DE GRUYTER OPEN

ARCHIVES OF CIVIL ENGINEERING
Vol. LXI ISSUE 1 2015

DOI: 10.1515/ace-2015-0003

FLEXURAL BEHAVIOUR OF STRENGTHENED RC BEAMS WITH MULTI-DIRECTIONAL BASALT FIBRE - REINFORCED POLYMER COMPOSITES

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The paper describes an experimental behaviour of the basalt fibre reinforced polymer composite by external strengthening to the concrete beams. The BFRP composite is wrapped at the bottom face of R.C beam as one layer, two layers, three layers and four layers. The different characteristics - are studied in - first crack load ,ultimate load, tensile and compressive strain, cracks propagation, crack spacing and number of cracks etc. To - investigate, total of five beams size 100mmx 160mmx1700mm were cast. One beam is taken as control and others are strengthened with BFRP composite with layers. From this investigation, the first crack load is increased depending on the increment in layers from 6.79% to 47.98%. Similarly, the ultimate load carrying - capacity is increased from 5.66% to 20%. The crack's spacing is also reduced with an increase in the number of layers

Keywords: basalt fibre reinforced polymer composite, multidirectional, stiffness, strengthened beam

1. INTRODUCTION

Recently more importance is given to the development of - infrastructures using concrete. The strengthening of structures is required for protection against degradation of structural materials due to some environmental effects. Nowadays, strengthening and rehabilitation of existing

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structures are - the most important challenges in Civil Engineering .Various rehabilitation technique have been developed to overcome the problems. In starting period, the external strengthening methods such as steel plates bonded to the tension side of the structure were used [1]. But it has several problems including durability, manipulation, and heavy weight. Thus the need for alternative solutions, leads to the introduction of advanced composite materials, particularly fibre reinforced polymer (FRP) [2], in structural engineering. It has - various benefits like good fatigue resistance corrosion free, excellent weight to strengthen the ratio and, flexibility to conform any - shape. Various FRP's are used such as Glass–FRP(GFRP) [3], Carbon FRP(CFRP) [4], and Slurry infiltrated fibrous concrete (SIFCON) laminates [5]. Recently a new - composite material BFRP [6] has been developed because of its superior properties like very high tensile strength , more modulus of elasticity and non-corrosiveness when compared to the previous FRPs [7].

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 at about 1,400 to1700 -- °C - for 6 hours. 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 are made 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 multi directional basalt fibre is shown in fig 1.and properties are shown in table 1.

Fig.1. Multi- directional basalt fibre fabric

Table 1. Material properties given by manufacturer

Material	Nominal thick (mm)	Surface weight (g/m^2)	Ultimate tensile strain(%)	Elastic modulus (Gpa)	Tensile strength (Mpa)
Multi-directional	0.45	660	3.15	84	2500

Recently, the experimental investigation on the Flexural Behaviour of Damaged RC Beams Strengthened in Bending - Moment - Region - with Basalt Fibre Reinforced Polymer (BFRP) Sheets resulted in high load carrying capacity [8]. In this research paper, the BFRP composite is wrapped in bottom - face - with full length - of the beam .The flexural behaviour of strengthened beams with number of layers were studied. In addition , Moment Vs Curvature , Load Vs Deflection, Crack Propagation and Number of Cracks are also observed.

2. EXPERIMENTAL PROGRAMME

2.1. MATERIAL PROPERTIES

Mix proportion 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 five reinforced concrete beams of size 100x160x1700mm were cast, strengthened after 28_days, water cured with Multidirectional BFRP composites and tested under static two point loading conditions. All the beams were provided with 2 numbers of 12mm diameter TMT bars of grade Fe415 at bottom as tension reinforcement and 2 numbers of 8mm TMT bars of grade Fe415 at top as compression reinforcement. Two legged stirrups of 6mm diameter of 100mm c/c at edges and 150mmc/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.2.

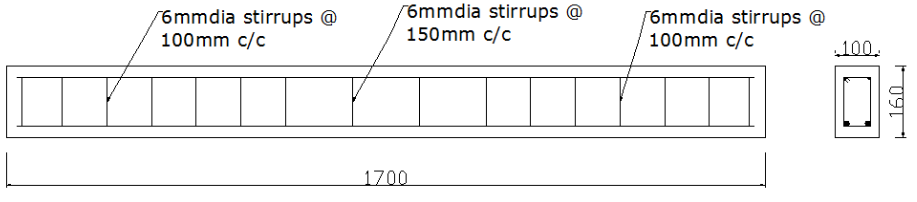

Fig.2. Reinforcement Details of Beams

2.2. 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 slow curing and has a long pot life. This allows the user to mix large quantity of materials and to perform coating neatly. These 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 fabric and in concrete extract. The proportion of resin: hardener = 1.0:0.5. The properties of resin and hardener are shown in table 2.

