

Development of Rubberized Fiber-Reinforced Concrete Blocks Incorporating NaOH-Treated Crumb Rubber for Sustainable and Earthquake-Resistant Construction: A Comprehensive Review

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Abstract—

The increasing accumulation of waste tyres has become a significant environmental concern due to their non-biodegradable nature and the challenges associated with their disposal. Simultaneously, the construction industry is seeking sustainable materials capable of improving the performance of structures subjected to seismic loading. Rubberized concrete, produced by partially replacing natural aggregates with crumb rubber obtained from waste tyres, has emerged as a promising eco-friendly alternative because of its superior ductility, energy absorption, vibration damping, and impact resistance. However, the reduction in compressive strength caused by the weak interfacial bonding between rubber particles and the cement matrix remains a major limitation.

This review critically examines the existing literature on rubberized concrete, polypropylene fiber-reinforced concrete, and NaOH-treated crumb rubber with particular emphasis on their combined application in concrete blocks intended for earthquake-resistant construction. More than thirty recent research studies were reviewed to evaluate material characteristics, mechanical behavior, durability performance, workability, and microstructural properties.

The literature indicates that polypropylene fibers effectively control crack propagation, improve tensile and flexural strength, and partially compensate for the strength reduction caused by crumb rubber. Furthermore, NaOH surface treatment enhances the roughness of rubber particles, resulting in improved adhesion with the cement paste and better overall mechanical performance. Although significant progress has been reported, limited research has focused on the combined use of NaOH-treated crumb rubber and polypropylene fibers in concrete blocks designed specifically for seismic applications.

This review identifies existing research gaps and highlights the need to optimise rubber replacement levels, fiber dosage, and treatment techniques to achieve a balance between strength, ductility, durability, and sustainability. The findings provide a comprehensive foundation for future experimental investigations aimed at developing lightweight, crack-resistant, energy-absorbing, and environmentally sustainable concrete blocks suitable for earthquake-resistant structures.

Index Terms—

(Rubberized Concrete ,Crumb Rubber ,Waste Tyres ,Polypropylene Fibers ,NaOH Surface Treatment ,Sustainable Construction ,Earthquake-Resistant Concrete ,Fiber-Reinforced Concrete ,Concrete Blocks ,Energy Absorption ,Vibration Damping ,Mechanical Properties)

I. INTRODUCTION

1.1 Background

Concrete is the most widely used construction material owing to its high compressive strength, durability, versatility, and economic feasibility. It is composed of cement, fine aggregates, coarse aggregates, and water, and its engineering properties can be modified through the incorporation of supplementary materials and fibers. Although conventional concrete exhibits excellent compressive strength, it is inherently brittle and possesses relatively low tensile strength, making it susceptible to crack initiation and sudden failure under impact and seismic loading. Consequently, there is an increasing demand for sustainable concrete materials that not only maintain adequate mechanical performance but also provide improved ductility, toughness, and energy absorption. The incorporation of recycled waste materials into concrete has emerged as an effective strategy for achieving both structural performance and environmental sustainability.

1.2 Problem Statement

The construction industry faces two major challenges: the growing accumulation of waste tyres and the need for

construction materials capable of withstanding dynamic and earthquake-induced loading. Conventional methods of tyre disposal, including landfilling and open burning, pose significant environmental and public health risks. Although crumb rubber can be incorporated into concrete to improve flexibility and impact resistance, its application is limited by the reduction in compressive strength caused by poor bonding between rubber particles and the cement matrix. Therefore, there is a need to develop sustainable concrete that balances strength, ductility, durability, and seismic performance through suitable material modifications.

1.3 Waste Tyre Scenario

Waste tyre generation has increased significantly worldwide due to rapid urbanization and the continuous growth of the automobile industry. Since tyres are non-biodegradable, they remain in the environment for decades, occupying landfill space and causing severe ecological problems. Recycling waste tyres into crumb rubber for concrete production provides an environmentally responsible alternative to conventional disposal methods. The use of recycled tyre rubber reduces landfill waste, conserves natural aggregates, lowers the environmental footprint

of concrete production, and supports the principles of sustainable and circular construction.

1.4 Rubberized Concrete

Rubberized concrete is produced by partially replacing natural fine or coarse aggregates with crumb rubber obtained from discarded tyres. Previous studies have demonstrated that rubberized concrete exhibits enhanced ductility, flexibility, vibration damping, impact resistance, and energy absorption capacity, making it suitable for structures subjected to dynamic loading. However, increasing the rubber replacement level generally results in reduced compressive strength because of the weak interfacial bond between rubber particles and the cement paste. Therefore, optimizing the rubber content and improving the bond characteristics remain key research objectives.

1.5 NaOH Treatment

One of the primary limitations of rubberized concrete is the hydrophobic and smooth surface of crumb rubber, which weakens its bond with the cement matrix. Surface modification using sodium hydroxide (NaOH) has been widely investigated to overcome this limitation. NaOH treatment increases the surface roughness of rubber particles by removing surface contaminants and enhancing mechanical interlocking with hydrated cement paste. Several studies have reported that NaOH-treated crumb rubber improves compressive strength, tensile strength, and overall bond performance compared with untreated rubber, making it a promising approach for developing high-performance rubberized concrete.

1.6 Polypropylene Fibres

Polypropylene fibres are among the most widely used synthetic fibres for concrete reinforcement because of their low density, high chemical resistance, and excellent crack-bridging capability. Their inclusion improves tensile and flexural strength, controls plastic and drying shrinkage cracks, enhances impact resistance, and increases the post-cracking behaviour of concrete. In rubberized concrete, polypropylene fibres compensate for part of the strength reduction caused by crumb rubber by improving stress transfer across cracks and increasing the toughness and durability of the composite material.

1.7 Scope of the Review

This review critically examines the published literature on rubberized concrete, polypropylene fibre-reinforced concrete, and NaOH-treated crumb rubber with emphasis on their combined application in concrete blocks for earthquake-resistant construction. The review evaluates the effects of crumb rubber replacement levels, fibre dosage, surface treatment techniques, workability, mechanical behaviour, durability, energy absorption, vibration damping, and microstructural performance. Furthermore, it identifies existing research gaps and establishes a foundation for future experimental investigations aimed at developing sustainable, lightweight, and earthquake-resistant concrete blocks.

1.8 Novelty of the Review

Although numerous studies have independently investigated rubberized concrete, fibre-reinforced concrete, and NaOH-treated crumb rubber, limited review articles comprehensively evaluate their combined application in concrete blocks specifically designed for earthquake-resistant construction. Most previous studies focus on conventional concrete members, pavements, or paver blocks, while research on structural and non-structural concrete blocks incorporating NaOH-treated crumb rubber and polypropylene fibres remains scarce. This review uniquely integrates the latest findings published between 2010 and 2025, identifies the current research gaps, and proposes future research directions for developing sustainable, ductile, lightweight, and energy-absorbing concrete blocks suitable for seismic regions.

II. COMPILED FINDINGS PLACEMENT

2.1 Background and Need for Sustainable Rubberized Concrete

Concrete remains the most extensively used construction material worldwide because of its high compressive strength, durability, versatility, and economic feasibility. However, the increasing consumption of natural resources and the growing generation of industrial and municipal wastes have created significant environmental challenges. Among these wastes, discarded automobile tyres represent one of the most serious global environmental concerns due to their non-biodegradable nature and the difficulties associated with their disposal. Approximately one billion waste tyres are generated annually worldwide, and this number is expected to continue increasing with the rapid growth of the automobile industry. Conventional disposal methods such as landfilling, stockpiling, and open burning occupy valuable land resources, create severe fire hazards, promote mosquito breeding, and release harmful pollutants into the environment. These issues have encouraged researchers to develop sustainable methods for recycling waste tyres into value-added construction materials.

The construction industry is increasingly adopting the principles of the **circular economy**, which promotes efficient resource utilization through reuse, recycling, and waste minimization. Incorporating crumb rubber obtained from waste tyres into concrete provides an environmentally responsible alternative that diverts tyre waste from landfills while reducing the extraction of natural aggregates. This approach conserves natural resources, lowers environmental pollution, and contributes to the development of sustainable construction materials that support long-term environmental protection.

Rubberized concrete has emerged as a promising sustainable material because the inclusion of crumb rubber improves flexibility, ductility, impact resistance, vibration damping, and energy absorption capacity. These characteristics are particularly beneficial for structures subjected to dynamic and seismic loading. However, the incorporation of rubber particles also leads to a reduction in compressive strength due to weak bonding between the rubber surface and the cement matrix. Consequently, current research focuses on improving the mechanical performance of rubberized concrete through surface modification techniques, fibre reinforcement, and optimized mix design to achieve a balance between strength, durability, and sustainability.

