EXPERIMENTAL AND ANALYTICAL INVESTIGATION ON FLEXURAL BEHAVIOUR OF HIGH STRENGTH FIBRE REINFORCED CONCRETE (HSFRC) BEAMS

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The structural integrity of concrete is known to improve by the incorporation of fibres in recent days. A 10% of Ground Granulated Blast furnace Slag (GGBS) and 10% of Silica Fume (SF) were used as replacements for cement binder along with 1.5% of fibre content dispersed in the mixture. This research discusses the influence of steel fibres, polypropylene fibres and supplementary cementitious materials in attaining High Strength Fibre Reinforced Concrete (HSFRC). Manufactured sand (M-sand) is employed as fine aggregate now that river sand has a commercial ban due to its scarce availability. A superplasticizer (SP) commercially marketed as Conplast SP430 is proportioned to 1.5% by weight of cement to improve the workability of the mixture. The study investigates the flexural behavior of three HSFRC beam specimens casted for a design characteristic compressive strength of 60MPa (M60 grade) under normal water curing conditions. The specimens were supported by a two-point loading setup and tested as per the Indian standards. It was evident from the results that the flexural strength of beams increased notably with the use of fibres in comparison with normal plain reinforced concrete beams and the same was validated through an analytical study using ANSYS software. The formation and width of cracks was much reduced in HSFRC beams compared to the conventional concrete beams. Reduction in cracks are an advantage in building up the durability of the specimens.

Keywords: *High Strength Fibre Reinforced Concrete (HSFRC), Ground Granulated Blast Furnace Slag (GGBS), Silica Fume (SF), Polypropylene fibre, Steel fibre and M-sand.*

1. Introduction

The use of high strength concrete in the construction industry has increased steadily over the past. The term high-strength concrete is generally used for concrete with compressive strength higher than 60MPa. The use of high- strength concrete leads to the design of smaller cross sections. This in turn reduces the dead weight, allowing longer spans and more usable area of building in tall structures. Reduction in mass is also important for economical design of earthquake resistant structures.

In high strength concrete use of supplementary cementitious materials enhance the filling property of the binder, reducing its permeability. Use of fibres have known to improve the strength behavior of structural elements. When subjected to bending fibre reinforced members (FRC) deduce propagation of cracks further thus reducing crack widths. Also, the energy absorption capacities are increased, followed by which the elements can withstand a greater number of cycles in cyclic loading.

Considerable efforts are still being made in every part of the world to develop new construction materials. High strength fibre reinforced concrete (HSFRC) is one of the most promising new construction materials. Many studies have been carried out to explore the mechanical properties and strength characteristics of fibre reinforced concrete. Most studied however, have so far been confined to the investigation of single type of fibre dispersed in concrete or as fibre reinforcement rods that replace mild steel reinforcements in use.

High strength concrete with compressive strength ranging to about 60MPa can be made with carefully selected cement, sand, coarse aggregate and by using very low water cement ratio. To decrease the water content, high range water reducing admixtures (superplasticizer) can be used to improve the workability of those concrete.

2. Fibres in Concrete

High strength concrete is a brittle material, and as the concrete strength increases the post-peak portion of the stress-strain diagram almost vanishes or descends steeply. The increase in concrete strength reduces its ductility. Higher the strength of the concrete lower it's ductility. This reverse relation between strength and ductility is a serious drawback for the use of high strength concrete and a compromise between these two characteristics of concrete can be obtained by adding discontinuous fibres.

When added to concrete mixes, steel fibres distribute randomly through the mix at much closer spacing than conventional reinforcing steel. Depending on their aspect ratio, fibres act to arrest cracking by decreasing the stress intensity factor at the tip of inherent internal cracks. Fibres also

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increase the shear-friction strength of concrete. Steel fibres have been used as web reinforcement. The presence of fibre reinforcement in concrete not only helps to control cracking and enhance the tensile strength and ductility of composite but also increases the pullout resistance of tension reinforcement. The addition of steel fibres to concrete helps to improve post-cracking tensile strength and hence leads to a significant increase in the shear strength of reinforced concrete and transforms the failure mode into a ductile one.

The increase in strength by the use of steel fibres depends on the strength characteristics of the fibres themselves, the bond in the matrix-fibre interface, the ductility of fibres, the volume of fibre reinforcement and its dispersion and orientation of fibres, and their shape and aspect ratio (the ratio of the length of the fibre to its diameter). High strength fibres, large volume of fibre, larger fibre lengths and smaller fibre diameter has been found independently to improve the strength.