Table 2. Typical properties of epoxy resin and hardener (values given by manufacturer)

PROPERTIES	EPOXY ESIN	HARDENER
Appearance	Clear low viscosity liquid	Pale yellow liquid
Viscosity 30deg.C	550-650 cps	300-400 cps
Type	Room temp.Cure	Room temp.Cure
Epoxy equivalent	180-200	-
Amine value	-	380-420
Specific Gravity at 30deg.C	1.1-1.2	0.96-0.98
Storage Stability	1 year	1 year

3. PREPARATION OF TEST BEAM SPECIMENS

The concrete surface where the Basalt Fibre was to be pasted were cleaned well to remove all unsound materials, by applying air with high pressure after the grinding process. The cleaned surfaces were coated with epoxy resin mixed with hardener without any pot holes. Basalt fibre fabric of size 100mm width and 1700mm length of one layer was spread without any folding. Again coating of epoxy resin over the first layer was applied to the MU1 specimen. For MU2 specimen, the above process was repeated. In addition the second layer of basalt fibre fabric was spread without any folding and again the epoxy coating was applied over the fabric . The same procedure was carried out for MU3 specimen, spreading the third layer of basalt fibre fabric and applying the epoxy coating again. For MU4 specimen, spread the fourth layer of basalt fibre fabric and applied with epoxy coating. To complete the full polymerization, all the specimens were cured for seven days. After seven days, pellets were fixed at compression zone and tension zone at the gauge length of 200mm to measure the demec gauge readings to calculate strain values for - different loadings. The wrapped specimens and the Pellets fixation on the specimens are shown in the Fig. 3. The specimen details with BFRP wrapping are shown in the Table 3.

Fig. 3. Wrapped Specimens and Pellets fixation

Table 3. Specimen Details

SPECIMEN ID	STATUS
C2	Control specimen without strengthening
MU1	Wrapped with 1 layer of BFRP Multidirectional cloth
MU2	Wrapped with 2 layer of BFRP Multidirectional cloth
MU3	Wrapped with 3 layer of BFRP Multidirectional cloth
MU4	Wrapped with 4 layer of BFRP Multidirectional cloth

4. TEST PROCEDURE AND INSTRUMENTATION

Beams are tested under - two point bending test with the span of 1500mm and loading point of 500mm(span/3). Three dial gauges were fixed, one at mid span and each one at loading points to measure the deflection. The load was applied through Universal Testing Machine of capacity 1000 kN. They were statically tested for failure, at equal 5 kN increment of load. On every increment of loading, the - deflections under load points, mid span were measured using dial gauge having a least count of 0.01 mm. In addition, demec gauge readings for four rows of pellets were taken to calculate the strain values. Crack spacing, crack propagation, number of cracks were also measured for each increment of load. Fig. 4 shows the test set up of the programme.

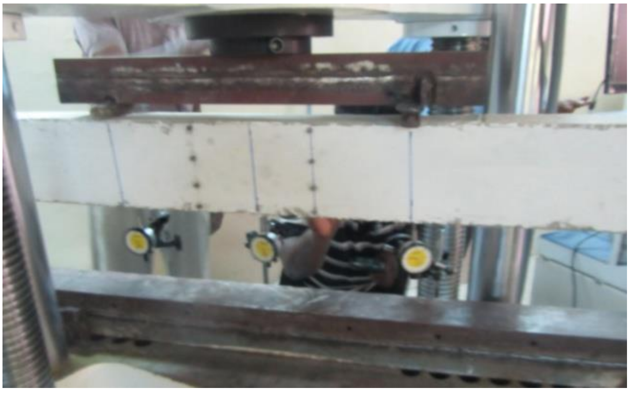

Fig. 4. View of Test Setup with Instrumentations

5. RESULTS AND DISCUSSIONS

5.1. TEST RESULTS

The test results of reference beams (C2), and strengthened with multidirectional BFRP (MU1, MU2, MU3 and MU4) are given in tables. Table 4 & Table 5 represents 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. Fig.5 Shows the load central deflection curve 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.6 and Fig.7. The load vs compressive and tensile strain, number of cracks, crack spacing, and crack propagation at different load levels are shown in Fig.8, Fig. 9, Fig.10 and Fig.11 respectively. The compression and tension strain profile at different loads are presented in Fig.12, Fig.13 and Fig.14. The deflection profiles at different load levels are illustrated in Fig.15, Fig. 16 and Fig. 17 respectively.

