INVESTIGATION ON EXPERIMENTAL BEHAVIOR ON FIBER REINFORCED CONCRETE AND CRACK STUDIES

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Abstract:

 This project reports on an experimental program to investigate the effect of using steel fiber as a replacement of fine aggregate on the strength properties. Fiber reinforcement is commonly used to provide toughness and ductility to brittle cementation matrices. The study of toughness of fiber reinforced concrete (FRC) is based on different fiber proportions. The experimental investigation is carried out on fiber reinforced concrete containing different hybrid combinations of crimpled steel and hooked end fibers are reported. The physical, workability tests and mechanical properties namely compressive strength, flexural strength test, split tensile strength, compaction factor test were studied for concrete prepared by using different fiber combinations –crimpled steel (Aspect ratio 50)-hooked steel (Aspect ratio 80), crimpled steel (Aspect ratio 65), crimpled steel fibers alone, hooked end fibers alone and a plain concrete specimen. Reinforcement of concrete with a single type of fiber may improve to desired properties to a limited level.

Keywords: *Steel fiber (crimpled + hooked end), Fine aggregate, Partial Replacement, M30 Grade Concrete, Workability, Compressive Strength, Flexural Strength, Split tensile Strength.*

INTRODUCTION

Concrete is a construction material composed of cement (commonly Portland cement) as well as other cementations materials such as fly ash and slag cement, aggregate (generally a coarse aggregate made of crushed rocks such as limestone, or granite, plus a fine aggregate such as sand), water, and chemical admixtures. The word concrete comes from the Latin word "concretus" (meaning compact or condensed), the past participle of "concresco", from "com-" (together) and

"cresco" (to grow). The paste fills the voids in the aggregate and after the concrete is placed and vibrated it hardens to form a solid structural member. Concrete has high compressive strength and low tensile strength. Concrete solidifies and hardens after mixing with water and placement due to a chemical process known as hydration. The water reacts with the cement, which bonds the other components together, eventually creating a stone-like material.

 Recent earthquakes in different parts of the world have revealed again the importance of design of reinforced concrete structures with high ductility. Strength and ductility of structures depend mainly on proper detailing of the reinforcement in beam-column joints. The flow of forces within a beam-column joint may be interrupted if the shear strength of the joint is not adequately provided. Under seismic excitations, the beam-column joint region is subjected to horizontal and vertical shear forces whose magnitudes are many times higher than those within the adjacent beams and columns. Conventional concrete loses its tensile resistance after the formation of multiple cracks. However, fiber

concrete can sustain a portion of its resistance following cracking to resist more cycles of loading. Beam-column joints have a crucial role in the structural integrity of the buildings. For this reason, they must be provided with

adequate stiffness and strength to sustain the loads transmitted from beam and columns. The formation of plastic hinges in columns must be prevented since it affects the entire structure. For adequate ductility of beam-column joints, use of closely spaced hoops as transverse reinforcement was recommended in the ACI-ASCE Committee 352 report (ACI, 2002). Due to the congestion of reinforcement, casting of beam-column joint will be difficult and will lead to honeycombing in concrete (Kumar et al., 1991). Review of literature indicates that numerous studies were conducted in the past to study the behaviour of beam-column joints with normal concrete (Shamim and Kumar, 1999; Gefken and Ramey, 1989; Filiatrault et al., 1994; Soubra et al., 1993; Tsonos et al., 1992). ACI-ASCE Committee 352 makes recommendations on the design aspects of different types of beam-column joints, calculation of shear strength, and on reinforcement details to be provided (ACI, 2002). However, those recommendations are not intended for the fibre reinforced concrete. Bakir (2003) has carried out extensive research on parameters that influence the behaviour of cyclically loaded joints, and has derived equations for calculating the shear strength of the joints. A study conducted on fibre reinforced normal strength concrete by Filiatrault et al. (1994) indicates that this material is an alternative to the confining reinforcement in the joint region. The result of the study conducted by Gefken and Ramey (1989) shows that joint hoop spacing specified by ACI-ASCE Committee can be increased by a factor of 1.7 by the addition of fibres in a mix. Jiuru et al. (1992) also have studied the effect of fibres on the beam-column joint and have developed equations for predicting the shear strength of joints for normal strength concrete. Bayasi and Gebman (2002) also experimentally proved the confinement effect of fibres in the joint region and a reduction in the lateral reinforcement by the use of fibre concrete.

