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Enhancing the Strength Characterisitics of Concrete Through the Use of Steel Fibre

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Authors' contributions

This work was carried out in collaboration between all authors. Authors FAO and GMA designed the study. While author GMA performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript and managed literature searches. Authors FAO and SOAO supervised the research. All authors read and approved the final manuscript.

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ABSTRACT

The paper aims at studying the strength characteristics of steel fibre reinforced concrete (SFRC), within the fibre dosage of 0.5 to 2%. Discontinuous discrete steel fibres were explored in concrete of grade M60, and normal concrete of 0% steel fibre dosage used as control. The concrete behavioural properties were investigated under compression at 3, 7, 14, 21, 28, 90 and 120 curing days. Steel fibre reinforced concrete sample with highest compression yield were further examined under tension and flexure respectively.

The findings revealed that, the addition of steel fibre to concrete improve the strength properties of the concrete, with better performance under compression, tensile and flexure compared to control concrete. The SFRC specimens were observed to yield a percentage increase of 3.96-10.54% in compression, 49.83-97.08% in tension and 13.63-28.27% flexural compare to the control. The presence of steel fibre was also observed to minimize crack propagation over conventional concrete, which shows that steel fibres helps in better bonding of the concrete and displays steel fibre reinforced concrete as to possess good ductility properties.

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Keywords: Steel fibre; concrete; compressive strength; split tensile strength; flexural strength.

1. INTRODUCTION

Steel fibres have been used in concrete, since the 1900s. Initially, round and smooth fibres were explored, after which modern commercially available steel fibres are contrived from cold drawn steel wire, slit sheet steel or the melt extraction process [1]. In addition, steel fibres have been produced by cutting or chopping wire into various shapes and sizes. Flat straight fibres are produced by a shearing sheet or flattening wire. Crimped and deformed steel fibres are produced by bending or crumpling the full-length or at the ends only in order to increase bonding as well as to facilitate handling and mixing [2,3]. A representation of common types of steel fibres are shown in Fig. 1.

Typically, steel fibres have equivalent diameters (based on the cross-sectional area) from 0.15 - 2 mm and lengths from 7 - 75 mm, and aspect ratio generally ranged from 20 - 100. The ultimate tensile strength of steel fibre ranges from 500 - 2000 MPa, and the young's modulus as 200 GPa. Steel fibre has been used in conventional concrete mixes, shotcrete and slurry infiltrated concrete. The content of steel fibres ranges from 0.25 - 2.0% by volume and fibre contents in excess of 2% by volume. They generally result in poor workability and fibre distribution but can be used successfully where the paste content of the mix increased and the size of coarse aggregate is not larger than 10 mm [1,4].

Steel fibre content up to 2% by volume has been used in shotcrete applications, using both wet and dry processes, while steel fibre content of up to 25% by volume has been obtained in slurry infiltrated concrete [5]. The use of steel fibre has been observed to prevent, control and modify concrete mechanical and physical properties [6,7] Song and Hwang [8] investigated concrete scenario with the addition of steel fibres. It was observed by the authors that compressive strength of fibre concrete reached a maximum at 1.5% volume fraction, with 15.3% improvement fibre concrete over plain concrete in compressive strength. However, the flexural improvement of 98.3% and 126.6% improvement of split tensile strength occurred at 2% volume fraction. They opined that the brittleness of concrete due to low tensile strength and strain capacities could be overcome by addition of steel fibres.

