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Assessment of the Mechanical Properties of Steel Fiber Reinforced Concrete for Low-Cost Construction

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ABSTRACT

The study explores the assessment of mechanical properties of steel fiber reinforcement in concrete production. Aimed at replacing the high cost conventional reinforcement in building constructions. The identical steel fibers are utilized at varied volume fractions of 0%, 1%, 2%, 3%, 4%, and 5% by the weight of cement. Compressive strength, flexural strength, and split tensile strength are among the strengths taken into account in this investigation. Eight beams and four cylindrical samples were prepared for the tests. Results obtained indicated that adding steel fiber to concrete with different volume fractions and the same aspect ratio significantly improved the results for compressive strength and flexure strength. The experimental results showed that the fibers alter the failure character from splitting of the concrete by significantly increasing the cracking resistance, and thereby noticeably increase the load bearing capacity of the elements. Therefore, fiber reinforcement can be used in place of high yield reinforcements in a low cost structures.

INTRODUCTION

Concrete is the most used material in construction industry due to its durability, high compressive strength and other mechanical strength characteristics (Lakhiar *et al.*, 2018). Its weakness in tensile strength brings about introduction of reinforcement bars which helps to complement the concrete tensile strength compression (Agarwal *et al.*, 2014) The reinforcements are mainly straight, long and continuous steel bars imbedded in the tensile axis of the concrete to take care of tensile and shear stresses (Behbahani *et al.*, 2011). The introduction of the steel bars resolved the problem of tensile stress, shear stress and cracking in the reinforced concrete but also increased the cost of construction (Jhatial *et al.*, 2018). The continuous skyrocketed increase in price of reinforcement bars has continuously increases the cost of constructions.

This phenomenon has caused high cost problems in affording accommodations especially in developing countries. Since construction industry is regarded as the backbone of any country due to its essentiality to social and economic growth (Sohu *et al.*, 2017). There is apparent need to source for alternatives to the conventional reinforcement bars for low-cost structural designs and construction. However, the inclusion of steel bars in concrete in addition to cement, aggregate, and water, its inherent weight further increases, this already significant increased self-weight, subjects the structures to additional dead-load stress.

LITERATURE REVIEW

The quest to ameliorate the problem of high cost of reinforcement bars necessitated a lot of research of which the introduction of fibers is one of them. Fibers, are generally short, discontinuous, and randomly distributed throughout the concrete member to produce a composite construction material known as fiber reinforced concrete (FRC). Behbahani *et al.* (2011) defined Steel fibre as discrete, short length of steel having ratio of its length to diameter (i.e. aspect ratio) in the range of 20 to 100 with any of the several cross-sections, and that are sufficiently small to be easily and randomly dispersed in fresh concrete mix using conventional mixing procedure. The random distribution results in a loss of efficiency as compared to conventional rebar's, but the closely spaced fibers improve toughness and tensile properties of concrete and help to control cracking. Although there are many different kinds of natural and synthetic fibers used in FRC, over the past 20years the usage of steel fibers has considerably expanded due to its diffused fiber, which may assist to improve the structural behavior of industrial pavements, highways, parking lots, and airports (Sorelli *et al.*, 2006).

Many researchers have continuously researched on the Fibre reinforced concrete technology. Naaman (1985) in his work claims that Porter was first to use Steel Fibres in concrete as far back as 1910. The first experimental work on fibre reinforced concrete in United States was carried out in 1963 (Romualdi and Batson, 1963). All over the world, the modern use of Steel Fiber reinforced concrete has gradually increased in civil engineering constructions (Meda *et al.*, 2012). It was recommended that the use of steel fiber than other fibre materials was due to its stiffness which increases the ductility characteristic of its reinforced concrete (Michels *et al.*, 2012). Steel fiber reinforced concrete (SFRC) can improve fatigue shock resistance, ductility, and crack arrest while also achieving greater tensile and flexural strengths (Kawde & Warudkar, 2017). A research (Ghaffar *et al.*, 2014) conducted on M35 grade of concrete using steel fibre

