



## RESEARCH ARTICLE

### FLEXURAL BEHAVIOUR OF STRUCTURAL RC SLAB RETROFITTED WITH BASALT FIBRE ALONG WITH MECHANICAL ANCHORAGE

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#### ABSTRACT

The experimental work was conducted on slabs to study the effect of BFRP on flexural behavior of the slabs under the static loads, using cross wrapping technique with mechanical anchoring. The BFRP was to be introduced to slabs in the form of cross wrapping at flexural zone by wet lay-up technique then it was anchored with bolts and plates as per the guidelines of the manufacturers. Control slabs were casted and tested after 28 days under uniformly distributed loading case. Strengthened slabs were tested after 6 days of strengthening and once after it were anchored. From the experimental results it was revealed that the initial crack strength and ultimate load strength of retrofitted slabs with mechanical anchoring are found to be increasing by at least 39.585% comparatively and stiffness of wrapped slabs were found to be increased.

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## INTRODUCTION

Strengthening of existing reinforced concrete structural elements has been one of the most important activities in civil engineering. The upgrading of existing structures is an integral part of structural engineering practice. Strengthening or retrofitting of older structures to resist higher design loads or increase ductility has been accomplished with traditional materials such as externally bonded steel plates and steel jackets since in the 1960s. In recent years an increased application of new repair and strengthening techniques of reinforced concrete structures has been noted. Structural repair and rehabilitation of reinforced concrete structures has become an increasing important option for all deteriorated/damaged structures to restore, enhance the load carrying capacity and increase the life span of the structure. A slab is a flat two dimensional planar structural element having thickness, small compared to its other two dimensions. Reinforced concrete slabs are among the most commonly used structural elements. The use of FRP to strengthen civil engineering structures started in 1980's. FRP system that is non-metallic material is considered to be a beneficial technique.

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Composites are used because overall properties of the composites are superior to those of the individual components. These new materials are applicable to both construction of new structures and maintenance and rehabilitation of existing structures. Fibre-reinforced composites are used in some of the most advanced constructions, and therefore most expensive. Basalt fibres are made from basalt rocks which are the most common rock type in the earth's crust. The fibres are manufactured from melted rock which is then extruded through small nozzles to produce continuous basalt fibre.

## RESEARCH SIGNIFICANCE

Various research works conducted using basalt are

- Usage of BFRP (bar, laminates and sheets) in strengthening of structural member.
- Physical and chemical properties of BFRP.
- Effectiveness of different wrapping technique using other FRP's.

Research works carried on beams using basalt fabric and obtained best positive results, but till now very little research work carried on two-way RC slabs using BFRP wrapping and less research work carried on FRP sheets using of anchor system.

In this work, an attempt was made by the authors, to evaluate the impact of BFRP sheet on flexure strength of slabs with anchorage.

## MATERIALS

Basalt fibres are made from basalt rocks which are the most common rock type in the earth's crust. The fibres are manufactured from melted rock which is then extruded through small nozzles to produce continuous basalt fibre. Basalt FRP (BFRP) is the latest FRP composite that has developed within the last ten years and has been proven to have advantages in achieving the goal of enhancing safety and reliability of structural systems compared with the conventional carbon, glass and aramid FRP composites. BFRP shows advantageous characteristics in mechanical, chemical and high ratio of performance to cost in comparison to CFRP, GFRP, AFRP, steel bars. BFRP has a higher strength and modulus, a similar cost, and more chemical stability compared with E-glass FRP; a wider range of working temperatures and much lower cost than carbon FRP (CFRP); over five times of strength and around one third of density than commonly used low-carbon steel bars. Due to above advantages, BFRP has already become an attractive alternative for replacing conventional construction materials and is expected to enhance structural safety and sustainability. The properties of the basalt fibre, which is used in the present work is represented in Table 1.