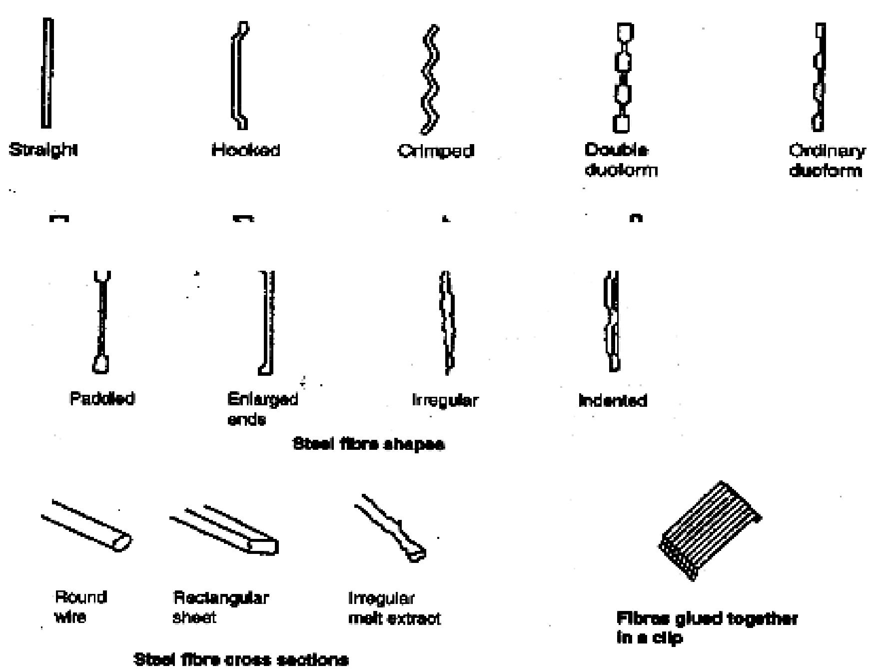

Fig. 1. Different steel fibre types [3]

In addition, Higashiyama and Banthia [9] observed that concrete properties such as tensile, flexure, fracture, toughness, fatigue, impact, wear and thermal shock had substantially been improved by fibres addition into concrete; The inclusion of the fibres were further noticed by the authors, to prevent crack propagation in concrete. Yazıcı et al. [10] also established the extent of the crack deterrence by fibre addition. The researchers observed it to be due to the ability of the randomly distributed fibres to excellently transfer the internal stresses developed within the concrete. Fibre such as horse hair, and straw were commonly used in ancient time. Asbestos fibre was employed as the first modern option in early 1970's, and then steel fibre was accepted as a visible alternative to traditional reinforcement in late 1970's.

Banthia [11] observed steel fibre to be the most used, out of 300,000 metric tonnes of fibres used for concrete reinforcement; with the percentage rating of 50% steel fibre to 25% of other fibre types. In addition, the research conducted by Shahiron [12] revealed steel fibre to possess excellent properties in floor and pavement concrete toughening, tensile and flexural strength, shock and fatigue resistance, ductility and crack arrest. On the contrary, Chen and Lieu [13] discovered that fibre reinforcement addition to concrete often results in a greater negative effect on workability; thus they submitted that mix design changes should be considered. Similarly, Brown and Atkinson [14] suggested three factors upon which the efficiency of fibre reinforcement in concrete depends on. These include; the uniform distribution of fibres in the concrete, its interaction with the cement matrix, and the ability of the concrete to be cast successfully.

Observations by several other researchers on concrete containing steel fibre, agreed that, steel fibre have substantially improved resistance to impact and greater ductility, improved resistance to compression, tension and higher flexural strength [4,15,16]. Similarly, it was reported that the elastic modulus in compression and modulus of rigidity in tension are no different before cracking when compared with plain concrete tested under similar conditions. It has been reported that steel fibres reinforced concrete, because of the improved ductility, could find applications where impact resistance is important, and fatigue resistance of the concrete is reported to be increased by up to 70% [2].

Thus, this paper is aimed at investigating the strength properties of steel fibre reinforced concrete, bearing in mind the aforesaid challenge of workability, and concomitantly producing efficient fibre reinforced concrete.

2. SIGNIFICANCE OF STUDY

Concrete has high compressive strength and low tensile strength; these properties often affect the behavioural properties of concrete. In tension, concrete stretches and shortens in compression. Besides, most of the loads induced at the time of construction are critical, and often cause failures of concrete members due to higher percentage of tensional stresses develop from these loads. Serdar [17] opined that, the low tensile strength and strain capability of concrete, causes breakdown, and shortens the life span of the wall in canal and dam construction.

