An Investigation on Mechanical Properties of Hybrid Fiber Reinforced Concrete

[1]Abhishek A. Bhutwala, [2]Dr. H.S. Patel, [3]Dr. V.S. Purani

[1]PG Student, L.D. College of Engineering, Ahmedabad, India,
[2] Professor, Applied Mechanics Department, L.D.College of Engineering Ahmedabad, Gujarat, India
[3] Professor, Applied Mechanics Department, L.D.College of Engineering Ahmedabad, Gujarat, India

***Abstract*:** A composite can be termed as hybrid, if two or more types of fibers are rationally combined in a common matrix to produce a composite that derives benefits from each of the individual fibers. The aim is to study the mechanical properties i.e. split-tensile strength and compressive strength on hybrid effect between steel fiber (SF) and chopped carbon fiber (CF). The test on Hybrid Fiber Reinforced Concrete (HFRC) is to be explored at steel fiber volume fraction 0.5%, 1%, 1.5% and carbon fiber 0.1%, 0.2%, 0.3% by the volume of cement with reinforcement and without reinforcement. For this study, 60 cubes of 150mm, 60 cylinders of 150mm diameter and 300mm height of different combination of SF and CF will be casted of M25 grade of concrete. After testing, effect of different combination and the optimized composition will be concluded. The testing results shows that the optimum of hybrid combination 0.3% CF and 1% SF gives the optimised response in terms of Split-Tensile Strength while hybrid combination of 0.3% CF and 1.5% SF gives the optimised response in terms of Compressive Strength.

Keywords: **Chopped Carbon Fibers, Concrete, Hybrid Composite, Mechanical Properties, Steel Fibers.**

1. INTRODUCTION

Cementitious materials are characterized by low tensile strength, low strain capacity and low fracture toughness: they are brittle materials. Reinforcement in the form of continuous steel bars and stirrups is used to resist imposed tensile and shear stresses in reinforced concrete which renders it a usable structural material. In the last five decades, another kind of reinforcement has been used to overcome the brittleness, namely discontinuous and randomly distributed fibers, producing a new structural material known as fiber reinforced concrete with improved strength, ductility and durability. The term Fiber Reinforced Concrete (FRC) is defined as concrete made of hydraulic cements containing fine and coarse aggregates and discontinuous discrete fibers. It is important to recognize that, in general, fiber reinforcement is not a substitute for conventional reinforcement. The role of these two types of reinforcement is different in concrete; continuous steel bars are used to increase the tensile and shear capacities of concrete while the primary reason for addition of discontinuous fibers to the concrete matrix is to improve the post cracking response by controlling the crack opening and propagation.

A composite can be termed as hybrid, if two or more types of fibers are rationally combined in a common matrix to produce a composite that derives benefits from each of the individual fibers and exhibits a synergetic response. According to Bentur and Mindess [A. Bentur and S. Mindess, 2005] the advantages of hybrid fiber systems can be listed as follows;

- To provide hybrid reinforcement in which one type of fiber is smaller, so that it bridges the micro cracks of which growth can be controlled. This leads to a higher tensile strength of the composite. The second type of fiber is larger, so that it arrests the propagating macro cracks and can substantially improve the toughness of the composite.
- To provide a system in which one type of fiber, which is stronger and stiffer, improves the first crack stress and the ultimate strength, and the second type of fiber, which is more flexible, and ductile leads to improved toughness and strain in the post-cracking zone.
- To provide a hybrid reinforcement, in which the durability of fiber types is different. The presence of the durable fiber can increase the strength and/or toughness relation after age while the other type is to guarantee the short-term performance during transportation and installation of the composite elements.

