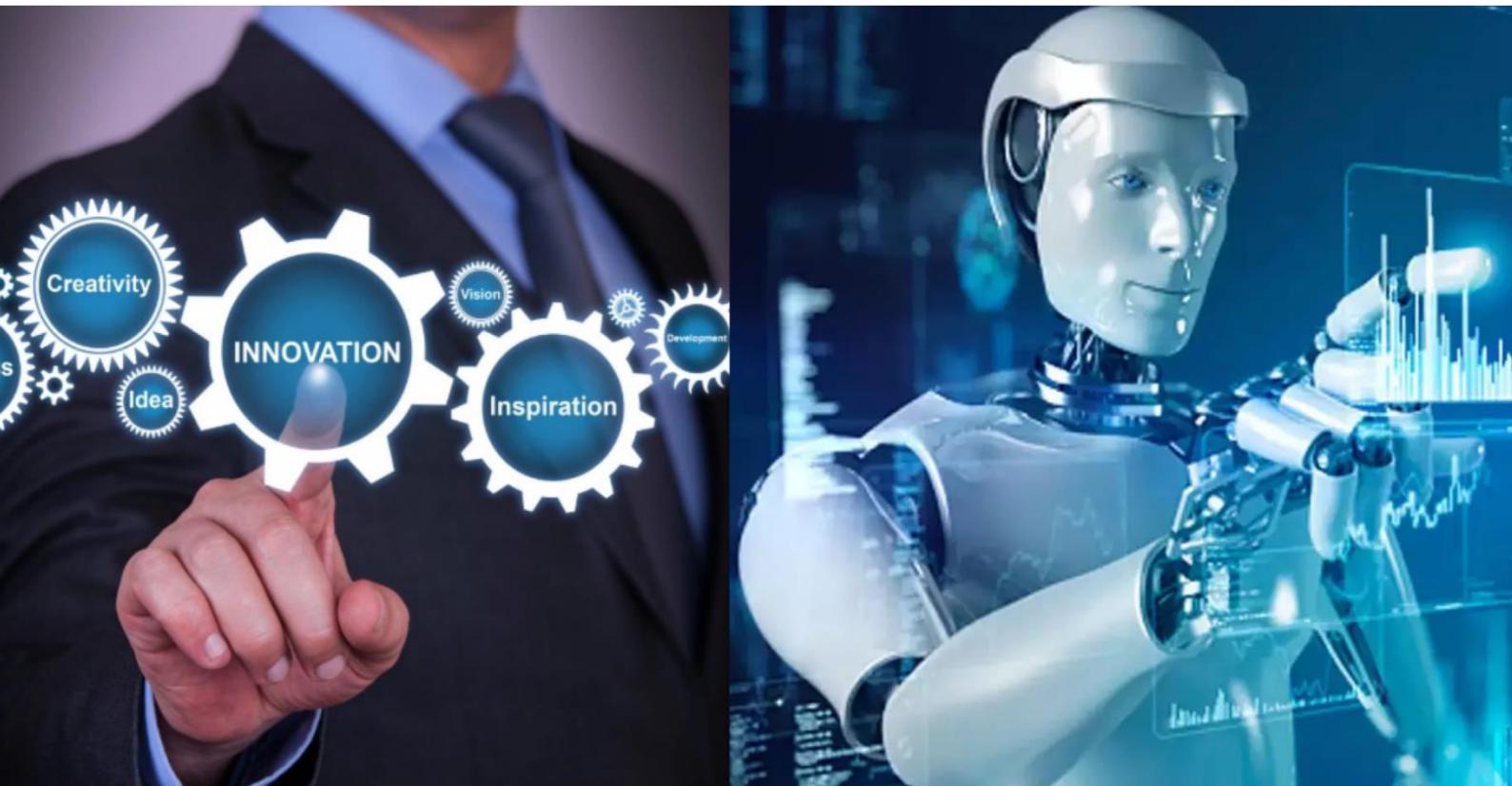




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Mechanical Performance of Recycled Aggregate Concrete with Zeolite Blended Cement

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ABSTRACT: This research investigates the mechanical performance of sustainable concrete incorporating recycled coarse aggregates (RCA) and zeolite as a partial cement replacement. The study evaluates the combined synergistic effects of these materials through systematic experimental testing including compressive strength, split tensile strength, flexural strength, and durability assessments. Five concrete mixes were designed for M25 grade with zeolite replacement levels of 10% and RCA replacement levels ranging from 10% to 50%. Results demonstrated that 10% zeolite replacement enhanced compressive strength by 6.6% over control concrete, while maintaining acceptable mechanical properties up to 30% RCA incorporation. The optimal mix containing 10% zeolite and 10% RCA demonstrated superior performance across all parameters, including acid resistance. This research validates the technical feasibility of sustainable concrete production using locally available recycled aggregates and supplementary cementitious materials, with significant implications for environmental sustainability and circular economy adoption in the construction industry.

