



Environmentally Sustainable Concrete Using Fly Ash and Recycled Tyre Steel Fibers

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Abstract: The global construction industry is currently confronted with major environmental concerns arising from the substantial carbon emissions produced during cement manufacturing and the growing accumulation of non-biodegradable waste materials, especially waste tyres from automobiles. Developing sustainable construction materials has therefore become critical to reducing environmental impact while ensuring the structural performance of modern infrastructure. This research focuses on developing eco-friendly concrete by incorporating two sustainable materials — fly ash, an industrial by-product generated from coal-fired thermal power plants, and recycled tyre steel fibers (RTSF), extracted from discarded vehicle tyres. In this study, fly ash is utilized as a partial replacement for cement to minimize cement consumption, while RTSF serves as a secondary reinforcement material to improve the concrete's mechanical properties. This study investigates the utilization of recycled tyre steel fibers (RTSF) in concrete at varying proportions within a defined range for experimental analysis. The research aims to evaluate the influence of incorporating RTSF at different dosage levels—0%, 0.25%, 0.40%, and 0.55% of the concrete volume using M25 grade concrete. The optimum dosage of recycled tyre steel fibers (RTSF) concrete is carried out amongst the taken various percentages. In addition, the inclusion of fly ash in varying percentages of 10%, 20% and 30% as a partially replacement of cement has been done in recycled tyre steel fibers (RTSF) concrete with the considering optimum dosage of fibre. An experimental program was executed to quantify the mechanical properties of the concrete. This evaluation included standard tests for compressive strength, split tensile strength, and flexural strength.

Keywords: Environmentally sustainable concrete, Fly ash, Recycled tyre steel fibers (RTSF), Mechanical properties, Sustainable construction.

I. INTRODUCTION

The construction sector is essential for building global infrastructure, yet it presents one of the most serious challenges regarding environmental pollution and degradation. This is largely due to its high demand for natural resources, vast energy requirements, and the considerable carbon emissions produced during cement manufacturing. The enormous worldwide consumption of concrete means that the cement industry is estimated to account for nearly 7% of the world's total greenhouse gas emissions, accelerating climate change [1]. The environmental intensity is high: generating 1 kilogram of cement releases about 0.75 to 1 kilogram of greenhouse gas [2]. Hence, nearly 88 percentage of the carbon footprint of concrete is associated with cement production [3,4]. Additionally, the improper disposal of non-biodegradable materials such as discarded automobile tyres has created severe ecological challenges, including land pollution and threats to human health. These environmental challenges have motivated researchers and engineers to investigate sustainable solutions that minimize waste while improving the performance of construction materials. To promote sustainable construction, a practical approach involves using industrial by-products like fly ash in concrete. This material, produced during coal combustion, acts as a pozzolanic supplement, improving the concrete's workability, long-term strength, and durability. By substituting for cement, fly ash reduces overall cement consumption and minimizes the carbon emissions associated with its production.

Another area of innovation is the incorporation of recycled tyre steel fibers (RTSF), which are recovered from waste automobile tyres. These fibers possess high tensile strength and elasticity, making them suitable as secondary reinforcement in concrete. Their inclusion improves crack resistance, ductility, and post-cracking behavior, addressing one of the key limitations of plain concrete—its brittle nature. Furthermore, using RTSF helps mitigate the environmental hazards associated with tyre disposal while contributing to circular economy principles.

Economical concrete production incorporating steel fibers can be achieved by utilizing waste steel fibers, which are significantly more cost-efficient than commercially manufactured ones. The process of obtaining these waste fibers involves separating the steel wires embedded in discarded tyres, followed by further shredding and grinding of the pre-treated tyre material. The remaining steel wires are then recovered through a magnetic separation process. This approach emphasizes the potential of recycled tyre steel fibers to serve as a cost-efficient and environmentally sustainable substitute for conventional steel fibers in concrete production.