The increase in strength was observed to be particularly larger (69% to 80%) for beams with a size to depth (a/d) ratio of 2, and they failed in combinations of shear and flexure. The increase in beam strength were smaller (22% to 38%) for beams with larger a/d ratio and they failed in flexure. The addition of steel fibre decreased crack spacing and size as studied by Yoon-Keunkwak, et, al (2002). Addition of steel fibres improves the tensile strength of HSC, particularly when fibres have higher aspect ratios. A tensile strength increase of 39% was achieved in the present experimental investigation with the addition of steel fibres (T.Tahenni,et al, 2016).The significant increase in compressive and split tensile strength is observed with the addition of hooked end steel fibre in plain concrete. However, this increase depends on addition of amount of fibre content. The ultimate shear stress is directly proportional to percent fibre content and inversely proportional to shear span to depth ratio. Maximum percentage increase in ultimate shear stress is 60.70% for shear span-depth ratio of 1.0 and fibre content of 2.0% (V. T. Babar,et,al 2015).Combined use of silica fume with steel or polypropylene fibre in concrete results in a significant decrease in the water absorption of concrete. The combined use of fibres and silica fume lead to mixes with lower water absorption compared to those seen in mixes containing only silica fume. Among all fibre-reinforced concretes, the mixture with 0.3% PP and 0.7% steel fibres has been found to exhibit the lowest water absorption (Vahida Froughsabet, et., al 2015). This study utilized previous experimental data to develop shear strength prediction models for SFRC beams without stirrups using both linear and non-linear regression analysis. Several equations were developed to predict the shear strength of SFRC beams based on span-depth ratio, concrete compressive strength and fibre shape, which were found to produce precise and accurate results. The equation for each beam type determined using linear regression could predict the shear strength of SFRC beams more accurately than any of the other previously proposed models (Emma Slater, et., al 2011), Theoretical approach was used to predict the shear strength of steel fibre reinforced concrete (FRC) slender beams without web reinforcement. In the FRC beam, the shear force applied to a cross section of the beam is resisted by both the compression zone and tension zone. The shear capacity of the compression zone was defined addressing the interaction with the normal stress developed by the flexural moment in the cross section (Kyoung - Kyuchoi, et., al,2007). A total of nine large-scale reinforced concrete beams without stirrups were constructed and tested up to failure. The beams measured 3250 mm long, 250 mm wide, and 400 mm deep and were tested in four-point bending. The test results indicated that the relatively low modulus of elasticity of FRP bars resulted in reduced shear strength compared to the shear strength of the control beams reinforced with steel(Ahmed K. El-Sayed, et., al,2016). They observed that the normal strength concrete converted the failure mode from shear to flexure completely at a dosage of 2% fibres. The high strength concrete beams began to exhibit significant flexure from 0.5% to 1% fibres and switched to flexure completely at approximately 1.5% fibre (Soon-HoCho and Yoon-IL Kim, 2003).

3. Objectives of the study

The main objectives of this study are listed as follows

- To arrive mix proportion for fibre reinforced high strength concrete
- To study the flexural behavior of Hybrid fibre High strength reinforced concrete beams
- To predict the flexural strength of Hybrid fibre High strength reinforced concrete beam based on the analytical study by using ANSYS software.
- To compare the present analytical results with that of the experimental test results.

4. Experimental Investigation

4.1 Materials used

4.1.1 Cement

Cement is a binder component that sets and hardens as it dries and reacts with carbon dioxide in the air to bind with other materials. Ordinary Portland cement (OPC) of 53 grades confirming to Indian standard IS 12269-1987 was used for casting. 53 Grade OPC is the high strength cement to meet the requirements in achieving high strength concrete. The Table 1 shows the physical properties of cement used for research. The properties were studied by testing as per Indian standard codes mentioned in the Table 1.

Tabel 1

Properties of cement

Properties	Test results	IS code
Specific gravity	3.15	IS4031(PART 11): 1988
Consistency	33%	IS4031(PART 4): 1988
Fineness of cement	8%	IS4031(PART 2): 1996

4.1.2 Fine Aggregate

Manufactured sand (M-Sand) is used as fine aggregate and an eco-friendly alternative for river sand in concrete construction. M-sand is produced from hard granite stones by crushing them to required sizes. The crushed sand particles are of cubical shape with grounded edges. These particles are washed and graded to be used as a construction material. The size of manufactured sand used for research is less than 4.75mm. The Table 2 lists the properties of M-sand studied.

