IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

A BEHAVIORAL STUDY OF BASALT FIBRE AS A RETROFITTING MATERIAL

[1]Tapsi Deven Sata, [2]Nirav Patel, [3]Prasad Karad

[1]Research Scholar, [2]Assistant Professor, [3]Assistant Professor
[1]Dept. of Civil Engineering,
[1]Parul Institute of Engineering and Technology, Parul University, Vadodara, Gujarat, India

Abstract: The concept of externally reinforcing damaged reinforced concrete members to restore their strength is well known today. Depending on the severity of the damage, the component is externally modified using methods such as cross-sectional enlargement, external panel bonding, external pre stressing, casting, and fiber-reinforced polymer (FRP) composites. This article describes FRP composite technique that is to apply FRP composites in fabric/tape form using adhesive on defects like cracks in structural members. Apart from retrofitting, this process can also be used to add strength or increase the load-bearing capacity of an element without increasing the section size. Fabrics made from carbon, glass and basalt fibers are generally used as external reinforcement. Each gives different results as per their characteristics, magnitude and type of load withstanding, type and form of fibre fabric used for that and also as per different wrapping patterns. For this purpose, the study considers structural reinforced concrete beams wrapped with different FRP composites fabric in different patterns and tested under four-point loading system as comparison criteria. The main focus of the paper revolves around basalt fiber fabric, and whether it is a better option as a retrofit material compared to others.

***Index Terms* – Adhesive, Four point bending test, Retrofitting, Woven Fabrics**

I. INTRODUCTION

When a person gets a paper cut or slight deep cut, he tries to cure it by applying bandage over the wound. The similar thing is FRP composite technique i.e. applying composite fibres fabrics over the crack like defects on RCC member. Only fibre reinforced composites (FRP) does not supplement the strength of the concrete member until should be applied at the bottom along the longer side where member will experience tension. Tensile strength of FRP is helpful in resisting tension in slab or beam. FRP tapes will function similar to the main tensile reinforcement of the concrete member. In order to strengthen beams in shear, FRP tapes should be applied vertically (perpendicular to longer side) in same manner as the stirrups inside. FRP fabrics are applied around the circumference of columns to restrain the lateral expansion. Polymer matrix is applied with it for bonding FRP composites with concrete surface. Generally Epoxy resin is used as it forms protective coatings that makes concrete resistant to moisture and chemicals is also used as filler and adhesive. Epoxy alone can increase the bearing capacity of concrete as it has good tensile strength of its own. Therefore, an FRP composite along with polymer matrix becomes great technique for retrofitting deteriorated concrete members and also to increase load carrying capacity of existing members. FRP tapes/fabric should apply as per direction of load acting on the member.

To support the flexural strength of slab or beam, fabric of FRP composites like Glass, Carbon, Aramid and Basalt can be used. These fibres are available in different forms such as long fibres, short fibres, chopped fibres, continuous fibres, non woven, mesh and fabrics. These different forms have different applications. For example, chopped fibres are directly mixed with concrete to improve its strength while fabrics and mesh are applied externally on casted concrete members. Fabrics are weaved in several different manners; each gives different strength as per its weaving technique.

II. TYPES OF WOVEN FABRIC

The Plain weave

Plain weave is the most basic and common in use weave pattern. Here, each warp fibre goes beneath and above each weft fibre alternatively. As this type of weave looks symmetrical, it evenly distributes the load and thus giving stability. It can be easily recognized as the squares are formed in the fabric due to overlapping of fibres. Also due to these square formation, fabric is porous[8].

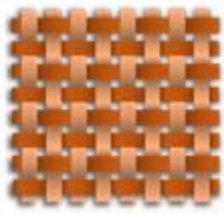


Figure 1. The plain weave

The Twill weave

This type of weave is characterized by diagonal rib pattern called the twill line. Here, each warp fibre goes beneath and above two weft fibre alternatively. Thus it enables more yarn per unit area without losing its stability. It looks darker on one side and lighter on other. It can be easily recognized as the stairs are formed in the fabric due to overlapping of fibres[8].

Figure 2. The twill weave

The Bi-Axial weave

In this type of weave, two different layers of fibres are kept perpendicular to each other and are stitched that way. This way it can sustain load from both directions and provides better strength than plain weave. By laying fabric aligning with direction of load, it will be able to resist them with full utilization of its strength[8].

