Flexural Strengthening of Reinforced Concrete Beams Using Basalt Fabric Reinforced Cementitious Mortar (FRCM)

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***Abstract*—Reinforced concrete (RC) beams are vital structural elements in infrastructure but are susceptible to deterioration due to aging, environmental exposure, and overloading. Traditional retrofitting using Fiber Reinforced Polymers (FRP) is effective but costly and environmentally sensitive. Fabric Reinforced Cementitious Mortar (FRCM) systems have emerged as an efficient alternative, offering enhanced bonding, durability, and sustainability. This study investigates the flexural performance of RC beams strengthened with basalt-based FRCM. Six beams were cast: two controls, two with one FRCM layer, and two with four layers. Experimental results under two-point loading revealed that basalt FRCM improved flexural strength by 15.25% (one layer) and 35.59% (four layers) compared to controls, with better pre-cracking stiffness and reduced crack widths. Failures were primarily due to fabric rupture. The findings validate basalt FRCM as a sustainable and effective strengthening material for RC structures.**

***Index Terms*—— Basalt fiber mesh, Fabric Reinforced Cementitious Mortar (FRCM) systems, Ductility, Load-Deflection, Ultimate load**

I. INTRODUCTION

Reinforced Concrete (RC) structures form the foundation of most modern infrastructure. Over time, factors such as environmental exposure, overloading, and material degradation reduce their strength and serviceability, particularly in flexural members like beams. Strengthening such elements has become a vital part of sustainable structural engineering, offering an economical and eco-friendly alternative to replacement. Traditional strengthening using Fiber Reinforced Polymers (FRP) has shown effectiveness but suffers from drawbacks including high cost, poor compatibility with concrete, and limited fire resistance. To overcome these limitations, Fabric Reinforced Cementitious Mortar (FRCM) systems have emerged as a promising solution. These systems combine high-strength fiber meshes with a cement-based matrix, providing superior bond performance, durability, and environmental compatibility. Among available fiber types, Basalt fibers, derived from volcanic rock, offer excellent tensile strength, corrosion resistance, and thermal stability at a lower cost compared to carbon or glass fibers. When integrated into an FRCM system, basalt fabric provides a strong and sustainable method for enhancing the flexural capacity and crack resistance of RC beams

This study investigates the flexural performance of RC beams strengthened with basalt FRCM, comparing the results of beams with one and four reinforcement layers to unstrengthened control beams.

II. MATERIALS USED

- Concrete: For this investigation, a pre-mixed concrete of grade M30 was utilized. The mix consisted of ordinary Portland cement (OPC), M sand, and gravel stones with coarse aggregates of 20 mm and 10 mm sizes.

- Reinforcement: Three different diameter of Bars were used in this experiment [12, 10, 8 mm], 12- & 10-mm bars are used as a primary reinforcement and 8mmforstirrups. All the Steel Bars are 550 grade Turbo steel TMT bars.
- Water: Water used for mixing and curing should be portable.
- Cement: OPC 53 grade cement was used in the entire project.
- Fine aggregates: The fine aggregates used to mix were Manufactured sand (M sand) with maximum particle size of 4.75 mm.
- Basalt fiber mesh: A basalt mesh composed of continuous basalt fibres interlaced into a grid formation. The fibre mesh was utilized in the same condition as provided by the local manufacturer.

Fig 1. Basalt fiber mesh

Table I. Quantity of concrete [mix design-M30]

Grade of Concrete	M30
Mix Ratio	1:2.2:3.04
Materials	Mix
Cement	450 Kg/ m ^{3}
Fine aggregate	1200 Kg/ m^{3}
Coarse aggregate	180 Kg/m^{3}
Water	158 liters
Admixture	1.8 liter

Table II. Properties of Basalt Fiber Mesh

Basalt fibre mesh properties	
Form	Solid
Colour	Brown
Thickness	0.5-0.6 mmm
Tensile Strength	3200-3850 MPa
Elastic modulus	75-90 GPa
Density	2.63 g/cm3)
Elongation at break	3.1 %

(Note: Properties as per the supplier)

