Investigation on Structural Behaviour of Distressed RC Beams Strengthened With Multi-Directional Basalt Fibre Reinforced Polymer Composites

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Abstract - This paper presents the structural behaviour of strengthened reinforced concrete (RC) beams with basalt fibre reinforced polymer (BFRP) composite. The basalt fibre has been used exclusively in recent years for strengthening and rehabilitation due to potential low cost of the material, easy to apply, corrosion resistant and effective due to high strength as well as low weight. To investigate, totally five beams of size 100mmx 160mmx1700mm were cast. One beam is taken as control and other fours are wrapped with BFRP composite. The BFRP composite is wrapped at the bottom face of distressed R.C beam as one layer, two layers, three layers and four layers for rehabilitation. The beams are tested under two- point loading. The different characteristics - are studied in - first crack load, ultimate load, cracks propagation, crack spacing and number of cracks etc. Results of the experimental program showed that the strengthened beams load carrying capacity and stiffness are increases when compared to control beam, .The Cracks spacing also reduced with increase in number of layers.

Keywords - Basalt fibre Reinforced polymer composite, Multidirectional, stiffness, strengthened beam.

I. INTRODUCTION

Nowadays, the infrastructure concerned with Reinforced Concrete (RC) structures are found to be structurally inadequate and the ageing of such structures also often reported due to various reasons. The performance of RC structures may reduced due to insufficient design, low-quality construction, or environmental conditions. Although the damage to concrete structure is unavoidable, it is necessary to repair and strengthen the distressed portion and to recover the original strength of the structure. Many of the existing concrete structures outlived their useful life and it is rather dangerous to continue to use them without any strengthening. Therefore the engineers are constrained to implement new materials and strengthening techniques to efficiently combat this problem

In earlier days, the external strengthening methods such as steel plates bonded to the tension side of the structure [1] was adopted. But it has several problems including durability, manipulation, and heavy weight. Thus the need for alternative, leads to the introduction of advanced composite material, particularly fibre reinforced polymers (FRP) [2]. 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 Glass–FRP(GFRP) [3] ,Carbon FRP(CFRP) [4] and Slurry infiltrated fibrous concrete (SIFCON) laminates [5]. Recently the new composite material Basalt Fibre Reinforced polymer composites 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 . Recently, the experimental investigation was carried out on the Flexural Behaviour of Damaged RC Beams Strengthened in Bending Moment Region with Basalt Fibre Reinforced Polymer (BFRP) Sheets results in high load carrying capacity [6].

In this research paper, the BFRP composite is wrapped at full length of bottom face of the beam. In general, this investigation was carried out to study the behaviour of the strengthened beams under static loading**.**

II. EXPERIMENTAL PROGRAMME

A. 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 five reinforced concrete beams of size

100x160x1700mm were cast, strengthened after 28 days water cured with Multidirectional BFRP composites and tested under static four 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 Figure 1.

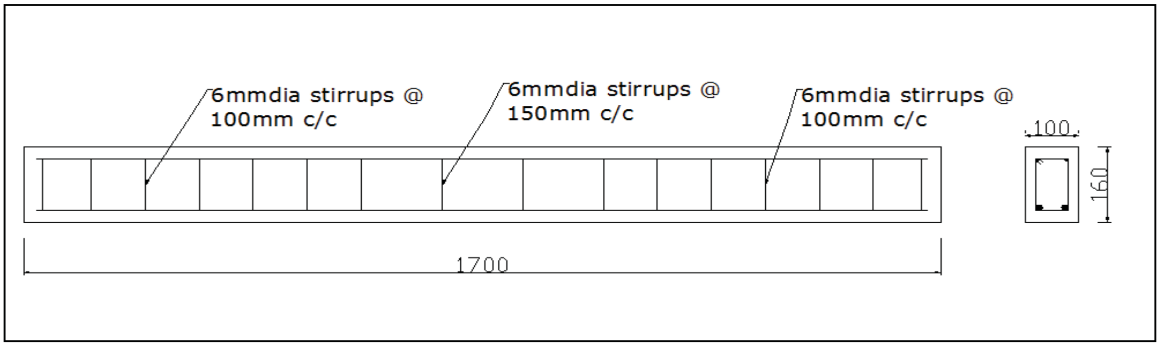

Figure 1. Reinforcement Details of Beams

B. 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 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 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 Figure 2 and the properties are shown in Table 1.

