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EXPERIMENTAL STUDY ON STEEL FIBRE-REINFORCED NATURAL AGGREGATE CONCRETE

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Abstract

The rising volume of pollution is a significant threat to achieving the United Nations' goal for a sustainable society. Various approaches have been used to tackle pollution, including recycling wastes into completely new products or utilizing them to improve other materials. In this respect, this article presents the results of an experimental study conducted on waste steel fiber sourced from waste tyres in concrete production. The fibers measuring 2, 4, and 6 cm were utilized using dosages of 0.5, 1, and 1.5% by mass of cement. The natural aggregate which is a bya -a product of the Precambrian deposits of the Bida trough was utilized as coarse aggregate. Iron moulds measuring 150 x 150 x 150mm were used for concrete production and were demoulded after 24 hours and cured. The optimum 28-day compressive strength of 27.19 N/mm^2 was recorded with a 4 cm fiber length and 0.5% fiber content. This represented a 36.36% gain in the 28-day compressive strength of the concrete when compared to the control.

Keywords: ***Compressive Strength, Natural aggregate, Reinforced Concrete, Steel Fibre.***

I. INTRODUCTION

The global increase in the number of waste tyres poses a great threat to the sustainability of the environment. Reports from countries in the European Union (EU), China, the United Kingdom (UK), and Nigeria reveal that the increase in the amount of available waste tyres is a major hurdle to achieving the goals of the United Nations for a green environment [1]. According to a study [2] more than a billion tyres are used for replacement every year globally with more than half of this figure being abandoned and waiting to be disposed of. Over a billion discarded tyres are produced worldwide. The accumulation of these tyres is a significant problem because tyre component materials are exceedingly complex and make natural degradation impossible. This necessitates the

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careful management of this massive quantity of trash. Waste tyres can be managed using various methods, including material recovery, energy recovery, retreating, export, and landfill disposal [2]. In Nigeria, the automobile sector generates about 10 million tyres each year. Of this Fig. 2 million wastes are generated. These wastes pose health challenges and are environmentally unfriendly [3]. This situation is aggravated by the absence of a scrap tyre waste collecting system as well as designated specially constructed landfill sites in the country for tyre wastes. This further highlights the need for a comprehensive national solid waste management policy that would incorporate this present scrap tyre menace. Recycling is still a nascent concept in Nigeria and as such has not received much attention from the government [4].

Aggregates occupy about 60-80% of the volume of normal-weight concrete; hence, their characteristics influence the properties of concrete. As opined by a study [5], the compressive strength of concrete depends on the aggregates' proportion used for production in addition to other factors. Aggregates used in concrete production are obtained either from natural sources or by crushing large-sized rocks. Coarse aggregate bonds with cement paste during the hydration process to form cement concrete, whereas fine aggregates are utilized to fill the gaps between the coarse aggregate particles. Some of the constituents of concrete have become very expensive because of high demand and are gradually becoming scarce. This reality has led engineers and researchers to seek the use of alternative materials. Several researches with different materials have been conducted with several recorded successes [6].

Natural Aggregates (NA) occur in the middle of the Niger basin of Nigeria in several Million metric tons. The Natural deposit of aggregates in Bida is generally located in and around the Bida area, Niger State, Nigeria. Located about 250km northeast of Bida inland from the federal capital city of Abuja. The natural deposit aggregates are extensively used in Bida for building constructions and domestic dwelling units.

The use of this NA sourced from Bida for concrete production has gained wide acceptance with the dwellers of the Bida basin the expenses in the production of crushed granite and its labor-intensive nature [7]. Against this background, investigating the potential application of waste tyre components in the production of NA concrete to encourage waste tyre recycling in Nigeria is timely and justifiable.

