SHEAR-FLEXURE BEHAVIOUR OF PARTIALLY PRESTRESSED BASALT FIBRE REINFORCED CONCRETE BEAMS

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ABSTRACT. Prestressed concrete has emerged very quickly as the predominant material in construction industry. The main drawback of prestressed concrete members is its vulnerability to reverse cyclic loading, which can be compensated by partial prestressing. It is a limiting case of conventional reinforced concrete and fully prestressed concrete. Compared with fully prestressed concrete structures, it may result in increased ductility, energy absorption capability, improved economy, and reduction of the camber and creep deformation due to prestress. The use of high strength concrete for prestressing makes it more brittle. Addition of fibres such as steel, glass, polypropylene etc. would improve the flexural strength, ductility, crack resistance and toughness of reinforced concrete. Basalt fibre is a newly developed fibre which improves properties of concrete and is economical, environmental friendly, corrosion and chemical attack resistant than other fibres. An experimental study was conducted to understand the influence of basalt fibre on the behaviour of partially prestressed beam under repeated loading cycles by varying the fibre volume and the shear span to depth ratio. Shear and shear-flexural behaviour of beams were investigated by adopting shear span to depth ratio of 1.5 and 2.5, respectively. The fibre contents used in the study are 0%, 0.10%, 0.30% and 0.50% by volume. The test results shows an improvement in load carrying capacity and ductility of partially prestressed concrete beams with the addition of basalt fibre when compared to those without fibres for both shear span to depth ratio.

Keywords: Partial prestressing, Basalt fibre, Shear span to depth ratio, Partial prestressing ratio

INTRODUCTION

The construction industry has made significant progress since the introduction of reinforced concrete. Apart from the inherent advantages of reinforced concrete, the use of it in multistorey buildings and long span bridges usually results in tedious construction processes and serviceability issues. This problem was later addressed by the introduction of prestressed concrete by Freyssinet [20]. Several limitations of conventional concrete regarding span and load can be solved by prestressing concrete. It also allows longer unsupported span for roofs, floors, walls and bridges.The main drawback of the prestressed concrete members is its vulnerability to reverse cyclic loading, which can be compensated by partial prestressing.

Freyssinet formulated the design criterion for prestressed concrete by permitting no tensile stress in the concrete [20]. Emperger and Abeles advocated a method of combining concrete and steel in which limited tensile stresses or even hair cracks would be permitted in concrete, which Abeles termed "Partially Prestressed Concrete" to distinguish it from "fully prestressed concrete" [20]. Partial prestressing has now been recognized as an intermediate case between full prestressing and conventional (nonprestressed) reinforcing. Compared with fully prestressed concrete structures, adoption of partial prestressing may result in increased ductility and energy absorption capability, improved economy, as well as reduction of the camber and creep deformation due to prestress. Cracks of a width which would otherwise be undesirable and subject to corrosion risk, can be controlled by prestressing part of the reinforcement.

Prestressed concrete requires the concrete to attain high compressive strength at an early age. So high strength concrete is necessary for prestressed concrete as the material offers high resistance in tension, shear, bond and bearing. But high strength concrete is more brittle than normal strength concrete. Therefore the problem of cracking is more obvious in high strength concrete structures. Researches on cracking mechanisms and its solutions suggest that the addition of randomly spaced discontinuous small fibres would help delaying the occurrence of cracks and also in arresting the crack propagation. The addition of fibres in concrete helps to improve properties like plastic cracking characteristics, tensile or flexural strength, toughness, impact strength and ductility.

Basalt fibre is the most recently developed fibre for use in concrete. It has recently gained popularity in concrete reinforcing applications due to its excellent mechanical properties and environmental friendly manufacturing process. Basalt fibre is an inorganic material produced from volcanic rock called basalt. The performance of this rock on the basis of strength, temperature range, and durability is superior. Basalt fiber has several advantages over fibers including steel such as reduced dead load, resistance against corrosion and acid attack, high energy absorption capacity, ductility etc. In normal strength concrete with conventional reinforcement, inclusion of fibres has been shown to improve flexural strength and ductility. But only limited studies have been conducted to assess the effect of fibres in prestressed concrete. The major emphasis of the present study has been to experimentally analyse the effect of basalt fibre in shear and shear-flexure behaviour of partially prestressed concrete beams.

EXPERIMENTAL PROGRAM

The investigation makes an effort to analyse the load deflection characteristics, strength in shear and shear flexure, cracking patterns and ductility variation of partially prestressed reinforced concrete beams reinforced with basalt fibre in varying percentages. Partially prestressed beams with partial prestressing ratio of 0.75 and four different volume fractions of basalt fibre were cast and subjected to repeated loading cycles for span to effective depth ratios of 1.5 and 2.5.