Table III provides the details of the test specimens along with the naming convention adopted

Table III. Details of test specimens

Specimen ID	Description
BFRB-1-1L	Beams Strengthened with 1-layer BFRP Mesh
BFRB-2-1L	Beams Strengthened with 1-layer BFRP Mesh
BFRB-1-4L	Beams Strengthened with 4-layer BFRP Mesh
BFRB-2-4L	Beams Strengthened with 4-layer BFRP Mesh

III OBJECTIVES

1.To assess the ability of reinforced concrete beams to resist bending strengthened with Basalt FRCM and to compare their performance with unstrengthened control beams in order to quantify the improvement in flexural capacity.
2.To investigate the influence of strengthening in relation to the enhancement in maximum load capacity, initial cracking load, Pre-cracking and post-cracking stiffness of strengthened beams with that of normal beams.
3.To investigate the impact of different number of layers (1 and 4 layers) of Basalt FRCM concerning the bending behavior of beams.
4.To study the mode of failures exhibited by the Basalt FRCM strengthened beamsconventional beams.

IV BEAM SPECIMENS

A. Details of Beam Specimens

In total, six beam specimens were casted and tested by varying the nod of layers of theBasalt fibre fabrics. Two beams served as control specimens, two were reinforced with a single layer of Basalt FRCM, and the remaining two were strengthened with four layers of Basalt FRCM.

Table IV. Specifications of the beam specimens

Type of test	Flexure
Overall length (L) mm	2300
Effective length (l) mm	2100
Overall depth (D) mm	200
Width(B) mm	150

B. Details of Reinforcement

Steel reinforcement design of all the six beams was performed as per IS 456:2000.

Table V. Reinforcement details

Grade of Concrete	M30
Grade of Steel	Fe550
Reinforcement	2-10mm Φ + 2-16mm Φ
Effective depth (d) mm	167
Areaof steel (Ast) mm2	201.06

C. Casting of Beam Specimens

For casting the beams, moulds were prepared by using the centring sheets of dimensions 200×2300 mm.Prior to casting the concrete, the inner surfaces of the moulds were thoroughly cleaned and adequately lubricated to facilitate easy removal of the beams from the moulds after 24 hours of casting. The uniform concrete mix was discharged and placed into the formwork in layers with maximum thickness of 150 mm, then compacted using a mechanical vibrator. The stripping was done after 24 hours of casting. The beams were covered by gunny bags and curing was continued for 28 days before testing the beams.

Fig 2. Fabrication of Reinforcement

Fig 3. Formwork with reinforcement cage

Fig 4. Placement of cover blocks

Fig 5. Finishing the top surface

Fig 6. Curing of the beams with gunny bags

Strengthening of Beam Specimens

The procedure for the application of basalt FRCM to the RC beams is detailed below

1.The exposed area is cleaned and undulations are performed over the surface of concrete, as presented in figure 7

2. Cement mortar has been prepared by mixing cement, sand and water. The ratio of cement and sand is 1:4. Water is added until the working consistency is obtained

3. A mortar layer was added to the beam's upper surface and spread evenly, as demonstrated in figure 8.

4. The basalt fiber mesh is then positioned on the mortar and pressed as demonstrated in figure 9.

5. Another layer of mortar is placed on this and the top layer is smoothened as demonstrated in figure 11.

6. For a four-layer TRM beam, the basalt fiber mesh is again placed, pressed and fabricated with mortar. The procedure is repeated until the beam is reinforced with four layers of basalt fiber fabric.

Fig 7. Surface prepared to receive FRCM


Fig 8. Placing of mortar


Fig 9. Placing of Basalt FRCM


Fig 10. Impregnation of cement mortar through the basalt fiber mesh


Fig 11.Placing of mortar on the basalt fibre mesh and smoothening the surface

V TEST SETUP AND INSTRUMENTATION

Beams were tested under two-point loading conditions. Before testing, beams were coated with whitewash so that it becomes easy to identify the cracks and its propagation throughout the beam. Two create the simply supported boundary conditions two steel rollers of diameter 25 mm were placed at 100mm distance from either end of the beam, which give rise to the effective span of 2100 mm. Shear span adopted in the present experimental program is about 700 mm from either side of the roller support. The beam is tested under a hydraulic jack-mounted loading setup of 500 kN capacity. A total of three dial gauges were mounted to capture the deflections that the beam undergoes during the loading process. One dial gauge is kept exactly at the central portion of the beam and two dial gauges are kept at 700 mm distant from the roller supports. A proving ring was fixed at the upper surface of the loading frame to determine the amount of load exerted during the testing.

