

Performance of Concrete Reinforced With Recycled Tyre Steel Fibres at Elevated Temperatures

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Abstract: Concrete is very low in ductility; to improve this property, the use of steel fibres spread in all its sections to reinforce it, has been studied by many researchers. Steel fibres are short metallic materials of small diameter, manufactured from steel ore, in the absence of adequate manufacturing steel factories in a third world country like Nigeria, the utilization of steel fibres derived from recycled waste tyre wire as reinforcement in concrete has been investigated in this study, focusing on its impact on the mechanical properties of concrete after exposure to elevated temperatures. Concrete specimens with varying fibre dosages (0%, 0.5%, 1%, and 1.5%) were evaluated for compressive, split tensile, and flexural strengths after 28days curing, at ambient temperature and high temperatures. Furthermore, concrete reinforced with steel fibres exhibited improved compressive strength retention after exposure to temperatures ranging from 200°C to 800°C compared to control concrete. However, there was no significant strength retention of split tensile strength at elevated temperatures. There was a direct correlation between flexural strength loss after elevated temperature exposure, and increase in fibre dosage. Microstructural analysis revealed differences in the morphology of concrete specimens before and after exposure to high temperatures. Overall, this study underscores the beneficial effects of incorporating recycled waste tyre wire as fibre reinforcement in concrete, offering a sustainable solution for enhancing the mechanical properties and resilience of concrete structures in both normal and high-temperature environments.

Keywords: Steel Fibre Reinforced Concrete (SFRC), Elevated Temperature, Waste tyre, Microstructure

I. Introduction

Concrete has evolved into the most important building material worldwide. This is attributed to its utilization of natural resources found universally and due to its versatility, offering architectural freedom [1]. Conventional plain concrete although very versatile lacks many desirable properties, like low ductility which is an intrinsic cause of its low tensile strength, this has led to the introduction of reinforced cement concrete [2]. Some researchers have as a result of this, suggested the distribution of reinforcing fibres throughout the entire cross section of the concrete, to help as a remedy to the weaknesses faced by conventional plain concrete [3]. This method of reinforcing the brittle matrix of concrete is called Fibre Reinforced Concrete (FRC). Steel Fibre Reinforced Concrete is (SFRC) is produced by incorporating dispersed and discontinuous, short steel fibres into a traditional concrete mix. Incorporating waste tyre wire into concrete serves three primary objectives: firstly, enhancing certain properties of conventional concrete; secondly, addressing the mounting environmental issue of accumulating waste tyres annually; and thirdly, diminishing the demand for natural resources in concrete production [4]. The Nigerian automobile industry produces a significant amount of waste tyres each year, a number expected to rise with population growth. Thousands of tons of scrap tyres accumulate in landfills across the country annually [5]. Therefore, it's crucial to establish environmentally friendly methods for disposing of waste tyres.

[6] opined that, with increase in popularity of SFRC, extensive studies have been carried out on its mechanical and durability properties after exposure to destructive conditions, among various conditions exposed to fire has been found to be one of the most challenging. During a fire, structures endure exceedingly high temperatures, resulting in substantial physical and chemical alterations in concrete constituents. Fire poses a significant risk to tunnels, high-rise buildings, and underground structures, making it one of the most serious hazards they face [6]. Therefore, to withstand the threat of fire, the investigation of mechanical properties of SFRC at elevated temperatures is of great significance.

In recent times, researchers have also investigated the effects of high temperatures on several material properties of SFRC [7], [6], [8], [9]. The addition of steel fibres has been found to increase the peak compressive, tensile and flexural strength of concrete at room temperature and after exposure elevated temperatures [8], [9], it has been reported that the addition of steel fibres to concrete lead to improved strength retention after elevated temperature exposure [10], [6], [11], [8], [9]. Previous studies examining the impact of steel fibres on concrete spalling after exposure to elevated temperatures have yielded inconsistent results. Some studies, in their review of SFRC exposed to elevated temperatures, reported no effect of steel fibres on spalling [12], [13], while others reported reduced spalling in SFRC when compared to plain concrete [10]. According to [14] Most research have focused on compressive strength of SFRC after exposure to elevated temperature.

Hence, the present study was conducted to investigate the tensile, flexural, and compressive strength of SFRC subsequent to exposure to elevated temperatures, alongside an examination of the microstructure of SFRC.

