EFFECT OF STEEL FIBRE REINFORCEMENT ON THE COMPRESSIVE STRENGTH OF NATURAL AGGREGATE CONCRETE

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ABSTRACT

The goal of this research is to investigate whether steel fibre (extracted from waste tyre) has a significant influence on compressive strength of concrete produced using Natural Aggregate (NA). Iron molds measuring 150 x 150 x 150mm were used for concrete casting, they were demolded after 24 hours and cured in a curing tank for seven (7) and twenty-eight (28) days. The cubes were tested for compressive strength using a Universal testing machine. The results showed that concrete reinforcement using steel fibres improves the compressive strength of the concrete, allowing it to withstand fracture. The steel fibres were added in three different lengths (2, 4 and 6cm) incorporating three percentage (%) volumes (0.5%, 1% and 1.5%). The average compressive strengths of the fibre reinforced NA concrete with 0% volume of steel fibres (control mix) at 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 28 days compressive strength of 27.19 N/mm^2 was recorded with 4 cm fibre length at 0.5% fibre content which signified a 36.36% percentage gain in the 28 days compressive strength of the concrete.

Keywords: Natural aggregate, Steel Fibres, Compressive Strength, Reinforced Concrete

1. Introduction

When structural engineers/civil engineers are faced with the problem of higher cost of production of concrete materials, especially coarse aggregates and industrial steel fibres, this leads to the investigating the effect of fibre reinforcement on the compressive strength of natural aggregate (NA) concrete. Aggregates occupy 60-80% of the volume of normal weight concrete, hence, their characteristics influence the properties of concrete. As noted by Okonkwo and Arinze, (2018), the compressive strength of concrete depends on the aggregates proportion used for its production, in addition to other factors. The Bida Natural Aggregates (BNA) in character occur in middle of Niger basin of Nigeria in several Million metric tons, the Natural deposits aggregates in Bida is generally located in and around Bida area, Niger

State. The natural deposits aggregates are extensively used in Bida for building constructions and for domestic dwelling units. The deposits samples used for this research work was taken from Bida, Niger State in the middle belt region of Nigeria, located at about 250km North-East of Bida inland from the Federal Capital city of Abuja.

According to Zia *et al.* (2022) more than one billion tires are used for replacement every year globally, with more than half of this figure being abandoned and waiting to be disposed. Over a billion discarded tires are produced worldwide. The accumulation of these tires is a significant difficulty because tire component materials are exceedingly complex, making natural degradation impossible. This necessitates the careful management of this massive quantity of trash. Waste tires can be managed using various methods, including material recovery, energy recovery, retreating, export, and landfill disposal (Zia *et al.,* 2022). In Nigeria, the automobile sector generates about 10 million tyres each year, out of which 2 million wastes are generated. These waste pose health challenges and are environmentally unfriendly (NESREA, 2023). 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 (Harrison- Obi, 2018).

The use of NA sourced from Bida for concrete production is gaining wide acceptance especially among the dwellers of the Bida basin because the production of crushed granite is more labour intensive and expensive (kolo *et al.,* 2020). Against this background, investigating the potential application of waste tire components in the production of NA concrete to encourage waste tire recycling in Nigeria is timely and justifiable. The concrete specimen tested 150x150x150 mm cubes of compressive strength in accordance to specifications BS EN 12390-3 (2019). All the apparatus used in this research work are available in the Department of Civil Engineering

Laboratory, Federal University of Technology Minna, Niger state. The Coarse Aggregate (BNA) used in this research work was collected from Bida L.G.A, Niger state, while fine aggregate was obtained from a river bed at kpakungu in Minna, Ordinary Portland cement (OPC) from Dangote Company was used, and steel fibres were extracted from waste tyres obtain from local vulcanizers. Laboratory tests were carried out on Constituent materials with more concentration on sample of Natural Aggregate to determine the physical properties (such as Sieve Analysis, Specific gravity and Aggregate Impact Value (AIV). Laboratory tests on concrete was carried out in accordance with ASTM and BS standard. Compressive strength test was carried out for 7 and 28 days of curing periods and the results were determined for the sixty (60) cubes produced.

1.1 Concrete

Concrete technology has been evolving over the years and because of its vastness, no researcher can cover all the necessary areas during a specific research work. Concrete is made of cement, fine, coarse aggregates and water, but due to high strength and durability demand by certain structures, concrete has to be modified to suit such purpose by reducing water-cement ratio and the use of mineral and chemical admixtures (Mansor *et al*., 2018).