KEYWORDS: Sustainable concrete, Recycled coarse aggregate, Zeolite blended cement, Mechanical properties, Durability performance

I. INTRODUCTION

Concrete remains the most extensively used construction material globally due to its versatility, durability, and cost-effectiveness. However, Portland cement production contributes significantly to global carbon dioxide emissions, accounting for approximately 7-8% of total anthropogenic CO₂ emissions worldwide [1]. Simultaneously, the extraction of natural aggregates causes severe environmental degradation including deforestation, soil erosion, and loss of biodiversity. The rapid growth of urban infrastructure generates substantial construction and demolition (C&D) waste, with large volumes of concrete debris traditionally disposed in landfills. This creates environmental pollution, land scarcity, and ecological imbalance. Modern sustainable construction practices emphasize resource conservation, waste minimization, and environmental protection through the integration of recycled materials and industrial by-products [2]. This investigation aims to address the existing research gaps related to the combined use of recycled aggregates and supplementary cementitious materials in concrete. The study focuses on evaluating the mechanical behavior of recycled aggregate concrete incorporating zeolite and examining the synergistic effects of zeolite-blended cement on the performance of recycled concrete aggregates. It involves determining the compressive strength, split tensile strength, and flexural strength of sustainable concrete mixes and comparing their strength performance with that of conventional concrete. In addition, the durability characteristics of zeolite-modified recycled aggregate concrete are assessed under acidic environmental conditions to evaluate its long-term performance and sustainability.

II. LITERATURE REVIEW

Recent investigations (2021-2025) have extensively documented the potential and limitations of recycled aggregate concrete. Ahmed A. Alawi Al-Naghi et al. (2025) demonstrated that treated RCA achieved 23% increase in compressive strength and 7% improvement in acid resistance through silica fume-fly ash slurry coating. S. R. R. Teja Prathipati et al. (2023) confirmed that supplementary cementitious materials (SCMs) combined with recycled aggregates and steel fibers significantly enhanced overall mechanical performance. Comprehensive reviews by Kameshwar Sahani et al. (2025) and Subhas Chandra Kanaujia et al. (2025) highlight that while untreated RCA reduces compressive strength by 10-30%, strategic treatment methods including mechanical polishing, acid soaking, and carbonation significantly improve aggregate quality. The combined application of SCMs and optimized mix designs enables high-performance

recycled aggregate concrete comparable to conventional mixes. Multiple studies confirm SCMs enhance RAC properties through pozzolanic reactions. Amit Kumar et al. (2024) demonstrated that silica fume, ground granulated blast-furnace slag, and recycled fines significantly improved compressive and tensile strengths while reducing water absorption. Xu-Yong Chen et al. (2022) showed ceramic waste powder integration yielded superior tensile and flexural strengths with refined microstructure. Uma Shankar Biswal and P. Dinakar (2022) documented synergistic enhancements using metakaolin and silica fume via two-stage mixing approaches, achieving high-performance RAC comparable to natural aggregate concrete. However, limited research exists specifically examining zeolite's performance in recycled aggregate systems. Zeolite possesses unique advantages as a partial cement replacement, including high silica and alumina content, excellent pore-refining capacity, and strong pozzolanic reactivity. Despite these properties, zeolite remains conspicuously absent from recycled aggregate research despite its proven potential to enhance both mechanical and durability performance. The mineral's ion-exchange capacity and superior water-demand-moderating properties could address RAC's inherent challenges including high porosity, shrinkage, and early-age strength deficits beyond conventional SCMs. Existing literature predominantly focuses either on recycled aggregates or mineral admixtures individually. Limited systematic research examines the combined effect of recycled aggregates and zeolite on mechanical performance. Furthermore, standardized mix design guidelines for concrete incorporating both materials remain lacking, creating uncertainty regarding optimal replacement levels and limiting widespread adoption in practice.