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II. CONSTITUENTS OF STEEL FIBRE-REINFORCED NATURAL AGGREGATE CONCRETE (SFRNAC)

Traditionally, concrete is made of cement, fine and coarse aggregates, and water. But, in the case of steel, fiber-reinforced natural aggregate concrete production, the constituents are cement, fine and coarse aggregate (NA), steel fiber reinforcement (extracted from waste tyres), and water. Fine and coarse aggregates are bonded with the cement paste during the hydration process to form cement concrete. The fine aggregate is utilized to fill the gap between the natural aggregate particles. Water is also an important component in concrete because it allows the other constituents to mix properly. Reinforced steel fiber adds strength and durability.

III. MATERIALS AND METHODS

A. Cement

Ordinary Portland Cement (OPC) Dangote brand was used throughout the production of the steel fiber-reinforced natural aggregate concrete. The cement was stored on a raised wooden platform at room temperature to prevent damage.

B. Fine Aggregate

A fine aggregate that is free from dirt and deleterious substances was obtained from a river bank in Kpakungu, Minna, Niger state, Nigeria. This fine aggregate was transported to the Civil Engineering departmental laboratory of the Federal University of Technology, Minna, Niger state, Nigeria. The fine aggregate conformed to the requirements for fine aggregate as specified in BS 882 (1992).

C. Coarse/Natural Aggregate

The Natural aggregate (NA) used in this research was sourced from Bida in Niger State, Nigeria. The particle size ranged between 5 to 20mm. It conformed to the specification for natural aggregate as specified in BS 882 (1992). The Natural aggregate (NA) is presented in Fig. 1.

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Fig. 1. Natural aggregate

D. Water

The water used was sourced from the borehole at the departmental laboratory of Civil Engineering, Federal University of Technology, Minna, Nigeria. It was ensured that the water was potable and clean. It satisfied the requirements stipulated in BS EN 1008 (2002).

E. Steel Fibre

The steel fiber used in this research work was obtained by the Pyrolysis process (burning of the waste tyre). The steel fiber had a diameter of 0.89 mm and was cut into lengths of 2, 4, and 6cm. Three steel fiber volume fractions were used: 0.5, 1.0, and 1.5% by weight of cement. The steel fiber is presented in Fig. 2.

Fig. 2. Steel fibre

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Fig. 3.: Fresh properties test in progress

F. Methods

Table I presents the breakdown of the proportions of the constituent materials used for concrete production.

Table I: Mix quantities of SFRNAC constituents

S/N	% Replacement Steel Fibres	Water (kg)	Cement (kg)	Sand (kg)	Gravels (kg)	Steel Fibres (g)
Control	0%	4.50	10.00	15.32	26.92	0.00
2cm	0.50%	4.50	9.95	15.32	26.92	50.00
	1%	4.50	9.90	15.32	26.92	100.0
	1.50%	4.50	9.85	15.32	26.92	150.0
4cm	0.50%	4.50	9.95	15.32	26.92	50.00
	1%	4.50	9.90	15.32	26.92	100.0

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	1.50%	4.50	9.85	15.32	26.92	150.0
6cm	0.50%	4.50	9.95	15.32	26.92	50.00
	1%	4.50	9.90	15.32	26.92	100.0
	1.50%	4.50	9.85	15.32	26.92	150.0

G. Compressive Strength Test of SFRNAC

This test provides us with an idea about all the characteristics of concrete. Compressive strength is the ability of a material or structure to carry the loads on its surface without any crack or deflection. A material under compression tends to reduce the size; while in tension, size elongates. The test was performed according to BS EN 12390-3 (2019). Concrete cubes measuring 150×150 × 150 mm were cast and utilized for this research. Each cube was placed on the universal testing machine and subjected to loading until failure occurred, the load at failure for each cube was noted and concrete compressive strengths were obtained using Equation (1).

Area of the specimen = 22,500 mm^2

$$\text{Compressive Strength} = \frac{Load}{Area}\ (N/mm^2) \qquad (1)$$

IV. RESULTS AND DISCUSSION

A. Specific Gravity of Fine Aggregate BNA and Cement

The results of the specific gravity of fine aggregate and Natural aggregate (NA) are presented in Tables II and III. The specific gravities obtained for fine aggregate and NA were 2.65 and 2.60, respectively. These values fall within the 2.6 - 2.7 limits for Natural aggregates [8]. This implies that the fine aggregate and NA can be conveniently used for concrete production.

