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Experimental Investigation of The Strength Properties of Concrete Containing Steel Fibres

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Abstract- This study was aimed at investigating the structural behaviour of steel fibre reinforced concrete at different volume fraction of the fibers. The experimental work was done to test the concrete specimens under compression and flexure. Concrete cubes and beam specimens were used for the production of all samples using a mix ratio of 1:1½:3 and water/cement ratio of 0.5. The compressive strength and flexural tests were conducted using the compression test machine for the concrete samples of different volume of steel fibres at 7, 14, 21 and 28 days to determine the strength properties of the various concrete specimens. It was observed that the highest compressive strength was at 28 days and was achieved at 2.0% SFRC with a strength value of 34.25N/mm2 greater than the control value of 27.40 N/mm2 while the highest flexural strength at 28 days was 10.24 N/mm2 at SFRC 3.0%. Therefore, the use of 2.0% of steel fibers by the volume of concrete was considered to be satisfactory.

Keywords: Compressive Strength, Flexural Strength, and Steel Fibre.

I. INTRODUCTION

Concrete is a composite, brittle material utilized in a variety of engineering structures, including foundations, pavements, tunnels, bridges, walls, reservoirs, and dams. Because of these numerous uses, a great deal of research has been conducted to enhance the characteristics of concrete for greater applicability. The addition of steel to concrete was one of many attempts to improve its performance. These traditional reinforcements are steel reinforcing bars positioned at precise locations inside the structure to resist applied tensile and shear stresses. In contrast, the integration of steel fibers is often discontinuous and random in the concrete mixture. For concrete mixtures in which the fibers are evenly scattered, they serve a significant role in reducing the incidence of cracks caused by variations in relative humidity and temperature. The addition of fibers (steel/natural/synthetic) to the concrete mixtures improves their mechanical properties. Although the role of fibre might not always involve an increase in strength, it has a considerable favorable effect on ductility, resilience to dynamic loading, and toughness. Concrete reinforcement with fibers is not a substitute for traditional steel reinforcing bars because steel bars and fibers serve distinctive, but both function in improving the concrete performance.
Steel fiber-reinforced concrete (SFRC) refers to the inclusion of short, discontinuous steel fibers into the matrix of concrete after mixing. Water, aggregates, cement, and steel fibers are the primary components of SFRC. Depending on the intended uses, SFRC may additionally comprise pozzolana and admixtures.

The main important effect of fibres as reinforcement is to influence and control the tensile cracking of concrete. Yet, the fibre reinforced concrete is known to have considerable impact on the slab cost owing to reduced thickness needs, prolonged useful life and reduction in maintenance costs.

Steel fibres are the most researched and more practical. Steel fibre reinforced concrete is a type of concrete that contains randomly oriented discrete steel fibres. The main aim of addition of steel fibres to concrete is to control crack widening and crack propagation after the concrete matrix has cracked. By control of the cracking the mechanical properties of the composite material as a result will be improved significantly.

Addition of randomly distributed steel fibres improves concrete properties, such as static flexural strength, ductility and flexural toughness. SFRC has been largely used in airport pavements due to the extreme and damaging loads acting on the pavement.

Some other examples of the structural and non-structural applications of SFRC are hydraulic structures, airport and highway paving and overlays, industrial floors, refractory concrete, bridge decks, concrete linings and coverings, and thin-shell structures. The elasticity modulus of steel fibres is as high as 210 MPa providing very high tensile strength with minimal deformation. The large number of fibres used for concrete members enables a uniform distribution of fibres through the compound, thereby creating a composite material possessing homogeneous mechanical behaviour. They provide a cohesive mix, creating a three dimensional reinforced net system. The important characteristic in FRC material is the bond between the fibers and the matrix. Fibres are designed in different geometries to increase the bond and interfacial friction between aggregates and cement paste. Fibre texture such as the end-hooked fibres improves the bond between the fibres within the matrix, thus increasing the necessary force required to pull out the fibre from the concrete. The forces induced in a SFRC when subjected to load are redistributed within the concrete, which restrains the formation and extension of cracks. The result is a more ductile reinforced concrete which is able to maintain a residual capacity in the post-cracking phase. Thus, resulting in an increased load-carrying capacity, improved shear and bending strength of concrete, superior flexural ductility, toughness, and fatigue endurance. In addition, SFRC has higher life cycle and the maintenance requirements are reduced resulting in lower costs. Another advantage of the SFRC is that at an adequate volume fraction they can replace conventional steel reinforcement when designed properly and it reduces the construction time since the steel fibres are added directly as one of the concrete mix constituents, hence no steel fixing or adjustment is required. (Association of Concrete Industrial Flooring Contractors)

The research on the SFRC members and slabs under static loads showed that they can provide equivalent performance compared to conventionally reinforced concrete slabs when equivalent amounts of reinforcement is used.

Researchers during recent years have stated that steel fibres significantly improve the impact resistance of concrete material making it a suitable material for structures subjected to impact loads. Overall, the above factors suggest that SFRC is potentially the most beneficial type of material from engineering and economical prospective to be considered for structural slabs subjected to high loads.

