Mechanical behavior of Reinforced Concrete Beams retrofitted by Basalt Fabric

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***Abstract*— The retrofitting of concrete structures has become increasingly important in view of ageing and the deterioration of infrastructure. Retrofitting involves strengthening existing structural elements to enhance their performance with new technology, features, and components. This study involves strengthening the Reinforced concrete (RC) beam by using basalt fibre as wrapping sheets. Basalt fibres, derived from natural volcanic rock, exhibit high tensile strength, corrosion resistance, and durability, making them ideal for enhancing the mechanical properties of concrete and thereby wrapped around RC beams. The U-wrap pattern is adopted for wrapping the beams with basalt fiber-reinforced polymer (BFRP) sheets. The flexural behavior of this strengthened beam is studied. After loading, the damaged beam is retrofitted using BFRP sheets. The flexural behavior of the retrofitted beam is compared with the undamaged one. The strength properties such as compressive strength, and tensile strength of the concrete specimen wrapped with BFRP sheets are also studied. The Rapid Chloride Permeability test (RCPT) was also performed to study the chloride ion ingression in concrete. The findings from this project have the potential to influence future infrastructure maintenance practices, promoting resilience and sustainability in the face of aging infrastructure challenges.**

Keywords: Reinforced Concrete Beam, Basalt fibre, Retrofitting, RCPT.

I. INTRODUCTION

The retrofitting of reinforced concrete (RC) beams has become a critical endeavor in contemporary civil engineering practices as the demand for extending the service life of existing structures continues to rise. Retrofitting involves the application of innovative techniques and materials to enhance the structural performance, durability, and safety of RC beams without the need for complete reconstruction. Retrofitting with Fiber Reinforced Polymer (FRP) sheets is a common and effective technique employed in civil engineering to enhance the structural performance of existing concrete structures[1]. The retrofitting process involves bonding or attaching these FRP sheets to the surface of the structure, providing additional strength, stiffness, and durability[2]. This project undergoes the study of using Basalt Fibre as a sheet for strengthening the structure.[3] Basalt fibers, derived from natural volcanic rock, exhibit high tensile strength, corrosion resistance, low thermal conductivity, fire resistance, and excellent durability, making them ideal for enhancing the mechanical properties of concrete structures [4]. BFRP sheets are lightweight and exhibit good fiber adhesion, facilitating easier handling and effective load transfer. [5] The retrofitting involves wrapping the damaged beams by Basalt fiber reinforced polymer(BFRP) sheets [6]. The retrofitting process using BFRP sheets involves several critical steps to ensure effective bonding and performance. Initially, surface preparation is essential to ensure proper adhesion of the basalt fiber sheets.[7] This includes cleaning and roughening the surface of the RC beam to promote optimal bonding[8]. The basalt fiber sheets are then applied using a combination of epoxy resins and hardeners, which provide the necessary adhesion and mechanical integration between the fiber sheets and the concrete surface [9]. By wrapping the beams with BFRP sheets, the retrofit process aims to provide additional reinforcement, effectively distributing stresses and preventing the propagation of cracks[10]. To further assess the effectiveness of the BFRP retrofitting, this study includes the Rapid Chloride Permeability Test (RCPT) on BFRP-wrapped concrete specimens. The

RCPT is a standard test used to measure the electrical conductance of concrete and provides an indication of its resistance to chloride ion penetration. Chloride ion ingress is a major cause of steel reinforcement corrosion in concrete structures. By performing RCPT on BFRP-wrapped specimens, we can evaluate the enhancement in durability and corrosion resistance provided by the basalt fiber reinforcement.

II. MATERIAL PROPERTIES AND MIX PROPORTIONING

A. Materials Required

Cement: Portland Pozzalano Cement (PPC) flyash based conforming to IS 1489 (Part 1):1991 [11] was used. Standard tests following the guidelines in IS: 4031 were carried on cement sample. The specific gravity of cement is found to be 2.88.

Fine Aggregate: Manufactured Sand was used as fine aggregate. The fraction of sand passing through 4.75 mm sieve and retained on 600 µm sieve with specific gravity of 2.67 was collected and used in the preparation of concrete mix for casting the specimens.

Coarse aggregate: Crushed granite coarse aggregates passing through 20 mm sieve and retained on 4.75mm sieve conforming to IS: 383 – 1970 [12] were used in the preparation of concrete mix.The specific gravity of coarse aggregates was found to be 2.8.

Water: Potable water available in the laboratory was used for mixing the ingredients as well as for curing the specimens.

Superplasticizer: Superplasticizers, named TEC MIX 550 of specific gravity 1.20+ 0.02 @ 30C and pH value of 7-9 are used in concrete to improve its workability, reduce water content, and increase the strength of the hardened concrete.

