Review On Comparative Study of Performance of Rubberized Concrete Beam Under Flexural and Shear Loading

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Abstract—**The growing accumulation of waste tires poses a serious environmental threat, prompting interest in rubberized concrete as a sustainable alternative. This paper presents a comprehensive review of the performance of rubberized concrete, with particular emphasis on the flexural and shears behaviour of reinforced concrete beams. Existing studies consistently show that replacing fine aggregate with crumb rubber reduces compressive strength but significantly improves ductility, toughness, energy absorption, impact resistance, and durability against aggressive environments. Despite extensive material-level investigations, fewer studies have examined full-scale structural elements, and those that do often involve high rubber contents (≥15%) where severe strength loss limits practical application. The review synthesizes recent findings on mechanical properties, bond-slip behaviour, structural performance of beams and slabs, and the effects of rubber pre-treatment methods. A critical research gap is identified: systematic experimental data on the load-deflection response, crack initiation and propagation, and failure modes of M30 grade reinforced concrete beams with low-to-moderate crumb rubber replacement (0–10% of fine aggregate) are lacking. To address this, the paper outlines an experimental programme comprising six beam specimens (2000 mm × 150 mm × 200 mm) and companion cube and cylinder specimens, with 0%, 5%, and 10% crumb rubber replacement, to be tested under two-point loading. The expected outcomes aim to demonstrate that conservative rubber dosages can enhance flexural and shear performance while maintaining acceptable strength, thereby supporting the development of design guidelines for sustainable rubberized concrete structures.**

Index Terms—**Rubberized concrete,Crumb rubber, Flexural behavior, Shear performance, Waste tire recycling, Reinforced concrete beams.**

I. INTRODUCTION

The exponential growth of the global automobile industry has led to a severe environmental crisis due to the accumulation of waste tires. Billions of tires reach the end of their useful life annually, and their non-biodegradable nature makes landfilling a hazardous and unsustainable solution . Disposal sites pose risks of uncontrolled fires, toxic gas emissions, and habitat for disease-carrying pests . Consequently, there is an urgent global demand for eco-friendly recycling methods.

One of the most promising solutions is the utilization of waste tire rubber in concrete production. Rubberized concrete (RuC), often termed "green concrete," involves partially replacing natural aggregates with crumb rubber or rubber chips . This approach not only addresses the waste disposal problem but also reduces the consumption of natural resources.

While conventional concrete is known for its high compressive strength, it exhibits brittle failure and poor tensile properties. Research has consistently shown that incorporating rubber particles alters the mechanical behavior of concrete. Although RuC typically suffers a reduction in compressive strength due to poor bonding between the hydrophobic rubber surface and the cement paste, it offers significant advantages, including lower density, enhanced ductility, higher toughness, superior energy absorption, and improved impact resistance.

Despite extensive studies on the material properties of RuC (cubes and cylinders), a critical gap exists in understanding the structural behavior of full-scale elements, particularly reinforced concrete beams subjected to flexural and shear loading. Most existing studies focus on static material strength, lacking comprehensive data on load-deflection responses, crack propagation mechanisms, and failure modes of rubberized beams. This research aims to fill that gap by experimentally investigating the flexural and shear performance of M30 grade RC beams incorporating 0%, 5%, and 10% crumb rubber as a partial replacement for fine aggregate.

II. LITERATURE REVIEW

This section discusses previous studies on the performance of rubberized concrete, with particular emphasis on its mechanical and durability properties. Different replacement percentages, rubber particle sizes, and treatment methods explored by various researchers are briefly considered. Greater importance is given to studies involving structural behaviour of rubberized concrete beams, including flexural and shear performance, load-deflection response, and crack propagation mechanisms. The collected information helps in recognizing major observations and also indicates where additional work is still required, particularly regarding full-scale structural elements.

