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Research Article

Investigation on Flexural Behavior of RC Beams Using Uni and Multi-directional BFRP Composites

[1]A. Chandran and [2]K.L. Muthuramu
[1]Department of Civil Engineering, T.J.S. Engineering College, Chennai, India
[2]Department of Civil Engineering, Shanmuganathan Engineering College, Pudhukottai, India

Abstract: Concrete structures are deteriorated due to environment conditions. Strengthening of existing structures are the most important challenges in the Civil Engineering. Recently, Basalt fibre are used for strengthening due to various advantages such as good range of thermal performance, high tensile strength, resistance to acids, good electromagnetic properties, inert nature, resistance to corrosion. This study presents the flexural behavior of Unidirectional and Multidirectional Basalt Fibre Reinforced Polymer (BFRP) composites, strengthened with reinforced concrete beams. For flexural strengthening of reinforced concrete beams, totally nine beams of size 100×160×1700 mm were cast using M20 grade concrete and tested under two point loading. One beam was used as reference and four beams were strengthened with uni directional BFRP composite and four beams were strengthened with Multi directional BFRP composite at bottom surface alone in the form of single layer, double layers, three layers and four layers, respectively. Test result indicates, the first crack load of strengthened beams with unidirectional BFRP increased by 14.98 to 66.79% when compared to reference beam and multi layered BFRP increased by 6.79 to 47.98%. The ultimate load carrying capacity increases from 8.6 to 34.6% in unidirectional BFRP and 5.66 to 20% in multidirectional BFRP when compared to reference beam. This study presents the enhancement in the structural behavior of BFRP strengthened beams compared with reference beam.

Keywords: Basalt fibre, flexural behavior, multidirectional, polymer composites, strengthening, unidirectional

INTRODUCTION

In recent years, repair and retrofitting of existing structures such as buildings, bridges etc., have been amongst the most important challenges in Civil Engineering. Various rehabilitation technique have been used such as steel plates bonded to the tension side of the structure (Rahimi and Hutchinson, 2001). But it has several problems including durability, manipulation and heavy weight. This leads to the introduction of advanced composite material, particularly Fibre Reinforced Polymer (FRP) in structural engineering. It has various benefits like good fatigue resistance, corrosion free, excellent weight to strength ratio and flexibility to conform any shape. Various FRP's are used such as Carbon FRP (CFRP) (Fanning and Kelly, 2001), Glass-FRP (GFRP) (Sawant *et al*., 2013) and Slurry Infiltrated Fibrous Concrete (SIFCON) laminates (Alaa and Ei Tony, 2013). Recently the new composite material BFRP has been developed because of its superior properties like very high tensile strength, more modulus of elasticity and non corrosive when compared with previous FRPs.

Basalt fibre: Basalt fibre is made from extremely fine fibres of basalt, which is composed of the minerals plagioclase, pyroxene and olivine. It is similar to carbon fibre and fibreglass, but having better physical and mechanical properties than fibreglass and significantly cheaper than carbon fibre. Basalt filaments are made by melting crushed volcanic basalt rock of a specific mineral mixture to about 1,400 to 1700°C for 6 h. The molten rock is then extruded through special platinum bushings to produce continuous filaments of basalt fibre. There are three main manufacturing techniques, which are centrifugal-blowing, centrifugal-multirole and die-blowing. The fibres cool into hexagonal chains resulting in a resilient structure substantially stronger than steel or fibre glass. Its production creates no environmental waste and it is non-toxic in use, or recycling. The Uni-directional and Multi-directional basalt fibre is shown in Fig. 1 and 2.