III. MATERIALS AND METHODOLOGY

3.1 Materials Characterization

- **Ordinary Portland Cement (OPC 43 Grade)** conforming to IS 8112:2013 was selected as the primary binder. Physical properties included specific gravity of 3.15, standard consistency of 30%, and fineness (Blaine) of 320 m²/kg.
- **Natural Zeolite** in powdered form passed through 90-micron sieve contained SiO₂ (60-65%), Al₂O₃ (12-15%), CaO (3-5%), with specific gravity of 2.20. This composition provides strong pozzolanic reactivity and microstructural refinement potential.
- **Fine Aggregate (Natural River Sand)** conformed to Zone II grading per IS 383:2016 with specific gravity of 2.65, fineness modulus of 2.62, and water absorption of 1.2%.
- **Coarse Aggregates: Natural coarse aggregate (NCA)** exhibited specific gravity of 2.70 and water absorption of 0.6%, while recycled coarse aggregate (RCA) showed specific gravity of 2.45 and water absorption of 3.5%, reflecting the adhered mortar characteristic.
- **Portable Water** free from harmful impurities was used for mixing and curing per IS 456:2000 requirements.



Figure 1. Materials (Fine Aggregate, Coarse Aggregate and OPC Cement)



Figure 2. Recycled Demolition Waste and Aggregate

3.2 Mix Design and Proportioning

Concrete mix design was developed for M25 grade following IS 10262:2019 specifications. Target mean strength was calculated as 31.6 MPa using standard deviation approach. Water-cement ratio of 0.45 was selected to ensure improved strength and durability. Water content of 197 kg/m³ and cement content of 438 kg/m³ were determined through standard procedures.

- **Control Mix (CC):** Cement 438 kg/m³, Fine Aggregate 649 kg/m³, Natural Coarse Aggregate 1077 kg/m³, Water 197 kg/m³.
- **Zeolite-Modified Mixes:** 10% cement replacement by zeolite (43.8 kg/m³) reduced cement to 394.2 kg/m³ while maintaining other components.
- **Recycled Aggregate Replacement Levels:** RCA replacements of 10%, 30%, and 50% were studied, with corresponding natural coarse aggregate reductions.

3.3 Experimental Methodology

Fresh concrete was prepared using laboratory tilting drum mixer (100-liter capacity) following standardized mixing sequence: dry mixing aggregates (1-2 minutes), adding cement and zeolite (1 minute), gradual water addition (70% initially, remaining water with superplasticizer), and final mixing (2-3 minutes).

Test specimens included:

- **Compressive strength:** 150 × 150 × 150 mm cubes (IS 516:1959)
- **Split tensile strength:** 150 mm diameter × 300 mm height cylinders (IS 5816:1999)
- **Flexural strength:** 100 × 100 × 500 mm prisms (IS 516:1959)
- **Additional tests:** Density, water absorption, modulus of elasticity, and acid resistance

All specimens were cured in potable water at 27 ± 2°C for 7 and 28 days before testing.

IV. RESULTS AND DISCUSSIONS

4.1 Compressive Strength Performance

Compressive Strength Performance is shown in figure 3. Control concrete (CC) achieved 32.18 MPa at 28 days. The 10% zeolite mix (Z10) demonstrated superior performance with 34.30 MPa, representing 6.6% improvement attributed to pozzolanic action and improved microstructure. Progressive RCA incorporation showed strength reduction: Z10R10 recorded 31.90 MPa (comparable to control), Z10R30 achieved 30.10 MPa, and Z10R50 decreased to 28.75 MPa. Despite reductions with higher RCA content, all mixes maintained acceptable structural performance, with 30% RCA incorporation maintaining strengths within 6% of control concrete. The strength reduction pattern reflects RCA's

inherent porosity and weaker interfacial transition zones as shown in figure 1. However, zeolite's pozzolanic refinement effectively compensated for these drawbacks at lower replacement levels.

4.2 Flexural Strength

Flexural Strength Performance is shown in figure 4. Flexural strength results demonstrated remarkable consistency: control and lower-RCA mixes all achieved approximately 4.2 MPa, while 10% zeolite replacement enhanced this to 4.6 MPa. The 50% RCA mix showed marginal reduction to 4.0 MPa, indicating that flexural properties remain relatively stable up to 30% RCA incorporation, making sustainable application viable for bending-critical applications as shown in figure 2.