A. Testing Procedure

Initially a seating load of small magnitude is applied in order to establish a perfect contact between roller supports, beam, hydraulic jack and proving ring which are interconnected to each other. Readings in all the three dial gauges and proving ring were set to zero. Load is applied on the beam at suitable load intervals, for each increment of load, readings of dial gauges are noted down. Up to some particular load uncracked behavior of beam is witnessed. The time when the beam gets cracked for the first time, corresponding load and deflection noted down were highlighted together with the width of crack is also measured using a microscope having a least count of 0.002 mm. With every increment under the effect of the imposed load, the number of cracks formed and propagation of these cracks goes on increasing. All these details need to be noted down along with crack widths. Finally, the load and deflection at which the beam fails is noted down. All the data that we have collected through this testing procedure were required to compare the response of strengthened beams with control beams.

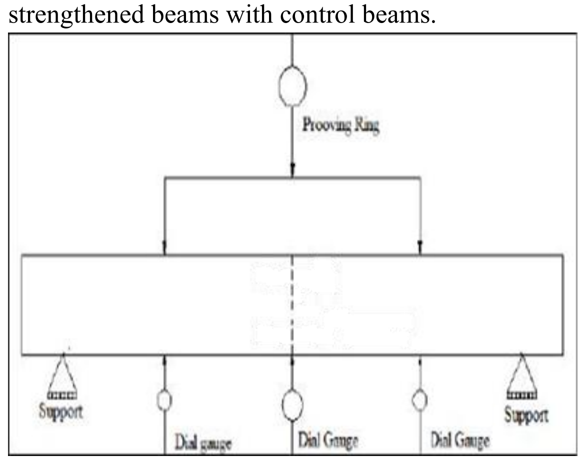

Fig 12. Typical test setup with the location of dial gauges

Fig 13. Typical Experimenal test set up

VI RESULTS AND DISCUSSION

An attempt has been made to bring out a comparative study between the experimental data of control and strengthened beams regarding ultimate load capacity, initial cracking load, pre-cracking stiffness and post-cracking stiffness. The experimental results summary has been tabulated in relation to each maximum and average load carrying capacity, for each set of the beams. Strength enhancement observed through the experimental investigations with respect to the control beams is 15.25% and 35.59% for beams strengthened with 1 and 4 layers of Basalt FRCM respectively. The table IV presents the summary of average first crack load with the corresponding average deflections and the pre-cracking stiffness.

A. Results of tested beams

- Control Beam

The average ultimate load at failure, Pu,avg, and the first crack load, Pcr,avg, found for the control set of beams were 59 kN and 15 kN respectively. All the two control beams failure occurred due to crushing of the concrete in compression zone after yielding of steel.

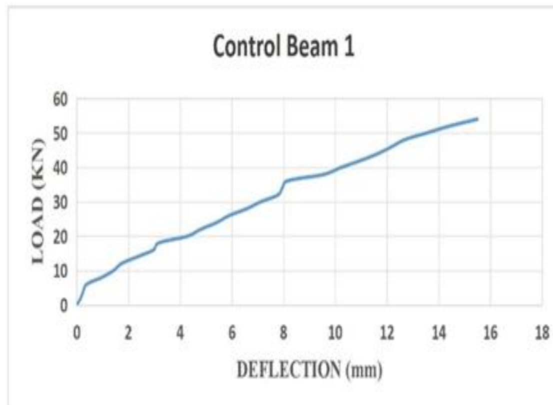

Fig 14. Experimental load–deflection response of Control Beam 1

Table III. Experimental results

Specimen ID	Maximum applied load,Pu (kN)	Average Maximum applied load,Pu,avg (kN)	Failure Mode	Strength enhancement Pu,avg, strenghtned/Pu, avg, control
CB-1	60	59	Crushing of concrete in the compression zone after yielding of steel	1.00
CB-2	58			
BFRB-1-1L	66	68	FRCM fabric rupture	1.23
BFRB-2-1L	70			
BFRB-1-4L	78	80	FRCM fabric rupture	1.45
BFRB-2-4L	82			