Recently, the retrofitting of concrete specimens and reinforced concrete piles using basalt fibres are investigated. The result shows that the specimen with double wrapping of basalt further gives better performance when compared to conventional and single wrapped specimen (Anandakumar *et al*., 2013). In another work the experimental investigation on the Flexural Behavior of Damaged RC Beams Strengthened in Bending Moment Region with Basalt Fibre Reinforced Polymer (BFRP) Sheets results in high load

Corresponding Author: A. Chandran, Department of Civil Engineering, T.J.S. Engineering College, Chennai, India

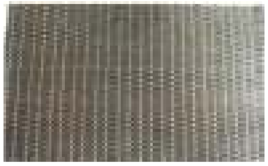

Fig. 1: Uni-directional basalt fibre cloth

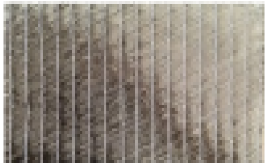

Fig. 2: Multi-directional basalt fibre cloth

carrying capacity (Gholkar and Jadhav, 2014). In this research paper, the BFRP composite is wrapped in bottom face full length of the beam. The flexural behavior of strengthened beams with number of layers were studied. In addition, Moment vs. Curvature, Load vs. Deflection, Crack Propagation, Number of Cracks are also observed.

METHODOLOGY

Material properties: Mix proportions for M20 grade concrete was designed based on the guide lines given in BIS-10262-2009 code. The designed mix proportion is 1:1.96:2.65/0.5. A total number of nine reinforced concrete beams of size 100×160×1700 mm were cast, strengthened after 28 days water cured with Unidirectional and Multidirectional BFRP composites and tested under static four point loading conditions. All the beams were provided with 2 numbers of 12 mm diameter TMT bars of grade Fe415 at bottom as tension reinforcement and 2 numbers of 8 mm TMT bars of grade Fe415 at top as compression reinforcement. Two legged stirrups of 6 mm diameter of 100 mm c/c at edges and 150 mmc/c in middle have been used as shear reinforcement. The reinforcements are designed to ensure flexural failure. The overall dimensions and details of reinforcement are shown in the Fig. 3.

Gluing material: Epoxy resin is a solvent less, modified epoxy resin manufactured from Epichlorohydrine and Bisphenol-A and further modified with reactive diluents. It can be cured at room temperature with polyamide hardener for various coating applications. Hardener is selected at suitable room temperature and the mix is a slow curing and has long pot life. This enhance the user to mix large quantity of materials and to perform coating neatly. This hardeners are generally low viscous, which enables users to incorporate more fillers. Epoxy resin with hardener was used as a bonding material to basalt fibre cloth and in concrete extract. The proportion of resin: hardener = 1.0:0.5. The properties of resin and hardener are shown in Table 1.

Preparation of test beam specimens: The concrete surfaces in which areas where Basalt Fibre to be pasted were cleaned very well by grinding wheel, were brushed and high pressure air jet and removed all unsound material on the surface. The cleaned surfaces were coated with epoxy resin mixed with hardener without any pot hole. Basalt fibre cloth of size 100 mm width and 1700 mm length of one layer was spread without any folding. Again coating of epoxy resin over the first layer was applied and spread the second layer of basalt fibre cloth without any folding applied one more epoxy coating and rolled. The same procedure was carried out for three layers and four layers. After seven days of air curing to complete the full polymerization, beams were prepared four point bending test. Pellets were fixed in compression and tension zone at the gauge length of 200 mm at equal distance to measure the strain profile at different load intervals. Beams are tested under two point bending test with the span of 1500 mm and loading point of 500 mm (span/3). Three dial gauges were fixed, one at mid span and two are at loading points to measure the deformation under different loading levels.

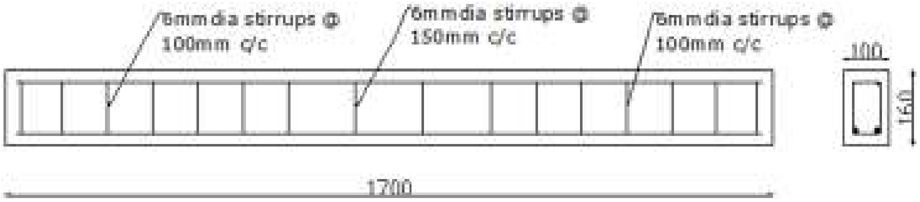

Fig. 3: Reinforcement details of beams

Table 1: Typical properties of epoxy resin and hardener (values given by manufacturer)

Properties	Epoxy resin	Hardener
Appearance	Clear low viscosity liquid	Pale yellow liquid
Viscosity 30°C	550-650 cps	300-400 cps
Type	Room temp. cure	Room temp. cure
Epoxy equivalent	180-200	-
Amine value	-	380-420
Specific gravity	1.1-1.2	0.96-0.98