Steel reinforcement: It includes four 12mm diameter steel bars for longitudinal reinforcement and ten 8mm diameter stirrups spaced at 150mm intervals.

Epoxy Resin: Epoxy Resin named LY 556 with Hardener HY 951, mixed in 10:1 proportion, were used for bonding Basalt Fibre Reinforced Polymer (AFRP) sheets to concrete samples.

Basalt fiber-reinforced polymer(BFRP) sheets: Basalt fibres have high tensile strength, greater failure strain, good resistance to chemical attack, and excellent fiber adhesion. Retrofitting is done by wrapping rc beam with using epoxy.

Table I Properties of BFRP Sheet

Type of fiber	Basalt Fibre
Weave type	Plain
Specific Surface Weight(g/m^2)	200
Density(kg/dm^3)	2.7
Thickness(mm)	0.2
Elastic Modulus(GPa)	85
Melting Point (ºC)	1350

B. Mix proportioning

The M40 grade of concrete consists of cement, fine aggregate, and coarse aggregate with mix ratio 1:1.79:2.8 and w/c ratio 0.35, confirming to IS 10262:2019 [13] is adopted. The quantities of cement, fine aggregate, coarse aggregate, and water to be filled in cubes, cylinder, and beams are calculated based on the mix ratio. Cure the samples under controlled conditions, usually moist curing for 28 days.

Table.II Mix proportion of M40 grade concrete

M40 Grade	For 1 m^3 cube of Concrete (kg/m^3)	Mix Ratio
Cement	412	1
Fine Aggregate	739	1.79
Coarse Aggregate	1166	2.8
Water	144	0.35
Admixture	6.12	0.015

III. EXPERIMENTAL PROGRAM

A.Mechanical Properties

Compressive strength: The cubes of size 150 mm × 150 mm × 150 mm were cast. The specimens were tested on a compression testing machine with a capacity of 2000 KN. The uniform load is applied. The loading rate on the cube is 35 N/mm2 per min. Nine cubes of grade M40 were cast for carrying out compression strength test and the test was performed at 7, 14 and 28 days after curing the concrete cube. Three cubes for wrapping basalt fiber sheet were cast and its compressive strength at 28 days was tested.

Fig.I Compression Testing on cube specimen

Split Tensile strength: Six M40 grade concrete cylinders of size 150mm diameter and 300mm height were cast and the test was performed at 7 and 28 days after curing the concrete cube. Three cylinders were cast for wrapping basalt fiber sheets. The cylinders are fully wrapped around the sides and its tensile strength at 28 days was tested.

Fig.II Split tensile testing on cylinder specimen

Flexural strength: Three beams of size 1700mm x 100mm x 150mm were cast for conducting flexural strength. Steel reinforcement includes four 12mm diameter steel bars for longitudinal reinforcement and ten 8mm diameter stirrups spaced at 150mm intervals. One control beam specimen, a beam to be strengthened with BFRP sheet and a damaged beam retrofitted with BFRP sheet were tested. After loading the beam is retrofitted by BFRP Sheets. U wrapping pattern is adopted. The flexural test is also carried out on the three retrofitted beams. The beam specimen underwent testing in a flexural testing machine loading up to 500 KN. The LVDT (Linear Variable Differential Transformer) is used to measure the deflection of the specimen. The Prosof-14-B software was employed which facilitated accurate reading and monitoring of defection while loading.

Fig.III Flexural strength test setup

B. Durability Test

Rapid Chloride Permeability Test: Two sets of disk specimen of size 100mm diameter and 50mm thickness were cast to conduct RCPT. One control specimen, one M40 grade specimen wrapped with BFRP sheet is cast. The disk specimen is prepared by ensuring proper curing and surface preparation to eliminate any contaminants. Then, electrodes are securely attached to both faces of the disk, ensuring good electrical contact. The disk is submerged in a chloride solution, and a constant electrical potential (60V) is applied across the specimen. The resulting current flow is measured over a specified duration, typically 6 hours, using specialized equipment. This current flow indicates the rate of chloride ion penetration into the concrete. Lower current values signify higher resistance to chloride penetration and thus better durability.

Fig.IV RCPT setup

IV. TEST RESULT AND DISCUSSION

A.Compressive strength

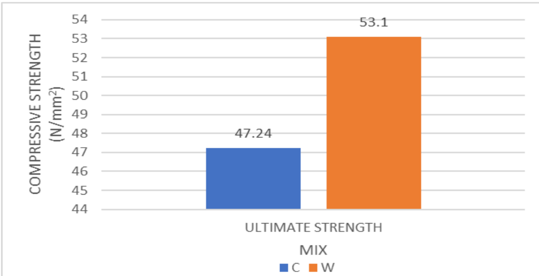

Fig.V Compressive strength at 28 days

The cube specimen achieves 97.9% compared to the Target Mean Strength of Concrete. The Cube specimen fully wrapped with a BFRP sheet increases by 11.41% of the control cube specimen.

