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Shear Strength Behavior of Reinforced Concrete Beams with Basalt Fibers Added to the Mix

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Abstract: *The thesis's objective is to study the behavior of shear strength of reinforced concrete with basalt fiber added to the mix. In this thesis fiber and stirrups ratio were variables. Nine beams were casted with basalt fiber ratios (0%, 0.25%, and 0.5%) from the volume of concrete, and stirrups were 5Φ8/m, 7Φ8/m, and 10Φ8/m respectively. All specimens were tested under two-point concentrated load to determine the maximum load capacity of beams. The objective of research is to study the load deflection behavior of tested specimens, crack pattern, crack loads, failure loads, stiffness, ductility, and energy absorption. Experimental study showed that basalt fiber has a good effect on concrete mechanical properties such as ductility, energy absorption, and stiffness. It also decreased the number of cracks and delayed the appearance of cracks. From the study, it is noted that basalt fiber improved the behavior of specimens and changes it from brittle to ductile.*

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I. Introduction

Concrete is one of the most widely used building materials in the world due to its low cost, ease in production and longevity , but the major drawback with concrete is its low tensile strength and its suddenly collapse . So it becomes very important to add new materials to concrete mix which improves its properties. Fibers are used in reinforced concrete mixes to improve tensile strength, toughness and reduce cracking.

Basalt fiber is a new kind of inorganic fiber extruded from melted rock. it is a natural fiber that is environmentally friendly and has excellent characteristics such as high tensile strength, high temperature resistance, light weight, non-corrosive and costs less than other advanced fibers such as glass or carbon fiber. Basalt fibers are helpful materials to improve the properties of high strength concrete (HSC) because it has good mechanical properties. Moreover, it is cheaper, available and chemically more stable than the other fibers. In addition, it can be work in a wide range of temperatures (-269 to 650 ◦C). **[1]**

Kunal Singha (2012) **[2]** provided a short review on basalt fiber and discussed its industry, properties and applications. Basalt arise from volcanic magma and molten lava. A very hot fluid under the crust of earth solidified in the open air. Basalt rock has no

toxic reaction with air or water and has good hardness and thermal properties . Xinjian Sun , Zhen Gao , Changjun Zhou (2019) **[3]** , Studied the influences of the basalt fiber's Length and content on the fundamental mechanical properties of concrete were investigated by multi-scale simulation. The test showed that compressive strength increased then decreased and mixes with 6mm CBF is better than 12 mm in length, Compressive strength is low when using CBF 12mm in length , and Basalt fiber with a length of 6 mm and 2% of volume can mostly improve the mechanical properties of concrete. The effect of chopped basalt fiber on fresh and harden properties of HSC was studied by A.E.A Elshekh (2014) **[4].** 100 mm cubes were casted for compressive strength , 100 x 200 mm cylinders for split tensile strength , and 100 x 100 x 500 mm beams for flexural tensile strength . 1 , 2 and 3 % of chopped basalt fiber (CBF) by weight of cement were used. It was found decrease in workability is typically proportional to the ratio of basalt fiber because hydration water was absorbed by basalt fiber , the early and long term compressive

strength is decreased by increasing of CBF , because of balling CBF together and make poor areas in the sample and An enhancement in the toughness and ductility of high strength concrete.

Julita Krassowska (2013) **[5]** Studied the effect of steel and basalt fiber on shear and flexural behavior of reinforced concrete beams. The compressive strength was measured by cubes 100 x 100 x 100 mm in dimension and flexural tensile strength was evaluated through four-point bending test on 100 mm × 100 mm × 400 mm prisms. It was noticed a cracking resistance in the specimens which have steel and basalt fiber and Failure behavior of SFRC and BFRC was improved without brittle. Tehmina Ayub , Nasir Shafiq , M. Fadhil Nuruddin (2013) **[6]** , Studied the mechanical properties of high performance concrete reinforced by basalt fiber. Three different mixes of high performance concrete (HPC) was investigated and had different basalt fiber volume fraction 1 , 2 and 3%. Results showed that Elastic modulus did not improved by adding basalt fiber and the Results of strains corresponding to maximum compressive strength and the splitting tensile strength were increased by increasing fiber content showing ductile behavior of the concrete with basalt fiber.

II. Material Properties

Cement: In order to produce HSC mixture while maintaining a good fresh property of mixture, it is required to investigate carefully the composition, fineness's and its compatibility of cement with the chemical admixtures. In this study, the cement used was ordinary Portland cement.

