Literature review on FRP wrapping over structural components

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Abstract – *Most of the researchers use FRP to strengthen and retrofit structural components. Fiber reinforced polymer is a composite, in which the matrix is a polymer and the fibers used for reinforcement are aramid fiber, carbon fiber, glass fiber, and basalt fiber. In which external wrapping of FRP on structural components has become a popular practice. Among these, AFRP (aramid fiber reinforced polymer) has the highest tensile strength, but it is not widely used in industries. Because AFRP has a cost, it is more than basalt and glass fiber. Using FRP for external strengthening does not change the buckling shape of steel tubular structures. It can effectively delay local buckling, prevent outward buckling, and also delay overall buckling.*

Key Words: Fiber reinforced polymer, Aramid, Steel structures, Wrapping, Strength.

1.INTRODUCTION

Several studies were conducted to determine the behavior of FRP - strengthened steel structures, subjected to static axial compression loading, and therefore the results are well documented in several analysis articles [5]. New developments in polymer technology have introduced new things like fibers and fiber reinforced polymers (FRP) to strengthen and improve the overall behavior of concrete structures [11]. Synthetic fiber reinforced compound (FRP) has been widely utilized in building construction, due to its high durability and low weight [8]. Retrofitting structures from natural calamities like floods, fire, and sensitive earthquakes has become a necessary construction activity for both concrete and steel structures. So, the introduction of FRP material is a great advantage for structural components. Previous experimental studies in this field demonstrated a significant positive impact on the retrofitting of structures using fiber reinforced polymers (FRPs) [7].

1.1 FRP

A fiber-reinforced polymer (FRP) is a chemical component. It consists of a matrix and fiber. It is usually used in industries like construction, transport, and marine to make structures resistant to deformation. Furthermore, it also improves the strength, safety, durability and reduces the formation of cracks. A skilled person will be needed for the installation process. Installation of FRP includes the following procedures, like site preparation, in which wet surfaces should be avoided because they cause the formation of bubbles. The next step is surface preparation. The surface should be cleaned and roughened to ensure the bond between resin and FRP. After that epoxy is applied on the surface and then FRP sheet is installed. There are various types of wrapping styles in the external bonding of FRP. They are fully wrapped in style, with strip type wrapping at various angles like 0°, 45°, 90°, and U- wrapping style.

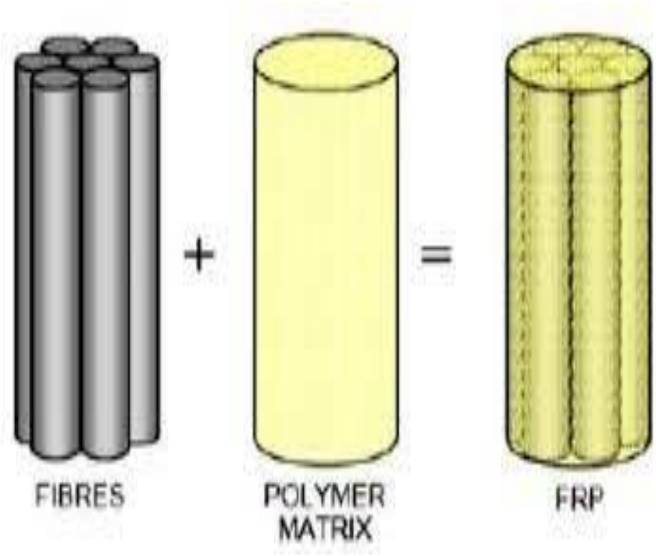

Fig -1: FRP (Fiber-reinforced polymer)

Some advantages of using FRP are

- It is lightweight, so the dead load will not increase.
- Corrosion-resistant
- High impact strength
- Electrical insulation
- Easy installation
- Low operating expenses
- Durable
- Low cost
- Waterproof

- Easily recyclable
- Long service life
- Reduces the formation of cracks.

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Fig -2: FRP wrapping on column

1.2 Epoxy resin

For the installation of FRP on the surface of structural components, polyester resins are most typically used. It is a viscous liquid resin containing polyester and a compound, chiefly phenylethylene. These resins are very easy to use, cure quickly, and can withstand high temperatures. They are made by the reaction of an epoxide with a hardener or polyamine. So, they will have a strong cross-linking bond to create a very tough and stiff structure. The most commonly used epoxy resin is diglycidyl ether bisphenol A. Some examples of hardeners are polyaminoamides, aromatic amines, and aliphatic amines. On curing, epoxy has very low shrinkage, so it gives more stability. The viscosity of epoxies is higher than that of polyesters. 900 centipoises are the starting range of most of the epoxies. Epoxy resins are applied to the dry fiber sheets in the field, and then they can be cured in-situ. This will ultimately provide strength. It acts as an adhesive that holds the fiber sheet to the substrate.