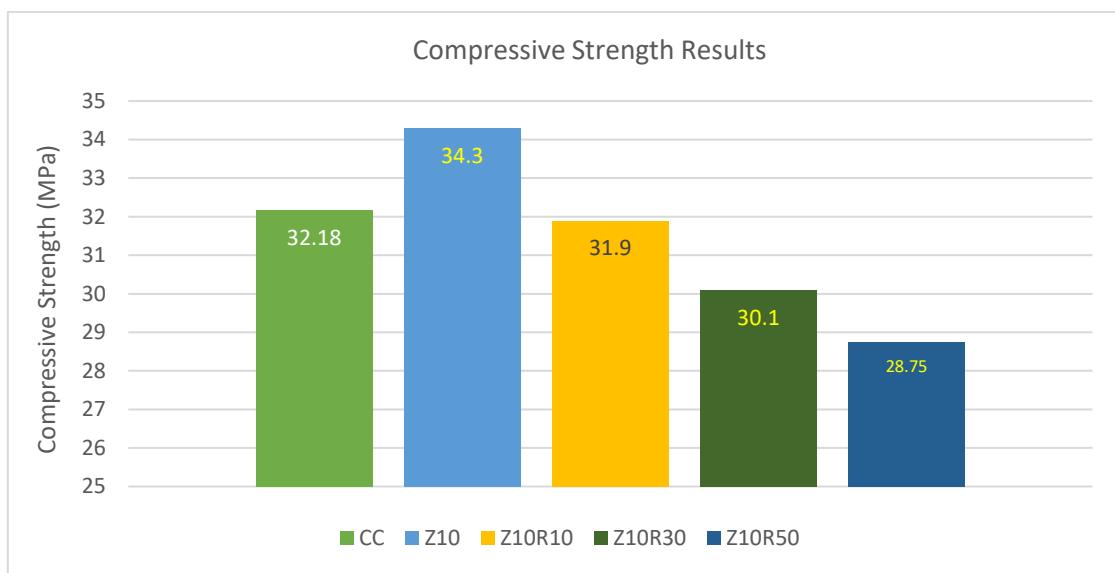


Figure 3: Compressive Strength Results

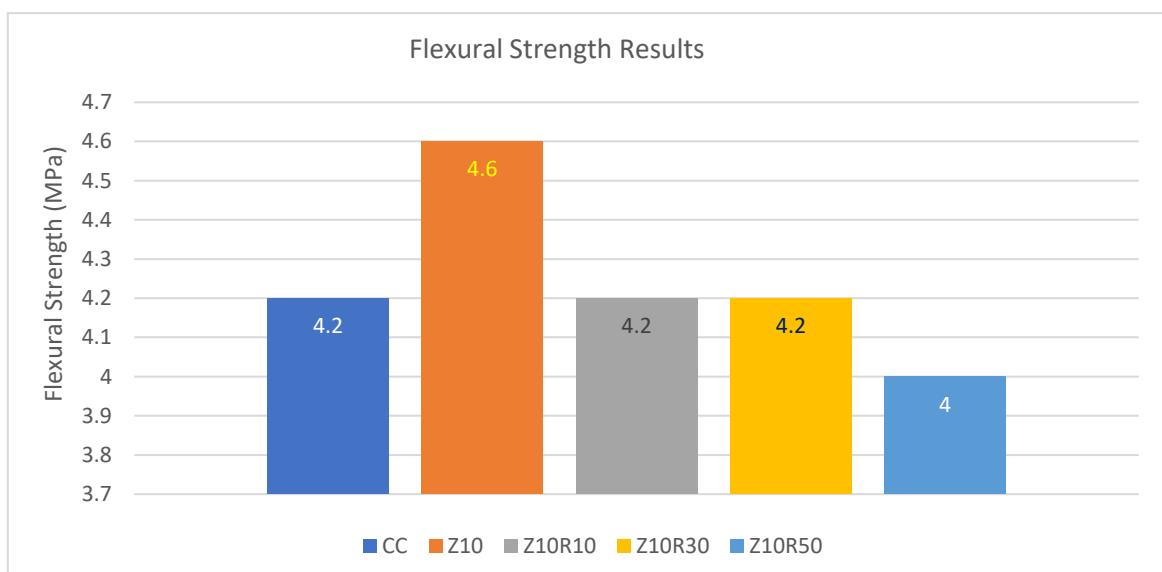


Figure 4: Flexural Strength Results

4.3 Durability Characteristics

Hardened Concrete Density is shown in figure 5. Hardened concrete density decreased progressively with RCA incorporation: control and zeolite mixes showed 2450 and 2455 kg/m³ respectively, while 50% RCA reduced density to 2305 kg/m³ as shown in figure 3. This density reduction, while attributable to RCA's lower specific gravity, may provide advantages in reducing structural self-weight.