Table II: Specific gravity of fine aggregate

Trial Number	**1**	**2**	**3**
Wt. of empty jar (W1)	46.00	43.60	69.00
Wt. of jar + sample (W2)	84.22	85.72	96.21
Wt. of jar + sample + water (W3)	168.53	168.18	185.25
Wt. of jar + Water (W4)	144.80	142.00	168.20
Specific Gravity	2.64	2.64	2.68
Average Specific Gravity		2.65	

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Table III: Specific gravity of Natural Aggregate (NA)

Trial Number	1	2	3
Wt. of empty jar (W1)	46.00	43.60	69.00
Wt. of jar + sample (W2)	93.20	84.20	95.00
Wt. of jar + sample + water (W3)	173.80	167.10	184.10
Wt. of jar + Water (W4)	144.80	142.00	168.20
Specific Gravity	2.59	2.62	2.57
Average Specific Gravity		2.60	

B. Sieve Analysis of Fine Aggregate

The result of percentage passing sieves (BS 410) complied with the grading limit of fine aggregate in zone II, NIS 87:2004; therefore, the aggregate is suitable for concrete production. From the curve (Fig.4), the fine aggregate coefficient of uniformity (CU) is 7.42 which is greater than 6, hence the soil is considered as well graded. Also, the coefficient of concavity (CC) is 2.15, which is between 1 and 3; this means that the aggregate is well-graded.

C. Sieve Analysis of Natural Aggregate

Fig. 5 reveals the curve for the NA is steep, which is an indication that the aggregate contains particles of almost the same sizes and is deemed to be poorly graded aggregate. The coefficient of uniformity (CU) of this aggregate is 1.93 which i s less than 6. Hence the NA is considered poorly graded [9].