The growing demand for environmentally friendly infrastructure has further increased the need for recycled construction materials capable of replacing conventional constituents without compromising structural performance. The utilization of waste tyre rubber in concrete aligns with global sustainability goals by promoting waste valorization, reducing the environmental footprint of construction activities, and supporting the development of durable, lightweight, and earthquake-resistant concrete products. Therefore, the development of sustainable rubberized concrete represents an important research direction for achieving resource-efficient and resilient infrastructure in the future.

2.1.1 Production Methods

Crumb rubber is a recycled material obtained from end-of-life vehicle tyres through various processing techniques after the removal of steel wires and textile fibres. The most commonly used production method is **ambient mechanical grinding**, in which tyres are shredded and mechanically ground at room temperature to produce rubber particles of different sizes. Another widely adopted method is **cryogenic grinding**, where tyres are cooled using liquid nitrogen, making the rubber brittle and easier to fracture into uniformly shaped particles with smooth surfaces. A less common technique is **water-jet grinding**, which employs high-pressure water jets to produce fine rubber particles while minimizing heat generation. Among these methods, ambient grinding is the most economical and widely used for producing crumb rubber intended for concrete applications because it generates rougher particle surfaces that enhance mechanical interlocking with the cement matrix.

2.1.2 Classification

Crumb rubber can be classified based on its particle size, production method, and intended application. According to particle size, it is generally categorized as fine, medium, and coarse crumb rubber. Fine crumb rubber is commonly used as a partial replacement for fine aggregates, whereas medium and coarse particles may replace fine or coarse aggregates depending on the concrete mix design. Crumb rubber may also be classified according to its manufacturing process, such as ambient-ground or cryogenically ground rubber. From an application perspective, crumb rubber is widely used in rubberized concrete, concrete blocks, asphalt pavements, playground surfaces, and vibration-isolation systems. The selection of crumb rubber type depends on the required mechanical performance, workability, and durability of the final concrete product.

2.1.3 Physical Properties

The physical properties of crumb rubber significantly influence the behaviour of rubberized concrete. According to the reviewed literature, crumb rubber is generally produced from waste vehicle tyres with a typical particle size ranging from **3 to 6 mm**. It possesses a **specific gravity of approximately 1.05–1.15** and a **density of about 500–700 kg/m³**, which is considerably lower than that of natural aggregates. Crumb rubber exhibits **very low water absorption** and has a **rough and irregular surface texture**, particularly when produced through ambient grinding. Its low density contributes to the production of lightweight concrete, while its elastic nature enhances flexibility, vibration

damping, and energy absorption, making it suitable for applications requiring improved seismic performance.

2.1.4 Chemical Composition

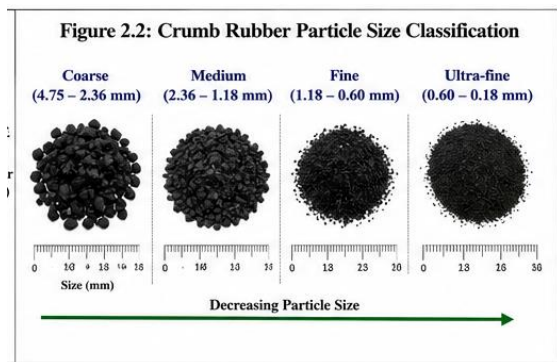
Crumb rubber is primarily composed of natural and synthetic rubber polymers that provide elasticity and durability. In addition to rubber polymers, it contains carbon black, sulphur, zinc oxide, silica, processing oils, antioxidants, and other chemical additives incorporated during tyre manufacturing. Carbon black improves strength and wear resistance, while sulphur is used during vulcanization to enhance the elasticity and durability of rubber. Zinc oxide and silica act as reinforcing and stabilizing agents, whereas antioxidants improve resistance to oxidation and environmental degradation. Although these constituents provide excellent durability and flexibility, the hydrophobic nature of rubber reduces its bonding capability with the cement paste, often necessitating surface treatments such as sodium hydroxide (NaOH) to improve the interfacial bond.

2.1.5 Advantages

The incorporation of crumb rubber in concrete provides both environmental and engineering benefits. It offers an effective solution for recycling waste tyres, thereby reducing landfill disposal and minimizing environmental pollution. Due to its low density, crumb rubber contributes to the production of lightweight concrete while significantly improving ductility, flexibility, impact resistance, vibration damping, and energy absorption capacity. These characteristics enhance the ability of concrete to withstand dynamic and seismic loading. Furthermore, rubberized concrete exhibits improved thermal and acoustic insulation, making it suitable for sustainable construction and non-structural applications where toughness and durability are more critical than high compressive strength.

2.1.6 Limitations

Despite its numerous advantages, the use of crumb rubber in concrete also presents several challenges. The most significant limitation is the reduction in compressive strength resulting from the weak interfacial bond between the hydrophobic rubber particles and the cement matrix. Higher rubber replacement levels may also reduce the modulus of elasticity and workability of fresh concrete, making mix design optimization essential. In addition, excessive rubber content may limit the structural applications of rubberized concrete. To overcome these shortcomings, researchers have recommended the use of surface treatment techniques such as sodium hydroxide (NaOH) treatment and the incorporation of reinforcing fibres, particularly polypropylene fibres, to improve bonding, mechanical performance, and overall durability.



2.2.1 Types of Polypropylene Fibres

Begin with a general introduction explaining that polypropylene (PP) fibres are among the most widely used synthetic fibres in cementitious composites because of their low density, chemical stability, excellent durability, and cost-effectiveness. Discuss how the classification of polypropylene fibres is based on their geometry, manufacturing process, fibre dimensions, and intended engineering applications.

Explain **monofilament polypropylene fibres** in detail, describing their manufacturing as single continuous filaments with circular cross-sections. Discuss their role in controlling plastic shrinkage, reducing early-age cracking, improving durability, and their suitability for conventional concrete and precast elements.

Continue with **fibrillated polypropylene fibres**, describing their mesh-like or net-shaped structure produced by stretching polymer films. Explain how this structure increases the bond between fibres and the cement matrix, enhances crack resistance, and improves toughness and impact resistance.

Then discuss **macro polypropylene fibres**, which are longer and thicker than conventional fibres and are specifically designed for structural applications. Explain their ability to replace secondary steel reinforcement in certain applications, improve post-cracking behaviour, increase residual strength, and enhance energy absorption in slabs, tunnel linings, industrial floors, and earthquake-resistant concrete.

Finally, compare the three fibre types by discussing their advantages, limitations, recommended dosage, and suitable applications in concrete technology.

2.2.2 Manufacturing of Polypropylene Fibres

Start with an overview of polypropylene as a thermoplastic polymer produced from propylene monomers through polymerization. Explain the chemical characteristics of polypropylene that make it resistant to alkalis, acids, moisture, and corrosion, making it highly suitable for concrete environments.

Describe the **polymerization process**, including the conversion of propylene gas into polypropylene resin using catalysts under controlled temperature and pressure conditions.

Then explain the **melt spinning process**, in which molten polypropylene is extruded through spinnerets to produce continuous filaments. Describe how the fibres are subsequently cooled, stretched, and drawn to improve molecular orientation, tensile strength, and elastic properties.

Continue with the **drawing and heat-setting process**, explaining how stretching aligns polymer chains, increases crystallinity, and enhances mechanical performance.

Discuss **surface modification techniques**, where fibres may undergo embossing, fibrillation, or texturing to improve the bond with cement paste.

Finally, explain the **cutting and packaging process**, where continuous filaments are cut into lengths commonly ranging from 6 mm to 50 mm for concrete applications. Conclude by explaining how manufacturing influences fibre geometry, bonding characteristics, mechanical properties, and overall concrete performance.

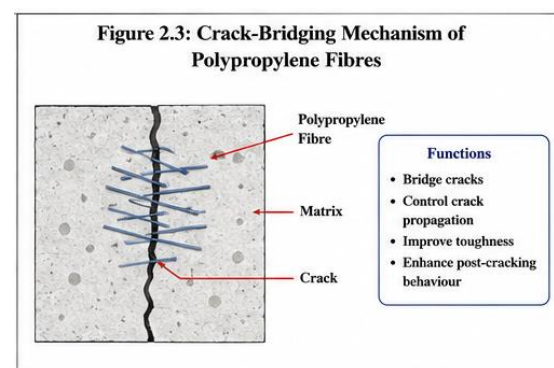
2.2.3 Properties of Polypropylene Fibres

Begin by introducing polypropylene fibres as lightweight, chemically inert reinforcement materials possessing excellent mechanical and durability characteristics. Discuss their physical properties, including density, diameter, length, colour, water absorption, and melting point. Explain why their low density contributes to lightweight concrete and why negligible water absorption prevents moisture-related deterioration.