In well-designed hybrid composites, there is positive interaction between the fibers and the resulting hybrid performance exceeds the sum of individual fiber performance. This phenomenon is often termed as synergy. “Synergy is the phenomenon where acting of two or more subjects together leads to a better result than the sum of action of the same subjects independently of each other. That means when applied to hybrid fiber concrete one could suppose that the synergy of short and long fibers leads to an improved tensile response of the hybrid fiber concrete, compared to the arithmetic sum of tensile responses of two concretes, one of which contains only long and the other only short fibers in the same dosage as the hybrid fiber concrete”

Hsie Machine et al [1] investigates the mechanical properties of polypropylene hybrid fiber reinforced concrete. There are two forms of polypropylene fibers including coarse monofilament, and staple fibers. The content of the coarse monofilament fiber is at 3 kg/m3, 6 kg/m3, and 9 kg/m3, and the content of the staple fiber is at 0.6 kg/m3. Wu Yao et al [2] studies on the mechanical properties of hybrid fiber reinforced concrete at low fiber volume fraction was carried out. Concretes containing steel, carbon and polypropylene (PP) fibers in hybrid form at the same volume fraction (0.5%). The carbon and PP fibers were smooth and straight, while the steel fibers were hooked end. Jyothis Jose Oommen and Mr. Tom George [3] presents an experimental study on the effect of hybrid fiber addition to M40 concrete mix using the steel-nylon hybrid fiber reinforced system. Four different volume fractions of fiber content i.e., 0.5%, 1.0%, 1.5% and 2.0% were studied for both fibers. N. Banthia and R. Gupta [4] investigates the effect of using different fiber types such as macro and micro-fibers of steel, polypropylene and carbon for a very high strength matrix of an average compressive strength of 85 MPa. Control, single, two-fiber and three fiber hybrid composites were cast using different fiber types. Volume fraction of fibers used in various mixes were 0.5%, 0.75%, 1% and 1.3% Flexural toughness tests were performed. M. K. Yew et al [5] investigates the effect of hybrid nylon-steel fiber-reinforced concrete were investigated in comparison to that of polypropylene-steel fiber-reinforced concrete, at the same volume fraction (0.5%). The content of macro steel fibers is at 0.4% volume fraction, and the content of micro nylon and polypropylene-fibers is at 0.1% volume fraction.

2. Experimental Program

2.1. Materials

The materials used for the control concrete mixture consisted of the normal Type I Portland cement, the gravel having a maximum size 2 cm, and the river sand having a fineness modulus of 2.186. The additives are Steel Fibers and Chopped Carbon Fibers, and they are showed in Fig. 1. The diameter of Steel fibers is 1.25mm, the length is 50mm, and the Tensile Strength is 1500 MPa. The Chopped Carbon Fiber having length of 6mm, diameter of 7 µmm and tensile strength is 2000MPa.


Fig. 1: Steel Fibers and Chopped Carbon Fiber

Table 1: Properties of Carbon and Steel Fibers

Material	**Carbon**	**Steel**
Length (mm)	6	50
Diameter (µmm)	7	1250
Geometry	Straight	Crimped
Tensile strength (MPa)	2000	1500

2.2. Mixing and Curing

The mixing process started with the dry mixing of the coarse and fine aggregates for 1 min. The cement and Fibers were added; then dry mixing kept for another 1min, then added water and the mixture was mixed for 3min to ensure that the fibers can evenly disperse throughout the concrete. The fresh concrete was filled in 150mm×300mm cylinder moulds and 150mm×150mmx150mm Cube molds. The former is for the tests of spilt tensile strengths, and the latter is for compressive strength. Both molds were removed after 24 h, and the specimens were allowed to cure in a water tank at 23±1 ◦C. Property tests were performed after the samples had cured for 28 days.

2.3. Mix Design

Table 2: Mix Proportion

Material	**Cement**	**Water**	**Fine Aggregates**	**Coarse Aggregates**
Mass (kg/m3)	383.16	207.07	670.66	1277.19
Mass (kg)	50	27.02	87.52	166.66
Proportion	1	0.5	1.73	3.3

2.4. Specimen Codes

Table 3: Specimen Codes

Specimen codes	Fiber volume fraction (%)	
	Carbon	Steel
N'	0	0
A-1	0.1	0.5
A-2	0.2	0.5
A-3	0.3	0.5
B-1	0.1	1
B-2	0.2	1
B-3	0.3	1
C-1	0.1	1.5
C-2	0.2	1.5
C-3	0.3	1.5