Besides these, there are a large number of investigations on the effect of addition of fibres on the strength and ductility of flexural members. The study carried out by (1992) indicates that ductility and ultimate resistance of flexural members are remarkably enhanced due to the addition of Hybrid steel fibres. Also it was emphasised that the neglect of fibre contribution may considerably underestimate the flexural capacity of fibre reinforced concrete beams. However, the investigation carried out by Espion (1994) contradicts the findings of Oh (1992). As reported by ACI Committee 544 based on a large number of investigations, there is a considerable improvement in strength, ductility, and energy absorption capacity with the addition of steel fibres (ACI, 1988). All these studies are limited to the normal strength concrete, and the research in the area of steel fibre reinforced high performance concrete (SFRC) beam-column joints is limited. In general, when fibres are added to concrete, tensile strain in the neighbourhood of fibres improves significantly. In the case of SFRC, since concrete is dense even at the microstructure level, tensile strain would be much higher than that of the conventional SFRC. This, in turn, will improve the cracking behaviour, ductility and energy absorption capacity of the composite. In order to tap the potential of SFRC, the existing body of knowledge must be expanded. Hence, an attempt has been made to study the behaviour of SFRC beam-column joint under the positive cyclic loading.

Concrete recycling is an increasingly common method of disposing of concrete structures. Concrete debris was once routinely shipped to landfills for disposal, but recycling is increasing due to improved environmental awareness, governmental laws and economic benefits. Concrete, which must be free of trash, wood, paper and other such materials, is collected from demolition sites and put through a crushing machine, often along with asphalt, bricks and rocks.

Reinforced concrete contains rebar and other metallic reinforcements, which are removed with magnets and recycled elsewhere. The remaining aggregate chunks are sorted by size. Larger chunks may go through the crusher again. Smaller pieces of concrete are used as gravel for new construction projects. Aggregate base gravel is laid down as the lowest layer in a road, with fresh concrete or asphalt placed over it. Crushed recycled concrete can sometimes be used as the dry aggregate for brand new concrete if it is free of contaminants, though the use of recycled concrete limits strength and is not allowed in many jurisdictions.

Material used:
Cement-

Cement is a binder, a substance that sets and hardens and can bind other materials together. Ordinary Portland cement of 53 Grade confirming to IS 12269-1987 was used.

The properties of the cement used were

    (a) Fineness of cement by Sieve analysis

      Fineness Index   =   3.9 %

    (b) Normal consistency   =   32 %

    (c) Initial setting time   =   45 Min 30 Secs

    (d) final setting time   =   600 min (10 hrs.)

    (d) Specific gravity   =   3.15

    (e) Compressive strength at an age of 28 days   =   36 N/mm^2

Coarse aggregate

    Coarse aggregate consists of river gravel, crushed stone or manufactured aggregate with particle size equal to or greater than 4.75mm. In this study coarse aggregate of maximum size 12.5 mm was used and the physical properties are as follows.

Physical properties:

Property	Value
Specific gravity	2.65
Water Absorption	0.495%
Fineness Modulus	6.1
Crushing Value	21.49%
Abrasion Value	23.50%
Impact Value	20.65%

Fine aggregate

  "Fine aggregate" is defined as material that will pass through 4.75mm sieve and will for the most part, be retained on a 75µ sieve.

Physical properties

Fineness modulus   :   3.2
Specific gravity   :   2.55
Grading zone   :   I

3.2.4 Water

  Water is needed for the purpose of hydration of cement and to provide workability during mixing and placing of concrete. For this study portable water available in the campus with pH value 7 and conforming to the specifications of IS456-2000 is used for concreting as well as curing of the specimens.

Fiber Reinforced Concrete

The term fiber reinforced concrete (FRC) is defined as a concrete made of hydraulic cements containing fine or fine and coarse aggregates and discontinuous discrete fibers. Inherently concrete is brittle under tensile loading. Mechanical properties of concrete can be improved by reinforcement with randomly oriented short discrete fibers, which prevent and control initiation, propagation, or coalescence of cracks. FRC can continue to sustain considerable loads even at deflections exceeding fracture deflections of plain concrete. The character and performance of FRC changes depending on matrix properties as well as the fiber material, fiber concentration, fiber geometry, fiber orientation, and fiber distribution.

The fibers used are mainly micro steel fiber, hooked steel fiber and polymer fibers.