Specimen Details And Testing Procedure

The main constituents used to cast all the specimens were ordinary Portland cement, fine aggregate conforming to IS 383, coarse aggregate conforming to IS 383 zone II classification, water, superplasticizer and chopped basalt fibres. Prestressed wire of 7 mm diameter, high strength deformed bars of 8 mm diameter and mild steel shear stirrups of 6 mm were used to cast the high strength concrete prestressed beams. The fibre content used in the study was 0%, 0.1 %, 0.30 % and 0.50 %. The partial prestressing ratio were adopted as 0.75. After determining the basic properties of constituent materials and checking its suitability design mix was developed for M 60 grade concrete.

The design of the beams was according to IS 1343:2012 as Type III prestressed concrete member in which tensile stresses are permitted. The study uses beams of size 100 x 200 x 1500 mm with an effective span of 1400 mm. the prestressing of the beams was done using 7 mm high tensile wires with the pretensioning of tendons by Gifford Udall system of prestressing. Eight prestressed beams with varying basalt fibre content were cast. Details of specimens used in the study were given in the Table 1. In the beam designation PP and PB denote partially prestressed concrete beams without fibre and with fibre content. First numerical value indicates the percentage of basalt fibre and second numerical value indicates the shear span to effective depth ratio (a/d ratio). Partially prestressed concrete beam cast with partial prestressing ratio of 0.75 is shown in Figure 1.

Table 1   Beam designation

BEAM DESIGNATION	PERCENTAGE OF FIBRE	A/D RATIO
PP 0.00/1.5	0.00	1.5
PB 0.10/1.5	0.10	1.5
PB 0.30/1.5	0.30	1.5
PB 0.50/1.5	0.50	1.5
PP 0.00/2.5	0.00	2.5
PB 0.10/2.5	0.10	2.5
PB 0.30/2.5	0.30	2.5
PB 0.50/2.5	0.50	2.5

Figure 1 Partially prestressed concrete beam (PPR = 0.75)

The loading of beams were done on a column testing machine. The schematic diagram of the test set up is shown in figure 2. The behaviour of the beams under shear and shear-flexure is analysed by adopting shear span to depth ratio 1.5 and 2.5 respectively. The mid span deflection was measured for every load incrememt using dial gauge of least count 0.01mm. Load was measured using a load cell of capacity 1000 KN. A hydraulic jack was used to apply load. The first load cycle starts from 0 kN to 20 kN with a load increment of 5 kN. Deflection at every 5 kN was measured upto 20 kN. Then load is released from 20 kN to 0 kN and deflections are noted. Again second cycle starts from 0 kN and increases upto 40 kN. Similarly, the load cycles continues as 0-60 kN, 0-80 kN etc. upto failure of specimen. The first crack load, crack pattern and ultimate load were noted for each specimen.

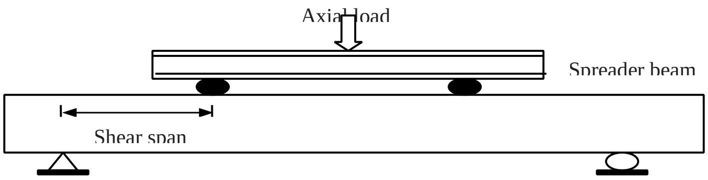

Figure 2 Schematic diagram of test set up

RESULTS AND DISCUSSION

Behaviour of Partially Prestressed Concrete Beams In Shear

Load-deflection characteristics

Figure 3 to 4 shows the load deflection characteristics of partially prestressed beams with basalt fibre content of 0 %, 0.1 %, 0.3 % and 0.5 % by volume respectively. The load-deflection curve for the beam without basalt fibre (Fig. 3) shows that the beam sustained loading up to fifth cycle and failure occurred during the sixth cycle. The first crack was observed at 70 kN during the fourth cycle of loading. Appreciable difference in deflection is not observed for all load levels. The beam failed in shear with visible shear cracks at a load of 130 kN.

