EXPERIMENTAL STUDY OF FIBRE SYNERGY TO INVESTIGATE THE TENSILE & COMPRESSIVE STRENGTH OF FIBRE REINFORCED CONCRETE

[a] Talha Rashid,[b] Muhammad Usman Rashid, [c] Irshad Qureshi, [d] Mohammad Zulqarnain*

a: Department of Civil Engineering, University of Engineering & Technology (UET) Taxila, engrtalharashid12@gmail.com
b: Department of Civil Engineering, University of Engineering & Technology (UET) Taxila, m.usman@uettaxila.edu.pk
c: Department of Civil Engineering, University of Engineering & Technology (UET) Taxila, irshad.qureshi@uettaxila.edu.pk
d: Department of Civil Engineering, University of Engineering & Technology (UET) Taxila, zuuki786@gmail.com
* Corresponding author: Email ID: m.usman@uettaxila.edu.pk

Abstract- The goal of this experimental research was to analyze the addition of carbon and glass fibers on the split-tensile and compressive strength of concrete cylinders. An approach to increase the strength of structures was carried out using fiber synergy. In this investigation, an effort was made by testing hybridized and mono fiber reinforced concrete (FRC) cylinders. Eighteen concrete cylinders were cast including six cylinders with different percentages of carbon fibers, six cylinders with different percentages of glass fibers, three control cylinders, and three hybridized cylinders were tested up to failure point. Eighteen samples each for split-tensile and compressive strength were tested in this experimental research. It was observed that the split-tensile and compressive strength of fiber reinforced concrete cylinders was improved using fiber synergy.

Keywords- carbon fibers, compressive strength, energy absorption glass fibers, hybrid fibres, split tensile strength

1 Introduction

Fibre reinforced concrete (FRC) is described as a composite material made with Portland cement, aggregate, and adding fibres that are discontinuous. FRC is super resistant against cracks formation and propagation. As a result of this ability to arrest cracks, fibre composites possess increased extensibility and tensile strength.

The strength of ordinary cement concrete is compromised by its least tensile resistance and very restricted ductility along with least resistance to cracking which makes it a brittle material leading to limited serviceability. Internal micro cracks lead to the brittle failure of concrete. The project specification led it to the durability requirements and being with the specific intended use it becomes necessary to modify the properties of concrete for broader use and durability limitations. Although, concrete has wide range of applications but it has some deficiencies too like low tensile strength, cracking capacity and brittleness.

The application of short and randomly distributed fibres to improve the properties of building materials is not a new concept and indeed its application is recorded in scriptures. Developing the concrete characteristics by strengthening fibre has its advantages including strength against cracks developing by contract dying and plastic, strength against moisture and thermal tension and increased formability.

Shabbir et al. [1] experimented the effect of carbon and steel fibres addition in concrete and analysed the cracking patterns. They concluded that the addition of carbon and steel fibres in concrete played a vital role in controlling the concrete cracks. Riyad et al. [2] investigated the load carrying capacity of glass fibre reinforced concrete and concluded that the load carrying capacity of GFRC increased as compared to ordinary concrete. Rashid [3] investigated durability characteristics of steel and polypropylene FRC exposed to natural weathering action and concluded that the durability is improved by natural weathering-exposure of polypropylene fibres. Anthony et al. [4] investigated optimum percentage of polypropylene fibre contents for enhancement of strength of concrete in compression and concluded that the strength of concrete is improved by 0.5% when low percentage fraction of fibres was added. Ali et al. [5] studied the effect of glass-fibres on properties of concrete with recycled aggregates and concluded optimum dosage of glass fibres to be 0.25% for natural coarse aggregates, and 0.5% for recycled coarse aggregate concrete respectively. Sohail et al. [6] studied the comparison of confined glass and carbon FRC and concluded that both glass and carbon FRC have more strength as compared to high strength concrete. Rashid et al. [7] experimented the strength of FRC girders in flexural containing steel and polypropylene fibres and concluded that flexural strength is increased by 47% and split-tensile strength is increased by 123% by the use of steel and polypropylene fibre. They also concluded that steel FRC girders improve the strength by 47% in flexural and energy absorption by 69%. Patil and Sangle [8] concluded that almost 30-50% load carrying capacity of FRC having steel fibres was greater than that of plain concrete. They also concluded that the use of fibres enhanced the resistance against cracking. Shakor and Pimplikar [9]investigated the difference in compressive strength of FRC specimens with and without glass fibres and concluded glass FRC to have higher potential in construction industry. Chen and Chung [10] used carbon fibres inside concrete mix design and concluded minimum 0.1% by volume of carbon fibres inside concrete mix design for increase in flexural strength. Song and Yin [11] evaluated compressive toughness of steel and carbon FRC and concluded increase in crack resistance property of concrete specimens by the addition of steel and carbon fibres. Chandramouli and Srinivasa [12] carried out experimental investigation on alkali resistance glass FRC and observed 20-25% increase in strength in comparison of controlled concrete specimens with zero percent fibres.