3. RESULTS AND DISCUSSION

3.1. Compressive strength

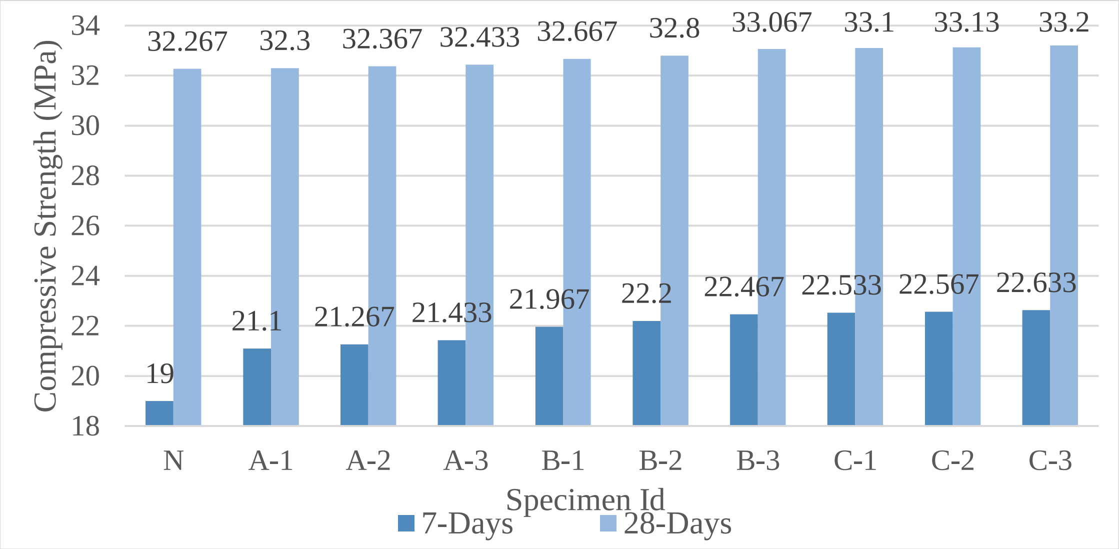

Fig. 2: Average Compressive Strength for 7- and 28- days

The Compressive Strength of the concrete keeps on increasing as the fiber contents of the concrete increases. The maximum Compressive strength was for 0.3% Chopped Carbon Fiber and 1.5% Steel Fiber, volume fraction is by the weight of the cement. The increase in compressive strength for A batch was from 0.1% to 0.5%, for B batch was from 1.24% to 2.48% and for C batch was from 2.58% to 2.89% as compared to conventional concrete.

3.2. Split-tensile strength

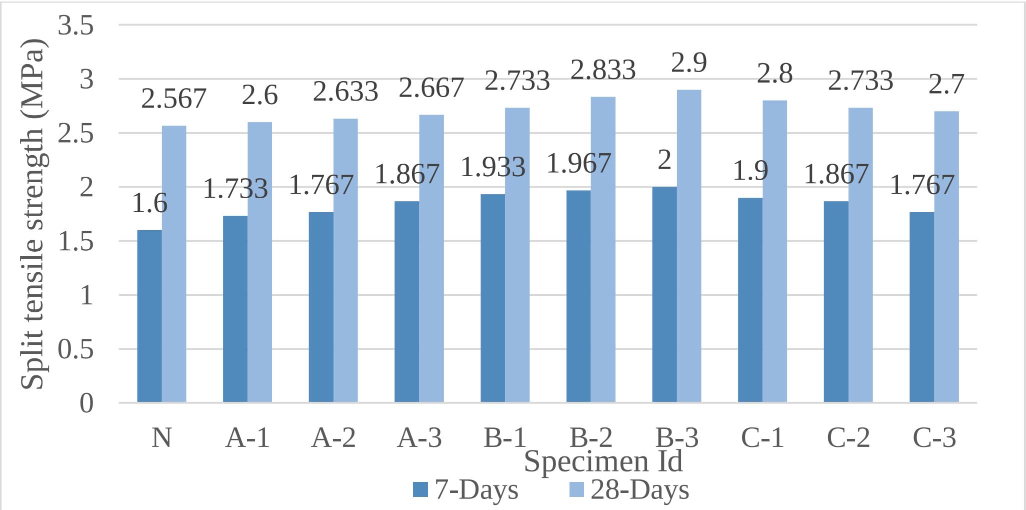

Fig. 3: Average Split-Tensile Strength for 7- and 28-days

The Split-tensile strength for 7-days and 28-days was maximum in B-3 which is 0.3% Chopped Carbon Fiber and 1% Steel Fiber, volume fraction is by the weight of the cement. The increase in split-tensile strength for A batch was from 1.28% to 3.89%, for B batch was from 6.46% to 12.97% and for C batch was from 9.08% to 5.81% as compared to conventional concrete.

