Experimental Test of Flexural Strength of Green Concrete Using 0%, 10%, 30% Waste Tire Rubber Powder as a Substitute for Fine Aggregate

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Abstract

The increasing demand for sustainable construction has driven the development of green concrete incorporating recycled waste materials. This study investigates the flexural strength of concrete partially substituting fine aggregate with waste tire rubber powder at 0%, 10%, and 30% replacement levels. Concrete beams measuring 150 mm × 150 mm × 600 mm were cast and tested at 28 days using third-point loading in accordance with ASTM C78. The experimental results show that the 10% rubber powder mix achieved the highest flexural strength, with a 52.5% increase compared to the control. In contrast, the 30% mix exhibited a moderate reduction in strength. Despite the slight decline at higher replacement levels, all mixes retained acceptable structural performance and workability without chemical admixtures. The findings suggest that partial substitution of fine aggregate with rubber powder up to 10% can enhance flexural behavior while promoting environmentally friendly concrete solutions.

Keywords: *flexural strength waste tire rubber powder, flexural behavior*

Introduction

The increasing concern over environmental degradation caused by industrial waste and natural resource depletion has prompted extensive research into green concrete technology. One major focus is the incorporation of waste tire rubber powder as a partial replacement for fine aggregate to reduce the environmental footprint of concrete production.

Previous studies have explored the mechanical and durability characteristics of rubberized concrete with varying replacement ratios. According to Liu et al. (2024), substituting up to 20% of fine aggregate with waste tire rubber powder results in a moderate reduction in compressive strength, yet maintains acceptable structural performance for non-load-bearing elements. Similarly, He et al. (2023) emphasized that incorporating industrial waste into concrete not only reduces CO_2 emissions but also contributes to sustainable material cycles within the construction sector.

Gao et al. (2022) analyzed the flexural behavior of rubber concrete reinforced with steel fibers and nanosilica. Their results suggested that such additives could compensate for the strength reduction typically caused by rubber inclusion at moderate replacement levels (10–20%). However, the reliance on chemical or mineral admixtures in many prior studies makes it difficult to isolate the intrinsic effect of rubber content on the mechanical behavior of concrete. Therefore, the present research focuses on plain rubberized concrete without admixtures to clearly determine the independent influence of rubber powder substitution. The selected replacement levels of 0%, 10%, and 30% are based on practical considerations: 10% represents a commonly reported threshold for acceptable performance, while 30% serves as a critical limit to evaluate the boundary of structural applicability. By systematically comparing these ratios under identical mix proportions and curing conditions, this study aims to provide new insight into the realistic potential of rubberized concrete in low-cost, resource-limited construction environments where chemical admixtures are not readily available. This approach constitutes the novelty of the present research, addressing the gap left by previous investigations that often employed modifiers or supplementary materials to offset rubber's inherent weakness.

In related works, Al-Tayeb et al. (2022) investigated the effect of rubber particle size on the dynamic and mechanical behavior of concrete and observed that smaller rubber particles improved energy absorption while larger particles enhanced damping properties. Sofi et al. (2021) reported that rubberized concrete exhibits superior impact resistance and ductility compared to conventional concrete, despite a decline in compressive strength. Likewise, Ismail and Ramli (2020) found that rubber powder substitution at 10–15% significantly improved the toughness and crack resistance of concrete beams under flexural loading. Rahman et al. (2019) demonstrated that replacing sand with rubber powder increases flexibility and energy dissipation under cyclic loads, suggesting potential applications for seismic-resistant structures.

Beyond rubberized concrete, other waste materials have also been studied to support sustainability in construction. Diana et al. (2021) examined the use of waste glass powder and bamboo leaf ash as cement and fine aggregate substitutes, showing a positive effect on strength development at optimized dosages. Haryanto (2018) and Wijaya (2018) explored polymer-modified concrete using natural latex waste combined with eggshell powder, revealing enhanced bonding and compressive strength. Umar (2022) investigated the substitution of crushed stone dust and eggshell powder, finding potential for partial cement replacement. Additionally, Thomas and Gupta (2020) emphasized that incorporating waste materials into concrete reduces landfill dependency and raw material consumption, while Meddah et al. (2021) concluded that using rubber and recycled aggregate concrete can reduce embodied energy without compromising structural integrity.

Despite these advancements, most studies rely on chemical admixtures or hybrid materials, limiting their applicability in simple, practical construction settings. Addressing this research gap, the present study systematically investigates the mechanical performance of concrete with 0%, 10%, and 30% waste tire rubber powder replacements under identical conditions and without admixtures—offering a clearer understanding of rubberized concrete's standalone performance and its potential role in sustainable, low-cost construction.