II. Materials And Methods

A. Materials

The materials used for this study are as follows; cement, fine aggregate, coarse aggregate, water and steel fibre. Details of the materials are as follows:

1) *Ordinary Portland cements*: Locally manufactured Dangote brand 3X 42.5 cement was utilized in all mixes. The chemical, physical and mechanical properties of the cement conform to the provisions of [15].

2) *Aggregates*: The aggregates used for the experiment were fine and coarse aggregates that were in conformity with the provisions of [16]. The fine aggregate used is sharp river sand with a maximum size of 4.75mm while the coarse aggregate used is crushed gravel with a maximum size of 20mm, both sourced from Zaria, the result is shown in Figure 1.

3) *Water*: Clean potable water, as specified by [17], available within Ahmadu Bello University, Zaria.

4) *Steel Fibres*: The steel fibres were obtained from the Zango abattoir in Sabon Gari LGA, Zaria, Kaduna State, the abattoir used the waste tyres as fuel for preparing meat, creating steel wires, as such the steel fibres used, were created by pyrolysis process, tyre wires of 1.67mm diameter obtained from waste heavy-duty truck tyres were used, they were cut into discrete sizes of 50mm. Preliminary tests were conducted on the steel fibres at the Department of Metallurgical and Material Engineering Laboratory, Ahmadu Bello University, Zaria. They were found to conform tensile strength requirements specified in [18] and the [19]. The result is presented in Table 1.

Table 1: Properties of Recycled Steel Fibre

Specimen	Breaking Force (N)	Tensile Strength (MPa)	Elongation at break (%)
Maximum	4300	1938.01	21.5
Minimum	1870	844.5	6.96
Mean	3005	1350.84	10.67

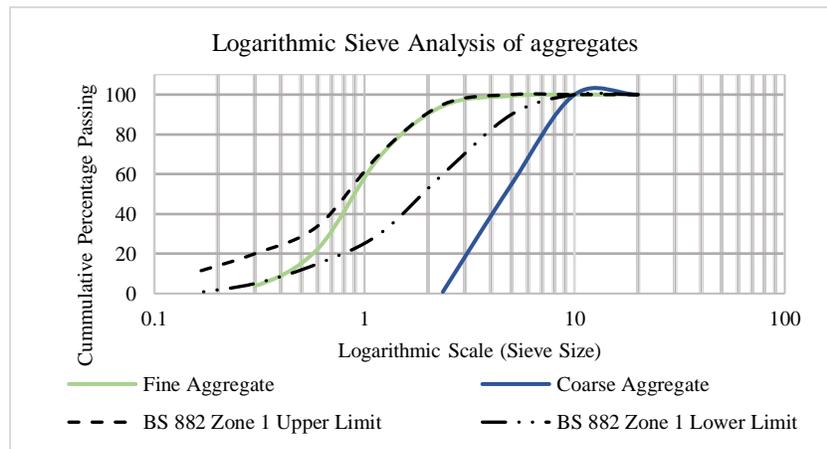


Figure 1: Particle Size Distribution of Aggregates

5) *Mix design*: Concrete Grade 25 was used in this study, the design has been carried out as per Building Research Establishment BRE design method, the quantity of materials as per mix design are tabulated in Table 2

Table 2: Quantity Of Materials

Materials	Cement	Water	Aggregate		Fibre		
			Fine	Coarse	0.5%	1%	1.5%
Quantity (Kg/m ³)	370	210	675	1150	12	24	36

A total of one hundred and eighty specimens were produced, consisting of four mixes; the control, 0.5% Fibre, 1% fibre and 1.5% fibre.

B. Methods

The study was carried using the following processes which include;

1) *Test on fresh properties of concrete*: Fresh property test carried out on concrete containing various dosages of the fibre include:

Workability Test: The slump values were measured in accordance with [20]. A slump cone with a height of 300 mm, a bottom diameter of 200 mm, and a top diameter of 100 mm was used for slump measurement.

2) *Test on hardened properties of concrete:* In order to determine the compressive strength of concrete, uniaxial compression test was carried out on 100mm x100mm x100mm cubes in accordance with [21], the split tensile test was carried out on test cylinders measuring 100mm x200mm in accordance with [21], flexural strength test was carried out on prisms measuring 100mm x100mm x500mm, using the three-point bending method, in accordance with [22], all tests were carried out after 28days curing.

