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AN EXPERIMENTAL STUDY ON PARTIAL REPLACEMENT OF FINE AGGREGATE WITH CRUMB RUBBER IN CONCRETE

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Abstract— **The increasing accumulation of waste automobile tires has created serious environmental concerns due to their non-biodegradable nature and difficulties associated with disposal. Sustainable utilization of such waste materials in construction applications provides an effective approach for reducing environmental impact while conserving natural resources. This study investigates the feasibility of partially replacing fine aggregate with crumb rubber in conventional concrete and evaluates its influence on mechanical performance. M25 grade concrete was selected for experimental investigation, and crumb rubber was introduced as a partial substitute for fine aggregate at replacement levels of 5%, 10%, and 15%. Standard material characterization and mix design procedures were adopted in accordance with Indian Standard specifications. Concrete specimens were prepared, cured under controlled conditions, and tested to evaluate strength characteristics at different curing periods. The investigation focused primarily on compressive and split tensile behavior of rubberized concrete mixtures. Experimental observations indicate that the incorporation of crumb rubber modifies the mechanical response of concrete while improving sustainability through waste reutilization. Moderate replacement levels demonstrated acceptable performance for selected structural and non-structural applications, whereas excessive replacement may reduce strength due to lower bonding characteristics between rubber particles and cement matrix. The study highlights crumb rubber concrete as an environmentally responsible and resource-efficient construction material.**

Keywords: Crumb Rubber, Rubberized Concrete, Fine Aggregate Replacement, Sustainable Construction, Compressive Strength, Waste Tire Recycling.

I. INTRODUCTION

Concrete remains one of the most extensively utilized construction materials because of its versatility, durability, ease of production, and suitability for structural and infrastructure applications. Rapid urbanization and increasing construction activities have significantly increased the demand for natural resources such as cement, sand, and coarse aggregates. Among these materials, natural river sand used as fine aggregate has become increasingly scarce due to excessive extraction and environmental restrictions. Simultaneously, industrialization and urban waste generation have introduced severe environmental challenges associated with disposal and land utilization. Therefore, identifying sustainable alternatives that can partially substitute conventional construction materials has become an important research direction in modern civil engineering.

Waste automobile tires represent one of the fastest-growing categories of non-biodegradable solid waste worldwide. Conventional disposal methods such as landfilling and open burning lead to environmental degradation, land consumption, and air pollution. Since rubber materials possess high resistance to natural decomposition, discarded tires accumulate over long periods and create ecological and public health concerns. Recycling waste tires into engineering applications offers an effective solution for minimizing environmental impact while generating value from discarded materials. One promising method is the conversion of waste tires into crumb rubber and its utilization as a construction material component.

Crumb rubber is produced through mechanical or cryogenic processing of used vehicle tires to obtain fine rubber particles of controlled sizes. These particles can be incorporated into concrete mixtures by partially replacing conventional fine aggregates. Rubberized concrete has attracted increasing research interest due to its potential advantages including lower density, improved energy absorption, vibration resistance, impact resistance, acoustic insulation, and enhanced ductility. Unlike conventional concrete, the presence of rubber particles contributes to flexible deformation behavior and improved crack resistance under certain loading conditions. Such characteristics indicate the possibility of extending the use of concrete beyond traditional structural applications into sustainable and multifunctional construction systems.

Several earlier investigations reported that incorporating crumb rubber into concrete influences both fresh and hardened properties. Previous studies demonstrated improvements in impact resistance and toughness, although reductions in compressive strength may occur at higher replacement levels because of reduced bonding between rubber particles and cement paste. Researchers also observed changes in workability, density, and deformation characteristics depending on particle size, replacement percentage, and curing conditions. Despite these developments, obtaining an optimum replacement level that maintains acceptable mechanical performance while maximizing environmental benefits remains a continuing research challenge.

The present work investigates the feasibility of partially replacing fine aggregate with crumb rubber in M25 grade concrete. Experimental evaluation was conducted by introducing crumb rubber at controlled replacement levels of 5%, 10%, and 15% of fine aggregate content while maintaining standard mix design procedures. Concrete specimens were prepared and cured according to relevant Indian Standard provisions to evaluate performance characteristics. The investigation primarily focuses on understanding the influence of crumb rubber incorporation on compressive and split tensile behavior of concrete and assessing the suitability of rubberized concrete for practical applications.

