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# Evaluation of Strength Characteristics of Recycled Tire Steel and Waste Polyethylene Terephthalate Fibers-Reinforced Concrete for Sustainable Development.

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## Abstract
*Many citizens in developing economies face socioeconomic and ecological challenges that limit their access to adequate, comfortable, and affordable housing. Despite global efforts by international institutions like UN-Habitat and the Sustainable Development Goals (SDGs) 2030 agenda, which call for citizens to own suitable dwellings, the severe housing shortage in developing countries continues. The rising costs of construction materials, especially reinforced concrete, have led professionals and scholars to collaborate on developing alternative, cost-effective materials such as fiber-reinforced concrete. In other sectors, experts report significant benefits from reusing and recycling household materials like used tires and plastic products. However, few studies have explored reusing domestic waste like used tires and PET plastic bottles as ingredients in construction to help lower costs. This research examines the potential of household waste for green building, aiming to decrease greenhouse gas emissions, reduce the carbon footprint, and provide socioeconomic benefits to the population. An experimental study was conducted to assess the effectiveness, workability, and strength of recycled tire steel fibers (RTSF) combined with waste polyethylene terephthalate fibers (PETF), a hybrid fiber, as reinforcement in conventional concrete. Tests were carried out for various curing periods, including 3, 7, and 28 days, following initial in-situ testing of fresh concrete using slump, compaction, and consistency methods. Scientific analysis focused on hardened concrete tests measuring compressive, split, and flexural strength, comparing the recycled domestic waste materials, RTSF and PETF, with traditional plain concrete. Observations show a notable improvement in workability with increasing PETF content. However, It was noticed that the workability decreases as the additional quantity of hybrid fibers in RTSF with PETF increases compared with the control plain concrete, which significant causes a significant effect on the slump. Meanwhile, tensile strength and toughness improved with the addition of RTSF. This is revealed as the tensile, and the compressive increases as the curing day progresses but the revered was the case as PETF percentage increases. The hybrid RTSF at 0.5 with PETF at 0.2 is recommended for maximum strength.*

**Keywords:** Fiber, Hybrid, Fiber-reinforced concrete, infrastructure, recycle, reuse, end-of-life, Tire, Plastic, Domestic waste.

## Introduction
Construction and housing project costs in recent years have become unaffordable owing to the high cost of construction materials (Ogunjiofor *et al*., 2023; Spaan & Abraham, 2023; Reid, 2023), especially concrete, which record confirms that about 30 billion tons are being consumed annually (Nithurshan & Elakneswaran, 2023), making it the second most used material next to water for construction and other activities (Alani & Aboutalebi, 2013; Imbabi *et al*., 2013). This cost has been analyzed and estimated to be associated with the cost of various resources required for building production, with more emphasis on the major concrete ingredients. Major concrete constituents widely recognized among the built environment professionals are binder, fine and coarse aggregate, water, and admixtures. This combination results in an inert compound that is low in required tensile strength, ductility, creep resistance, and shrinkage, and is prone to micro- and macro-cracks.

On that account, reinforcement (rebar) was incorporated, which accounts for approximately 0.8% to 4% of the volume of the reinforced concrete (RC) and about 25% to 30% of the total RC cost. From an observation point of view, the manufactured steel bar provided a structural solution that left behind many other economic and ecological challenges (Kalaivani *et al*., 2020; Ogunjiofor *et al*., 2023; Zaragoza-Benzal *et al*., 2025). This provides a strong drive for this study. Previous studies opined that most structural failures are traceable to the substandard quality of rebar used on the job site due to cost-cutting (Qurix & Doshu, 2020) and human error.

Several research efforts for cost reduction encourage the reuse and recycling of waste materials and steel scraps (Falco, 2025; Raheem *et al*., 2021) for reinforcement in concrete, but the implication is the proliferation of unregulated materials, causing environmental pollution and multiple occupational health and safety issues, and accidents in major cities. Hence, an alternative construction material that could reduce the economic impact by minimizing construction costs, mitigating environmental carbon footprint effects (Imbabi *et al*., 2013), and maximizing structural strength becomes a compelling task for the built environment researchers and professionals.

