

# Strength Characteristics of Hybrid Fiber Reinforced Concrete

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**ABSTRACT:** This study presents a study on the strength characteristics of hybrid fiber reinforced concrete. The different fiber volume fractions influences on the strength characteristics of hybrid fiber reinforced concrete specimens were investigated. The parameters investigation included compressive strength, split tensile strength, flexural strength and impact strength. A total of 36 specimens, 150x150x150mm cubes, a total of 36 specimens of cylinder (Cylinder size 150 mm diameter and 300 mm height), A total of 36 specimens, 100x100x500mm beams were tested to study the above parameters. The specimens incorporated 0.5 to 1.5% volume fraction of steel and glass fibres in equal proportions. The strength characteristics of hybrid fiber reinforced concrete specimens were compared with that of plain concrete. The test results show that the addition of 1.5% by volume of hybrid fibers improves the strength characteristics appreciably.

**KEYWORDS:** Fiber content, Hybrid fiber reinforced concrete, Fiber volume, Steel and glass fibers, Plain concrete.

## I. INTRODUCTION

Concrete is a major material used in the construction industry. General awareness of the deterioration of concrete structures in early eighties prompted many researchers to find a new civil engineering material which not only satisfies the strength criterion, but also the durability requirements, as otherwise, maintenance or repair costs could be high and cause inconvenience to the public. Many modifications have been proposed in conventional concrete in order to improve its overall performance, including strength, durability, ductility and constructability. At present concrete is not just a mixture of cement, fine aggregate, coarse aggregate and water, instead several chemical and mineral admixtures are being widely used so as to improve the properties of concrete both in plastic and hardened state.

Concrete is considered a brittle material, primarily because of its low tensile capacity and poor fracture toughness. Concrete can be modified to perform in the more ductile form of the addition of fibers in the concrete matrix. In fibre reinforced concrete fibres can be effective in arresting cracks at both macro and micro levels. For an optimal response, different type of fibres may be suitably combined to produce hybrid fibre Reinforced Concrete. The use of optimized combinations of two or more types of fibres in the same concrete mixture can produce a composite with better engineering properties than that of individual fibres.

A principal role of fibres in brittle matrix composites is to increase their toughness. The behaviour of fibres in a brittle matrix is dependent on their length and composition and on the quality of the fibre - matrix bond. When a crack appears in the matrix, short steel fibres are pulled out after progressive debonding. Longer fibres or fibres of low strength would break. In both cases, fibres serve as crack arrestors. As the cracks are inevitable but brittle, a fracture should be avoided.

Anshida Haneefa et al. [1] studied the influence of fiber content, fiber loading and hybrid effect on the mechanical properties such as tensile strength, Young's modulus, elongation at break, and flexural properties of the composites was evaluated. N. Bantia and S. Cangiano [2] investigated the combination of different fibre types provides a higher toughness. In [3], the authors conducted experimental studies on flexural behaviour of large size reinforced concrete beam. Beam size of 1800 mm x 208 mm x 100 mm was used. S. Eswari et al. [4] focused on the polyolefin-steel hybrid fibre reinforced system. A total of 27 specimens was tested and found that increasing the fibre content from 2 to 5% increase the modulus of rupture. Henagar [5] described a method for estimation of the ultimate strength of RC

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Vol. 7, Issue 7, July 2018

beams with randomly oriented steel fibres. Kumar et al. [6] conducted a comparative study to determine the rotational capacity and toughness of reinforced concrete beam with and without fibers. Moens and Nemegeer [7] explained the procedure for designing fibre reinforced concrete based on toughness characteristics of steel fibre reinforced concrete. K. Nagamani et al. [8] have presented the contribution of steel fibres on the splitting tensile strength of high strength steel fibre reinforced concrete. even Krstulovi-opara et al. [9] studied the effect of increased tensile strength and toughness on reinforcing bar bond behavior. Nguyen Van Chanh [10] described the important properties of steel fibre reinforced concrete is its superior resistance to cracking. Pakotiprapha et al. [11] carried out an experimental and analytical investigation on mechanical properties of cement mortar reinforced with randomly oriented short steel fibres. H. Wang and A. Belarbi [12] developed a nonferrous hybrid reinforcement system for concrete bridge decks by using continuous fibre reinforced polymer rebar's and discrete randomly distributed polypropylene fibres. Wu Yao and Jie Li [13] conducted a study on different types of hybrid fibers at the same volume fraction (0.5%).

Most of the literatures were based by using a unique fibre either steel or glass. Hybrid fibre reinforced concrete projects are very minimal. In above Hybrid fibre reinforced concrete projects the volume of fibre added is mostly high fraction i.e., above 5%. In addition, there was minimal information on fibre reinforced concrete with an effect of different strength of concrete.

In this project low volume of fraction of fibre i.e., 0.5%, 1%, 1.5% volume of fibre is added to the total volume of concrete. Hence an attempt has been made to study the strength characteristics of hybrid fibre reinforced concrete with different percentage of hybrid fibres. The present study concentrates the fibre reinforced concrete with two different concretes viz., M25 and M50.

The Present study aims to

- To explore the possibility of using the hybrid fibre system to improve the performance of fibre reinforced concrete specimens.
- To examine an enhancement in strength characteristics of hybrid fibre reinforced concrete specimens.
- To study the behaviour of FRC on different structural element.

## II. MATERIALS AND TEST PROCEDURE

### A. Materials

#### 1. Cement

The ordinary Portland cement of grade (53) is used for the present investigation and tested as per IS 4031-1988.

#### 2. Fine aggregate

Natural river sand with fraction passing through a 4.75mm sieve and retained on 60micron sieve is used and will be tested as per IS2386 (part 1)-1963. The fineness modulus of sand is 3.12 with a specific gravity of 2.5.

#### 3. Coarse aggregate

Coarse aggregate of size 20mm has been selected for the study. The physical properties will be tested as per IS2386 (part 1)-1963. The fineness modulus of coarse aggregate is 5.95 with a specific gravity of 2.7.

#### 4. Water

Portable tap water available in the laboratory with a pH value of 7.0 and conforming to the requirements of IS456-2000 is used for making concrete and curing the specimen.

For the present work the following steel and glass fibres are chosen. and Physical and mechanical Properties are shown in below.

#### 5. Steel fibers

Mechanical and Physical Properties of steel fibers.