Figure 2. Multi-directional basalt fibre cloth

Table - 1 Material Properties Given By Manufacturer

Material	**Nominal thick (mm)**	**weight (g/m^2)**	**Ultimate tensile strain(%)**	**Elastic modulus (GPa)**	**Tensile strength (MPa)**
Multi- directional	0.45	464	3.15	84	2500

C. 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 enhances 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 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

D. Preparation of Test Beam Specimens

The concrete substrate in which areas where Basalt Fibre to be pasted of four beams 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 100mm width and 1700mm 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 at compression at the gauge length of 200mm to take demec gauge readings at different load intervals. Pellets are also fixed in between the compression and tension zones at equal distance to measure the strain profile at different load intervals. The specimen details are given in the Table 3.

Table - 3 Specimen Details

SPECIMEN ID	STATUS
C2	Control specimen without strengthening
SMU1	Wrapped with 1 layer of BFRP Multidirectional cloth
SMU2	Wrapped with 2 layer of BFRP Multidirectional cloth
SMU3	Wrapped with 3 layer of BFRP Multidirectional cloth
SMU4	Wrapped with 4 layer of BFRP Multidirectional cloth

III. 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. Figure 3 shows the test set up of the programme.

Figure 3. View of Test Setup with Instrumentations

IV. RESULTS AND DISCUSSIONS

A. Load Deflection Behaviour

The load vs. deformation capacity of the tested specimens varied significantly depending on the number of BFRP composites layers wrapped at the bottom face of the beam. Measured response of the specimens strengthened with different layers is shown in the Figure 4.

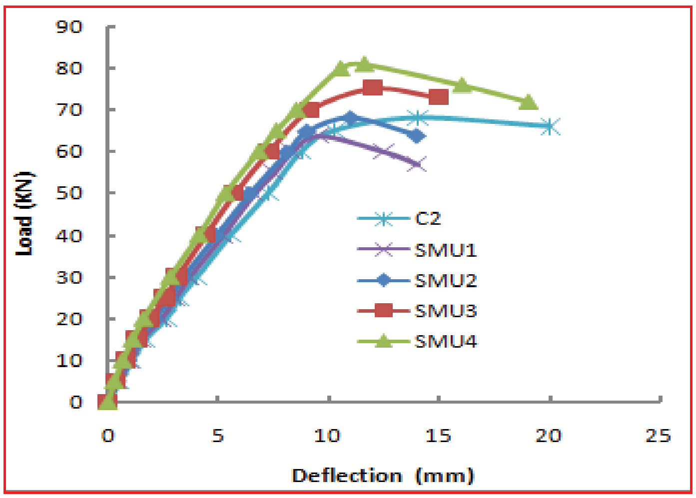

Figure 4. Load-Central Deflection of Reference and Strengthened Beams

B. First crack load

The observed first cracking load for C2, SMU1, SMU2, SMU3 and SMU4 are 15.15, 10.50, 11.60, 13.00 and 14.60kN respectively. First cracks are appeared only in the constant bending moment zone in all the beams when compared to control .

C. Ultimate load

The ultimate loading capacity of C2, SMU1, SMU2, SMU3 and SMU4 are 68.00 kN, 63.85 kN, 68.25kN, 75.20 kN and 81.00 kN, respectively. By increasing the number layers showed increase in load carrying capacity from beam SMU1 – SMU2 ,SMU2-SMU3 and SMU3 – SMU4 are 6.89%, 9.24% and 7.71% , respectively.