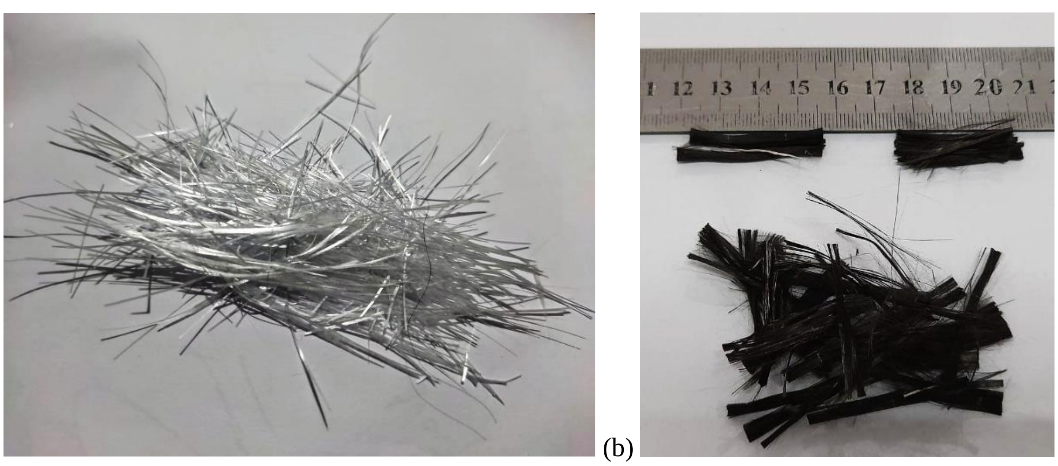
There is not much research on strengthening of reinforced concrete using hybridized fibres (carbon and glass fibres). This gap is covered after testing hybrid and mono FRC cylinders. This experimental program provides evaluation of compressive & tensile strength, stress & strain curves, load & deflection curves and cracking patterns.

2 Research Methodology

The effect of the carbon & glass fibres on the strength of concrete was studied by varying the percentages of carbon and glass fibres in the concrete for which others parameters were remained constant. The compressive strength (ASTM C39-19) [13] and split-tensile strength (ASTM C496-12) [14] was tested by casting the concrete cylinders in casting yard of commercial suppliers working in Pakistan.

2.1 Materials

The concrete mix design of 1:1:2 was used for this experimental research consist of ordinary Portland cement (ASTM C 150-14) [15], coarse aggregates from Margalla crush with 70% (by 9.5mm sieve passing) and 30% (by 20mm sieve passing) (ASTM C-33) [16], fine aggregates from Lawrencepur sand having 2.12 Fineness Modulus, simple tap water and 0.7% superplasticizer (ASTM C 494-14) [17]. Chopped Glass and Carbon fibers are shown in Figure 1. were also used with varying percentages.



(a) (b)

Figure- 1: Different fibers used in this research (a) Glass Fibers (b) Carbon Fibers

The materials for $1m^3$ of concrete are estimated as shown in Table 1.

Sr.#	Specimen	Cement Content (kg/m^3)	Water Content (L)	Sand Content (kg / m^3)	Coarse Aggregates Content (by 9.5mm passing) (kg / m^3)	Coarse Aggregates Content (by 20mm passing) (kg /m^3)	Admixture Content (kg /m^3)	Carbon Fibers Content (kg /m^3)	Glass Fibers Content (kg / m^3)
1	S1-CM	132.3	66.2	132.3	185.27	79.4	0.7	0	0
2	S2-CFRC-1							2.9	0
3	S3-CFRC-2							3.7	0
4	S4-GFRC-1							0	1.8
5	S5-GFRC-2							0	2.6
6	S6-HyFRC							3.3	2.2

Table 1: Concrete mix design and material calculations

2.2 Casting of Specimens

A total 36 number of concrete cylinders were casted in Banu Mukhtar Plant located in KPK as shown in Figure- 2a. For all concrete specimens, the concrete mix ratio was kept same. The compaction of concrete carried out via an external vibrator After 24 hours, the moulds were removed and cylinders were placed in curing tanks as shown in Figure- 2b in accordance with ASTM C-31 [18].