Aggregate, besides cement and water, form one of the main constituent materials of concrete since it occupies 70% - 80% of concrete volume, and can therefore be expected to have important influence on their properties (Ogunboyo *et al.*, 2018). The aggregate utilized are coarse aggregate (with particle size more than 4.75mm) and fine aggregate (with particle size less than 4.7.5mm) American society for testing and materials (ASTM, C33). Aggregate which are used in concrete are obtained either from natural sources or by crushing large size 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 scares, this reality has led engineers & researchers to seek the use of alternative materials. Several researches with different materials have been conducted with a number of recorded successes (Alade *et al.*, 2018).

1.1.1 Compressive Strength test

Strength is the ability of materials to resist an induced amount of stress that would make it fail, mostly expressed in (N/mm^2). It is one of the desirable properties of concrete, especially for designer and quality control engineers. Compressive strength is generally considered to be the most important strength because of its application in reinforced concrete construction and the dependency of most other properties on it, in most structural application, it is customary to estimate the strength of the concrete using compressive strength tests on cubes specimen of 150mm x 150mm x 150mm according to BS EN 12390-3 (2019). Metal moulds (for cube) are filled with fresh concrete using the standard methods or procedures. After 24 hours the specimens are taken out of the moulds, moist cured for 7 or 28 days, then tested using compression strength test machine.

1.1.2 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 fibre reinforced natural aggregate concrete production the constituents are cement, fine and coarse aggregative (NA), steel fibre reinforcement (extracted from waste tyres) and water. Fine and coarse aggregate are bond with the cement paste during the hydration process to form cement concrete, therefore fine aggregate is utilized to fill the gap between the natural aggregate particles. Water is also the important component in concrete because it allows the other constituents to mix properly, reinforced steel fibre add strength and durability.

2. Materials and Methods

2.1 Materials

2.1.1 Cement: Ordinary Portland Cement (OPC) Dangote brand grade 43N was used throughout the production of the steel fibre reinforced natural aggregate concrete, the cement was stored on a raise wooden platform at room temperature to prevent damage as a result of moisture and other environmental factors. Specific gravity test was performed on the cement and it conformed to the requirement of ordinary Portland cement as recommended by BS 4550, part 3 (1978).

2.1.2 Fine Aggregate (River sand): Good quality sharp sand that is clean, free from dirt and organic matters, which consist of uniform particle size of between 2 to 3.35mm, was obtained from a river in Kpakungu, Minna, Niger state. The fine aggregate was transported to the laboratory Department of Civil Engineering, Federal University of Technology Minna, preliminary analysis was carried out to ensure its stability for production of steel fibre reinforced natural aggregate concrete. It conformed to requirements for FA as specified in BS 882 (1992).

2.1.3 Coarse Aggregates (NA): The NA was used with particles size between 5 to 20mm, for production of steel fibre reinforced natural aggregate concrete. The NA was obtained from Bida town. The coarse aggregate conforms to specification for natural aggregate as in BS EN 12620:2002+A1 (2008). The following tests were carried out on the coarse aggregate; Specific gravity, Sieve analysis and Aggregates Impact Test. The NA is presented on Plate I.

Plate I: Natural Aggregate photo

2.1.4 Water: The source of the water was bore-hole water, from Civil Engineering Department, Federal University of Technology, Minna. The water is portable and clean, it contains balanced materials that are not harmful to health and concrete. It has a pH value of seven (7), hence it satisfied the requirement described in BS 1008 (2002) for concrete production.

2.1.5 Steel Fibre (bead wires): The steel fibre that was used in this research work was obtained by Pyrolysis process (burning of waste tyre) of light trucks or normal size cars and since the diameter and tensile strength of steel fibre in a tyre vary from one factory product to another, the tyres used for the extraction of steel fibres are all from the same brand and were obtained from local vulcanizers in Minna metropolis. The Steel fibre has a diameter of 0.89mm and were cut into the lengths of 2, 4 and 6cm. Three steel fibre volume fractions were used namely 0.5%, 1.0% and 1.5% incorporating three different fibre lengths (2, 4 and 6cm). The Steel Fibre is presented on Plate II.