Table 2: Test results of reference and strengthened beams (first crack load)

Spec Id.	No. of layer	Load (KN)	Deflec. (mm)	No. of cracks	Mcr (KN m)	Φ_D	Φ ε
C_2	0	15.15	1.69	1	3.78	1.26E-05	1.66E-05
U_1	1	17.42	1.57	3	4.36	6.62E-06	1.44E-05
U_2	2	20.35	1.45	4	5.09	5.71E-06	1.37E-05
U_3	3	22.18	1.34	4	5.55	4.49E-06	7.02E-06
U_4	4	25.27	1.10	5	6.32	3.09E-06	4.02E-06
MU_1	1	16.18	1.54	1	4.05	1.02E-05	1.23E-05
MU_2	2	18.15	1.48	3	4.54	7.87E-06	1.21E-05
MU_3	3	20.34	1.40	4	5.08	5.65E-06	7.23E-06
MU_4	4	22.42	1.35	4	5.61	3.97E-06	4.97E-06

Table 3: Test results of reference and strengthened beams (ultimate load)

Spec Id.	No. of layer	Load (KN)	Deflec. (mm)	No. of cracks	Mcr (KNm)	Φ_D	Φ ε
C2	0	68.00	14.0	15	17.00	2.00E-05	2.03E-05
U_1	1	73.85	16.1	23	18.46	6.59E-06	2.75E-05
U_2	2	78.50	18.0	28	19.63	5.60E-06	9.06E-06
U_3	3	86.00	15.0	28	21.50	4.83E-06	9.92E-06
U_4	4	91.50	18.0	30	22.88	3.04E-06	6.89E-06
MU_1	1	71.40	16.1	21	17.85	4.97E-05	5.65E-05
MU_2	2	74.80	18.0	26	18.70	3.26E-05	4.31E-05
MU_3	3	78.20	15.0	27	19.55	2.88E-05	4.51E-05
MU_4	4	81.60	18.0	29	20.40	2.82E-05	4.42E-06

Fig. 4: View of test setup with instrumentations

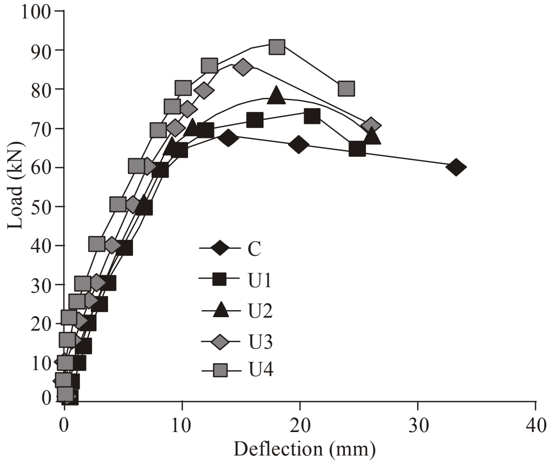

Fig. 5: Load-deflection of reference and strengthened beams (unidirectional BFRP)

Test procedure and instrumentation: Nine identical beams were constructed as mentioned in the previous section were tested in this program. The First specimen control C_2, was a control specimen without strengthening. The Second specimen U1, strengthened with one layer of BFRP Uni-directional cloth by wrapping throughout the length. The Third specimen U2, was strengthened with two layer of BFRP Uni-directional cloth by wrapping throughout the length. The Fourth specimen U3, was strengthened with three layer of BFRP Uni-directional cloth by wrapping throughout the length. The Fifth specimen U4, was strengthened with four layer of BFRP Uni-directional cloth by wrapping throughout the length. The Sixth specimen MU1, strengthened with one layer of BFRP Multi directional cloth by wrapping throughout the length. The Seventh specimen MU2, was strengthened with two layer of BFRP Multi directional cloth by wrapping throughout the length. The Eight specimen U3, was strengthened with three layer of BFRP multi-directional cloth by wrapping throughout the length. The Ninth specimen MU4, was strengthened with four layer of BFRP multi directional cloth by wrapping throughout the length. Figure 3 shows the test set up of the programme. All beam specimens were instrumented and loaded and supported simply as shown in Fig. 4. The load was applied through Universal Testing Machine of capacity 1000 kN. All beams were tested under four point loading. They were statically tested for failure at equal 5 kN increment of load. During loading, the mid span deflection was measured using dial gauge having a least count of 0.01 mm. Deflections under the load points also measured for every increment of load. The strain values form pellets using demec gauge were taken at every load increment.