Table 2

Properties of M-sand

Properties	Test results
Specific gravity	2.9
Bulk density	1200 kg/m³
Fineness	>350m²/Kg

4.1.3 Coarse Aggregate

Coarse aggregates are particles greater than 4.75 mm, however they could range between 10 mm and 40 mm in size. Gravels constitute most of the coarse aggregate used in concrete with crushed one making up most of the remainder. The Coarse aggregates contributes to the strength, toughness, and hardness properties of concrete. It also provides resistance to abrasion. Coarse aggregate used in the experimental study was confirming to IS 383:1970. Table 3 shows the physical properties of coarse aggregate.

Table 3

Properties of coarse aggregate

Properties	Test results
Specific gravity	2.74
% water absorption	0.4%
Free surface moisture	Nil

4.1.4 Ground-Granulated Blast-Furnace Slag (GGBS)

The chemical composition of a slag varies considerably depending on the composition of the raw materials in the iron production process. Silicate and aluminate impurities from the ore are combined in the blast furnace with a flux which lowers the viscosity of the slag. In the case of pig iron production, the flux consists mostly of a mixture of limestone and forsterite and in some cases flux encompasses dolomite. In the blast furnace, the slag floats on top of the iron and is decanted carefully for separation.

The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and MgO (1-18%). In general, increasing the CaO content of the slag elevates the basic nature of the slag (pH increases) followed by an increase in compressive strength. The MgO and Al_2O_3 content shows the same trends as 10-12% and 14% respectively, beyond which, no further improvement was witnessed. Several compositional ratios or hydraulic indices have been used to correlate slag composition with hydraulic activity; the latter being mostly expressed as the binder compressive strength. The Table 4 shows the properties of GGBS used in the experiment.

Table 4

Properties of GGBS

Properties	Test results	IS code
Specific gravity	2.63	IS2386(PART 3): Clause 2.4.2
% water absorption	1.2%	IS383(PART 3): 1970
Fineness modulus	2.6	IS383(PART 3): 1970 table 2

Table 5

Properties of Micro Silica

Properties	Test results
Specific gravity	2.2
Bulk density	1350-1510 kg/m³
Fineness	15000 m²/Kg

4.1.5 Silica Fume

Silica fume is a by-product in the carbothermic reduction of high-purity quartz with carbonaceous materials like coal, coke, wood-chips, in electric arc furnaces in the production of silicon and ferrosilicon alloys. Table 5 shown above gives the properties of silica fume used in this research. Silica fume is an ultrafine material with spherical particles less than 1μm in diameter, the average being about 0.15μm accounting to approximately one hundred times smaller than the average cement particle commercially available. Because of its extreme fineness and high silica content, silica fume is recognised a very effective pozzolanic material.

4.1.6 Steel Fibre

Steel fibres of circular cross section are generally used. The properties noticed are shown in Table 6. The diameter varied from 0.25 to 0.75mm. Steel fibre were known to establish considerable improvements in flexural, impact and fatigue strength of concrete. The fibre acts as crack-arrestors that resisted growth of flaws in the exterior surface of concrete specimens, controlling them from widening. Thereby the fibres play a remarkable role in preventing failure.

Table 6
Properties of Steel Fibres

Properties	Value
Fibre Diameter(mm)	0.60
Fibre length (mm)	30
Aspect ratio l/d	50
Ultimate tensile Strength (Mpa)	1450
Elastic Modulus (Gpa)	210

4.1.7 Polypropylene Fibre

The capability of durable structure to resist weathering action, chemical attack, abrasion and other degradation processes during its service life with the minimal maintenance is equally important as the capacity of a structure to resist the loads applied on it. Although concrete offers many advantages regarding mechanical characteristics and economic aspects of the construction, the brittle behavior of the material remains a larger handicap for the seismic and other applications where flexible behavior is essentially required. Recently, however the development of polypropylene fibre-reinforced concrete (PFRC) has provided a technical basis for improving these deficiencies. The Table 7 lists the properties of polypropylene fibre evaluated.