Plate II: Steel Fibres (bead wires) photo

2.2 Methods

Table 1 presents the breakdown of proportions of the constituent materials used for concrete production.

Table 1: 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
	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

2.2.1 Test on Hardened concrete

Compressive strength test of SFRNAC

This test gives us an idea about all the characteristics of concrete. With the help of this test, we can check whether concreting has been done properly or not. Compressive strength is the ability of 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 done according to BS EN 12390-3 (2019) and sixty (60) cubes were cast. Each cube was place 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).

Size of the cube =150 x 150 x 150 mm

Area of the specimen =22500 mm^2

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

3. Results and Discussion

3.1 Specific gravity of Fine aggregate BNA and Cement

The results of specific gravity of fine aggregate, NA and cement were obtained to be 2.65, 2.60 and 3.15 respectively. The aggregates values obtained fall within the limit for NA with values between 2.6 - 2.7. The specific gravity of cement also fell within the standard range, this implies that the fine aggregate, NA and cement can be conveniently used for concrete production without much need for mix proportioning adjustment.

3.2 Sieve analysis of Fine aggregate

For sharp sand; 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 (Figure 1), the sharp sand coefficient of uniformity (C_U) is 7.42 which is greater than 6, hence the soil is considered as soil with difference particle size ranges and well graded. Also coefficient of concavity (C_C) is 2.15, which is between 1and 3, this means that the aggregate is well graded.

3.3 Sieve analysis of BNA

The result of sieve analysis the fine aggregated and NA is presented on Figures 1 and 2 respectively. From Figure 1, it is seen that the curve takes the S shape, which suggestsnthe fine aggregate contains particle of almost same sizes and is suitable for concrete production. Furthermore, it can be seen from Figure 2 that the curve for the NA is steep, which is an indication that the aggregate contains particle of almost same sizes. Thus, this type of aggregate is known as poorly graded aggregate; the coefficient of uniformity (C_U) of this aggregate is 1.93 which is less than 6. Hence the soil is considered as poorly graded (Omopariola *et. al.*, 2022).

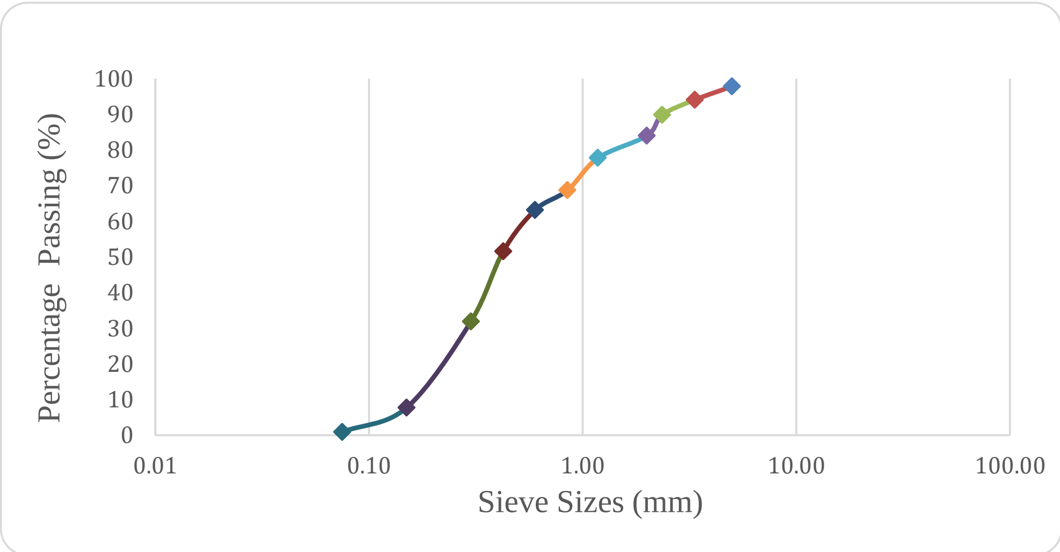

Figure 1: Sieve analysis of fine aggregate (BS 812: 1995)