Steel fibre reinforced concrete (SFRC) is a composite material similar to normal concrete but with fibres as part of mixture constituent. It is made of cement, fine aggregate, coarse aggregate and other components or admixtures that can commonly be used in concrete with dispersion of discrete small steel fibres. It has been used in concrete since the early seventies and for different applications like slab on ground, pavements, and bridge decks. Fibres have different geometries also they vary in dimensions. The length of fibres could vary from 25mm to 75mm and the diameter from 0.5mm to 1.3mm.

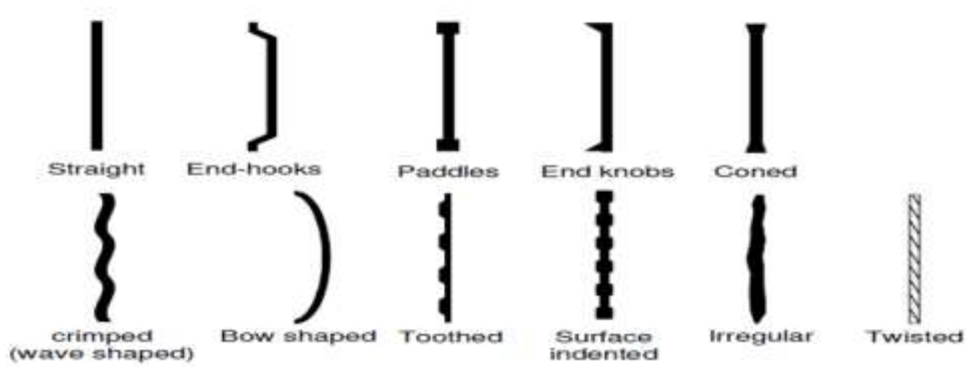

Figure 1: Different Fibre Shapes

The addition of fibres to concrete has shown improvement in concrete flexural strength, toughness, ductility, impact resistance, fatigue strength and resistance to cracking. In addition the deformation at peak stress is much greater than plain mortar. Fibres help to alter the behaviour of concrete after the initiation of cracking. The crack bridging behaviour of fibres is what improves the ductility of matrix.

The main advantageous property of SFRC is its superior resistance to cracking and crack propagation. The fibres are able to hold the matrix together even after extensive cracking due to its bridging effect. SFRC has the ability to arrest cracks; therefore fibre composites retain increased extensibility and tensile strength, both at first crack and at ultimate stress. The net result this is the fibre composite will have a marked post-cracking behaviour and ductility which is unremarked in ordinary concrete in which the tension post crack is negligible. The material is therefore transformed from a brittle to a ductile type of material which would increase substantially the energy absorption characteristics of the fibre composite and its ability to withstand repeating applied load such as shock or impact loads.

Steel fibres are generally made of carbon steel or stainless steel, where the latter is used for structures that require corrosion-resistant fibres. Tensile strengths may be in the range 200- 2600 MPa and ultimate elongations between 0.5% and 5%. Although a tensile strength is significantly higher than that of the matrix is needed, very strong fibres may have an adverse effect on the reinforcing efficiency; pull-out experiments have shown that in low-strength matrices high tensile strength steel fibres cause more severe matrix spalling around the fibre exit point.

II. MATERIALS AND METHODS

The materials used in this research are:
Cement, Coarse Aggregate (Granite), Fine Aggregate (Sand), Straight Steel Fibre, Water.

A. Cement

Ordinary Portland Cement (OPC) manufactured by Dangote Nigeria Limited was used in all mixes throughout this research. A total mass of about 34.32kg of Ordinary Portland Cement (Dangote) was used to produce concrete specimens tested throughout the experimental phase of the project.

B. Coarse Aggregate (Granite)

Coarse aggregate (granite) which has been selected for present work, was bought from local trader. It source was from a quarry in Port Harcourt in Rivers State. It was ensured that a maximum nominal particles size of 25mm was used as coarse aggregate which was of irregular shape and with Specific gravity 2.6. A total mass of about 102.96kg of granite was used to produce concrete specimens throughout the experimental phase of the project. The particle size distribution for granite was done using sieve analysis. The granite used for this project are granite that passed through the 25 mm sieve and retained on 4.75mm test sieve and containing only so much finer material as permitted from the various sizes as specified by BS 410 and BS 882.

C. Fine Aggregate (Sand)

Fine aggregate (sand), which has been selected for present work, was bought from a local trader in Port Harcourt, Rivers State. The fine aggregate has 4.75mm maximum size with irregular particle shape and rough texture with Specific gravity 2.61. In all concrete batches the sand was dried in air before being used. A total mass of about 51.48kg of sand was used to produce concrete specimens tested throughout the experimental phase of the project. The particle size distribution for sand was done using sieve analysis. It was ensured to be clean and not contaminated by clay and salt ingredient.

D. Water

Portable water available in Choba campus of the University of Port Harcourt (UNIPORT) was used in all the experiments. Special consideration was given to the water used for mixing, as part of water assisted in the hydration of cement particles and in generating a mix with reasonable workability for easy placing. The drinking tap water was entirely satisfactory and it satisfied the requirement of BS 3148. A total mass of about 17.16kg of water was used to produce concrete specimens throughout the experimental phase of the project.