Test results: The test results of reference beams (C2) and strengthened with Uni-directional BFRP Composites beams (U1, U2, U3 and U4) and Multi-directional BFRP composite beams (MU1, MU2, MU3 and MU4) are given in Table 2 and 3. Table 2 and 3 gives the first cracking load, ultimate load, deflection at first cracking and ultimate load, number of cracks and crack spacing of reference beam and strengthened beams and moment-curvature of the tested beams. Figure 5 and 6 shows the load central deflection curve

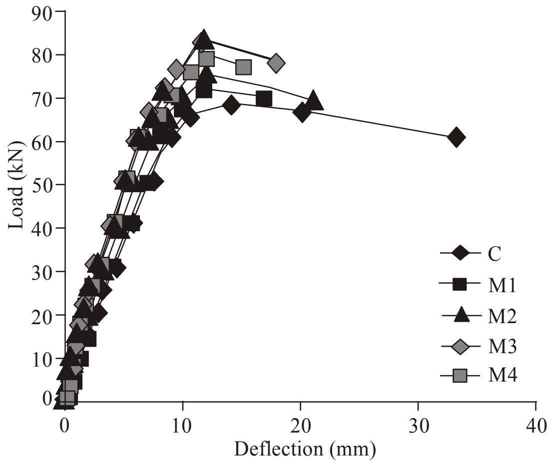

Fig. 6: Load-deflection of reference and strengthened beams (multi directional BFRP)

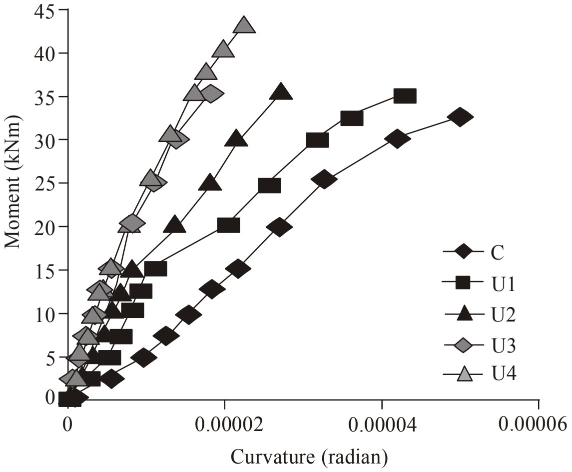

Fig. 7: Moment-curvature (deflection) of reference and strengthened beams (unidirectional BFRP)

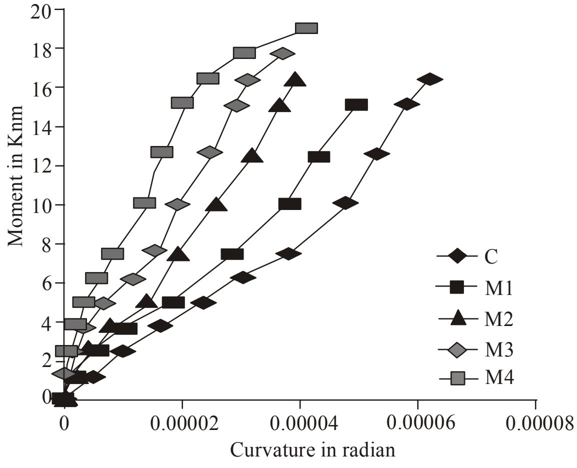

Fig. 8: Moment-curvature (deflection) of reference and strengthened beams (multidirectional BFRP)