Table 4. Test Results of Reference and Strengthened Beams (First Crack Load)

Sl No	Spec Id.	No. of layer	First crack			Mcr (KN-m)	ϕ_D	ϕ_ε
			Load (KN)	Deflection (mm)	No. of cracks			
1	C_2	0	15.15	1.69	1	3.78	1.26E-05	1.66E-05
2	MU_1	1	16.18	1.54	3	4.05	1.02E-05	1.23E-05
3	MU_2	2	18.15	1.48	5	4.54	7.87E-06	1.21E-05
4	MU_3	3	20.34	1.4	8	5.08	5.65E-06	7.23E-06
5	MU_4	4	22.42	1.35	12	5.61	3.97E-06	4.97E-06

Table 5. Test Results of Reference and Strengthened Beams (Ultimate Load)

Sl No	Spec Id.	No. of layer	Ultimate			Mul (KN-m)	ϕ_D	ϕ_ε
			Load (KN)	Deflection (mm)	No. of cracks			
1	C2	0	68.00	14.0	15	17.00	2.00E-05	2.03E-05
2	MU_1	1	71.85	11.9	23	17.85	4.97E-05	5.65E-05
3	MU_2	2	74.80	11.8	28	18.70	3.26E-05	4.31E-05
4	MU_3	3	78.20	11.8	28	19.55	2.88E-05	4.51E-05
5	MU_4	4	81.6	11.6	30	20.40	2.82E-05	4.42E-05