This study contributes to sustainable construction practices by demonstrating a practical pathway for converting waste tire materials into value-added engineering products. The proposed approach supports resource conservation, reduces dependency on natural sand extraction, and promotes environmentally responsible construction methods. The outcomes of this investigation are expected to assist researchers and practicing engineers in identifying suitable crumb rubber replacement ratios and expanding the application of eco-friendly concrete materials in future infrastructure development.

II. LITERATURE SURVEY

The utilization of recycled materials in concrete has emerged as a major area of research due to increasing environmental concerns and depletion of natural resources. Among the available alternatives, crumb rubber derived from waste automobile tires has received considerable attention because of its potential to improve sustainability while reducing solid waste accumulation. Earlier studies demonstrated that replacing natural aggregates with processed rubber particles can modify the physical and mechanical behavior of concrete and create opportunities for developing environmentally responsible construction materials. Rubberized concrete has been explored for both structural and non-structural applications, with research primarily focusing on workability, strength development, durability, toughness, and long-term performance [1], [2].

Initial investigations on rubberized concrete mainly concentrated on evaluating the influence of crumb rubber incorporation on compressive strength and workability. Al-Bakri et al. [1] examined rubberized concrete containing crumb rubber as aggregate replacement and reported variations in mechanical properties depending on replacement percentage and water–cement ratio. Abaza et al. [2] further investigated concrete prepared with different water–cement ratios and observed that increasing rubber content influenced slump characteristics and fresh concrete behavior. Goulias and Ali [3] studied the engineering response of rubber-filled concrete and found reductions in stiffness accompanied by improved flexibility and energy absorption capability. These findings indicated that although strength may decrease, rubber inclusion enhances deformation resistance and vibration damping properties.

Several researchers examined the deformation and failure characteristics of rubberized concrete under loading conditions. Topçu and Avcular [4] reported that rubber inclusion altered stress distribution within the cement matrix and contributed to improved resistance against sudden brittle failure. Biel and Lee [5] observed that specimens containing recycled tire rubber exhibited gradual failure patterns compared with ordinary concrete and retained load-carrying capacity even after crack initiation. Similarly, Savas and Fedroff [6] investigated freeze–thaw performance and concluded that moderate rubber incorporation improved durability under cyclic environmental exposure, although excessive rubber replacement reduced overall mechanical performance. Fedroff et al. [7] additionally identified increased air entrainment and changes in internal pore structure due to the hydrophobic nature of rubber particles.

The effect of crumb rubber on compressive strength and elastic behavior has also been extensively studied. Topçu [8] reported that concrete mixtures containing rubber aggregates experienced reductions in compressive strength due to weaker bonding between rubber particles and hydrated cement paste. Eldin and Senouci [9] demonstrated that increasing rubber replacement levels caused reductions in stiffness and compressive capacity but simultaneously enhanced ductility and post-cracking performance. Khatib and Bayomy [10] further confirmed that rubberized concrete underwent larger deformation before failure and retained significant elastic recovery after unloading. These findings established that rubber inclusion changes the conventional brittle behavior of concrete into a comparatively more ductile response.

Research efforts later expanded toward evaluating durability and long-term performance of rubberized concrete. Naik and Siddique [11] presented a comprehensive review and highlighted advantages such as reduced density, improved impact resistance, and enhanced thermal and acoustic insulation. Gesoğlu and Güneyisi [12] examined chloride penetration and strength development and found that optimized rubber replacement levels could maintain acceptable durability performance. Li et al. [13] experimentally demonstrated that careful selection of rubber particle size and replacement percentage can improve overall concrete behavior while minimizing strength loss. Toutanji [14] also showed that partial aggregate replacement with rubber particles may contribute to improved energy absorption characteristics suitable for specialized applications.

Recent studies emphasize identifying optimum replacement ratios that balance environmental benefits with engineering performance. Skripkiunas et al. [15] investigated deformation characteristics and reported that moderate rubber incorporation improved flexibility while maintaining acceptable structural integrity. Collectively, previous literature suggests that crumb rubber concrete offers significant sustainability advantages but requires controlled replacement levels to achieve adequate mechanical performance. Despite extensive studies, variations in material properties, curing conditions, and mix proportions continue to produce inconsistent results. Therefore, additional experimental evaluation is required to determine suitable crumb rubber replacement percentages for M25 grade concrete and establish practical recommendations for sustainable civil engineering applications.