Yasser et al., (2023) [1] A study experimentally investigated the durability of rubberized concrete using local Egyptian materials, with crumb rubber replacing fine aggregate at 0%, 10%, 15%, and 20% by volume in two grades (target 40 and 60 MPa). Up to 20% replacement did not significantly affect workability, while density decreased gradually (up to 9.34%) due to rubber's low specific gravity. Compressive strength dropped progressively (about 30% at 20% replacement), yet the remaining strength (25–40 MPa) remained suitable for structural use. Water absorption and sorptivity decreased with higher rubber content, indicating better resistance to capillary water penetration. Rubberized concrete also showed lower chloride permeability (up to 33.6% reduction) and superior resistance to sulfuric acid attack, with higher residual compressive strength (68–71% retention) versus control mixes. Under elevated temperatures (300°C and 600°C), rubberized specimens exhibited less spalling and more ductile failure. The authors concluded that rubberized concrete is highly resistant to aggressive environments and recommended further research on structural elements.

Gerges et al., (2018) [2] reviewed previous studies on rubberized concrete. Khatib and Bayomy (1999) reported a decrease in slump with increased rubber content, while fine crumb rubber mixtures exhibited better workability than coarse tire chips. Hernandez-Olivares et al. (2002) found advantages in reducing vibration and impact effects due to rubber's elasticity. Topcu (1995) concluded that compressive strength generally decreased with rubber addition at 15%, 30%, and 45% by volume. Most literature shows significant reduction in mechanical properties, with coarse rubber particles affecting properties more negatively than fine ones. However, plastic energy capacity and impact resistance increased with rubber addition. Fattuhi and Clark (1996) proposed applications in machinery foundation pads, railway stations, trench filling, pipe bedding, railway buffers, and barriers. More recently, Gupta et al. (2014–2016) explored the combined effect of waste rubber and silica fume on durability, mechanical properties, and impact resistance. Gerges et al. (2018) concluded that rubberized concrete has reduced compressive strength but offers lower density, higher toughness, and superior impact resistance compared to conventional concrete.

Azunna et al., (2024) [3] reviewed the properties of crumb rubber concrete (RuC), focusing on rubber replacement, aggregate size, and treatment techniques. Workability generally decreases with higher rubber content, though some studies reported no significant effect up to 20% replacement. Density reduces due to rubber's lower specific gravity (0.6–1.15) versus natural aggregates (≈2.65). Compressive strength decreases with higher rubber content and larger particle size; fine rubber retains strength better than coarse chips. Rubberized concrete exhibits enhanced ductility, toughness, impact resistance, and energy absorption. Treatment methods to mitigate strength loss include water soaking, NaOH, silane coupling agents, partial oxidation at 250°C, and cement mortar/paste coating. Partial oxidation at 250°C improved compressive strength by 18.4% above control, while cement mortar coating improved flexural strength by 10.5% and split tensile strength by 19.2%. The review also noted that rubberized concrete resists freeze-thaw cycles, chloride penetration, acid attack, and provides thermal insulation. Thus, despite lower strength, its ductility and durability suit pavements, crash barriers, and seismic elements, especially with confinement (steel tubes or FRP)

Rana & Yadav. (2020) [4] investigated the use of scrap tyre rubber chips as a partial replacement for coarse aggregate in M25 grade concrete. Based on previous studies, they noted that waste tyres pose a serious environmental threat due to their non-biodegradable nature, and using them in concrete offers a sustainable disposal method. Earlier research has shown that incorporating rubber aggregates generally reduces compressive strength, workability, and density, while improving ductility, impact resistance, and energy absorption. The authors observed that slump values decreased as rubber content increased from 0% to 15%, indicating reduced workability. Compressive strength tests at 7 and 28 days revealed that 5% rubber replacement gave the highest strength, whereas 10% and 15% replacements resulted in progressive strength loss. Despite the reduction, the authors concluded that rubberized concrete with 5–10% rubber replacement is suitable for non-structural applications such as lightweight concrete or fill concrete. They also recommended further study on different rubber particle sizes and treatment methods to enhance performance.