Continue by discussing mechanical properties such as tensile strength, elastic modulus, elongation at break, toughness, and fatigue resistance. Explain how these properties influence crack control, stress redistribution, and post-cracking performance.

Describe their chemical properties, emphasizing their resistance to alkalis, acids, sulphates, chlorides, and other aggressive chemicals found in concrete environments. Explain their immunity to corrosion, unlike steel fibres.

Conclude by relating these properties to concrete applications, showing how polypropylene fibres improve durability, service life, impact resistance, and seismic performance while maintaining compatibility with cementitious materials. Your uploaded presentation includes the key physical and mechanical property ranges that can be incorporated here.



2.2.4 Fibre Mechanism

Introduce the concept of fibre reinforcement in concrete by explaining that polypropylene fibres are randomly distributed throughout the cement matrix during mixing. Describe how fibres become embedded within the hydrated cement paste and create a three-dimensional reinforcing network.

Explain how fibres redistribute tensile stresses that develop due to shrinkage, temperature changes, and external loading. Discuss their role in delaying crack initiation, increasing energy

dissipation, improving ductility, and enhancing the post-cracking load-carrying capacity.

Relate this mechanism specifically to rubberized concrete by explaining how polypropylene fibres compensate for the reduced stiffness associated with crumb rubber, thereby improving overall structural behaviour.

2.2.5 Crack-Bridging Mechanism

Begin by explaining the process of micro-crack formation in conventional concrete under tensile loading. Describe how these micro-cracks gradually propagate and combine to form larger cracks, ultimately leading to brittle failure.

Explain that polypropylene fibres intercept these cracks before they widen significantly. Because the fibres remain anchored on both sides of the crack, they transfer tensile stresses across the crack surfaces, thereby reducing crack width and delaying crack propagation.

Discuss fibre pull-out, debonding, and stress transfer mechanisms, emphasizing how fibre geometry, aspect ratio, and bond characteristics influence crack resistance. Explain how the crack-bridging mechanism increases fracture toughness, impact resistance, fatigue resistance, and seismic performance.

Conclude by highlighting why this mechanism is particularly important for earthquake-resistant concrete, where repeated cyclic loading requires high ductility and energy absorption.

2.2.6 Advantages

Discuss the environmental, structural, and durability benefits of polypropylene fibres in separate paragraphs. Explain how they effectively control plastic shrinkage cracking, reduce drying shrinkage, improve tensile and flexural strength, enhance toughness and ductility, increase impact resistance, improve fatigue life, and provide better post-cracking behaviour.

Describe their resistance to corrosion, moisture, alkalis, sulphates, and chloride attack, which significantly enhances concrete durability in aggressive environments. Mention their lightweight nature, ease of mixing, and compatibility with various concrete mixes.

Finally, discuss their contribution to sustainable construction by extending service life, reducing maintenance requirements, and improving the resilience of concrete structures exposed to seismic loading.

2.2.7 Limitations

Conclude the section by discussing the limitations of polypropylene fibres. Explain that their relatively low elastic modulus compared with steel fibres limits their ability to significantly increase compressive strength. Discuss the reduction in workability associated with higher fibre dosages and the possibility of fibre balling if mixing procedures are inadequate.

Describe the challenges associated with achieving uniform fibre dispersion and explain that excessive fibre content may increase entrapped air and reduce concrete density. Mention that polypropylene fibres soften at elevated temperatures and therefore require careful consideration in fire-resistant structural applications.

Finish by emphasizing that optimum fibre dosage, proper mixing procedures, and compatibility with other concrete constituents

are essential for maximizing the benefits of polypropylene fibre reinforcement while minimizing its limitations.

2.3.1 Need for Treatment

Begin this section by explaining that one of the major challenges associated with rubberized concrete is the poor bond between crumb rubber and the cement matrix. Discuss how the hydrophobic nature, smooth surface texture, and chemical inertness of rubber particles result in a weak interfacial transition zone (ITZ), leading to reductions in compressive strength, tensile strength, stiffness, and durability. Explain that surface treatment techniques are employed to modify the rubber surface, improve wettability, increase surface roughness, and enhance adhesion with cement hydration products. This subsection should also introduce the concept that several physical and chemical treatment methods have been investigated to overcome these limitations, thereby improving the structural performance of rubberized concrete.

2.3.2 NaOH Treatment

Provide a comprehensive discussion on sodium hydroxide (NaOH) treatment, as it is the most widely adopted surface modification technique for crumb rubber. Explain the treatment procedure, including cleaning, immersion in NaOH solution, washing, and drying. Discuss how the alkaline solution removes impurities, increases surface roughness, improves wettability, and strengthens the interfacial transition zone between rubber particles and cement paste. Summarize the improvements reported in the literature regarding compressive strength, tensile strength, flexural strength, durability, and crack resistance. Finally, discuss the optimum treatment concentration and duration reported by different researchers, emphasizing that excessive treatment may damage the rubber surface.

2.3.3 Silane Treatment

Introduce silane coupling agents as chemical compounds capable of forming molecular bridges between inorganic cement hydrates and organic rubber surfaces. Explain the mechanism by which silane molecules react with hydroxyl groups in cement paste while simultaneously bonding with the rubber surface, thereby improving chemical compatibility. Discuss the influence of silane treatment on interfacial bonding, durability, water resistance, and long-term mechanical performance. Compare the effectiveness of silane treatment with NaOH treatment and identify situations where silane treatment provides superior durability despite its relatively higher cost.

2.3.4 Acid Treatment

Discuss the use of acidic solutions, such as sulphuric acid or hydrochloric acid, for modifying the surface characteristics of crumb rubber. Explain that acid treatment removes surface contaminants and increases surface roughness, thereby enhancing mechanical interlocking with the cement matrix. Describe the chemical modifications induced by acid treatment and summarize the reported improvements in bond strength and concrete performance. Also discuss the disadvantages of acid treatment, including safety concerns, disposal of acidic waste, and the possibility of excessive surface degradation when high concentrations are used.

2.3.5 Cement Slurry Treatment

Explain the cement slurry coating method as a physical surface modification technique in which crumb rubber particles are coated with a thin layer of cement paste before mixing with concrete. Discuss how this coating improves compatibility between rubber particles and the surrounding cement matrix by providing a rough and cementitious surface. Review the influence of cement slurry treatment on workability, interfacial transition zone characteristics, compressive strength, and durability. Mention that this technique is relatively simple and economical but requires additional processing time before concrete production.

2.3.6 Water Washing

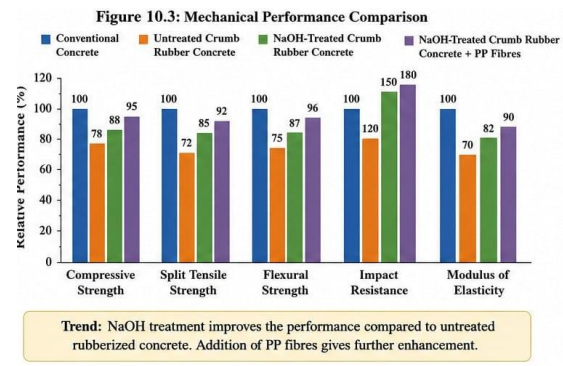
Describe water washing as the simplest pre-treatment method used to remove dust, loose particles, oils, and contaminants from recycled crumb rubber. Explain that although water washing improves cleanliness and slightly enhances bonding, it does not significantly modify the chemical characteristics or surface roughness of rubber particles. Consequently, its influence on the mechanical properties of rubberized concrete is generally limited compared with chemical treatment methods such as NaOH or silane treatment. However, water washing is frequently used as a preliminary cleaning step before other surface modification techniques.

2.3.7 Comparison of Treatment Methods

Provide a critical comparison of all surface treatment techniques discussed in the previous sections. Compare NaOH treatment, silane treatment, acid treatment, cement slurry coating, and water washing with respect to treatment mechanism, effectiveness in improving interfacial bonding, influence on mechanical properties, durability enhancement, processing complexity, environmental impact, cost, and practical applicability. Include a comparative table summarizing these parameters to help readers understand the relative advantages and limitations of each method. Discuss why NaOH treatment remains the most extensively investigated method in the literature while highlighting situations where alternative treatments may be more suitable.

2.3.8 Advantages and Limitations

Conclude the chapter by critically evaluating the overall benefits and drawbacks of crumb rubber surface treatment. Discuss how surface modification improves bonding, compressive strength, tensile strength, durability, crack resistance, and long-term structural performance of rubberized concrete. At the same time, explain the additional processing time, increased production cost, chemical handling requirements, and environmental considerations associated with different treatment techniques. Finally, identify existing research gaps, emphasizing the need for environmentally friendly, cost-effective, and scalable surface treatment methods that can be implemented in large-scale construction applications.