(a)  *(b)* 

Figure- 2: Casting and Curing of Specimens (a) Preparation of Concrete mixing in Plant (b): Placement of concrete cylinders inside curing tanks for 28 days

The ratios of various types of fibres used inside all concrete cylinders is shown in Table 2.

Sr. No.	Specimen	Fiber Content (by % of weight of concrete)	
		Carbon Fibers	Glass Fibers
1	S1-CM	-	-
2	S2-CFRC-1	0.65%	-
3	S3-CFRC-2	0.85%	-
4	S4-GFRC-1	-	0.40%
5	S5-GFRC-2	-	0.60%
6	S6-HyFRC	0.75%	0.50%

Table 2: Percentages of fibres in concrete specimens

2.3 Testing of Specimens

The determination of compressive strength and split-tensile strength of concrete specimens was carried out at each 25kN load interval. Load was applied via compression testing machine with capacity of 3000kN at the centre of cylinders, and deflection of the cylinder was measured using linear displacement sensors (LDS) at each respective load interval. The strains were recorded by using P3-strain indicator and data recording device (Figure 4) connected to LDS. The complete setup installation is shown in Figure- 3(a) along with complete setup schematic diagram in Figure- 3(b).

(a) (b)

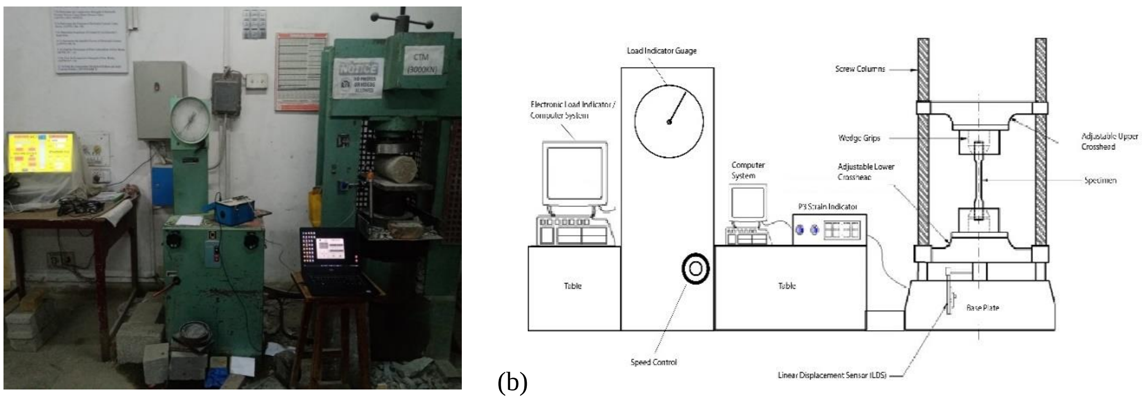


Figure- 3: Complete Testing Setup (a): Compression Testing Machine (3000 kN), Computer Setup, P3 Strain Indicator and Linear Displacement Sensor; (b): Schematic Diagram of Complete Setup

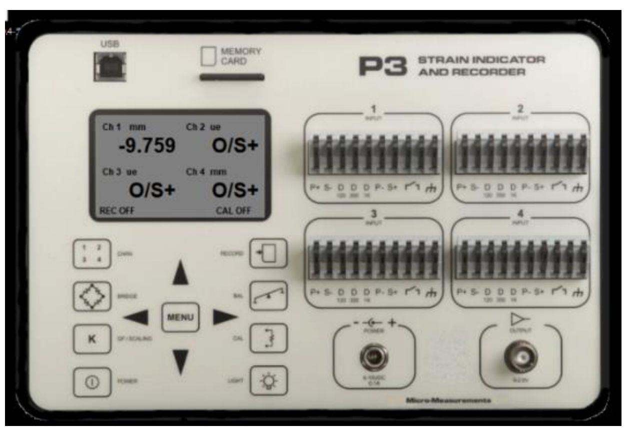


Figure- 4: P3 Strain Indicator and Recorder

3 Results

3.1 Compressive Strength of Concrete Mixes

Three number of cylinders were tested for each type of concrete mix and average of three is reported in this section. Load-Deflection and Stress-Strain graphs are shown in Figure--5 and Figure--6 respectively. The average maximum compressive strength of all specimens are shown in Figure- 7.