Fawzy et al., (2020) [5] presented a comprehensive overview of rubberized concrete properties and its structural engineering applications. The review compiled that rubberized concrete exhibits lower compressive strength than conventional concrete, with losses becoming severe when rubber replacement exceeds 20% of total aggregate volume. However, rubber inclusion significantly enhances ductility, energy dissipation, impact resistance, sound absorption, and freeze-thaw resistance. Workability generally decreases with increased rubber content, though some studies reported improved slump with rubber shreds. Density reduces by 2–45% depending on rubber type and replacement level due to rubber's low specific gravity. Abrasion resistance increases with rubber content, while modulus of elasticity decreases. Water absorption shows mixed results but often increases with rubber content, though silica fume or fly ash can mitigate this. Rubberized concrete also exhibits improved resistance to sulfuric acid attack and chloride ion penetration. In structural applications, rubberized concrete filled steel tubes (RUCFST) demonstrate enhanced ductility with acceptable strength due to confining effects. Strengthening with FRP sheets further recovers strength loss while maintaining ductility. The authors concluded that rubberized concrete is suitable for non-structural and seismic-resistant applications, especially when combined with confinement techniques.

Elbialy et al., (2024) [6] reported that 5–20% crumb rubber (C-Ru) replacing fine aggregate improves durability (reduced water absorption, chloride permeability, and corrosion resistance). Bu et al. (2022) found that higher rubber content reduces compressive strength but enhances toughness and durability. Ataria et al. (2022) noted decreased compressive strength and elastic modulus but improved ductility. Assaggaf et al. (2021) confirmed lower strength with increased ductility, toughness, and durability. Regarding treatment, Najim and Hall (2013) showed that cement mortar coating improved compressive strength by 40.6%, while NaOH gave only 3–5% gains. Assaggaf et al. (2022) reported $KMnO_4$ and NaOH treatments improved flexural strength by 33% and compressive strength by 64%. For structural elements, Al-Azzawi et al. (2018) tested beams with 25–50% rubber and found enhanced ductility and energy absorption but reduced load capacity. Ismail and Hassan (2017) reported that up to 20% C-Ru improved deformability and narrowed crack widths, though strength decreased beyond 15%. Elbialy et al. concluded that untreated C-Ru up to 15% balances strength retention, workability, economy, and safety, while rubber increases ductility and deflection but reduces flexural capacity.

Lin J. (2024) [7] reviewed rubber concrete, highlighting its lightweight, ductility, impact resistance, and thermal/acoustic insulation. Toutanji (1996) found that adding rubber reduces compressive strength (loss twice that of flexural) but increases ductile failure and toughness. Xiong Jie et al. (2004) reported compressive strength decreases with higher rubber content, not necessarily particle size. Zhang Jun et al. (2020) observed larger specimens show better post-damage integrity, with rubber reducing size effect. Hu Yanli et al. (2020) noted shear strength decreases and failure becomes more irregular with higher rubber content. Topçu (1997) confirmed rubber concrete suits non-load-bearing impact applications. Atahan et al. (2012) found 20–40% rubber improves impact resistance, but exceeding 60% reduces it. Eltayeb et al. (2022) reported 17% and 47.8% rubber increased damping ratio by 21.1% and 17.3%. Modification techniques like UV, heat, and NaOH pretreatment improve the rubber-cement interface and recover strength loss. Xu Jinhua et al. (2012) found 5–10% rubber powder (≤0.27 mm) enhances freeze-thaw resistance. Záleská et al. (2019) reported rubber concrete improves water vapor transmission but thermal conductivity changes at 400°C. Lin concluded that while rubber concrete offers toughness and environmental resistance, strength loss remains a major obstacle, requiring further research on dynamic loading and cost-effective modifications.

PRajiv Gandi & Saritha. (2025) [8] reviewed high-strength rubberized concrete (HSRC) with steel fibers (SF) and GGBS. High temperatures cause pore pressure buildup, cracking, and strength loss, with spalling worsened by low thermal conductivity. GGBS improves pore structure and compressive strength while reducing CO_2 emissions. Rubber particles melt at high temperatures, creating vapor pathways that reduce spalling. Steel fibers enhance ductility and crack control. However, research on combined SF and GGBS effects on fire behavior and global warming potential is limited. The authors concluded that 4% rubber with 20% GGBS and 1% SF balances strength, fire resistance, and environmental impact, making HSRC promising for high-temperature applications.