Hence, the paper intends to examine the possibility of steel fibre in improving these undesired behaviours and properties of concrete. Also, it explores the optimum design mix capable of making up for the inadequacy in mixes has asserted by some researchers. Thus, the research paper provides very useful information on the suitable mix for steel fibre reinforced concrete while sustaining the requirement of concrete; and concrete quality in general.

3. MATERIALS AND METHODS

3.1 Materials

The materials used in this study include ordinary Portland cement, fine aggregate coarse aggregate, mixing water, super plasticizer and steel fibre. Preliminary tests were carried out on materials, the test aimed at examining the physical and mechanical properties of the materials used. Details of the test performed on materials include fineness test, consistency test, soundness test, setting time, bulk density, specific gravity and particle size distribution test. The properties of some of these materials are described below:

3.1.1 Cement

The cement used in all mixtures of this research was ordinary Portland cement of 43 grade; which was in accordance to BS 12 [18]. The cement was produced by Elephant Portland cement in Ewekoro, Nigeria. The conforming weight of each bag of cement is 50 kg. The results for the physical and mechanical properties of cement are as presented in Table1 and its chemical composition is presented in Table 2.

Table 1. Physical and mechanical properties of cement used as per manufacturer's specifications

Test	Results
Density	3.09 g/cm^3
Fineness	92%
Normal consistency	30%
Soundness	0.8 mm
Setting time: Initial	2 hrs 10 mins
Final	3 hrs 10 mins
Compressive strength 7 days	33 MPa
28 days	43 MPa

Cement shows early strength development pattern, of about 77% of 28 days strength in 7 days. Cement users can remove forms in early days. Initial setting time of the cement sample was 130 minutes while final setting time occurs 190 minutes. This implies that the cement has quite stable setting times. According to both SLS 107 [19] requirements and EN 197 [20], initial setting time should be higher than 60 minutes while final setting times should be less than 600 minutes according to BS12 [18] requirements. Cement sample was within limits stated by EN and SLS standards. The cement was said to be fine since 92% of sample passed through 0.425 µm sieve size. Cement sample shows much soundness, compared to both SLS 107: Part 2 2008 and EN 197 [20] standards requirements of not more than 10 mm.

According to EN 197 [20] limits for maximum sulphate (SO_3) content to 3.5%. According to SLS 107 [19], limit maximum sulphate (SO_3) content to 3% if C_3A content is more than 5% and maximum sulphate (SO_3) content should not exceed 2.5% if C_3A content is less more than 5%. Cement sample was found to be within limits stated by EN and SLS standards. According to SLS 107 [19], limit maximum Magnesium oxide (MgO) content to 5%. Cement samples are within limits stated by SLS standards

3.1.2 Aggregates

The main aggregates type used in this research work were crushed limestone fine sand and crushed rock coarse aggregate. The fine aggregate was well graded sharp sand from a locally available river that passes through 4.75 mm and retained on 2.36 mm sieve and the coarse aggregate was granite with a maximum aggregate size limited to 12.5 mm, obtained from a quarry in Abeokuta. The fine aggregate was air-dried. Specific gravity and sieve analysis test were carried out for fine and coarse aggregate in the Moshood Abiola Polytechnic Civil Engineering Laboratory. They were carried out in accordance with BS 882 [21]. The results of the test carried out on samples of the specific gravity of aggregates are presented in Table 3 and their particle size distribution curves are also illustrated in Fig. 2.

The particle size distribution of the aggregates meets the ASTM C33 [22] grading requirement for fine and coarse aggregates respectively. The sieve analysis graph divulges the aggregates to be well graded; with fineness modulus of fine and coarse aggregates of 2.76 and 3.49 respectively.