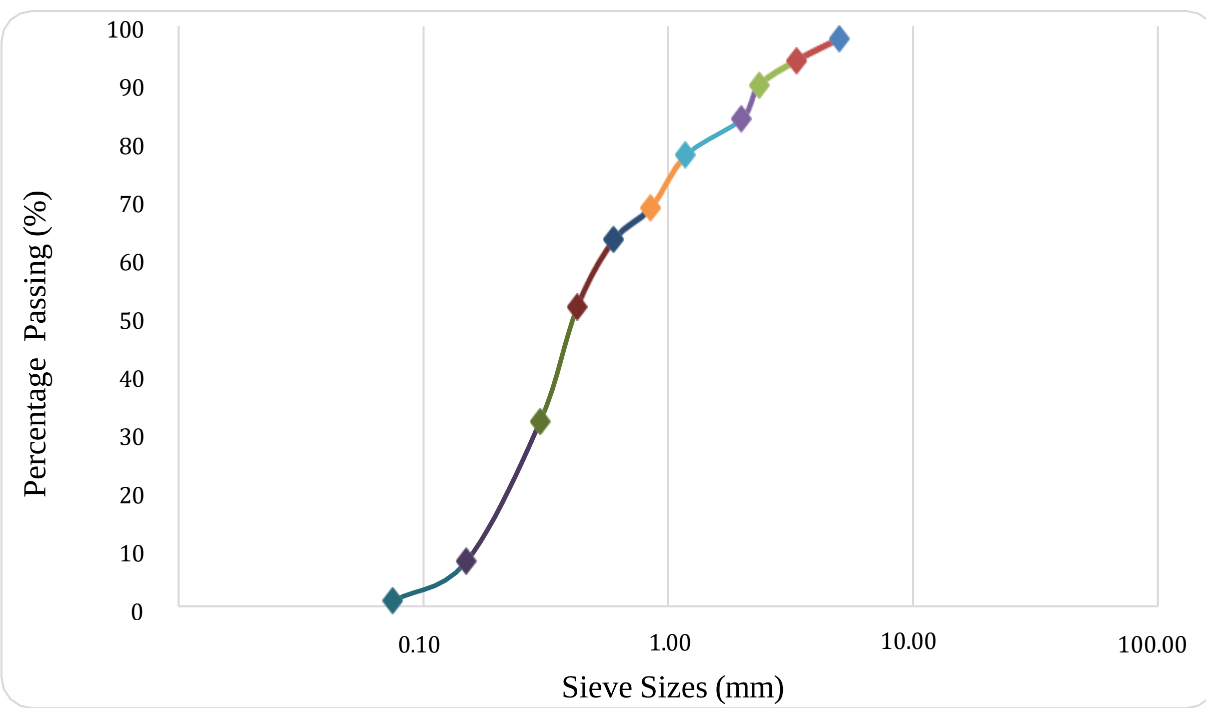

Fig.4. Sieve analysis of fine aggregate (BS 812: 1995)

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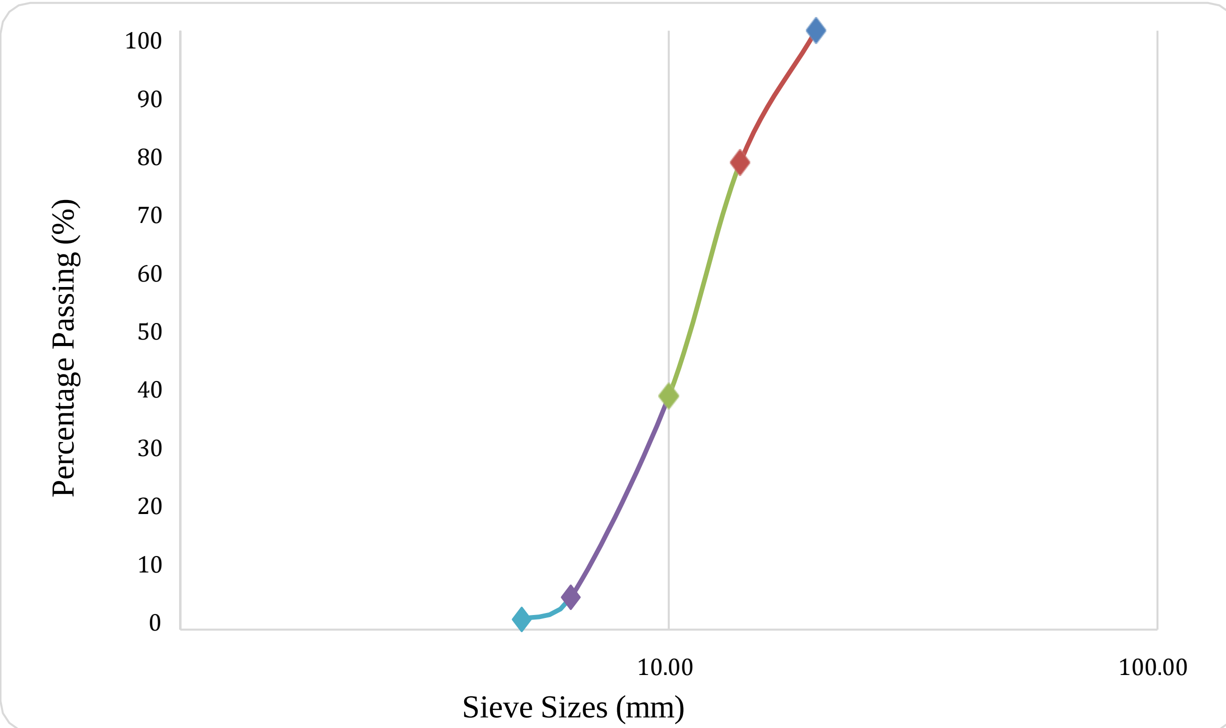

Fig. 5. Sieve analysis of NA (BS 812:1995)

D. Aggregate Impact Value (AIV) of NA

The average result of AIV of NA following BS 812 (1995) is 18.6%. BS-EN 13043 (2002) identified that the AIV of material for concrete pavement must not exceed 30% and must be less than 45% for concrete wearing surface. Therefore, this aggregate with an AIV of 18.6, which is less than 30%, is suitable for concrete-wearing surfaces.