E. Steel Fibre
Straight mild steel fibre with 75mm length was used at a volume fraction of 1%, 2% and 3%.

PRIMILINARY TESTS
A. Sieve Analysis
Sieve analysis test was conducted for all the aggregates used in this research which are sand and granite. The procedure used is outlined below:
Purpose: This test is performed to determine the percentage of different grain sizes contained within the aggregates used during the course of this study. It helps to determine the distribution of the aggregates.
Apparatus:

Balance, Set of sieves, Cleaning brush, Sieve shaker
Test Procedure:

1. The weight of each sieve as well as the bottom pan to be used in the analysis was measured and recorded.
2. The weight of the given dry aggregate sample was also recorded.
3. It was ensured that all the sieves are clean, and they were assembled in the ascending order of sieve numbers. The pan was placed below the bottom sieve. The aggregate sample was then carefully poured into the top sieve and the cap was placed over it.
4. The sieves were then shaken manually by hand for 10 minutes.
5. The weight of each sieve with its retained aggregate was then measured and recorded. The weight of the bottom pan with its retained fine aggregate was also recorded.

Data Analysis:

1. The mass of aggregate retained on each sieve was obtained by subtracting the weight of the empty sieve from the mass of the sieve + retained aggregate, and it was recorded as the weight retained on the data sheet. The sum of these retained masses should approximately equal the initial mass of the soil sample. A loss of more than two percent is unsatisfactory.
2. The percent retained on each sieve was calculated by dividing the weight retained on each sieve by the original sample mass.
3. The percent passing (or percent finer) was calculated by starting with 100 percent and subtracting the percent retained on each sieve as a cumulative procedure.

A semi-logarithmic plot of grain size vs. percent passing was made.

B. Specific Gravity
Specific gravity is the ratio of the density of a substance to the density (mass of the same unit volume) of a reference substance (water). Apparent specific gravity is the ratio of the weight of a volume of the substance to the weight of an equal volume of the reference substance (water). The specific gravity of a soil is often used to describe the relationship between the weight of soil and its volume. As soil contains different particles with different specific gravities; the term Gs represents an average specific gravity value for all the particles.

Apparatus:

1. Density Piezometre bottle
2. Glass rod
3. Wash bottle containing distilled water
4. Drying Oven

Procedures:

1. Weigh the dried density bottle, (Ws).
2. Obtain about 25.0g of the oven dried material and transfer into density bottle. Replace the stopper and weigh the bottle and contents. (W2).
3. Add distilled or tap water so that the soil in the bottle is just covered. Thoroughly stir the mixture with a glass rod or shake to remove air trapped in the soil.
4. Fill the bottle with distilled or tap water and replace the stopper. Shake the bottle and its contents carefully to remove any remaining air.(W3)
5. Empty the contents of the bottle, wash and fill the bottle with distilled water only. (W4).

$$G_s = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)}$$

Where;
W1 = Weight of bottle
W2 = Weight of bottle and dry

W3 = Weight of bottle, soil and water
W4 = Weight of bottle filled with water only.

The specific gravity is used in the laboratory to help with the calculation of the void ratios of soil specimens, in the determination of the moisture content of a soil, and in the particle-size analysis, also known as the sedimentation test.

C. Bulk Density
Apparatus:
1. A 150mm diameter open-ended steel cylinder with plunger and base plate.
2. A standard metal tamping rod
3. Weigh balance

The steel cylinder was then filled to overflowing with aggregate being discharged from a height of not more than 50mm above the top of the container. The aggregate in the mould was leveled with the tampering rod and then weighed and divided by the volume of the container to give the bulk density in kg/m3.

EXPERIMENTAL DESIGN
A. Mix Design
The mix design which was adopted for this project work is of grade M30 concrete which has a mix ratio of 1:11/2:3 with water mix ratio of 0.5 which was used for both control samples and SFRC samples.

B. Concrete Cube Moulds
Steel moulds of size 150mm x 150mm x 150 mm was used for casting the concrete cubes. The concrete production phase involved a careful procedure in the calculation of materials for the batching process. The moulds were lubricated with oil in order to allow for easy removal of the cubes after hardening. After pouring, tamping rod was used to ensure even distribution of the aggregates within the cubes and also ensure adequate compaction. At about 24 hours after casting, the cubes were de-moulded and cured by total immersion in water for 7, 14, 21 and 28 days of curing ages respectively.

Apparatus:
These includes: Trowels, mixing trays, weighing pans, weighing instrument, tamping rods, steel cube moulds (150mm x150mm x 150mm), lubricant, iron and soft brushes, set of B.S. sieves, mixing table, head pans, calculator, recording sheets, curing tanks, crushing machine.

The strength parameters were set after which the start button was pressed and the machine automatically starts the compression process on the sample until failure occurs on the sample at which point the compressive strength stops.

The maximum load and compressive strength at which failure occurred was then recorded. After average results are obtained, the optimum compressive strength was computed with the optimum strength of normal concrete without superplasticizer.