3.1.3 Mixing water

The Moshood Abiola Polytechnic Campus tap water was used as mixing water. It was drinkable, clear, free from oil and apparently clean. It does not contain any substance at excessive amounts that can be harmful to making concrete.

Table 2. Chemical analysis of the cement used as per manufacturer's specifications

Oxide	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3^{2-}	LOI
Content (%)	65.81	20. 60	4.98	3.89	1.89	0.56	0.35	1.35	2.70

Table 3. Results of specific gravity of aggregates

Property	Aggregates	
	Fine	Coarse
Specific gravity	2.60	2.70

3.1.4 Steel fibre

The steel fibre used in this research work is the hooked steel fibre of size 0.6 mm × 30 mm. The specifications of steel fibre as provided by the manufacturer are presented in Table 4. The fibre type is commonly used due to its availability. The steel fibres were in the loose state (single or discrete) in order for the mixture to infiltrate the fibre bed without clogging or honeycombing. A representative sample of the fibre is presented below in Fig. 3.

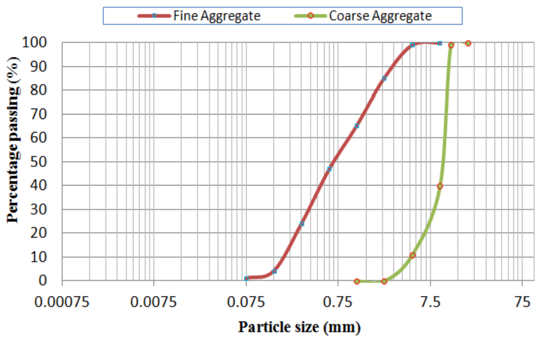

Fig. 2. Particle size distribution of aggregates

Fig. 3. Steel fibre sample

3.1.5 Chemical admixture

Super plasticiser (SP) used in the course of this research is a high range water reducing super plasticizing admixture named Conplast SP432MS. It was obtained from Pure-Chem Nig. Ltd in Lagos. It is a ready-to-use, chloride free, liquid admixture which meets BS 5075 [23] requirements. The super plasticiser was used for SFRC and control mixes to improve the flow properties of the concrete, and for the control concrete mix due to low water-cement ratio.

3.2 Methods

3.2.1 Mix proportioning

Five mixes were prepared in five batches using design concrete grade 60 MPa. The concrete was designed to have good properties notably in the area of strength and impermeability. Water cement ratio was kept constant throughout the mixes. Super-plasticizer (SP) was used in all the mixes and the dosages were carefully chosen as the minimum possible dosage that will produce the required workability. Batching was done by weighing the materials for the concrete specimens using a weighing balance. The mix proportions by weight and the mix designations are presented in Table .

3.2.2 Preparation and casting of concrete specimens

The concrete mixture was prepared using a rotating planetary mixer of 120 kg capacity. The internal surface of the mixer was first dampened with water. The steel fibre volume fraction required was added to the coarse aggregate at the point of mixing and allowed to mix for 1 minute; then, the fine aggregate was added and mixed with one-third of the mixing water for another 1 minute. Then cement and one-third of the mixing water was added and mixed for an additional 1 minute. Lastly, the rest of the water and superplasticizer were pre-mixed and added to the mixture and mixed for 3 minutes. Mixing of control concrete was similar to that of SFRC, except that the fibre addition was eliminated from the concrete mixture. The mixing was done in sequence to allow sufficient time for thorough mixing and good dispersal of the fibre in the constituents. The fibre dispersion image is shown in Fig. 4.