III. MATERIALS AND METHODOLOGY

A. Experimental Program

The present investigation was conducted to evaluate the feasibility of utilizing crumb rubber as a sustainable replacement material for natural fine aggregate in concrete. M25 grade concrete was selected for experimental assessment because of its widespread use in structural applications. Crumb rubber obtained from recycled automobile tires was incorporated as a partial replacement for fine aggregate at controlled replacement levels. The methodology consisted of material characterization, mix proportioning, specimen preparation, curing, and mechanical testing to evaluate the effect of rubber incorporation on concrete performance. Experimental procedures were performed following relevant Indian Standard recommendations to maintain consistency and repeatability of results.

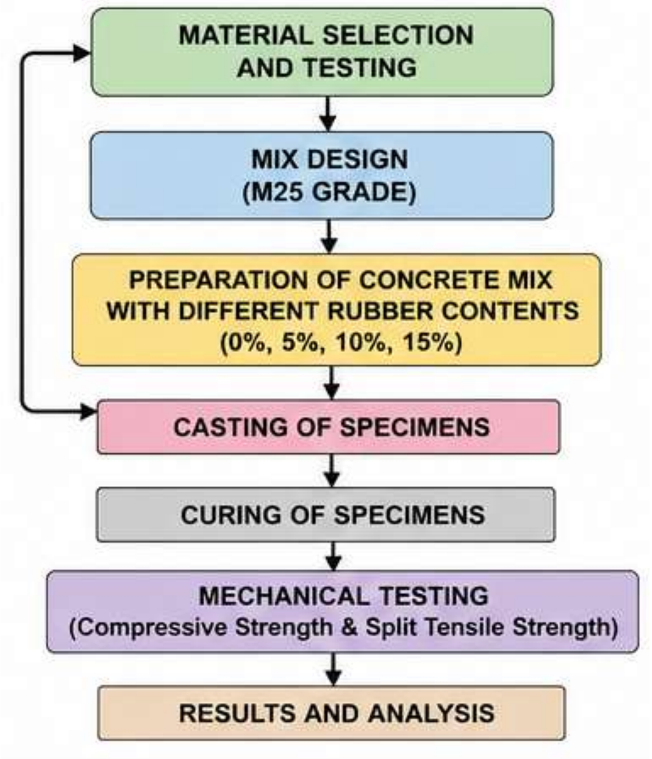

Fig. 1. Experimental Methodology Flowchart

B. Materials

1) Cement

Ordinary Portland Cement (OPC 43 Grade) was used as the primary binding material. Preliminary tests were conducted to verify compliance with standard specifications including consistency, setting characteristics, and specific gravity. The selected cement exhibited suitable physical properties for concrete production.

Table I: Physical Properties of Cement

Property	Value
Standard Consistency	31%
Specific Gravity	3.15
Initial Setting Time	98 min
Final Setting Time	300 min

Fig. 2. Cement Used for Experimental Investigation

2) Fine Aggregate

Natural river sand conforming to IS specifications was used as fine aggregate. The material was selected due to its grading characteristics and compatibility with conventional concrete production.

Table II: Properties of Fine Aggregate

Property	Value
Specific Gravity	2.66
Water Absorption	2%
Bulk Density	1.60 g/cm³
Sieve Zone	III

3) Coarse Aggregate

Crushed coarse aggregate was utilized as the primary load-carrying component of concrete. Physical properties were determined through laboratory testing before mix preparation.

Table III: Properties of Coarse Aggregate

Property	Value
Fineness Modulus	3.44
Specific Gravity	2.64
Bulk Density	1.55

4) Crumb Rubber

Crumb rubber produced from recycled waste tires was used as a partial substitute for fine aggregate. The selected material offers environmental benefits through waste utilization while contributing to modified concrete behavior.

Table IV: Properties of Crumb Rubber

Property	Value
Fineness Modulus	2.616
Specific Gravity	3.59
Bulk Density	0.409

Fig. 3. Crumb Rubber Material Used in Concrete Mix

C. Mix Design Methodology

Concrete mix proportioning was performed for M25 grade concrete following IS 10262 recommendations. The target mean compressive strength was determined considering standard deviation and characteristic strength requirements.