Some advantages of epoxy are

- Good adhesion
- Chemical resistance
- Heat resistance
- Good mechanical properties.
- Outstanding electrical insulation properties.

It is used in construction, automotive, electrical, and aerospace. The chemical resistance of epoxies is good against basic solutions. Epoxies are costlier than polyesters, and cure times are longer.

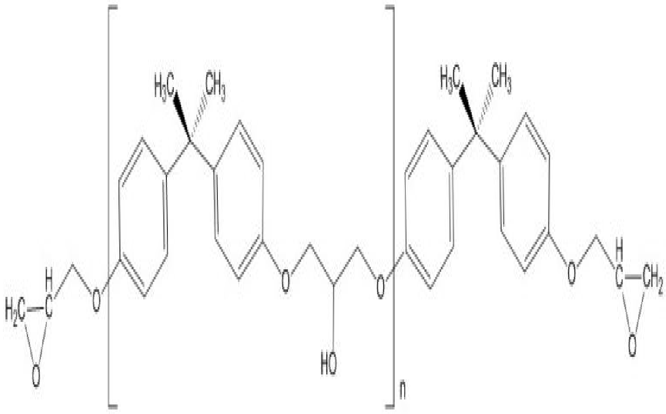

Fig -3: A epoxy resin structure (Di glycidyl ether of bisphenol

2. TYPES OF FIBER

2.1 Aramid Fiber

Aramid fiber was first developed by Stephanie Kwolek (a Polish-American chemist) in the 1970s. The development of aromatic polyamides was mainly due to the discovery of lyotropic liquid crystalline aramid. They are mainly a bright golden yellow. They have a density of 1.44 g/cm3 and a Young's modulus of 70.5-112.4 GPa. Aramid Fiber is additionally called Kevlar fiber. It is the primary organic fiber with a high tensile modulus and strength.

Aramid shares a high degree of orientation with alternative fibers like ultra-high-molecular-weight synthetic resin, a characteristic that dominates their properties. Aramid fiber is additionally known for its high durability, toughness, and extremely high-destined organic fiber manufactured from polymeric amide. This fiber has abrasive resistance; they may abrade against one another by weakening the sheets. Aramid fiber is created from artificial products characterized by strength (five times stronger than steel on an equal weight basis) and heat-resistance. [12].

Fig -4: Aramid fiber

2.2 Carbon fiber

Carbon fiber (CFRP) is a strong fiber. CFRPs have high rigidity. The primary content of CFRP is produced from a precursor polymer such as polyacrylonitrile (PAN), rayon, or petroleum pitch. The tensile strength of CFRP is 3500- 7000 MPa, and the elastic modulus is about 230-650 GPa with an elongation of 0.6 to 2.4%. It is anisotropic in nature. It has many applications in the fields of civil engineering, automotives, aerospace, ships, etc. Likewise, it can cause galvanic corrosion when CRP parts are wrapped in aluminium or mild steel. CFRP has become an important material in structural engineering. It is a very cost-effective material and can be used in many fields of applications, such as strengthening of concrete, masonry, steel, cast iron, and timber structures.

It can be used either for retrofitting to strengthen an existing structure or for pre-stressing of material. CFRP can enhance shear strength by wrapping fabrics or fibers around the section of reinforced concrete to be strengthened. Sections like bridges or building columns can also enhance the ductility greatly, as well as increase the resistance to collapse under earthquake loading. It is a more economical method.