D. Service Load

In the present investigation, service load was identified as the load required for the central deflection of span/350mm (1500/350 = 4.3mm) as per IS: 456-2000. From the experimental results, the obtained service load for C2, SMU1, SMU2, SMU3 and SMU4 beams are 30, 34.13, 36.67, 39.22 and 41.67KN respectively. The observed number of cracks at service load level for C2, SMU1, SMU2, SMU3 and SMU4 are 5, 16, 12, 13 and 12 respectively and cracks spacing are 70mm, 65mm, 80mm, 65mm and 65mm. The crack propagation height from bottom of the beam for C2, SMU1, SMU2, SMU3 and SMU4 are 65mm, 120mm, 95mm, 93mm and 95mm respectively at service load level.

E. Moment – Curvature relationship

Figure 5 and Figure 6 gives the moment-deflection curvature and strain curvature of control and all the strengthened beams. In both the deflection and strain curvature curves, the stiffness of beams are increased by increasing the number of layers of basalt fibre for strengthening. The curvature values computed from deflection and strain values showed marginal difference and the strain curvature shows slightly higher than deflection curvature. The same trends in load-deflection behaviour also followed in moment-deflection and strain curvature relationship.

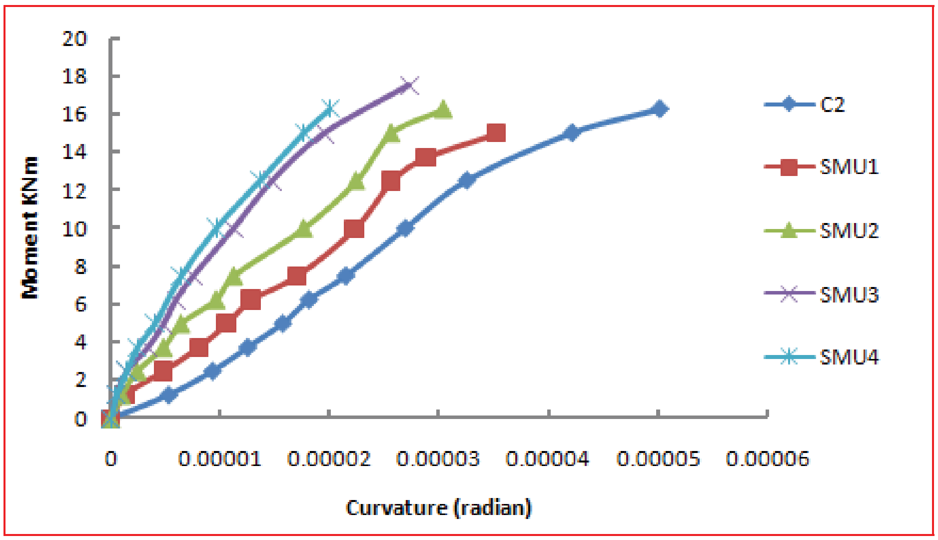

Figure 5. Moment-Curvature (deflection) of Reference and Strengthened Beams

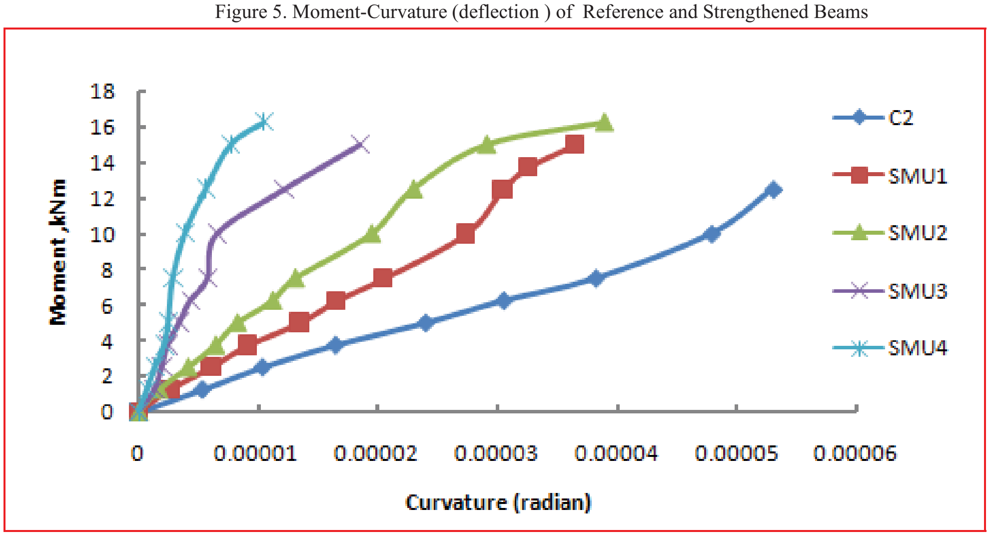