3.3 Beams

3.3.1 Load vs Deflection curve for Reinforced Concrete Beams

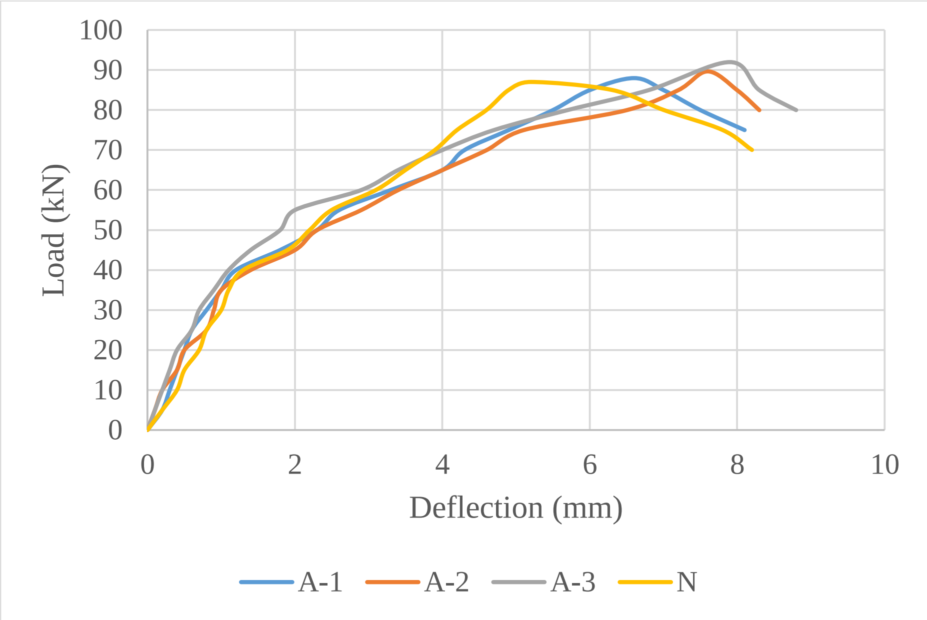

Fig. 4: Comparison of N' and A batch

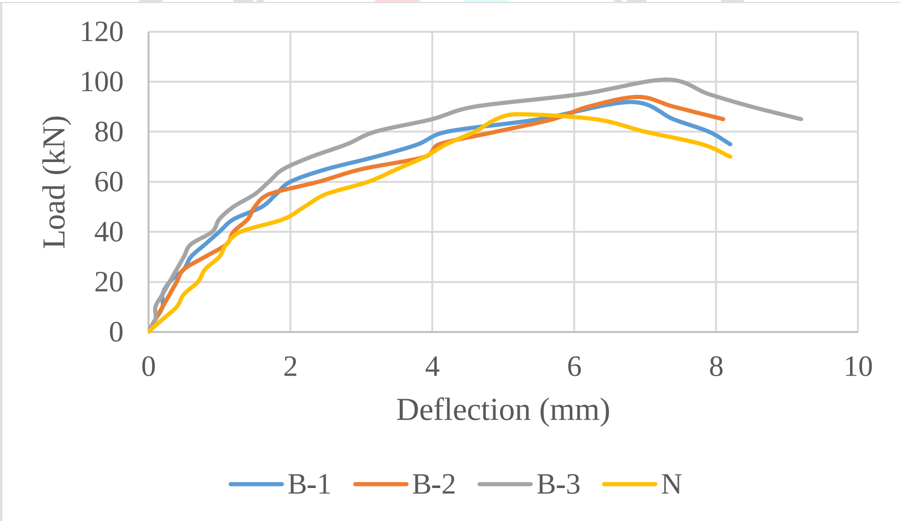

Fig. 5: Comparison of N' and B batch

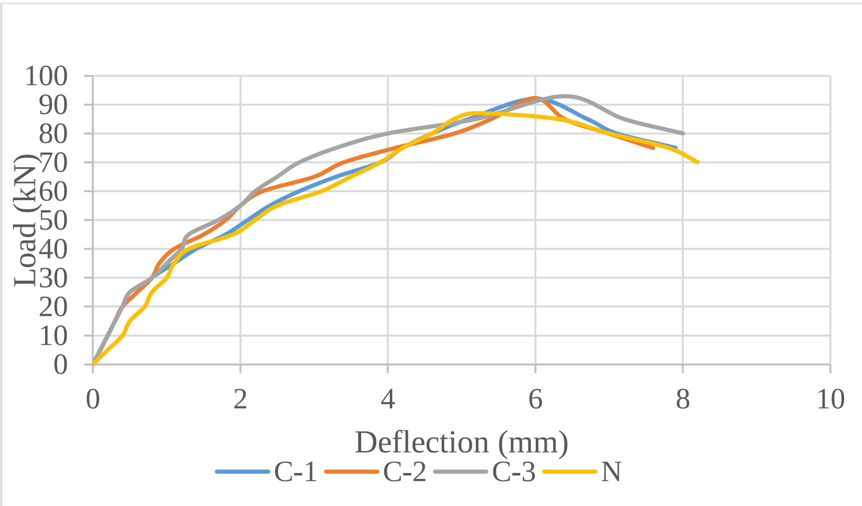

Fig. 6: Comparison of N' and C batch

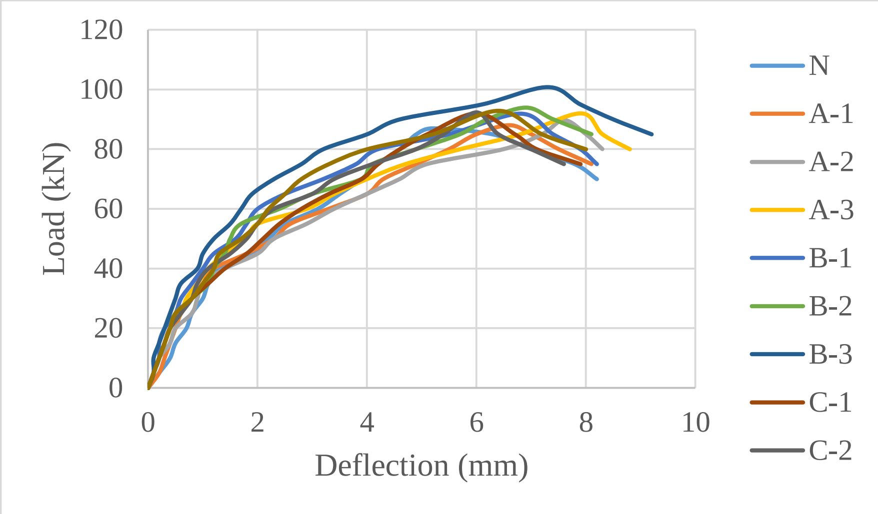

Fig. 7: Comparison for all specimen

From the result it can be concluded that the first cracking load increases with the addition of fibers in concrete, also there is increase in the ultimate load carried by the Hybrid Fiber Reinforced Concrete and the deflection of the beams reduce when compared to conventional concrete.