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content ranged from 0% to 5% showed that there is continuous increase in compressive and flexural strength of the concrete at every 0.5% increase in steel fibre. The peak strength was observed at 3% steel fibre content. The effect of the steel fibre reinforcement was equally agreed with (Mohod, 2012) research who reinforced M30 grade of concrete with it using 0.25%, 0.50%, 0.75%, 1%, 1.5% and 2% steel fibres by volume of cement. It was observed that there was decrease in workability of the reinforced concrete. On the aspect of shear behavior, (Lim *et al*, 2020) investigated the Shear behavior of 0.6 % and 0.7 % steel fibre reinforced concrete beams without stirrups. The results depict that ultimate shear strength was improved up to 36 % at addition of 0.7 % steel fibre content after the structural performance of the shear beams was evaluated in the response of load-deflection, load-steel strain, crack patterns and failure modes. The findings were in line with findings of (Ranjan Sahoo & Sharma 2014) who investigated the possibility of replacing stirrup reinforcement with steel fibre reinforcement by eliminating the sheer size effect in beam depth and increasing shear strength. Fibre reinforced concrete has been found useful in so many structural infrastructures such as underground structures, machine foundations, airport runways roads and dynamically loaded structures such as seismic and earthquake prone areas (Błaszczyńskia & Przybylska-Fałeka, 2015; Vitt, 2005).

MATERIALS AND METHODS

Materials

Cement

Dangote cement, an Ordinary Portland Cement (OPC), class 42.5R according to EN 197:1, (2011) was the kind of cement used. This cement was purchased at a nearby market (Uli/Afor-egbu timber and building material market, Afor-egbu, Imo State).

Figure 1: Bundles of 2mm diameter of steel

Coarse Aggregate

The coarse aggregate used had no finer particles and had a nominal size of 3/8 inch, or roughly 10 mm. The coarse aggregate met BS: 882 requirements (1992). Concrete specifications for natural-source coarse aggregate.

In order to guarantee that the water cement ratio of the relative mix percentage remains unaffected, the coarse aggregate was dried to a saturated surface condition. The local Uli/Afor-egbu building material market at Afor-egbu, Uli, Imo State, was where the coarse aggregate was purchased.

Fine Aggregate

This study's fine aggregate was a sharp sand known locally as "wall-white." It didn't contain any coarse materials and was purchased locally from the building materials market in Uli, Anambra state. Prior to purchasing, it was filtered using a 4.75mm sieve. To guarantee that the water-cement ratio was not impacted by the moisture content in the sand, it was dried on air to saturated surface dried. The sand underwent a sieve analysis test (particle size distribution) before to usage.

Steel Fibers

The mild steel bar utilized in this investigation had straight ends, a length of 25mm, and a diameter of 2mm. This steel fiber was purchased at the Onitsha iron and steel market. It has good ductility, rust free and has the good workability with concrete as shown in Figure 1. Using a cutter, the steel fibers were cut into 25mm-long pieces to easily mixed with concrete as seen in Figure 2.

The steel fiber utilized has an aspect ratio of 12.5 (25mm/2mm steel fiber length to diameter). Throughout the mixes, the aspect ratio remained the same. In this investigation, steel fibers were employed in fractions of 1%, 2%, 3%, 4%, and 5% by volume of cement.