Table 7
Properties of Polypropylene fibres

Properties	Value
Specific Gravity	0.91
Fibre Length (mm)	12
Melting Point	162°C
Ultimate Tensile Strength (MPa)	500-550
Elongation index	15%

4.1.8 Super Plasticizer

The super plasticizers are used where high degree of workability is to be achieved without increasing the water cement ratio. As a lower water content is maintained to improve the strength gain in concrete a commercially available super plasticizer named Conplast SP430 is used in the process. It is a chloride free super-plasticizer (SP). This admixture is based on selected sulphonated naphthalene polymers. Table 8 shows the properties of the SP used for mixing. It is supplied as a brown solution which instantly disperses in water. Conplast SP430 has been specially formulated to give high water reductions up to 25% without the loss of workability or to produce high quality concrete of reduced permeability. It complies with IS 9103:1999 and BS: 5075 Part 3 and ASTM-C-494 type F as high range water reducer.

Table 8
Properties of Super Plasticizer

Properties	Value
Appearance	Brown Liquid
Specific Gravity	1.20 at 20°c
Chloride Content	Nil to BS 5075
Air Entrainment	Less than 2% at normal dosage

4.1.9 Water

Water is an important parameter for concrete as it actively participates in chemical reaction with the cement to form the hydration products and most importantly the calcium-silicate-hydrate (CSH) gel. The strength of cement concrete depends mainly on the binding action of hydrate cement paste gel. The water used for making should be free from desirable salts that may react with cement. Potable water available in the college and campus was used for concreting and curing process.

4.1.10. Mix Proportion

The mix description for three different combinations was adopted as in Table 9 and the mix proportion for HSFRC for three different combinations was adopted as in Table 10.

Table 9
Mix Legendary

Mix ID	Mix Description
CC	Control Mix with no fibres
CF 1.5%	Concrete with Combination of 2 Fibres (steel fibre of 0.9% weight of cement + Polypropylene fibres of 0.6% weight of cement)
SF 1.5%	Concrete with Steel Fibres only 1.5% weight of cement

Table 10
Mix Proportion

Material	Quantity in kg/ m³		
	CC	SF 1.5%	CF 1.5%
Cement	496	488.56	488.56
Fine Aggregate	693	693	693
Coarse Aggregate	988	988	988
Micro Silica	49.6	49.6	49.6
GGBS	49.6	49.6	49.6
Water	149.73	149.73	149.73
Steel Fibres	0	7.44	4.41
Polypropylene fibres	0	0	2.93

4.2. Mechanical Properties of the Beam
4.2.1. Compression and Splitting Tensile Strength of HSFRC cubes and cylinders

The High strength fibre reinforced concrete used for casting of beam specimens was initially casted in control mix, concrete with 1.5% steel fibres and 1.5% combined fibres into 24 cubes and 24 cylinders (6 in each mix) to test their mechanical properties. The cubes of size 150x150x150mm and cylinders of 150mm diameter and 300mm height were cast, cured and tested as per Indian standards. The average compressive strength and average split tensile strength as obtained from test results on 7days and 28 days are listed in Table 11

Table 11
Compression and Tensile Strengths

Mix Id	Compressive Strength N/mm^2		Split Tensile Strength N/mm^2	
	Cubes		Cylinders	
	7 Days	28 Days	7 Days	28 Days
CC	28	35	1.64	2.343
SF 1.5%	33.9	63.4	3.06	3.353
CF 1.5%	38.9	69.5	3.536	3.790

Both compression and split tensile strength was found to be satisfactorily higher for specimens with combined fibres (0.9% of Steel Fibres and 0.6% of Polypropylene fibres) in them.

4.2.2. Flexural Strength of the beam

Direct measurement of tensile strength of concrete is difficult. By number of investigations beam tests are found to be dependable to measure the flexural strength property of concrete. The system of loading used to in finding out the flexural tension is two-point loading method. In this method the critical crack may appear at any section, not strong enough to resist the stress within the middle third, where the bending moment is maximum. It can be expected that the two-point loading will yield a lower value of the modulus of rupture than the center point loading. All the beams were tested at the age of 28 days under two-point loading conditions. The load is applied to the test beam as two equal concentrated loads through a spreader steel beam (I section) as shown in Fig. 1. Two-point loads were applied to the beams by hydraulic machine, up to their failure. The deflection was measured at three points using dial gauges, one at the mid span and the others just below the loading points. The loads were applied in the small increments and at every increment of loading, the deflection, strain gauge readings, were recorded.