Name	: DRAMIX 45/50-BN
Length	: 50mm
Diameter	: 1.05mm
Aspect Ratio	: L/D = 48
Tensile Strength	: 1160 N/mm <sup>2</sup>
Anchorage	: Hooked End

#### 6. Glass fibers

# International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 7, Issue 7, July 2018

Mechanical and Physical Properties of glass fibers.

Name : E-Glass fibre  
Density : 2600 kg/m<sup>3</sup>  
Tensile Strength : 2000 N/mm<sup>2</sup>  
Young modulus : 73000 N/mm<sup>2</sup>  
Elongation : 0-3.2%

### B. Test Procedure

The general method used for conducting tests on the strength aspect is by casting concrete specimens and conducting the tests as per the IS456-2000 codal provisions. For this study the numbers of specimens to be cast and the tests to be conducted are given Table 1 these specimens will be tested after 7days and 28days.

Table I: Specimens details

Sl.No.	Tests	Fibre content											
		M25						M50					
		0.5%		1%		1.5%		0.5%		1%		1.5%	
1	Compressive strength	3	3	3	3	3	3	3	3	3	3	3	3
2	Splitting tensile strength	3	3	3	3	3	3	3	3	3	3	3	3
3	Flexural strength	3	3	3	3	3	3	3	3	3	3	3	3
4	Impact Strength	3	3	3	3	3	3	3	3	3	3	3	3

### Compressive strength test

The Compressive strength test was conducted as per IS 516-1959. The specimens were kept in water for 28 days and surface dry conditions were obtained by wiping water on the surface. The maximum load applied to the specimen was recorded and the type of failure was noted. An average of three values was taken as the representative of the batch. The compression test setup is shown in Fig.1.

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Vol. 7, Issue 7, July 2018



Fig.1: Specimen in compression testing machine

### Flexural strength test

A beam specimen should be cast for determining the flexural strength of concrete. The standard specimen size is 10cm X 10cm X 50cm. A UTM can be used for the test. The testing machine may be set for any reliable type of sufficient capacity for the test. Two steel rollers of 38 mm diameter provided in machine bed on which the specimen is supported. Rollers are supported at a centre-to-centre distance of 60 cm for the 15 cm specimen and at 40 cm for the 10 cm specimen as shown in Fig.2. The test specimen should be cast for 28 days and tested for maximum load. The flexural strength or modulus of rupture should be calculated using the formula given below

$$f_b = (PL) / (BD^2)$$

where B is the measured width (cm) of the specimen, a is the distance between supports (cm), D is the measured depth (cm), L is the length (cm) of the span on which the specimen is supported, and P is the maximum total load (kg) applied to the specimen. Modulus of rupture is about 60% to 100% higher than the direct tensile strength.



Fig.2: Specimen under flexural test

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Vol. 7, Issue 7, July 2018

### Splitting tensile strength test

The IS 5816: 1999 methods adopted for this test. The specimens for splitting tensile were kept in water for curing for 28 days. Central line was drawn on the two opposite faces so as to ensure that lines are in the same axial plane. Care was taken so that the upper platen is parallel with the lower platen. The load is applied without shock and increased continuously at a nominal rate within the  $1.2 \text{ N/mm}^2/\text{min}$  until failure. Splitting tensile strength testing is shown in Fig.3.



Fig.3: Specimen in compression testing machine

### Impact strength test

The test was conducted as per ACI Drop weight method (Recommended by ACI Committee 544.2R -5, 1989). The Disc specimens were cast in steel moulds and the mould was assembled using bolts. The oil was applied thoroughly to the bottom of the moulds. Concrete was poured in two layers. For each layer, the concrete was compacted using vibrator. The top surface of the specimen was levelled using trowel. The specimens were demoulded after 24 hours and cured for 28 days. A standard manually operated 4.5 kg Drop hammer with an 457 mm drop (ASTM 1557-70). A 63.4 mm diameter hardened steel ball. Thickness of the specimen is recorded to the nearest millimetre at its center and at the ends of the diameter prior to the test. The white washed specimen was placed on the base plate with the finished face up and positioned within four lugs of the impact testing equipment. The hammer was dropped repeatedly through a height of 457 mm and the number of blows required for the first visible crack to form at the top surface of the specimen and for ultimate failure was recorded. Impact strength test setup is shown in Fig.4.

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(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 7, Issue 7, July 2018



Fig.4 : Specimen under impact load

### III. TEST RESULTS AND DISCUSSIONS

#### A. Compressive strength

Tests were conducted on cylindrical specimens to calculate compressive strength of M25&M50 after 7, 28 days of curing. The results of compressive strength for 0.5 to 1.5% volume fraction of steel and glass fibers in equal proportions are given in Table 2 and Table 3. Control specimen is represented by a notation 'C<sub>1</sub>'. Similarly, the fibre reinforced concrete specimens are represented by FC<sub>1</sub>, FC<sub>2</sub>, and FC<sub>3</sub> for 0.5%, 1% and 1.5% replacement of fibres.

Table II: Compressive Strength test result (M25)

Fiber content (%)	7 days		28 days	
	Load in (kN)	Compressive strength (N/mm <sup>2</sup> )	Load in (kN)	Compressive strength (N/mm <sup>2</sup> )
C <sub>1</sub> - 0%	486	21.60	684	30.37
FC <sub>1</sub> - 0.5%	501	22.29	721	32.05
FC <sub>2</sub> - 1%	514	22.84	737	32.76
FC <sub>3</sub> - 1.5%	518	23.02	749	33.29

Fig.5. shows the compressive strength improvement on three different percentages of fiber replacement. The addition of hybrid fibers by 0.5 % volume fraction results in an increase of 3.21% in the compressive strength when compared to the plain concrete for 7 days. The addition of hybrid fibers by 1% volume fraction results in an increase of 5.76% in the compressive strength when compared to the plain concrete for 7 days. The addition of hybrid fibers by 1.5 % volume fraction results in an increase of 6.56% in the compressive strength when compared to the plain concrete for 7 days.