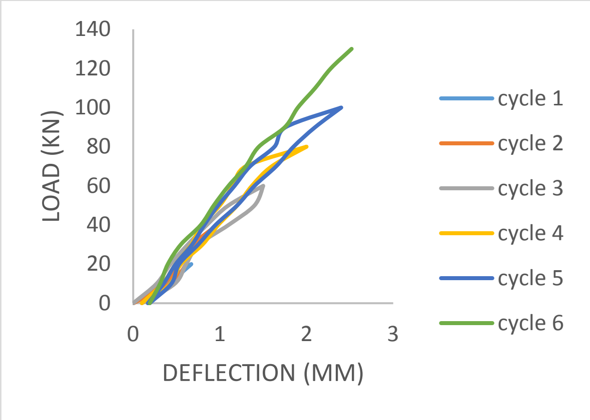

Figure 3 Load-deflection curve for PP 0.00/1.5

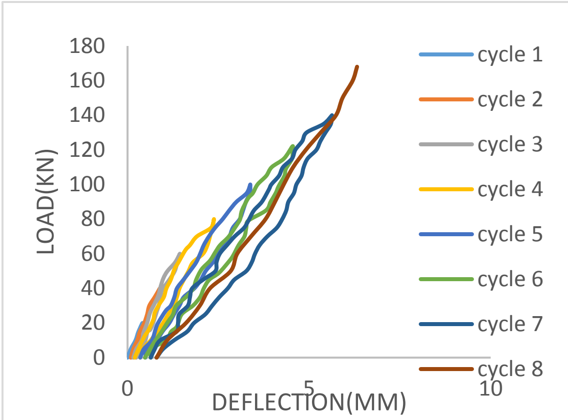

Figure 4 Load-deflection curve for PB 0.10/1.5

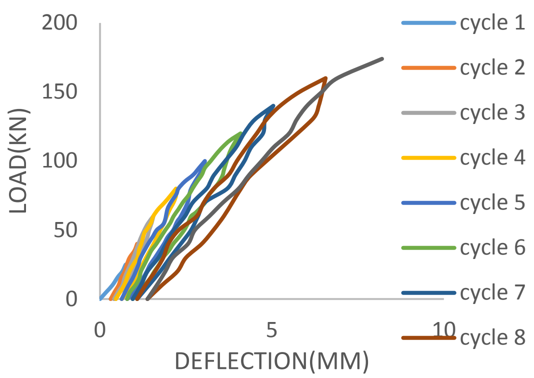

Figure 5 Load-deflection curve for PB 0.30/1.5

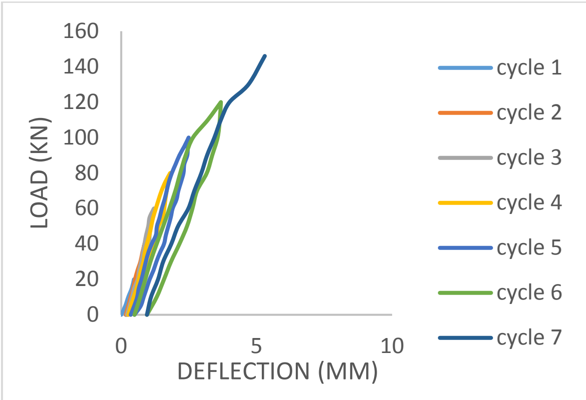

Figure 6 Load-deflection curve for PB 0.50/1.5

In the figure 4 showing load – deflection characteristics of prestressed beam with 0.1% basalt fibre, it is observed that the beam sustains load upto the seventh cycle and failure occurs at eighth cycle in shear. The first crack was observed at 75 kN during the fourth cycle of loading. Deflection in each cycle for all load levels increases for beams with 0.10 % basalt fibre. Compared to beams without fibre deflection in each load level is higher for beams with 0.10 % basalt fibre. The ultimate load was found to be 168 kN. Mode of failure of beam was in shear.

From load – deflection characteristics of prestressed beam with 0.3% basalt fibre (Figure 5), it is evident that the beam sustains more load compared to PP 0.00/1.5 and PB 0.10/1.5 upto eighth cycle and failure occurs at nineth cycle. The first crack was observed at 80 kN during the fifth cycle of loading. There is reduction in deflection at different load levels compared to specimens with 0 % and 0.10 % basalt fibre. The ultimate load was found to be 174 kN during nineth cycle. Shear failure was occurred to the beam at ultimate load.

In the figure 6 showing load – deflection characteristics of prestressed beam with 0.5% basalt fibre, it is evident that the beam sustains load only upto sixth cycle and failure occurs at seventh cycle. The first crack was observed at 80 kN during the fifth cycle of loading as for PB 0.30/1.5. Deflection at first crack load is lower than that of specimen PB 0.30/1.5. Deflection at each load level is comparatively less for beams with 0.50 % fibre than that of other fibre specimens. Hence specimen with 0.50 % fibre showed better load deflection characteristics for different load cycles. The ultimate load was found to be 146 kN during

seventh cycle which is less than that of other specimens. Shear failure was occurred to the beam at ultimate load.
For all the specimens, increase in deflection was observed for all load levels which indicates that there is stiffness degradation in the subsequent cycle. Specimen with 0.10 % basalt fibre shows poor load deflection characteristics may be because 0.10 % fibre addition may not play a considerable role in energy absorption. While specimens with 0.30 and 0.50 % fibres shows improved load deflection characteristics may be due to better energy absorption capacity of these fibres.