Table IV. Experimental crack load results

Specimen ID	CB	BFRB-1L	BFRB-4L
Average first crack load (Pcr,avg)	15	17	21
Average first crack deflection(Δcr,avg)(mm)	2.42	1.84	2.16
Increase in first crack load	1.0	1.13	1.4
Pre- cracking stiffness,K=Pcr,avg /Δcr,avg (kN/mm)	6.19	9.24	9.72
Increase in pre-cracking stiffness(Kstregthened / KControl)	1	1.49	1.58
Post-cracking stiffness(Kstregthened / KControl)	2.99	3.86	10
Increase in post-cracking stiffness(Kstregthened / KControl)	1	1.29	3.34

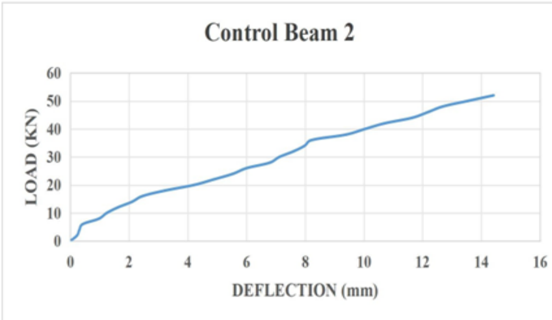

Fig 15. Experimental load–deflection response of Control Beam 2

- Beams strengthened with 1 layer of Basalt FRCM (BFRCM – 1L)

The average ultimate load at failure and the average first crack load were found to be 63 kN and 16 kN. Ultimate strength enhancement, increase in the first crack load and the pre-cracking stiffness observed with respect to control set of beams were 15.25%, 11.3% and 40% respectively. The failure of all beams was primarily due to fabric rupture, occurring predominantly at the midspan.

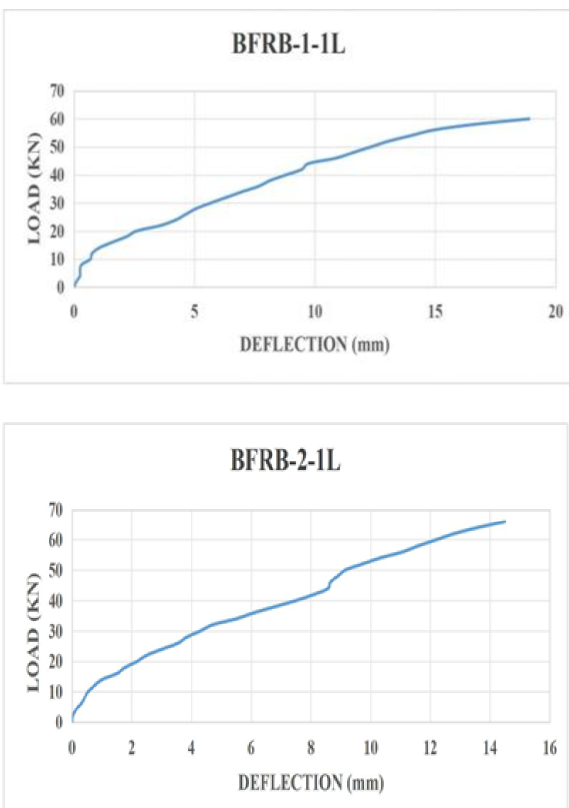

Fig 16. Experimental load–deflection response 1 layer Basalt Fabric Reinforced Beam

Fig 17. Fabric rupture failure in typical Basalt FRCM-1L strengthened beams

- Beams strengthened with 4 layer of Basalt FRCM (BFRCM – 4L)

The average ultimate load at failure and the average first crack load were found to be 86 kN and 64 kN. Ultimate strength enhancement, increase in the first crack load and the pre-cracking stiffness observed with respect to control set of beams were 35.59%, 50% and 58.6% respectively.The failure modes of all the beams were again governed by fabric rupture more exactly at the midspan.