The compressive strength of S6-HyFRC concrete specimens was achieved up to 33.90MPa which was maximum as compared to other concrete mix specimens. The concrete mixes with mono-fibers i.e. (i.e., mixes of S2-CFRC-1, S3-CFRC-2, S4-GFRC-1, S5-GFRC-2) didn't showed much difference in compressive strength as compared to that of control specimen. The fiber synergy (hybridization of carbon and glass fibers) played a vital role in increasing the compressive strength of S6-HyFRC concrete specimens.

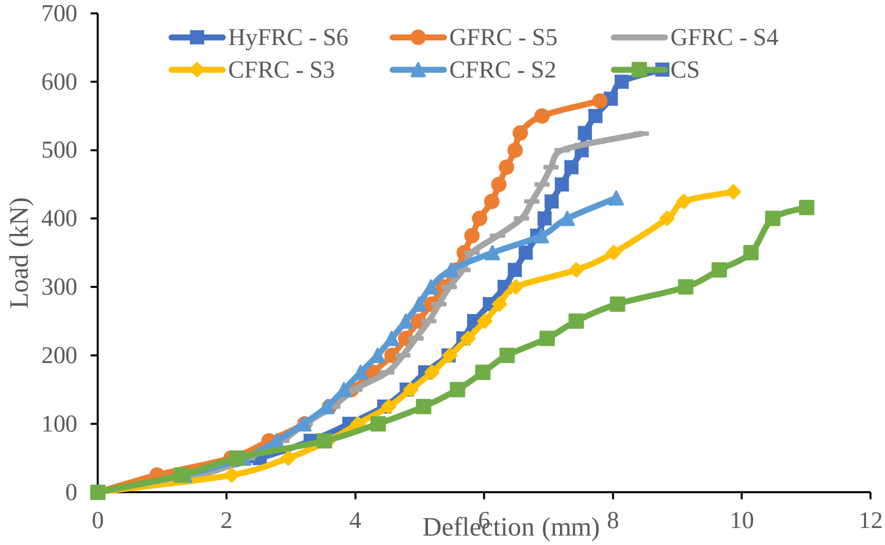


Figure- 5: Load-Deflection curves against compressive strength testing of all concrete specimens

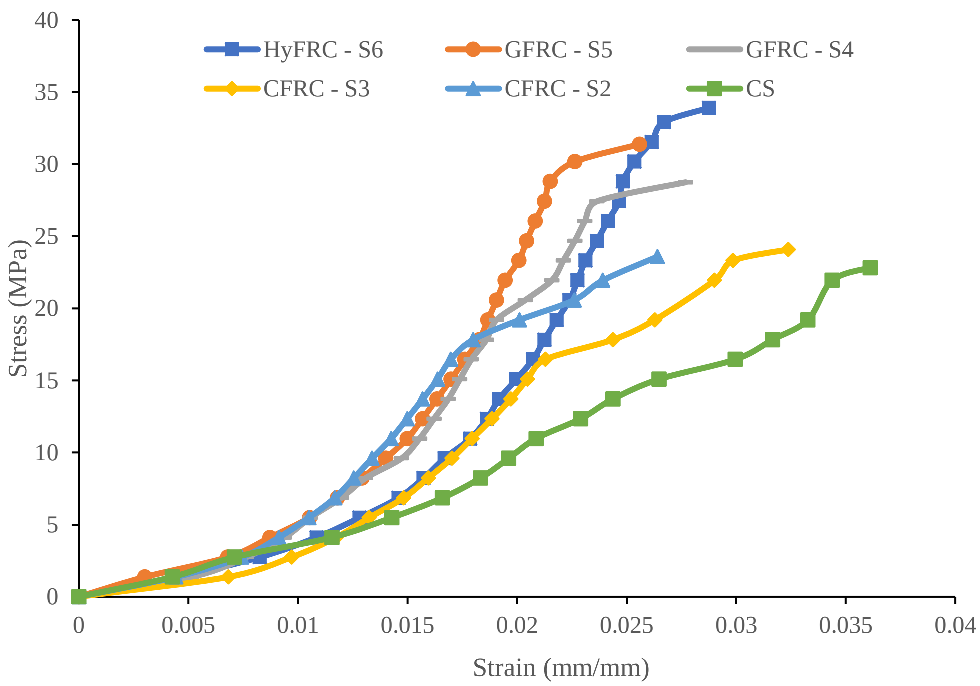


Figure- 6: Stress-Strain curves against compressive strength testing of all concrete specimens