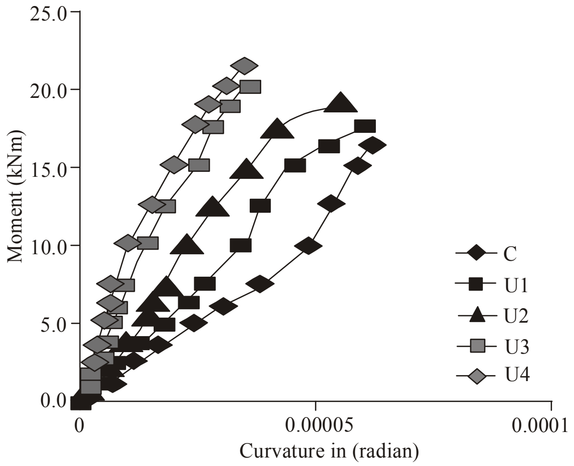

Fig. 9: Moment-curvature (strain) of reference and strengthened beams (unidirectional BFRP)

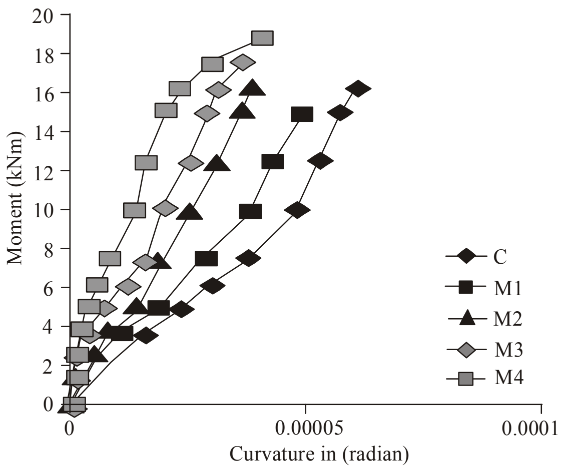

Fig. 10: Moment-curvature (strain) of reference and strengthened beams (multidirectional BFRP)

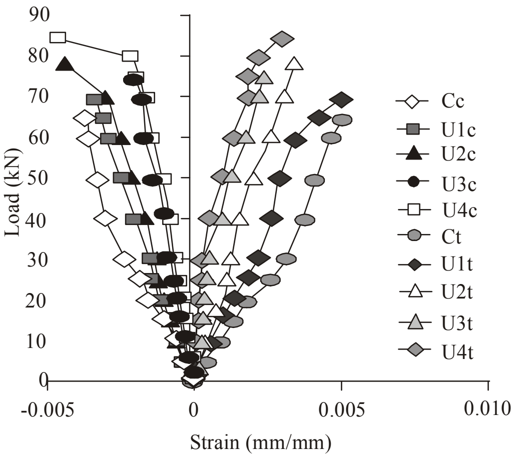

Fig. 11: Load-compressive and tensile strain of reference and strengthened beams (unidirectional BFRP)

of reference and strengthened beams. The moment-curvature obtained by using strain values and with deflection values respectively of all the beams are shown in Fig. 7 to 10, respectively. The load vs.

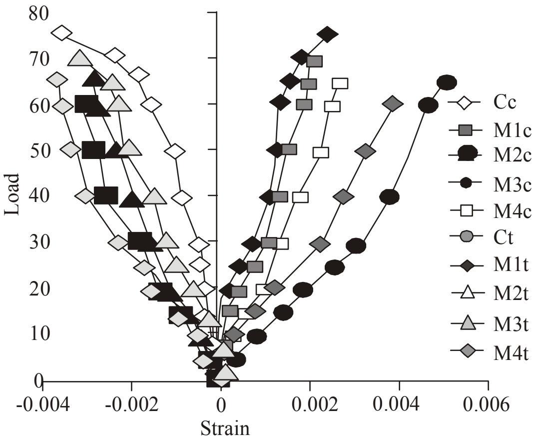

Fig. 12: Load-compressive and tensile strain of reference and strengthened beams (multidirectional BFRP)