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Vol. 7, Issue 7, July 2018

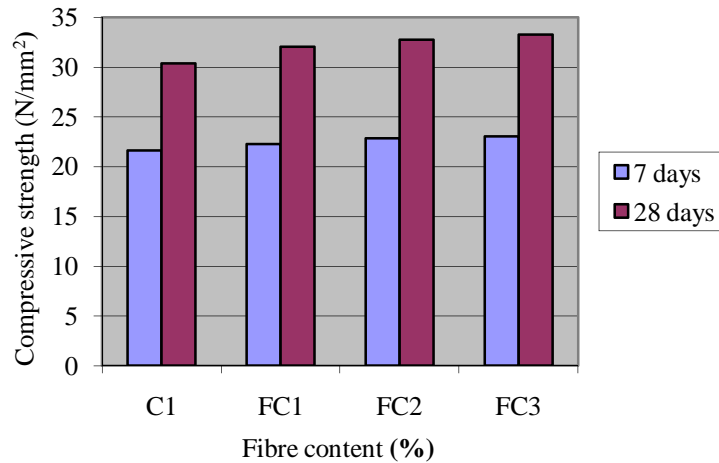


Fig.5: Compressive Strength Variations (M25)

The addition of hybrid fibers by 0.5 % volume fraction results in an increase of 5.56% in the compressive strength when compared to the plain concrete for 28 days. The addition of hybrid fibers by 1% volume fraction results in an increase of 7.89% in the compressive strength when compared to the plain concrete for 28days. The addition of hybrid fibers by 1.5 % volume fraction results in an increase of 9.62% in the compressive strength when compared to the plain concrete for 28 days.

Table III: Compressive Strength test result (M50)

Fibre content (%)	7 days		28 days	
	Load in (kN)	Compressive strength (N/mm <sup>2</sup> )	Load in (kN)	Compressive strength (N/mm <sup>2</sup> )
C <sub>1</sub>	858	38.10	1435	63.74
FC <sub>1</sub>	896	39.84	1529	67.95
FC <sub>2</sub>	915	40.68	1550	68.90
FC <sub>3</sub>	940	41.77	1601	71.16

The addition of hybrid fibers by 0.5 % volume fraction results in an increase of 4.57% in the compressive strength when compared to the plain concrete for 7 days. The addition of hybrid fibers by 1% volume fraction results in an increase of 6.78% in the compressive strength when compared to the plain concrete for 7 days. The addition of hybrid fibers by 1.5 % volume fraction results in an increase of 9.65% in the compressive strength when compared to the plain concrete for 7 days.

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Vol. 7, Issue 7, July 2018

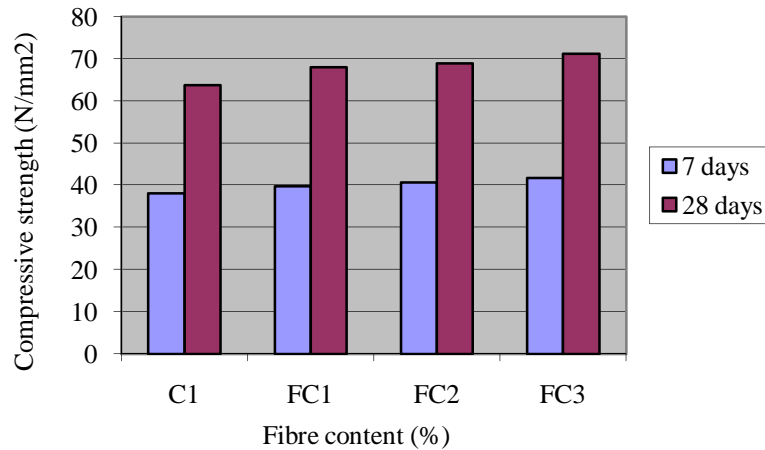


Fig. 6: Compressive Strength Variations (M50)

Fig. 6. shows the compressive strength improvement on three different percentages of fibre replacement. The addition of hybrid fibers by 0.5 % volume fraction results in an increase of 6.61% in the compressive strength when compared to the plain concrete for 28 days. The addition of hybrid fibers by 1% volume fraction results in an increase of 8.10% in the compressive strength when compared to the plain concrete for 28 days.

The addition of hybrid fibers by 1.5 % volume fraction results in an increase of 11.65% in the compressive strength when compared to the plain concrete for 28 days. From Fig.7. it was noticed that the compressive strength improvement, increased by increasing the fibre content, number of days. This increase was mainly contributed by the addition of fibres in concrete. However, the percentage of increase is very minimal, which is the addition of fibres in concrete. As the compressive strength of the hybrid fiber reinforced concrete depends not only on the fiber type and volume, but mainly on the mix characteristics and as compressive testing is quite simple, it is recommended to evaluate the compressive strength by testing, rather than by analytical expressions. Compared to the M25 concrete, M50 concrete shown increases in compressive strength. This is due to the concrete strength to fibre volume ratio. The ratio of concrete strength to fibre volume ratio of two different concretes is shown in Fig.7.

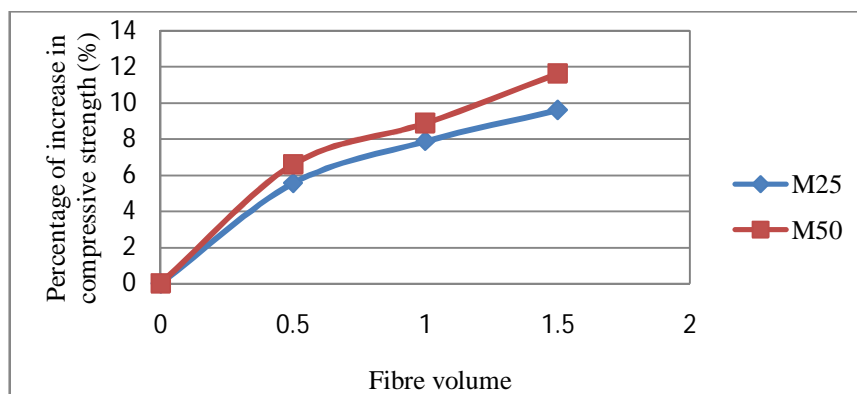


Fig.7: Compressive strength variations (M25&M50)



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Vol. 7, Issue 7, July 2018

### B. Split tensile strength

Tests were conducted on cylinder to calculate splitting tensile strength 7, 28 days of curing. The results of splitting tensile strength for 0.5 to 1.5% volume fraction of steel and glass fibers in equal proportions are given in Table 4 and Table 5.

Table IV: Splitting tensile strength test result (M25)

Fibre content (%)	7 days		28 days	
	Load in (kN)	Tensile strength (N/mm <sup>2</sup> )	Load in (kN)	Tensile strength (N/mm <sup>2</sup> )
C <sub>1</sub>	142	1.99	165	2.33
FC <sub>1</sub>	147	2.08	175	2.48
FC <sub>2</sub>	149	2.11	177	2.50
FC <sub>3</sub>	153	2.16	180	2.55

Fig. 8. shows the split tensile strength improvement on three different percentages of fibre replacement. The addition of hybrid fibers by 0.5 % volume fraction results in an increase of 4.55 % in the splitting tensile strength when compared to the plain concrete for 7 days. The addition of hybrid fibers by 1 % volume fraction results in an increase of 6.23 % in the splitting tensile strength when compared to the plain concrete for 7 days. The addition of hybrid fibers by 1.5 % volume fraction results in an increase of 8.71 % in the splitting tensile strength when compared to the plain concrete for 7 days.