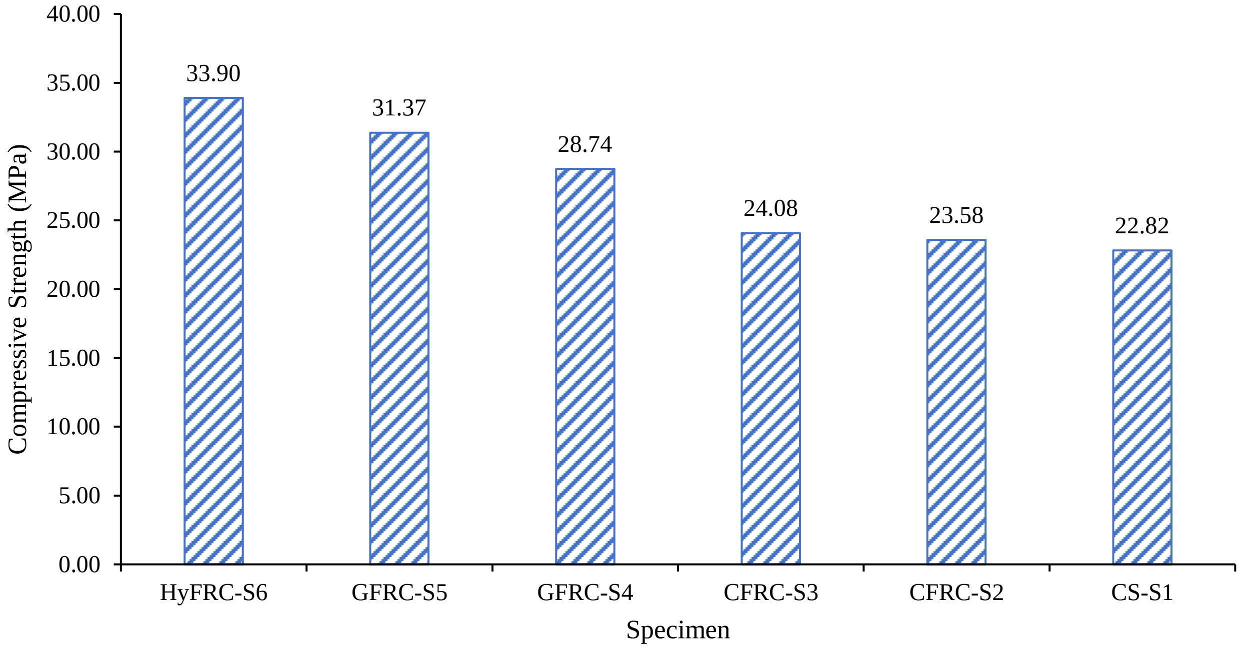


Figure- 7: Average Max. Compressive strength of all concrete specimens

3.2 Split-tensile Strength of Concrete Mixes

The concrete cylinders were tested for split-tensile strength as per ASTM C496-12 [14]. Load-Deflection and Stress-Strain graphs are shown in Figure- 8 and Figure- 9 respectively. Maximum load carrying capacity and average maximum compressive strength of all specimens are shown in Figure- 10.

S6-HyFRC concrete specimens have shown maximum tensile strength due to their composition containing hybridized fibres that improved the capability of both fibres' types inside the concrete matrix. The tensile-strength of 12.5 MPa was observed for mix of concrete cylinder S6-HyFRC. The use of carbon and glass fibres (S2-CFRC-1, S3-CFRC-2, S4-GFRC-1 and S5-GFRC-2) improved the tensile-strength of concrete, but negligible in comparison to that of S6-HyFRC concrete specimens.