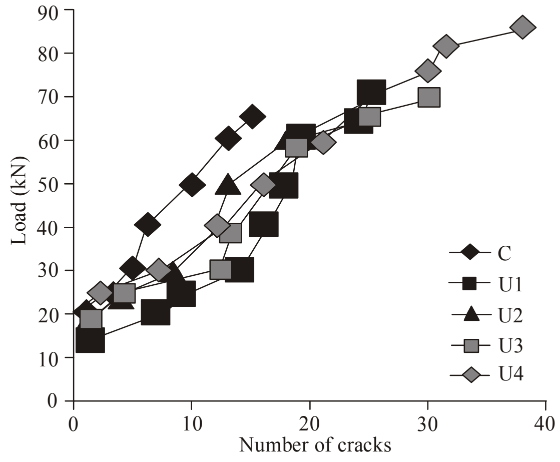

Fig. 13: Load-number of cracks of reference and strengthened beams (unidirectional BFRP)

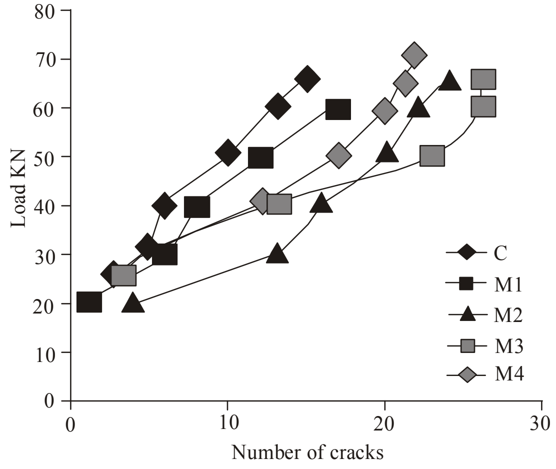

Fig. 14: Load-number of cracks of reference and strengthened beams (multidirectional BFRP)

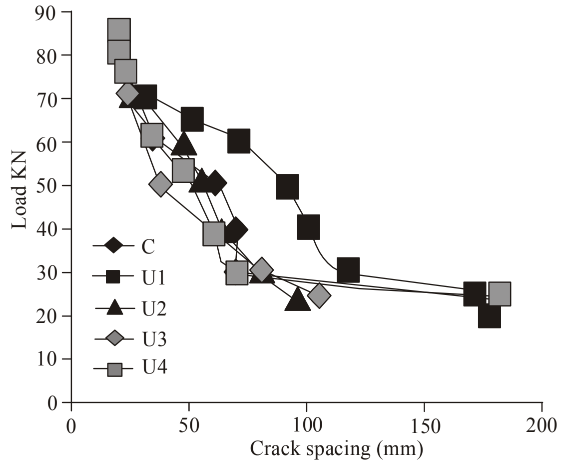

Fig. 15: Load-crack spacing of reference and strengthened beams (unidirectional BFRP)

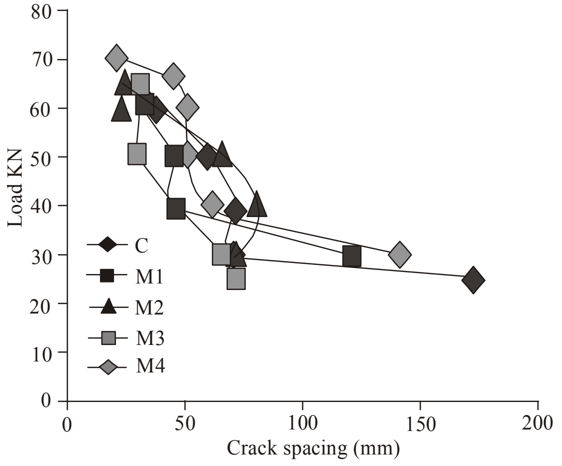

Fig. 16: Load-crack spacing of reference and strengthened beams (multidirectional BFRP)

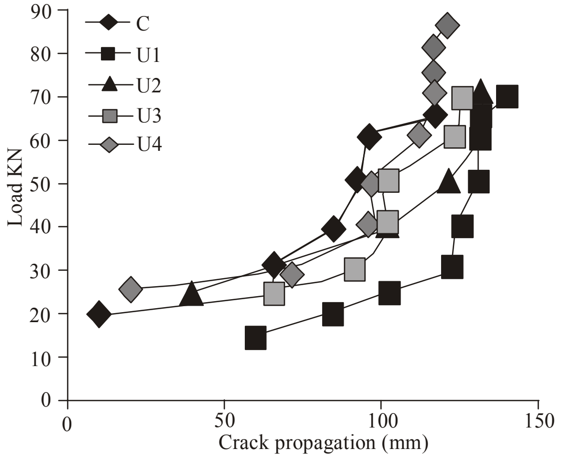

Fig. 17: Load-crack propagation of reference and strengthened beams (unidirectional BFRP)

compressive and tensile strain, number of cracks, crack spacing and crack propagation at different load levels are shown in Fig. 11 to 16, respectively. The compression and tension strain profile at different loads are presented in Fig. 17 to 20. The deflection profile at