Al-Quraishi et al., (2021) [9] investigated the shear behavior of rubberized concrete beams. Earlier research shows that replacing aggregate with fine waste tire rubber reduces shear strength, though rubberized concrete offers improved energy dissipation. Ahmed et al. (2020) studied rubberized concrete beams with steel fibers, using 2–3 mm crumb rubber at 5–20% replacement and 1% steel fiber volume fraction. Four-point load tests showed that steel fibers improved performance for replacements over 10%. Bompa and Elghazouli (2017) provided mix design data. Other studies examined the static and fatigue performance of rubberized concrete slabs and bond-slip response. Liu et al. (2013) reported on mechanical and fatigue performance. The literature indicates that while rubber reduces shear strength, steel fibers compensate for this loss. Shear failure modes of rubberized concrete beams are similar to those of conventional concrete.

Safiee et al., (2020) [10] investigated punching shear behavior of rubberized concrete flat slabs. Previous research shows that crumb rubber replacement reduces compressive strength and modulus of elasticity due to poor bonding and void formation . However, rubberized concrete exhibits improved flexural and split tensile strength because rubber particles delay crack propagation and enhance energy absorption. Existing punching shear equations from Eurocode 2 and ACI 318, based on normal concrete, may not accurately predict rubberized concrete slab behavior . Studies confirm that while rubberized concrete has lower compressive strength, it offers enhanced ductility and post-cracking deformation capacity . Safiee et al. concluded that rubberized concrete slabs exhibit larger critical perimeters and more ductile failure modes, but code equations overestimate punching shear strength, necessitating modified provisions.

Kadhim and Kadhim. (2021) [11] studied loading capacity prediction of rubberized reinforced concrete continuous deep beams (RCCDBs). Waste tire rubber offers higher ductility and lower density but reduces concrete strength, making load prediction difficult. Design codes like ACI 318M-19 and EC2-2004 recommend the strut-and-tie method (STM) for deep beams. Ashour and Morley (1996) noted that STM models differ mainly in the effectiveness factor for concrete ductility. Yang et al. (2008) found ACI 318-05 predictions conservative for beams with $a/d > 1.0$ or low web reinforcement. Khatab et al. (2016)

reported ACI 318M-11 reasonably predicted shear resistance, though STM gave conservative results. Kadhim and Kadhim tested fourteen continuous deep beams with 0–20% rubber replacement and a/h ratios of 1.66 and 1.33. Existing effectiveness factors failed to account for rubber content, so they proposed a new factor incorporating compressive strength and rubber percentage, achieving accurate predictions (mean exp./calc. = 1.004, COV = 1.158%).

Mohd Nasir et al., (2023) [12] reviewed blended-rubberized concrete containing metakaolin and crumb rubber. Waste tire rubber is non-biodegradable, and its use in concrete preserves natural aggregates. Rubberized concrete has been used as lightweight landfill repair (Read et al., 1991) and asphalt paving (Heitzman, 1992). According to Sofi (2018), crumb rubber (0.425–4.75 mm) replaces fine aggregate. Kumaran et al. (2008) attributed low strength to poor rubber-cement bonding. Noor Azline et al. (2022) confirmed microcracks form around rubber due to its elastic behavior. Other studies (Mirzahosseini & Riding, 2015; Ling & Hasanan, 2007) reported significant strength reductions. Based on this, Mohd Nasir et al. investigated concrete with 10% and 15% NaOH-treated crumb rubber and 15% metakaolin. Results showed mechanical strengths decreased with higher rubber content, with a 13% reduction between 10% and 15% rubber. However, BR10 (10% rubber) achieved 30 MPa compressive strength, exceeding the 25 MPa structural minimum. SEM confirmed microcracks around rubber. The authors concluded that blended-rubberized concrete has promising potential when rubber content does not exceed 15%.