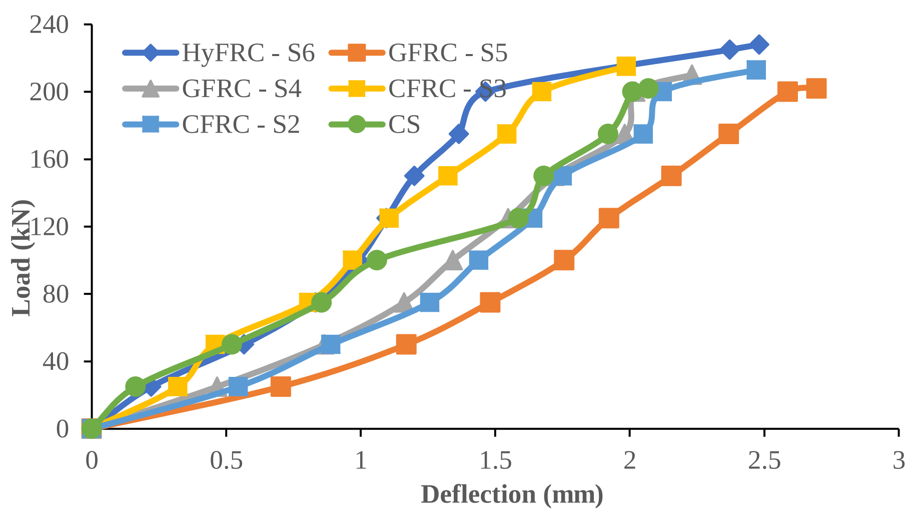


Figure- 8: Load-Deflection curves of split-tensile strength testing of all concrete specimens

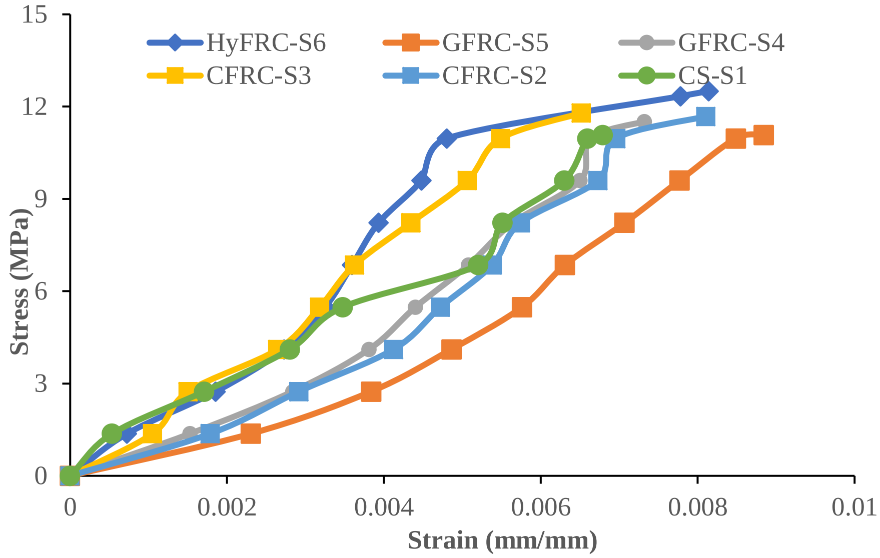


Figure- 9: Stress-Strain Curves of split-tensile strength testing of all concrete specimen

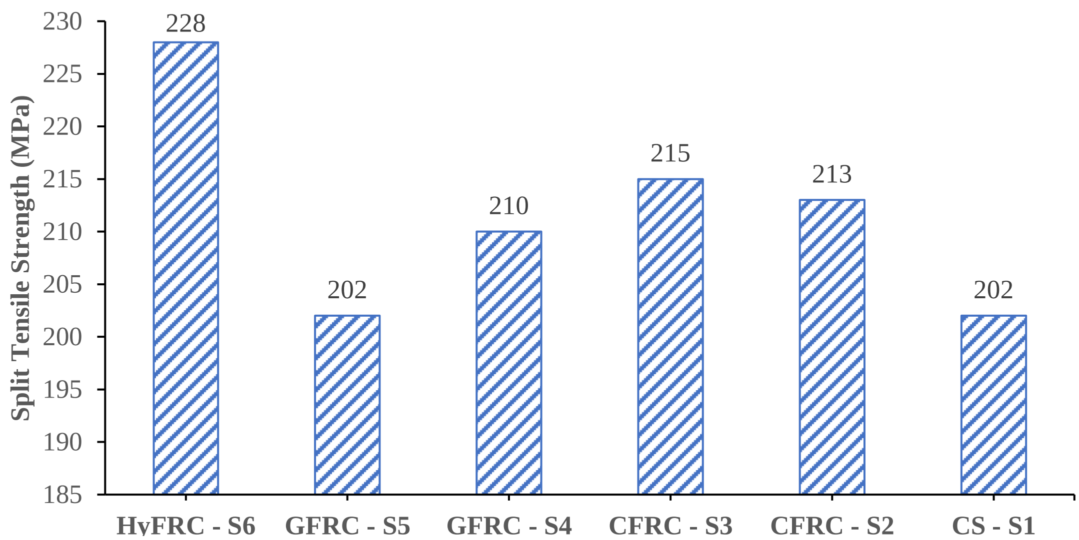


Figure- 10: Average split-tensile strength of concrete specimens

3.3 Slump of Different Concrete Mixes

The slump test for every concrete batch was performed according to ASTM C-143 [19] as shown in Figure 11.