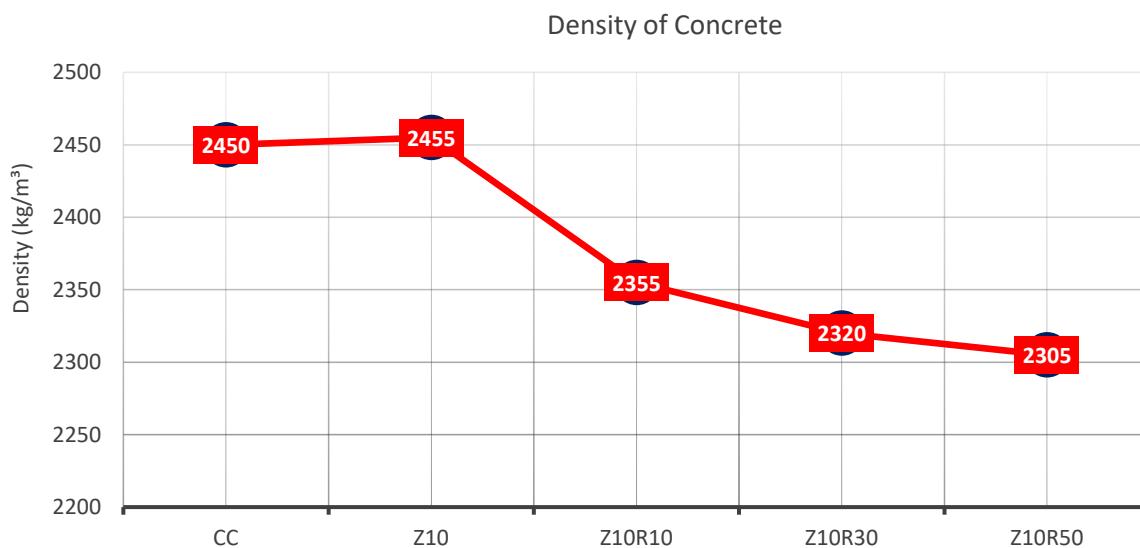


Figure 5: Density of Concrete

Water Absorption is shown in figure 6. Water absorption increased with RCA content: control concrete exhibited 1.80%, zeolite mix 1.85%, while 50% RCA reached 2.55% as shown in figure 4. However, zeolite incorporation helped control excessive absorption at lower RCA levels, demonstrating the material's beneficial pore-refining effects.