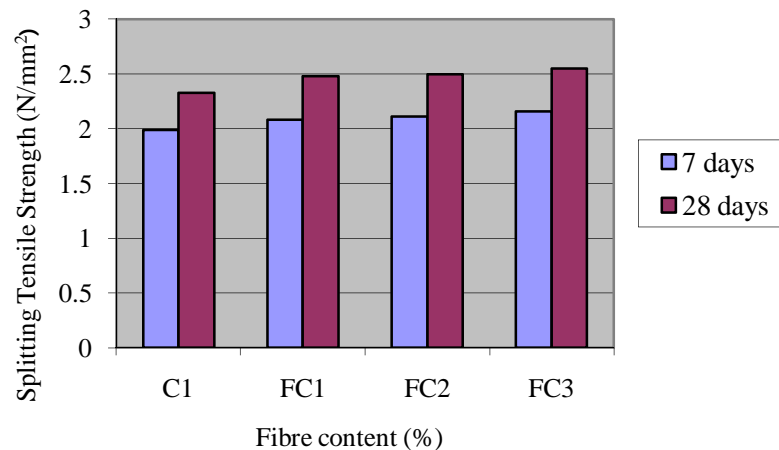


Fig.8: Test result of splitting tensile strength (M25)

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Vol. 7, Issue 7, July 2018

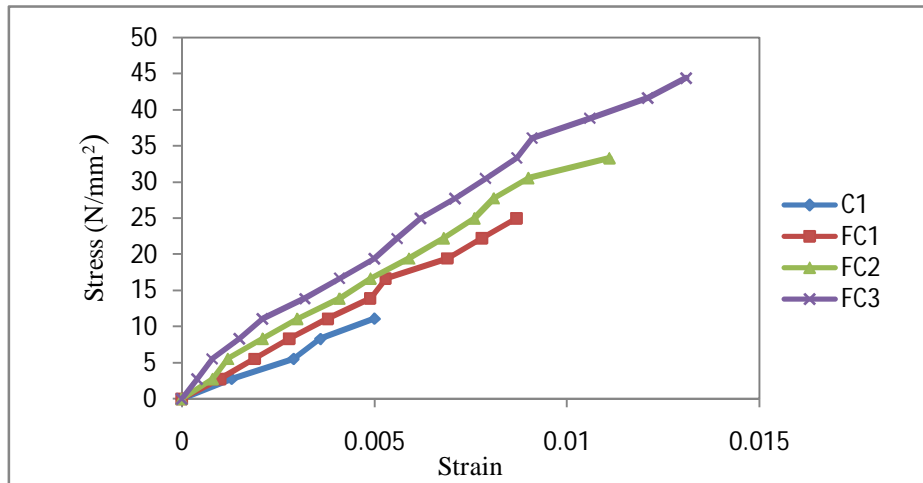


Fig. 9: Stress-Strain curve for M25 -28 days

From Fig. 9. it was noticed that the tensile strength improvement, increased by increasing the fibre content, number of days. This increase was mainly contributed by the addition of fibres in concrete. However, the percentage of increase is very minimal, which is the addition of fibres in concrete. The addition of hybrid fibers by 0.5 % volume fraction results in an increase of 6.63 % in the splitting tensile strength when compared to the plain concrete for 28 days. The addition of hybrid fibers by 1 % volume fraction results in an increase of 7.44 % in the splitting tensile strength when compared to the plain concrete for 28days. The addition of hybrid fibers by 1.5 % volume fraction results in an increase of 9.83 % in the splitting tensile strength when compared to the plain concrete for 28 days.

Table V: Splitting tensile strength test result (M50)

Fibre content (%)	7 days		28 days	
	Load in (kN)	Tensile strength (N/mm <sup>2</sup> )	Load in (kN)	Tensile strength (N/mm <sup>2</sup> )
C <sub>1</sub>	197	2.80	387	5.48
FC <sub>1</sub>	209	2.96	416	5.88
FC <sub>2</sub>	214	3.03	424	6.00
FC <sub>3</sub>	219	3.10	436	6.17

Fig. 10.and Fig.11. shows the split tensile strength improvement on three different percentage of fibre replacement. The addition of hybrid fibers by 0.5 % volume fraction results in an increase of 5.89 % in the splitting tensile strength when compared to the plain concrete for 7 days. The addition of hybrid fibers by 1 % volume fraction results in an increase of 8.55 % in the splitting tensile strength when compared to the plain concrete for 7 days. The addition of hybrid fibers by 1.5 % volume fraction results in an increase of 10.56% in the splitting tensile strength when compared to the plain concrete for 7 days.

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Vol. 7, Issue 7, July 2018

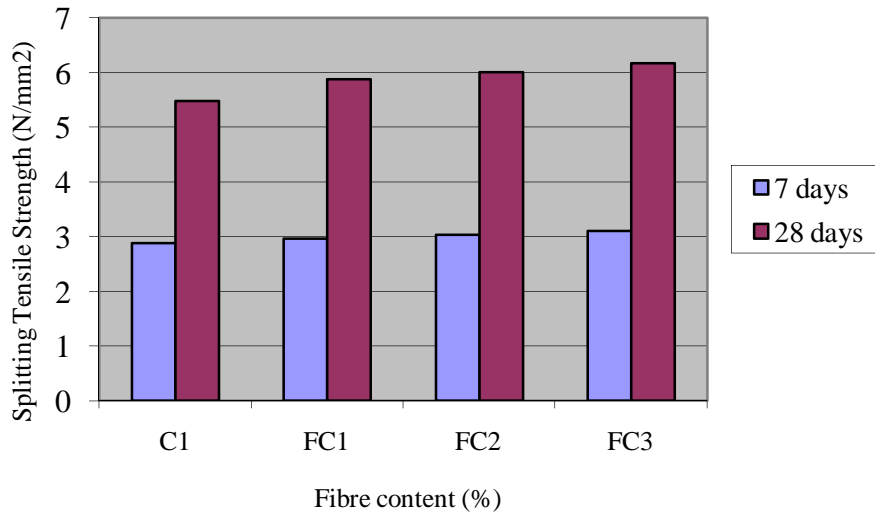


Fig. 10: Test result of splitting tensile strength (M50)