2.4.1 Compiled Findings from Literature Review

A comprehensive review of the selected research papers published between 2013 and 2025 indicates that the use of crumb rubber as a partial replacement for natural aggregates has emerged as an effective approach for utilizing waste tyres in sustainable construction. Almost all researchers reported that the incorporation of crumb rubber reduces the density of concrete, resulting in lightweight concrete blocks. The reduction in self-weight makes these blocks suitable for non-load-bearing applications and helps reduce the overall dead load on structures, particularly in earthquake-prone regions where lower structural weight is beneficial.

The literature consistently indicates that the compressive strength of concrete decreases with increasing crumb rubber content. The primary reason for this reduction is the poor interfacial bonding between rubber particles and the cement paste. Rubber particles possess a smooth and hydrophobic surface, creating weak transition zones within the concrete matrix. Several studies using Scanning Electron Microscopy (SEM) confirmed the presence of voids and weak bonding around rubber particles, leading to lower compressive strength. Nevertheless, many researchers concluded that rubber replacement levels between 5% and 15% provide a reasonable balance between strength and ductility.

Another significant observation from the literature is the improvement in ductility, toughness, and impact resistance of rubberized concrete. Unlike conventional concrete, which fails suddenly under loading, rubberized concrete exhibits gradual failure with higher deformation capacity. The elastic nature of crumb rubber enables the concrete to absorb more energy before failure, making it more resistant to impact and dynamic loading conditions. These characteristics make rubberized concrete particularly attractive for earthquake-resistant construction.

The reviewed studies also highlight that polypropylene fibres significantly enhance the mechanical behaviour of concrete. The fibres act as crack-bridging elements that restrict the formation and propagation of micro-cracks. Consequently, fibre reinforcement improves split tensile strength, flexural strength, post-cracking behaviour, and overall durability. The inclusion of fibres also reduces shrinkage cracking and improves resistance to repeated loading.

Several researchers investigated the combined use of crumb rubber and fibre reinforcement. Their findings demonstrate that fibres compensate for a portion of the strength reduction caused by rubber inclusion. The combined system provides a better balance between compressive strength, ductility, toughness, and

energy absorption than rubberized concrete without fibres. Studies consistently reported that fibre-reinforced rubberized concrete exhibits improved load-deflection behaviour, crack resistance, and structural stability under dynamic loading.

The literature further indicates that the workability of concrete generally decreases as crumb rubber content increases because rubber particles absorb less water and create greater internal friction within the mix. However, acceptable workability can be maintained through proper mix design and the use of suitable superplasticizers where necessary.

Durability-related studies reveal that rubberized fibre-reinforced concrete possesses improved impact resistance, vibration damping capacity, thermal insulation, and sound absorption compared with conventional concrete. Although water absorption may increase at higher rubber replacement levels, appropriate mix proportioning and surface treatment of rubber particles can minimize this effect. Surface treatment using sodium hydroxide (NaOH) has been reported to improve the surface roughness of rubber particles, resulting in better adhesion with cement paste and enhanced mechanical performance.

Most previous investigations concentrated on concrete cubes, cylinders, beams, paver blocks, and structural concrete elements. Comparatively fewer studies have specifically focused on rubberized fibre-reinforced concrete blocks intended for masonry applications in earthquake-resistant structures. Moreover, only limited research has evaluated the combined influence of crumb rubber and polypropylene fibres on the mechanical, durability, and energy absorption characteristics of concrete blocks.

Based on the reviewed literature, it can be concluded that the combined use of crumb rubber and polypropylene fibres has significant potential for developing sustainable, lightweight, ductile, and crack-resistant concrete blocks. However, further investigation is required to determine the optimum rubber replacement percentage and fibre dosage that can achieve a suitable balance between compressive strength, durability, and seismic performance. This research therefore aims to address these gaps by developing and experimentally evaluating rubberized fibre-reinforced concrete blocks suitable for earthquake-resistant construction.

III. REVIEW METHODOLOGY

3.1 Databases

This section should describe the scientific databases used to identify relevant literature for the review. Explain that a comprehensive search was conducted using internationally recognized databases to ensure broad coverage of peer-reviewed studies related to rubberized concrete, polypropylene fibres, and crumb rubber surface treatment. The databases may include **Scopus, Web of Science, ScienceDirect, SpringerLink, Taylor & Francis Online, Wiley Online Library, MDPI, ASCE Library, IEEE Xplore, and Google Scholar**. Briefly explain why multiple databases were selected, emphasizing that this approach minimizes publication bias and ensures the inclusion of high-quality and recent research.

3.2 Search Strategy

Describe the systematic search procedure used to retrieve the literature. Explain that a combination of predefined keywords and Boolean operators (**AND, OR, NOT**) was used to identify

relevant publications. Mention that the search included terms such as Rubberized Concrete, Crumb Rubber, Waste Tyre Concrete, Polypropylene Fibre Reinforced Concrete, NaOH Surface Treatment, Surface Modification of Crumb Rubber, Sustainable Concrete, and Earthquake-Resistant Concrete. State the publication period covered (e.g., **2010–2025**) and note that only peer-reviewed English-language articles were considered. This section should demonstrate that the search process was systematic, reproducible, and comprehensive.

3.3 PRISMA Flowchart

Explain that the literature selection process followed the **Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020)** guidelines to improve transparency and reproducibility. Describe the four stages of the PRISMA framework: **Identification, Screening, Eligibility, and Inclusion**. Present a PRISMA flow diagram illustrating the number of records identified through database searching, duplicate records removed, records screened, full-text articles assessed for eligibility, studies excluded with reasons, and the final number of studies included in the review. Including this figure enhances the credibility of the review and aligns with international standards for systematic reviews.

3.4 Inclusion Criteria

Clearly define the criteria used to select studies for detailed analysis. State that only **peer-reviewed journal articles** published in **English** between **2010 and 2025** were included. Explain that the selected studies focused on crumb rubber as a replacement for natural aggregates, polypropylene fibre-reinforced concrete, surface treatment techniques for crumb rubber, and the mechanical, durability, or microstructural performance of rubberized concrete. Review papers and experimental studies from reputable scientific databases were also considered when they were directly relevant to the objectives of the review.

3.5 Exclusion Criteria

Describe the criteria used to exclude publications from the review. Mention that duplicate records, conference abstracts without complete data, editorials, magazine articles, patents, non-English publications, and studies unrelated to concrete technology were excluded. Explain that studies focusing solely on tyre recycling without applications in cementitious materials, or papers lacking sufficient experimental or analytical information, were also removed. Applying these exclusion criteria ensured that only reliable and technically relevant studies contributed to the review.

3.6 Paper Selection Process

Summarize the complete literature selection procedure. Explain that all records retrieved from the selected databases were first screened for duplicates, followed by title and abstract screening to remove irrelevant studies. The remaining publications were subjected to full-text evaluation using the predefined inclusion and exclusion criteria. Finally, only the most relevant and high-quality studies were selected for critical review and synthesis. A summary table may be included showing the number of papers identified, screened, excluded, and finally reviewed. This section

demonstrates the systematic and transparent approach adopted in selecting the literature and provides confidence in the reliability of the review findings.

IV. COMPREHENSIVE LITERATURE REVIEW

4.1 Literature Review Method

Begin the chapter with a brief explanation that the selected studies were critically reviewed using a uniform framework. Explain that each paper was analysed based on its research objective, materials used, mix design, crumb rubber replacement level, surface treatment method, polypropylene fibre dosage, concrete grade, experimental programme, major findings, and reported limitations. Mention that this standardized approach enables direct comparison among studies and facilitates the identification of research trends and gaps.

4.2 Comparative Analysis of Reviewed Studies

After reviewing all papers individually, provide a comparative discussion rather than repeating the individual findings. Compare:

- Crumb rubber replacement levels
- NaOH treatment methods
- Polypropylene fibre dosage
- Concrete grades
- Mechanical properties
- Durability performance
- Microstructural behaviour
- Seismic and impact performance
- Optimum mix proportions
- Common trends reported by different researchers

Discuss similarities and differences among studies and explain possible reasons for variations in the reported results.