Coarse aggregate: The course aggregates used for making concrete for cubes and beams was crushed dolomite stone aggregates with maximum size of 20 mm . The coarse aggregate was angular and free from clay and other impurities.

Fine Aggregates: The fine aggregates used in the making concrete for cubes and beams was purchased from a local supplier . The sand was free from clay and other impurities.

Reinforcement steel: The used steel was high tensile (36/52) as main steel of the beams. Deformed steel bars of 16, 10 mm in diameter were used at the top and the bottom of tested beams respectively. Mild smooth steel 8 mm diameter was used as stirrups in all specimens.

Chopped basalt fiber: Chopped basalt fiber CPFS used in this research was provided by (Norway). Basalt fiber is a variety of volcanic rocks, which are grey dark in color created from the molten lava after solidification. Table (1) shows the chemical properties of basalt rock **[7],** Table (2) shows physical properties of chopped basalt fiber.

Table 1: Chemical composition of basalt rock

SiO_2	52.8
Al_2O_3	17.5
Fe_2O_3	10.3
MgO	4.63
CaO	8.59
Na_2O	3.34
K_2O	1.46
TiO_2	1.38
P_2O_5	0.28
MnO	0.16
Cr_2O_3	0.06

Table (2): physical properties of basalt fiber

Property	Standard
Density	2670 kg/m^3
Chop length	25.4 mm
Filament diameter	13 µm
Melting point	1350 ±100 °C
Elongation at break (Fracture strain)	2.5 ±10 %
E- Modulus	84 GPa
Color	Golden brown

Fig. (1): Chopped basalt fiber used in the study

III. Mixing

The mixing process started with the dry mixing of the coarse and fine aggregates and the half amount of basalt fiber for 1 min. Then, the cement was added further, fibers were added into the dry mixture for another 1 min. Finally, water was added slowly. The fresh concrete was mixed for 3 min to ensure even dispersion of fibers in the concrete. It was observed that the workability in the control mixes were higher than that those had basalt fiber in there mixes , so W/C was increased from 0.5 to 0.65 for this mixes which have basalt fiber to ensure dispersion of fibers in concrete mix.

IV. Preparing and Casting of specimens

Nine beams were prepared in order to address the primary objective of this research. These specimens divided into three groups B1, B2, B3. The first group contains three specimens which are identified as (B1-1) with main steel of 4φ16, 2φ10 as Secondary steel and 5ϕ8/m stirrups in the whole beam. The second beam (B1-2) is similar in main steel and secondary steel, but the difference was in the number of stirrups. Stirrups were increased in the shear zone area so it were 7ϕ8/m only in the shear zone, and 5ϕ8/m at the rest of the specimen. The same in the last specimen (B1-3), but the number of stirrups were 10ϕ8/m in the shear zone and 5ϕ8/m at the rest of the beam. The three specimen's in-group B1 were the control beams, so there was no basalt fiber in their mix. Second group was B2 divided into three beams also (B2-1), (B2-2), (B2-3), This group consists of 4φ16 as main steel, and 2φ10 as secondary steel .The number of stirrups is also as much as group 1, 1/3 within the beam from each side were filled with basalt fiber with Vf = 0.25% by volume and the other beams in the group were the same. Third group consists of three beams (B3-1), (B3-2), (B3-3) which the same in main steel, secondary steel, and the increase of number of stirrups. This specimens also were filled with basalt fiber Vf = 0.5 % by volume in the third part from each side. Dimension of tested beams showed in fig.

(2).

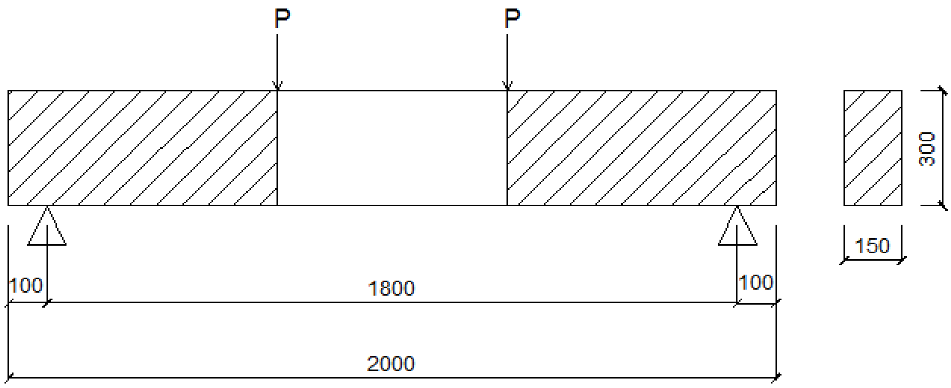

Fig. (2): Dimension and location of basalt fiber for tested beams.