This study investigates the combined utilization of recycled tyre steel fibers and fly ash to produce sustainable and high-performance concrete. The research aims to evaluate the influence of incorporating RTSF at varying proportions—0%, 0.25%, 0.40%, and 0.55% by volume of concrete—using M25 grade mix. The optimum fiber content is determined based on performance among the selected proportions. Furthermore, fly ash is incorporated as a partial replacement for cement at levels of 10%, 20%, and 30% in the RTSF concrete, considering the identified optimum fiber dosage. The primary objective of this study is to identify the optimal combination of materials that improves the mechanical properties of concrete, such as compressive, split tensile, and flexural strength. This research further aims to demonstrate that waste-derived materials can serve as effective substitutes for conventional concrete constituents without compromising performance, thereby promoting sustainable construction practices and supporting environmental preservation.

1.1 Importance of the study

The present study holds significant importance in advancing sustainable construction practices and addressing two major environmental concerns: the excessive carbon emissions from cement production and the accumulation of waste automobile tyres. By utilizing fly ash as a partial replacement for cement and incorporating recycled tyre steel fibers (RTSF) as secondary reinforcement, this research promotes the development of eco-friendly and resource-efficient concrete. The use of fly ash not only minimizes the dependency on cement—one of the most energy-intensive materials in construction—but also contributes to the effective utilization of an industrial by-product that would otherwise pose disposal challenges. Similarly, the inclusion of RTSF provides a productive use for waste tyres, thereby reducing the volume of non-biodegradable material in landfills and lessening the environmental burden of tyre waste management. From an engineering perspective, this study is important because it investigates the potential of combining these two waste-derived materials to achieve desirable mechanical properties such as compressive, tensile, and flexural strength. The findings can guide the optimization of mix proportions for achieving both strength and sustainability objectives. Economically, the use of recycled materials can lower production costs, making high-performance concrete more affordable for large-scale infrastructure projects. Overall, the study contributes to sustainable material innovation by demonstrating that industrial by-products and waste materials can be successfully reused in structural concrete without compromising performance. It aligns with global goals of reducing carbon footprints, conserving natural resources, and moving toward circular economy practices in the construction sector.

1.2 Objectives

1. To determine and compare the mechanical properties (compressive, tensile, and flexural strength) of concrete containing recycled tyre steel fibers (RTSF) with a conventional concrete mix.
2. To determine the optimum recycled tyre steel fibers (RTSF) dosage amongst taken dosages.
3. To evaluate and compare the compressive strength, split tensile strength, and flexural strength of conventional concrete and recycled tyre steel fiber (RTSF)–fly ash concrete by considering the optimum dosage of RTSF among the selected proportions.

II. MATERIAL AND THEIR PHYSICAL PROPERTIES

The characteristics of materials employed in concrete production play a crucial role, as they have a direct impact on its strength and overall performance. Prior to mix preparation, a series of preliminary tests were performed to assess the properties of each constituent material. The primary materials utilized in this research include Ordinary Portland Cement (OPC) of 53 grade, water, fine aggregates, and coarse aggregates. All these materials were examined according to the respective Indian Standard specifications to verify their suitability for concrete production. Tests such as determination of cement setting time, sieve analysis for both fine and coarse aggregates, evaluation of specific gravity, fineness modulus, and water absorption were conducted to ensure uniformity and quality. These assessments confirm that the materials selected for the mix design are appropriate for achieving the required workability and compressive strength of the concrete.

2.1 Cement

Table 1: Physical Characteristics of OPC – 53 Grade	
Properties	Results
Fineness (SSA), m ² /kg — by Sieve Analysis	285
Standard Consistency (%)	30%
Initial Setting Time	40 min
Final Setting Time	245 min
Soundness	2.12 mm
28 days Compressive strength	56.14 Mpa



OPC, known for its superior strength and stable performance, was used as the principal cementitious component in this investigation. Ambuja 53-grade cement was specifically adopted for the mix preparation. When mixed with water, it undergoes hydration, forming a hardened structure and releasing heat. The typical cement content ranges from 350 to 450 kg/m³ to achieve strength while preventing shrinkage cracks. The fineness of OPC 53 grade generally varies between 350 to 500 m²/kg, ensuring proper strength development.