Construction of infrastructures, housing projects, and related activities are predicted to contribute 18% of global carbon emissions (Adesina, 2020), making the production of construction materials and execution detrimental to the environment and unsustainable if efforts to reduce them are neglected. Additionally, the overall dead load of concrete components derived from traditional reinforced concrete, due to the load of rebar included, accounts for 0.8% to 6% of the total reinforced concrete component. Therefore, the percentage of steel in such reinforced concrete is significant to the total weight of the components (Ogunjiofor *et al*., 2023), resulting in additional dead load, serviceability challenges (maintenance), and the potential for damage or collapse of buildings. In recent decades, scholars have recommended reducing the dead load of structures, advocating for the use of nanostructured materials (UNCTAD, 2021); however, no political will has been dedicated to implementing these measures.

Globally, plain concrete is regarded as durable, weather-resistant (Rajendran & Yesudas, 2025; Joshi, 2016), and insulating against sound, thermal, and fire impacts, making it a dependable load-bearing construction material. However, concrete has some disadvantages, including but not limited to shrinkage, creeping, brittleness, and low tensile strength (He *et al*., 2022). Over the years, the weaknesses related to toughness and ductility have been significantly improved by the use of reinforcement bars (rebar) or fibers. Fibers from various sources, such as straw, steel, plastic, glass, and rubber, have been incorporated, and their inclusion in modern concrete production has been successfully exploited (Hassan & Saeed, 2024). Fiber-reinforced concrete, demonstrating strong performance in strength, although this practice dates back to ancient Egypt and Rome, in the contemporary era, it has received limited interest among the built environment professionals.

Recent trends in Recycled Tire Steel Fiber (RTSF) have led to the proliferation of studies attracting researchers who posit that there is a significant cost reduction and major environmental benefits in using RTSF over the Manufactured Steel Fibers (MSF) in fiber-reinforced concrete (Bobrowicz *et al*., 2022; Alshammari *et al*., 2023; Prieto *et al*., 2025). Albeit, there is comparatively better performance with RTSF concrete (Alshammari *et al*., 2023) in improving concrete`s ductility, toughness, reducing ingress of chlorine, and post-crack control, which makes it more sustainable and cost-effective. However, research findings have shown some backdrop attributes of RTSF, like irregular shapes, higher dosage requirement, or specific treatment, such as blending it with other fibers to offer optimal workability (Issa *et al*., 2022; Imbabi *et al*., 2013).

In the few studies on Steel Fiber Concrete (SF), scholars have placed a strong emphasis on associated demerits for its usage, particularly in relation to dosage increments, creating the need for incorporating other fibers, such as Polyethene Fibers (PF), which improved its performance significantly. The present study on RTSF with PETF underscores the economic and ecological importance since statistic indicates that 1000 million tires reach end-of-life and 300,000 million PET bottles are consumed annually. While there is growing interest in literature postulating the potential of blended or hybrid (RTSF with PETF) fiber-reinforced concretes, limited comparative and combined experimental data exist. Hassan and Saeed (2024) posit that adding polypropylene and steel fiber enhances compressive strength by 22%, flexural strength by 46%, and impact strength by 64%. Further empirical studies support the postulation that fiber-reinforced concrete production improves performance (Alshammari *et al*., 2023) regarding toughness, crack resistance, resistance to fire and high temperatures, prevents concrete spalling, controls plastic shrinkage, and extends the life of such concrete.

Despite its potential, there is a lack of systematic assessment to evaluate and compare the effects of hybrid fiber-reinforced concrete (RTSF with PETF) on compressive, tensile, and flexural strength to determine their effectiveness and suitability for structural components. Several complementary reports about fiber-reinforced concrete *(*Alshammari *et al*., 2023; Bobrowicz *et al*., 2022) as a sustainable alternative to cement concrete and as an effective retrofitting material have been published, but the study on waste plastic bottles (PETF) combined with RTSF is rare among scholars. Therefore, using RTSF blended with PETF in hybrid fiber-reinforced concrete emerges as a potential solution to provide important information for decision-making stakeholders and helps reduce the carbon emission footprint, which supports environmental protection and sustainable goals (Ihsan *et al*., 2022; Tsal *et al*., 2021). Objectively, the experimental study was structured to examine the influence of fiber-reinforced concrete, the blended or hybrid RTSF with PETF, on the mechanical behavior of conventional plain concrete. Whilst the compressive, tensile, and flexural strength of hybrid fiber-reinforced concrete (RTSF and PETF) in its hardened-cured state, and also the workability of the fresh concrete. Therefore, the experimental research data will add to the knowledge base of hybrid RTSF and PETF combinations in fiber-reinforced concrete production for construction sites and aid policymakers.