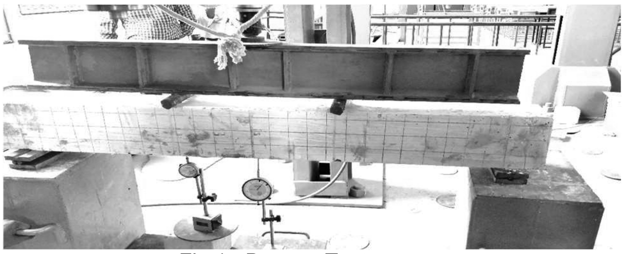

Fig.1 - Beam – Test setup.

4.3 Specimen details

Three beam specimens of size 150 mm wide and 175 mm depth in cross section were casted. The beams were 1500 mm long in span. High yield strength deformed (HYSD) steel bars of diameter 12mm and hanger bars of 10mm diameter were used as the longitudinal reinforcement in the specimens with a clear cover of 25mm. Two legged vertical stirrups of 8 mm diameter at a spacing of 100mm center to center were provided. The Figure 2 depicts the cross section of the beam with the reinforcement details.

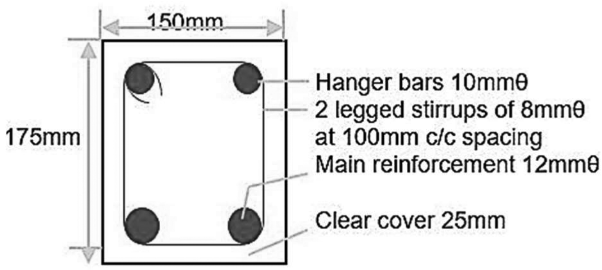

Fig. 2 - Cross section of Beam

4.4 Testing of Beam Specimen

The specimens were tested as in Figure 3 for flexure. The test specimen was mounted in a Loading frame of 100T Capacity. The supports of the beam were made to rest on a stiffened steel box girder. The effective span of the beam was 1400mm (clear span 1500mm) and the support width was 50mm center to center both sides of the beam. The load was applied on two points each 433.3 mm away from the center of the beam towards the support. Dial gauges 0.01 mm least count was used for measuring the deflections under the load points and at mid span.

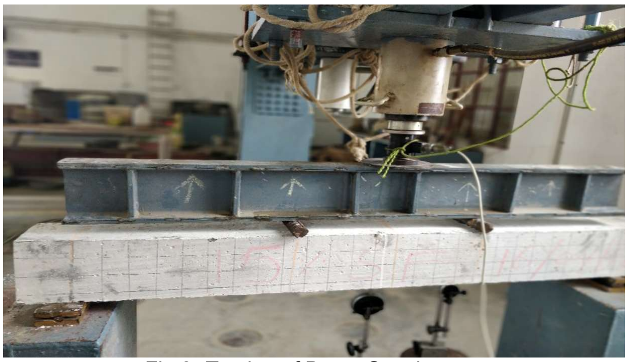

Fig 3 -Testing of Beam Specimen.

The dial gauge readings were recorded at different loads. The load was applied at intervals of 1Ton until failure. The behavior of the beam was observed carefully. The first crack load, ultimate load and deflection at ultimate load were noted for two beams. Stiffness of the Beams were calculated from the load deflection curves.

5. Analytical Investigation

ANSYS- finite element analysis software that has an element library consisting of more than 150 differential element formulations can be used to model all types of structures that are either one, two or three dimensional. It has a comprehensive graphical user interface that offers an easy and interactive access to its users. ANSYS has many finite element analysis capabilities ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis.

It has three phases in analysis viz., preprocessing, solution and post processing. The preprocessing phase defines the problem, solution phase allocates forces and boundary conditions and runs the analysis of the modelled element or structure. In post-processing results are examined and interpreted.

5.1 Steps Involved in the Analytical Investigation

Preprocessing

1. Set preference.
2. Define element types and options.
3. Define real constant.
4. Define material properties Create Beam using concrete with fibre.
5. Create steel bars
6. Set element attributes and meshing controls
7. Mesh the beam.