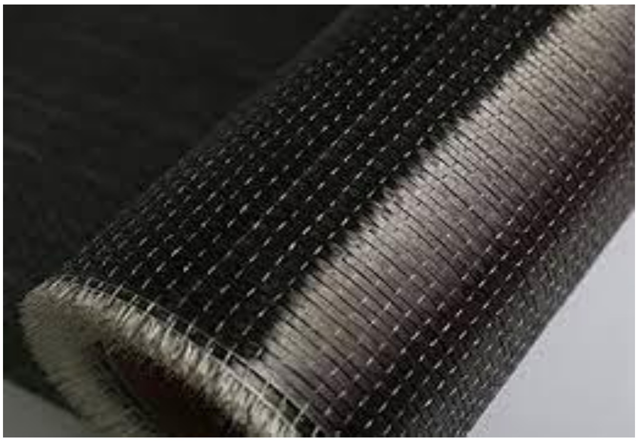

Fig -5: Carbon fiber

2.3 Glass fiber

GFRP (glass fibre reinforced plastic) was first developed in the 1930s. It is isotropic in nature and has a low cost when compared with other frps. The formation of GFRP is done by mixing glass with plastic under polymerization. Popular glass fibres are E-Glass, A-Glass, S-Glass, C-Glass, and AR-Glass. A-glass (alkali glass) and C-glass (chemical glass) have resistance to chemicals. E-glass (electrical glass) is a good insulator of electricity. S-glass (structural glass) is mainly used for mechanical properties. Its tensile strength ranges from 483 – 4580 Mpa, with an elongation of 1.2% to 5%. It is a lightweight material, which helps in the faster installation process.

It has high strength and durability, as well as high resistance to salt water, chemicals, etc. It is incombustible and a good electric insulator. Applications of GFRP are, that it can be used for new buildings and for retrofitting work. It has high design flexibility, so it can be used in a variety of shapes and styles. It can be used in fountains, the automotive industry, aerospace, docks, cooling towers, facades, panels, and domes.

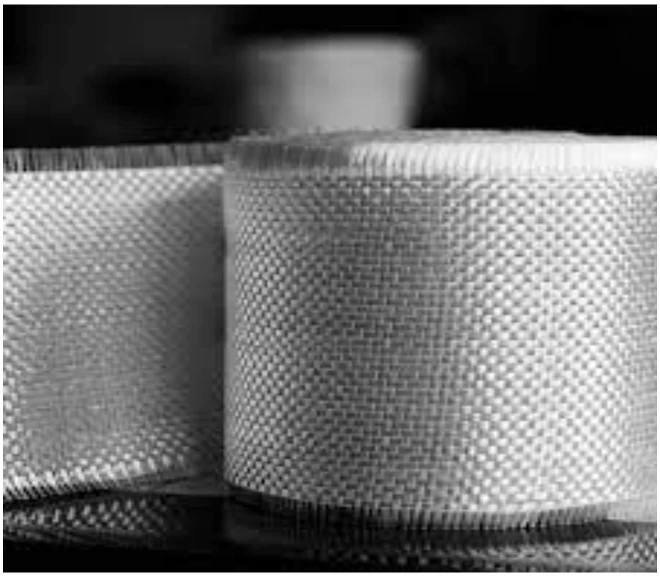

Fig -6: Glass fiber

2.4 Basalt fiber

Basalt fiber (BFRP) is a natural, lightweight fiber. Basalt fiber was first developed in 1923 in the United States by Paul Dhe. The raw material required for the manufacturing of basalt fiber is crushed basalt rock. It is an igneous rock formed by the cooling of lava. It is a golden-brown color. The tensile strength of basalt fiber is 992.4 MPa, the elastic modulus is 7600 MPa, and the elongation is 2.56%. When we compare it with other fibers its use in infrastructure is very low. Its chemical composition is similar to glass fiber; so, it can be used as an alternative to glass fiber.

It has many advantages, such as high shear strength, high resistance to alkaline, resistance to radiation, vibration, corrosion, high oxidation resistance, fire resistance, and good resistance to chemicals. It has high permeability to electromagnetic waves. Basalt fiber is used to retrofit structures by wrapping them around them. The filament diameter of basalt fiber ranges between 10 and 20 μm. It has many applications in marine civil infrastructure since it has high resistance to salt. It is used in the transportation field for such things as highways, runways, railways, and pavement linings. Other than that, it is used in mining and military fields.

Fig -7: Basalt fiber

3. LITERATURE REVIEW

These are the following experimental study carried out by various researchers.

3.1 R. Al- Rousan et al.,2013

A nonlinear finite element analysis was conducted on a concrete beam model retrofitted with FRP wrapping around it. Where the u-wrap had fiber orientations of 45° and 90°. Two types of fiber were used: carbon and glass. FRP was used in strips as well as in sheets to improve the load carrying capacity of the RC beam, which was sulphate damaged and had a deficiency in shear carrying capacity. When using the strip type of frp wrapping, the load carrying capacity was enhanced by 10-39%, and for the sheet type of frp, the load carrying capacity was improved by 4-32%. Glass FRP sheet gives an overall better performance than carbon fibers [1].