Figure 6. Moment-Curvature (strain) of Reference and Strengthened Beams

At curvature level of 2.00×10^{-6}, the corresponding moment values for beams U1, U2, U3 and U4 are 6.94, 9.73, 13.82, 17.95 and 20.4 kNm respectively, calculated from deflection values and 4.13, 5.41, 8.52, 13.04 and 14.95 kNm in strain values. When compared to control beam C2, the strengthened beam U1, U2, U3 and U4 increase in moment at deflection curvature level of 2x10-6 are 41.07, 99.4, 158.65 and 193.95% respectively and strain curvature and calculations are 30.99, 107.99, 215.74 and 261.99%.

F. Strain Profile

Strain profile at the load of 20, 40 and 60KN are presented in Figure 7, Figure 8 and Figure 9 respectively for control and all the strengthened beams. The neutral axis depth from top of the beam is reduced more in control beam compared to strengthened beams at all the load levels. The neutral axis depth for beams C2, SU1, SU2, SU3 and SU4 at 20KN load level are 84, 90, 84, 88 and 88mm respectively, at the load level 40KN are 68, 76, 76, 80 and 82mm and at load level 60KN are 64, 70, 72,76 ,and 74 mm from top of the beam, Control beam and SU1 showed enormous reduction in neutral axis depth (20mm reduced from 20KN to 60KN load levels), but the strengthened beams registered only 12 to 14mm reduction in neutral axis depth.

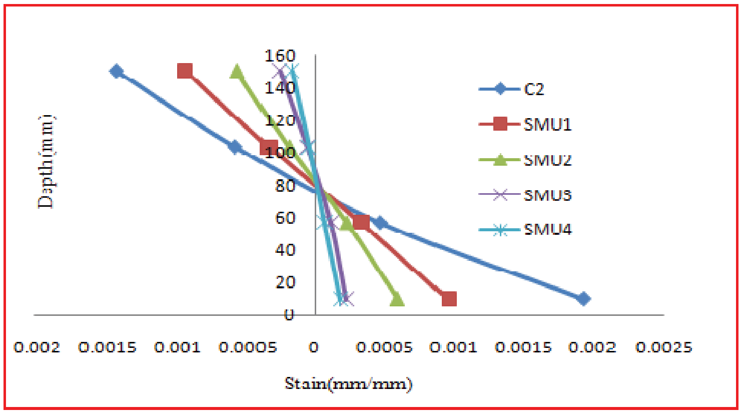

Figure 7. Compressive and Tensile Strain Profile of Reference and Strengthened Beams at the Load Level of 20kN