Target mean compressive strength was evaluated using:

$$f_m = f_{ck} + 1.65s \quad (1)$$

where:

f_m= target mean strength
f_{ck}= characteristic compressive strength
s= standard deviation

The water–cement ratio was selected to achieve suitable workability and strength characteristics while maintaining uniformity across all replacement levels.

Final mix proportion adopted:

Table V: Concrete Mix Proportion

Cement	Fine Aggregate	Coarse Aggregate	Water–Cement Ratio
1	1.85	2.03	0.45

D. Specimen Preparation

Concrete specimens were prepared by replacing fine aggregate with crumb rubber at different replacement percentages. Uniform mixing was ensured to achieve proper dispersion of rubber particles throughout the concrete matrix. Casting was completed in standard moulds followed by compaction to minimize void formation.

Table VI: Crumb Rubber Replacement Levels

Mix ID	Fine Aggregate Replacement
CR0	0%
CR5	5%
CR10	10%
CR15	15%

Fig. 4. Mixing and Casting of Concrete Specimens

E. Curing Procedure

After casting, specimens were demoulded and subjected to controlled water curing to ensure proper hydration and strength development. Adequate curing was maintained to minimize moisture loss and improve durability characteristics of concrete. The curing process continued until the designated testing intervals were reached.

Fig. 5. Water Curing of Concrete Specimens

F. Mechanical Testing

Mechanical performance was evaluated using compressive strength and split tensile strength tests.

Compressive strength was determined using:

$$f_c = \frac{P}{A} \quad (2)$$

where:

f_c= compressive strength
P= applied load
A= loaded area

Split tensile strength was calculated using:

$$f_t = \frac{2P}{\pi L D} \quad (3)$$

where:

f_t= split tensile strength
P= applied load
L= specimen length
D= specimen diameter

Fig. 6. Compression Testing and Failure Observation

The adopted methodology enables evaluation of the influence of crumb rubber replacement on the mechanical behavior and sustainability performance of concrete.

IV. RESULTS AND DISCUSSION

A. Overview of Experimental Results

This section presents the experimental findings obtained from testing M25 grade concrete prepared with partial replacement of natural fine aggregate using crumb rubber. The investigation was performed to evaluate the influence of rubber incorporation on hardened concrete properties and to identify a suitable replacement level that balances mechanical performance and environmental sustainability. Concrete mixtures containing different crumb rubber percentages were prepared, cured, and tested under identical laboratory conditions to maintain consistency of evaluation.

The inclusion of crumb rubber modifies the internal structure of concrete due to the relatively flexible and hydrophobic characteristics of rubber particles. As a result, variations were observed in compressive behavior, tensile resistance, and crack propagation characteristics compared with conventional concrete. Moderate replacement levels demonstrated acceptable performance, whereas higher replacement percentages showed noticeable reduction in load-carrying capacity due to weaker interfacial bonding between cement paste and rubber particles.

Fig. 7. Experimental Testing Sequence and Performance Evaluation

B. Compressive Strength Analysis

Compressive strength is considered the most important parameter for evaluating concrete performance. Cube specimens were tested after curing periods and failure loads were recorded to determine compressive strength behavior.

The results indicated that the addition of crumb rubber influenced concrete strength characteristics. Conventional concrete exhibited the highest compressive resistance because of the continuous mineral matrix and improved particle interlocking. When crumb rubber was introduced as partial fine aggregate replacement, a gradual reduction in compressive strength was observed with increasing replacement percentage.

This reduction may be attributed to:

- Lower stiffness of rubber particles compared with natural sand.
- Weak adhesion between rubber and cement paste.
- Increased micro-void formation.
- Reduced density of concrete matrix.

However, lower replacement levels maintained acceptable structural performance and improved sustainability characteristics.