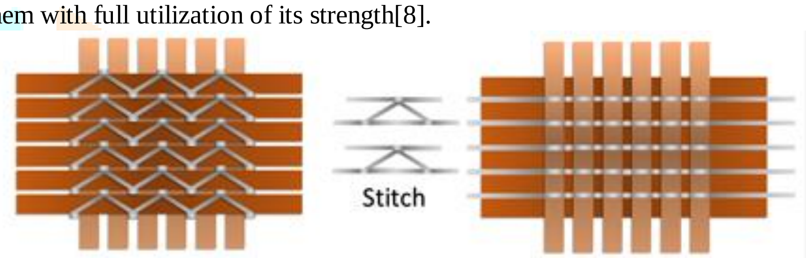


Figure 3. The Bi-Axial weave

The Tri-Axial weave

This type of weave is characterized by diagonal rib pattern called the twill line. Here, each warp fibre goes beneath and above two weft fibre alternatively. Thus it enables more yarn per unit area without losing its stability. It looks darker on one side and lighter on other. It can be easily recognized as the stairs are formed in the fabric due to overlapping of fibres[8].

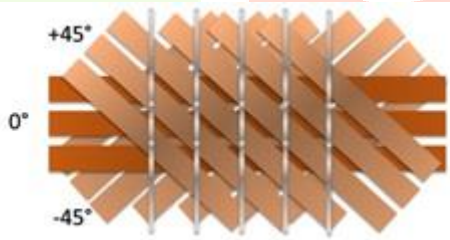


Figure 4. The Tri-Axial weave

III. Related Studies

In practice, carbon fabrics are mostly used for retrofitting RCC members that are beams, slabs, columns and also beam-column joints. Researchers have tested carbon, glass and basalt fibres for their durability, mechanical characteristics and strengthening effects. Tensile test of single filament of each was conducted to get mechanical properties of each fibre. Result showed that basalt had 30% of tensile strength of carbon fibre and 60% of tensile strength of S- glass fibre. For durability comparison of all 3 fibres, tests conducted were Alkali- resistance, weathering resistance, autoclave stability and thermal stability. Tensile strength test was conducted after each test as comparison criteria. In alkali resistance test, all 3 fibres were immersed in 1M NaOH solution for 7, 14, 21&28 days. Later volume reduction was determined using SEM images and tensile strength of each was tested. Both basalt and glass fibre showed significant amount of volume and strength reduction compared to carbon but glass fibre showed the most reduction in least time. Fibres were not much affected by weathering test and fibres differed by 1-2 % in test for autoclave stability. Fibres were heated for 2 hours at 100, 200, 400, 600 and 1200°c and later checked for tensile strength under thermal stability test. Up to 600°c, reduction was noticed in carbon and glass fibre but basalt fibre retained 90% of its strength at normal temperature. At 1200°c which may be considered as good as fire, carbon fibres were completely molten and glass fibre too but basalt maintained its shape and did not lose its mechanical integrity. These tests concluded that basalt fibres are better in tensile strength than glass fibres. Also have more failure strain compared to carbon fibres. As a positive advantage to other fibres, basalt fibres are resistant to impact load, chemical attacks as well as they are fire resistant [8]. Due to these qualities basalt fibre may be use like a retrofitting material or strengthening material.

Table 1. Material Properties of Basalt fabric [6]

Material characteristics	Basalt characteristics
Density (g/cm)	2.67
Coefficient of thermal expansion	8
Tensile strength (Gpa)	4.8
Elastic modulus (Gpa)	89
Poisson ratio	0.26

Researchers strengthen RCC beams for flexure with basalt fibre fabric to test basalt fibre as a flexure strengthening material for reinforced concrete beam members. They casted RCC beam of dimension 150x200x3200 using M25 grade of cement. Conducted necessary tests (specific gravity, fineness modulus, water absorption, compressive strength etc) for knowing material properties of cement, coarse & fine aggregate and basalt fibres. Initially they tested one casted beam (control beam) to know its failure load. Later they applied 80% of this failure load to the rest of the beams to retrofit them with basalt fabric and then tested again for four – point bending configuration. Properties of Basalt Fabric are mentioned in table 1 [6].