3.2 Alabdulhady et al.,2017

The paper presents the results of an experimental study on the effect of externally strengthening rectangular RC beams with PBO-FRCM composite material in different wrapping configurations. To study the torsional behavior as a function of strength, rotational ductility, failure mode, and yield strength. “PBO-FRCM” stands for Fiber Reinforced Cementitious Matrix with PBO composite fiber (p-Phenylene Benzobis Oxazole) [2].

The specimen used is an RC beam with a rectangular shape. The dimensions of the specimen are 203.2 mm wide, 304.8 mm tall, and 2133.6 mm long, with reinforcement detailing according to code ACI 318. A four-sided wrapping configuration resulted in greater cracking torque, greater torsional strength, and higher values of twist, relative to a control beam. A three-sided wrapping configuration, on the other hand, was less effective than a four-sided wrapping configuration.

3.3 Kandekar et al., 2018

He studied the torsional behavior of an RC beam wrapped with aramid fiber. The cross -section of the beam is 150 mm x 300 mm and its length is 1 m. And he only considers fully and strips with a width of 100 mm wrapping. The load applied to the beam was 1000 KN using UTM. Torsional reinforcement design detailing was according to IS the code 456-2000. Overall, twelve specimens were used in the test. The result shows that a fully wrapped RC beam has taken 140% more moment at first crack as compared to the control beam. In addition, the strip type of wrapping required 80% more moments than the control. A RC beam wrapped with aramid has 25% less torsional moment. And there is an overall reduction in crack formation when it is wrapped with aramid fiber [3].

3.4 Bouziadi et al.,2019

A nonlinear numerical analysis is carried out to predict the creep response of reinforced concrete (RC) beams externally strengthened using carbon fiber-reinforced polymer (CFRP) and glass fiber-reinforced polymer (GFRP) laminates. A static four -point bending test was used. Different orientations of fibers were used in the test. These were 0°, 45°, and 90°. The elastic modulus of GFRP and CFRP plates is 21 GPa and 165 Gpa, respectively [4].

A burger rheological model was used for the evaluation of creep response. Both compressive and flexural creep were validated during the test. As compared to compressive creep, tensile creep is more pronounced at all the stages. By increasing the thickness of CFRP, creep strain is lowered. And CFRP laminates show a better result than GFRP in creep response. CFRP with fibre orientation at 45° shows the overall best result when compared with other fibres and orientations.

3.5 Djerrad et al., 2019

In this paper, 15 specimens of a thin-walled circular hollow section (CHS) steel tube strengthened with AFRP in the hoop direction were subjected to a static axial compressive load. All specimens were tested to study the effect of AFRP (Aramid fiber-reinforced polymer) retrofitting on maximum load carrying capacity, stiffness and failure modes. For the test, both experimental and analytical studies were conducted. For modelling, ANSYS Workbench Ver. 19.0 and ACP (ANSYS Composite Prep/Post) tools were used. Long and short circular hollow tubes of length 900 mm and 200 mm were used. For the study, various AFRP thicknesses such as 1, 2, and 3 mm were used. The slenderness ratio was 10 kl/r for short tubes and 47 kl/r for long tubes. The result showed that by using AFRP externally, the strength of the short column was enhanced by 96 % and that of the long column by 23 % by using 3 mm thick AFRP [5].

3.6 Abu-Sena et al.,2019

He conducted experimental and numerical investigation into twenty short square and rectangular beams. The length of the steel specimen was 700 mm. A load of 2000 KN was applied to the specimen using a universal testing machine. Both experimental as well as analytical studies were conducted. The software used for the analytical study was ANSYS.15.0. The CFRP wrapping effectively delays the local buckling of fully strengthened specimens [6].

Mainly, failure occurs at non- strengthened zones between the strips of CFRP in the case of partially strengthened specimens. The enhancement in ultimate capacity ranges between 19.1% and 34.5% for SHS (square hollow section), and between 18% and 41.3% for RHS (rectangular hollow section) specimens. The improvement in the strength of a specimen having two-layer strips of CFRP is limited when compared with one layer of strips of CFRP.