## Materials and Methods

This experimental study involved the preparation of three specimens, the control, A, (concrete without hybrid RTSF and PETF), samples of hybrid fiber-reinforced concrete constituent of RTSF and PETF, B, at different percentages of 0.5, 1.0%; 0.2%, 0.4, and the curing days (3, 7, 28 days) were marked $A_0$, $B_{1-3}$, and $C_{1-3}$, respectively. The test for workability and consistency on fresh, and strength on hardened concrete was conducted and analysed to infer comparative strength.

### *Materials*

Fibre-reinforced concrete materials sourced from recycled and reused household waste components, which include recycled used tire steel fibre, and polyethylene terephthalate used bottles, were blended in a percentage ratio to replace industrial fibres. This is in line with the international hierarchy policies and environmental waste management, and the reduction of waste generation domestically (Ihsan *et al*., 2022; Tsal *et al*., 2021). The fine aggregate particles distribution curve pattern is represented in Figure 1.

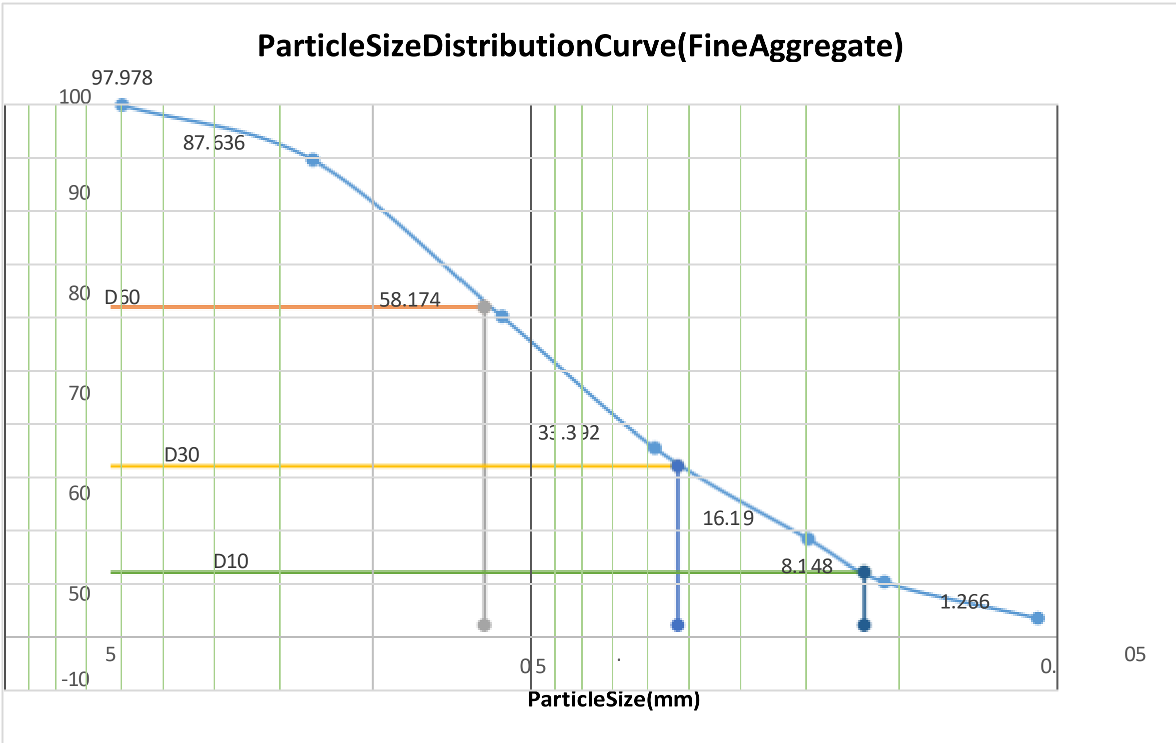


**Figure 1: Particle Distribution Curve**

**Results on Sieve Analysis (Fine Aggregate)**

| | |
|---|---|
| D60(mm) | 0.9213 |
| D30(mm) | 0.3830 |
| D10(mm) | 0.1643 |

Cc = Coefficient of Curvature = D60/D10 = 5.6080
Cu = Coefficient of Uniformity = D302(D10*D60) = 0.9692
Fineness Modulus = Sum %
Cumulative Retained/100 = 3.03