Beams were retrofitted using two wrapping profiles that are U – shaped that covers three side of the beam and other is Bottom layer that provides only bending resistance. Control beam showed 19.8KNm ultimate moment. Retrofitted beams showed ultimate moment of 27.2KNm and 23.1KNm for U shaped and Bottom layer wrapping respectively. This shows that U shape wrapping had been more effective than just bottom layer wrapping as u shape wrapping provides shear resistance along with flexure support. Basalt fabric increase load carrying capacity of conventional RC beam by 40% [6].

Few researchers also tried different wrapping profiles to know which gives satisfactory result to improve flexure performance of the beam. Few of them are shown in figure below [1].

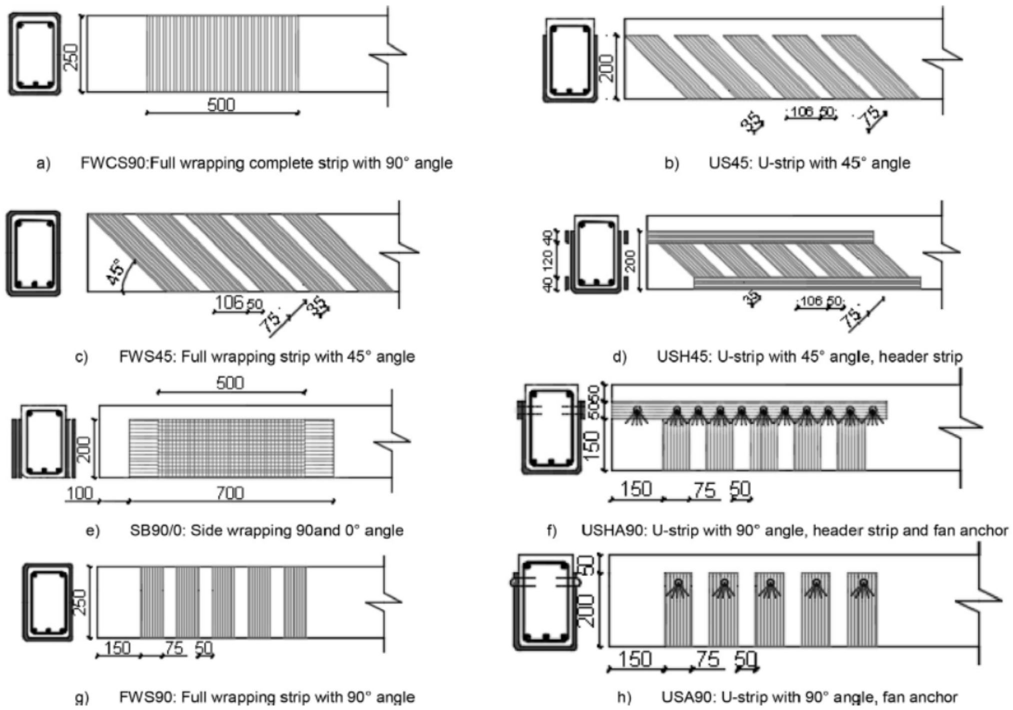
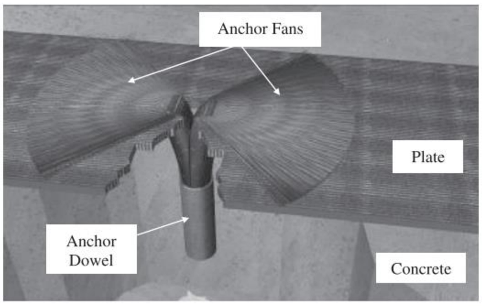