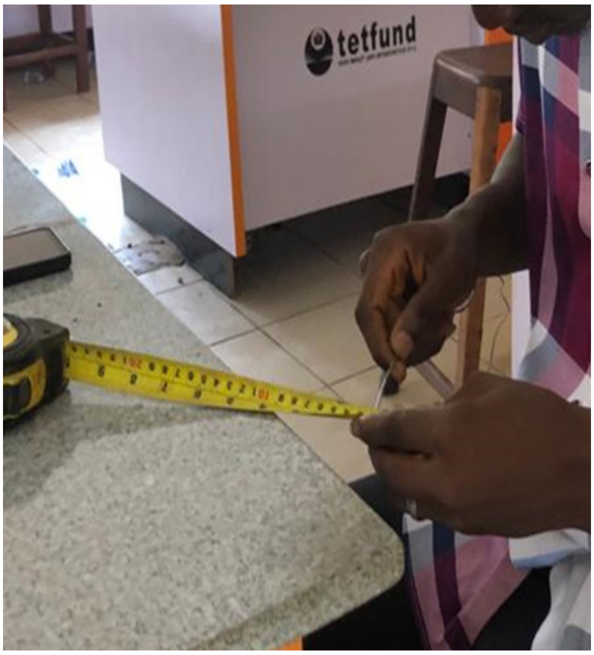

Figure 2: Cutting of the 25mm steel fibers

A sample of the beam used for the tensile strength test was presented in Figure 3. The fibre was properly and homogenously mixed the mould was standard metal mould to avoid deflection or deformation of the concrete beam during and after setting.

Figure 3: Flexural beam

Water

The water that was used for this study is a portable tap water obtained from civil engineering concrete/soil laboratory Uli campus. The water is a drinkable water and free from impurities.

Table 1: Quantity of Cement, Aggregates and Steel Fiber Required for Mix 1-6

Mix No.	% of Steel Fibers	No.of Cubes	No. of Beams For Flexural Test	No. of Cylinder For Split Tensile Test	Total Vol. of Concrete Req.	Qty. of Cement Req. (kg)	Qty. of Fine Agg. Req. (kg)	Qty. of Coarse Agg. Req. (kg)	Qty. of Steel Fibers Req. (kg)
1	0%	8	4	4	0.1m3	41.04	68.48	133.5	---
2	1%	8	4	4	0.1m3	41.04	68.48	133.5	0.41
3	2%	8	4	4	0.1m3	41.04	68.48	133.5	0.82
4	3%	8	4	4	0.1m3	41.04	68.48	133.5	1.23
5	4%	8	4	4	0.1m3	41.04	68.48	133.5	1.64
6	5%	8	4	4	0.1m3	41.04	68.48	133.5	2.05

RESULTS AND DISCUSSION

Presentation of Result

To ascertain the proportion of various grain sizes of the fine aggregate, a particle size distribution test was conducted as shown in Figure 4. A predetermined fine aggregate from Uli, Ihiala Local Government Area in Anambra State was used for the test. The BS EN 933-2 (2020) standard was followed in performing this test. Sample weight in total: 500g

Table 2: Sieve Analysis for the used fine aggregate

New Sieve No.	IS Sieve Size	Mass Retained (g)	Percentage Retained	Cumulative Percentage Passing	Percentage Retained
10	2.00mm	11.07	3.69	96.31	3.69
16	1.18mm	38.68	12.89	83.41	16.58
30	0.60mm	83.31	27.77	55.64	44.35
40	0.425mm	56.82	18.94	36.70	63.29
50	0.30mm	61.72	20.57	16.13	83.86
100	0.150mm	32.12	10.71	5.43	94.57
200	0.075mm	14.15	4.72	0.71	99.29
Pan	Pan	2.13	0.71	0	100

Figure 4: Different sizes of sieve used

CALCULATIONS

Percentage Retained= (Average)/(total weight of sample) x 100

Percentage passing=100-cumulative percentage retained

The result in Table 1 shows that the fine aggregate was properly graded and was in conformity with the BS standard.

Slump Test

This test was carried out in order to determine the workability of identical steel fibers utilized at varied volume fractions of 0%, 1%, 2%, 3%, 4%, and 5%. The

results obtained were presented in Table 3. Mix Ratio: 1:1.5:3. Concrete Grade: M20. Water Cement Ratio: 0.5
The slump test result showed that as the volume of fibre increases, the workability reduces.