V. FRESH PROPERTIES OF RUBBERIZED FIBER-REINFORCED CONCRETE

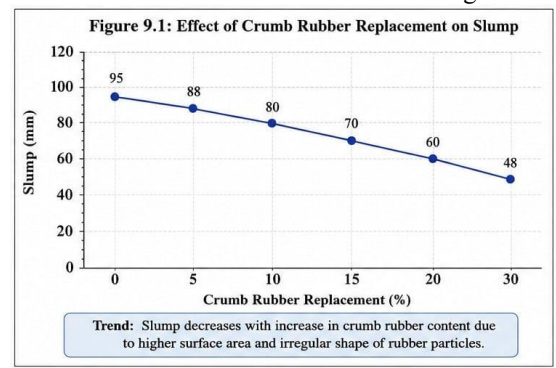
5.1 Workability

Workability is one of the most important fresh properties of concrete, as it determines the ease with which concrete can be mixed, transported, placed, compacted, and finished without segregation or excessive bleeding. In rubberized fiber-reinforced concrete, workability is significantly influenced by the incorporation of crumb rubber particles and polypropylene fibres. Numerous researchers have reported that the addition of crumb rubber generally decreases workability because rubber particles possess a rough texture, irregular shape, and hydrophobic surface, which interfere with the flow of the cement paste. Unlike natural aggregates, crumb rubber does not absorb water effectively and exhibits poor adhesion with the cement matrix, thereby increasing internal friction during mixing. Furthermore, polypropylene fibres create a three-dimensional reinforcing network within the concrete, restricting the movement of fresh concrete and reducing its fluidity. Consequently, higher fibre dosages usually require additional water or chemical admixtures, such as superplasticizers, to maintain the desired consistency. Although the reduction in workability presents certain practical challenges during casting, the combined use of crumb rubber and

fibres enhances the overall cohesiveness of the concrete and minimizes segregation, making it suitable for applications requiring improved toughness and seismic performance. Previous studies indicate that careful optimization of rubber content, fibre dosage, water-cement ratio, and admixture content is essential to achieve acceptable workability without compromising the mechanical performance of concrete.

5.2 Slump

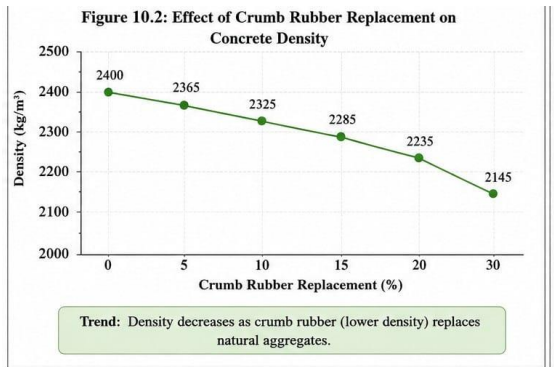
The slump test is the most widely used method for evaluating the consistency and workability of fresh concrete. It provides an indirect measure of the ease with which concrete can be placed and compacted. Most studies on rubberized concrete have reported a gradual reduction in slump value with increasing crumb rubber replacement. This reduction is mainly attributed to the irregular geometry of rubber particles, increased internal friction, and poor compatibility between rubber and cement paste. The incorporation of polypropylene fibres further decreases the slump because the fibres interlock within the concrete mixture and resist free movement of the constituents. Research has shown that although the slump decreases, the concrete remains sufficiently workable when appropriate dosages of superplasticizers are incorporated into the mix. Several researchers have concluded that moderate crumb rubber replacement levels combined with low polypropylene fibre content provide an acceptable balance between workability and mechanical performance. Therefore, slump testing remains an essential quality control procedure during the production of rubberized fiber-reinforced concrete blocks to ensure consistent fresh concrete characteristics before casting.



5.3 Fresh Density

Fresh density represents the mass of freshly mixed concrete per unit volume and serves as an important indicator of concrete quality and uniformity. The incorporation of crumb rubber generally reduces the fresh density of concrete because rubber possesses a significantly lower specific gravity than conventional mineral aggregates. As the proportion of crumb rubber increases, the overall weight of the concrete decreases, resulting in lightweight concrete suitable for non-load-bearing masonry units and earthquake-resistant construction. Polypropylene fibres have only a minor influence on fresh density because they are used in relatively small quantities. However, they contribute to improved homogeneity by distributing stresses more uniformly throughout the concrete matrix. The reduction in density achieved through rubber incorporation is considered beneficial in seismic applications because lighter structural components experience lower inertia forces during earthquakes. Nevertheless, excessive

reductions in density may also be associated with reduced compressive strength, requiring careful optimization of the rubber replacement level. Consequently, fresh density measurements provide valuable information regarding mix consistency, lightweight characteristics, and expected structural performance.



5.4 Air Content

Air content refers to the volume of entrapped or intentionally entrained air present within fresh concrete. The incorporation of crumb rubber generally increases the air content because of the irregular surface texture and hydrophobic characteristics of rubber particles, which facilitate the entrapment of microscopic air voids during mixing. These additional air voids contribute to improved impact resistance, vibration damping, and energy absorption but may simultaneously reduce compressive strength if present in excessive quantities. Polypropylene fibres also influence air content by modifying the internal structure of the fresh concrete and affecting the distribution of entrapped air bubbles. Although a moderate increase in air content may improve freeze-thaw durability and crack resistance, excessive air entrainment can adversely affect strength and durability. Therefore, controlling air content through proper mix proportioning and adequate compaction is essential to ensure the desired balance between lightweight characteristics and mechanical performance in rubberized fiber-reinforced concrete.

5.5 Segregation

Segregation is the separation of coarse aggregates from the cement mortar during handling, transportation, or placement of fresh concrete. Excessive segregation results in non-uniform concrete with poor strength and durability. In rubberized concrete, segregation behaviour is influenced by the lower density of crumb rubber compared to natural aggregates. Rubber particles tend to migrate upward during mixing if the concrete lacks sufficient cohesiveness. However, polypropylene fibres significantly reduce segregation by forming a reinforcing network that restrains the movement of aggregates and improves mixture stability. The fibres enhance internal cohesion and maintain a more uniform distribution of rubber particles throughout the concrete matrix. Researchers have observed that properly proportioned rubberized fiber-reinforced concrete exhibits lower segregation than mixtures containing crumb rubber alone. The use of suitable admixtures, optimized water-cement ratio, and adequate mixing procedures further minimizes segregation and improves the overall quality of the concrete.

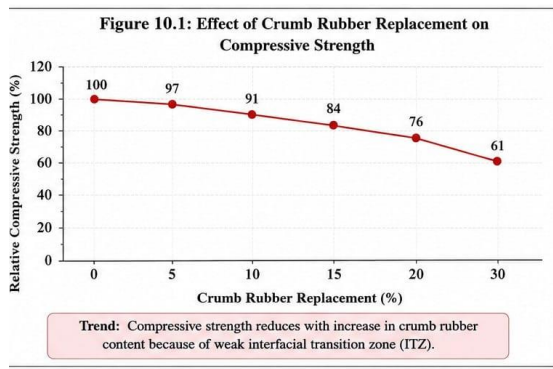
5.6 Bleeding

Bleeding is the upward movement of water to the surface of freshly placed concrete due to the settlement of solid particles. Excessive bleeding may lead to weak surface layers, poor bond between concrete and reinforcement, increased permeability, and plastic shrinkage cracking. In rubberized concrete, bleeding behaviour is influenced by the presence of lightweight rubber particles and the modified internal structure of the fresh mix. Polypropylene fibres effectively reduce bleeding by restricting the upward migration of water and improving the cohesiveness of the concrete. The fibres form an interconnected network that retains water within the cement matrix, thereby reducing surface water accumulation and promoting more uniform hydration. Several studies have reported that fibre-reinforced rubberized concrete exhibits lower bleeding than conventional rubberized concrete, resulting in improved surface quality and durability. Consequently, controlling bleeding through appropriate fibre dosage, optimized mix design, and proper curing practices is essential for producing high-quality rubberized fiber-reinforced concrete blocks suitable for sustainable and earthquake-resistant construction.

VI. MECHANICAL PROPERTIES OF RUBBERIZED FIBER-REINFORCED CONCRETE

6.1 Compressive Strength

Compressive strength is the most fundamental mechanical property used to evaluate the load-carrying capacity of concrete under axial compression. Numerous studies have reported that incorporating crumb rubber as a partial replacement for natural aggregates generally leads to a reduction in compressive strength. This reduction is primarily attributed to the lower stiffness, elastic nature, and hydrophobic surface of rubber particles, which create a weak interfacial transition zone (ITZ) between the rubber and the cement matrix. The poor bond results in increased microcracking and reduced stress transfer efficiency under compressive loading. However, the inclusion of polypropylene fibres helps compensate for this strength reduction by bridging microcracks, delaying crack propagation, and improving the integrity of the concrete matrix. Surface treatment methods, particularly NaOH treatment of crumb rubber, further enhance compressive strength by increasing surface roughness and improving the bond between rubber particles and cement paste. Most researchers have concluded that moderate crumb rubber replacement combined with a suitable polypropylene fibre dosage provides an acceptable balance between compressive strength, ductility, and sustainability. According to the uploaded seminar report, compressive strength decreases with increasing rubber content due to weak bonding, whereas fibre reinforcement contributes to improved overall mechanical performance.