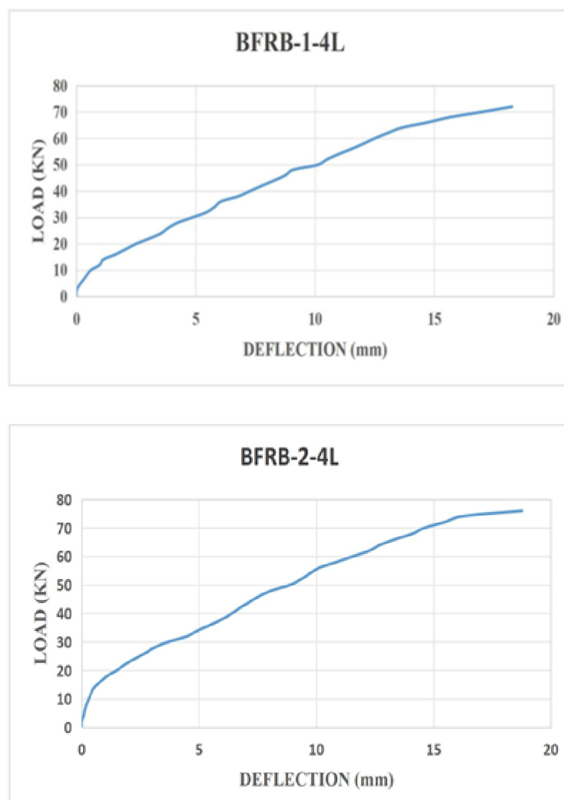

Fig 18. Experimental load–deflection response of 4-layer Basalt Fabric Reinforced Beam

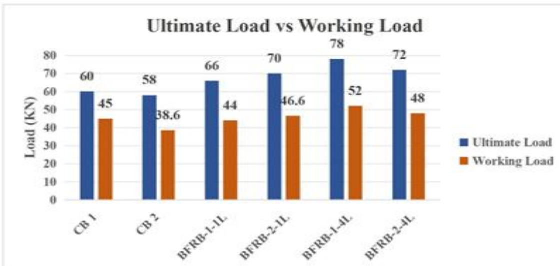

Fig 19. Fabric rupture failure in typical Basalt FRCM-4L strengthened beams

B.Combined load v/s deflection relationship

It is observed that:

1.All the beams shows linear behaviour up to cracking, once the beams get cracked, they start exhibiting nonlinear behaviour to failure.

2.Stiffness degradation starts at the first crack load and it continues until the beam fails.

3.Strengthening technique adopted here efficiently increases the cracking load and rigidity of the beam - rise in the initial cracking load together with the pre-cracking stiffness observed with respect to control set of beams were 11.3% and 40% respectively for one layer strengthened beams. Similarly increase in the first crack load and the pre- cracking stiffness observed with respect to control set of beams were 50% and 58.6% respectively for four layers strengthened beams.

4.Post-cracking stiffness of both strengthened and control beams were observed as approximately same.

Fig 20. Combined load v/s deflection relationship of the control beam (CB), Basalt Fabric Reinforced beams (BFRB-1L and BFRB-4L)

The ultimate loads displayed by the control beams (CB1 and CB2) were 60 KN and 58 KN, respectively. The beams strengthened using 1 layer Basalt mesh (BFRB-1-1L and BFRB-2-1L) demonstrated a significant gain in strength as seen by their higher ultimate loads of 66 KN and 70 KN. Similarly, the ultimate loads of beams strengthened using 4-layer Basalt mesh (BFRB-1-4L and BFRB-2-4L) were 78 KN and 72 KN, respectively.