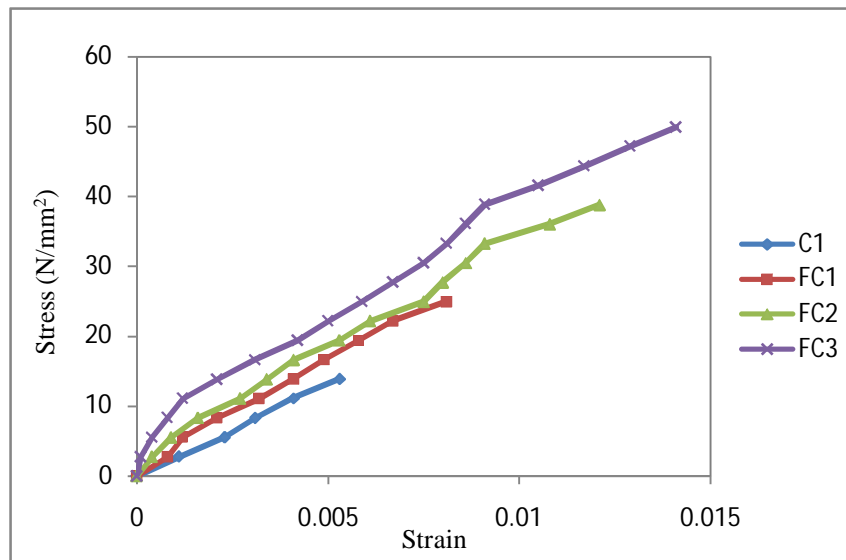


Fig. 11: Stress-Strain curve for M50-28 days

The addition of hybrid fibers by 0.5 % volume fraction results in an increase of 7.43 % in the splitting tensile strength when compared to the plain concrete for 28 days. The addition of hybrid fibers by 1 % volume fraction results in an increase of 9.56 % in the splitting tensile strength when compared to the plain concrete for 28 days. The addition of hybrid fibers by 1.5 % volume fraction results in an increase of 12.62% in the splitting tensile strength when compared to the plain concrete for 28 days.

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Vol. 7, Issue 7, July 2018

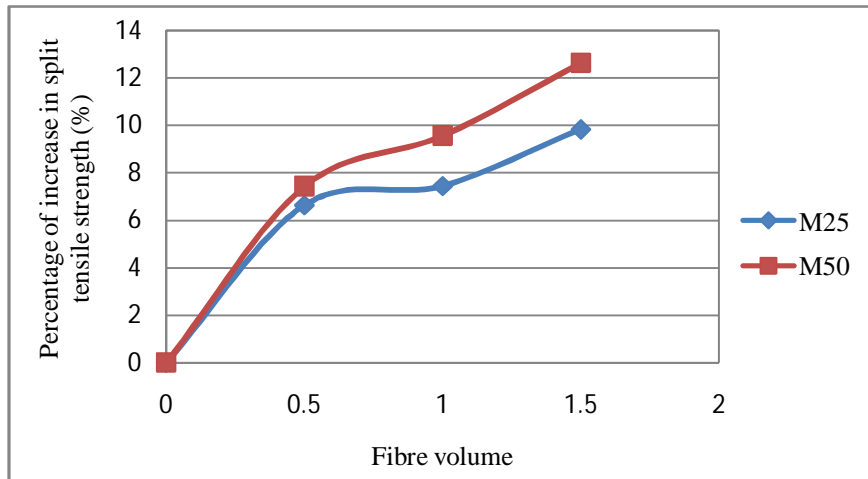


Fig .12: Split tensile strength comparison (M25&M50)

From Fig.12,by comparing M25&M50 concretes, tensile strength improvement is more in M50 concretes than the M25 concrete. This is due to effect of fibres. In addition to this, the failure pattern of control concrete is more brittle, compared to the FRC. The failure patterns of control and FRC is shown in Fig.13.



Fig.13: The failure patterns of control and FRC

### C. Flexural strength

Tests were conducted on beams to calculate the flexural strength after 7, 28 days of curing. The results of flexural strength for 0.5 to 1.5% volume fraction of steel and glass fibers in equal proportions are given in Table 6 and Table 7.

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Vol. 7, Issue 7, July 2018

Table VI: Flexural strength test result (M25)

Fibre content (%)	7 days		28 days	
	Load in (kN)	Modulus of Rupture (N/mm <sup>2</sup> )	Load in (kN)	Modulus of Rupture (N/mm <sup>2</sup> )
C <sub>1</sub>	9.12	3.93	12.50	4.99
FC <sub>1</sub>	11.45	4.38	15.83	5.67
FC <sub>2</sub>	14.46	5.14	17.67	6.83
FC <sub>3</sub>	16.75	5.84	21.16	7.70

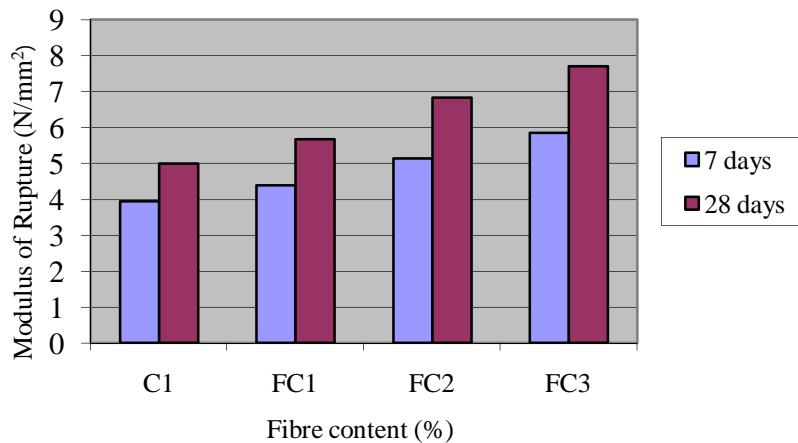


Fig. 14: Flexural Strength Variation (M25)

Fig. 14.and Fig.15. shows the flexural strength improvement on three different percentages of fibre replacement. The increase in modulus of rupture was found to be 4.63% with 0.5% hybrid fibre content when compared to the plain concrete for 7 days. The increase in modulus of rupture was found to be 7.74% with 1% hybrid fibre content when compared to the plain concrete for 7 days. The increase in modulus of rupture was found to be 9.12% with 1.5% hybrid fibre content when compared to the plain concrete for 7 days.