Table 4. Specifications of steel fibre used as per manufacturer's manual

Fibre brand name	Fibre type	Length l (mm)	Diameter d (mm)	Aspect ratio l/d	Specific gravity	Density of steel fibre (kg/m^3)	Tensile strength (MPa)
YS-60/30	Hooked	30	0.6	50	7.9	7800	1100

Table 5. Mixture proportions

Mix designation	Mix type	Volumetric fibre dosage v_f (%)	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)
M_1	Control	0	32.34	43.68	70.98	12.94	0.26
M_2	SFRC	0.5	32.34	43.68	70.98	12.94	0.26
M_3	SFRC	1.0	32.34	43.68	70.98	12.94	0.26
M_4	SFRC	1.5	32.34	43.68	70.98	12.94	0.26
M_5	SFRC	2	32.34	43.68	70.98	12.94	0.26

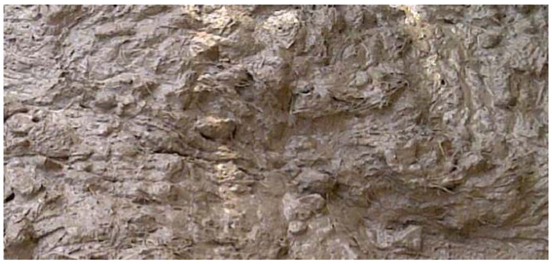

Fig. 4. Automatic image of steel fibre dispersion in the matrix

Each of the concrete mixtures prepared was tipped inside a wheelbarrow, where it was transported and placed in the moulds. The inside of the moulds were smeared with oil so as to enhance easy removal of the set concrete and it's based clamped together Several test specimens were cast inside moulds of varying shapes and sizes according to the standard specifications for each test. The concrete mixes for each batch were compacted by the use of tamping rods and the moulds were externally vibrated to remove trapped air which can reduce the strength of the concrete. After casting of the specimen, the specimens were covered with polyethene to aid in curing and the specimens were left to cure for 24 hours in the moulds in the laboratory environment. De-moulding took place on the second day after casting; when the final setting had been reached and the specimens were stored at room temperature in a curing tank of water until their curing age were reached. All the test specimens were cured for 120 days.

3.3 Experimental Procedures

Series of tests were carried out on fresh and hardened concrete (SFRC and plain concrete) in order to determine their physical and mechanical properties. The details of the tests carried out on strength characterization of the concrete and their procedures are discussed in the sections below.

3.3.1 Compressive strength test

The specimens for compression test were cast in cube moulds of dimensional size of 150 mm × 150 mm × 150 mm. 21 specimens were made from every batch, thus the total number of tested specimen under compression were 105. The specimens were left to cure for 24 hours in the moulds in the laboratory environment as earlier discussed. The next day the specimens were de-moulded and placed in a curing tank filled with water till curing ages. After the curing ages, specimens were tested under the bearing surface of the compressive testing machine. Prior to testing, the specimens were drained off excess water from the surface, weighed and then placed in the machine; load was gradually applied till the specimens failed. The maximum load at failure was noted. In each category, three specimens were tested and their average value and compressive strength were determined.

3.3.2 Flexural strength test

Prisms of size 100 mm × 100 mm × 500 mm were cast using methods earlier discussed and cured for 7, 14, 21, 28, 90 and 120 days. After curing, specimens from the three mix designations were tested for flexure, under three point bending using a universal testing machine. Specimen was simply supported on the two steel rollers of the machine which are 400 mm apart, with a bearing of 50mm from each support. The bearing surface of the supporting and the loading rollers were cleaned and all loose sand and other materials removed from the surface of the specimen where they are to make contact with the rollers.

The load was transmitted through a load cell from the flexural testing machine; the load was applied at the midspan of the specimen. The load increased till the specimen fails. The maximum value of the load applied was noted. The appearance of the fracture faces of concrete and any unique features were also noted.

(a) Compressive strength test **(b) Prism under flexural test** **(c) Splitting tensile test**

Fig. 5. Strength characteristics tests set-up of specimens

3.3.3 Split tensile strength test

Cylinders of size 150 mm (diameter) × 300 mm (height) were cast as discussed in earlier sections and cured for 7, 14, 21, 28, 90 and 120 days. The test was carried out by placing a cylindrical specimen horizontally between the loading surface of a compression testing machine and the load is applied until the failure of the cylinder, along the vertical diameter. In each category, three cylinders were tested and their average tensile strength values were evaluated.