Table 2: Mix proportion for plain concrete

Cement	300 kg / m3
Coarse aggregate	1200 kg / m3
Sand	800 kg / m3
Water	150 kg / m3
W/C	0.5

Table 3: Mix proportion for beams with CBF

Cement	300 kg / m3
Coarse aggregate	1200 kg / m3
Sand	800 kg / m3
Water	180 kg / m3
W/C	0.6
Basalt fiber (group 2) 0.25%	6.675 kg / m3
Basalt fiber (group 3) 0.50%	13.35 kg / m3

V. Testing methods

Nine cubes with 15x15x15 cm in dimensions were used for compression test. Every basalt fiber ratio had three specimens and all of them had tested after 28 days of casting using compression test machine. Another nine cylinders with 15cm in diameter and 30cm height were used for Splitting tensile test. Every basalt fiber ratio also had three specimens and all of them had tested after 28 days of casting.

VI. Results and discussions

Compressive strength: Fig.3 shows the effect of chopped basalt fiber on compressive strength. The compressive strength decreases with increasing of CBF.

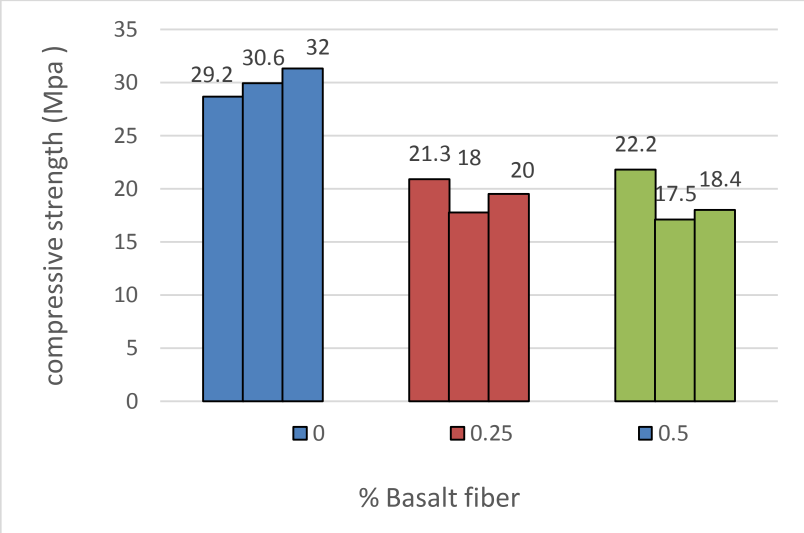

Fig. 3: Results for all tested cubes for compressive strength test.

Due to low results of compressive strength for cubes, the test was repeated. 12 cubes were casted again, 6 cubes contained 0.25% BF and the other 6 for 0.5% BF. After 7 days compressive strength was measured for 3 cubes for each ratio of BF . Other 6 cubes were tested after 28 day and compressive strength was measured. New results were lower than the old one as shown in table 4. It might be because basalt fiber absorbed water too match because cubes were submerged in water all curing period so voids ratio increased inside concrete mix. Failure modes after cracking showed that no spilling of concrete and fiber bonded concrete parts together.

Table 4: Compressive strength results for cubes after 7 and 28 days.

% Bf	Specimen	Old compressive strength after 28 day (MPA)	Average Compressive strength after 28 day (MPA)	New Compressive strength after 28 day (MPA)	New Average Compressive strength after 28 day (MPA)	New average compressive strength after 7 day (MPA)	New compressive strength after 7 day (MPA)
0.25	C2-1	21.3	19.8	12.9	12.9	9.1	9.03
	C2-2	18		12.5		9.2	
	C2-3	20		13.3		8.8	
0.5	C3-1	22.2	19.4	9.1	9.6	6.1	6.83
	C3-2	17.5		10		7.4	
	C3-2	18.4		9.7		7	

Effect of fiber on model of failure: Eight of nine tested beams were failed in shear. Only B2-3 has failed due to local failure. Diagonal cracks of tested beams shown in Fig.4.