2.2 Water

Water is a crucial component in concrete production as it initiates the hydration process of cement, which is essential for strength development. To ensure good quality and durability, the water used must be free from impurities such as salts, acids, alkalis, or any other harmful substances. In this experimental study, tap water conforming to the requirements of the relevant Indian Standard specifications was utilized. The water–cement ratio was kept at 0.5 to ensure an optimal balance between workability and strength of the concrete mix. Generally, water suitable for drinking is considered appropriate for preparing concrete of satisfactory quality.

2.3 Aggregate

Aggregates form the bulk of concrete, comprising nearly 60%–75% of its total volume, and play a vital role in determining its mechanical strength and durability. Generally, 2 types of aggregates are utilized—fine aggregates (sand) and coarse aggregates (crushed stone or gravel). The overall performance, strength, and longevity of concrete are greatly influenced by the quality, hardness, and cleanliness of these aggregates. Aggregates must be strong, non-reactive, and free from impurities to ensure long-term durability. Proper grading and sieve analysis are essential to control particle size distribution, which affects workability, water–cement ratio, and strength. The selection of suitable aggregates ensures stability, wear resistance, and uniform quality in the concrete mix.

2.3.1 Fine Aggregate (FA)

Table 2: Physical Properties of Sand of Zone- II .	
Properties	Results
Sp. Gravity of Sand	2.67
Fineness Modulus of Sand	3.0
Water Absorption (%)	1.1
Silt Content in % (finer than 75 μ)	2.2

Fine aggregate, commonly referred to as sand, is generally sourced from natural deposits such as riverbeds or produced through the crushing of stones. It comprises particles that pass through a 4.75 millimeter sieve and are retained on a 150 micrometer sieve, serving as a filler material that fills the voids between coarse aggregates and improves the workability of concrete. In the present study, fine aggregate corresponding to Zone II as specified in IS 383:1970 was utilized, and all testing procedures were conducted in accordance with IS 2386:1963.

2.3.2 Coarse Aggregate (CA)

Table: - 3 Physical Properties of coarse aggregate.	
Properties	Results
Sp. Gravity of Aggregate	2.78
Aggregate crushing value	29.32%
Aggregate Abrasion Value (%)	13.36%
Water Absorption (%)	0.91
Aggregate Impact value (%)	11.19

As per the requirements, the strength improvement can be achieved by using the crushed angular aggregates due to its good interlocking manners. The used coarse aggregates are having particle size larger than 4.75 mm and the max. size of coarse aggregate should be depends on the requirements and it should be 10 mm or 20 mm of size for use in practical.



2.4 Fly ash

Fly ash is a fine mineral residue used as a **supplementary cementitious material (SCM)** in concrete, primarily consisting of silica, alumina, iron oxide, and calcium oxide (with variations depending on the source). Its inclusion enhances the concrete's workability, durability, and long-term strength. Based on its chemical makeup, fly ash is categorized into different classes. **Class F fly ash**, typically derived from burning anthracite or bituminous coal, has a low calcium content and therefore requires a separate cementing agent to achieve strength development. In this study, Class F fly ash was selected to partially replace cement, thereby promoting a more sustainable concrete mix.

2.5 Fibers

Recycled Tyre Steel Fibers (RTSF) were produced from twisted and cut bead wires recovered from discarded tyres. According to ISO 16650:2004, the tensile strength of new tyre bead wires varies between 1500 N/mm² and 2300 N/mm², based on wire thickness [5]. Even after extended use, these wires maintain significant tensile strength and flexibility, making them effective for improving the tensile performance of concrete.