Senin et al., (2017) [13] reviewed rubberized concrete for bridge decks, focusing on properties relevant to impact and vibration resistance. Workability can be maintained with superplasticizers, and replacement up to 10% does not severely affect workability (Moustafa & ElGawady, 2015). Bulk density decreases by 2–11% with rubber addition (Gesoglu et al., 2014), and finer rubber gives higher density (Zheng et al., 2008). Air content increases; crumb rubber (<0.5 mm) provides freeze-thaw protection (Richardson et al., 2016). Compressive strength generally declines, but pre-coated crumb rubber with silica fume improves strength (Onuaguluchi & Panesar, 2014). Flexural behavior is mixed; Al-Akhras and Smadi (2004) observed increased strength with up to 10% tire rubber ash. Abrasion resistance improves (Thomas et al., 2014; Da Silva et al., 2016), while water absorption increases (Hall & Najim, 2014). Damping ratio is significantly enhanced: Xue and Shinozuka (2013) reported a 62% increase, though optimal rubber content should be below 30% to avoid modulus reduction. Senin et al. concluded that rubberized concrete is suitable for bridge decks due to improved damping and ductility, but recommended further studies on durability and full-scale applications.

Wang. (2025) [14] reviewed the stress-strain behavior of rubberized concrete, focusing on rubber content and particle size. Yan et al. (2024) found an optimal rubber content for fracture properties similar to normal concrete. Su et al. (2024) reported flexural strength decreases with larger rubber particles, and low-temperature toughness declines. Shaaban et al. (2021, 2024) identified silica fume as critical for enhancing durability. Chen (2024) found rubber reduces strength by ~12%, with optimal impact resistance at 8–12% content. Li et al. (2024) noted rubber content significantly reduces mechanical properties. Liu et al. (2024) proposed a constitutive model aligning well with experiments. Cao et al. (2024) established compressive strength models with only 1.03% error. Bompa et al. (2017) proposed $ft=0.088\sigma cft=0.088\sigma c$. Wang noted existing models lack systematic theoretical frameworks. His experiments showed 20% rubber reduced slump by 44.7%, peak stress by 26.9%, and elastic modulus by 30.5%, but increased peak strain by 26.2% and toughness index by 36.8%. A new analytical model (R^2 = 0.92) was proposed. Wang concluded rubberized concrete offers energy dissipation benefits for seismic applications but requires balanced design.

Bušić et al., (2023) [15] reviewed bond-slip behavior of self-consolidating rubberized concrete (SCRC). Rubber improves ductility, freeze-thaw resistance, and HCl resistance but reduces compressive strength and modulus of elasticity. Hall and Najim (2014) found that rubberized concrete exhibits lower maximum bond strength and slip at peak stress. Bompa and Elghazouli (2017) examined bond-slip of deformed bars under low confinement. Anu Bala et al. (2014) noted rubber decreases bond strength, while fly ash improves it up to 20% replacement. Gesoglu et al. (2015) reported lower bond strength due to rubber's softness reducing friction. Bušić et al. tested 24 specimens with three bar diameters (12–20 mm) and 0–15% crumb rubber. Results showed compressive strength dropped 28.5%, modulus 8.6%, and bond strength decreased 31.9%, 24.1%, and 12.4% for 12, 16, and 20 mm bars. Rubber led to ductile failure without splitting. They concluded rubber content and bar diameter significantly affect bond strength and failure modes.

Al-Khuzaie et al., (2020) [16] reviewed mechanical properties of concrete pavement with crumb rubber (CR). Eldin and Senouci (1993) found compressive strength dropped 85% for coarse rubber replacement and 65% for fine rubber. Benazzouk et al. (2007) reported that 10–50% CR reduced compressive strength but slightly improved flexural strength at 20–30% due to rubber's elasticity. Ganjian et al. (2009) noted 5% chipped rubber gave a small strength increase, while fine powder caused reduction. Lv et al. (2015) and da Silva et al. (2015) confirmed that mechanical strengths decrease with higher CR content. Moustafa and ElGawady (2015) found strength reduction high with or without superplasticizer. Treatment methods: NaOH solution removes zinc stearate and roughens rubber surfaces (Balaha et al., 2007; Mohammadi et al., 2016; Youssf et al., 2016), while water soaking reduces air entrapment (Mohammadi et al., 2014; Pham et al., 2018). Al-Khuzaie et al. tested 2–10% CR with untreated, NaOH-treated, and water-soaked CR across three particle sizes. NaOH treatment performed best, with coarser particles (sieves No.16/No.50) better than finer ones. Replacement of 2–4% treated CR met 30 MPa pavement requirement; 6% gave 28 MPa. Water soaking caused 52–66% strength loss, far higher than NaOH treatment (7.6–28%).

