



International Journal of Research Publication and Reviews

Journal Homepage: www.ijrpr.com ISSN 2582-7421

Crumb Rubber Concrete: A Review of Mechanical, Durability and Structural Performance

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ABSTRACT

Recycling end-of-life tyres as aggregate in Portland cement concrete offers a potential route to divert persistent rubber waste from disposal and reduce the consumption of natural aggregates. This narrative review synthesizes the literature survey and thematic investigations assembled in the supplied thesis, focusing on crumb rubber particle characteristics, replacement strategies, fresh and hardened properties, durability, elevated-temperature behavior, and reinforced-concrete member response. Across the studies described in the thesis, increasing rubber dosage often decreases compressive strength and elastic stiffness, a trend commonly attributed to weak rubber–cement paste bonding, lower rubber stiffness, and additional voids. In contrast, rubber inclusion may improve deformability, post-cracking response, impact-energy absorption and selected insulation characteristics. Workability and transport properties vary with grading, replacement basis, admixtures, and treatment. Alkali treatment and supplementary cementitious materials are reported as possible methods for mitigating performance losses, although responses are not uniform. The review identifies a need for comparable volume-based mixture designs, well-defined surface treatments, longer-term durability measurements, and full-scale validation before structural or pavement applications can be generalized. This is a narrative synthesis, not a systematic review or new experimental investigation.

1. Introduction

Waste tyres are difficult to degrade and can pose environmental and land-management challenges when improperly stockpiled, burned or discarded. Their conversion into granular crumb rubber creates an alternative raw material for civil engineering. In cement concrete, rubber can partly replace fine or coarse mineral aggregate, creating a composite with properties distinctly different from conventional concrete. The source thesis addresses this topic through an extensive historical literature survey and investigations of M25-grade concrete, durability, elevated-temperature exposure and reinforced-concrete beams. This paper reorganizes that material into a critical overview relevant to material selection and engineering use.

A central challenge is the trade-off between rubber-induced deformation capacity and conventional strength requirements. The physical properties of rubber, particularly its low elastic modulus and hydrophobic surface, mean that replacement cannot be treated as a simple one-for-one substitution. Aggregate fraction (fine or coarse), particle morphology, dosage, treatment method and testing conditions must be considered jointly [1–5].

2. Review scope and approach

This article is a narrative review derived from the thesis's Chapter 2 literature survey and the introductory, experimental and concluding chapters. Emphasis is placed on literature specifically addressing waste-tyre rubber in cement-based concrete. Studies of rubber-modified bitumen and unrelated industrial by-products are contextual background rather than core evidence. The source bibliography contains some repeated and incomplete entries; the reference list below selects identifiable items present in that bibliography. The studies were not independently retrieved or bibliographically verified. Consequently, the synthesis should not be interpreted as an exhaustive systematic search or meta-analysis.

3. Crumb rubber sources and incorporation

3.1 Production and characteristics

The thesis distinguishes ambient mechanical grinding from cryogenic grinding. Ambient processing breaks down tyre material by shredding and granulation, followed by removal of steel and textile contamination. Cryogenic processing embrittles rubber at low temperature before size reduction.

These routes can produce particles of different shape, surface texture and size distribution. The source describes particles ranging broadly across fine to coarse fractions, underscoring the importance of reporting a sieve analysis rather than using “crumb rubber” as a single material category.

3.2 Replacement method and mixture design

Published investigations reviewed in the thesis consider rubber as a partial fine-aggregate replacement, coarse-aggregate replacement or dispersed addition. Comparisons become difficult when dosages are expressed interchangeably as a mass fraction of aggregate, a volume fraction of aggregate, or a percentage of the entire mixture. Owing to rubber’s lower density, equal mass and equal volume replacements yield different aggregate volumes. Future reporting should specify the original aggregate fraction, replacement basis, particle grading, rubber density, water-to-binder ratio, admixtures, curing conditions and entrained air.

4. Fresh properties and density

Workability trends are not consistent across the literature. Eldin and Senouci observed that particle shape and size influence slump: irregular, elongated pieces tend to increase internal resistance to flow compared with rounded particles [1, 2]. Fattuhi and Clark reported difficulty handling mixtures with high amounts of shredded rubber [4]. Other studies summarized by the thesis observed acceptable or altered workability at moderate dosage, sometimes aided by admixtures. This variation is plausible because grading, surface texture, particle proportion and water content differ between studies. Fresh density and hardened unit weight often decrease as rubber replaces denser natural aggregate, but the magnitude depends on actual replacement volume and void content [3, 5].

5. Mechanical performance

5.1 Compressive strength and elastic modulus

A frequently reported response is reduced compressive strength as rubber percentage increases [1, 3, 5–8]. Rubber particles are more deformable than the cementitious matrix and may generate stress concentrations, weak interfaces and increased air voids. Khatib and Bayomy linked high replacement levels with pronounced strength penalties [5], while Toutanji observed decreasing strength with increasing rubber-tyre-particle content [3]. The thesis also summarizes studies showing reduced elastic modulus with higher rubber fraction. These trends do not establish a universal optimum percentage: any proposed optimum depends on the design strength threshold and the performance objective.