B.Tensile Strength

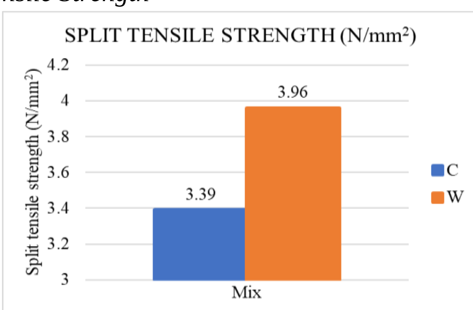

Fig.VI Split tensile strength at 28 days

The Cylinder specimen fully wrapped by BFRP sheet shows an increase of 14.39% of tensile strength than the control specimen. This shows that the BFRP shows better tensile behaviour than conventional concrete.

C. Flexural Strength

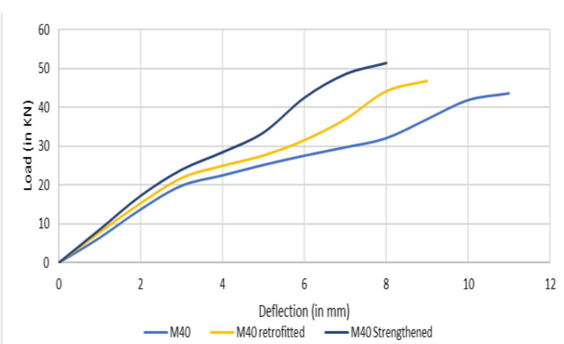

Fig.VII Load vs Deflection graph

The ultimate load of the RC beam which is strengthened by wrapping it with BFRP sheet is increased by 17.92% and deflection is decreased by 27.27 % from the control specimen. The ultimate load of the damaged RC beam which is retrofitted by BFRP sheet is increased by 7.36% and deflection is reduced by 18.2% from the control specimen. The reduction in deflection suggests an increase in stiffness, indicating that the BFRP wrapping not only increases strength but also improves the rigidity of the beams. This reduced deflection contributes to the overall stability of the structure, making it less prone to deformation under applied loads.

D. Crack pattern Investigation

Fig.VIII Crack pattern of beam

The crack pattern is significantly reduced in cube specimen wrapped with BFRP sheets. The crack width in split tensile of cylinder specimen wrapped with BFRP sheet is also controlled. The flexural shear cracks are developed in conventional beam. The crack pattern in damaged beam retrofitted by BFRP sheets is not visible due to adoption of u-wrap pattern of sheets but crushing of concrete is seen in top loaded surface of the beam.

E. Chloride Permeability

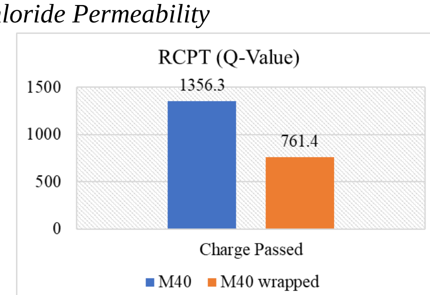

Fig.IX RCPT result

The charge of 1356.3 columb was passed through the control disk. The concrete wrapped with BFRP sheet shows 43.86% reduction in charge passed than the control disk. This shows BFRP wrapping significantly reduces the chloride ion penetration.. This shows that BFRP wrapping significantly reduces the chloride ion penetration.

V. CONCLUSION

The wrapping of concrete specimens by Basalt fiber sheet shows increased strength behavior in concrete. The compressive strength of the cube specimen is increased by 11.41 % when fully wrapped with BFRP sheets. The tensile strength of the cylinder specimen is increased by 14.39% when wrapped with BFRP sheets. It reduces the crack width in the split tensile of the cylinder specimen. The flexural performance of damaged beams wrapped with BFRP sheets shows improved results. The load-carrying capacity of the rc beam U-wrapped by BFRP sheet is increased by 7.36% and deflection is decreased by 18.2% from the control specimen. This clearly demonstrate that BFRP sheets significantly enhance both the strength and stiffness of RC beams, whether used for strengthening new structures or retrofitting damaged ones. This depicts that the BFRP sheet can be effectively used for retrofitting the damaged beam. While conducting the RCPT test, the concrete wrapped with BFRP sheet showed a 43.86% reduction in charge passed than the control disk. The BFRP sheet shows improved behavior in view of strength gaining and durability, hence recommended for retrofitting the existing structural elements.

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