Covatariu et al., (2024) [17] reviewed high-temperature behavior of rubberized concrete. Using crumb rubber as aggregate replacement has been studied for about 20 years (Ganjian et al., 2009), with mechanical properties documented (Najim & Hall, 2010; Sukontasukkul, 2009). Fire testing is expensive, making model validation important. Their study cast concrete with 40–80% fine aggregate replaced by rubber. Flat-cylindrical specimens were exposed to 550°C, with temperature measured by thermal imaging. FEM simulations (LISA 8.0) were calibrated against experiments. Rubberized concrete showed higher thermal inertia than plain concrete, though RC60 trends were inconsistent due to heterogeneous properties. Calibrated simulations (340–390°C) matched experiments well. At uniform 500°C input, RC40 and RC60 performed similarly to plain concrete. The authors concluded that small-scale specimens with validated simulations offer a cost-effective alternative for fire testing.

Bashandy et al., (2020) [18] reviewed crumb rubber treatment effects on high-strength rubberized concrete slabs. One billion tires are discarded annually, causing environmental issues (Siddique & Naik, 2004). Rubberized concrete increases ductility but reduces strength due to weak rubber-cement bonding (Gerges et al., 2018). More et al. (2015) found 3% rubber reduced split tensile strength by 30%. Al-Tayeb et al. (2012) reported 5–20% rubber decreased compressive strength by 5–20% and tensile strength by 11–17%, but increased impact loads. Sallam et al. (2008) noted 10% fine rubber gave acceptable strength loss and improved crack resistance. Hassanli et al. (2017) observed rubberized concrete beams had 7.7–27.9% higher deflection capacity, recommending it for ductile flexural members. Based on this, Bashandy et al. tested high-strength slabs with 5% sand replacement by coarse/fine rubber using various treatments (NaOH, $NaOH/KMnO_4/NaHSO_3$, and 200°C heat). Untreated rubber reduced performance, but chemical and heat treatments improved ultimate load and ductility, with CNKS24 treatment (soaked in 20% NaOH, then 10% $KMnO_4$, then 5% $NaHSO_3$, each 24h) giving the best results.

Bhavani et al., (2021) [19] reviewed geopolymer rubberized concrete with zeolite. Integrating industrial wastes into concrete is growing (Dash et al., 2016). Rubberized Portland cement concrete reduces wear and tear (Gerges et al., 2018) and offers high ductility and impact resistance for bridges and runways (Luhar et al., 2019). Geopolymer concrete with rubber suffers strength loss due to poor bonding (Yeluri & Yadav, 2020), but NaOH treatment improves bonding (Jokar et al., 2019). Zeolite replacement enhances properties (Jokar et al., 2019). Based on this, Bhavani et al. developed geopolymer concrete with fly ash, GGBS, 5% zeolite, 2.5% rubber chips, and 5–20% rubber powder (treated/untreated). Compressive and tensile strengths decreased with higher rubber, but impact and freeze-thaw resistance improved. Treated rubber (1M

NaOH) gave better strength, suitable for high-impact applications.

Liu . (2024) [20] reviewed rubberized concrete, focusing on rubber content and KH-570 pretreatment. Jiang et al. (2023) found rubber improves toughness, crack resistance, and impact resistance while reducing elastic modulus. Beiram and Al-Mutairee (2022) noted lower density and workability but better energy absorption and ductility. Guan et al. (2023) showed increased rubber decreases ITZ microcracks but increases porosity. Han et al. (2024) demonstrated frost resistance improves with rubber, especially when pretreated. Regarding pretreatment, Kou (2024) found NaOH-treated rubber enhances freeze-thaw durability; Bu et al. (2022) concluded pretreatment improves bond strength. Jing et al. (2024) introduced high-temperature mixing (180°C) achieving better properties than NaOH or KH-570 alone. Based on this, Liu tested 0–25% rubber (KH-570 treated and untreated). Workability decreased with rubber, but KH-570 mitigated loss. At 15% rubber, pretreated concrete maintained control peak stress; beyond that strength dropped sharply. Rubber increased peak strain and toughness but reduced secant modulus. KH-570 reduced drying shrinkage by 22.7% after 60 days. Rubberized concrete lowered CO_2 emissions (up to 61% reduction) and performed well in airport pavement.