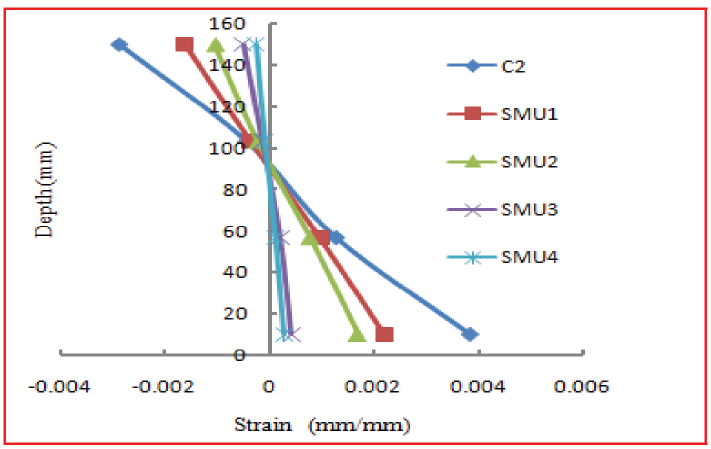

Figure 8. Compressive and Tensile Strain Profile of Reference and Strengthened Beams at the Load Level of 40kN

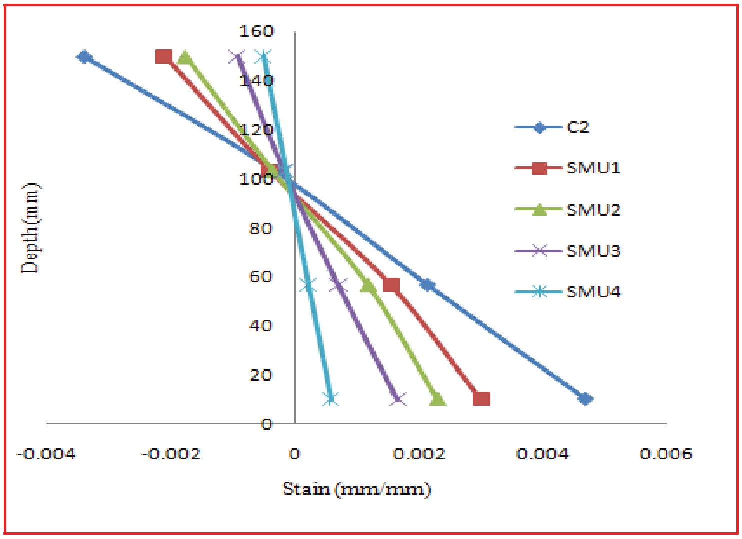

Figure 9. Compressive and Tensile Strain Profile of Reference and Strengthened Beams at the Load Level of 60kN

G. Deflection Profile

Figure 10, Figure 11 and Figure 12 shows the deflection profile along the span at the load level of 20kN, 40kN and 60kN respectively. The control beam showed higher deflection than strengthened beams. Deflection values decreased by increasing number of layers of basalt fibre strengthened beams both in central deflection and load point deflections. The maximum deflection at 20kN for C2, SMU1, SMU2, SMU3 and SMU4 are 2.64, 2.4, 2.1, 1.90 and 1.60mm, 5.54, 5.18, 4.9, 4.4 and 4.1mm at 40KN and 8.74, 8.10, 7.26 and 6.8mm at 60KN load level respectively. When compared to control beam C2, the reduction in deflection strengthened beams SMU1, SMU2, SMU3 and SMU4 are 9.09,20.45,28.03 and 39.90% at load level of 20KN, 6.5,11.55,20.58 and 25.99% at load level of 40KN and 5.03, 7.32, 16.93 and 22.20% respectively.

The average deflection at load points for C2, SMU1, SMU2, SMU3 and SMU4 are 2.15, 2.07, 1.90, 1.75 and 1.48mm at 20KN load, 4.70, 4.49, 4.35, 4.05 and 3.80mm at 40KN load and 7.43, 7.2, 7.30, 6.65 and 6.25mm at 60KN load level respectively. The percentage reduction in deflection when compared to control beam with strengthened beams SMU1, SMU2, SMU3 and SMU4 are 3.72, 11.63, 18.60 and 31.16 at 20KN load level, 4.47, 7.45, 13.83 and 19.15 at 40KN load level and 2.96, 1.75, 10.50 and 15.88at 60KN load level respectively.