**Table 1. Properties of UD Basalt Fabric (Bas Uni 230)**

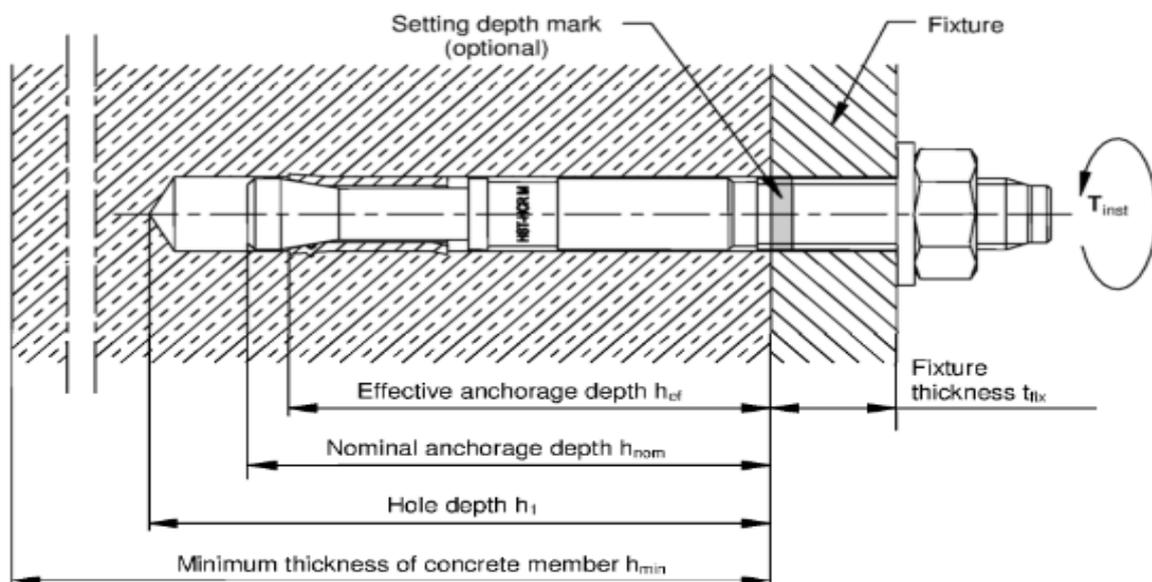
Properties	UD Basalt Fabric (BAS UNI 230)
Fiber orientation	Uni-directional
Weight of fiber g/m <sup>2</sup>	230
Fiber thickness mm	0.100
Ultimate elongation (percentage)	2.6
Primary fiber tensile strength Mpa	2100
Tensile modulus Gpa	105

An anchor bolt is used to attach objects or structures to concrete. There are many types of anchor bolts, consisting of designs that are mostly proprietary to the manufacturing companies.

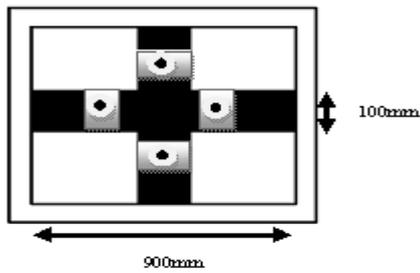
All consist of a threaded end, to which a nut and washer can be attached for the external load. Mechanical anchors are the type of anchors bolts which works in the mechanical means to hold the base material such as brickwork, blockwork, stone, standard and reinforced concrete. Generally mechanical type anchor bolts are simple, effective and reliable use in hard base materials, common type of mechanical anchors bolts are expansion or wedge type anchors and screw anchors. Mechanical type anchors are commonly used because their ease of installation and economical, compared to chemical anchors. Wedge or expansion anchors are used in this research work. An anchor plate is a MS plate which is used as a fixture with a specified diameter of hole, through which certain diameter of anchor bolt runs into the base material such as brickwork, blockwork, stones and reinforced hardened concrete. The main purpose of the plate used is to hold the FRP sheets against the load and prevent de-bonding. The different parts of a bolt with label is shown in Fig.1

## METHODOLOGY

The experimental study was conducted to test the reinforced concrete slabs. This includes testing a control slab and retrofitted slabs. The main objective of the investigation was to study the flexural and ductility behaviour of concrete slabs retrofitted with BFRP sheets with mechanical anchorage bonded onto the flexural zone of the slab. Bolts used in this research work are HILTI's wedge anchors or expansion anchors of 8mm diameter 3inch length HST wedge anchor bolts. And 0.118in (3mm) thickness of 2.559in x7.874in (65mm×200mm) dimension MS plate as a fixture or anchor plates used in this work. Totally 24 anchors bolts and 4 MS plates were used per anchored slabs. A typical layout a slab with wrapping of basalt fibre and mechanical anchoring is shown in Fig 2. The FRP application included the resin system made of two parts namely the resin, the hardener and the fiber sheets. The concrete surface was cleaned and completely dried before the resin is applied. A first coat of thin layer of resin was applied and the FRP fabric precut to the desired dimension was then wrapped directly onto the surface.



**Fig. 1. Labeling of a typical bolt**



**Fig.2. Externally bonded BFRP sheets with anchorage system**

After the application of the FRP sheet wrap, a second layer of resin was applied to the surface to allow impregnation. The second layer of FRP sheet was then impregnated on top of the first layer. Adequate pressure was applied until the resin was squeezed out. The wrapped specimens were left at room temperature to allow air curing for seven days to allow bonding of the laminates.

**Installation of wedge or expansion anchor bolts performed in four steps as follows:**

- Drill a hole with the prescribed diameter mond core bit. Diameter of drill bit used should equal to diameter of anchor bolt.
- Cleaning of hole.

- Using a hammer, tap the pre-assembled anchor through the object being anchored and into the hole. The anchor should be seated firmly against the base plate.
- Tighten bolt or nut to the specified torque, using a torque wrench or with handy mechanical tools.