*Methods*

The binder was grade 42.5N Type I Ordinary Portland Cement, which conforms to the specification by NIS 444-1: 2003 and EN 197-1:2011. It is the available product from the construction market of the study area, sold in 50kg waterproof bags. The river bed type of fine and coarse aggregates procured from the crushed rocks was specifically controlled to ensure purity and consistency. The available portable water for consumption in the civil engineering campus laboratory of the University of Ibadan was used for the mixture. Crushed stone coarse aggregate passing through a 20mm sieve size and conforming to ASTM C33, while the fine aggregates are from the river bed. The Mix design method, the Department of Environmental – British Method (DOE), was adopted. A target strength of 40MPa for 30 to 60mm slump at 0.32 w/c. The density of the cement was designed to be 562.50kg/m$^3$, the fine aggregate was 569.625 kg/m$^3$, the coarse aggregate was 1057.8750kg/m$^3$, and the water was 180kg/m$^3$

*Mixing*

In this experimental work, the approach for batching was by weight in kilograms (Figure 2) for proportioning all constituents as shown in Table 2, and mixing of concrete was achieved in a 0.045m³ mechanical metal drum (concrete-mixer machine) for 3-5 minutes in accordance with BS ISO 18650-1,2:2021 and BS 1881-125, carried out in a controlled environment of the campus laboratory. Fixed parameter of water-to-cement ratio, cement, and some percentage of superplasticiser by weight of cement for all concrete production. The hybrid fibre-reinforced concrete (RTSF and PETF) for various percentages, $B_1$ as labelled.

**Table 2:** Composition of the Fiber-reinforced concrete mixture per batch

| S/N | Constituents | Unit | Batch | | |
|---|---|---|---|---|---|
| | | | A | B | C |
| 1 | Cement | kg/m$^3$ | 562.5 | 562.5 | 562.5 |
| 2 | River Sand | kg/m$^3$ | 569.63 | 569.63 | 569.63 |
| 3 | Crushed Stone | kg/m$^3$ | 1057.88 | 1057.88 | 1057.88 |
| 4 | Superplasticizer | kg/m$^3$ | 1.0% | 1.0% | 1.0% |
| 5 | RTSF | kg/m$^3$ | 0 | 0.50% | 1.00% |
| 6 | PETF | kg/m$^3$ | 0 | 0.20% | 0.40% |
| 7 | Water | kg/m$^3$ | 180 | 180 | 180 |

*Experimental Test on Fresh and Hardened Concrete*

Workability tests, shown in Figure 3 and Figure 4, for fresh concrete were conducted using the slump cone test, which conforms with ASTM C143-05, compaction factor in accordance with BS EN 12350-4:2000, and Vee-Bee consistency test in accordance with BS EN 12350-4:2000. Hardened concrete tests were conducted to conform to the British Standard, BS EN 12390-3:2019. Compressive cube test (BS EN 12390-1:2000), conducted on cured concrete cube formed in (150 x 150 x 150) mm metal moulds, while the slit tensile test (BS EN 12390-6:2000 & ASTM C496-04) was cast and compacted in layers into a plastic mould of (100 x 200) mm cylinders. The flexural test conforms with BS EN 12390-5:2009, cast in layers into a metal mould of 100 x 100 x 500 mm.

The method of curing used in Figure 5, was by immersion in water for 3 days, 7 days, and 28 days, thereafter proceeded with destructive method of compressive test. After the cubes were removed from water, they were allowed to drain well and weighed to obtain the density and crushed on a universal machine by compression, and tensile as shown in Figure 6, and Figure 7 respectively.