Fig. 4: Crack pattern for specimen B2-3

Effect of fiber on shear capacity of specimens

Fig.5 shows the test results for failure load for all specimens. It has obtained that the enhancement in failure load with increasing basalt fiber content.

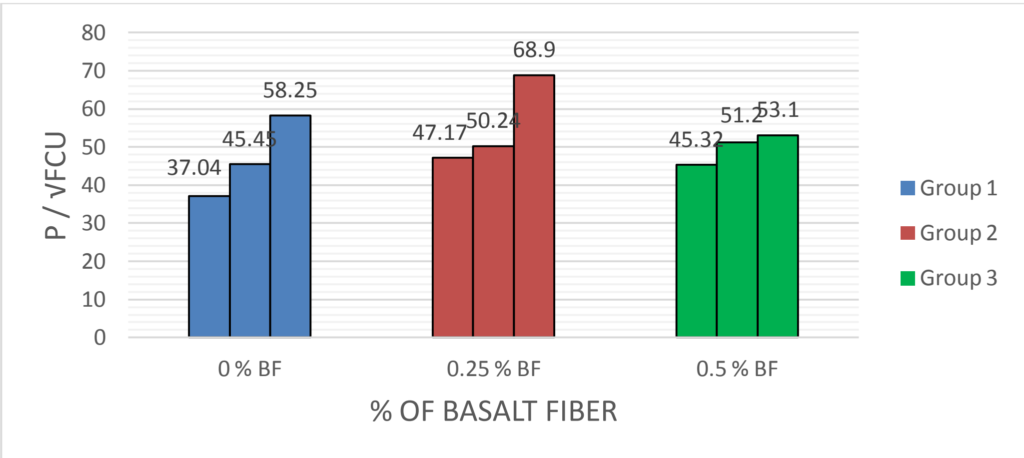

Fig. 5: Failure load for each group

Fig.6 shows first crack load for all beams. It has obtained that the appearance of the first crack was delayed by using basalt fiber. This mean that basalt bridged shear cracks from transferring loads to concrete.

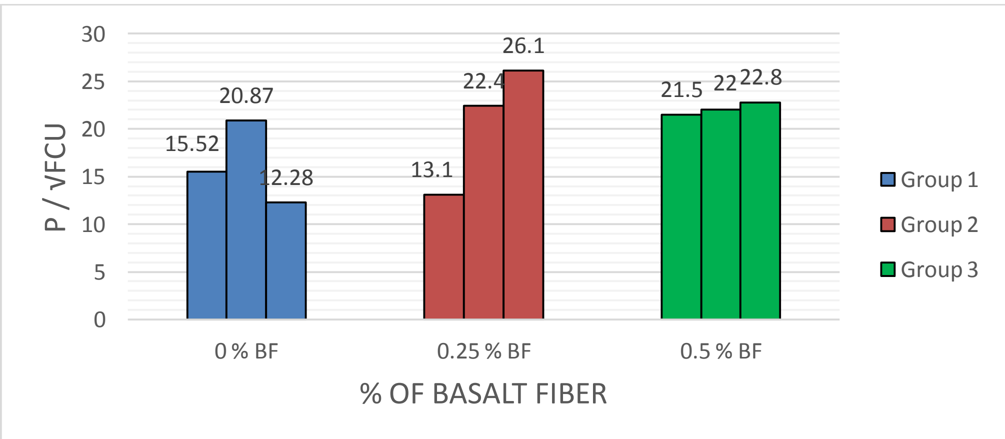

Fig. 6: First crack for each group

Effect of fiber on stiffness of SHC

Two values of stiffness were calculated un-cracked or initial stiffness (K_i) and ultimate stiffness or secant stiffness (K_s) . Un-cracked stiffness (K_i) is defined as the slope of load deflection curve before cracks happened . Secant stiffness (K_s) is defined as:

$$K_u = \frac{P_u - P_{cr}}{\Delta_u - \Delta_{cr}}$$

Table 5 shows the value of initial stiffness (K_i) and secant stiffness (K_s) for all specimens .