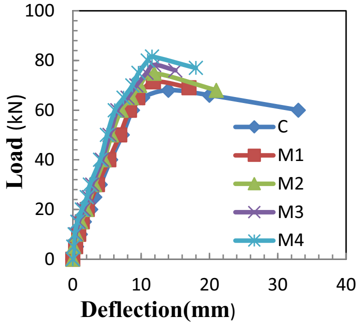

Fig. 5. Load-Central Deflection of Reference and Strengthened Beams

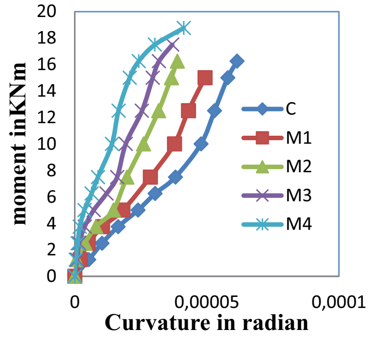

Fig. 7. Moment-Curvature (Strain) of Reference and Strengthened Beams

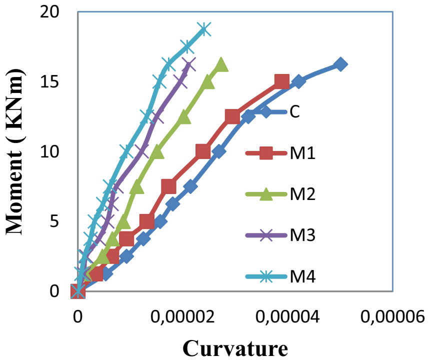

Fig. 6. Moment-Curvature (deflection) of Reference and Strengthened Beams

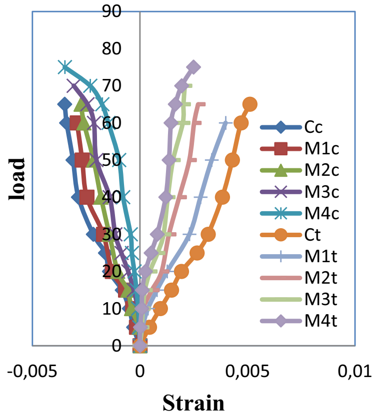

Fig. 8. Load-Compressive and Tensile Strain of Reference and Strengthened Beams

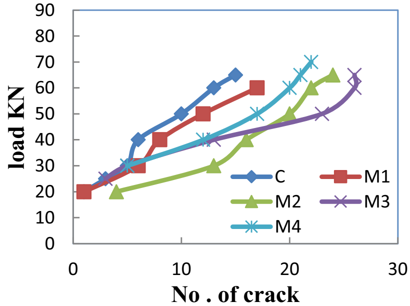

Fig. 9. Load-Number of Cracks of Reference and Strengthened Beams

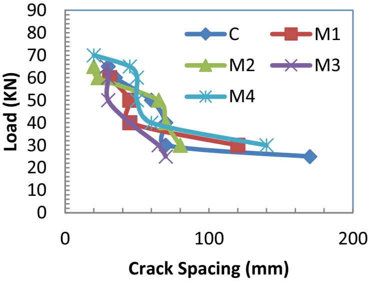

Fig. 10. Load-Crack Spacing of Reference and Strengthened Beams

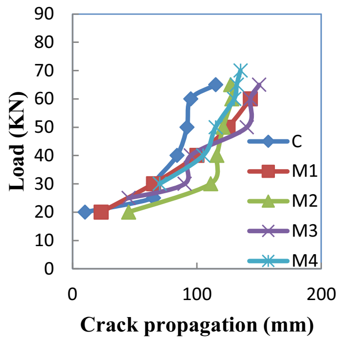

Fig. 11. Load-Crack Propagation of Reference and Strengthened Beams

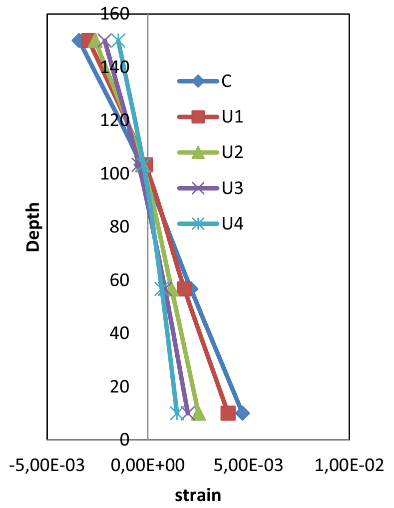

Fig. 13. Compressive and Tensile Strain Profile of Reference and Strengthened Beams at the Load Level of 40kN

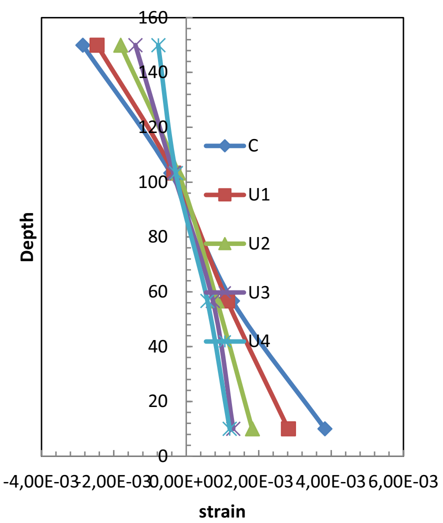

Fig. 12. Compressive and Tensile Strain Profile of Reference and Strengthened Beams at the Load Level of 20kN

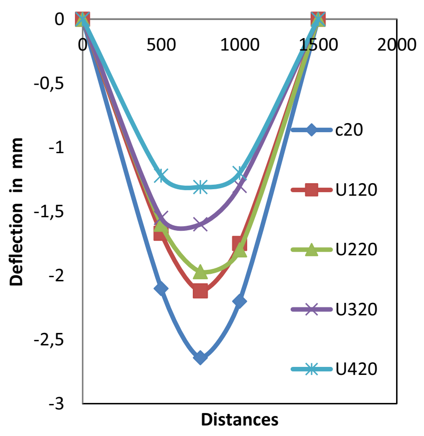

Fig. 14. Compressive and Tensile Strain Profile of Reference and Strengthened Beams at the Load Level of 60KN

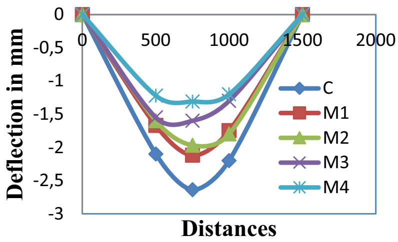

Fig. 15. Deflection Profile of Reference and Strengthened Beams at the Load Level of 20kN