6.2 Split Tensile Strength

Split tensile strength is an important parameter for evaluating the tensile behaviour and cracking resistance of concrete. Conventional concrete possesses relatively low tensile strength and is highly susceptible to brittle cracking under tensile stresses. The incorporation of crumb rubber alone generally reduces split tensile strength because of the weak bond between rubber particles and the surrounding cement paste. However, polypropylene fibres significantly improve tensile performance by acting as crack-bridging elements that transfer tensile stresses across developing cracks. The fibres delay crack initiation, reduce crack width, and increase the post-cracking load-carrying capacity of concrete. Researchers have consistently reported that fibre-reinforced rubberized concrete exhibits higher split tensile strength than rubberized concrete without fibres. Furthermore, NaOH-treated crumb rubber improves the interfacial bond with the cement matrix, thereby contributing to additional improvements in tensile strength. The combined use of treated crumb rubber and polypropylene fibres has therefore emerged as an effective approach for improving the tensile performance of sustainable concrete.

6.3 Flexural Strength

Flexural strength represents the ability of concrete to resist bending stresses and is particularly important for pavements, slabs, blocks, and other structural components subjected to transverse loading. Most research indicates that crumb rubber reduces flexural strength because of the decreased stiffness and weaker aggregate–paste interface. Nevertheless, polypropylene fibres effectively improve flexural behaviour by distributing tensile stresses throughout the concrete matrix and preventing sudden brittle failure. Fibre reinforcement increases crack resistance, enhances post-cracking behaviour, and improves energy absorption during bending. Several studies have shown that although rubberized concrete alone experiences reductions in flexural strength, the incorporation of polypropylene fibres substantially compensates for these losses. Consequently, rubberized fiber-reinforced concrete exhibits greater flexibility and better deformation capacity than conventional concrete, making it suitable for applications requiring improved seismic resistance and impact performance.

6.4 Elastic Modulus

The modulus of elasticity is an important indicator of concrete stiffness and deformation characteristics under applied loads. The inclusion of crumb rubber generally decreases the elastic

modulus because rubber particles possess a much lower stiffness than natural mineral aggregates. As the rubber replacement level increases, the concrete becomes more deformable and exhibits greater elastic strain under the same applied stress. Although this reduction in stiffness may appear disadvantageous for certain structural applications, it improves the ability of concrete to absorb impact energy and dynamic loads. Polypropylene fibres have only a limited influence on the elastic modulus but contribute to maintaining structural integrity by restricting crack development during deformation. Surface treatment of crumb rubber improves stress transfer at the interfacial transition zone and partially offsets the reduction in stiffness. Therefore, optimization of rubber content remains essential for achieving a desirable balance between flexibility and structural rigidity.

6.5 Stress–Strain Behaviour

The stress–strain behaviour of rubberized fiber-reinforced concrete differs significantly from that of conventional concrete. Ordinary concrete typically exhibits a steep ascending stress–strain curve followed by sudden brittle failure after reaching peak stress. In contrast, the incorporation of crumb rubber produces a more gradual stress–strain response characterized by increased deformation capacity and delayed failure. Polypropylene fibres further modify the stress–strain relationship by maintaining load transfer after crack initiation and preventing sudden collapse. Consequently, the descending portion of the stress–strain curve becomes less abrupt, indicating improved post-peak behaviour and greater energy dissipation. Researchers have reported that treated crumb rubber combined with fibre reinforcement produces a more stable stress–strain response suitable for structures subjected to dynamic or seismic loading.

6.6 Ductility

Ductility refers to the ability of a material to undergo significant deformation before failure while maintaining its load-carrying capacity. This property is particularly important in earthquake-resistant structures because ductile materials absorb seismic energy more effectively than brittle materials. Crumb rubber significantly enhances the ductility of concrete due to its elastic behaviour and ability to deform under loading. Polypropylene fibres further improve ductility by controlling crack propagation and maintaining structural continuity after cracking. Numerous investigations have demonstrated that rubberized fiber-reinforced concrete exhibits greater deformation capacity, improved load redistribution, and enhanced resistance to catastrophic failure compared with conventional concrete. These characteristics make it a promising material for earthquake-resistant concrete blocks and other structures subjected to cyclic loading.

6.7 Toughness

Concrete toughness represents the ability of concrete to absorb energy before complete failure. The inclusion of crumb rubber substantially increases toughness because rubber particles deform elastically and dissipate impact energy throughout the concrete matrix. Polypropylene fibres complement this behaviour by bridging cracks and increasing the amount of energy required for crack propagation. As a result, rubberized fiber-reinforced concrete exhibits significantly greater toughness

than ordinary concrete, with improved resistance to repeated loading, impact forces, and seismic actions. The combination of treated crumb rubber and fibres therefore provides a more resilient concrete capable of sustaining larger deformations while maintaining structural integrity.

6.8 Impact Resistance

Impact resistance is the ability of concrete to withstand sudden dynamic loading without experiencing severe cracking or complete failure. Numerous studies have reported substantial improvements in the impact resistance of rubberized concrete because rubber particles absorb and dissipate impact energy more effectively than conventional aggregates. Polypropylene fibres further enhance impact performance by preventing rapid crack growth and increasing the number of impacts required to initiate and propagate cracks. The synergistic effect of crumb rubber, fibre reinforcement, and improved interfacial bonding through surface treatment produces concrete with excellent energy absorption, vibration damping, and resistance to dynamic loading. These properties make rubberized fiber-reinforced concrete particularly suitable for earthquake-resistant construction, protective structures, industrial flooring, and transportation infrastructure. The uploaded seminar report also highlights improved energy absorption, ductility, crack resistance, and dynamic load performance as important advantages of combining crumb rubber with polypropylene fibres.

VII. DESIGN STANDARDS FOR RUBBERIZED FIBER-REINFORCED CONCRETE

7.1 IS 456:2000 – Plain and Reinforced Concrete – Code of Practice

IS 456:2000 is the principal Indian Standard governing the design, construction, and quality control of plain and reinforced concrete structures. The code provides recommendations for material selection, durability requirements, exposure conditions, reinforcement detailing, structural design, workmanship, and quality assurance. Although IS 456 does not specifically address rubberized concrete or fibre-reinforced concrete, it forms the foundation for designing concrete structures incorporating alternative materials. Researchers developing rubberized fiber-reinforced concrete generally follow the provisions of IS 456 for determining minimum cement content, water-cement ratio, cover to reinforcement, curing practices, and acceptance criteria for compressive strength. Since rubberized concrete exhibits different mechanical characteristics from conventional concrete, the code provisions are generally supplemented with experimental investigations before structural application.

7.2 IS 10262:2019 – Concrete Mix Proportioning

IS 10262:2019 provides guidelines for proportioning concrete mixes to achieve the required strength, durability, and workability. The standard describes procedures for selecting suitable water-cement ratios, aggregate proportions, cement content, admixtures, and target mean strength based on the desired concrete grade. In studies involving rubberized concrete, this standard serves as the starting point for conventional mix design before replacing natural aggregates with crumb rubber and incorporating polypropylene fibres. Researchers typically

modify the mix proportions experimentally because the lower density and different surface characteristics of crumb rubber significantly influence workability, density, and strength. Consequently, IS 10262 forms the basis for preparing control concrete mixtures, while rubberized mixes are optimized through laboratory trials.

7.3 IS 383:2016 – Coarse and Fine Aggregates for Concrete

IS 383 specifies the grading, physical properties, quality requirements, and permissible limits for natural coarse and fine aggregates used in concrete. The standard defines requirements related to particle size distribution, specific gravity, water absorption, deleterious materials, and aggregate strength. Although crumb rubber is not covered under IS 383 because it is an artificial recycled material, researchers generally characterize crumb rubber by comparing its physical properties with the requirements specified for conventional aggregates. Understanding these differences helps evaluate the influence of rubber particles on concrete density, workability, strength, and durability. Therefore, IS 383 remains an important reference for aggregate selection and quality control during rubberized concrete production.

7.4 IS 516:2021 – Methods of Tests for Strength of Concrete

IS 516 provides standardized testing procedures for evaluating the mechanical properties of hardened concrete. The code includes detailed methods for determining compressive strength, flexural strength, split tensile strength, modulus of elasticity, and other performance characteristics. Researchers investigating rubberized fiber-reinforced concrete widely adopt IS 516 to ensure consistency and reliability in experimental testing. Standardized specimen dimensions, curing periods, loading rates, and testing procedures enable accurate comparison of results reported by different researchers. Compliance with IS 516 enhances the credibility and reproducibility of experimental investigations involving innovative concrete materials.