**Figure 2:** Weight Batching


**Figure 3:** Slump Measurement

**Figure 4:** Compaction Test

**Figure 5:** Water Curing

**Figure 6:** Cube Compressive test

**Figure 7:** Flexural test.

Experimental **Result and Discussion**

*Result*

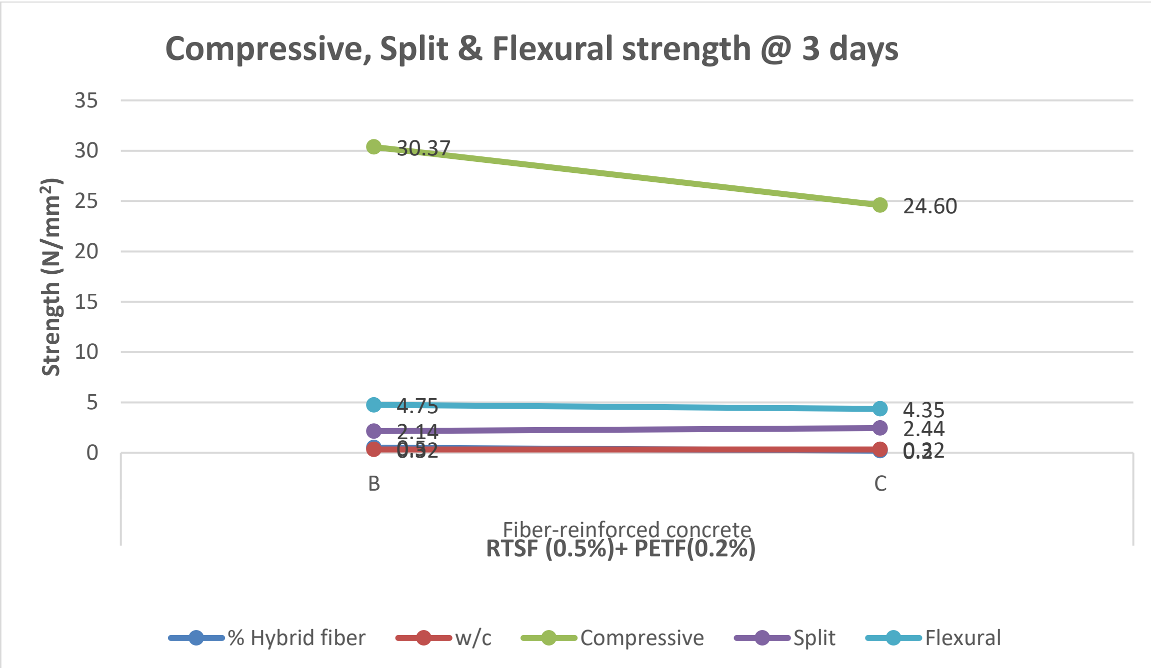


**Figure 8:** Variation of Strength vs Hybrid Fiber-reinforced Concrete @ 3 Days

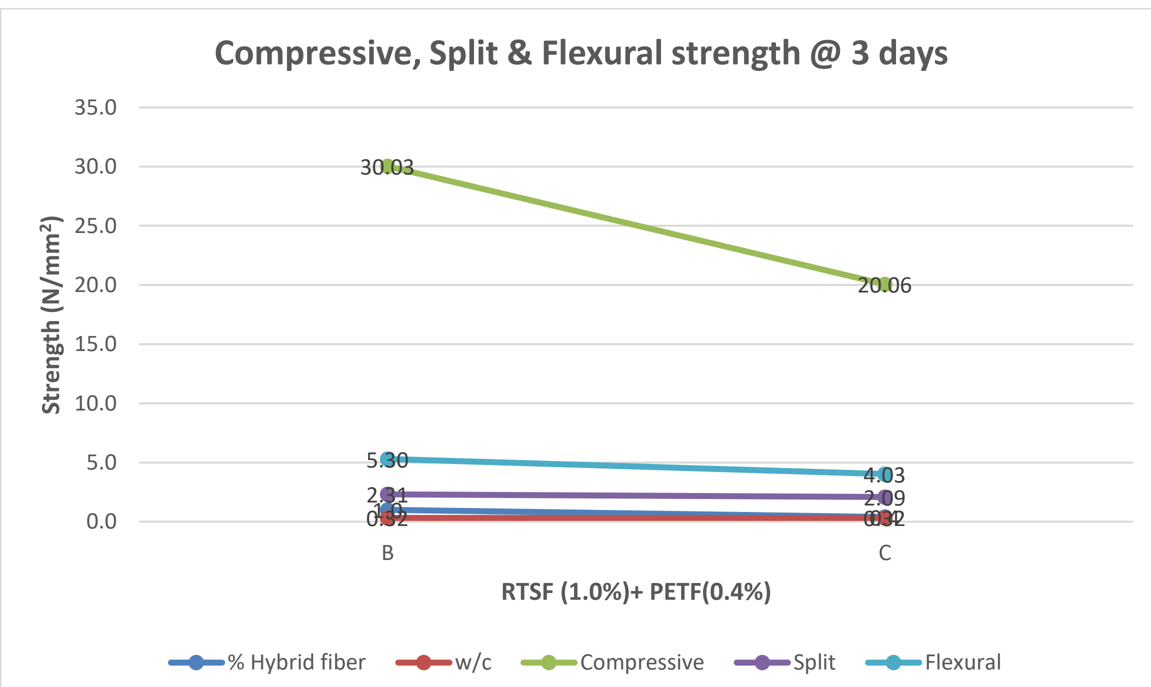


**Figure 9:** Variation of Strength vs Hybrid Fiber-reinforced Concrete @ 3 Days

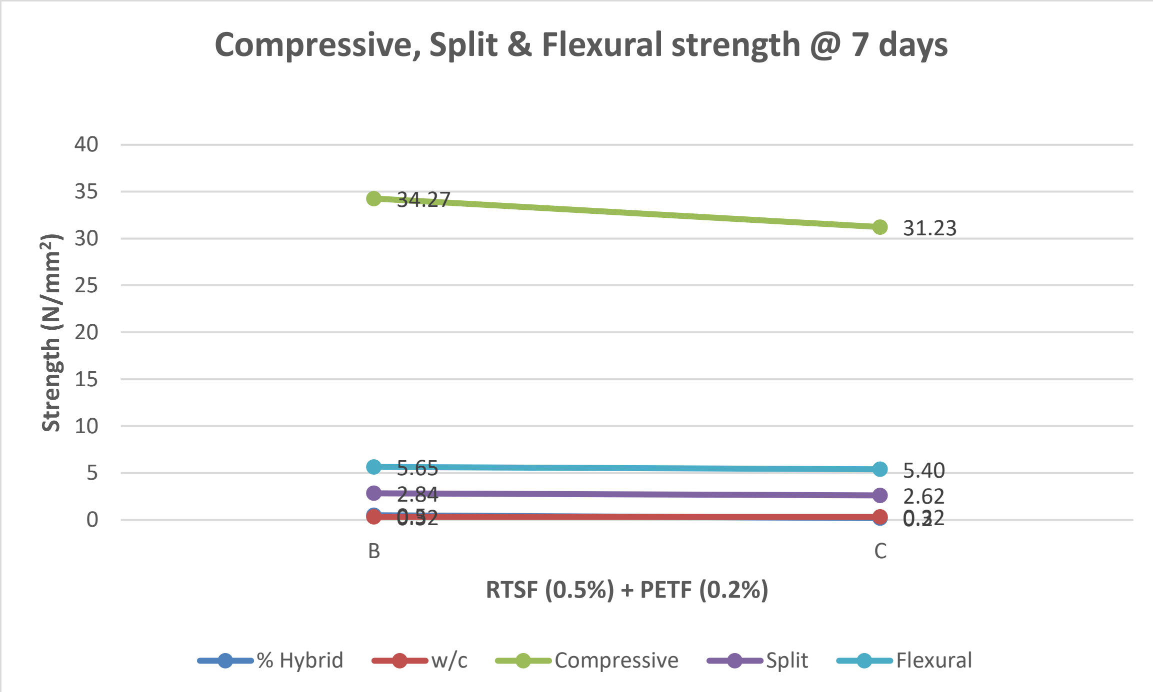


**Figure 10:** Variation of Strength vs Hybrid Fiber-reinforced Concrete @ 7 Days

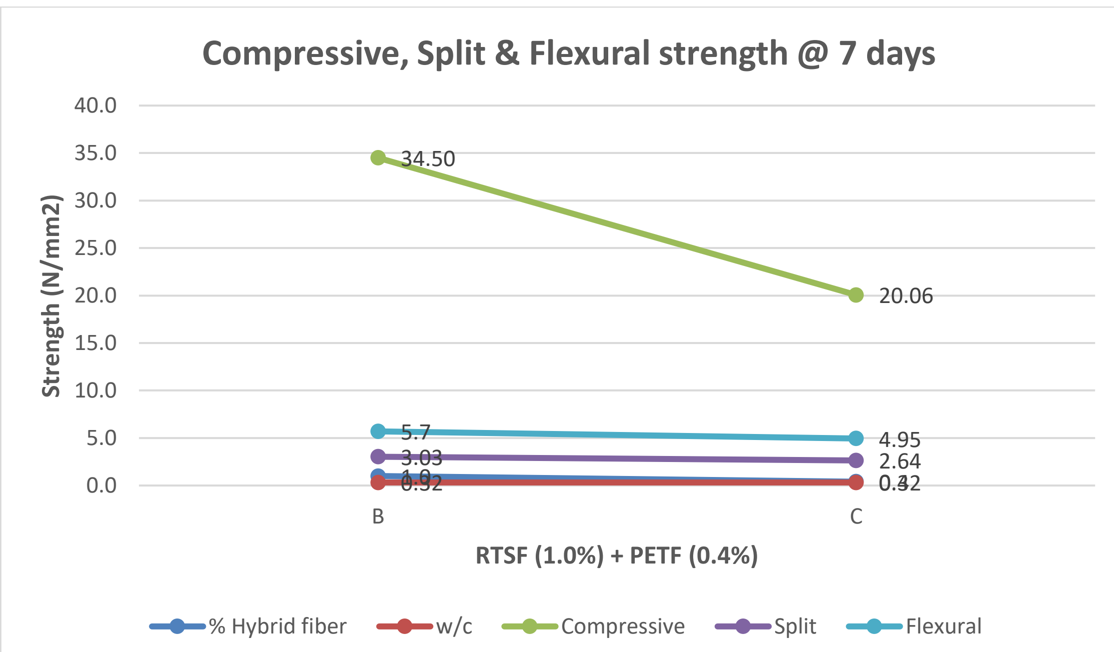


**Figure 11:** Variation of Strength vs Hybrid Fiber-reinforced Concrete @ 7 Days

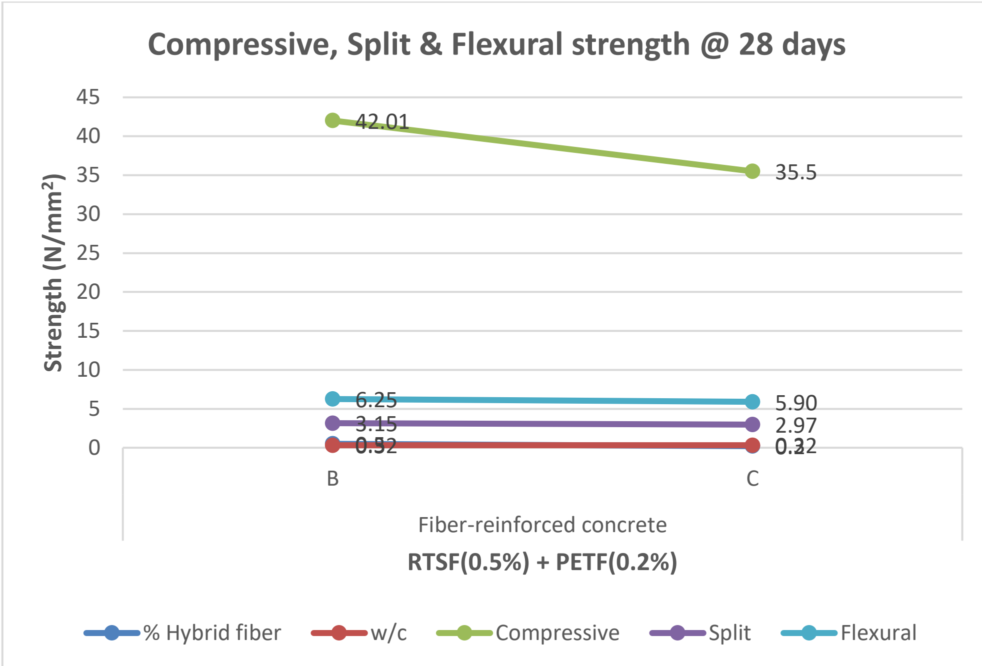


**Figure 12**: Variation of Strength vs Hybrid Fiber-reinforced Concrete @ 28 Days

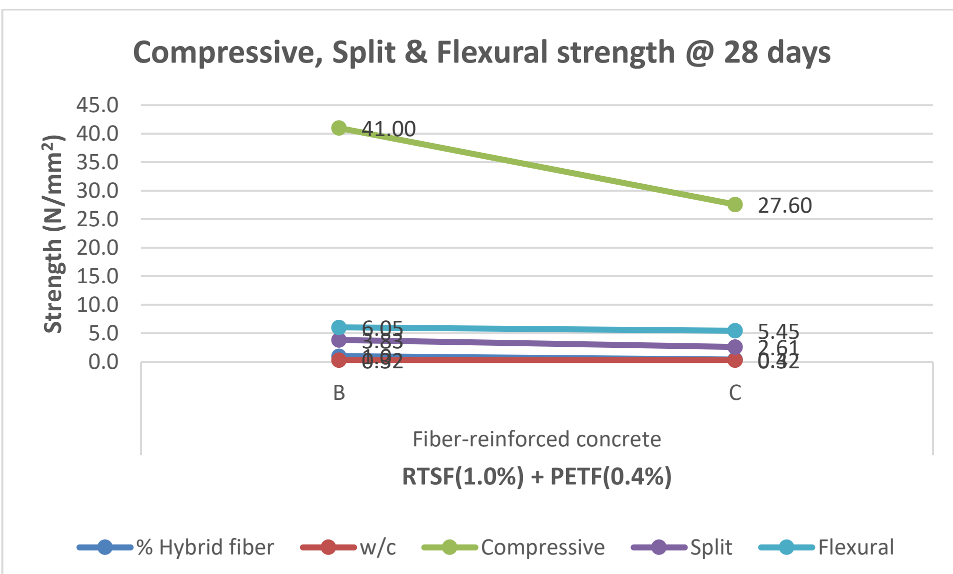


**Figure 13**: Variation of Strength vs Hybrid Fiber-reinforced Concrete @ 28 Days

*Discussion*