3.3.2 Load vs Deflection curve for Plain Cement Concrete Beams

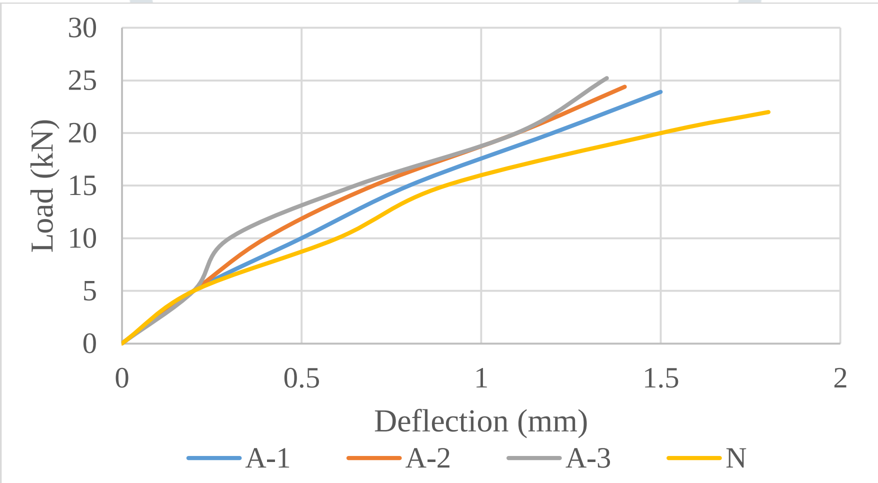

Fig. 8: Comparison of N' and A batch

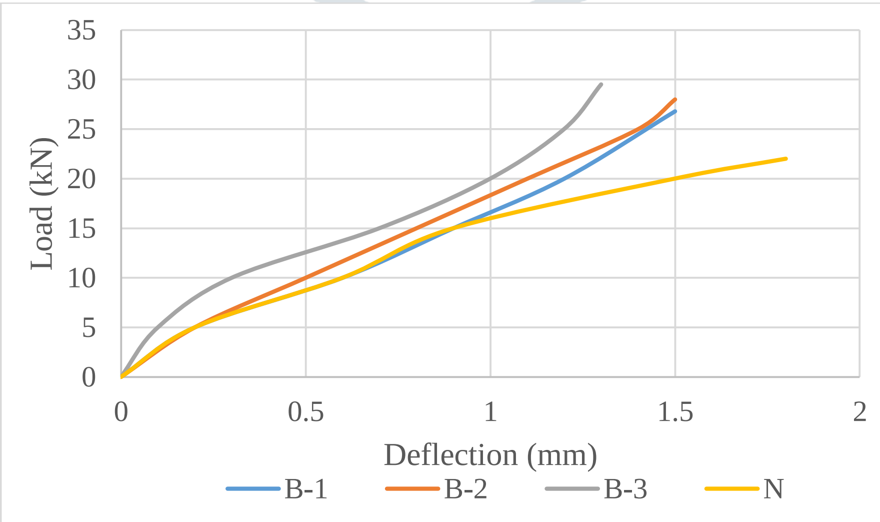

Fig. 9: Comparison of N' and B batch

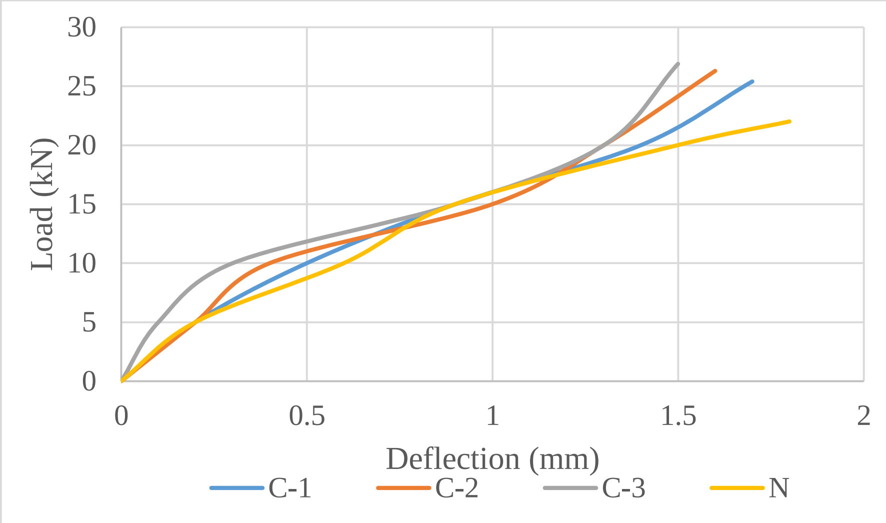

Fig. 10: Comparison of N' and C batch

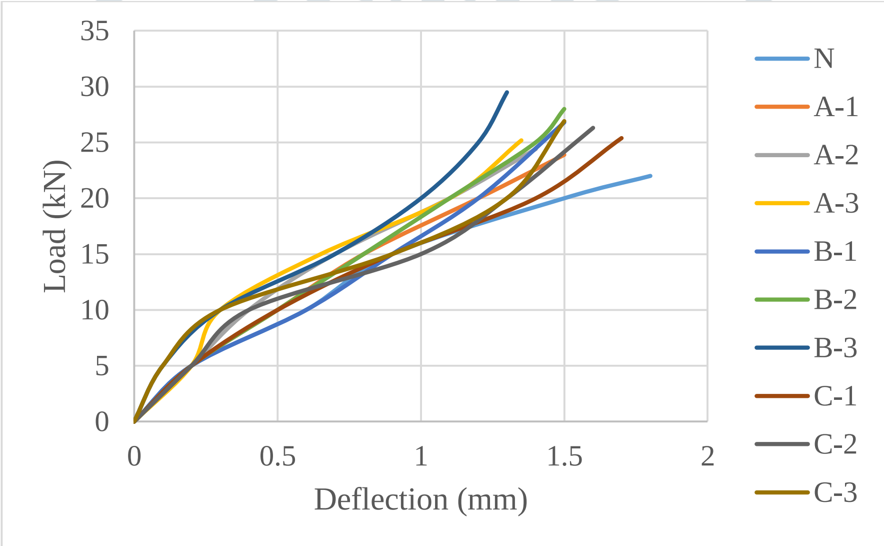

Fig. 11: Comparison for all specimen

From the result it can be concluded that there is increase in the ultimate load carried by the Hybrid Fiber Concrete and the deflection of the beams reduce when compared to conventional concrete.

3.4 Initial Crack load and Ultimate load

The first crack load increased with the addition of fibers. The ultimate load carried by the fiber reinforced concrete beams was more than the of the conventional concrete beam. The first crack load and ultimate load of hybrid fiber reinforced concrete was maximum in B-3 compared to conventional concrete.

Table 4: First crack load and ultimate load

Specimen Id	Initial Crack Load (kN)	Ultimate Load (kN)	
		Absolute	Relative
N'	26	87	1
A-1	30.1	88.3	1.01
A-2	31.2	89.7	1.03
A-3	31.2	92.1	1.06
B-1	31.9	91.9	1.05
B-2	32.4	93.9	1.08
B-3	33.6	100.8	1.16
C-1	32.1	92	1.06
C-2	32.7	92.3	1.06
C-3	33	92.9	1.07

3.5 Flexural Strength

Table 5: Hardened Properties of concrete

Specimen Id	Compressive Strength (MPa)	Split Tensile Strength (MPa)	Flexural Strength (MPa)	
			Reinforcement	Without Reinforcement
N'	32.267	2.567	21.92	3.91
A-1	32.3	2.6	22.25	4.25
A-2	32.367	2.633	22.60	4.34
A-3	32.433	2.667	23.20	4.48
B-1	32.667	2.733	23.15	4.76
B-2	32.8	2.833	23.66	4.98
B-3	33.067	2.9	25.39	5.24
C-1	33.1	2.8	23.18	4.52
C-2	33.13	2.733	23.25	4.67
C-3	33.2	2.7	23.40	4.78

4. CONCLUSION