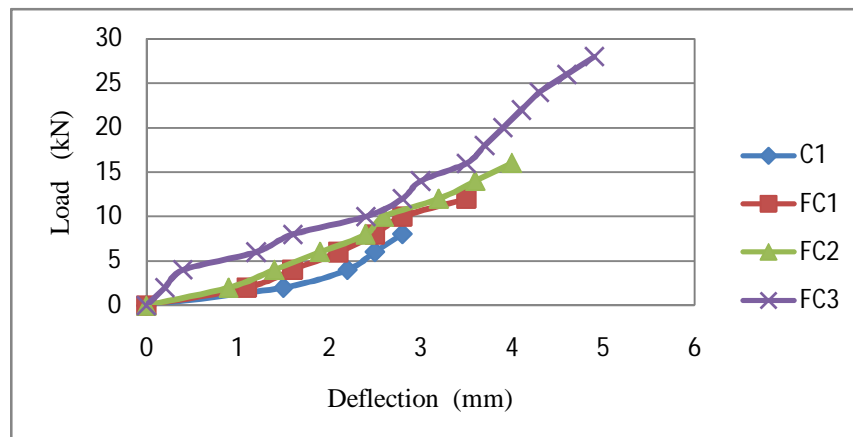


Fig. 15: Load deflection curves for M25-7days

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Vol. 7, Issue 7, July 2018

From Fig. 16. the increase in modulus of rupture was found to be 7.34% with 0.5% hybrid fibre content when compared to the plain concrete for 28 days. The increase in modulus of rupture was found to be 8.67% with 1% hybrid fibre content when compared to the plain concrete for 28 days. The increase in modulus of rupture was found to be 10.66% with 1.5% hybrid fibre content when compared to the plain concrete for 28 days.

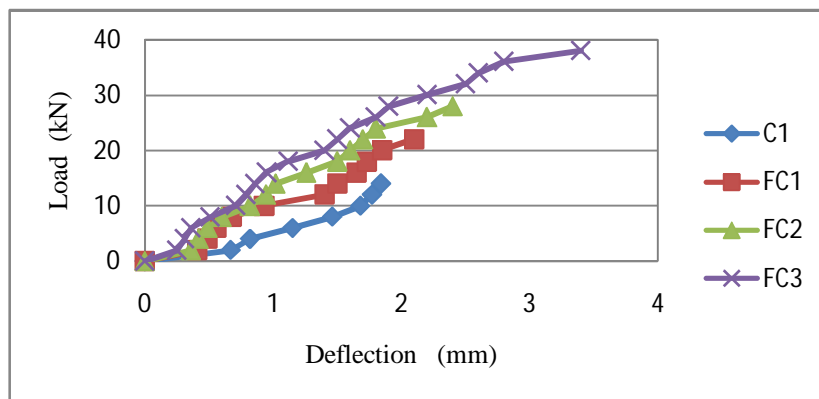


Fig. 16: Load deflection curves for (M25) -28days

Table VII: Flexural strength test result (M50)

Fibre content (%)	7 days		28 days	
	Load in (kN)	Modulus of Rupture (N/mm <sup>2</sup> )	Load in (kN)	Modulus of Rupture (N/mm <sup>2</sup> )
C <sub>1</sub>	9.98	4.74	18.64	7.03
FC <sub>1</sub>	14.56	5.33	23.48	8.42
FC <sub>2</sub>	16.68	6.64	25.72	9.93
FC <sub>3</sub>	19.65	7.29	28.24	11.24

Fig. 17. and Fig. 18. shows the modulus of rupture improvement on three different percentages of fibre replacement. The increase in modulus of rupture was found to be 6.22% with 0.5% hybrid fibre content when compared to the plain concrete for 7 days. The increase in modulus of rupture was found to be 9.12% with 1% hybrid fibre content when compared to the plain concrete for 7 days. The increase in modulus of rupture was found to be 11.65% with 1.5% hybrid fibre content when compared to the plain concrete for 7 days.

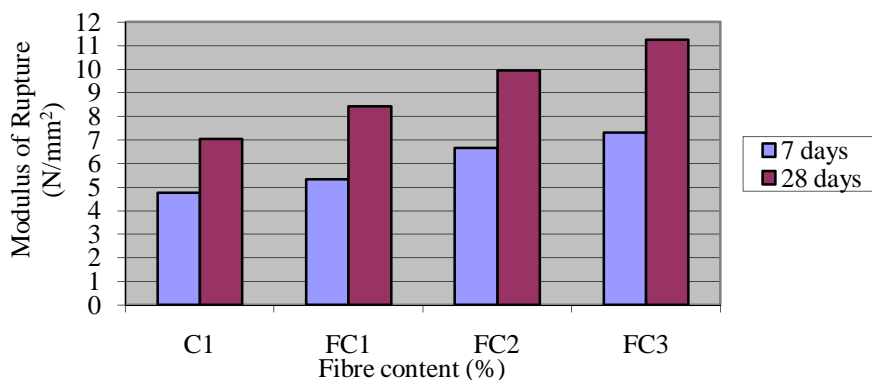


Fig. 17: Flexural Strength Variation (M50)