The production of conventional concrete contributes significantly to carbon emissions and the excessive consumption of natural aggregates. As a result, the development of green concrete incorporating industrial or post-consumer waste has become increasingly essential for achieving sustainable construction practices (He et al., 2023). One promising approach is the partial substitution of fine aggregates with waste tire rubber powder. A recent study by Liu et al. (2024) investigated the mechanical behavior of rubberized concrete and found that although compressive and flexural strength declined with rubber inclusion, up to 20% replacement still yielded acceptable structural performance. However, investigation will be compared to different replacement levels particularly 0%, 10%, and 30% waste tire rubber powder under identical mix proportions and without chemical admixtures. This gap limits a comprehensive understanding of how rubber content alone influences the mechanical behavior of green concrete, especially its flexural performance and potential for structural applications.

Du et al. (2024) demonstrated that both rubber particle size and content significantly influence the static and dynamic behavior of rubberized concrete, particularly in terms of flexural strength and energy absorption capacity. Similarly, Albidah and Alsaif (2024) evaluated the flexural behavior of functionally graded rubberized concrete beams, revealing that while flexural strength decreases with higher rubber content, ductility and crack resistance improve.

In terms of static performance, Gao et al. (2022) analyzed the flexural behavior of rubber concrete reinforced with steel fibers and nanosilica. Their results suggested that such additives could compensate for the strength reduction typically caused by rubber inclusion at moderate replacement levels (10–20%). However, the reliance on chemical or mineral admixtures in many prior studies makes it difficult to isolate the intrinsic effect of rubber content on the mechanical behavior of concrete. Therefore, the present research focuses on plain rubberized concrete without admixtures to clearly determine the independent influence of rubber powder substitution. The selected replacement levels of 0%, 10%, and 30% are based on practical considerations: 10% represents a commonly reported threshold for acceptable performance, while 30% serves as a critical limit to evaluate the boundary of structural applicability. By systematically comparing these ratios under identical mix proportions and curing conditions, this study aims to provide new insight into the realistic potential of rubberized concrete in low-cost, resource-limited construction environments where chemical admixtures are not readily available. This approach constitutes the novelty of the present research, addressing the gap left by previous investigations that often employed modifiers or supplementary materials to offset rubber's inherent weakness. Islam et al. (2022–2023) conducted a series of reviews on the use of rubber aggregates in both lightweight and structural concrete. These reviews emphasize the importance of surface treatment and supplementary additives (e.g., silica fume, fibers) to sustain flexural strength under up to 30% substitution rates.

Using high-performance concrete technology, Zhang et al. (2024) reported that although flexural strength still decreased in ultra-high-performance rubberized concrete (UHPRuC), the reductions were less severe due to strong matrix-aggregate bonding. However, the decline remained approximately 1.5 to 3 times greater than compressive strength loss. Research by Meng et al. (2023) on self-compacting rubberized concrete found that both rubber type and mixture density significantly affect compressive and flexural responses under triaxial loading. In summary, numerous studies have concluded that rubber powder substitution up to 20% typically reduces flexural strength, but significantly enhances characteristics such as ductility, energy absorption, and crack resistance (He et al., 2023). However, most previous research has focused on combinations of rubber substitution with additives, high-volume (>30%) replacements, or high-performance concretes. There is a lack of systematic experimental investigations on the flexural behavior of green concrete with 0%, 10%, and 30% waste tire rubber powder as fine aggregate replacement without additional admixtures, which constitutes a research gap.

Method

The flexural strength test is a method used to determine the ability of concrete to resist indirect tensile stress resulting from bending. This test is essential because concrete generally possesses low tensile strength compared to its compressive strength. Therefore, flexural testing provides insight into the material's resistance to cracking and tensile failure, especially in structural beams elements as shown in Figure 1.

Figure. 1 Experimental Test Setup

The test is typically performed using prismatic concrete beams with standard dimensions (e.g., 150 mm × 150 mm × 600 mm), subjected to either third-point loading or center-point loading until failure occurs as presented in Figure 1. During the test, the maximum bending stress at failure is recorded to calculate the modulus of rupture of the concrete. Flexural Strength Formulas was shown in Equation:

$$f_r = \frac{PL}{bd^2}$$

Where, Fr is flexural strength (MPa), P is maximum load at failure (N), L is span length between supports (mm), b is width of the beam (mm), d is depth of the beam (mm).