E. Compressive Strength Test of SFRNAC

The 7 and 28-day compressive strength of the SFRNAC were obtained in accordance with BS EN 12390 – 3 (2019) and are presented in Fig. 6 and 7, respectively. The 7-day results show that the mix containing a 4cm length of steel fiber at 1% volume returned the highest compressive strength value of 19.20N/mm^2 while the control mix returned a compressive strength value of 16.39 N/mm^2. Furthermore, the 28 days compressive strength of SFRNAC shows that mix with 4cm length of steel fiber at 0.5% fiber content returned the highest compressive strength value of 27.19N/mm^2 with the percentage increase of 27.8% when compared with control which had a 28 days compressive strength of 19.64N/mm^2.

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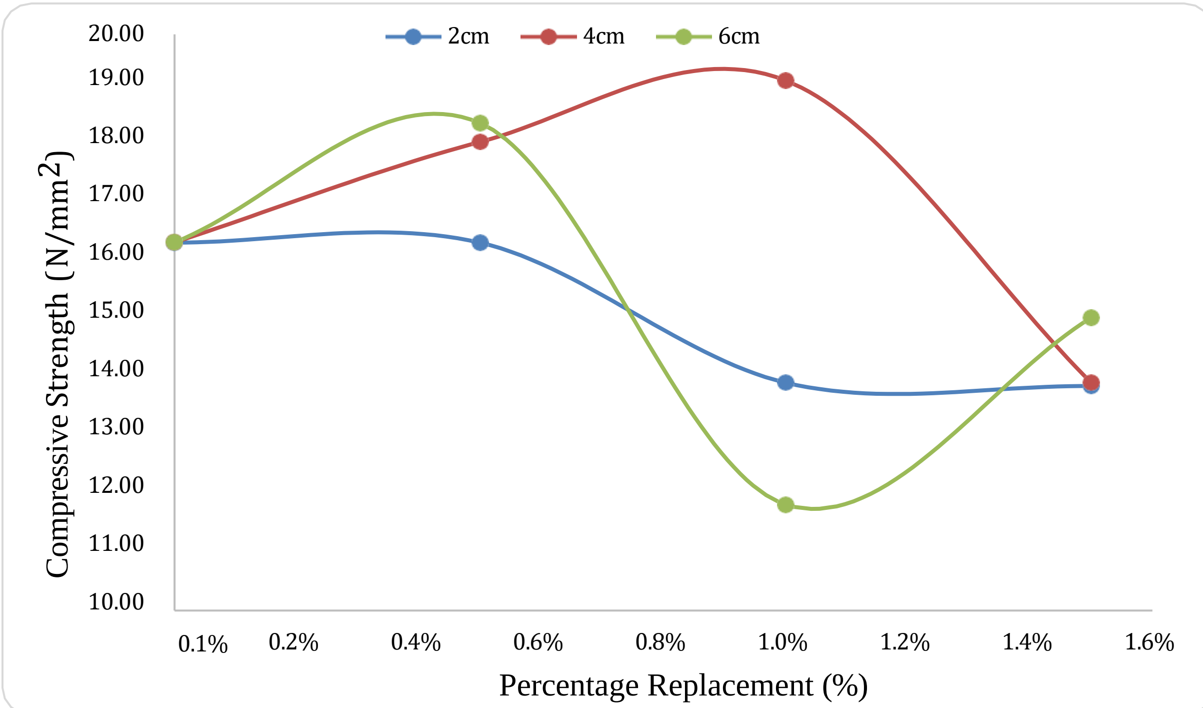