C. Concrete Beam Moulds
Beam wooden moulds of length 400mm with height and width of 100 mm were used for casting the concrete. Eight concrete beam test specimens were produced. The concrete production phase involved a careful procedure in the calculation of materials for the batching process. The moulds were lubricated with oil in order to allow for easy removal of the cubes after hardening. After pouring, tamping rod was used to ensure even distribution of the aggregates within the beams and also ensure adequate compaction. At about 24 hours after casting, the beams were de-moulded and cured by total immersion in water for 28 days of curing age.

III. SECONDARY INVESTIGATION

A. Slump Test
The concrete slump test is an empirical test that measures the workability of fresh concrete. More specifically, it measures the consistency of the concrete in that specific batch. This test is performed to check the consistency of freshly made concrete. The slump test was carried out for each design mix so as to be able to describe the workability of the concrete at various mix proportions.

Procedures:
The slump test mould was dampen then placed on a flat, moist, nonabsorbent, rigid surface, in this case a

steel plate. The cone was filled to 1/3 full by volume; the bottom layer was roded with 25 evenly spaced strokes. The cone was then filled to 2/3 full (about 6 inches), and rod the second layer was roded with 25 strokes penetrating the top of the bottom layer. The tapping was evenly distributed over the entire cross section of this layer. The concrete was then heaped on top of the mould and the top layer was roded with 25 strokes penetrating the top of the second layer.

Excess concrete was removed from the top of the cone using the tamping rod making the top of the concrete even with the mould. The cone was carefully removed in the vertical direction and it was ensured that the cone do not tilt during the process (taking about five seconds).

The cone was immediately inverted and placed beside the slumped concrete with the rod horizontally placed across the top of the cone. The slump was then measured. The slump test is very important in understanding the workability of the concrete.

B. Placing Of Concrete in Moulds

Cube of 150mmx150mmx150mm and beam moulds of 400mmx100mx100mm was used to produce the test samples. Compaction was done in 3 layers each of 35 blows using a 16mm rod for the compaction.

Figure 5: Showing Specimens production process

C. Demoulding and Curing of Concrete Specimen

After 24 hours, the concrete specimens were cautiously demoulded and transferred to the curing tanks. This is necessary in order for the concrete to be able to attain full strength and also, it helps in minimizing cracking and drying shrinkage in concrete. The cubes were cured for 7, 14, 21 and 28 days before they were tested.

Curing is the maintenance of a satisfactory moisture content and temperature in concrete for a period of time immediately after casting and placing, so that the desired properties may develop. It is important in the gradual attainment of strength of hardened concrete.

IV. TEST ON HARDENED CONCRETE SPECIMENS

A. Compressive Strength Test

Test Procedures:

The compressive strength test was carried out on the cubes for the varying mix proportion adopted for the purpose of this study. The cubes were cured for 7, 14, 21 and 28 days respectively. Eight cubes were made from each mix proportion two of which were tested after the 7th day of curing, then another two after the 14th day of curing, another two after the 21st day of curing, and the final two after 28 days of curing.

Summary of test:

1. The test specimen was removed from the curing tank after it has been cured for the proper length of time (age) in water.
2. The test specimen was then placed in the machine and slowly brought the blocks to bear on the specimen without shock until failure occurs.
3. The machine was operated at a constant rate.
4. The maximum load at failure was recorded and thus used in calculating the compressive strength for each concrete cube tested.

$$f_{cu} = \frac{F}{A_c}$$

Where $f$cu = compressive strength (N/mm2)

F= Maximum load at failure (N)

A_c = Cross sectional area of specimen on which compression force act (mm2)

B. Flexural Strength Test

The flexural strength test was carried out on the beam specimens for the varying mix proportion adopted for the purpose of this study. The beams were cured for 28 days.

Summary of test:

1. The test specimen was removed from the curing tank after it has been cured for the proper length of time (age) in water.
2. The test specimen was then placed in the machine and slowly brought the blocks to bear on the specimen without shock until failure occurs.

3. The machine was operated at a constant rate.
4. The maximum load at failure was recorded and thus used in calculating the flexural strength for each concrete beam tested using:

$$f_{cf} = \frac{Pl\prime}{bd^2}$$

Where $f$cf = Flexural strength (N/mm2)
P= Maximum load at failure (N).
l' = Distance between axis of supporting rollers (mm).
b = Width of specimen (mm).
d= Depth of specimen (mm).

V. RESULTS AND DISCUSIONS

The preliminary tests carried out on the aggregate gave the following results:

A. Sieve Analysis for Sand and Granite

The sieve analysis was used to evaluate the particle size distribution of the aggregates used for this research work. The size distribution is of critical importance to the way materials perform in use. The fineness modulus is obtained by adding the total percentage of the sample of an aggregate retained on each of a specified series of sieves and dividing the sum by 100. A smaller value indicates a finer aggregate and a higher value a coarser aggregate. The results can be seen on table 1 and 2.