Fig 21. Ultimate Load Versus Working Load

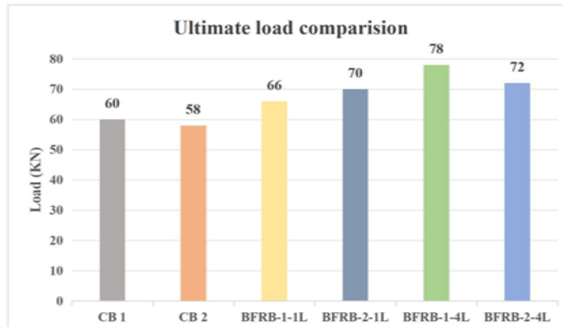

Fig 22. Ultimate Load of Control Beams and Strengthened Beams

Deflection measurements further highlight the advantages of strengthening. CB1 and CB2 had deflections of 8.13 mm and 8.21 mm, respectively, both within the allowable limit of 9.2 mm. However, the strengthened beams displayed varying deflection behaviors. BFRM-1-1L possessed a diversion of 8.8 mm, within the allowable limit, while BFRM-2-1L possessed a diversion of 8.58 mm, staying within the limit.The beams BFRM-2-4L and BFRM-2-4L, showed deflections of 9.06 mm and 8.88 mm, respectively, also within the allowable range. This suggests that the strengthened beams provided better deflection control compared to the control beams.

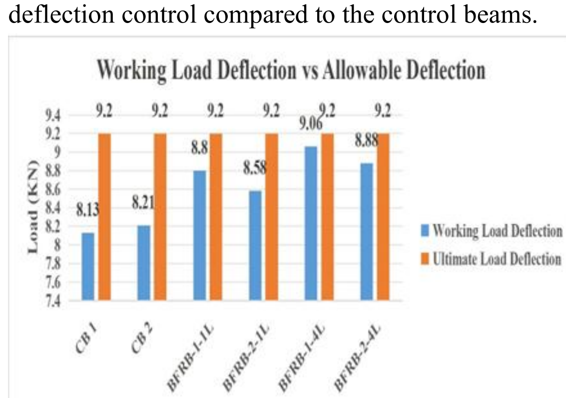

Fig 23. Working Load Deflection Versus Allowable Deflection

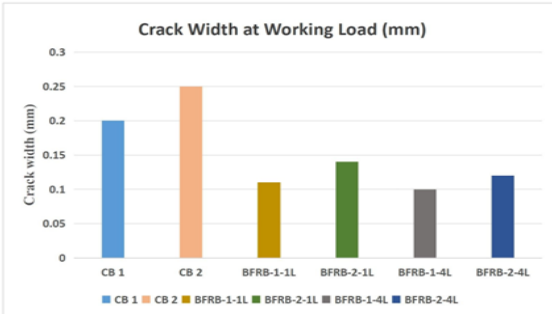

Fig 24. Crack Width at Working Load

Fig 25. Typical crack pattern in Control beams (CB-1 and CB-2)

Fig 26. Typical crack pattern in Basalt Fabric Reinforced beams (BFRB-1-1L and BFRB-2-1L)

Fig 27. Typical crack pattern in Basalt Fabric Reinforced beams (BFRB-1-1L and BFRB-2-1L)

VII CONCLUSION

1 Flexural strengthening of beams using Basalt FRCM is an effective strengthening technique and easy to adopt.

2 Results of the experiment showed with that the Basalt FRCM significantly increases the flexural strength capacity of the RC beams. Depending on the amount of the Basalt FRCM, 15.25% (1 layer) and 35.59% (4 layers) increase in flexural capacity was observed.

3 As depicted by the load deflection behavior, pre-cracking stiffness of beam increases due to the rise in the amount of Basalt FRCM, 49% (1 layer) and 58.6%(4layer).

4 As depicted by the load deflection behavior, pre-cracking stiffness of beam increases due to the rise in the amount of Basalt FRCM, 49% (1 layer) and 58.6%(4 layer).

5 Experimental results show that cracking load of the beam increases with the respect to increase in the amount of basalt FRCM, 11.3% (1 layer) and 40%(4layer).

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