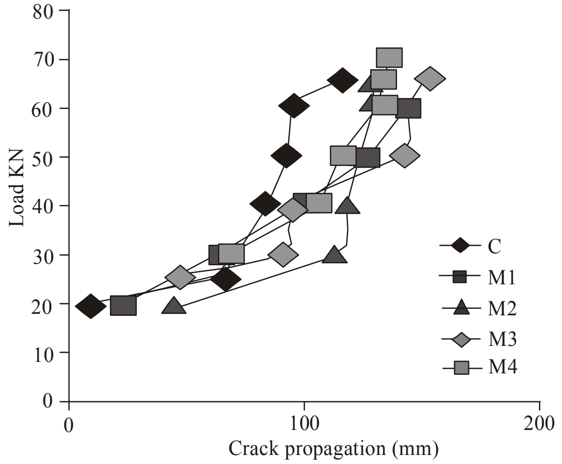

Fig. 18: Load-crack propagation of reference and strengthened beams (multidirectional BFRP)

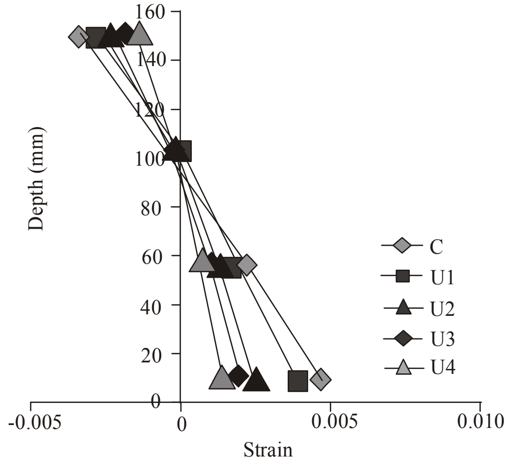

Fig. 19: Compressive and tensile strain profile of reference and strengthened beams at the load level of 60 kN (unidirectional BFRP)

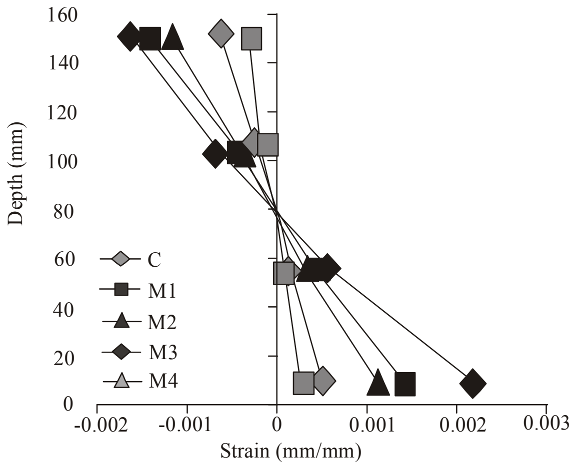

Fig. 20: Compressive and tensile strain profile of reference and strengthened beams at the load level of 60 kN (multidirectional BFRP)

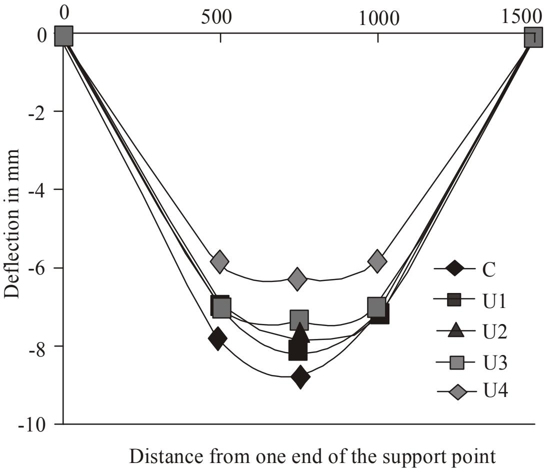

Fig. 21: Compressive and tensile deflection profile of reference and strengthened beams at the load level of 60 kN (unidirectional BFRP)