First crack load and ultimate load carrying capacity

First crack load, ultimate loads and corresponding deflections are shown in table 2. The crack resistance of partially prestressed basalt fibre reinforced beams is higher than that of partially prestressed plain concrete beam. First crack load increases as the percentage of fibre increases. For PB 0.10/1.5 the increase in first crack load is about 7 % and for PB 0.30/1.5 and PB 0.50/1.5 it is about 14 %. The load carrying capacity also increases and the increase is about 34% for beams with basalt fibre content of 0.3%. The deflection corresponding to 0.3% fibre volume is 8.20 mm. The load carrying capacity and ductility of beams increased with the addition of basalt fibres. From the results of first crack load, ultimate load and deflections it can be seen that superior performance was observed in beams upto a fibre percentage of 0.30. After this percentage, the capacity of beams decreases. This may be due to the balling of fibres at higher percentages.

Table 2 First crack load and ultimate load of tested beam specimens

BEAM DESIGNATION	FIRST CRACK LOAD (KN)/CYCLE OF LOADING	DEFLECTION AT FIRST CRACK LOAD (MM)	ULTIMATE LOAD P_U (KN)/CYCLE OF LOADING	ULTIMATE DEFLECTION (MM)
PP 0.00/1.5	70/4	1.30	130/6	2.52
PB 0.10/1.5	75/4	2.30	168/8	6.32
PB 0.30/1.5	80/5	2.28	174/9	8.20
PB 0.50/1.5	80/5	1.87	146/7	5.30

Shear capacity of beams

Shear strength values of beams were computed from the ultimate load values listed in Table 2. Compared with partially prestressed specimen without fibre, shear strength increased to 29.23, 33.85 and 12.31 percentage for specimens with fibre volume of 0.10, 0.30 and 0.50 respectively. The reduction in shear strength at 0.50 % may be due to the poor bonding of fibres with cement paste at this percentage. Figure 7 shows the variation of shear strength of the tested beams.

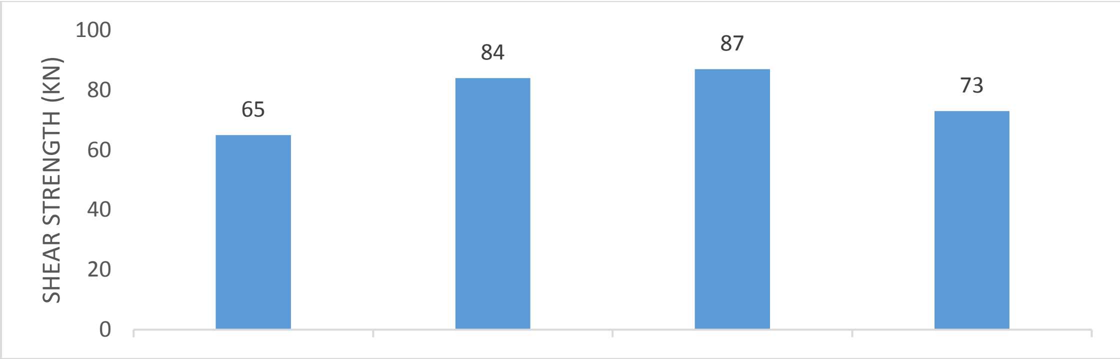

Figure 7 Variation of shear strength of the tested beams

Ductility factor

Both strength and the ductility are combined together to improve seismic safety of a structure. Low ductlity values leads to brittle failures, which are often catastrophic in RC design. According to the method suggested by Padmarajaiah and Ramaswamy (2004) the ductility factor of fully prestressed beams is the ratio of deflection at 90 % peak load to the deflection at first crack load and that of partially prestressed beam; it is the ratio of deflection at 80 % of peak load to the deflection at first crack load. Ductility factor of the computed beams are tested as per the above method and plotted in Figure 8. From the test results it is evident that the partially prestressed basalt fibre reinforced concrete beams with fibre percentage of 0.3% shows maximum ductility. The increase is about 73 % than the plain prestressed beam.