III. RESULT ANALYSIS

3.1 Compressive Strength Test

Cube specimens, measuring 150 x 150 x 150 mm were prepared using M25 grade concrete for the compressive strength testing. The recycled tyre steel fibers (RTSF) were incorporated at varying proportions of 0%, 0.25%, 0.40%, and 0.55% by volume. For each mix proportion, nine cubes were prepared, including nine control specimens without fibers. In this study, fly ash was used as a partial replacement for cement by weight at proportions of 10%, 20%, and 30%. In addition, the optimum percentage of recycled tyre steel fibers (RTSF) was determined based on experimental results. The compressive strength of recycled tyre steel fibers fly ash concrete which contains optimum dosage of recycled tyre steel fibers with the inclusion of various proportions of class F fly ash is determined. To ensure proper compaction during casting, a table vibrator was utilized. The surfaces of the cubes were subsequently leveled and finished. After a 24-hour setting period, the concrete cubes were demolded and submerged in a water-curing tank for proper hydration. Compressive strength tests were performed on the specimens at curing ages of 7, 14, and 28 days, strictly following the guidelines of IS 516:1959. For each test, the maximum failure load (N) was recorded, and the compressive strength (N/mm²) was calculated using the formula:

$$\text{Compressive Strength (N/mm}^2\text{)} = \text{Failure Load (N)} / \text{Cross-Sectional Area of Cube (mm}^2\text{)}$$

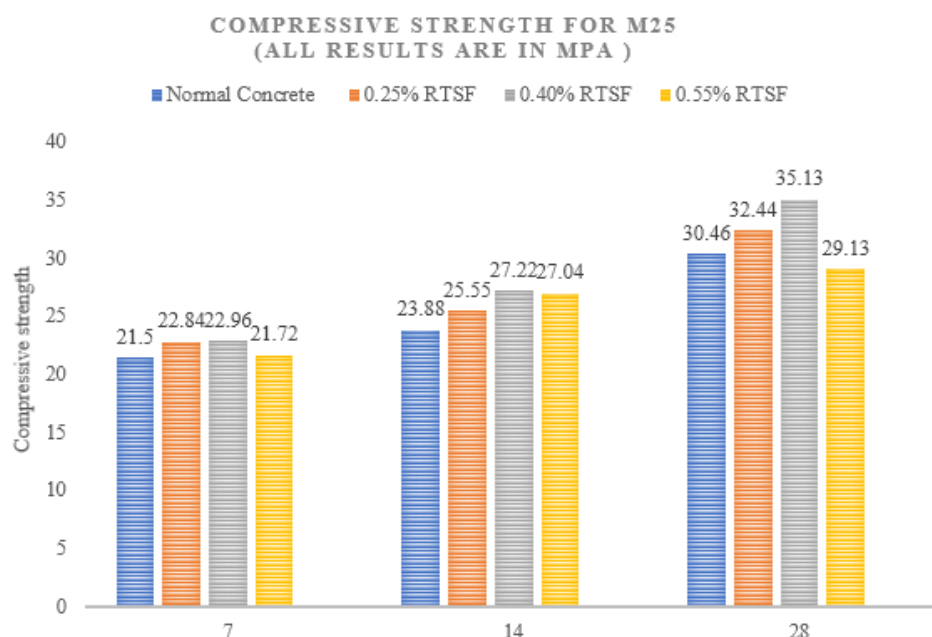


Fig:1 Compressive Strength Results of M25 Grade Concrete with Varying Recycled Tyre Steel Fiber (RTSF) Content