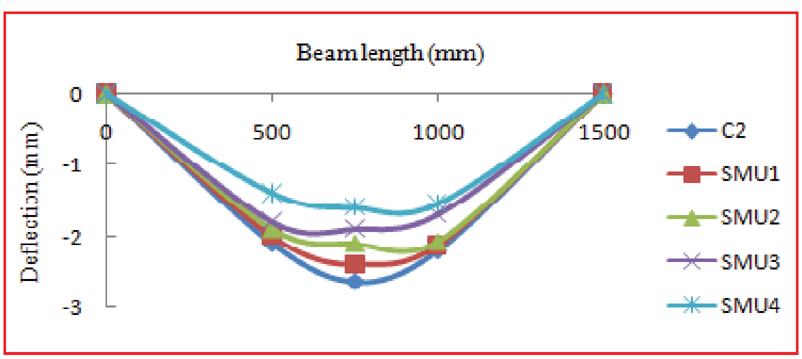

Figure 10. Deflection profile along the span for control and strengthened beams at the load level of 20KN.

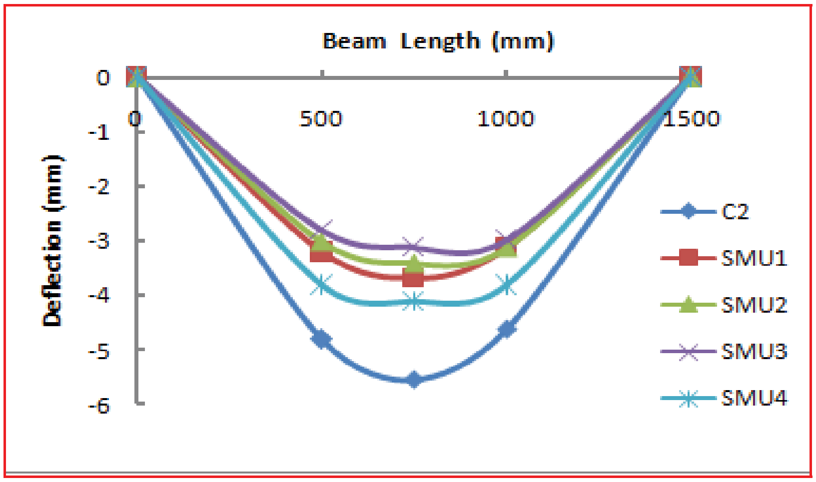

Figure 11. Deflection profile along the span for control and strengthened beams at the load level of 40KN.

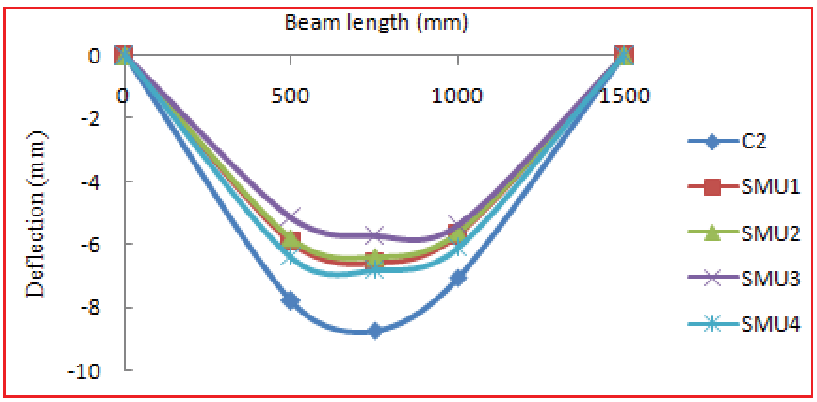

Figure 12. Deflection profile along the span for control and strengthened beams at the load level of 60KN.