Result and Discussion

Testing of Specific Gravity and Water Absorption of Coarse Aggregate

The test results for the specific gravity of coarse aggregate showed that the average bulk specific gravity was 2.619, the saturated surface dry (SSD) specific gravity was 2.640, and the apparent specific gravity was 2.67. The average water absorption value of the coarse aggregate was found to be 0.8%. The test results showed that the coarse aggregate used had an average bulk specific gravity of 2.619, a saturated surface dry (SSD) specific gravity of 2.640, and an apparent specific gravity of 2.67. These values fall within the typical range for natural aggregates, which is generally between 2.4 and 2.9.

The differences among the three types of specific gravity indicate the internal porosity characteristics of the aggregate. The higher apparent specific gravity reflects the total mass of the solid aggregate, excluding the volume of permeable pores. In contrast, the

SSD and bulk specific gravity account for water within accessible pores. The small difference between the SSD and bulk specific gravity values (approximately 0.021) suggests that the aggregate has relatively low open porosity, which is a sign of good-quality aggregate.

Meanwhile, the average water absorption value of 0.8% also indicates that the coarse aggregate has low porosity. According to common standards (e.g., ASTM C127), aggregates with water absorption values below 2% are considered good, as they do not absorb excessive amounts of water from the concrete mix. This is important for maintaining the water-cement ratio and ensuring the desired concrete strength.

Overall, the test results indicate that the coarse aggregate meets the quality requirements for use in concrete mixtures, both in terms of specific gravity and water absorption capacity.

Testing of Coarse Aggregate Abrasion

The test results for coarse aggregate abrasion showed that the average abrasion value was 21.033%. This indicates that the tested coarse aggregate has good abrasion resistance, as the value falls below the acceptable maximum limit. According to standard specifications such as SNI 2417:2008 or ASTM C131/C535, coarse aggregate is considered to be within acceptable quality if its abrasion value is less than 40%.

This relatively low abrasion value reflects the aggregate's sufficient hardness and durability, making it suitable for use in concrete mixtures, especially in structures that require high resistance to mechanical wear, such as highways, runways, and rigid pavements. Therefore, the tested coarse aggregate can be deemed appropriate for use in infrastructure construction projects.

Gradation Test of Fine Aggregate

The results of the fine aggregate gradation test indicated that the Fineness Modulus (FM) was 2.1. This value falls within the acceptable range of 1.5 to 3.8, as specified by standards such as SNI 03-2834-2000 or equivalent international guidelines.

The fineness modulus is a key indicator of the particle size distribution of fine aggregates. A value of 2.1 classifies the aggregate as having a medium gradation, which is generally desirable in concrete mixtures because it provides a good balance between workability and strength. Aggregates with excessively low FM tend to have too many fine particles, increasing water demand, while excessively high FM indicates a coarser mix that can reduce cohesion in the concrete. Therefore, an FM value of 2.1 confirms that the fine aggregate meets the specification requirements and is suitable for use in concrete production.

Specific Gravity and Water Absorption Test of Fine Aggregate

The results of the specific gravity tests revealed that the average bulk specific gravity of the material was 1.58, the saturated surface dry (SSD) specific gravity was 2.04, and the apparent specific gravity was 2.95. Additionally, the average water absorption was found to be 2.93%.

The considerable difference between the bulk and SSD specific gravity values indicates the presence of open pores that can absorb water under SSD conditions. Furthermore, the gap between the SSD and apparent specific gravity suggests the existence of impermeable or closed pores within the aggregate particles. These characteristics provide insight into the internal structure and porosity of the material, which are critical factors influencing its interaction with water and cement paste in concrete mixtures.

The water absorption value of 2.93% is relatively moderate but still higher than the commonly recommended threshold of 2% for high-quality fine aggregates, as defined in standards such as ASTM C128. This level of absorption implies that the material has a significant capacity to retain moisture, which can affect the effective water-to-cement (w/c) ratio if not properly accounted for during mix design. An inaccurate w/c ratio may lead to reduced workability, potential issues with consistency, and diminished compressive strength in the hardened concrete.

Despite the moderately high absorption, the tested material remains suitable for use in concrete production, provided that appropriate moisture corrections are made in the batching process. Ensuring accurate water content adjustments is essential to achieve the desired performance characteristics of the final concrete product.