Figure 5 illustrated the depreciation in value of the slump at the constant water-cement ratio. This implies that there is need for an increase in quantity of water as the fibre content increase in order to improve the concrete workability. Therefore, the degree of workability decreases slightly with increase in the percentage of steel fibres. Hence, concrete with steel fibre have a low degree of workability.

Table 3: Table of slump test values

Mix No.	Steel Fibres	Height of Cone	Height of Slump Concrete	Slump Value	Type of Slump
1	0%	300mm	280mm	20mm	True slump
2	1%	300mm	285mm	15mm	True slump
3	2%	300mm	290mm	10mm	True slump
4	3%	300mm	295mm	5mm	True slump
5	4%	300mm	297.5mm	2.5mm	True slump
6	5%	300mm	299mm	1mm	True slump

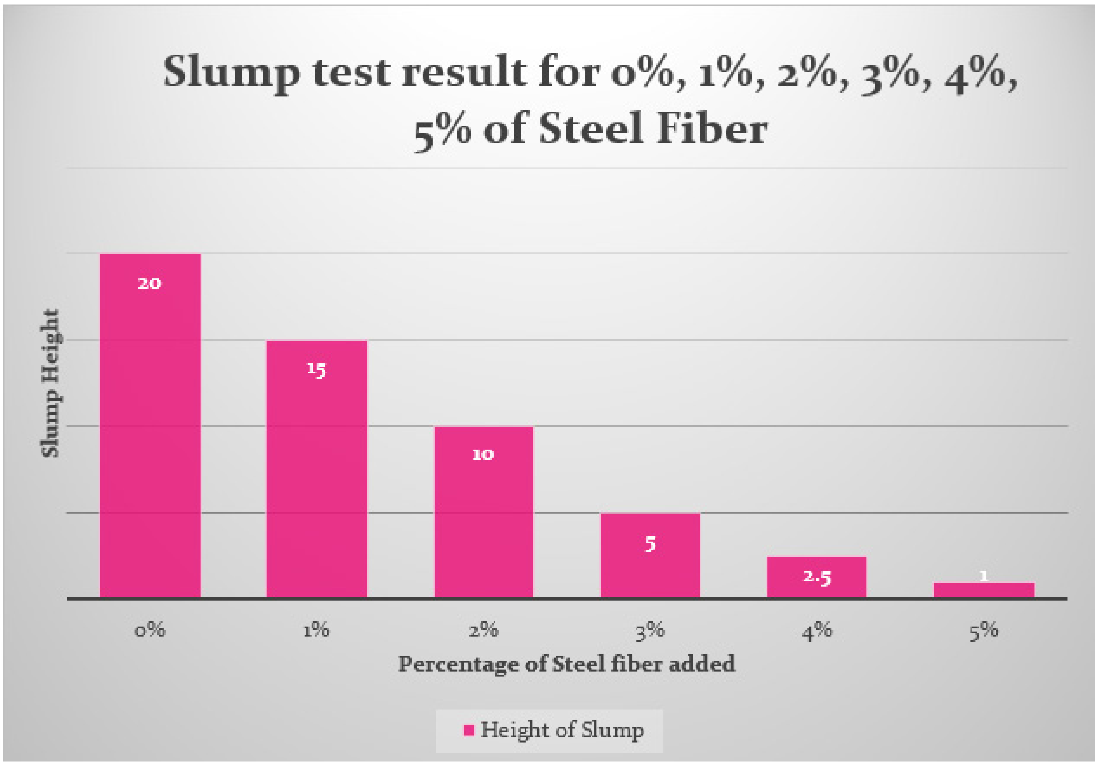

Figure 5: A bar chart of the slump test result

Result of Flexural Strength Test

The Flexural strength result for the concrete was presented in Table 4. The result showcased that as the fibre content increases, the flexural strength of the concrete increases