Solution

8. Define analysis type and options.
9. Apply boundary condition and load
10. Solve for static

Post Processing

11. Interpret & Evaluate the results

6. Results

6.1 Experimental Test Results

6.1.1 Load Deflection Curve

The deflection was measured at the two points using the dial gauge, one at the mid span and under the load points. The deflection increased gradually as there was increase in load. A maximum of 11 mm deflection was obtained for beam CF1.5%, which is for 1.5% of steel fibre and polypropylene fibre in combination. Similarly, the deflection of 10.8 and 9.3 mm were obtained for beam SF1.5% and CC respectively. The graphical representation of load and deflection at L/2 and L/3 are shown in Fig. 4 and 5 respectively.

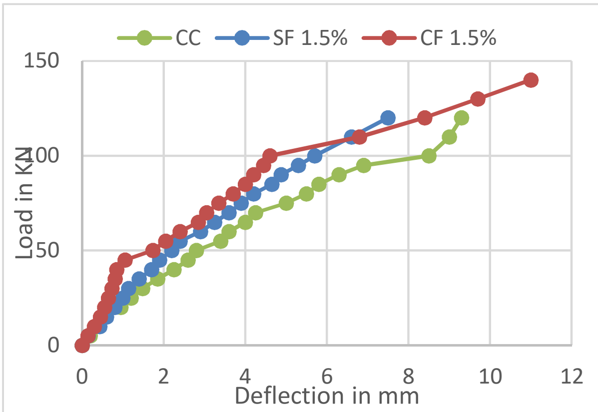

Fig. 4 - Load-Deflection Behavior of beam at L/2

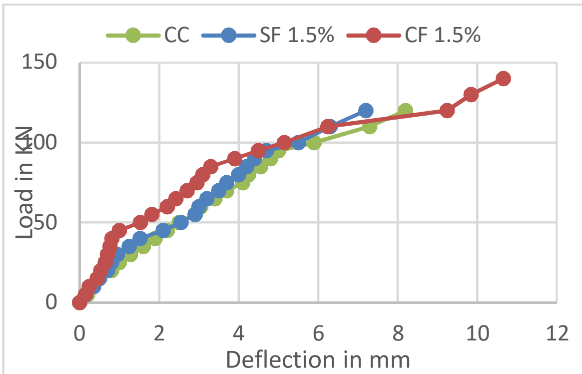

Fig. 5 - Load-Deflection Behavior of beam at L/3

6.1.2 Inference

The beams were tested after 28 days of proper curing. The cracking point and the maximum deflection are shown in Fig.6.4. The Table 6.2 compares the experimental results of CC, SF 1.5% and CF 1.5% beams.

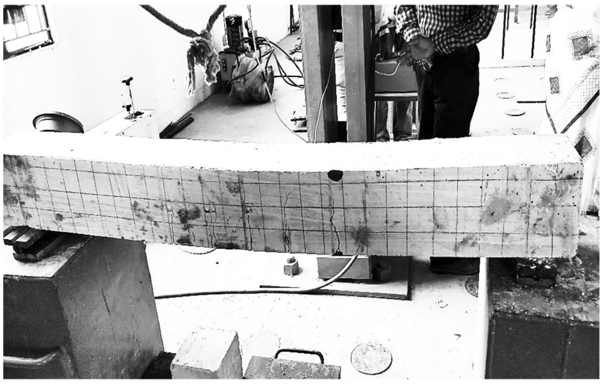

Fig. 6 -Beam – Failure by Bending

6.2 Analytical Results

The results obtained from ANSYS Software were compatible with that of the experimental results whereas the experimental values were influenced only by the field conditions. The Table 12 gives compares the experimental and analytical results for the beams. The Fig. 7 presents the analytical model analyzed and the reinforcement detailing of the beam longitudinally. Fig.8 shows the deflected shape of the beam under loading.