Resistance to Elevated Temperature: Concrete samples underwent exposure to temperatures 200, 400, 600 and 800 degrees Celsius for 2 hours using a Nabertherm electric furnace at the Department of Chemical Engineering Laboratory, Ahmadu Bello University, after 28 days curing. The heating rate was set at 10 degrees Celsius per minute until reaching the desired peak temperatures, where they were maintained constant for the duration of 2 hours. Subsequently, the samples were allowed to cool naturally to room temperature before undergoing tests for compressive strength, flexural strength, splitting tensile strength, and microstructure analysis [23].

III. Results And Discussions

A. Properties of Fresh Concrete Specimen

1) *Slump:* Figure 2 displays the outcomes of the slump test performed on fresh concrete specimens. It illustrates the slump values for concrete mixes with different fibre dosages: 0%, 0.5%, 1%, and 1.5% additions. As anticipated, the test results indicate a decrease in workability with the increase in fibre volume. The addition of fibres restricts the mobility of the concrete mixture, leading to reduced workability, consistent with the findings presented in [24].

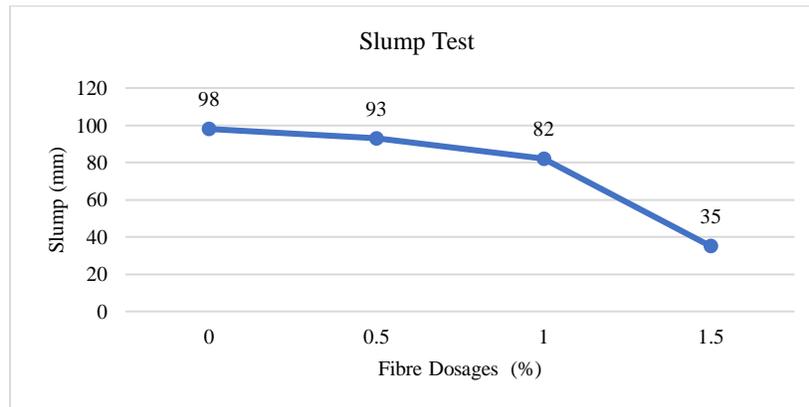


Figure 2: Slump Values at Fresh stage

B. Properties of Hardened Concrete Specimen

1) *Effect of Elevated Temperature on Hardened Concrete:* The hardened concrete specimens were subjected to elevated temperatures of 200°C, 400°C, 600°C and 800°C, after 28days curing age.

Residual compressive strength of hardened concrete specimen: Figure 6 displays residual compressive strength of concrete samples after exposure to temperatures from 200°C to 800°C, compared to ambient temperature. At 800°C, significant strength reduction was observed, with 1% dosage showing the least reduction 51.87% and 1.5% dosage the highest 58.88%. 0% and 0.5% dosages had reductions of 54.07% and 52.3% respectively. There is improved strength retention compared to 0% fibre dosage, in the 0.5% and 1% fibre dosage this is in line with decreased strength loss reported by [8] and [9].

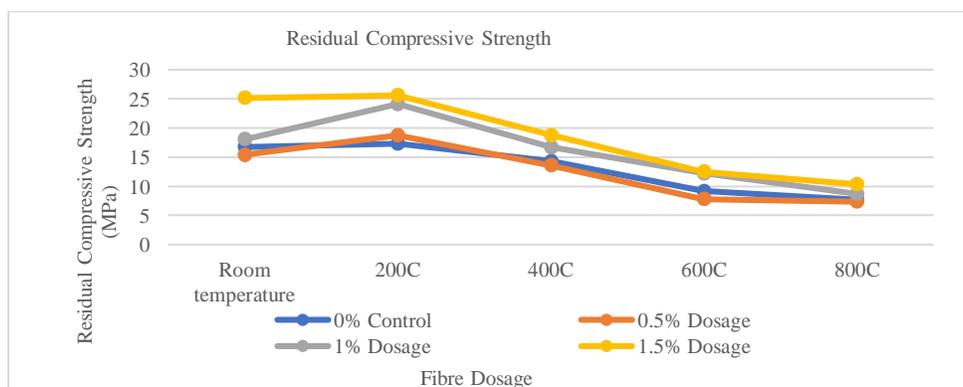


Figure 3: Residual Compressive strength after elevated temperature exposure

Residual split tensile strength of hardened concrete specimen: Figure 7 shows the residual split tensile strength of concrete subjected to 200°C, 400°C, 600°C and 800°C elevated temperatures alongside the control concrete specimen at room temperature. At 800°C, significant strength reduction was observed, with 0.5% dosage showing the least reduction 72.23% and 1% dosage the highest 79.01%. 0% and 1.5% dosages had reductions of 76.07% and 75.26% respectively. There is insignificant improved strength retention in 1.5% and 0.5% fibre dosage, this is not in-line with [8] and [9].