An observation of the fine aggregate reveals the uniformity indicated in the particle size distribution curve in Figure 1. The observed fresh concrete workability decreases as the additional quantity of hybrid fibers in RTSF with PETF increases compared with the control plain concrete, indicating that the hybrid fibers have a significant effect on the slump. The implication of this is that the RTSF requires more water and cement paste to cover its surfaces. This reduces the fluidity of the mixture, which agrees with the study by Zhang *et al*. (2024). However, the additional percentage of PETF in the hybrid fiber improves the mixture, but negatively influences workability of the hybrid as PETF is hydrophobic in nature (Issa *et al*., 2022).

According to the experiment, observations reveal a gradual increase in compressive, split, and flexural strength as the curing days increased; however, this trend was reversed when the PETF percentage in the hybrid fiber was increased. Figures 8 to 13 display the data in graphical forms and suggest that a maximum strength exists when the RTSF and PETF percentages are 0.5% and 0.2%. As viewed, the hybrid fiber-reinforced concrete in comparison with the plain concrete had rapid compressive strength at 3 days curing, which increased progressively on days 7 and 28 till the maturity age. At a further increase in the hybrid percentages to 1.0% and 0.40%, the experiment decreases in compressive strength. In contrast, the split and flexural strengths increase as the days progress from 3, 7, and 28 days for 0.5% and 0.2% of hybrid percentages. The addition of PETF may have impacted the hybrid fiber-reinforced concrete, which supports the study for toughness and cracks (Bobrowicz *et al.*, 2022; Zhang *et al*., 2024).

## Conclusion and Recommendation

The experimental study investigated the potential and mechanical properties of hybrid fiber-reinforced concrete in comparison with the conventional plain concrete with the view to proffer a more economical and ecologically sustainable construction and building material. Hybrid fiber-reinforced concrete was a collection of end-of-life tires, RTSF blended with waste plastic bottles, PETF. Experimental outcome drawn and conclusion reveals that the presence of PETF percentage negatively impacts the workability of the fresh concrete but enhances the toughness and crack resistance of the hardened concrete. Albeit the existence of a higher percentage of RTSF in the hybrid fiber-reinforced concrete improves the compressive strength concurrently with the conventional plain concrete. Further research is recommended to analyze the economic and ecological potentials of plastic waste, PETF, and end-of-life tire, RTSF, quantitatively. Also, further testing with water resistance, microstructure (SEM), etc.

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