VIII. CRITICAL DISCUSSION

8.1 Reasons for Variation in Experimental Results

Although numerous researchers have investigated rubberized fiber-reinforced concrete, considerable variations are observed in the reported mechanical, durability, and fresh properties. These differences arise because each study employs different material characteristics, mix proportions, curing conditions, testing procedures, and specimen dimensions. Variations in cement type, aggregate grading, rubber replacement percentage, fibre dosage, chemical admixtures, and curing duration directly influence the hydration process and the development of the cement matrix. Furthermore, differences in laboratory equipment, environmental conditions, and testing standards contribute to inconsistent experimental results. Consequently, direct comparison among different studies is often difficult, emphasizing the need for standardized testing procedures and optimized mix design for rubberized concrete.

8.2 Effect of Rubber Particle Size

Rubber particle size is one of the most influential parameters affecting concrete performance. Fine crumb rubber generally

produces better mechanical and durability properties than coarse rubber particles because smaller particles disperse more uniformly throughout the cement matrix and create fewer stress concentration zones. Fine rubber also provides a larger surface area for bonding with cement paste, thereby improving the interfacial transition zone. Conversely, coarse rubber particles create larger voids and weaker interfaces, resulting in greater reductions in compressive strength and stiffness. However, coarse rubber exhibits superior energy absorption and impact resistance because of its greater elastic deformation capacity. Therefore, the selection of rubber particle size should depend on the intended structural application and the desired balance between strength and ductility.

8.3 Influence of NaOH Treatment

Surface treatment of crumb rubber using sodium hydroxide (NaOH) is one of the most widely adopted techniques for improving the bond between rubber particles and cement paste. Untreated rubber possesses a smooth and hydrophobic surface that limits cement hydration around the particle and creates a weak interfacial transition zone. NaOH treatment removes surface contaminants, increases surface roughness, and introduces chemically active sites that enhance mechanical interlocking with hydrated cement products. However, the effectiveness of NaOH treatment depends on the concentration of the solution and the duration of treatment. Lower concentrations may produce only limited improvements, whereas excessively high concentrations or prolonged treatment may damage the rubber surface and reduce its elastic properties. Therefore, optimization of treatment parameters is essential for maximizing the mechanical performance of rubberized concrete.

8.4 Effect of Polypropylene Fibre Dosage

Polypropylene fibres play an important role in improving the tensile performance, crack resistance, toughness, and post-cracking behaviour of rubberized concrete. At low dosages, fibres effectively bridge microcracks and enhance stress redistribution without significantly affecting workability. As the fibre content increases, improvements in tensile and flexural strength become more pronounced due to enhanced crack control. However, excessive fibre dosage may reduce workability, promote fibre balling, increase internal friction, and create difficulties during mixing and compaction. These effects may ultimately reduce compressive strength because of poor concrete consolidation. Consequently, an optimum polypropylene fibre dosage is necessary to achieve maximum mechanical performance while maintaining satisfactory fresh concrete properties.

8.5 Influence of Water–Cement Ratio

The water–cement ratio remains one of the most critical parameters controlling the behaviour of rubberized fiber-reinforced concrete. A lower water–cement ratio generally increases compressive strength and durability by producing a denser cement matrix with lower porosity. However, because crumb rubber reduces workability, excessively low water–cement ratios may make concrete difficult to mix and compact. Conversely, higher water–cement ratios improve workability but increase capillary porosity, reduce strength, and adversely affect durability. Most researchers therefore recommend maintaining a

relatively low water–cement ratio while incorporating suitable superplasticizers to compensate for the reduction in workability caused by crumb rubber and polypropylene fibres.

8.6 Role of Supplementary Cementitious Materials (SCMs)

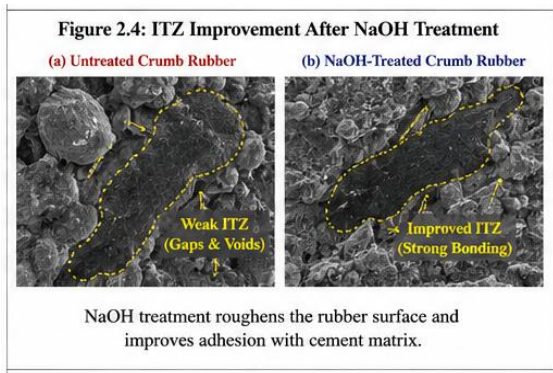
Supplementary cementitious materials such as fly ash, ground granulated blast furnace slag (GGBS), silica fume, metakaolin, and rice husk ash have been extensively used to improve the performance of rubberized concrete. These materials participate in secondary pozzolanic reactions, producing additional calcium silicate hydrate (C-S-H) gel that refines the pore structure and strengthens the interfacial transition zone. The incorporation of SCMs reduces permeability, improves long-term strength, enhances durability, and partially compensates for the strength reduction associated with crumb rubber incorporation. Consequently, the combined use of crumb rubber, polypropylene fibres, and SCMs represents an effective strategy for developing sustainable high-performance concrete with improved mechanical and durability characteristics.

8.7 Failure Mechanism

The failure behaviour of rubberized fiber-reinforced concrete differs significantly from that of conventional concrete. Ordinary concrete typically exhibits brittle failure characterized by rapid crack propagation immediately after reaching peak load. In contrast, crumb rubber particles deform elastically and absorb significant amounts of energy during loading, resulting in a more gradual failure process. Polypropylene fibres bridge developing cracks and continue transferring tensile stresses after crack initiation, thereby delaying crack widening and preventing sudden collapse. Consequently, failure becomes more ductile, with increased deformation capacity and improved post-peak load-carrying behaviour. This progressive failure mechanism is particularly advantageous in structures subjected to dynamic, cyclic, or seismic loading.

8.8 Interfacial Transition Zone (ITZ) Behaviour

The interfacial transition zone (ITZ) between aggregate particles and cement paste is widely recognized as the weakest region of concrete. In rubberized concrete, untreated crumb rubber forms a relatively weak ITZ because of its smooth surface, hydrophobic nature, and poor chemical compatibility with cement hydration products. This weak interface becomes the primary location for microcrack initiation under loading, resulting in reduced compressive strength and stiffness. Surface treatment of crumb rubber using NaOH improves the ITZ by increasing surface roughness and enhancing mechanical interlocking with the cement matrix. Polypropylene fibres further strengthen the composite by bridging cracks that originate within the ITZ, reducing crack propagation and improving load transfer throughout the concrete. Therefore, improving the quality of the interfacial transition zone remains one of the most important research directions for developing high-performance rubberized fiber-reinforced concrete with superior structural performance.



IX. RESEARCH GAPS

9.1 Limited Studies on Treated and Untreated Crumb Rubber

Most published studies investigate either untreated crumb rubber or chemically treated crumb rubber separately. Very few researchers have conducted a systematic comparison between treated and untreated crumb rubber under identical mix proportions and testing conditions. Consequently, the actual influence of NaOH surface treatment on fresh properties, mechanical performance, durability, and long-term behaviour remains insufficiently understood. Comparative studies using identical materials and standardized testing procedures are therefore required to quantify the true benefits of surface treatment.

Research Area	Gap Identified
Combined Treatment	Limited studies on both untreated and NaOH-treated crumb rubber with PP fibres.
Long-Term Performance	Lack of studies beyond 5–10 years.
Concrete Blocks	Very limited research on block applications.
Structural Behaviour	Limited seismic, fatigue, and cyclic loading studies.
Design Standards	No dedicated IS, ACI, or Eurocode provisions for rubberized concrete.
AI Applications	Very limited use of machine learning for mix optimization.

9.2 Limited Research on Rubberized Concrete Blocks

The majority of published investigations focus on concrete cubes, cylinders, beams, slabs, or paving blocks, whereas comparatively little attention has been given to structural and non-structural concrete masonry blocks incorporating crumb rubber and polypropylene fibres. Since concrete blocks are widely used in sustainable and economical construction, additional research is required to evaluate their compressive strength, thermal

insulation, acoustic performance, durability, and seismic behaviour under practical service conditions.

9.3 Insufficient Long-Term Durability Studies

Most experimental investigations evaluate concrete properties only up to 28 or 90 days. Limited information is available regarding the long-term durability of rubberized fiber-reinforced concrete under aggressive environmental conditions such as chloride exposure, sulphate attack, carbonation, freeze-thaw cycles, wetting-drying cycles, and prolonged chemical exposure. Long-term durability studies extending over several years are required before widespread structural implementation can be recommended.

9.4 Limited Seismic Performance Studies

Although rubberized concrete exhibits improved ductility and energy absorption, only a limited number of studies have investigated its behaviour under cyclic and earthquake loading. Existing research primarily focuses on static mechanical properties, while comprehensive evaluations involving cyclic loading, structural joints, full-scale wall systems, and masonry block assemblies remain scarce. Additional experimental and numerical investigations are required to assess the suitability of rubberized fiber-reinforced concrete for earthquake-resistant construction.