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Vol. 7, Issue 7, July 2018

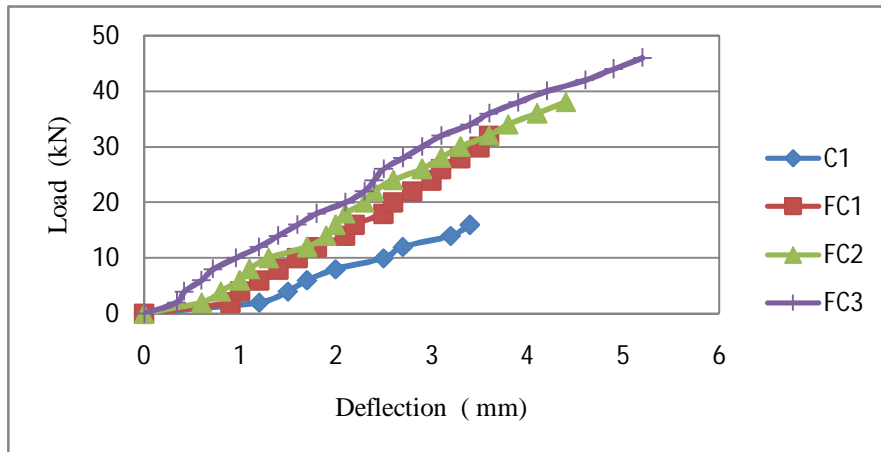


Fig. 18: Load deflection curves for (M50) -7days

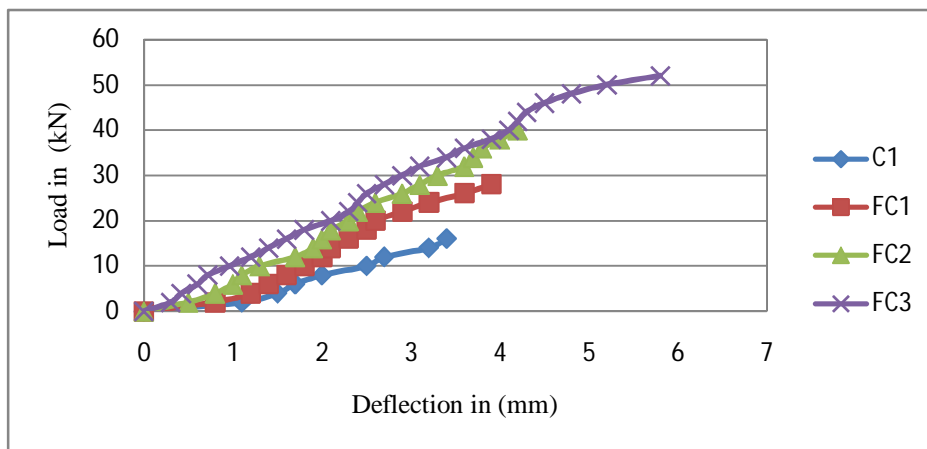


Fig. 19: Load deflection curves for (M50) -28 days

From Fig. 19, the increase in modulus of rupture was found to be 8.64% with 0.5% hybrid fibre content when compared to the plain concrete for 28 days. The increase in modulus of rupture was found to be 10.23% with 1% hybrid fibre content when compared to the plain concrete for 28 days. The increase in modulus of rupture was found to be 13.71% with 1.5% hybrid fibre content when compared to the plain concrete for 28 days. Flexural strength improvement shows contribution of fibres in concrete. It was noticed that the M50 concrete, the failure was sudden without warning. In addition, fibre reinforced concrete shows more ductile than the control specimens. The cracking patterns of control and fibre reinforced concretes are shown in Fig.20.

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 7, Issue 7, July 2018



Fig. 20: Failure pattern of control and FRC

### D. Impact strength

Tests were conducted on discs to measure an impact strength test failure result after 7, 28 days of curing. The results of impact strength for 0.5 to 1.5% volume fraction of steel and glass fibers in equal proportions are given in Table 8 and Table 9.

Table VIII: Impact Strength test failure result (M25)

Fibre content (%)	7 days		28days	
	No of Drops at Failure	Energy absorption due to impact at Failure (N-m)	No of Drops at Failure	Energy absorption due to impact at Failure (N-m)
C <sub>1</sub>	8	161.39	15	302.61
FC <sub>1</sub>	14	282.44	18	363.14
FC <sub>2</sub>	17	342.96	22	443.83
FC <sub>3</sub>	20	403.48	25	504.35

Fig. 21. and Fig. 22. shows the impact strength improvement on three different percentages of fibre replacement. The increase in impact strength was found to be 7.5% with 0.5% hybrid fibre content when compared to the plain concrete for 7 days. The increase in impact strength was found to be 12.5% with 1% hybrid fibre content when compared to the plain concrete for 7 days. The increase in impact strength was found to be 15.2% with 1.5% hybrid fibre content when compared to the plain concrete for 7 days. The area underneath the load deflection graphs can be calculated to give an indication of the energy absorption which is approximately equal to the impact energy.



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Vol. 7, Issue 7, July 2018

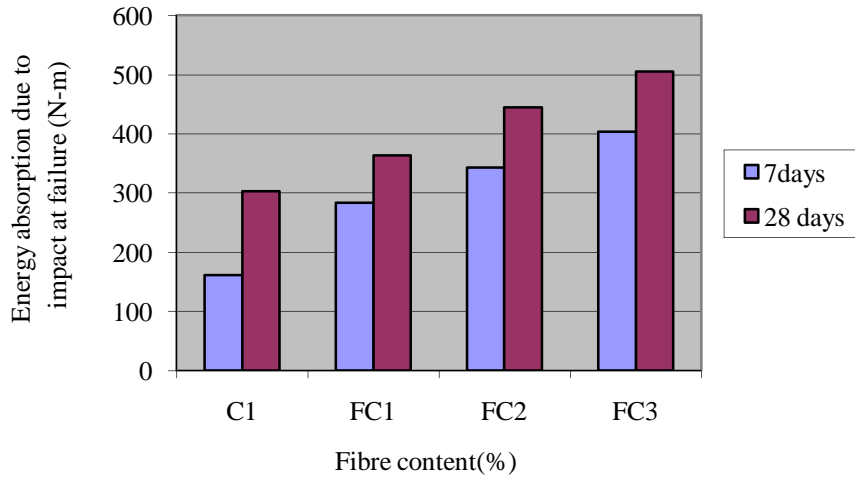


Fig. 21: Impact Strength Variation (M25)

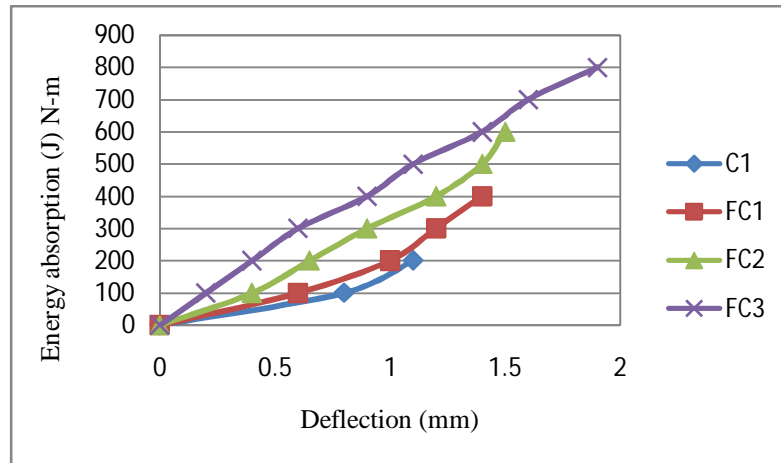


Fig. 22: Energy absorption Vs deflection

The increase in impact strength was found to be 20.10% with 0.5% hybrid fibre content when compared to the plain concrete for 28 days. The increase in impact strength was found to be 24.50% with 1% hybrid fibre content when compared to the plain concrete for 28 days. The increase in impact strength was found to be 31.15% with 1.5% hybrid fibre content when compared to the plain concrete for 28 days.