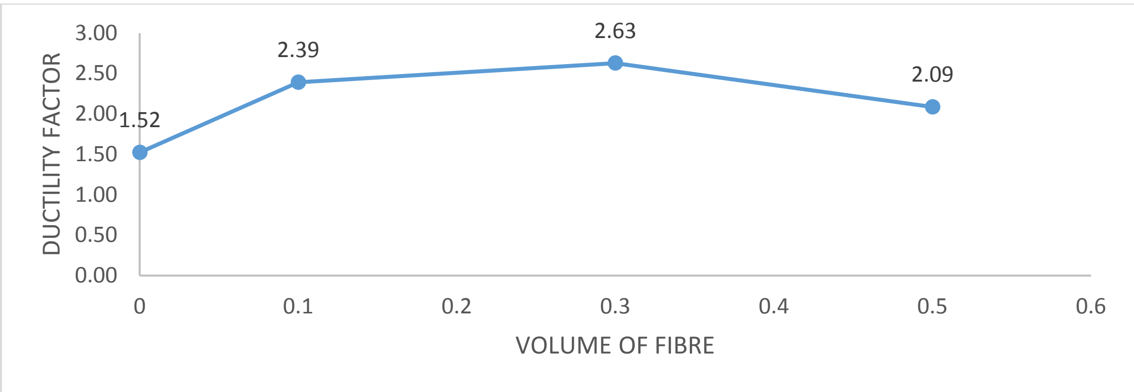

Figure 8 Variation of ductility factor with percentage of basalt fibre

Energy dissipation capacity

A reinforced concrete member dissipates energy by experiencing inelastic behaviour during cyclic loading. The energy dissipation capacity of a specimen is a measure of its behaviour in seismic performance. It is measured as the area under the load-deflection curve. Since the reinforced concrete member or a prestressed concrete member is composed of concrete and reinforcing steel, its energy dissipation can be defined by the sum of the energy dissipated by concrete and reinforcing steel. Figure 9 shows the variation of energy dissipation capacity with load cycles. The energy dissipation is maximum for fibres with 0.3% basalt fibre by volume. For 0.50% fibre volume the capacity decreases than that of 0.10% basalt fibre volume.

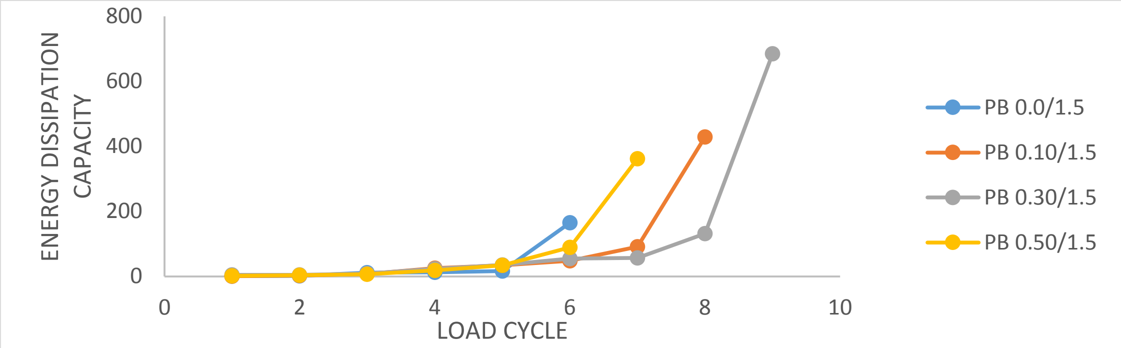

Figure 9 Energy dissipation capacity

Behaviour Of Partially Prestressed Concrete Beams In Shear Flexure

Load – deflection characteristics

Figure 10 to 13 shows the load deflection characteristics of partially prestressed beams with basalt fibre content of 0%, 0.1%, 0.3% and 0.5% respectively.