Figure- 11: Slump Cone Test for concrete specimens

The results of slump test are elaborated as shown in Table 3:

Sr. No.	Specimen	Mix Design Ratio	Slump (mm)
1	S1-CM	1:1:2	50
2	S2-CFRC-1		38
3	S3-CFRC-2		40
4	S4-GFRC-1		42
5	S5-GFRC-2		45
6	S6-HyFRC		47

Table 3: Average Slump values for each concrete specimen

3.4 Energy Absorption of Concrete Mixes

Toughness of concrete cylinders is indicated by the amount of energy being absorbed [20]. The area under Load-Deflection curves is calculated and depends on both ultimate load and maximum deflection achieved at failure point. S6-HyFRC concrete cylinders absorbed 82% more energy as compared to S1-CS as shown in Figure- 12.

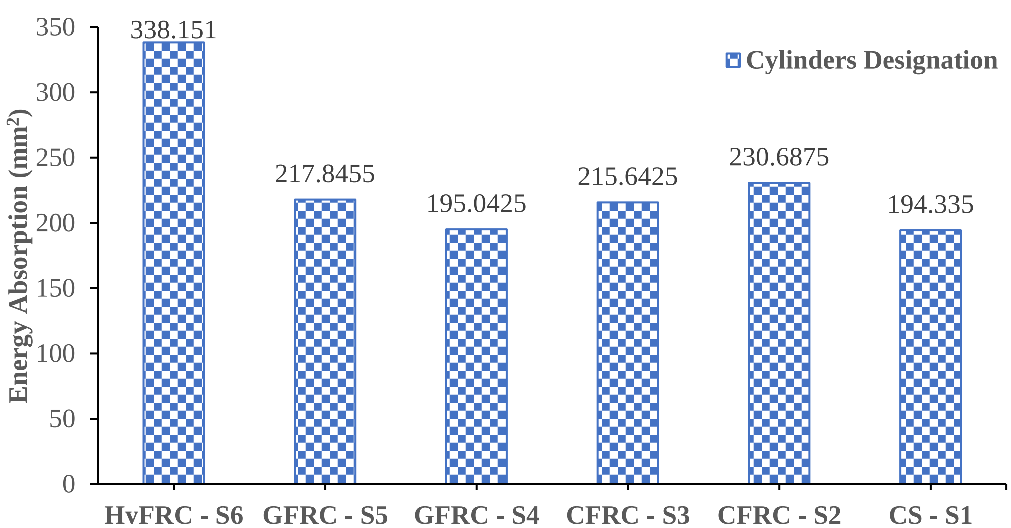


Figure- 12: Average Energy Absorption Capacity for each Concrete Specimen

3.5 Crack Patterns

The propagation of the cracks was observed before and after testing each specimen of concrete during experimental work. The cracks were vertical in majority and inclined along the height of cylinder and they differ with various fibre contents inside the specimens. The cracking patterns under compression testing along with their development can be observed in Figure- 16, 17 and 18.

The specimens were also tested under split-tensile strength test. The concrete specimens were put horizontally to get the tensile strength after splitting them apart. The initiation of tensile cracks from the top and propagation to the bottom of cylinder was observed. All the concrete specimens have resulted in horizontal under split-tensile strength testing and can be observed in Figure- 19, 20 and 21.

Figure- 13: HyFRC-S6 Cylinder after compressive strength test

(a)  (b)  (c) 

Figure- 14: CFRC and GFRC mixed Cylinders after compressive strength test (a) S3-CFRC (b) S4-GFRC (c) S5-GFRC

Figure- 15: Control Concrete Cylinder (CS) after compressive strength test

Figure- 16: HyFRC-S6 Cylinder after split-tensile strength test

(a) 

(b) 

(c) 

Figure- 17: CFRC and GFRC mixed Cylinders after split-tensile strength test (a) S3-CFRC (b) S3-CFRC (c) S4-GFRC

Figure- 18: Controlled Concrete Cylinders after split-tensile strength test

4 Practical Implementation

Fiber reinforced concretes play important role to arrest cracks and due crack resisting nature of FRC it will considerably improve the mechanical strength of structural members. This research focuses on practical implementation of fiber reinforced concrete in structural members to enhanced compressive and split-tensile strength along with better crack resistance. Furthermore, this approach is also very beneficial from economical perspective as it will reduce the cross section of members which will greatly reduce the project cost.