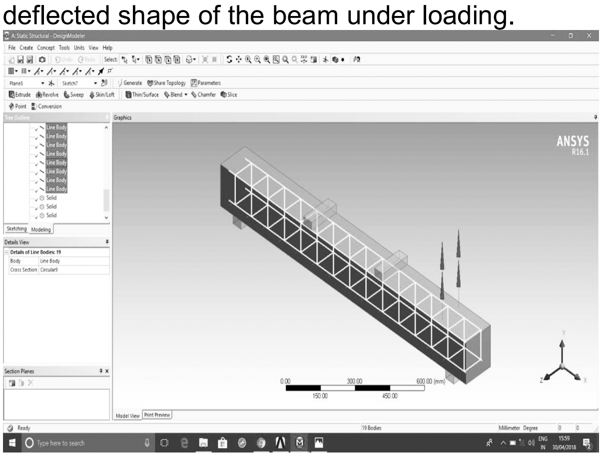

Fig. 7 - Reinforcement of Beam

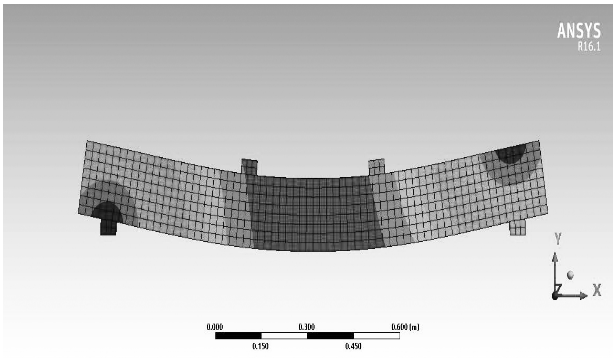

Fig. 8 - Deflected shape of Beam

Table 12

Comparison of Experimental and Analytical Results of Beams

Parameters	Beam ID	Results		Variation %
		Experimental	Analytical	
Ultimate Load Capacity (kN)	CC	120	107	10.81
	SF1.5 %	135	115	11.25
	CF1.5 %	140	125	11.2
Deflection at Mid span (mm)	CC	9.3	9.13	10.9
	SF1.5 %	10.8	10.3	10.43
	CF1.5 %	11.5	11.2	10.14
Deflection mode		Pure Bending		

7. Discussion

1. The 28 days compressive and split tensile strengths are higher for combined fibres combination (CF 1.5%) by 8.77% and 11.61% respectively compared to that of steel fibres combination (SF 1.5%) and compared to control mix (with no fibres) they are higher by 49.64% and 30.26% respectively. The Steel fibres possess a compression and splitting tensile strength, greater by 44.79% and 30.12% respectively compared to control mix. The incorporation of fibres in concrete thus prove to be an effective way in improving the mechanical behavior of conventional concrete.
2. When beams where tested for flexural strength, the initial crack load of CF 1.5% and SF 1.5% was found to be higher by 20kN. Also, the ultimate load capacities were higher for CF 1.5% by 5kN than that of the SF 1.5% combination. Considering load capacities, the combined fibre combination (CF 1.5%) exhibited a satisfactory behavior.
3. The higher deflection of CF 1.5% mix depicts that combination of fibres when dispersed in concrete can undergo large deformations before the ultimate load capacity. This ability increases the energy absorption capacity of beams.
4. The analytical results from ANSYS varied not greater than 12% compared to the experimental results. The mode of failure is by pure bending and it is clearly illustrated from Figure 8 showing the deflected shape of the beam done in ANSYS. The stress is higher at the midspan and gradually decreases along the supports. Irrespective of presence of fibres, the mode of failure remained uniform for all types of beams.

5. Experimental deflection was compared with the results obtained from the ANSYS software. The mean variance obtained for ratio between analytical and experimental deflection are 1.08, 1.125 and 1.12 for the beam CC, SF 1.5% and CF1.5%respectively
6. The crack formation as observed in all three beams described the effectiveness of CF1.5% mix in reducing the width of cracks in the flexure zone compared to the conventional CC mix. The SF 1.5% mix exhibited an appreciable reduction in cracks compared to the CC beams. Thereby addition of fibres to concrete play a vital role in deducing the crack widths of concrete specimens when exposed to bending loads.

8. Conclusions

1. Mix proportion for hybrid fibre high strength concrete (M60) using steel fibre, polypropylene fibre, 10% GGBS and 10% silica fume is arrived.
2. Combined fibres are effective in increasing the flexural strength of concrete. The ultimate flexural strength of HSFRC beams increase when the fibres are used in combination and also the addition of fibres restricts the propagation of cracks.
3. The analytical results showed good agreement with that of the experimental results.
4. The HSFRC can be used in various places that demand high energy absorption, reduced deflection and durable structures as reduction in crack and crack width prevent permeation of undesirable foreign particles into concrete.

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MANIFESTĂRI ȘTIINȚIFICE / SCIENTIFIC EVENTS

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