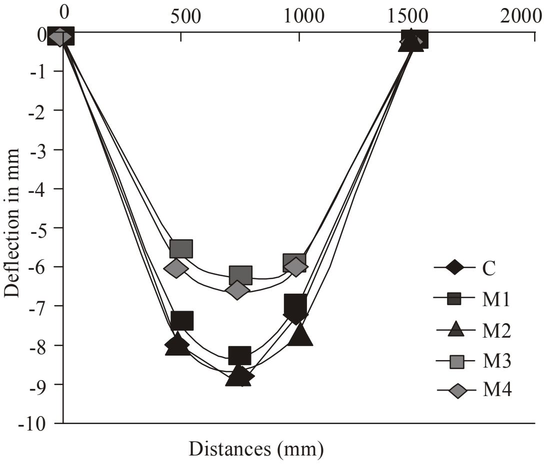

Fig. 22: Compressive and tensile deflection profile of reference and strengthened beams at the load level of 60 kN (multidirectional BFRP)

different load levels are illustrated in Fig. 21 and 22. Failure crack pattern of tested beams are shown in Fig. 23.

RESULTS AND DISCUSSION

First crack load and deflection: The percentage increase in first cracking load when compared to control beams are 14.98, 34.32, 46.0 and 66.79%, for U_1, U_2, U_3U_4 and 6.79, 19.80, 34.21 and 47.98%, for MU_1, MU_2, MU_3, MU_4, respectively when compared to control beam.

Ultimate load and deflection: The ultimate load carrying capacity of all the strengthened beams showed increase in load carrying capacity. The registered ultimate load carrying capacity for U_1, U_2, U_3 and U_4 are 8.6, 15.44, 26.47 and 34.6%, respectively and MU_1,

Fig. 23: Failure crack pattern of reference and strengthened beams

MU_2, MU_3 and MU_4 are 5.66, 10.00, 15 and 20%, respectively, when compared to control beam.

Crack behavior and pattern: The first cracks are developed in the constant bending moment zone in control and strengthened beams. All the cracks are in flexural zone except a few. Some of the cracks propagated from bottom towards top of the beam. Thus crack spacing are reduced by increasing the number of layers. The failure mode of U_1 is flexure cum shear failure, U_2 is flexural cum compressive failure, U_3 and U_4 is flexure cum peeling of laminates. Similarly the failure mode of MU_1 is flexure, MU_2 is flexural cum compressive failure, MU_3 and MU_4 is flexure cum peeling of laminates.

CONCLUSION

Based on the test results discussed above, the following conclusions are arrived on the control and uni-directional and multi directional BFRP strengthened beam tested under two point bending test:

- The deflection at first cracking load reduced to 7.10, 14.2, 20.71 and 34.9%, for U1, U2, U3 and U4 strengthened beams, respectively when compared to control concrete beam.
- The deflection at first cracking load reduced to and 8.88, 12.42, 17.16 and 20.12%, for MU1, MU2, MU3 and MU4 strengthened beams respectively when compared to control concrete beam.
- The increase in ultimate load carrying capacity of strengthened beam U1, U2, U3 and U4 are 8.6, 15.44, 26.47 and 34.60%, respectively when compared to control concrete beam.
- The increase in ultimate load carrying capacity of strengthened beam MU1, MU2, MU3 and MU4 are 5.66, 10, 15 and 20%, respectively when compared to control concrete beam.
- By increasing the load, the number of cracks developed also increased with increasing the number of layers of BFRP.

- Most of the strengthened beams in unidirectional BFRP showed flexure cum crushing of compression modes.
- The stiffness of the beams are increased by increasing the number of layers.
- Curvature of strengthened beams are also decreased and by increasing the basalt fibre layers increase.
- In cracking behavior the number of cracks increase crack spacing decreased by increasing basalt fibre layers increase.

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