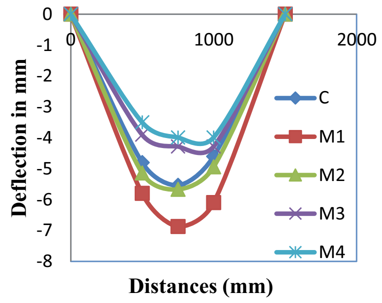

Fig. 16. Deflection Profile of Reference and Strengthened Beams at the Load Levels of 40KN

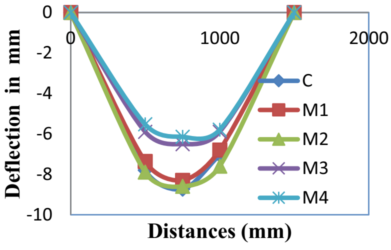

Fig. 17. Deflection Profile of Reference and Strengthened Beams at the Load Level of 60kN

5.2. Discussion on test results

5.2.1. First crack load and deflection

The first crack load of the control beam C2 is 15.15KN whereas the corresponding values for single layer, double layer , third layer and fourth layer were 16.18 KN, 18.15 KN, 20.34 KN and 22.42 KN respectively. The deflections at first crack loads are 1.69mm, 1.54mm, 1.48mm, 1.40mm and 1.35mm for C2, MU1, MU2, MU3 and MU4 respectively.

5.2.2. ULTIMATE LOAD AND DEFLECTION

The ultimate load carrying capacity of control beam C2, MU1, MU2, MU3 and MU4 are 68KN, 71.85KN, 74.80KN, 78.20KN and 81.6KN respectively. The deflection value for control beam is 14mm under ultimate load.

5.2.3. CRACK BEHAVIOUR AND PATTERN

The first cracks 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.

The total number of the cracks developed at the ultimate load are 15 numbers in C2 beam. Many of the flexural cracks propagated for a height of 100mm from the bottom. The number of cracks at first cracking load for control C2, MU1,MU2,MU3 and MU4 are 1,3,5,8 and 12, respectively.

The strengthened beam MU1,MU2,MU3 and MU4 showed 23,28,28 and 30 number of cracks, respectively at ultimate load.

5.2.4. FAILURE MODE OF THE SPECIMEN

For RC beams, crushing and spalling of concrete takes place after the yielding of steel in the tension zone. Beams when wrapped with Basalt fibre reinforced polymer (BFRP) composites in one layer, two layers , three layers and four layers, faces lesser damage when compared with the reference beam (C2).

The failure mode of MU1 is flexure cum shear failure, MU2 is flexural cum compressive failure, MU3 and MU4 are flexure cum peeling of laminates. The Failure Crack pattern of tested beams are shown in the Fig. 18.

Fig. 18. Failure Crack Pattern of Reference and Strengthened Beams

6. CONCLUSIONS

Based on the test results discussed above, the following conclusions are drawn on the control and unidirectional BFRP strengthened beam tested under four point bending test:

1) The increase in first crack load carrying capacity of strengthened beam MU1, MU2, MU3 and MU4 are 6.79%, 19.80%, 34.26%, 47.98% respectively when compared to control concrete beam.
2) The deflection at first cracking load reduced to 8.88%, 12.42%, 17.15% , 20.11% for MU1,MU2,MU3 and MU4 strengthened beams, respectively when compared to control concrete beam.
3) 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.

4) By increasing the load , the number of cracks developed also increased with increasing the number of layers of BFRP.
5) Most of the strengthened beams in unidirectional BFRP showed flexure cum crushing of compression modes.
6) The stiffness of the beams is increased by increasing the number of layers.
7) Curvature of strengthened beams is also decreased by increasing the basalt fibre layers increase.
8) In cracking behaviour the number of cracks increase crack spacing decreased by basalt fibre layers increase.

SYMBOLS USED:

C2 - Reference Beam

MU1 - Beam strengthened with single layer of BFRP

MU2 - Beam strengthened with two layers of BFRP

MU3 - Beam strengthened with three layers of BFRP

MU4 - Beam strengthened with four layers of BFRP

Mcr - Moment at first crack load,

Mul - Moment at ultimate load,

ϕD - Curvature due to deflection,

$\phi \varepsilon$ - Curvature due to strain.

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Received 20. 02. 2015
Revised 24. 03. 2015