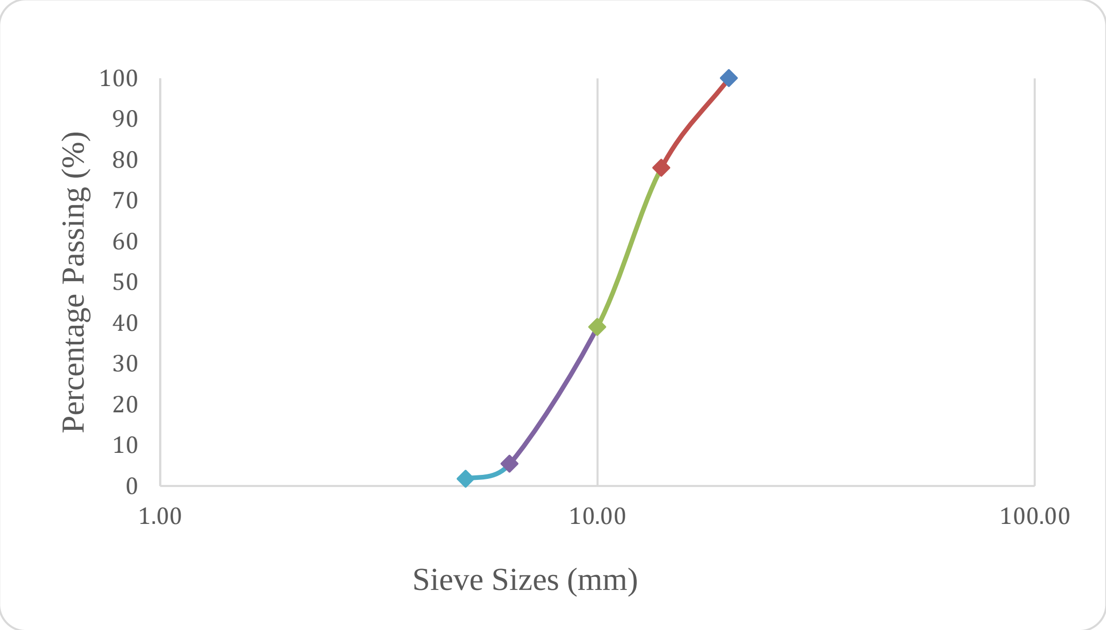

Figure 2: Sieve analysis of NA (BS 812:1995)

3.4 Aggregate impact value (AIV) of NA

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

3.5 Compressive strength test of SFRNAC

The compressive strength of 7 and 28 days curing period obtained in accordance to BS EN 12390 – 3 (2019) are presented on Figures 3 and 4 respectively. The 7 days curing age shows that mix batch of 4cm length of steel fibre at 1% volume has the highest compressive strength value of 19.20N/mm^2 and the percentage of gain and loss of strength of 17.1% and 27.8% when compare with control mix batch of 16.39 N/mm^2. The compressive strength of 28 days curing period shows that mix batch of 4cm length of steel fibre at 0.5% volume, has the highest compressive strength value of 27.19N/mm^2 and the percentage of gain of strength of 27.8% when compare with control mix batch of 19.64N/mm^2.