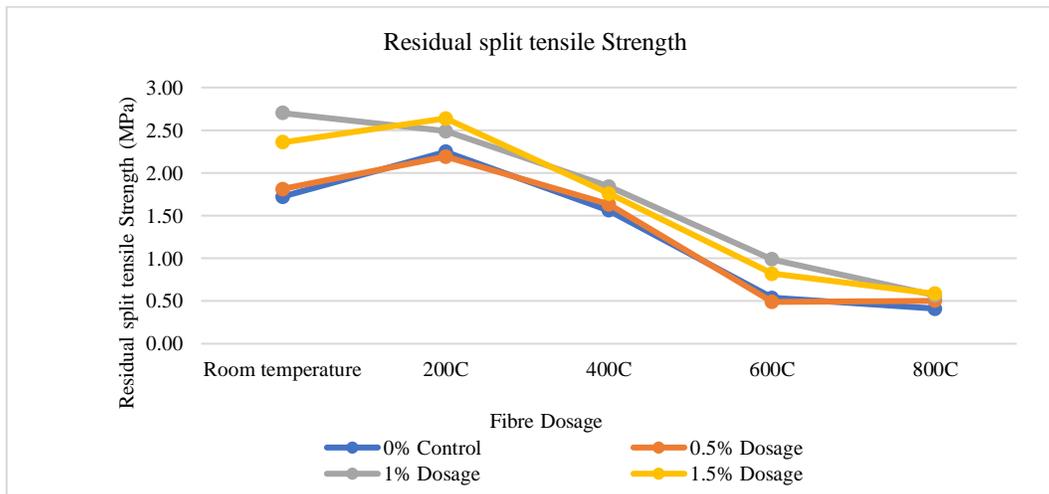


Figure 4: Residual Split Tensile Strength of Hardened concrete Specimen

Residual flexural strength of hardened concrete specimen: Figure 8 shows the residual flexural strength of concrete subjected to 200°C, 400°C, 600°C and 800°C elevated temperatures, at 800°C, significant strength reduction was observed, with 0% dosage showing the least reduction 39.3% and 1.5% dosage the highest 58.55%. 0.5% and 1% dosages had reductions of 45.24% and 48.46% respectively. The results show increasing flexural strength loss with increase in fibre dosage, this is not accordance with results reported by [8], [25] and [9].