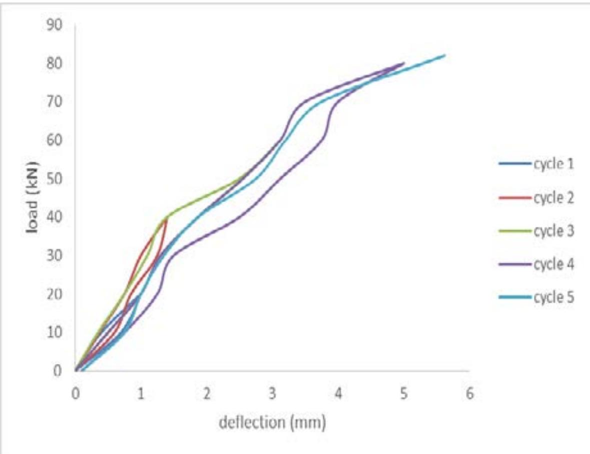

Figure 10 Load-deflection curve for PP 0.00/2.5

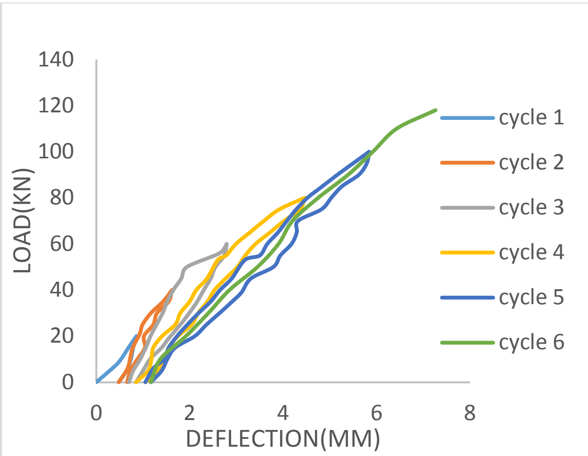

Figure 11 Load-deflection curve for PB 0.10/2.5

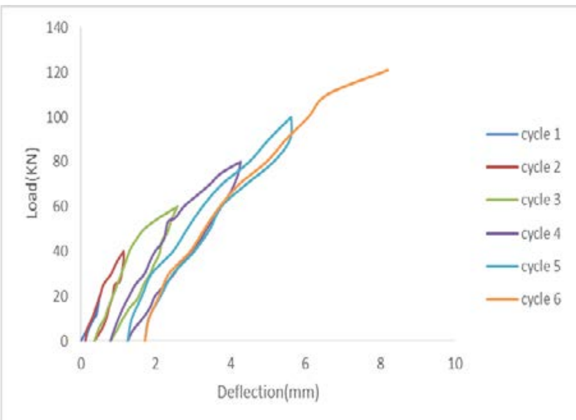

Figure 12 Load-deflection curve for PB 0.30/2.5

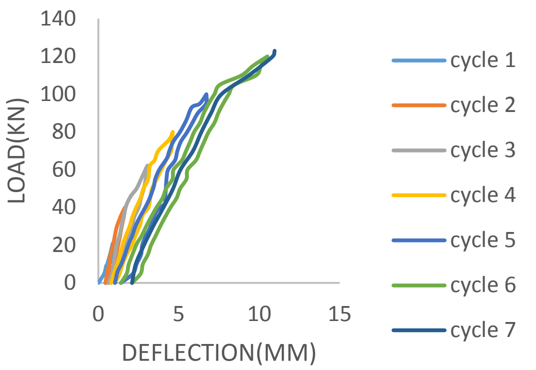

Figure 13 Load-deflection curve for PB 0.50/2.5

From the load-deflection curve for beams without basalt fibre shown in Fig. 10, it is observed that the partially prestressed beam without fibres sustained load up to fourth cycle and then failed in the fifth cycle. The first crack was observed in the third cycle at 40 kN. There is no considerable change in deflection in each load levels. The beam failed at a load of 82 kN in the fifth cycle. The beam failure was in shear accompanied by the widening of flexural cracks.

From the load – deflection characteristics of prestressed beam with 0.1% basalt fibre (Figure 11), it is evident that the beam sustains load upto fifth cycle and failure occurs at sixth cycle. The first crack was observed at 50 kN during the third cycle of loading. The ultimate load was found to be 118 kN. There is higher deflection in each cycle for all load levels for beams with 0.10 % basalt fibre. Compared to beams without fibre deflection in each load level is higher for beams with 0.10 % basalt fibre. The beam failed in shear- flexure at ultimate load. The deflection at peak load for each cycle is higher especially after the post cracking stage.

In the figure 12 showing load – deflection characteristics of prestressed beam with 0.3% basalt fibre, it is evident that the beam sustains load upto fifth cycle and failure occurs at sixth cycle. The first crack was observed at 53 kN during the fourth cycle of loading. The ultimate load was found to be 121 kN. Deflection at each load level is comparatively less for beams with 0.30 % fibre than that of other fibre specimens. Hence it shows better load deflection characteristics. The failure of beam at ultimate load was in shear accompanied by flexural cracks.

In the figure 13 showing load deflection characteristics of prestressed beam with 0.5% basalt fibre, the beam sustained load upto sixth cycle and failure occurs at seventh cycle. The first crack was observed at 62 kN during the fourth cycle of loading. The ultimate load was found to be 123 kN. The beam does not show more deflection after the sixth cycle. Deflection at first crack load and ultimate load is higher than that of the other specimens. Shear-flexure failure occurred to the beam.