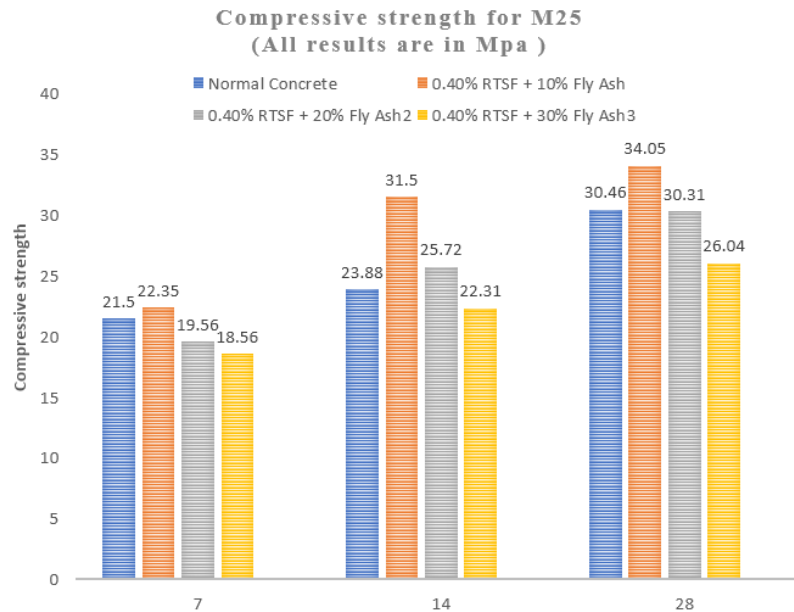


Fig:2 Compressive Strength Results of M25 Grade Concrete Containing Optimum RTSF with Varying Fly Ash Replacement Percentages

3.2 Split Tensile Strength Test

Cylindrical concrete specimens measuring 150 mm in diameter and 300 mm in height were cast using M25 grade concrete to evaluate the split tensile strength. Recycled tyre steel fibers (RTSF) were incorporated into the mix at varying volume fractions of 0%, 0.25%, 0.40%, and 0.55%. For comparison, nine control specimens without fibers and nine specimens for each RTSF proportion were prepared to study the effect of fiber inclusion on the tensile performance of concrete. Fly ash was used as a partial replacement for cement by weight, at substitution levels of 10%, 20%, and 30%. The split tensile strength of concrete containing the optimum percentage of RTSF combined with different proportions of Class F fly ash was also assessed. After 24 hours of casting, all specimens were demolded and placed in a water-curing tank to ensure proper hydration. The split tensile strength tests were performed using a Compression Testing Machine (CTM) after curing periods of 7, 14, and 28 days, following the procedure specified in IS 5816:1999. During testing, the maximum load sustained by each specimen prior to splitting failure was recorded. The split tensile strength was calculated using the standard formula.

$$\text{Split Tensile Strength (MPa)} = (2P) / (\pi DL)$$

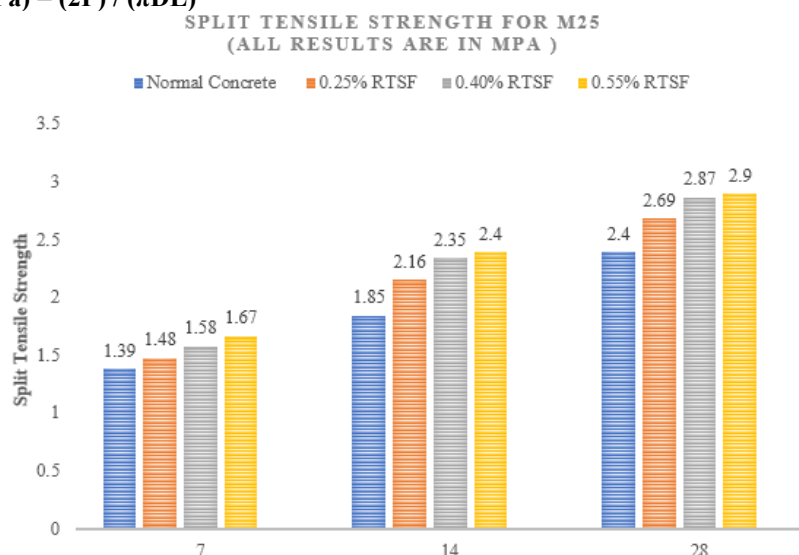


Fig:3 Split Tensile Strength Results of M25 Grade Concrete with Varying Recycled Tyre Steel Fiber (RTSF) Content