Following conclusions are drawn from the experimental investigations conducted to assess the influence of fibers on the mechanical response of the concrete

- The combination of SF-1% and CF-0.3% gives the optimum response of the concrete in terms of split tensile strength. While the compressive strength of the concrete keeps on increasing as the percentage of fibers are increased in the concrete.
- The Split tensile strength was increased by 12.98% compared to conventional concrete for the optimum response combination. The Compressive Strength was increased by 2.48% compared to conventional concrete for the optimum response combination.
- The first crack load increased with the addition of fibers. The first crack load of hybrid fiber reinforced concrete was increased by 29.23% compared to conventional concrete for the optimum response combination.

- The ultimate load carried by the fiber reinforced concrete beams was more than the of the conventional concrete beam. The increase in the ultimate load was 15.86% compared to conventional concrete for the optimum response combination.
- The Flexural strength was also more than the conventional concrete. The increase in the flexural strength was 15.83% and 34% for with and without reinforcement respectively compared to conventional concrete for the optimum response combination.
- All the beams exhibited similar trend of crack propagation and failed by yielding of tensile reinforcement and subsequent crushing of concrete in the compression zone.

REFERENCES

[1] Hsie M., Tu C., Song P.S. "Mechanical properties of polypropylene hybrid fiber-reinforced concrete", Materials Science and Engineering A 494, 2008, Pg.: 153–157.