Figure 5. The Customization of strengthening of specimens

In figure:5(a) basalt fabric is wrapped at midspan where maximum deflection is likely to occur. Fabric was fully wrapped on all four sides of beam. This helped the beam to increase its shear and flexure capacity to 100% of the controlled beam. This pattern gave the satisfactory result than all others. There was 89% increase in flexure and shear capacity of the beam by following pattern in fig (c), where basalt strips were used. These strips can be cut from the fabric and also is available in form of tape. In market, basalt tapes of bidirectional weaving come with 40, 50 and 75mm of width. In pattern shown in fig (e), two layers of basalt fabric is applied on sides of the beam leaving its bottom. So strengthening beam only for shear. That resulted in increase of 73% of its shear capacity. In pattern (g), tapes are wrapped fully at 90° angle leaving 50mm gap in between tapes. There was 67% increment in flexure performance of this pattern which is less compared to beam with pattern (a) which has no gap in between. This shows that if our need of increasing or regaining strength is not much then pattern (g) should be applied instead of pattern (a) as it will be more economical in practical life. Fig (b) has U shaped profile. Strips are wrapped at 45° angle on just three sides of the beam. This resulted in increasing bearing capacity to only 61%. This pattern mainly fails due to de bonding of fabric with concrete surface (side face of beam) and not due to reaching ultimate strength of the fabric. This shows selection of pattern is very important as applying less effective pattern would not make fabric to get to its maximum use. Altering this pattern by just applying an additional horizontal strip at the start and bottom end of the beam over the slanted strips as shown in fig (d) can increase strength by 72% of the control beam. This additional horizontal strip sticks with slanted strips and prevents them from detaching [1].

Another technique of keeping u shape profiles in place is FRP anchor technique as shown in fig (f) and (h). FRP anchor technique works similar as push pins on pin up board. Push pins are pushed through the paper in to the board to hold it there. Similarly holes are made in concrete surface by drilling over FRP strips and then part FRP anchor is inserted inside it and remaining part is sticked with FRP strip using resin.

(a) Bow-tie anchor (b) Single fan anchor



(c) Bow-tie anchor system

Figure 6. FRP anchors

These anchors are basically same bundled fibres that are used as strips. Initially they are saturated with resin completely and excess resin is drained out. Holes drilled in the concrete surface are filled with resin. The bundled part of the fibres is inserted in resin filled hole about 25mm. It is called dowel. The unbundled part that looks like fan is then attached with FRP strip using resin. This system is better as it bonds fibres with fibres and it easily overcomes the problem of de bonding of fabric with the concrete surface. Here the anchors can be inserted at different angles i.e. perpendicular to the surface (90°), at angle below 90 or angle above 90. Each gives different result. Anchors should also be inserted at a distance of not more than 10 inches. Study on this has been done in [1]. Studying result of different wrapping profiles, we found that full wrapping profiles were more effective then U profiles. However in practice as beams already exist in structure, we can retrofit them with U profiles only. So anchorage system should be studied more to get its proper advantage[2].

Using carbon or glass fabric instead of basalt can give different performance for these patterns. It is shown in the study [3] that considering similar patterns to basalt, CFRP (carbon fibre reinforced polymer) enhance flexure and shear performance of the beam in range of 40 to 125%. While GFRP (glass fibre reinforced polymer) can enhance up to 60% of load carrying capacity.

Density of basalt is 2600kg/m^3 which is one third of density of steel (7850kg/m^3). This implies that basalt is lighter than steel which helps in decreasing dead load of the structure. So researcher studied the behaviour of basalt as reinforcement replacement [5].