Equations:
% retained on any sieve =

$$\frac{Weight\ of\ soil\ retained}{Total\ Soil\ weight}\ x\ 100\% \qquad (1)$$

Cumulative % retained on any sieve = Σ% retained……………...………….. (2)
Cumulative % passing =100% - Cumulative % retained…………………….. (3)

Table 1: Sieve Analysis Result for Fine Aggregate:

FINE AGGREGATE				
Sieve Diameter (mm)	Weight Retained (g)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Percentage Passing (%)
10	0	0.0	0.0	100.0
4.75	4.0	0.2	0.2	99.8
2.00	52.0	2.6	2.8	97.2
1.18	162	8.1	10.9	89.1
0.25	1648	82.4	93.3	6.7
0.212	58.0	2.9	96.2	3.8
0.125	60.0	3.0	99.2	0.8
0.09	16.0	0.8	100	0

Table 2: Sieve Analysis Result for Granite:

COARSE AGGREGATE				
Sieve Diameter (mm)	Weight Retained (g)	Percentage Retained (%)	Cumulative Percentage Retained (%)	Percentage Passing (%)
37.5	0	0	0.00	100.00
25	216	10.8	10.8	89.20
19	983	49.15	59.95	40.03
13.2	615	30.75	90.70	9.3
6.7	186	9.3	100.00	0.00
4.75	0	0	100.00	0.00

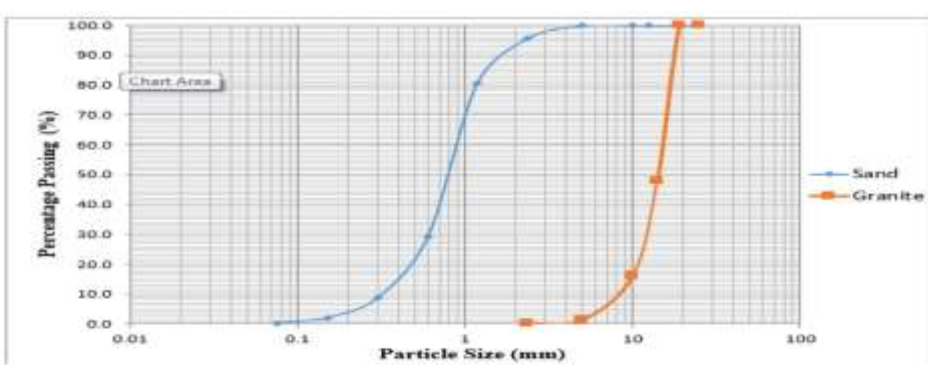

Figure 6: Sieve Analysis Graph of Sand and Granite

B. Coefficient of Uniformity and Coefficient of Cuvature

A higher value of Cu indicates that the particle size distribution is wider and lower values indicate that the particle size distribution is closer. Cu= 1 means uniform, all grains are in the same size, such as the case of dune sands. A soil is said to be well graded if the coefficient of curvature Cc between 1 and 3, with Cu greater than 4 for granites and 6 for sands (Holtz, 2009).

For granite to be classified as well graded: Cu > 4 & 1 < Cc < 3

For a sand to be classified as well graded: Cu ≥ 6 & 1 < Cc < 3

These criteria are in accordance with the Unified Soil Classification System ASTM D6913 – 04 (2009)

Table 3: Different Particle sizes for Sand and Granite:

Different Particle Sizes for Sand and Granite			
Particle Size	D_{10}	D_{30}	D_{60}
Sand (mm)	0.32	0.60	0.90
Granite (mm)	8.50	12.50	15.00

Equations and the Calculation for the grading Parameters of Concrete.

Effective size= D_{10} (4)

Coefficient of Uniformity = $C_u = \frac{D_{60}}{D_{10}}$ (5)

Coefficient of curvature= $C_c = \frac{D_{30}^2}{D_{60} x\, D_{10}}$ (6)

SAND:

Coefficient of Uniformity = $C_u = \frac{0.9}{0.32} = 2.81$

Coefficient of curvature= $C_c = \frac{0.60^2}{0.9x\, 0.32} = \frac{0.36}{0.288} = 1.25$

Fineness Modulus = FM= $\frac{402.6}{100}$= 4.03

GRANITE:

Uniformity coefficient = $C_u = \frac{15}{8.5}$= 1.76

Coefficient of curvature= Cc = $\frac{12.5^2}{15x\, 8.5} = \frac{156.25}{127.5} = 1.23$

Fineness Modulus = FM= $\frac{361.5}{100}$ = 3.61

Table 4: Gradation Parameters.

Measure of Gradation		
Parameters	Sand	Granite
Coefficient of Uniformity (Cu)	2.81	1.76
Coefficient of Curvature (Cc)	1.25	1.23
Fineness Modulus (FM)	4.03	3.61

From the results above, with the fine aggregate having a Cu value of 2.81 and a Cc value of 1.25, it can be classified according to unified soil classification as a well graded medium to coarse sand. The coarse aggregate can be classified as medium graded coarse aggregate with its Cu value of 1.76 and Cc value of 1.23.

A fineness modulus of 4.03 was obtained for the sand which lies around the fine aggregate boundary. The granite also has a fineness modulus of 3.61 which implies that the granite can be classified as a coarse aggregate.