Radhy et al., (2023) [21] reviewed rubberized continuous deep beams (CDBs) under monotonic and repeated loads. Repeated loads on bridges necessitate ductile rubberized concrete (Kadhim & Kadhim, 2021). Scrap tire rubber enhances ductility but reduces mechanical properties (Hernández-Olivares et al., 2002). Rubber aggregates are classified by size: shredded, crumb, ground, and fibers. The strut-and-tie method (STM) is a lower-bound theorem for deep beams (Kadhim & Kadhim, 2021). Radhy et al. tested six CDBs (conventional, sand-replaced, and gravel-replaced with 10% rubber) under monotonic and repeated loads. Rubberized CDBs lost 39% (sand) and 30.1% (gravel) of ultimate capacity, but deflection increased. Under repeated loads, ultimate strength decreased by 14%, 8%, and 9% for conventional, gravel, and sand beams vs. static loads. Residual deflection increased per cycle. A fuzzy nonparametric regression system produced third-degree polynomials for load-deflection data.

Ali and Hasan. (2019) [22] reviewed concrete containing waste tire rubber. In normal rubberized concrete, workability generally decreased with higher rubber content, though admixtures helped. Compressive, splitting tensile, and flexural strengths decreased as rubber increased; Antil (2014) reported reductions of 37%, 30%, and 31% at 20% crumb rubber. For self-compacting rubberized concrete (SCRC), studies showed fresh properties remained within acceptable limits, but strengths reduced with rubber addition. Water absorption increased with rubber content (Gesoglu & Guneyisi, 2011). Notably, the failure mode changed from brittle to ductile, with enhanced post-cracking resistance and energy absorption (Benazzouk et al., 2003; Batayneh et al., 2007). The authors concluded that rubber reduces mechanical strength but improves ductility and impact resistance, making it suitable for vibration damping and blast-resistant applications.

Irmawaty et al. (2020) [23] reviewed rubberized concrete using crumb rubber and tire chips. Eldin and Senouci (1993) found that complete replacement of fine aggregate with crumb rubber reduced compressive strength by 65%, while coarse aggregate replacement with tire chips reduced compressive strength by 85% and flexural strength by 50%, with rubberized concrete showing increased toughness. Khatib and Bayomy (1990) reported that over 20% rubber by volume caused significant strength loss. Segre and Joekes (2000) showed that NaOH treatment improves bond strength, flexural strength, modulus of elasticity, and abrasion resistance. Based on this, Irmawaty et al. tested 0–30% crumb rubber + tire chips (NaOH-treated). Concrete weight decreased ~3.5% per 10% rubber. Compressive strength dropped 24% at 10% replacement and 53–65% at 20–30%; split tensile strength decreased 16% at 10% and 41–49% at higher replacements. Modulus of elasticity also decreased. The authors concluded that rubber addition beyond 10% of aggregate volume is not recommended due to weak rubber-cement bonding.

Mounika & Mounika. (2024) [24] reviewed coir fiber-based crumb rubber concrete. Liu et al. (2016) reported positive impacts of crumb rubber on strength and durability. Jadhav et al. (2018) found that replacing cement with rice husk ash and coarse aggregate with rubber decreased compressive strength and workability but reduced concrete weight.

Sam and Sheeja (2016) noted that coir fiber reinforced concrete improved durability. Dharashan et al. (2017) observed better sound insulation and thermal resistance in rubberized concrete due to lower density. Ahmad et al. (2022) emphasized that optimum coir fiber dosage depends on fiber dimensions. Based on this, Mounika and Mounika tested concrete with 0–15% crumb rubber (fine aggregate replacement), 0–3% coir fiber (cement replacement), and 5–15% fly ash. The optimum mix (1% coir fiber + 5% crumb rubber + 5% fly ash) achieved 28-day compressive strength of 29.40 N/mm², split tensile strength of 2.79 N/mm², and flexural strength of 4.68 N/mm², with lower water absorption than conventional concrete.