H. Crack behaviour 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. The total numbers of the cracks developed at the ultimate load are 15 numbers in SMU2. Many of the flexural cracks propagated for a height of 100mm from the bottom. The number of cracks at first cracking load for control, SMU1, SMU2, SMU3 and SMU4 are 1,3,5,8 and 12, respectively. The mode of failure is pure flexural. The strengthened beam SMU1, SMU2, SMU3 and SMU4 showed 23,28,28 and 30 number of cracks, respectively at ultimate load. Thus crack spacing are reduced by increasing the number of layers. The failure mode of SMU1 is flexure cum shear failure, SMU2 is flexural cum compressive failure, SMU3 and SMU4 is flexure cum peeling of laminates.

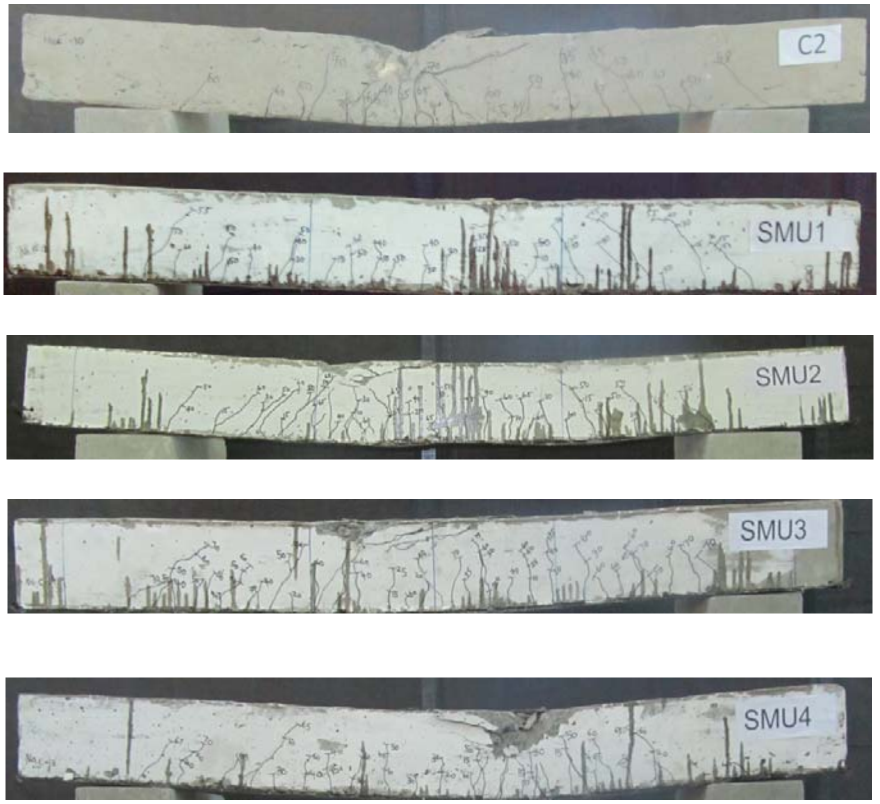

Figure 13. Failure Crack Pattern of Reference and Strengthened Beams

V. CONCLUSION

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

1. The increase in ultimate load carrying capacity of strengthened beam SMU1, SMU2, SMU3 and SMU4 are 0%, 0.4%, 10.6%, and 19.1%, respectively when compared to control concrete beam.
2. The percentage increase in service load when compared to control concrete for SMU1, SMU2, SMU3 and SMU4 are 13.77, 22.23, 30.73 and 38.90 respectively.
3. By increasing the load, the number of cracks developed also increased with increasing the number of layers of BFRP.
4. Most of the strengthened beams in Multi-directional BFRP showed flexure cum crushing of compression modes.
5. The stiffness of the beams are increased by increasing the number of layers.
6. Curvature of strengthened beams are also decreased and by increasing the basalt fibre layers increase.
7. In cracking behaviour the number of cracks increase crack spacing decreased by basalt fibre layers increase.

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