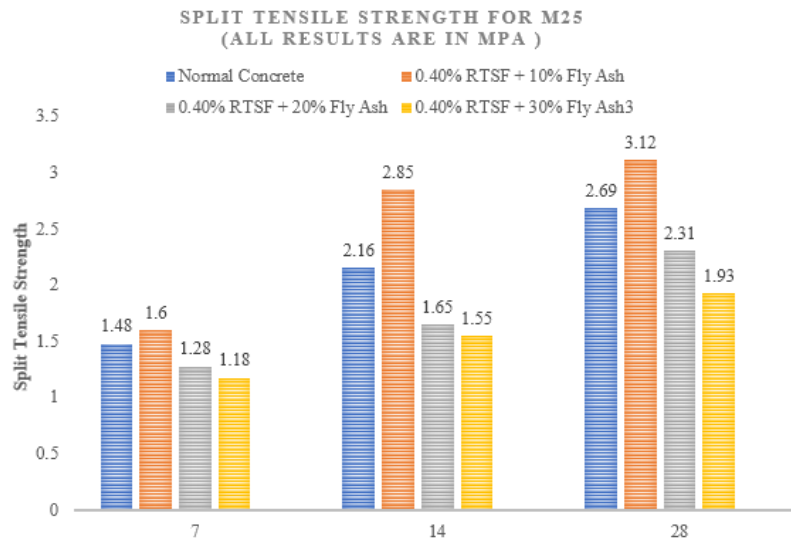


Fig:4 Split Tensile Strength Results of M25 Grade Concrete Containing Optimum RTSF with Varying Fly Ash Replacement Percentages

3.3 Flexural Strength Test

M25 concrete was used to cast beam specimens, which measured 150mm by 150 mm by 700 mm, for the purpose of a flexural strength assessment. The recycled tyre steel fibers (RTSF) were incorporated at varying proportions of 0%, 0.25%, 0.40%, and 0.55% by volume. For each mix proportion, nine beams were cast, along with nine control beams without fibers, to evaluate the influence of RTSF on the flexural behavior of concrete. Fly ash was used as partially replacement of cement by weight and it was taken as 10%, 20% and 30% respectively. In addition, the flexural strength of recycled tyre steel fibers fly ash concrete which contains optimum dosage of recycled tyre steel fibers with the inclusion of various proportions of class F fly ash is determined. After casting, the top surfaces of all beam specimens were properly leveled and finished to achieve a smooth surface. After being demolded at 24 hours, the specimens were cured in water for proper hydration. Flexural strength was evaluated at 7, 14, and 28 days using a three-point loading setup compliant with IS 516:1959. The ultimate load before failure was recorded for each test. Three beams were tested per age, and the mean flexural strength was used as the reported value. The flexural strength was computed using the following relation:

$$\text{Flexural Strength (MPa)} = (3PL) / (2bd^2)$$

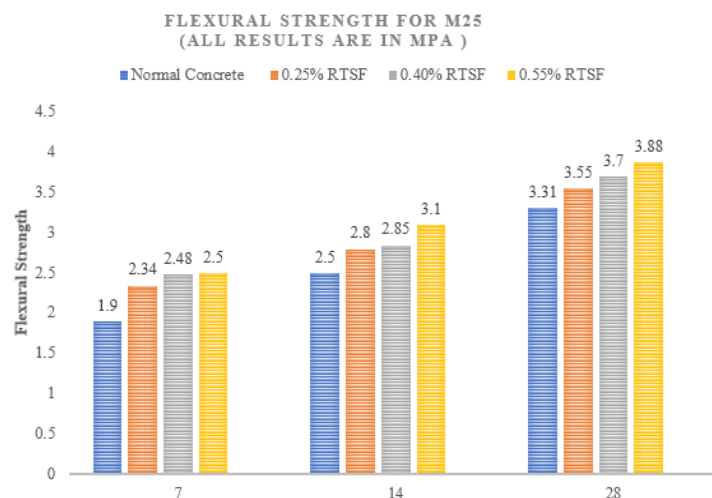


Fig:5 Flexural Strength Test Results of M25 Grade Concrete with Varying Recycled Tyre Steel Fiber (RTSF) Content