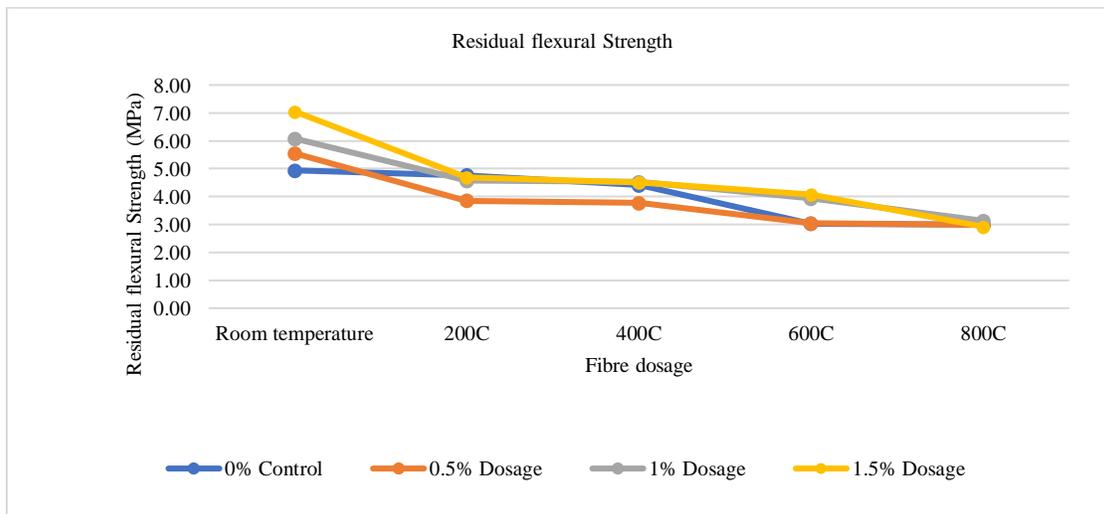


Figure 5: Residual Flexural Strength of Hardened Concrete Specimen

C. Microstructural examination of concrete exposed to elevated temperature

Figure 6 show the Scanning Electron Microscope (SEM) images of concrete with fibre dosages of 0% and 1.5% at ambient temperature and after exposure to 800°C. At room temperature there is good bonding and small pores with presence of tiny cracks at the interfacial zones, due to hydration reaction of the Calcium-Silica-Hydrate (CSH) gel, at 800°C there are long cracks on the specimen majorly along the Interfacial Transition Zone (ITZ), as a result of differential thermal expansion of aggregates and cement paste in the ITZ. There is development of large pores and rough patterns across the cement paste to show dehydration of concrete specimen, as against a smooth and consistent surface at room temperature.

For SFRC cement paste is noticeably denser around steel fibre at room temperature, with less microcracks and pores, at 800°C there are more dislodged loose particles all over the specimen with some noticeable pores interconnected by cracks, this cracks now run around the ITZ between the steel fibre and the cement paste, as stated previously due to different thermal expansion

coefficient of the steel fibre, aggregates and cement paste. The pores in the control concrete are significantly larger than the pores in the SFRC specimen after exposure to 800°C.

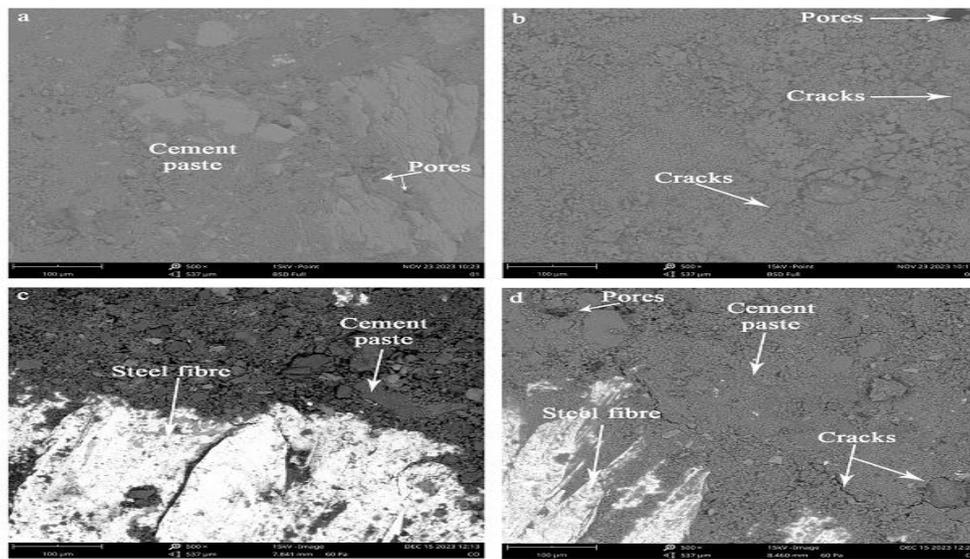


Figure 6: SEM Images of concrete specimen exposed to 800°C elevated temperature: (a) Control before exposure; (b) Control after exposure; (c) SFRC before exposure; (d) SFRC after exposure

IV. Conclusions

- i. Recycled waste tyre wire as fibre reinforcement has significant positive effect on the compressive, split tensile and flexural strengths of concrete at 0.5%, 1% and 1.5% weight dosage.
- ii. Concrete reinforced with recycled tyre steel fibres have higher compressive, tensile and flexural strength than control concrete, after exposure to high temperatures of 200°C, 400°C, 600°C and 800°C.
- iii. There is improved compressive strength retention in concrete reinforced with recycled tyre steel fibres, compared to control concrete, after exposure to elevated temperatures of 200°C, 400°C, 600°C and 800°C.
- iv. There is no significant improvement of split tensile strength retention after exposure to elevated temperatures by the addition of recycled tyre steel fibre
- v. There's a direct correlation between higher steel fibre dosage and increased loss of flexural strength.

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