[2] Wu Yao, Jie Li, Keru Wu, "Mechanical properties of hybrid fiber-reinforced concrete at low fiber volume fraction", Cement and Concrete Research 33, 2003, Pg.: 27–30.

[3] Jose J. O., George T., "Flexural Behaviour of Mono fiber and Hybrid fiber Reinforced Concrete using Steel and Nylon", International Journal of Science Technology & Engineering, 2015, Volume 2, Issue 3.

[4] N. Banthia and R. Gupta, "Hybrid fiber reinforced concrete (HyFRC): fiber synergy in high strength matrices", Materials and Structures, Vol. 37, December 2004, Pg.: 707-716.

[5] Yew M. K., Othman I., Yew M. C., Yeo S. H. and Mahmud H. B. "Strength properties of hybrid nylon-steel and polypropylene-steel fiber-reinforced high strength concrete at low volume fraction", International Journal of the Physical Sciences Vol. 6(33), 2011, Pg.:7584 – 7588.

[6] Meng W. And Khayat K. H. "Effect of Hybrid Fibers on Fresh Properties, Mechanical Properties, and Autogenous Shrinkage of Cost-Effective UltraHigh-Performance Concrete (UHPC)", Journals of materials in civil engineering, 2018, 30(4): 04018030, ASCE.

[7] Bentur, A., Mindess, S. : "Fibre reinforced cementitious composites", Elsevier Applied Science, London, 1990, ISBN 1-85166-393-2

[8] Fehling, E., Bunje, K., Leutbecher, T.: "Design relevant properties of hardened Ultra High Performance Concrete", 1st Int. Symp. on Ultra High Performance Concrete, Kassel, 2004, pp. 327-338,

[9] Markovic, I., Van Mier, J.G.M., Grünewald, S., Walraven J.C. : "Characterization of Bond Between Steel Fibres and Concrete - Conventional Fibre Reinforced Versus Self-Compacting Fibre Reinforced Concrete", 4- 195 - in 3rd International Symposium "Bond in Concrete - from research to standards", Budapest, 2002, pp. 520 - 529.

[10] Soroushian, P., Lee, C.: "Distribution and Orientation of Fibers in Steel Fibre Reinforced Concrete", in ACI Materials Journal, Vol. 87, No. 5, 1990, pp. 433-439.

[11] Rossi, P., Acker, P., Malier, Y.: "Effect of steel fibres at two stages: the material and the structure", Materials and Structures, Vol. 20, 1987, pp. 436-439.

[12] Amir A. M. and Banthia N., "Shear Strength of Steel Fiber-Reinforced Concrete", ACI Materials Journal, V. 99, No. 5, 2002, pp 473-479.

[13] Ashour, S.A., Mahmood, K., Wafa, F., "Influence of steel fibers and compression reinforcement on deflection of high-strength concrete beams", ACI Structural Journal, V.94, No.6, 1997, pp 611-624.

[14] C.X. Qian and P. Stroeven, "Fracture properties of concrete reinforced with steelpolypropylene hybrid fibers", Cement & Concrete Composites, Vol. 22, No.4, 2000, pp 343–351.

[15] G. Pons, M. Mouret, M. Alcantrara, J.L. Granju, "Mechanical behaviour of selfcompacting concrete with hybrid fiber reinforcement", Materials and Structures, Vol. 40, 2007, pp 201-210.

[16] Vandewalle L., 'Hybrid fiber concrete: is there a synergetic effect?' Advances in construction material, Part II, 2007, pp 219-228.

[17] Y. Hua; J.Y. Lian; and T.Q. Zhou, "Relationship between the mechanical properties of hybrid fiber reinforced concrete and length/diameter aspect ratio of hybrid fiber", Jianzhu Cailiao Xuebao/J. Build. Mater. Vol. 8, No.1, 2005, pp. 71–76

[18] IS:2386(part-3)-1963, Methods of test for aggregate for concrete, Part 3: Specific gravity, density, voids, absorption and bulking.

[19] IS 456:2000, Plain and Reinforced concrete – Code of Practise.

[20] IS 10262: 2009 Concrete Mix Proportioning – Guideline

[21] IS 383:2016, Coarse and Fine Aggregate for concrete – Specification.