Fig. 6. 7 days compressive strength of SFRNAC

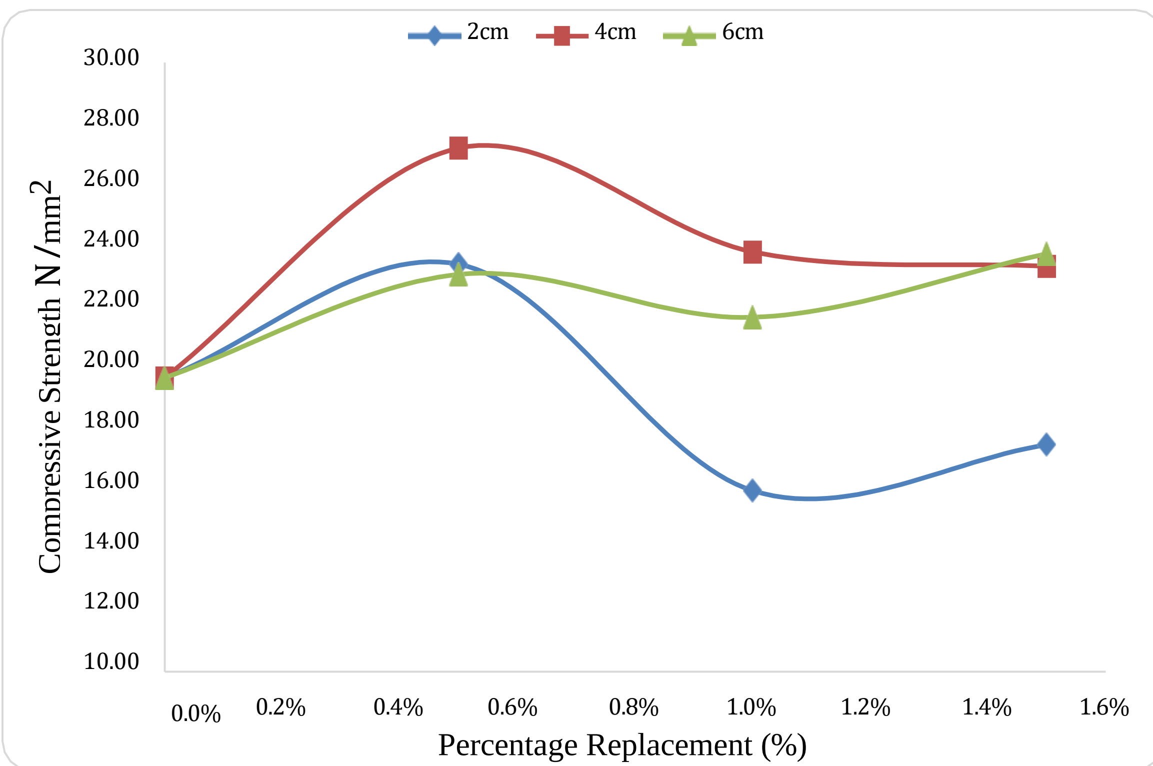

Fig. 7. 28 days compressive strength of SFRNAC

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V. CONCLUSION

Based on the results of this research, the following conclusion is drawn. The physical properties of constituent materials show that they have satisfactory properties and can be used in concrete production. The average compressive strengths of concrete with 0% volume of steel fibers (control mix) of curing ages of 7 and 28 days were determined to be 16.39 N/mm^2 and 19.64 N/mm^{2,} respectively. The highest compressive strengths at curing ages of 7 and 28 days were determined to be 19.20 N/mm^2 at 4cm length of steel fibers and 1% volume replacement with cement, and 27.19 N/mm^2 at 4cm length of steel fibers and 0.5% volume replacement with cement, respectively. From the experimental study, the use of steel fibers as reinforcement improved the compressive strength of concrete by 36.36%.

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Conflict of Interest: Authors have claimed no conflict of Interest

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