Ramakrishana & Karthik. (2018) [25] reviewed crumb rubber in concrete for vibration damping. Rubberized pavements reduce vibrations and offer environmental benefits (Cao, 2007; Zheng et al., 2007). However, higher rubber content lowers strength (Fattuhi & Clark, 1996; Xie et al., 2015) and reduces damping ratio and dynamic modulus while increasing flexibility (Zheng et al., 2007; Skripkianas et al., 2009). Rapid strength loss occurs at ~20% replacement due to weak bonding (Issa & Salem, 2013). NaOH pre-treatment removes zinc stearate, roughens rubber surface, and improves strength (Youssif et al., 2015). Based on this, Ramakrishnan and Karthik tested three mixes: raw rubber, NaOH-treated rubber, and treated rubber with 10% cement replaced by UFGGBS, at 5–20% crumb rubber. The treated rubber with UFGGBS achieved M30 strength, improved damping, lower sorptivity, better bonding (SEM), and suitable flexural properties for roadside structures.

A. Summary of Literature Review

Studies consistently show that partially replacing fine or coarse aggregate with crumb rubber reduces concrete's workability and density. However, rubberized concrete significantly improves ductility, toughness, energy absorption, impact resistance, and post-cracking behaviour, transforming brittle failure into a ductile response. Durability also increases, with better resistance to freeze-thaw cycles, chloride penetration, acid attack, and thermal insulation. Pre-treatment methods like NaOH soaking, cement coating, or partial oxidation can partially recover strength by enhancing the rubber–cement interface. In beams and slabs, rubberized concrete typically shows lower ultimate load and shear capacity but larger deflections, narrower cracks, higher ductility, and greater energy dissipation; steel fibres or confinement can offset strength losses. Code predictions often overestimate capacity, so modified approaches (e.g., adjusted strut-and-tie factors) have been proposed. Overall, rubberized concrete is a sustainable material suited to applications requiring toughness, vibration damping, or seismic resistance, provided rubber content is limited to about 10–15% of fine aggregate and design balances strength and deformability.

B. Research Gap

From the literature review, the following observations were made:

1. Lack of systematic data on load-deflection response, crack initiation/propagation, and failure modes for reinforced concrete beams with low-to-moderate crumb rubber replacement (0–10% of fine aggregate) under two-point loading.
2. Insufficient quantification of the simultaneous improvement in flexural and shear performance specifically crack width control and post-cracking ductility in M30 grade beams.
3. Underexplored potential of conservative replacement levels (5–10%) that are more suited to practical structural applications.

V. CONCLUSION

This review has established that rubberized concrete, despite a well-documented reduction in compressive strength, offers substantial improvements in ductility, energy absorption, impact resistance, crack control, and durability compared to conventional concrete. Most structural investigations, however, have utilised elevated rubber contents (≥15%) where strength losses become severe, limiting direct structural applicability. A critical gap exists in the literature regarding the flexural and shear behaviour of full-scale reinforced concrete beams incorporating conservative crumb rubber dosages (0–10% of fine aggregate) that preserve adequate strength while delivering enhanced ductility and crack width control.

To bridge this gap, the planned experimental programme will systematically evaluate the load-deflection response, crack initiation and propagation patterns, failure modes, and ultimate capacity of M30 grade RC beams with 0%, 5%, and 10% crumb rubber replacement under two-point loading. Companion material tests will correlate the beam performance with compressive and split tensile strengths. It is expected that the rubberized beams will exhibit improved post-cracking ductility, narrower crack widths, and enhanced energy dissipation without catastrophic loss of load-carrying capacity, thereby demonstrating that low-level crumb rubber replacement can safely enhance structural performance.

The outcomes of this investigation will provide essential experimental data to validate the use of rubberized concrete in flexural and shear-critical structural elements, supporting the development of design guidelines for sustainable, waste-tyre-derived concrete in building constructions.

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