C. Specific Gravity

The specific gravity is important in that it can be converted to density. Specific gravity compares the mass of a given volume of material to the mass of the same volume of water. The results obtained from the specific gravity test are tabulated below:

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Table 5: Specific Gravity Result:

S/No	TEST NO	1	2
	OBSERVATIONS		
1	Weight of density bottle alone (W_1)	26.69	26.73
2	Weight of density bottle alone + Oven dry soil (W_2)	60.73	52.43
3	Weight of density bottle alone + Oven dry soil + Distilled Water (W_3)	100.80	95.72
4	Wt. of density bottle + water (W_4)	79.82	79.82
5	(W_3-W_2)	40.07	43.29
6	(W_4-W_1)	53.13	53.09
7	(W_4-W_1)- (W_3-W_2)	13.06	9.80
8	(W_2-W_1)	34.04	25.70
9	Gs = (W_2-W_1)/ (W_4-W_1) - (W_3-W_2)	2.606	2.622
10	Average specific gravity	2.61	

Table 6: Summary of the Physical Properties of the Materials for Specimens:

Physical Properties	Sand	Granite
Uniformity Coefficient (Cu)	2.81	1.76
Coefficient of Curvature (Cc)	1.25	1.23
Fineness Modulus	4.84	4.35
Specific Gravity	2.61	2.6
Bulk Density (kg/m3)	1601.2	1718.23
Dry Density (kg/m3)	1602	1713.36

D. Workability/ Slump Test

Workability is a measure of the amount of useful internal work necessary to be done on a concrete mix to produce full compaction. A standard measure of workability is the slump test. The workability of the fresh concrete was determined by the Slump test method in accordance with BS 1377. To measure the slump, a slump cone was used on a plate and concrete is poured inside the cone. When 1/3 of the cone is filled the concrete is tamped with tamping rod 24 times. This is repeated when 2/3 of the cone is filled. When the cone is filled with concrete the top surface is made to be smooth. Then the cone was lifted within 5 seconds and the distance from the top of the concrete to the top of the cone is the slump value.

The higher the slump flow (SF) value, the greater the concrete ability to fill form-work under its own weight. Therefore, more compaction effort was needed as the percentage of steel fibre increased from 0% to 3.0%. Below is the table containing the results of the slump test. This experiment produced a range of slump values between 50mm and

Table 7: Slump Values and Degree of Workability

Batch	Slump (mm)	Type of Slump	Degree of Workability
B-01	100	True	High
B-02	150	True	High
B-03	78	True	Medium
B-04	70	True	Medium
B-05	67	True	Medium
B-06	50	True	Medium

V. RESULTS FOR COMPRESSIVE STRENGTH OF CUBES

This test was carried out to determine the strength of concrete at different curing ages and also to determine the effect of steel fibre on concrete with age. The test was performed using different percentage of steel fibre from 0% to 3.0%, so as to be able to correlate the strength of each percentage of steel fibre. The compressive strength is determined on concrete cube specimens. A total of 8 plain concrete cubes were cast, while 8 concrete cubes were cast for each percentage steel variation. The average compressive strength was recorded for each of the test age. The results obtained for each variation is given below in Table 8.

Table .8: Average Compressive Strength of Concrete Cube:

Average Compressive Strength (N/mm^2)					
(%) Steel Fibre	0.0	0.5	1.0	2.0	3.0
Days					
7	22.05	22.43	23.30	27.28	24.66
14	23.57	24.68	24.88	29.19	26.69
21	26.18	28.23	28.32	32.29	27.40
28	27.40	30.15	30.65	34.25	28.95

It can be seen that the strength has an increasing trend with the increase of volume fraction of steel fibres and the increase in strength from SFRC 0.5% to SFRC 2.0% is noticeable while increasing volume of fibers from 2% to 3% doesn't have any increasing effect on the compression strength. This could be attributed to the air content of the concrete, which previous researchers believe that the air content increases with the increase of steel fiber volume fraction, hence decreasing the compressive strength. However, the presence of steel fibers in many amounts can also reduce the compressive strength of concrete.