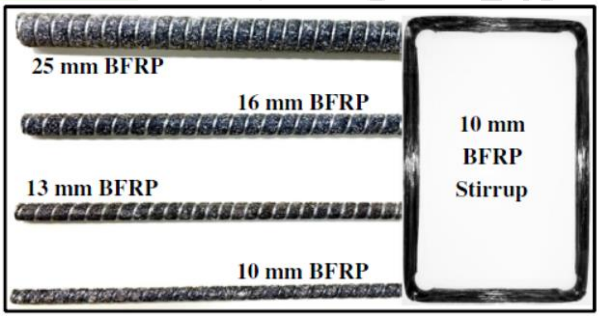


Figure 7. Basalt rebars

Mohsen A. Issa did the flexure test on basalt reinforced beams. Few beams were reinforced with basalt stirrups and few of them were not. They were checked for different modes of failure, different crack patterns, its load vs. deflection behavior, its load vs. strain behavior and finally increment in their shear strength. This experiment was performed considering that the shear strength of beams with FRP stirrups are weak than beams with steel stirrups. This is because of difference created in transfer of shear through dowel action and aggregate interlock unlike flexure. Also there is low axial stiffness in FRP reinforcements compared to steel which in turn will lead to increase width and depth of the diagonal cracks. Due to which there will be reduction in shear transfer through aggregate interlock. Due to less transverse strength of FRP reinforcement, their contribution in shear through dowel action is negligible. Certain numbers of beams were casted considering only longitudinal reinforcement and no shear reinforcement with various reinforcement and span to depth ratios. Those beams with shear reinforcement also varied in span to depth ratios and no. of basalt stirrups provided one each span of specific beam. In of the beams they provided basalt fibre stirrups at one and steel stirrups at other end. Steel stirrups were provided at the mid-span of every beam. In flexure, there were steel rebars in compression zone while 10, 13, 16 and 25 mm of basalt fibre rods in tension zone of respective beams. This study showed that shear capacity of both shear reinforced and non-shear reinforced beams increased when the no. of basalt stirrups increased for the same span to depth ratio and decreased as the span to depth ratio increased. Also under the same applied load in shear reinforced beams, the strain in the stirrups decreased with increase in reinforcement ratios of beams with same span to depth ratio but with the increase in span to depth ratio, the strain in BFRP stirrups also increased. This shows that basalt functions great as tensile reinforcement due to its high tensile capacity but does not function satisfactorily as shear reinforcement.

By gluing continuous basalt fibre together using resin, basalt tendons can be formed. Tensile strength of these tendons is in between 1000 to 1300 MPa while that of steel reinforcement is 500 MPa. There is no yielding during tensioning of basalt fibres. Also considering anti corrosive nature of basalt fibres, BFRP tendons are good replacement for steel bars. Such study has been done in [4].

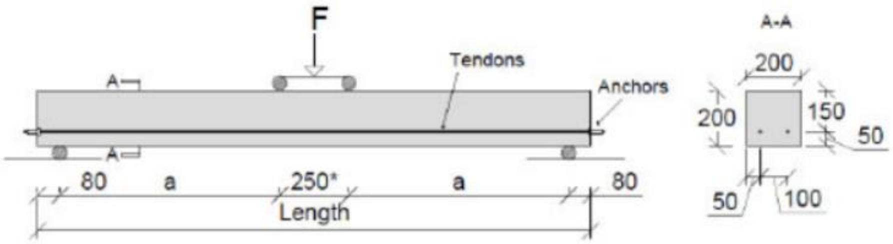


Figure 8 Flexure test for basalt tendons

Marianne Inman made comparison between basalt fibre tendon and steel rebar in concrete beams on their mechanical and environmental performance. Under mechanical performance, 9 basalt reinforced and 3 conventional beams were tested for four-point loading test to get maximum shear force value before fracture of concrete, maximum bending moment at mid-span, the value of shear force when micro cracks starts developing, deflection value at maximum load value which fails beam and lastly maximum strains in mid-span were calculated by attaching strain gauges. 2 x 10mm diameter tendons were placed in bottom of beams and pre-stressed to 50% of its ultimate strength. They were tightened with end anchors and glued with steel plates at the end of beam using M24 threaded bolts. Tendons were formed by gluing basalt fibres with epoxy resin and made sanded finish to increase concrete bonding. Under environmental performance, Life cycle assessment has been carried out which includes the acquisition of basalt rock from mine, its crushing, transporting it to factories for carrying out its melting in furnace and drawing them into continuous basalt fibre (CBF). The LCA was done using software SimaPro Analyst v.8.0.5.This result from LCA were compared with life cycle emission data from environmental product declarations (EPD). In BFRP concrete beams, 93.7% which is largest contribution to emissions was done by concrete, 5.5% by resin used and 0.4% by furnace electricity consumption, mining and transport and also in steel reinforced beams, largest contributor to emission was concrete by 56.2% and 43.8% by steel. She has conclusively proven that BFRP rebar is lighter and stronger alternative to steel. And the only drawback of BFRP rebar they have found is low value of elastic modulus of BFRP tendons compared to steel which results in excessive deformation at service limit state.

IV. CONCLUSIONS

Basalt fibre in form of rebars, as tendons for pre-stressed concrete, as fabric for FRP composite technique or alone as a fibre in different forms has excellent advantages over other FRP composites. Manufacturing and production of basalt fibres is cheaper and easy than glass or carbon fibres. Even carbon has slight more tensile strength than basalt, basalt outruns carbon in chemical resistance, fire resistance and resistance to weathering effect. The main advantage of basalt is it's very cheaper than others and give same results as carbon and better than glass in retrofitting. Considering these points, basalt should be use in daily life as a retrofitting material.

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