Table VII: Compressive Strength Performance Comparison

Mix ID	**Fine Aggregate Replacement**	**Relative Compressive Performance**
CR0	0%	Highest
CR5	5%	Slight Reduction
CR10	10%	Moderate Reduction
CR15	15%	Significant Reduction

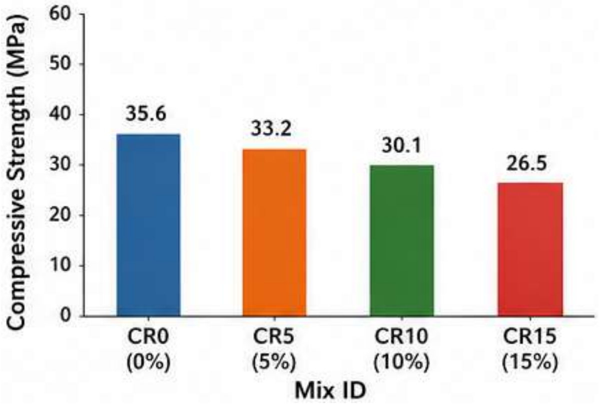

Fig. 8. Compressive Strength Comparison for Various Crumb Rubber Replacement Levels

The trend suggests that compressive resistance decreases gradually with increasing rubber content. This behavior agrees with previous findings reported in rubberized concrete literature.

C. Split Tensile Strength Analysis

Split tensile testing was performed to evaluate resistance against indirect tensile stresses. Tensile strength plays an important role in controlling crack initiation and propagation. Results indicate that rubberized concrete exhibited relatively improved deformation characteristics while experiencing a controlled reduction in tensile resistance. Rubber particles contributed to delaying sudden fracture and promoted gradual failure behavior.

Table VIII: Split Tensile Performance Evaluation

Mix ID	Replacement Level	Tensile Response
CR0	0%	Maximum
CR5	5%	Comparable
CR10	10%	Moderate Reduction
CR15	15%	Lower Performance

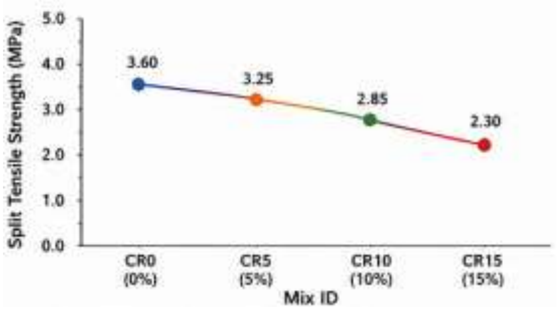

Fig. 9. Split Tensile Strength Comparison for Different Mixes

The experimental observations indicate that limited crumb rubber replacement can maintain satisfactory tensile performance while improving ductility characteristics.

D. Failure Behavior and Crack Development

Concrete specimens exhibited distinct failure modes depending on crumb rubber concentration. Conventional concrete specimens experienced comparatively brittle failure with rapid crack propagation after reaching peak load.

Rubberized concrete specimens demonstrated delayed crack widening and gradual failure behavior. The rubber particles acted as localized energy absorbers and reduced sudden fragmentation.

Observed failure characteristics showed reduced crack intensity at moderate crumb rubber replacement levels, increased deformation before failure, improved post-cracking integrity, and enhanced energy absorption, resulting in a more gradual and ductile failure behavior compared with conventional concrete.

Table IX: Failure Characteristics of Specimens

Mix	Failure Type	Observation
CR0	Brittle	Sudden fracture
CR5	Semi-ductile	Controlled cracking
CR10	Ductile tendency	Gradual crack growth
CR15	Flexible	Reduced stiffness

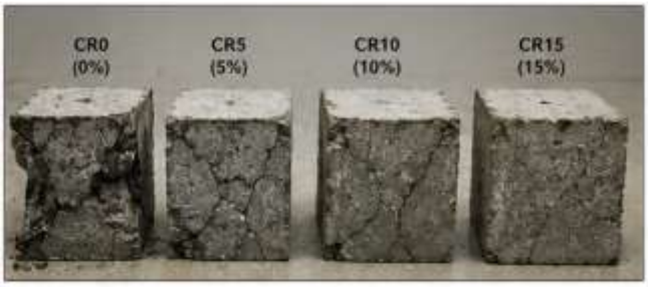

Fig. 10. Compression Failure Pattern of Concrete Cubes

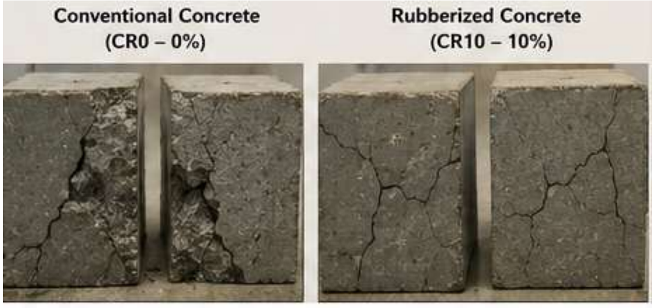

Fig. 11. Comparative Crack Propagation in Conventional and Rubberized Concrete

E. Effect of Crumb Rubber on Concrete Performance

The incorporation of crumb rubber produced both beneficial and adverse effects on concrete properties.