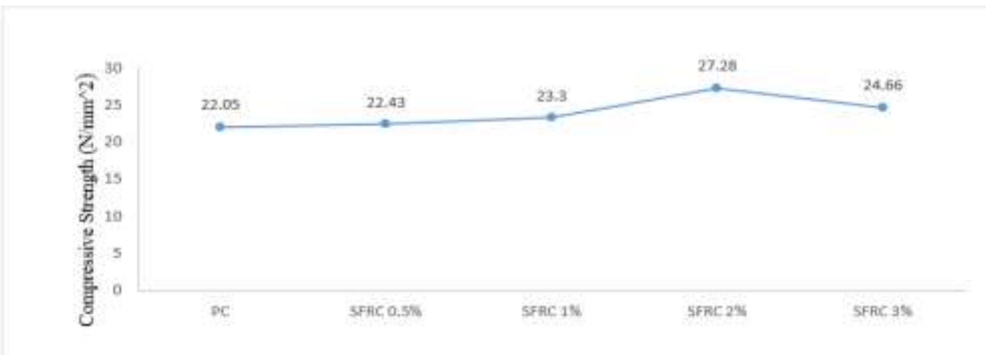

Figure 7: Cube Compression Result Graph-7 Days

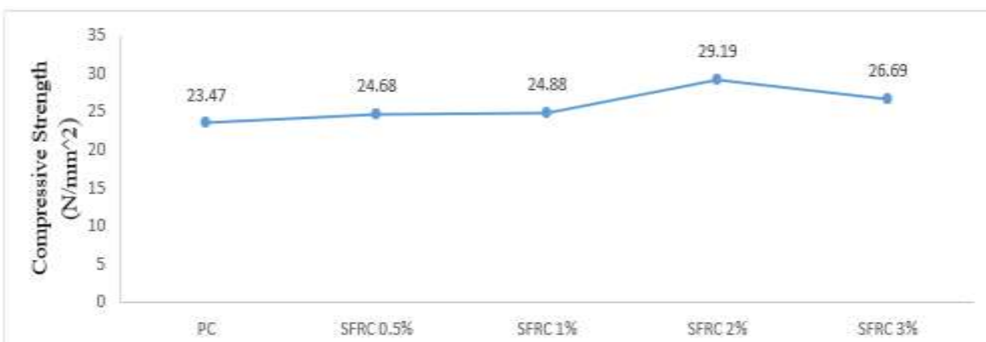

Figure 8: Cube Compression Result Graph-14 Days

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Figure 9: Cube Compression Result Graph-21 Days

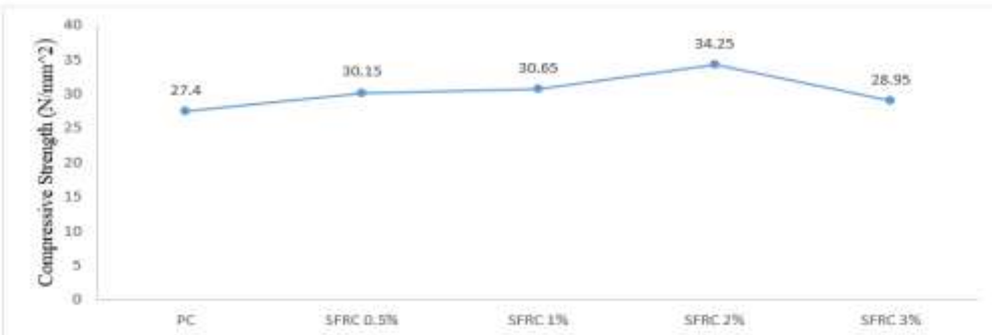

Figure 10: Cube Compression Result Graph-28 Day

A. Percentage of Steel Fibre (0%)

The compressive strength at curing age of day-7, day-14, day-21 and day-28 were 22.05 N/mm2, 23.57 N/mm2, 26.18 N/mm2 and 27.40 N/mm2 respectively. It was observed that the following percentage increase in compressive strength occurred with reference to the compressive strength at day-7; there was an increase of 6.89% in compressive strength at day-14; and an increase of 18.73% in compressive strength at day-21; and an increase of 24.26% in compressive strength at day-28.

The compressive strength of concrete increased by 6.89% between day-7 and day-14. The compressive strength of concrete increased by 11.07% between day-14 and day-21. The compressive strength of concrete increased by 4.66% between day-21 and day-28.

B. Percentage of Steel Fibre (0.5%)

The compressive strength at curing age of day-7, day-14, day-21 and day-28 were 22.43 N/mm2, 24.68 N/mm2, 28.23 N/mm2 and 30.15 N/mm2 respectively. It was observed that the following percentage increase in compressive strength occurred with reference to the compressive strength at day-7; there was an increase of 10.03% in compressive strength at day-14; and an increase of 25.86% in compressive strength at day-21; and an increase of 34.42% in compressive strength at day-28.

The compressive strength of concrete increased by 10.03% between day-7 and day-14. The compressive strength of concrete increased by 14.47% between day-14 and day-21. The compressive strength of concrete increased by 6.8% between day-21 and day-28.

C. Percentage of Steel Fibre (1%)

The compressive strength at curing age of day-7, day-14, day-21 and day-28 were 23.30 N/mm2, 24.88 N/mm2, 28.32 N/mm2 and 30.65 N/mm2 respectively. It was observed that the following percentage increase in compressive strength occurred with reference to the compressive strength at day-7; there was an increase of 6.78% in compressive strength at day-14; and an increase of 21.55% in compressive strength at day-21; and an increase of 31.55% in compressive strength at day-28. The

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compressive strength of concrete increased by 12.81% between day-7 and day-14.

The compressive strength of concrete increased by 13.83% between day-14 and day-21. The compressive strength of concrete increased by 8.23% between day-21 and day-28.

D. Percentage of Steel Fibre (2%)

The compressive strength at curing age of day-7, day-14, day-21 and day-28 were 27.28 N/mm2, 29.19 N/mm2, 32.29 N/mm2 and 34.25 N/mm2 respectively. It was observed that the following percentage increase in compressive strength occurred with reference to the compressive strength at day-7; there was an increase of 7.0% in compressive strength at day-14; and an increase of 18.37% in compressive strength at day-21; and an increase of 25.55% in compressive strength at day 28.