Table 5: Value of initial stiffness (K_i) and secant stiffness (K_s)

Group	Specimens name	Crack		Ultimate		Stiffness	
		Pcr (KN)	Δ cr (mm)	Pu (KN)	Δ u (mm)	Ki = $\frac{Pcr}{\Delta cr}$	Ks = $\frac{Pu - Pcr}{\Delta u - \Delta cr}$
B1	B1-1	83.82	2.868	202.2	8.531	29.23	20.91
	B1-2	114.8	3.859	250	9.629	29.75	23.40
	B1-3	70	2.414	332.4	13.109	29.00	24.53
B2	B2-1	60.2	1.935	217	8.137	31.11	25.28
	B2-2	94	3.196	213.5	9.569	29.41	18.81
	B2-3	117.2	4.094	309	14.405	29.30	18.60
B3	B3-1	101.1	3.05	213.1	8.055	33.70	22.40
	B3-2	92.4	3.563	218	10.738	26.4	17.51
	B3-3	98	3.403	228	9.256	28.82	22.21

Effect of fiber on ductility of SHC

It is estimated as the deflection compatible with 70% of the failure load. It shows how the beam stands before failure.

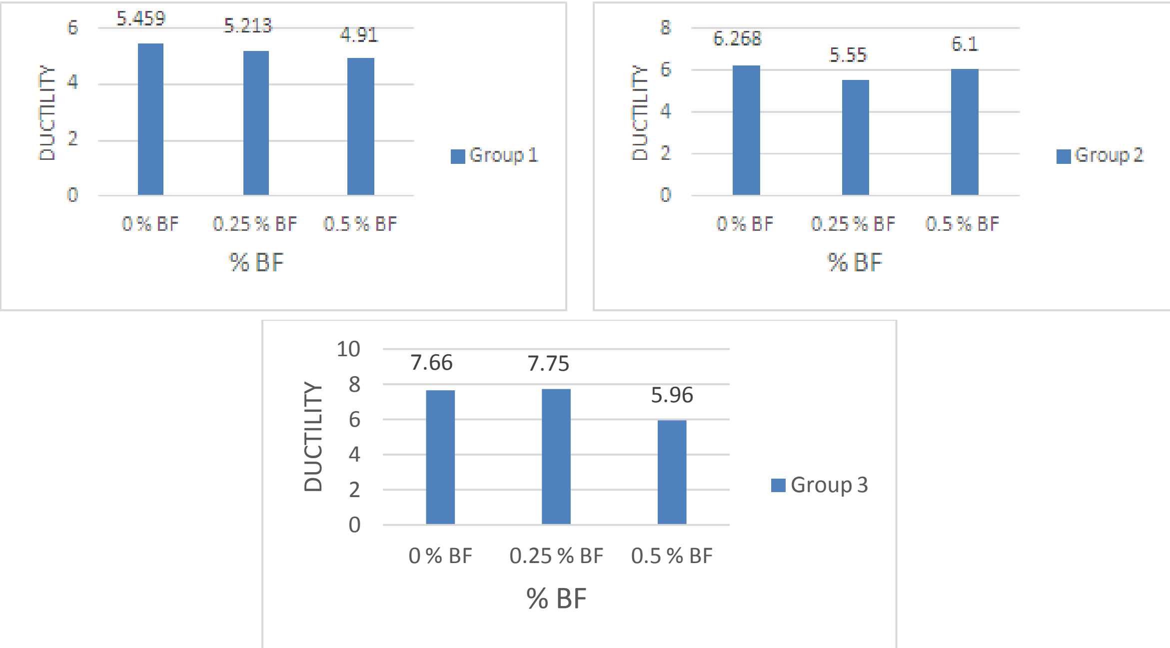

Fig. 7: Ductility for all specimens

Effect of fiber on Energy absorption

Energy absorption calculated as area under load deflection curve for all specimens.