5 Conclusion

The experimental research, after performing compressive strength and split-tensile strength tests on all concrete specimens, concludes following points:

1. The use of hybridized fibre reinforced concrete (HyFRC) has increased the compressive strength by 49% and the split-tensile strength by 12.5% as compared to control specimen.
2. The crack resistance property of HyFRC was increased as compared to control specimen.
3. HyFRC specimens has absorbed 345% higher energy as compared to control specimens.

Acknowledgment

The authors are thankful to Banu Mukhtar Pvt. Ltd who assisted during this experimental work. The suggestions by the reviewers are gracefully be taken into consideration. The careful review and constructive suggestions by the anonymous reviewers are highly acknowledged.

References

[1] F Shabbir, MU Rashid, A Muslim and A Raza, "The Efficiency of Hybrid Fibers (Steel and Carbon Fibers) in Controlling Micro Cracking of Concrete Beams," *Iranian Journal of Science and Technology, Transactions of Civil Engineering*, pp. 1-21, 2022.

[2] Y RIYAD, B KISSI and I MRANI, "Reinforcement of concrete using Glass Fiber Reinforced Polymer," *Journal of Materials and Engineering Structures,* vol. 9, pp. 141-152, 2022.

[3] MU Rashid, "Experimental investigation on durability characteristics of steel and polypropylene fiber reinforced concrete exposed to natural weathering action," *Construction and Building Materials,* vol. 250, p. 118910, 2020.

[4] A. N. Ede and A. OluwabambiIge, "Optimal polypropylene fibre content for improved compressive and flexural strength of concrete," *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* vol. 11, pp. 129-135, 2014.

[5] B Ali, LA Qureshi, A Raza, MA Nawaz and SU Rehman, "An investigation on shear behavior of prestressed concrete beams cast by fiber reinforced concrete," *Arabian Journal for Science and Engineering,* vol. 43, no. 10, pp. 5605-5613, 2018.

[6] MR Sohail, N Ahmad, MU Rashid, R Waqas and U Muhammad, "Comparison of GFRP and CFRP confinement of normal and high strength concrete," *Građevinar,* vol. 72, no. 06, pp. 475-484, 2020.

[7] MU Rashid, LA Qureshi and MF Tahir, "Investigating flexural behaviour of prestressed concrete girders cast by fibre-reinforced concrete," *Advances in Civil Engineering,* vol. 2019, 2019.

[8] S. P. Patil and K. K. Sangle, "Shear and flexural behaviour of prestressed and non-prestressed plain and SFRC concrete beams," *Journal of King Saud University-Engineering Sciences,* vol. 29, pp. 321-328, 2017.

[9] PN Shakor and SS Pimplikar, "Glass Fibre Reinforced Concrete Use in Construction," *International Journal of Technology And Engineering System (IJTES),* vol. 2, 2011.

[10] PW Chen and DDL Chung, "Concrete reinforced with up to 0.2 vol% of short carbon fibres," *Composites,* vol. 24, no. 1, pp. 33-52, 1993.

[11] W Song and J Yin, "Hybrid effect evaluation of steel fiber and carbon fiber on the performance of the fiber reinforced concrete," *Materials,* vol. 9, p. 704, 2016.

[12] K Chandramouli and RP Srinivasa, "Strength properties of glass fiber concrete," *ARPN Journal of Engineering and Applied Sciences,* vol. 5, pp. 1-6, 2010.

[13] A. C39/C39M-11, "Standard test method for compressive," *Annual Book of ASTM Standards,* 2011.

[14] A. C496/C496M-11, "Standard test method for spitting tensile strength of cylindrical concrete specimens," *Annual Book of ASTM Standards,* 2011.

[15] A. C150-14, "Standard Specification for Portland Cement," *Annual Book of ASTM Standards,* 2011.

[16] A. C33, "Standard specification for concrete aggregates," *Annual Book of ASTM Standards,* vol. 4, 1994.

[17] A. C494-14, "Standard Specification for Chemical Admixtures for Concrete," *Annual Book of ASTM Standards,* 2011.

[18] A. C31/C31M-19, "Standard Practice for Making and Curing Concrete Test Specimens in the Field," *Annual Book of ASTM Standards,* 2019.

[19] A. C143, "Slump of Hydraulic Cement Concrete," *Annual Book of ASTM Standards*, 2011.

[20] KT Soe, YX Zhang and L Zhang, "Advances in Engineered Cementitious Composites," *Woodhead Publishing Series in Civil and Structural Engineering*, pp. 77-120, 2022.