Table X: Overall Effect of Crumb Rubber Addition

Parameter	Effect
Sustainability	Improved
Density	Reduced
Compressive Strength	Decreased
Ductility	Improved
Crack Resistance	Improved
Energy Absorption	Improved

The improvement in flexibility and environmental performance indicates that crumb rubber concrete may be suitable for selected applications including lightweight concrete components, non-structural members, pavement elements, and vibration-resistant structures.

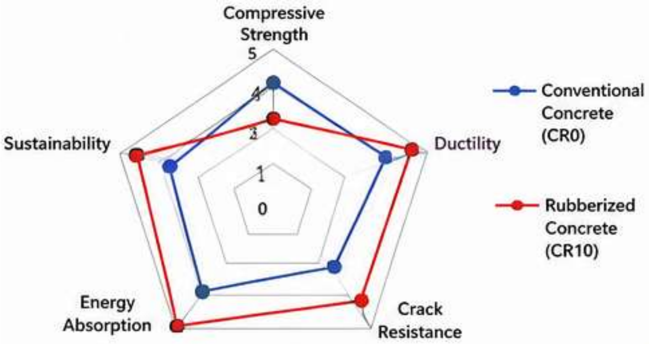

Fig. 12. Overall Performance Comparison of Conventional and Rubberized Concrete

F. Discussion and Engineering Implications

The overall experimental findings demonstrate that crumb rubber can be effectively utilized as a partial substitute for fine aggregate within controlled limits. Increasing rubber content generally decreases compressive and tensile strength because of reduced bonding and lower rigidity; however, improved deformation characteristics and sustainable material utilization provide practical advantages.

Among the investigated mixtures, moderate replacement percentages exhibited a favorable balance between mechanical performance and environmental benefits. The outcomes suggest that rubberized concrete can serve as a promising material for sustainable construction applications while contributing to reduction of waste tire disposal problems.

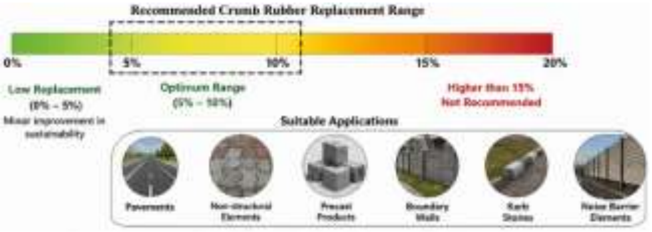

Fig. 13. Recommended Crumb Rubber Replacement Range for Practical Applications

V. CONCLUSION

This study evaluated the effect of partially replacing natural fine aggregate with crumb rubber in M25 grade concrete as a sustainable approach for waste tire utilization. Experimental observations showed that the incorporation of crumb rubber influences the mechanical performance of concrete by modifying its internal structure and aggregate–paste interaction. Moderate replacement levels produced acceptable behavior while improving flexibility, controlling crack propagation, and increasing energy absorption capacity. However, increasing the percentage of crumb rubber resulted in a gradual reduction in compressive and tensile performance because of lower stiffness and weaker bonding characteristics compared with conventional aggregates. Overall, the study demonstrates that controlled use of crumb rubber can support sustainable construction practices while reducing dependence on natural resources and minimizing environmental issues associated with tire disposal.

Future research may focus on improving the performance of rubberized concrete through optimization of rubber particle size, surface treatment techniques, and advanced mix proportioning methods. Additional investigations can examine long-term durability characteristics such as permeability, shrinkage, fatigue resistance, thermal behavior, and structural performance under dynamic loading conditions. The use of supplementary cementitious materials and chemical admixtures may further enhance strength and durability while maintaining sustainability benefits. Large-scale validation and practical implementation studies may also expand the application of crumb rubber concrete in pavement systems, precast elements, lightweight construction, and environmentally sustainable infrastructure development.

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