Steel fibres

There are a number of different types of steel fibres with different commercial names. Basically, steel fibres can be categorized into four groups depending on the manufacturing process viz: cut wire (cold drawn), slit sheet, melt extract and mill cut. It can also be classified according to its shape and/or section. In addition, the high tensile stresses localized at cracks necessitate that steel fibers have high tensile strength. Typical steel fiber tensile strengths are ranged between 1100 and I700MPa.

Advantages and disadvantages

Generally the increase of ductility, toughness, strength, fatigue endurance, deformation characteristics are the reasons for major saving in time, cost, and materials when using the SFRC.

Main factors influencing the flexural strength of SFRC

a. Degree of consolidation of the matrix, which is a function of water to cement ratio, consolidation technique, and type and content of the steel fiber. Uniformity of fiber distribution, which is mainly influenced by the workability and mixing procedure used

b. The surface conditions of the steel fibers, which relates to the bond stresses generated between the steel fibers and the concrete, for instance a hydrophobic film on the steel fiber surface can prevent the development of an adequate fiber bond.

c. Theoretically, the improvement in flexural strength of SFRC is being brought by the crack arresting mechanism that the steel fiber provides. In fact, the steel fibers can sustain stress after cracking at strains beyond the normal for failure of plain concrete.

d. Some sort of stress distribution is promoted which approaches the fully plastic condition in the tension zone, while remaining elastic in the compression zone.

Methods:

Workability: Various workability criteria were checked during this experimental investigation from which the Slump test, Compaction factor test are common

Water cement ratio is 0.42

COMPRESSION STRENGTH TEST

COMPACTION FACTOR TEST
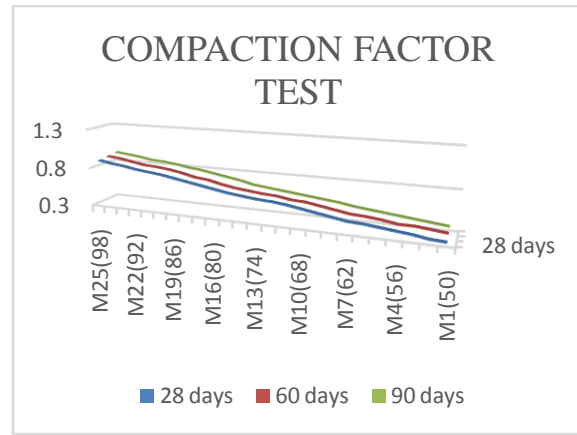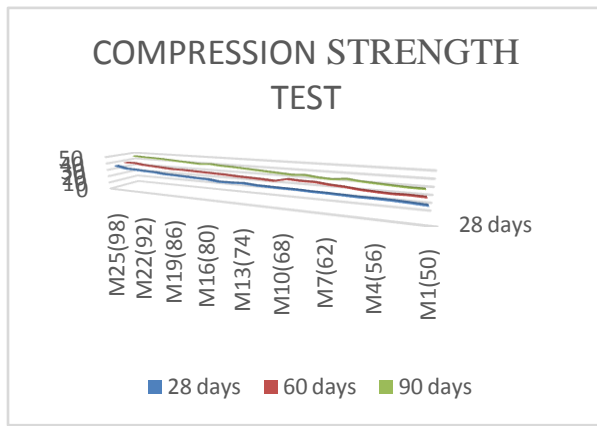
Grade of concrete (M30)	SLUMP CONE VALUES (mm)	COMPACTION FACTOR TEST		
		28	60	90
M25(98)	120	0.89	0.91	0.93
M24(96)	118	0.86	0.89	0.91
M23(94)	115	0.84	0.86	0.89
M22(92)	112	0.81	0.83	0.86
M21(90)	109	0.79	0.82	0.85
M20(88)	107	0.77	0.8	0.83
M19(86)	105	0.74	0.77	0.8
M18(84)	104	0.71	0.73	0.78
M17(82)	101	0.68	0.71	0.75
M16(80)	100	0.65	0.67	0.72
M15(78)	98	0.62	0.64	0.69
M14(76)	95	0.6	0.62	0.65
M13(74)	93	0.58	0.6	0.63
M12(72)	91	0.57	0.59	0.61
M11(70)	89	0.55	0.56	0.59
M10(68)	86	0.52	0.55	0.57
M9(66)	84	0.49	0.52	0.55
M8(64)	82	0.46	0.49	0.53
M7(62)	80	0.43	0.46	0.5
M6(60)	78	0.42	0.45	0.48
M5(58)	75	0.4	0.43	0.46
M4(56)	74	0.38	0.4	0.44
M3(54)	72	0.36	0.4	0.42

|				
M2(52)	70	0.33	0.38	0.4
M1(50)	65	0.32	0.36	0.38

Compression strength test:

One of the most important properties of concrete is the measurement of its ability to withstand compressive loads. This is referred to as a compressive strength and is expressed as load per unit area. One method for determining the compressive strength of concrete is to apply a load at a constant rate on a cube (150×150×150 mm), until the sample fails. Compressive strength has been calculated by performing the test for 3 times on a compressive Testing machine and calculated by using the formula as given below.

$$Compressive\,Strength = \frac{Ultimate\,Load}{Area\,of\,Cross-Section}$$

25 different mixes (**M1(50%)-M25(98%)**) were prepared using Fine aggregate replaced by steel fibers. Seventy two number standard specimens of dimensions $150 \times 150 \times 150$ mm were casted according to the mix proportions mentioned in the table above and cured in water for period of 28,60 and 90 days. At the end of each curing period, three specimens for each mixes were tested for compressive strength and the average strength was recorded. The size of the specimen is as per the IS code 10086 – 1982. The compressive strength test on both conventional and concrete prepared by partial replacement of fine aggregate was performed on standard compression testing machine of 3000kN capacity, as per IS: 516-1959.

Grade of concrete (M30)	COMPRESSIVE STRENGTH TEST (N/mm2)					
	load (KN)	28	load (KN)	60	load (KN)	90
M25(98)	742.50	33	855.00	38	1035.00	46
M24(96)	731.25	32.5	832.50	37	1012.50	45
M23(94)	720.00	32	810.00	36	1004.40	44.64
M22(92)	697.50	31	787.50	35	990.00	44
M21(90)	686.25	30.5	765.00	34	967.50	43
M20(88)	652.50	29	742.50	33	945.00	42
M19(86)	641.25	28.5	742.50	33	922.50	41
M18(84)	630.00	28	731.25	32.5	900.00	40
M17(82)	614.25	27.3	720.00	32	922.50	41
M16(80)	607.50	27	708.75	31.5	890.10	39.56
M15(78)	562.50	25	697.50	31	877.05	38.98
M14(76)	568.13	25.25	675.00	30	855.00	38

M13(74)	585.00	26	664.20	29.52	832.50	37
M12(72)	553.95	24.62	652.50	29	810.00	36
M11(70)	546.75	24.3	630.00	28	787.50	35
M10(68)	540.00	24	720.00	32	765.00	34
M9(66)	537.53	23.89	697.50	31	787.50	35
M8(64)	522.00	23.2	697.50	31	742.50	33
M7(62)	517.50	23	652.50	29	720.00	32
M6(60)	506.03	22.49	630.00	28	765.00	34
M5(58)	495.23	22.01	585.00	26	720.00	32
M4(56)	495.00	22	562.50	25	697.50	31
M3(54)	490.05	21.78	546.75	24.3	675.00	30
M2(52)	472.50	21	554.40	24.64	655.20	29.12
M1(50)	450.00	20	540.00	24	652.50	29