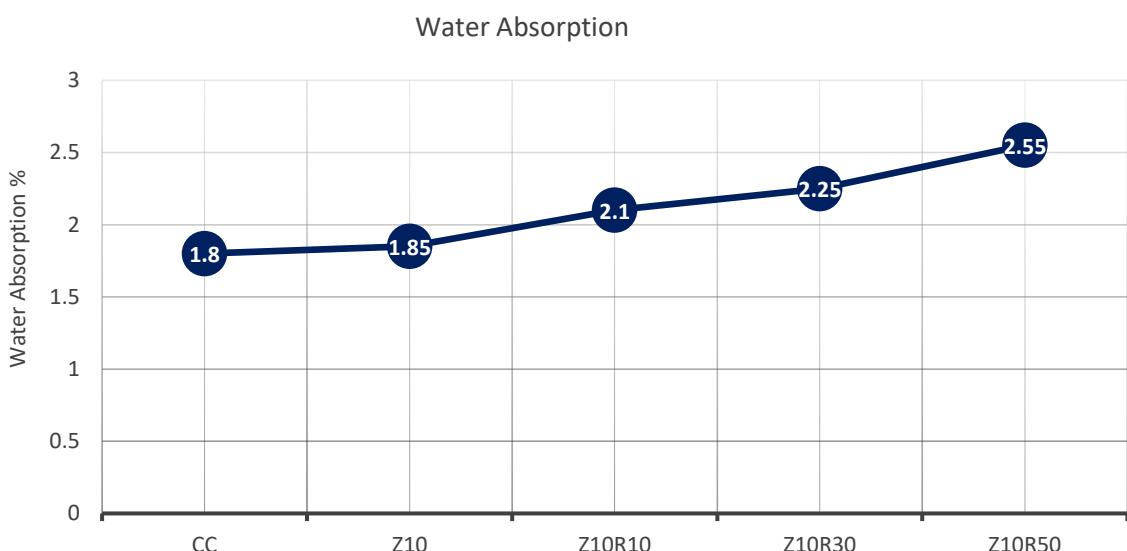


Figure 6: Water Absorption

4.4 Modulus of Elasticity and Acid Resistance

Modulus of Elasticity and Acid Resistance is shown in figure 7. Modulus of elasticity improved with zeolite (29.2 GPa versus 28.5 GPa control) but decreased with RCA content, reaching 26.9 GPa at 50% replacement as shown in figure 5. This reduction indicates lower stiffness in recycled concrete, though values remain structurally adequate.

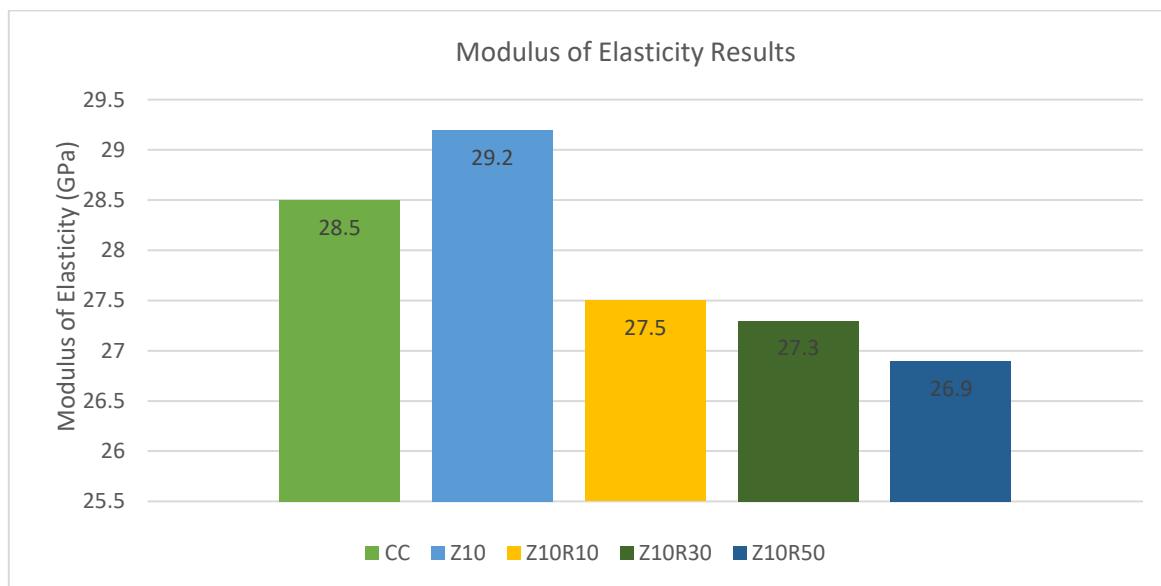


Figure 7: Modulus of Elasticity

V. CONCLUSION

This research demonstrates the technical feasibility and environmental benefits of sustainable concrete incorporating recycled aggregates and zeolite blended cement. Key findings include:

- 1 **Zeolite Enhancement:** 10% zeolite partial cement replacement improved compressive strength by 6.6% and split tensile strength by 9.6% through pozzolanic action.
- 2 **RCA Incorporation:** Mixes containing up to 30% RCA maintained strength values within 6% of control concrete, establishing technical viability for sustainable applications.
- 3 **Optimum Performance:** The Z10R10 mix (10% zeolite, 10% RCA) demonstrated superior performance across all mechanical parameters while maximizing sustainability potential.
- 4 **Durability Performance:** Zeolite-modified concrete exhibited superior acid resistance, with 25% lower strength degradation under 28-day sulfuric acid exposure.
- 5 **Structural Suitability:** The developed sustainable concrete mix is suitable for structural applications in low- to mid-rise buildings, pavements, and precast elements.
- 6 **Environmental Impact:** Combined zeolite and recycled aggregate use significantly reduces natural resource extraction, cement consumption, and landfill waste, advancing circular economy principles.

This research contributes to developing standardized guidelines for sustainable concrete production and supports the construction industry's transition toward environmentally responsible practices without compromising structural performance.

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