First crack load and ultimate load carrying capacity

Table 3 First crack load and ultimate load of tested beam specimens

BEAM DESIGNATION	FIRST CRACK LOAD(KN)/CYCLE OF LOADING	DEFLECTION AT FIRST CRACK LOAD (MM)	ULTIMATE LOAD (KN)/CYCLE OF LOADING	ULTIMATE DEFLECTION (MM)
PP 0.00/2.5	40/3	1.40	82/5	5.62
PB 0.10/2.5	50/3	1.94	118/6	7.26
PB 0.30/2.5	53/4	2.32	121/6	8.20
PB 0.50/2.5	62/4	3.20	123/7	10.95

First crack load, ultimate loads and corresponding deflections are shown in table 3. When compared to partially prestressed beams without fibre, first crack and ultimate load improved by a maximum of 55% and 50% respectively in partially prestressed fibre reinforced beam. First crack load increases as fibre volume increases. For fibre volumes of 0.1%, 0.3% and 0.5% the first crack load increases by 25%, 32.5% and 55% respectively. Ultimate load is maximum for fibre percentage of 0.5 and this beam exhibited maximum deflection also. This shows a definite increase in load carrying capacity as the percentage addition of basalt fibre improved.

Shear capacity of beams

Shear strength values of beams were computed from the ultimate load values listed in Table 3. Compared with partially prestressed specimen without fibre, shear strength increased to 43.9, 47.56 and 50 percentage for specimens with fibre volume of 0.10, 0.30 and 0.50 respectively. Figure 14 shows the variation of shear strength of the tested beams. Shear strength increases as the fibre content increases. But there is no considerable increase after 0.30 % of fibre content.

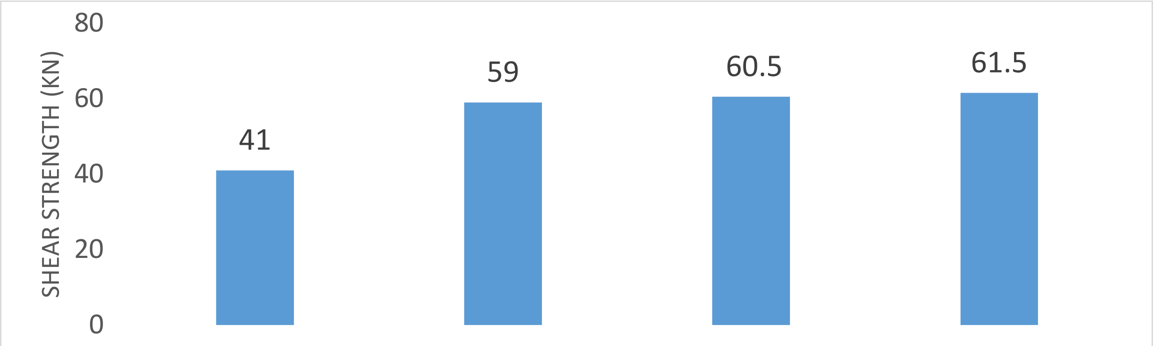

Figure 14 Variation of shear strength of the tested beams

Ductility factor

Figure 15 shows the variation of ductility factor with volume fraction in partially prestressed beams. Ductility is maximum for fibre volume of 0.30%. Then it decreases as fibre percentage increases. The value even falls below that of control specimens for fibre volume of 0.50%. Considering ductility, 0.30% fibre volume is optimum.