COMPRESSION STRENGTH TEST
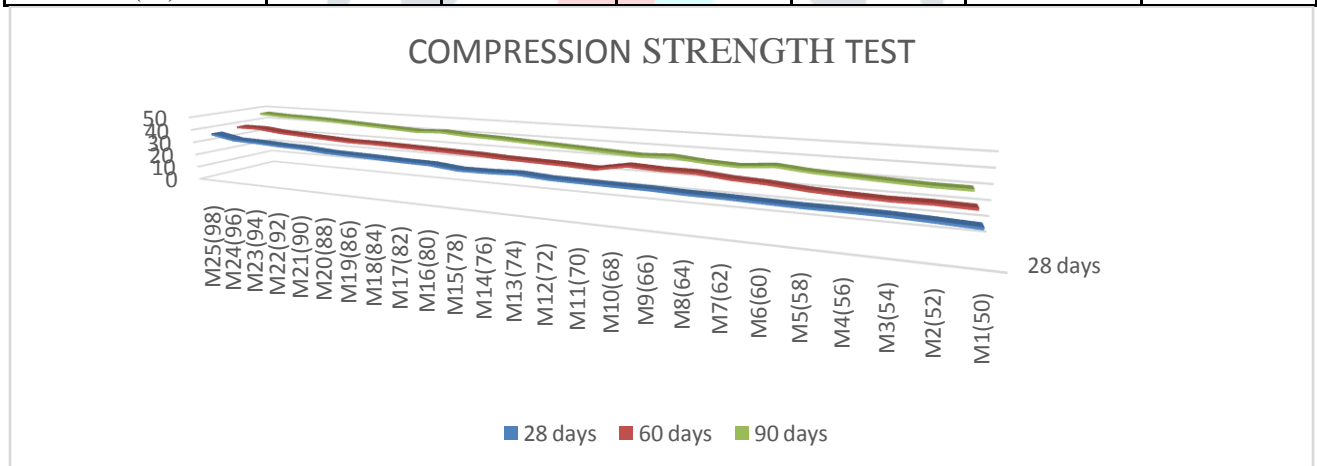
Split tensile strength test:

The splitting tests are well known indirect tests used for determining the tensile strength of concrete sometimes referred to as split tensile strength of concrete. The test consists of applying a compressive line load along the opposite generators of a concrete cylinder placed with its axis horizontal between the compressive platens. Due to the compression loading a fairly uniform tensile stress is developed over nearly 2/3 of the loaded diameter as obtained from an Elastic analysis.

The ratio of the split tensile strength to cylinder strength not only varies with the grade of the concrete but is also dependent on the age of concrete. This ratio is found to decrease with time after about a month.

36 number cylinders of 300mm X150mm were casted for different mixes. Apparatus used in Split tensile test is Compression testing machine, tamping rods. Pour concrete in moulds oiled with medium viscosity oil. Fill the cylinder mould in four layers each of approximately 75 mm and tamp each layer more than 30 times with evenly distributed strokes. Applied the load without shock and increase it continuously at the rate to produce a split tensile

stress of approximately 1.4 to 2.1 N/mm2/min, until no greater load can be sustained. Record the maximum load applied to specimen and the readings were noted when the cracks appear on the cube

Split Tensile Strength = 2P/Πld

Grade of concrete (M30)	SPLIT TENSILE STRENGTH TEST(N/mm2)					
	load (KN)	28	load (KN)	60	load (KN)	90
M25(98)	219.72	3.11	247.98	3.51	276.24	3.91
M24(96)	295.32	3.36	323.58	3.59	351.84	4.26
M23(94)	256.46	3.63	284.72	4.03	313.69	4.44
M22(92)	274.83	3.89	293.20	4.15	332.06	4.7
M21(90)	291.08	4.12	307.33	4.35	394.23	4.58
M20(88)	274.83	3.89	291.08	4.12	307.33	4.35
M19(86)	276.95	3.92	281.89	3.99	286.84	4.06
M18(84)	262.82	3.72	276.95	3.92	291.08	4.12
M17(82)	286.13	4.05	309.45	4.38	332.76	4.71
M16(80)	279.77	3.96	286.13	4.05	292.49	4.14
M15(78)	284.01	4.02	288.25	4.08	292.49	4.14
M14(76)	281.89	3.99	284.01	4.02	286.13	4.05
M13(74)	291.10	4.12	281.89	3.99	289.67	4.1
M12(72)	296.73	4.2	269.88	3.82	284.01	4.02
M11(70)	299.56	4.24	302.38	4.28	305.21	4.32
M10(68)	303.80	4.3	308.03	4.36	312.27	4.42
M9(66)	305.21	4.32	306.62	4.34	308.03	4.36
M8(64)	308.03	4.36	309.25	4.4	313.69	4.44
M7(62)	313.69	4.44	319.34	4.52	324.99	4.6
M6(60)	328.52	4.65	343.36	4.86	358.20	5.07
M5(58)	342.65	4.85	356.78	5.05	370.91	5.25
M4(56)	351.84	4.98	361.02	5.11	368.11	5.24

M3(54)	335.59	4.75	351.84	4.98	368.09	5.21
M2(52)	328.52	4.65	335.59	4.75	342.65	4.85
M1(50)	324.99	4.6	328.52	4.65	332.06	4.7