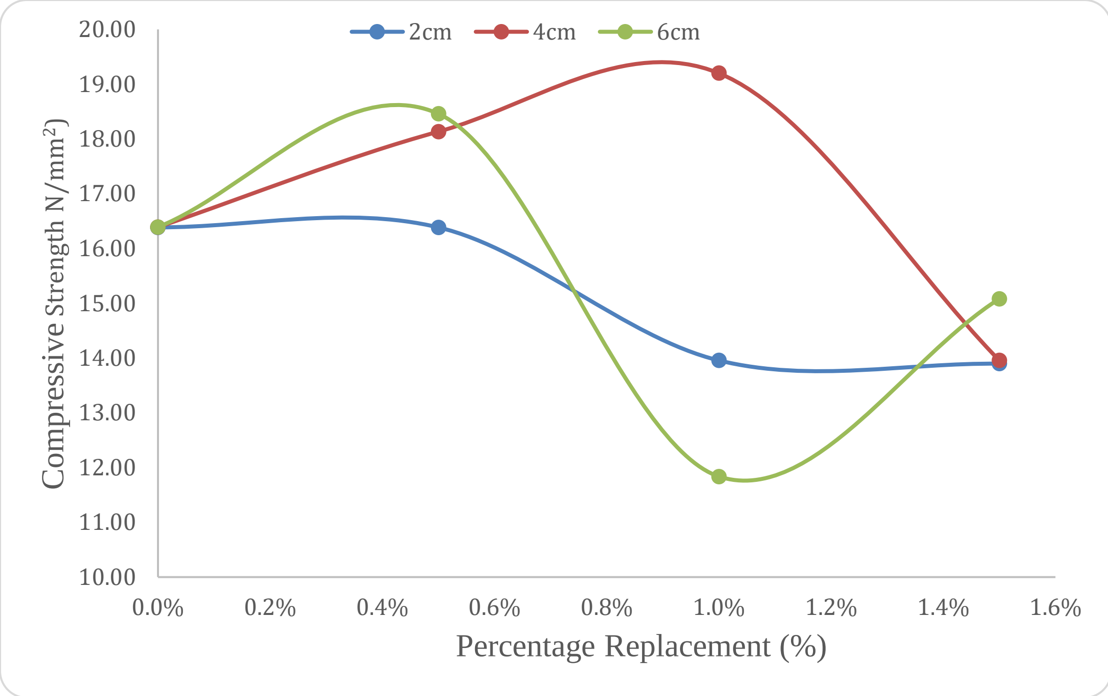

Figure 3: 7 days Compressive Strength of SFRNAC

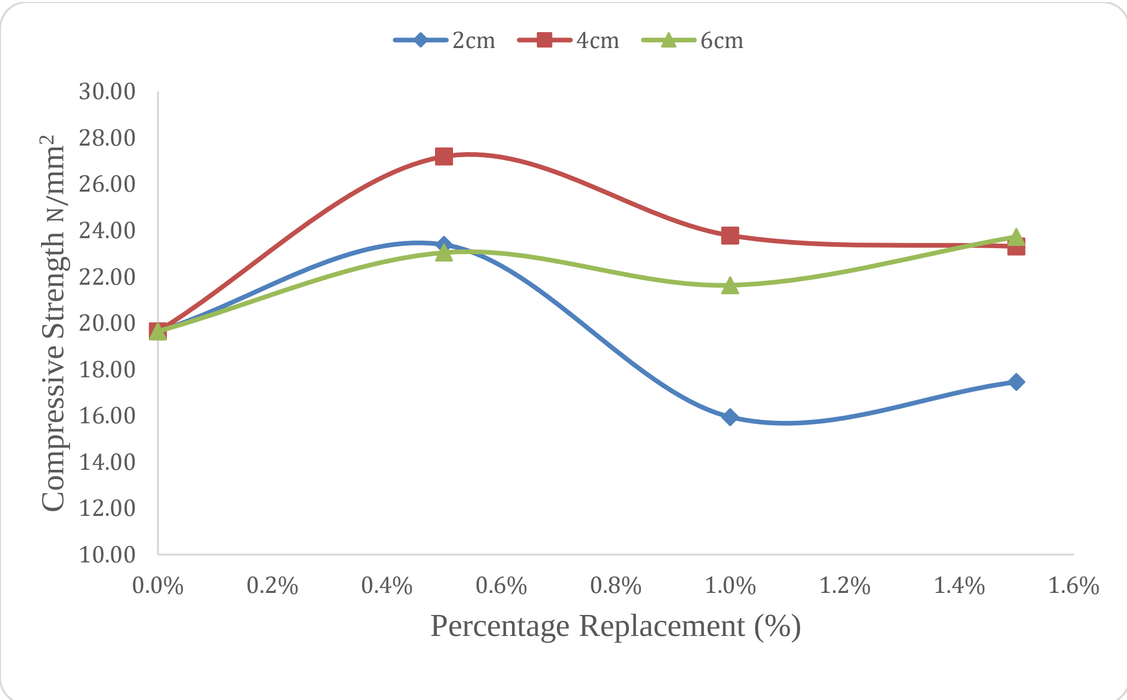

Figure 4: 28 days Compressive Strength of SFRNAC

4. Conclusion

The reinforcement of concrete using steel fibres changes the compressive strength property of concrete. Based upon the results of the experiment, the following conclusions are drown;

The physical and mechanical properties of constituent materials, including Bida natural aggregate shows that, they have the satisfactory properties and can be used in concrete production.

The average compressive strength of concrete with 0% volume of steel fibres (control mix) of curing ages of 7 and 28 days was 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 fibres and 1% volume replacement with cement, and 27.19 N/mm^2 at 4cm length of steel fibres and 0.5% volume replacement with cement respectively. From the experimental study, the use of steel fibres as reinforcement improved the compressive strength of concrete by 36.36%.

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