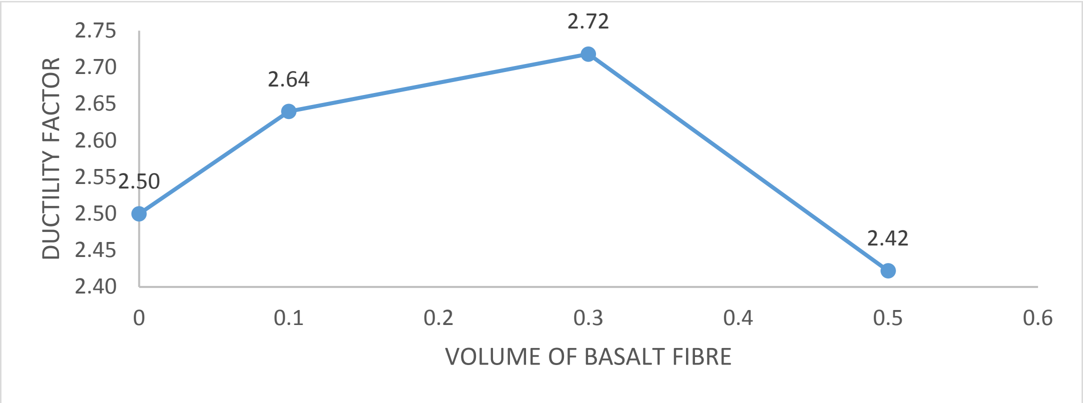

Figure 15 Variation of ductility factor with percentage of basalt fibre

Energy dissipation capacity

From the figure 16 the energy dissipation capacity of partially prestressed beams without fibre is very less compared to that of beams with fibres. Also as the percentage of fibre increases the beam dissipates more energy and beams with 0.50% basalt fibre shows much improvement in energy dissipation.

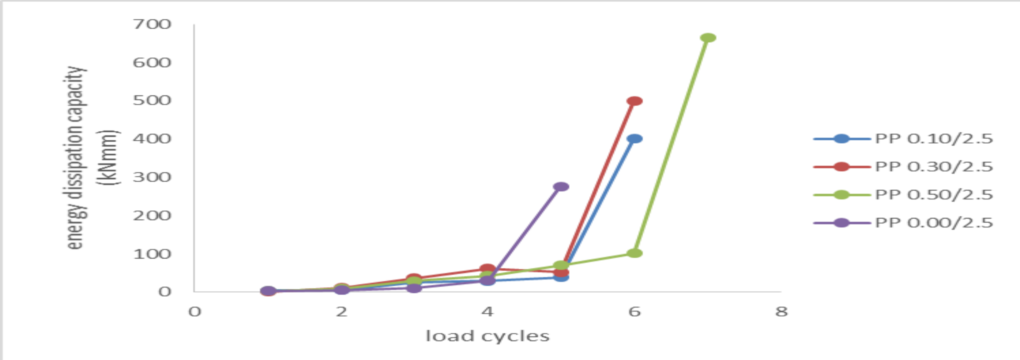

Figure 16 Energy dissipation capacity

CONCLUDING REMARKS

The study investigated the parameters such as load deflection characteristics, first and ultimate crack load, shear capacity, ductility factor, energy dissipation capacity and cracking patterns of partially prestressed concrete beams with and without including basalt fibre. Repeated loading was adopted and the parameters were analysed for both shear and shear-flexure behaviour by varying the shear span to effective depth ratio (1.5 and 2.5). The partial prestressing ratio was fixed as 0.75 and the percentage of fibres by total volume was varied as 0.1%, 0.3%, and 0.5%. After the analysis of the test results the study arrived at certain conclusions.

For shear span to depth ratio of 1.5

- First crack load increases with increase in basalt fibre content.
- The maximum increase of first crack load is about 14% for fibre volumes of 0.30 % and 0.50% when shear span to depth ratio of 1.5 is adopted.
- The initiation of crack is delayed when fibres are added.
- For a/d ratio 1.5, load carrying capacity and shear strength increases upto 0.30% and then decreases. The increase in load carrying capacity for 0.30 % fibre inclusion is about 34 %.
- Linear pattern of load deflection curves were obtained upto cracking. But the non-linearity becomes significant for higher fibre content in the post cracking stage.
- The ductility improved significantly by about 73% with the addition of 0.30% basalt fibre by volume for a/d ratio of 1.5.
- Energy dissipation capacity of specimens with basalt fibre were much higher than that of specimens without fibre. Maximum energy dissipation capacity was obtained for fibre inclusion of 0.30 %.
- The beams tested with shear span to depth ratio 1.5 failed in shear with inclined shear cracks.

For shear span to depth ratio of 2.5

- When the shear flexural behaviour is analysed it is obtained that the first crack load and ultimate load improved as the percentage of fibre increases.
- For fibre percentages of 0.30 and 0.50, almost similar results is obtained regarding crack initiation, ultimate load, energy dissipation and shear capacity.

- The percentage increase of first crack load is about 55% for fibre volume of 0.50% and the increase in deflection at the same fibre volume is about 128%.
- Maximum improvement in load carrying capacity and shear strength is obtained for specimens tested for shear span to depth ratio of 2.5. The ultimate load is improved by almost 50% for fibre volume of 0.50%, compared to plain prestressed beam specimens.
- Ductility factor increases upto 0.30% and then decreases.
- Maximum energy dissipation capacity is obtained at 0.50 percentages of fibres for shear span to depth ratio of 2.5.
- For every load cycle the number of flexural cracks increased and failure of specimens was in shear accompanied by widening of flexural cracks.

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