SPLIT TENSILE STRENGTH TEST

■ 28 days ■ 60 days ■ 90 days
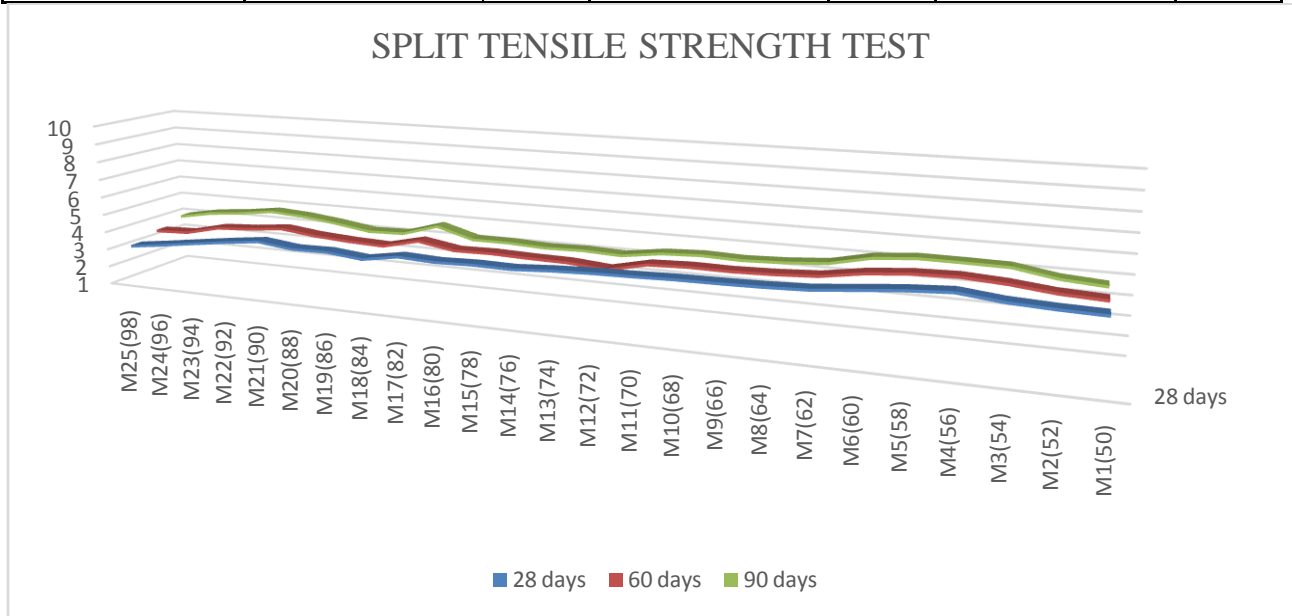
Flexural strength test:

Another important strength property of concrete is the flexural strength of a concrete. 36 Samples were casted as per IS: 516-1959 using beam size (15cm x 15cm x70cm) and 3 samples were tested for flexural strength at 28,60,90 days of curing for each mix. The testing machine apparatus used to measure the flexural strength of concrete in this project is operated by hydraulics and has Dial Gauge displays for monitoring the rate of loading and the peak load on the sample at the time of failure.The beams are placed in the machine in such a manner that the load is applied to the uppermost surface along the two lines spaced 13.3 cm apart. The strain rate was manually controlled by turning a knob either clockwise or counter clockwise.

$$f_{cr} = \frac{Pl}{bd^2}$$

Where $f_{cr} =$ Flexural Strength of Concrete, (KPa or psi)

P = Maximum load applied (KN or lb), l= Length of the specimen between the lower supports (mm

or in), b = Width of the beam (mm or in), and d = Depth of the beam (mm or in)

Grade of concrete (M30)	FLEXURAL STRENGTH TEST(N/mm2)					
	load (KN)	28	load (KN)	60	load (KN)	90
M25(98)	35.44	3.15	37.24	3.31	40.28	3.58
M24(96)	37.24	3.31	39.04	3.47	43.31	3.85