3.3.4 Pundit test

Specimens of size 150 mm × 150 mm × 30 mm were cast and cured for 90 days. After the curing age, the specimens were tested with the aid of portable ultrasonic non-destructive digital indicating tester with the aim of examining the quality of the concrete specimens. The pulses were initiated into the concrete by a piezoelectric transducer and a similar transducer was used as a receiver to monitor the surface of vibration caused by the arrival of the pulse. A timing digital indicating circuit was used to measure the time it takes for the pulse to travel from the transmitter to the receiving transducer. In each category, three slabs were tested and their average values were reported. The pulse velocity was obtained from the ultrasonic pundit testing machine and recorded.

4. RESULTS AND DISCUSSION

4.1 Results of Tests on Fresh Concrete

The results carried out on fresh properties of concrete are presented in Table 6.

The slump and the compaction factor of all the concrete could be termed as good, with the control concrete possessing the highest workability value.

4.2 Results of Strength Property Test

The results of strength properties of hardened concrete are presented in the sections below.

4.2.1 Results of compressive strength

The results of compressive strength are presented in Fig. 6.

Table 6. Slump and compacting factor of concrete

Matrix designation	Matrix type	Volumetric fibre dosage v_f (%)	Average slump (mm)	Compacting factor
M_1	Control	0	100.00	0.97
M_2	SFRC	0.5	97.00	0.95
M_3	SFRC	1.0	96.80	0.96
M_4	SFRC	1.5	95.00	0.94
M_5	SFRC	2	91.55	0.93

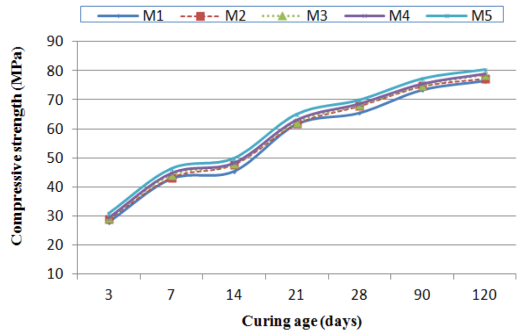

Fig. 6. Comparison of characteristics compressive strength values

The results indicate that all specimens had substantial strength values within the early age of curing; and the strength continued to build up as curing age advance, which implies that the hydration process within the mass concrete was steady and continuous. Also, significant increases in compressive strength of SFRC specimens compared to the control were noticed from the results. The SFRC specimens exhibits percentage increase in compressive strength of 3.96 - 10.54%, 1.19 - 8.12%, 5.34 - 9.86%, 0.44 - 5.56%, 3.85 - 6.79%, 1.88 - 5.24% and 1.20 - 5.05% within the fibre dosage range of 0.5 - 2.0% compare to the control at 3, 7, 14, 21, 28, 90 and 120 days respectively. In addition, the results reveal the compressive strength of the concrete specimens to increase with fibre dosage; with 2 percent fibre dosage having the highest compressive strength value. This, therefore, denotes that, the fibres were uniformly dispersed within the concrete and in a way, improving the concrete integrity.

4.2.2 Results of flexural strength

The results of flexural strength are presented in Fig. 7.

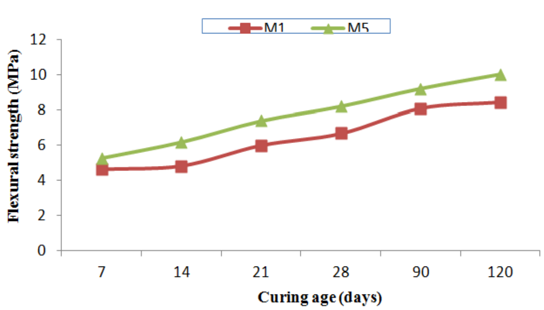

Fig. 7. Comparison of ultimate flexural strength values

The results of the flexural strength in Fig. 7 show a proportionate increase for all concrete specimens as the curing age advanced. Also, considerable increase in flexural strength of SFRC specimens compared to the control were noticed from the results, with the percentage improvements in flexural strength of SFRC specimens compare to the control of 13.63%, 28.27%, 23.21%, 22.94%, 13.84% and 18.86% at 7, 14, 21, 28, 90 and 120 days respectively. Also, the SFRC specimens were noticed to have appreciable strength increase under flexure, and likewise; found to exhibit greater ductility and fewer cracks during the test. This connotes that SFRC displays adequate serviceability requirements that will arrest crack formation.