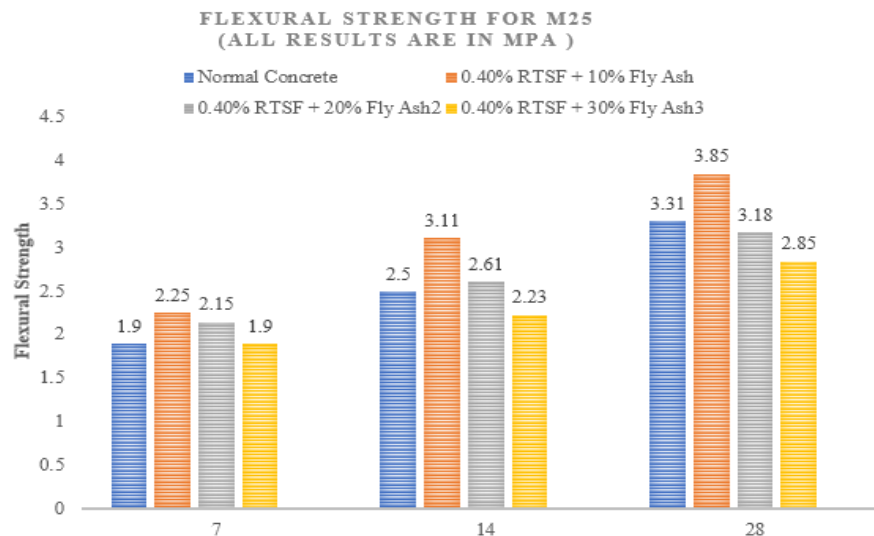


Fig:6 Flexural Strength Results of M25 Grade Concrete Containing Optimum RTSF with Varying Fly Ash Replacement Percentages

IV. CONCLUSION

The primary objective of this study is a two-phased experimental assessment of concrete properties. The first phase involves determining the impact of various recycled tyre steel fiber (RTSF) contents on concrete performance compared to a non-fibrous control. The second phase focuses on the synergistic effects of substituting cement with different fly ash proportions while utilizing the most effective RTSF content established in the preceding phase.

The inclusion of recycled tyre steel fibers (RTSF) enhanced the compressive strength of concrete at both 7 and 14 days of curing when compared to the control mix. However, after 28 days, the mix containing 0.55% fiber exhibited a marginal reduction in compressive strength relative to the plain concrete. Among all the fiber proportions evaluated, the mixture incorporating 0.40% RTSF achieved the maximum compressive strength, surpassing the performance of both fiber dosages as well as the conventional mix.

An increase in fiber content resulted in a consistent improvement in the split tensile strength of concrete at all curing ages compared to the mix without fibers. Among the different proportions evaluated, the concrete containing 0.55% recycled tyre steel fibers exhibited the highest split tensile strength.

The inclusion of recycled tyre steel fibers (RTSF) led to a noticeable enhancement in the flexural strength of concrete at all curing ages compared to the control mix. Among the different fiber dosages tested, the specimen containing 0.55% RTSF achieved the maximum flexural strength. The findings clearly demonstrate that increasing the fiber content contributes to a gradual and consistent improvement in the flexural performance of concrete.

Based on the experimental investigation, it can be concluded that the concrete mix incorporating 0.40% recycled tyre steel fibers along with 10% fly ash as a partial replacement for cement exhibited the highest compressive strength among all tested mixes. In contrast, the mix containing 0.40% fiber combined with 30% fly ash demonstrated comparatively lower compressive strength, indicating that higher fly ash content may adversely affect the early strength development of concrete.

The concrete mix containing 0.40% recycled tyre steel fibers combined with 10% fly ash demonstrated superior performance in terms of both flexural and split tensile strength. In comparison, the mix with the same fiber dosage and 30% fly ash replacement exhibited relatively lower strength values for these parameters. Overall, the inclusion of recycled tyre steel fibers led to a significant enhancement in the split tensile and flexural strength of concrete, with strength generally increasing as the fiber content was raised.

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