Fine Aggregate Silt Content Test

The silt content test conducted on the fine aggregate showed that the average silt content was 1.0%. This value is well below the maximum allowable limit of 5%, as specified in the Indonesian Standard SNI S-04-1989-F, which governs the acceptable level of fine material (such as silt and clay) in fine aggregates used for concrete production.

A low silt content indicates that the fine aggregate is clean and free from excessive dust or clay-like particles. This condition is favorable in concrete mixtures, as a high percentage of silt can interfere with the bonding between the cement paste and aggregate, reduce the strength of the concrete, and increase water demand, ultimately compromising the durability and long-term performance of the material.

With a measured silt content of only 1.0%, the tested fine aggregate satisfies the requirements for use in concrete production and can be classified as clean and suitable. The result ensures that the material will not significantly alter the water-cement ratio or impair the mechanical properties of the hardened concrete.

Slump Test of Concrete

Slump tests were performed to evaluate the effect of different mix proportions on the workability of fresh concrete. The results are presented in the following Table 1:

Table 1. Slump Test

No	Mix Proportion (%)	Slump Value (cm)
1	0% (control)	5
2	10%	6
3	30%	7

The results indicate that increasing the substitution proportion up to 30% did not reduce the workability of the fresh concrete. On the contrary, a slight increase in slump was observed at the 30% level. The slump values remained within the plastic range (5–7 cm), as defined by ASTM C143, indicating that the mixtures retained acceptable consistency without the need for additional water or chemical admixtures.

This behavior suggests that the introduced material, even at higher replacement levels, does not negatively affect the rheological properties of the concrete and can be considered compatible with standard mix workability requirements.

Flexural Strength Test

Flexural strength tests were carried out to evaluate the influence of different mix proportions on the bending resistance of concrete beams at 28 days of curing. The results are presented in the following Table 2 and the crack pattern are presented in Figure 2 - Figure 5:

Table 2. Flexural strength tests results

Mix Proportion (%)	Age (days)	Concrete Weight (kg)	Average Flexural Strength (MPa)
0% (control)	28	33.00	3.145
10%	28	32.50	4.797
30%	28	31.80	3.622

The data indicate that a 10% substitution level results in a significant increase in flexural strength, from 3.145 MPa (control) to 4.797 MPa, representing an approximate 52% improvement. This enhancement may be attributed to a positive interaction between the substituting material and the cementitious matrix, potentially due to improved packing density or additional binding effects.

At a 30% replacement level, the flexural strength decreased to 3.622 MPa, although it remains slightly higher than the control mix. This reduction may be caused by excessive substitution, which could disrupt the homogeneity of the matrix or increase internal porosity. Additionally, the reduced weight (31.80 kg) of the concrete at 30% suggests a less dense mix, which might contribute to the lower mechanical performance. Overall, the findings suggest that a 10% replacement level yields the optimum flexural strength, whereas higher proportions may compromise structural integrity.

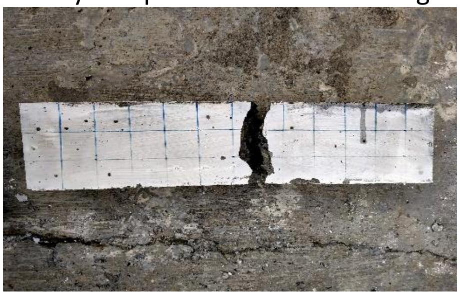

Figure 2. Failure pattern of the 0% sample specimen

Figure 3. Failure pattern of the 10% sample specimen

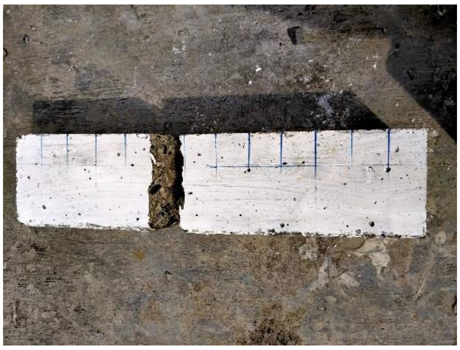

Figure 4. Failure pattern of the 30% sample specimen

Conclusion

This study evaluated the flexural performance of green concrete incorporating 0%, 10%, and 30% waste tire rubber powder as a partial replacement for fine aggregate. The results indicate that a 10% substitution level enhanced flexural strength by approximately 52% compared to the control mix, while 30% substitution led to a slight decrease. All mixes maintained adequate workability without admixtures. Thus, incorporating up to 10% rubber powder offers an optimal balance between sustainability and mechanical performance, making it a viable alternative for eco-friendly concrete production.

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