Strengthening of slabs explained above is represented with pictures in Fig. 3, Fig. 4 and Fig. 5. Test specimens were subjected to flexural test. The same testing program was applied to both controlled as well as on retrofitted slabs with mechanical anchoring. The specimen was also painted with lime wash in order to easily note the crack pattern of the specimen. The setup was carried out with a 27.5578 U S ton (25 ton) loading frame, a loading jack was fixed on top of the specimen to apply load. To give the udl effect to the slab, loading channels were used such that the loads that were centrally applied were uniformly distributed on the slab as shown in Fig 6. The deflection at the bottom of the slab was measured using dial gauge. Totally five dial gauge's were used for this experiment. The placement of these dial gauges are as one at the centre of the slab and other four at different points as shown in the Fig 6.

The load was applied using a hand held lever with uniform increment up to the failure load. The dial gauge readings were noted down to calculate the deflection of the slab. The load was incremented manually and the readings of the dial gauge were taken at an interval of 449.4 lb (2kN).



**Fig.3. Compacted concrete, Curing of slab using gunny bags, and anchor bolts and plate**



**Fig.4. -Application of BFRP Sheets**



**Fig.5. Installation of anchors carried out as per previously specified steps in this project work**



Fig.6. Layout and positioning of dial gauges, Test setup

Table 2. Comparison of Experimental Results

Type of slab	Type of wrapping	Failure load lb (kN)	% Variation
Control slab	-	26964(120)	-
Basalt fibre retrofitted with mechanical anchoring slab 1	Cross type wrapping	38199(170)	41.67%
Basalt fibre retrofitted with mechanical anchoring slab 2	Cross type wrapping	37075.5(165)	37.5%

The results and the graphs are discussed separately. The deflection was tabulated at each increment of loading. Also the complete crack patterns and the failure load were recorded in each test.

## RESULT AND DISCUSSION

For the control and retrofitted with mechanical anchoring slab, the deflection was measured at the mid span and other four points.

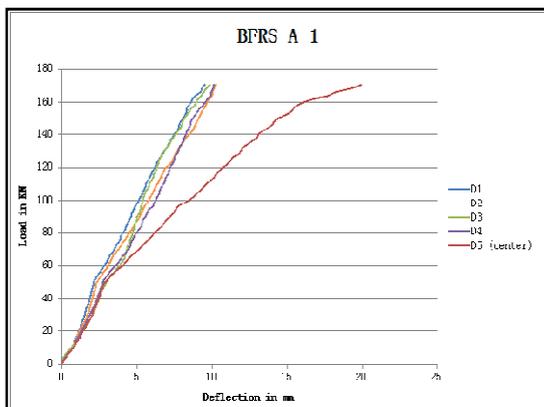
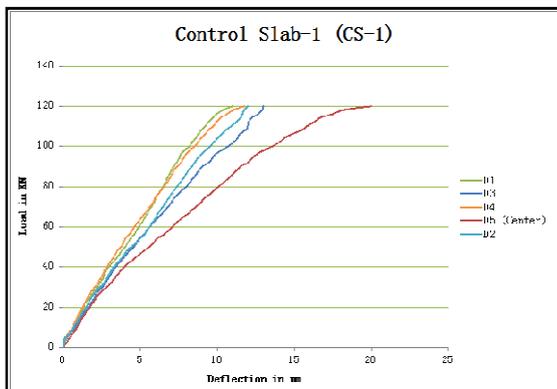


Fig.7. Load v/s Deflection Curves for Control Slab and retrofitted slab

The load-deflection curve has been plotted for the same as shown in Fig 7 and the failure crack pattern is shown in Fig 8.

A comparative study of failure load between control slab and Basalt fibre retrofitted with mechanical anchoring slab is shown in Table 2.



Fig .8. Crack pattern of control slab and retrofitted slab, Mode of failure: Fracture of FRP and Failure of anchor Bolt

## Conclusion

This experimental study investigate the cross type BFRP wrapping effect on ultimate load carrying capacity, deflection and stiffness of slabs compared with control slab.

- All the two-way RC slabs strengthened with BFRP with mechanical anchoring in single layer were capable to take more load than the slab without strengthening (control slab).
- Suitable anchorage system was introduced to prevent the de-bonding of BFRP wrap in the flexural zone to utilize the complete strength of the BFRP sheets.
- The 8mm wedge or expansion anchor bolts with MS plate of 3mm thick compositely acts as an anchorage system was provided at the de-bonded region in the flexural zone.
- The slabs retrofitted with BFRP cross wrap with mechanical anchoring were found to effective in the increase of load carrying capacity by 39.5% as compared to control slab.
- The slabs retrofitted with BFRP sheets with anchorage were failed by fracture of BFRP wrapped in the flexural zone with complete utilization of its strength and anchor bolts loosened due to increase of crack width.
- The stiffness was found to be high for slabs retrofitted with BFRP sheets as compared to control slabs.
- Overall it shown that BFRP sheets effectively increases the load carrying capacity and stiffness of slabs.

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