3.7 Sivasankar et al.,2019

He used AFRP (Aramid Fiber Reinforced Polymer) sheets to improve the performance of the RC cylindrical members, and it was found to be useful. An axial load test was conducted on the universal testing machine. When compared to the unwrapped specimen, the load-carrying capability of the RC cylinders wrapped with three layers of AFRP sheets increased by 39.60%. And the vertical displacement of the specimen was decreased. The cost of AFRP is less when compared with CFRP [7].

3.8 Chen et al., 2020

In this paper, the flexural strengthening of an RC beam with natural FRP (NFRP) was analyzed. Instead of synthetic FRP, here NFRP was used because it is eco-friendly, and biodegradable. The main two types of NFRP used for the study were jute and flax. Of these, flax FRP shows a higher ultimate strain and ultimate tensile strength as compared with jute FRP. Lica-100 was the epoxy resin used to bind the FRP to the specimen. Overall, six specimens were used for the study, and the loading was four-point bending. A cost analysis was also conducted, and it showed a 20% to 40% efficiency in cost as compared with carbon fiber. And it has a 41% higher load -carrying capacity than CFRP [8].

3.9 Nayak et al., 2021

In this paper, the effect of AFRP on a steel beam was studied. Five types of strengthening were applied to a hollow square section. Experimental as well as analytical studies were conducted on this test. Ansys 16 software was used to model the section. Five types of wrapping styles were used in that tubular steel beam. First is wrapping on one side of the beam, second is wrapping on two sides of the beam, then three sides and four sides of the AFRP sheet, and finally the strip type of wrapping style was tested.

Compressive and flexural tests were conducted on the specimen. The four-side wrapping styles give a better performance than the other styles. In the compression test, there was an overall increase of 24.77% for beams strengthened using afrp sheet as compared to unstrengthened beams. And for flexural tests, an increase of 25.71% for strengthened beams [9].

3.10 Chittaranjan et al.,2021

In this research, the flexural and cracking behavior of an RC T-beam strengthened with BFRP (Basalt Fiber Reinforced Polymer) was analyzed. The strip type of wrapping was adopted with the orientation of fibers at 45 ° and 90 °, in which each stripe is 50 mm wide. Experimental and analytical studies were conducted. The software used for the analytical study was ABAQUS CAE. A one-point loading system with a load of 100KN was applied to a simply supported T-beam. The result shows that the wrapping of BFRP reduced the deflection of the beam by 19.56% and 22.34% for the strip type of wrapping with an orientation of 90 °and 45 °, respectively.

Load-carrying capacity was increased by 46.61% for 45 ° wrapping and 39.94% for 90 ° strip wrapping. The yield points of 45 ° BFRP and 90 ° BFRP are 92.33 KN and 90.13 KN, respectively. By using BFRP sheets, Von misses' stresses were reduced. 45° BFRP strip wrapping shows a better performance when compared with 90 ° BFRP because it covers more surface area. Over all, by using the BFRP sheet, the load carrying capacity was increased, and it is more economical when compared to the control RC T -Beam [10].

3.11 Kheyroddin et al., 2021

He studied the impact resistance of concrete structures with GFRP wrapping and polypropylene fibers. He uses 52 samples of concrete cylinders with dimensions of 150 x 300 mm2. Compressive strengths of 20, 30, and 40 MPa were used for the test. For the load test, an impact loading device was used. A square shaped cast iron weight was used for dropping in the impact test. The dimension of the weight is 300 x 300 mm2.

GFRP wrapping along shows an impact resistance of 150% higher than polypropylene fibers. Combining the use of polypropylene fibers and GFRP wrapping shows a better result when compared with GFRP wrapping alone. But in the case of using GFRP fibers only, it is more cost-efficient than the combined use of GFRP and polypropylene. Overall, there is improvement in the impact resistance of concrete cylinders by wrapping them in GFRP, and it reduces the number of cracks and damage intensity [11].

4. CONCLUSION

FRP will be in high demand in the future since it is an innovative material. It has many advantages, like it increases the life span of structures, durability, less maintenance cost, high strength to weight ratio, high tensile strength, high resistance to corrosion, etc. Other than that, it has some disadvantages like high initial cost, lack of design code, lack of technology, and moisture absorption. Much research work has been conducted for the application of FRP. There is no standard code for FRP in India, so the real-life application of FRP is limited.

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