9.5 Lack of Fatigue Performance Studies

Repeated loading caused by traffic, machinery, wind, and seismic vibrations significantly influences the service life of concrete structures. However, very few investigations have examined the fatigue behaviour of rubberized fiber-reinforced concrete under repeated loading conditions. Comprehensive fatigue studies are necessary to evaluate crack initiation, crack propagation, residual strength, stiffness degradation, and service-life prediction for practical structural applications.

9.6 Lack of Standardized Design Guidelines and Code Provisions

Current national and international design standards, including IS 456, ACI 318, Eurocode 2, and the fib Model Code, do not contain specific provisions for the structural design of rubberized fiber-reinforced concrete. Consequently, engineers rely primarily on experimental findings rather than standardized design procedures. Future research should focus on generating sufficient experimental evidence to support the development of design recommendations, material specifications, and acceptance criteria for innovative sustainable concrete.

9.7 Limited Full-Scale Field Applications

Despite encouraging laboratory results, the practical implementation of rubberized fiber-reinforced concrete in real construction projects remains limited. Most published investigations are restricted to laboratory-scale specimens, while very few studies evaluate full-scale buildings, pavements, retaining structures, or masonry systems under actual field conditions. Long-term field monitoring and performance evaluation are essential to validate laboratory findings and

establish confidence among engineers, contractors, and regulatory authorities.

9.8 Scope for Future Research

Based on the reviewed literature, future investigations should focus on developing optimized mix designs incorporating treated crumb rubber, polypropylene fibres, and supplementary cementitious materials to improve both strength and durability. Greater emphasis should be placed on long-term durability assessment, fatigue performance, seismic evaluation, life-cycle assessment, and full-scale structural applications. In addition, standardized testing procedures and design guidelines should be developed to facilitate the practical implementation of rubberized fiber-reinforced concrete in sustainable construction. Such research will contribute to the effective utilization of waste tyres, reduce environmental pollution, and promote the development of durable, lightweight, and earthquake-resistant concrete structures.

Future Area	Expected Outcome
AI-based mix optimization	Improved mix proportion prediction
Nano-materials	Enhanced strength and durability
Hybrid fibre systems	Better crack resistance
Life Cycle Assessment	Sustainable material evaluation
Field-scale applications	Practical implementation
Code development	Design recommendations for structural applications

X. PRACTICAL APPLICATIONS OF RUBBERIZED FIBER-REINFORCED CONCRETE

10.1 Concrete Masonry Blocks

Rubberized fiber-reinforced concrete has significant potential for manufacturing non-load-bearing and lightweight concrete blocks. The incorporation of crumb rubber reduces the self-weight of the blocks, while polypropylene fibres improve crack resistance, toughness, and durability. These characteristics make the material suitable for partition walls, boundary walls, compound walls, and other masonry applications where reduced weight and improved energy absorption are desirable. Furthermore, the utilization of waste tyre rubber contributes to sustainable construction by reducing landfill disposal and promoting resource conservation.

10.2 Earthquake-Resistant Construction

One of the most promising applications of rubberized fiber-reinforced concrete is in earthquake-prone regions. The elastic nature of crumb rubber improves energy absorption and damping capacity, while polypropylene fibres enhance ductility by controlling crack propagation and delaying structural failure. These characteristics enable concrete elements to withstand cyclic loading and dissipate seismic energy more effectively than conventional concrete. Lightweight concrete blocks

manufactured using treated crumb rubber may therefore reduce seismic forces acting on buildings because lower structural mass results in reduced earthquake-induced inertia forces.

10.3 Pavements and Paver Blocks

Rubberized concrete has been widely investigated for road pavements, pedestrian walkways, footpaths, parking areas, and interlocking paver blocks. The improved impact resistance, abrasion resistance, vibration damping, and flexibility provided by crumb rubber contribute to enhanced pavement performance under repeated traffic loading. Polypropylene fibres further improve crack resistance and reduce the formation of surface defects, thereby increasing the service life of pavement systems.

10.4 Industrial Floors and Warehouses

Industrial floors and warehouse pavements are frequently subjected to heavy machinery, impact loading, and continuous vibration. Rubberized fiber-reinforced concrete provides improved toughness, impact resistance, and crack control compared with conventional concrete. These characteristics reduce maintenance requirements and improve the long-term durability of industrial flooring systems. The enhanced energy absorption capacity also minimizes surface damage caused by falling equipment and dynamic loading.

10.5 Highway Safety Barriers and Protective Structures

The excellent energy absorption characteristics of crumb rubber make rubberized concrete suitable for highway crash barriers, median barriers, protective walls, retaining structures, and impact-resistant infrastructure. Polypropylene fibres enhance post-cracking behaviour by maintaining structural integrity after impact. Consequently, rubberized fiber-reinforced concrete can dissipate collision energy more effectively than conventional concrete, reducing the likelihood of sudden brittle failure.

10.6 Marine and Coastal Structures

When combined with suitable supplementary cementitious materials and proper mix design, rubberized fiber-reinforced concrete has potential applications in marine and coastal environments. The addition of fibres helps control cracking, while optimized concrete mixtures improve durability against chloride penetration, sulphate attack, and repeated wetting and drying cycles. Nevertheless, further long-term durability studies are required before widespread implementation in aggressive marine environments.

10.7 Noise and Vibration Control Structures

The elastic properties of crumb rubber provide excellent vibration damping and sound absorption characteristics. Consequently, rubberized concrete can be used in railway platforms, metro stations, machine foundations, acoustic barriers, and buildings located near highways or industrial facilities. The improved damping capacity reduces noise transmission and structural vibrations, thereby enhancing user comfort and structural performance.

10.8 Sustainable Green Construction

Rubberized fiber-reinforced concrete represents an environmentally sustainable construction material by utilizing waste tyres that would otherwise occupy landfill space or contribute to environmental pollution. The replacement of natural aggregates with recycled crumb rubber conserves natural resources, reduces aggregate extraction, and supports circular economy principles. When combined with supplementary cementitious materials such as fly ash, GGBS, or silica fume, the environmental footprint of concrete can be reduced further. Therefore, rubberized fiber-reinforced concrete offers significant potential for achieving sustainable infrastructure development while maintaining satisfactory engineering performance.

10.9 Future Industrial Applications

With continued improvements in surface treatment techniques, fibre technology, and mix design optimization, rubberized fiber-reinforced concrete is expected to find broader applications in precast concrete products, modular housing, lightweight structural components, bridge barriers, airport pavements, railway sleepers, tunnel linings, and resilient infrastructure. Future research aimed at improving long-term durability, developing standardized design guidelines, and validating field performance will further accelerate its adoption in modern construction practices.

This review identified several research gaps that still need attention. Very few studies have investigated the combined use of treated and untreated crumb rubber with polypropylene fibres in concrete blocks. In addition, limited information is available on long-term durability, fatigue behaviour, seismic performance, field applications, and the development of design guidelines for rubberized concrete. More experimental studies are also required to establish standard recommendations for practical applications. Overall, the findings of this review indicate that concrete incorporating NaOH-treated and untreated crumb rubber together with polypropylene fibres has significant potential as a sustainable construction material. With further research and optimization, this type of concrete can be effectively used in concrete blocks, partition walls, pavement blocks, lightweight construction, and other applications where improved durability, energy absorption, and sustainability are important. It is expected that future research in this area will contribute to the wider use of rubberized concrete and support the development of environmentally friendly construction practices.

XI. CONCLUSIONS

This review paper presented a comprehensive study on the use of untreated and NaOH-treated crumb rubber along with polypropylene fibres in concrete. Based on the literature reviewed, it can be concluded that the use of crumb rubber in concrete is an effective way to recycle waste tyres and reduce the consumption of natural aggregates, thereby supporting sustainable construction practices. Although the incorporation of crumb rubber improves properties such as ductility, impact resistance, vibration damping, and energy absorption, it also causes a reduction in compressive strength and stiffness because of the weak bond between rubber particles and the cement paste. The review also showed that NaOH treatment improves the surface characteristics of crumb rubber by increasing its roughness, which results in better bonding with the cement matrix. Similarly, polypropylene fibres help in controlling crack development, improving tensile and flexural behaviour, and increasing the toughness and post-cracking performance of concrete. The combined use of NaOH-treated crumb rubber and polypropylene fibres appears to be a promising approach for producing concrete with improved overall performance while maintaining the environmental benefits of waste tyre recycling. From the reviewed studies, it was observed that the performance of rubberized concrete depends on several factors such as rubber replacement percentage, particle size, NaOH concentration, fibre dosage, water–cement ratio, and curing conditions. Therefore, proper selection and optimization of these parameters are necessary to achieve a balance between mechanical strength and durability. The literature also indicates that lower replacement levels of crumb rubber generally provide better mechanical performance than higher replacement levels.

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