The compressive strength of concrete increased by 7.0% between day-7 and day-14. The compressive strength of concrete increased by 10.62% between day-14 and day-21. The compressive strength of concrete increased by 6.07% between day-21 and day-28.

E. Percentage of Steel Fibre (3%)

The compressive strength at curing age of day-7, day-14, day-21 and day-28 were 24.66 N/mm2, 26.69 N/mm2, 27.40 N/mm2 and 28.95 N/mm2 respectively. It was observed that the following percentage increase in compressive strength occurred with reference to the compressive strength at day-7; there was an increase of 8.23% in compressive strength at day-14; and an increase of 11.11% in compressive strength at day-21; and an increase of 17.40% in compressive strength at day-28.

The compressive strength of concrete increased by 8.23% between day-7 and day-14. The compressive strength of concrete increased by 2.66% between day-14 and day-21. The compressive strength of concrete increased by 5.66% between day-21 and day-28.

VI. FLEXURAL BEAM TEST AND RESULT

Flexural beam test is another indirect method of testing and evaluating the tensile strength of the concrete. For each batch numbers of beams were casted to be tested under compression load. The beams had the cross-section dimension of 100×100mm and a length of 400mm. The clear span was set to 360mm and the upper bearer distance was set to 300mm. The displacement at the centre of the beam was measured by the use of two displacement transducers at both sides of the beam.

The test was conducted under displacement control and the load was applied axially at uniform rate. The flexural strength of the concrete is given by the following equation:

Flexural Strength was calculated using

Flexural Strength $\sigma = \frac{PL}{bd^2}$ (1)

P= Maximum load at failure (N)
L=Distance between axis of supporting roller support and fixed support (mm)
B=width of beam (mm)
D=depth of beam (mm)

RESULTS

The failure process for the fiber reinforced concrete is that when the beam reaches its maximum flexural strength it starts to crack from the bottom centre point of the beam, where the concrete is under tensile stress. Concrete pavements are usually designed using a mean 28-day flexural strength of 4.5 N/mm2 based on 3-point loading.

Table 4.9: Average Flexural Strength of Concrete Beams at 28 days:

Average Flexural Strength (N/mm^2)				
(%) Steel Fibre	0.0	1.0	2.0	3.0
Days				
28	4.59	5.24	7.0	10.24

It was observed that the following percentage increase in flexural strength occurred with reference to the standard flexural strength of beams at day-28; there was an increase of 2% in flexural strength at 0% SFRC; an increase of 16.44% in flexural strength at SFRC 1%; an increase of 55.6% in flexural strength at SFRC 2% and an increase of 127.56% in flexural strength at SFRC 3%.

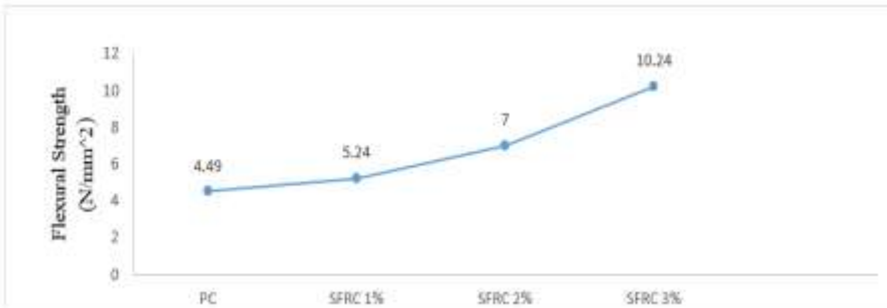

Figure 11: Flexural Strength Graph-28 Days

The optimum value of steel fibers for is suggested to be 2.0% as it affects the mechanical performance greatly. Also the literature and industry consider the 2.0% to be a practicable and cost-effective amount. It should be noted that this amount of fibers decreases the consistency and workability of the concrete which can be undesirable, therefore the use of additives to enhance the workability would be essential. In conclusion the use of 2.0% of steel fibers by the volume of concrete is considered to be satisfactory.

VII. CONCLUSION

The behaviour of the structural members under extreme loads is quite vital in some applications in structural engineering industry. The development of new materials such as steel fibre reinforced concrete has shown that these can be effective in structural member performance. Research up to date on SFRC has been mostly focused on static performance of members and there is lack of research on the effect of these materials on impact behaviour of slabs with varying parameters in the concrete such as steel fibre type and volume fraction. This research aims to investigate SFRC material behaviour and conclude how SFRC can enhance the performance of concrete hence structural members. Experimental investigation was carried out on the behaviour of steel fibre reinforced concrete material using end straight steel fiber with different volume fractions of the fibers consisting of: 0.5%, 1.0%, 2.0% and 3.0% as well as plain concrete. Tests included the cube compression test and flexural test to evaluate the basic material behaviour. The results showed that the use of fibers enhanced all aspects of material capacity namely compression strength and flexural strength. This was

more evident with the increase in the amount of fibers. The performance of SFRC2.0% was the best out of all concrete types while PC showed the highest damage with the least capacity. The presence of steel fibers increases the load capacity of the samples and makes the concrete a more ductile material as opposed to a conventionally known brittle material. This is very important when designing structural members especially for those under extreme loads such as impact load.

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