4.2.3 Results of split tensile strength

The results of split tensile strength are presented in Fig. 8 below.

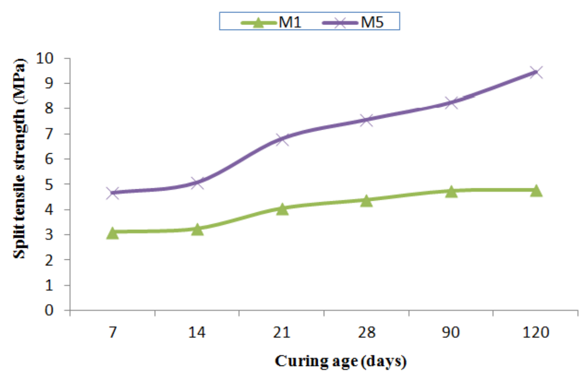

Fig. 8. Comparison of ultimate split tensile strength values

The splitting tensile strength results reveal that the specimens appreciate with regard to split tensile strength as curing age progresses; with the percentage improvements in split tensile strength of SFRC specimens compare to the control of 49.83%, 56.48%, 67.90%, 71.98%, 73.89% and 97.08% at 7, 14, 21, 28, 90 and 120 days respectively. The control concrete specimens were observed to split into equal halves under the loaded area while SFRC specimens depict an extra toughness, thus preventing the specimen from yielding to sudden breakage. The steel fibre in SFRC specimen was found to bridge the gap within the concrete, thereby leaving the concrete with a single crack line at the surface. The presence of steel fibre in the matrix was noticed to improve the tensile strength capability of the concrete by increasing the capacity of SFRC specimens to resist greater load under tensile stress than the control specimen.

4.2.4 Results of pulse velocity

The results of pulse velocity are presented in Fig. 9 below.

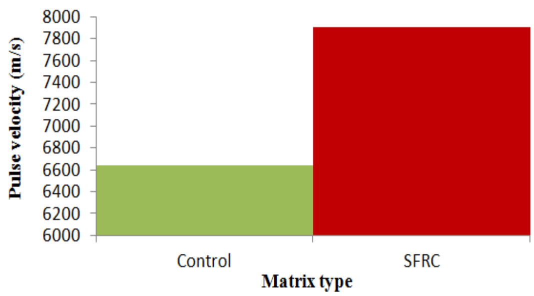

Fig. 9. Comparison of pulse velocity values

The pulse velocity results show that the pulse velocities increase with increase in fibre dosage. The higher values of the pulse velocity of the specimen were greater than 4.5 km/s, which depict excellent characteristics of steel fibre in improving the quality of the concrete.

5. CONCLUSION

The findings revealed that the addition of steel fibre to concrete improve the strength properties of the concrete, with better performance under compression, tensile and flexure compared to normal concrete. The compressive strength of the steel fibre reinforced concrete increases with increase in curing age, as well as split tensile and flexural strength properties. Workability of steel fibre reinforced concrete was also improved upon addition of super plasticizer in the mix, which indicate proper mix selection for the study, although with little reduction in the workability rate of steel fibre concrete to the control, such that the workability rate decreases with fibre dosage increases in the matrix. The presence of steel fibre was also observed to minimize crack propagation over conventional concrete, which shows that steel fibres helps in better bonding of the concrete and displays steel fibre reinforced concrete as concrete with good ductility properties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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