Table 4: The flexural strength result

Mix No.	Percentage Of Steel fibres	Flexural strength at various curing days							
		7 days		14 days		21 days		28 days	
		kN	N/mm^2	kN	N/mm^2	kN	N/mm^2	kN	N/mm^2
1	0%	286.4	1.27	310.6	1.38	334.5	1.49	356.6	1.59
2	1%	342.0	1.52	365.4	1.62	390.1	1.73	415.2	1.85
3	2%	380.4	1.69	399.5	1.78	425.6	1.89	475.4	2.11
4	3%	420.9	1.87	458.7	2.04	495.0	2.20	542.0	2.41
5	5%	598.2	2.66	647.8	2.87	708.4	3.14	743.7	3.30

respectively. This can be attributed to the increase in flexural characteristics of concrete associated with steel fibre. Therefore steel fibre can serve as a replacement for conventional steel bars.

Split Tensile strength

Table 5: The result of the split tensile strength of the cylinder is presented below

Mix No.	Percentage Of Steel fibres	Split tensile strength at various curing days							
		7 days		14 days		21 days		28 days	
		kN	N/mm^2	kN	N/mm^2	kN	N/mm^2	kN	N/mm^2
1	0%	364	1.53	379	1.68	406	1.80	423	1.88
2	1%	394	1.75	412	1.83	432	1.92	454	2.01
3	2%	402	1.79	415	1.84	454	2.02	462	2.05
4	3%	423	1.88	432	1.92	480	2.13	495	2.20
5	5%	468	2.08	479	2.13	502	223	512	2.27

Compressive Strength Test

Table 6: The results of for compressive strength cubes

Mix No.	Percentage Of Steel fibres	Compressive strength at various curing days							
		7 days		14 days		21 days		28 days	
		kN	N/mm^2	kN	N/mm^2	kN	N/mm^2	kN	N/mm^2
1	0%	239.0	10.6	290.4	12.9	347.4	15.4	388.6	17.3
2	1%	379.9	12.9	418.6	18.6	434.1	19.3	457.5	20.3
3	2%	392.5	17.4	407.8	18.1	425.6	18.9	459.8	20.4
4	3%	409.6	18.1	420.8	18.7	443.0	19.7	467.3	20.8
5	4%	411.5	18.2	427.2	18.9	439.6	19.5	466.1	20.7
6	5%	423.0	19.11	431.2	19.2	458.9	20.4	478.5	21.3

The result of the compressive strength obtained after 7, 14, 21 and 28 days of curing is presented in the table 6.

CONCLUSION

The need to reduce the cost associated with use of conventional steel bars in construction necessitated this research. Some low cost building sometimes refuse to reinforce their structures properly due to cost which results to compressive, tensile and split strength failure. But with the recent findings, it is now cheaper to provide minimal reinforcement using steel fibre. The inferences that come next are predicated on the expected result. Concrete is reinforced with steel fibers to enhance its mechanical properties. Among other properties, concrete has better compressive and flexural strengths. In comparison to conventional concrete, the concrete is also less porous and has a lower absorption capacity. The results and discussion show that concrete generally improves with a 5% addition of steel fibers.

Many researches have different approach to steel fibre reinforcement and majority proposed that adding steel fibers with hooked ends to regular concrete typically improves various strengths noticeably. But it has been found in this research that the highest gain in concrete strength depends on the fiber content. Depending on the strength, a different amount of fiber should be added for that strength. As the fiber content rises, the failure mode shifts from brittle to ductile when squeezed and bent. Therefore, the study encouraged the use of fiber reinforcement in place of the conventional steel bars in low cost structural construction.

In this study, the use of steel fiber is restricted to structural components for low-rise and residential structures that need the least amount of reinforcement during construction. In oversite concrete, it can be applied successfully to minimize the effects of thermal cracking, short columns, short beams, and narrow spanning slabs with fewer loads to transport.

Further study on the use of steel fiber for reinforcing high-rise building structural elements, such as long columns, long beams, and broader spanning slabs, is advised.

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