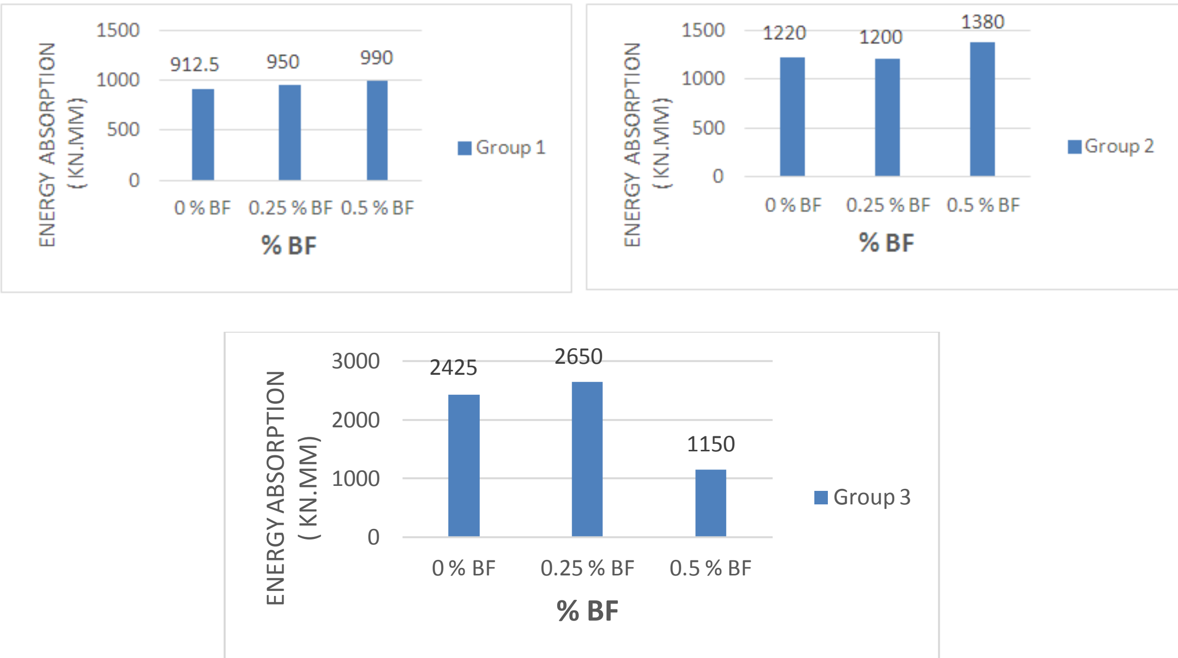

Fig. 8: Energy absorption for all specimens

Figures shows that energy absorption increased by adding fiber into the mix. It can be considered as an enhancement in energy absorption capacity.

VII. Conclusion

- The results showed that compressive strength wasn't provided by chopped basalt fiber (CBF) as internal strengthen material even though its decreased by increasing of CBF content.
- From test results it has been concluded that there was an enhancement in delaying first crack from appear. For first group which has stirrups 5φ8 /m basalt fiber added in a 0.5% volume ratio showed a 38.5% increase in delaying the appearance of cracks. For second group which has stirrups 7φ8 /m

basalt fiber added in a 0.25% volume ratio showed a 7.3% increase in delaying the appearance of cracks. For group 3 which has 10φ8 /m stirrups 0.25% basalt fiber volume ratio showed a 112.5% enhancement in delaying the appearance of first cracks.

- 0.25% basalt fiber volume ratio showed a 27.3% increase in failure load for group 1 , 10.5% for group 2 and 18.3% for group3.
- For all specimens which did not have basalt fiber its collapse were suddenly on the other hand specimens had basalt fiber give warning before failure like width of cracks increased and decreases deflection at failure and The type of collapse had moved from brittle to ductile failure.
- After failure it was noticed that all specimens which have basalt fiber its failure load was gradually and slowly decreased , but control specimens its failure load decreased suddenly and The type of collapse had moved from brittle to ductile failure.
- Initial stiffness (Ki) was increased at group1 with increasing basalt fiber ratio, 0.25% BF content increased it by 6.7% and for 0.5% BF ratio the increase was 15.3% in (Ki). For group 3 the enhancement was 1%. Secant stiffness (Ks) in group 1 was increased by 21% for 0.25% BF content, and by 7.6% for 0.5% BF volume.
- Toughness and ductility of specimens were remarkably improved using CBF as strengthened material. For group 2 almost ductility at control specimen and which has 0.5% BF content were equal. For group 3 at 0.5% BF ratio there was a little enhancement by 2.6%.
- All beams which had BF give higher energy absorption than specimens which hadn't. 0.5% BF ratio increased the energy absorption by 8.5% and 4.2% at 0.25 BF content for group 1, at group 2 adding 0.5% BF to the mix increased the energy absorption by 13.1% and at group 3 the higher value for energy absorption was at 0.25% BF ratio.

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