## International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: [www.ijirset.com](http://www.ijirset.com)

Vol. 7, Issue 7, July 2018

Table IX: Impact Strength test failure result (M50)

Fibre content (%)	7 days		28days	
	No of Drops at Failure	Energy absorption due to impact at Failure (N-m)	No of Drops at Failure	Energy absorption due to impact at Failure (N-m)
C <sub>1</sub>	18	363.13	24	484.18
FC <sub>1</sub>	22	443.83	31	625.40
FC <sub>2</sub>	26	524.53	38	766.62
FC <sub>3</sub>	31	625.40	54	1089.41

From Fig.23, the increase in impact strength was found to be 17.5% with 0.5% hybrid fibre content when compared to the plain concrete for 7 days. The increase in impact strength was found to be 22.5% with 1% hybrid fibre content when compared to the plain concrete for 7 days. The increase in impact strength was found to be 29.2% with 1.5% hybrid fibre content when compared to the plain concrete for 7 days. Toughness of higher strength concrete is more sensitive to fiber reinforced.

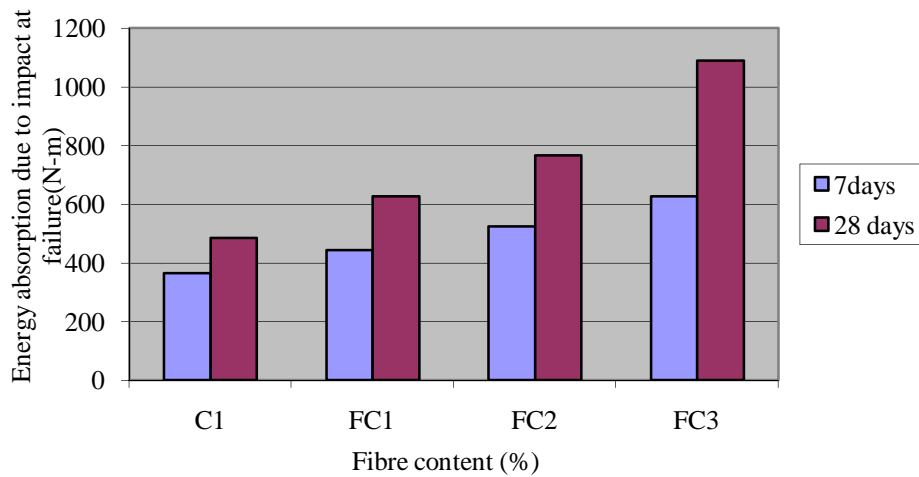


Fig. 23: Impact Strength Variation (M50)

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(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 7, Issue 7, July 2018

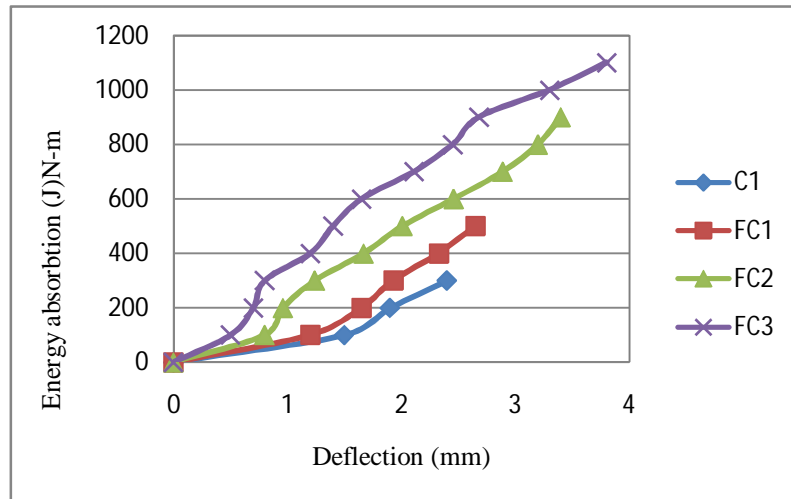


Fig. 24: Energy absorption Vs deflection

From Fig.24, the increase in impact strength was found to be 22.13% with 0.5% hybrid fibre content when compared to the plain concrete for 28 days. The increase in impact strength was found to be 37.5% with 1% hybrid fibre content when compared to the plain concrete for 28 days. The increase in impact strength was found to be 42.2% with 1.5% hybrid fibre content when compared to the plain concrete for 28 days. From Fig. 4.20, it was noticed that the impact strength improvement, increased by increasing the fibre content, number of days. This increase was mainly contributed by the addition of fibres in concrete. Toughness of higher strength concrete is more sensitive to fiber reinforced.

### IV. CONCLUSIONS

From the tests conducted and the results obtained, the following conclusions made:

In M25 concrete the addition of hybrid fibers by 1.5 % volume fraction results in an increase of 9.62% in the compressive strength, an increase of 9.83% in the splitting tensile strength, the increase in modulus of rupture was found to be 10.66% and the increase in impact strength was found to be 31.15% when compared to the plain concrete for 28 days.

In M50 concrete the addition hybrid fibers by 1.5 % volume fraction results in an increase of 11.65% in the compressive strength, an increase of 12.62% in the splitting tensile strength, the increase in modulus of rupture was found to be 13.71%, the increase in impact strength was found to be 42.2% when compared to the plain concrete for 28 days.

As the compressive strength of the hybrid fiber reinforced concrete depends not only on the fiber type and volume, but mainly on the mix characteristics. By bridging across macro crack and reducing its opening, the fibers obviously affect the post- peak flexural softening response of the hybrid fibre reinforced concrete.

It was noticed that the compressive strength improvement, increased by increasing the fibre content, number of days. This increase was mainly contributed by the addition of fibres in concrete. However, the percentage of increase is very minimal, which is the addition of fibres in concrete.

It was noticed that the tensile strength improvement, increased by increasing the fibre content, number of days. This increase was mainly contributed by the addition of fibres in concrete. However, the percentage of increase is very minimal, which is the addition of fibres in concrete. The steel-glass combination gave concrete of the high strength and flexural strength because of the similar modulus and the synergistic interaction between the two reinforcing fibers.

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Vol. 7, Issue 7, July 2018

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