M23(94)	39.04	3.47	40.84	3.63	46.35	4.12
M22(92)	40.84	3.63	42.00	3.79	49.39	4.39
M21(90)	42.00	3.79	42.64	3.95	52.43	4.66
M20(88)	42.64	3.95	46.24	4.11	55.46	4.93
M19(86)	46.24	4.11	48.04	4.27	58.50	5.20
M18(84)	48.04	4.27	49.84	4.43	61.54	5.47
M17(82)	49.84	4.43	51.64	4.59	64.58	5.74
M16(80)	51.64	4.59	53.44	4.75	67.61	6.01
M15(78)	53.44	4.75	55.24	4.91	70.65	6.28
M14(76)	55.24	4.91	57.04	5.07	73.69	6.55
M13(74)	57.04	5.07	58.84	5.23	76.73	6.82
M12(72)	58.84	5.23	60.64	5.39	79.76	7.09
M11(70)	60.64	5.39	62.44	5.55	82.80	7.36
M10(68)	62.44	5.55	64.24	5.71	85.84	7.63
M9(66)	64.24	5.71	66.04	5.87	88.88	7.90
M8(64)	66.04	5.87	67.84	6.03	91.91	8.17
M7(62)	67.84	6.03	69.64	6.19	94.95	8.44
M6(60)	69.64	6.19	71.44	6.35	97.99	8.71
M5(58)	68.85	6.12	70.43	6.26	97.20	8.64
M4(56)	68.18	6.06	70.20	6.24	96.75	8.60
M3(54)	67.50	6	69.75	6.2	96.47	8.58
M2(52)	65.93	5.86	69.58	6.185	95.63	8.50
M1(50)	64.13	5.7	69.19	6.15	95.06	8.45

FLEXURAL STRENGTH TEST
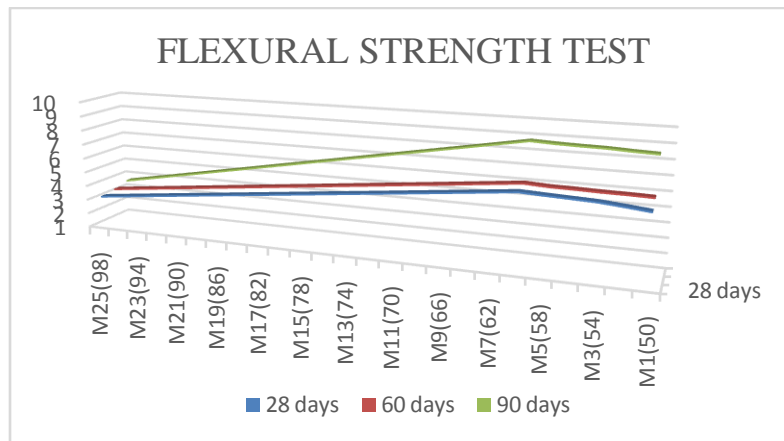
Crack Width, Failure Load and Deflection for tested beams

Beam Notation M30(M25)	Initial load (KN)	Ultimate load (KN)	Initial crack width (mm)	Final crack width (mm)	Deflection (mm)
0%	30	60	0.20	3.7	15
0.50%	33	66	0.17	2.8	17.25
1%	38	72	0.16	2.3	17.59
Beam Notation M30(M1)	Initial load (KN)	Ultimate load (KN)	Initial crack width (mm)	Final crack width (mm)	Deflection (mm)
0%	30	60	0.159	3.59	13
0.50%	33	66	0.20	4.155	15.2
1%	38	72	0.19	5.52	15.7

CONCLUSIONS

The action of fibres at different volume fractions has enhanced the mechanical properties of fibre reinforced concrete for all the test results. Results from the study indicate the following:

1   It is possible to produce concrete composites using Hooked end Steel Fibers and Crimpled steel fibres with an enhanced performance of 100% when compared to concrete without fibres.

2   Fibre inclusion of all types increased compressive strength by only 5%, although this increase was not that significant and could have been obtained with simpler and more economical methods like reducing water-cement ratio. steel fibre proved to be efficient in strengthening the matrix.

3   The addition of micro fibres in hybrid systems produces a favorable effect on both the strain softening and multiple cracking behavior of fibre reinforced concrete. As the amount of fibres increases, the tensile properties increases and the number of cracks were significantly improved.

4   Among all fibre combinations, the steel fibers (Crimped + H1 (Aspect ratio 50+80 & volume fraction 0.5%+0.5%) performed better in Compressive strength aespects compared to the double fibres in concrete. All the other combinations gave similar and better results.

5   Among all fibre combinations, the steel fibers (Crimped + H1 (Aspect ratio 50+80 & volume fraction 0.5%+0.5%) performed better in Split tensile strength aespects compared to the double fibres in concrete. All the other combinations gave similar and better results.

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