5.2 Tensile, flexural and post-cracking behavior

Tensile and flexural strengths frequently decrease after aggregate replacement, but rubberized mixtures can exhibit less sudden failure and increased deformation capacity. Hernández-Olivares and co-workers investigated static and dynamic response of recycled tyre-rubber-filled concrete [9], while Li and colleagues investigated waste-tyre-modified concrete [10]. The broader literature survey reports improved toughness or energy absorption in certain rubber-containing systems, suggesting potential utility under impact or vibration. Such advantages should be described using measured fracture energy, ductility indices or load–deflection curves, not assumed from visual crack patterns alone.

5.3 Particle treatment and admixtures

Weak bonding is a recurring obstacle. Segre and Joekes investigated tyre rubber particles added to cement paste [6], and the thesis discusses alkaline surface modification as a means of altering rubber–paste interaction. Treatment effects, however, appear dependent on processing, rubber size and cementitious composition. Fly ash, silica fume and other supplementary cementitious materials may modify the pore structure and compensate for some strength loss in particular mixtures. The evidence summarized in the thesis does not support a single treatment recipe applicable to every rubber concrete.

6. Durability and thermal response

6.1 Water transport, chloride ingress and aggressive media

The durability discussion in the thesis includes sorptivity, rapid chloride penetration, and acid exposure to hydrochloric and sulfuric acids. Existing studies report mixed water-transport responses, which may reflect two competing mechanisms: hydrophobic rubber particles can reduce direct water uptake, while weak interfaces and entrapped voids may provide connected paths for ingress. Resistance to aggressive solutions must be evaluated with exposure concentration, duration, mass change and residual strength specified. Electric charge passed in a chloride-penetration test should not be interpreted in isolation as an exact chloride diffusion coefficient.

6.2 Elevated temperatures

The thesis evaluates responses at 200 °C and 400 °C. Rubber's organic composition introduces additional concerns under heating, including softening, decomposition, increased porosity and possible emissions. Accordingly, ambient-temperature ductility benefits do not automatically imply fire resistance. A robust comparison requires a clearly stated heating rate, exposure duration, cooling regime and residual strength testing protocol.

7. Structural behavior and applications

The source thesis considers reinforced-concrete beams under two-point flexural loading and examines load–deflection behavior and crack widths. Concrete incorporating rubber may be attractive where deformation, energy dissipation, acoustic performance or reduced density is valuable. Nevertheless, a material-level increase in strain capacity does not establish structural adequacy: serviceability deflection, cracking, shear capacity, reinforcement bond and ultimate load all need direct testing. Potential applications discussed in the thesis include pavement-related components and selected nonstructural or low-demand uses. Structural adoption should remain conditional on verified design performance and applicable standards.

8. Comparative synthesis

Property	Commonly reported trend	Key qualification
Density	Generally decreases	Strongly governed by volume and air content
Workability	Variable; often reduced with irregular rubber	Depends on grading, shape and admixtures
Compressive strength	Often decreases as rubber increases	Low-dose effects and treatments vary
Elastic modulus	Generally decreases	May improve deformability while raising deflection
Flexural / tensile strength	Often decreases	Post-crack toughness can behave differently
Impact / energy absorption	May increase in selected mixes	Requires direct experimental measurement
Water / chloride transport	Mixed findings	Connected porosity and test type matter
Elevated-temperature response	Potential residual-property degradation	Heating protocol and decomposition critical

Table 1. Qualitative synthesis of the patterns reported in the thesis's literature survey. These are not pooled effect sizes or universally observed outcomes.

9. Research gaps and directions

The evidence assembled in the thesis supports several priorities. First, future experiments should standardize replacement by volume while reporting rubber particle size, density and pretreatment, because unclear mixture definitions undermine comparison. Second, workability, air content, strength and modulus should be measured together so that mechanisms of strength loss can be distinguished from artifacts of compaction. Third, durability studies should compare chloride transport, sorptivity, acid attack and thermal response over practical exposure periods using replicates and uncertainty estimates. Fourth, structural beam tests should include reinforcement detailing, shear and bond behavior, serviceability limits, crack widths and complete load–deflection histories. Fifth, environmental claims should be assessed using life-cycle impacts and local processing/transport assumptions rather than assuming that all tyre replacement automatically produces net environmental benefits.

10. Conclusions

The literature surveyed in the thesis indicates that crumb rubber is a technically promising but property-sensitive substitute for part of the natural aggregate in concrete. Rubber addition typically lowers density, compressive strength and stiffness, while some mixtures show improved toughness, deformation capacity and energy absorption. Fresh behavior and durability outcomes vary substantially with replacement fraction, rubber morphology, treatment, cementitious materials and testing methods. Consequently, rubberized concrete should be proportioned to a defined application instead of relying on a universal optimum rubber dosage. Further standardized material tests and reinforced-member validation are needed to establish performance envelopes for safe, durable and environmentally beneficial use.

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