement grades (400, 380, 360, 340, and 320). Based on the experimental results, the following conclusions can be drawn:

1. **Compressive Strength Dynamics:** The incorporation of zeolite exhibited a dual-phase effect on compressive strength. At early ages (7 days), a reduction in strength was observed across all cement grades, primarily due to the dilution of clinker content. However, at 28 days, an optimal replacement level of 8% was identified, which enhanced the compressive strength of all tested mixes. Beyond this threshold (at 12% and 15% replacement), a progressive decline in strength was observed, indicating that excessive pozzolanic substitution disrupts the paste-aggregate matrix and reduces reactive clinker availability.
2. **Sensitivity to Cement Grade:** The efficacy of zeolite modification is significantly influenced by the cementitious intensity. While all grades benefited from the pozzolanic activity at the 8% threshold, the 400-grade cement exhibited higher sensitivity to

substitution levels compared to lower-grade cements. This suggests that the optimal pozzolanic dosage is intrinsically linked to the initial clinker content of the matrix.

3. **Water Absorption and Durability:** The water absorption capacity of the concrete was found to increase with higher cement grades. Furthermore, the integration of zeolite at certain replacement levels influenced the absorption rate, reflecting changes in the interconnected porosity and the microstructural densification of the hardened paste.
4. **Summary of Findings:** Overall, the results demonstrate that zeolite can be effectively utilized as a partial cement replacement to enhance long-term mechanical properties, provided the replacement level is optimized (approximately 8%) to balance the pozzolanic synergy with the dilution effect.

References

[1] Ojo, A.O., et al., 2024. A review of natural zeolite as a supplementary cementitious material in sustainable concrete production. Journal of Building Engineering, 86, 108920.

[2] Doan, C.C., Tran, V.K., Huynh, T.P., 2026. Natural zeolite powder as a cement substitution in sustainable concrete: influence on engineering properties, durability, and microstructure characteristics. Materials Research Express, 13(3), 035503.

[3] Fan, J., Zhang, B., 2025. Study on the effect of modified zeolite powder on curing mechanism of concrete. Construction and Building Materials, 483, 141830.

[4] Wang, Y., et al., 2024. Synergistic effect of zeolite and nano-silica on the hydration and pore structure of cement-based materials. Cement and Concrete Composites, 152, 105670.

[5] Efe, M., Öz, A., Bayrak, B., Kaplan, G., Aydın, A.C., 2024. Effect of Na2SiO3/NaOH rate and natural zeolite content on basalt fiber reinforced eco-efficient slag-based geopolymer mortar synthesis. Archives of Civil and Mechanical Engineering, 24, 185.

[6] Ahmadi, B., Shekarchi, M., 2010. Use of natural zeolite as a supplementary cementitious material. Cement & Concrete Composites, 32(2), 134-141.

[7] Valipour, M., Pargar, F., Shekarchi, M., Khani, S., 2013. Comparing a natural pozzolan, zeolite, to metakaolin and silica fume in terms of their effect on the durability characteristics of concrete: A laboratory study. Construction and Building Materials, 41, 879–888.

[8] ASTM C125-07, 2007. Standard Terminology Relating to Concrete and Concrete Aggregates. ASTM International.

[9] National Iranian Standard No. 1-12284, 2009. Concrete - Part 1: Technical Specification Guide.

[10] BS 1881-Part 122, 1983. Method for Determination of Water Absorption. British Standards Institution.

[11] Jahangir, H., Bagheri, M., Delaware, S.A., 2018. Estimating Compressive Strength of Concrete by Swapping Pinion Ash for Cement. Journal of Structural and Construction Engineering, 5(Special Issue 2), 5-19.

[12] Dahir, R.K., McCarthy, M.J., Tittle, P.A.J., 2006. Role of cement content in specification for concrete durability: Aggregate type influences. Structures & Buildings, 159, 229–242.

[13] Poon, C.S., Lam, S.C., 2008. The effect of aggregate-to-cement ratio and types of aggregate on the properties of pre-cast concrete blocks. Cement & Concrete Composites, 30, 283–289.

[14] Shi, C., 2004. Effect of mixing proportions of concrete on its electrical conductivity and rapid chloride permeability test (ASTM C 1202 or AASHTO T277) results. Cement and Concrete Research, 34, 537–545.

[15] ACI 237R-07, 2007. Self-Consolidating Concrete. American Concrete Institute.