EXPERIMENTAL STUDIES ON REPLACEMENT OF STEEL STIRRUPS BY SISAL FIBER REINFORCED POLYMERS

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Abstract. Growing awareness about natural resources the environmental guidelines are fortified researchers to practice it for structural claims. Sisal fibers are abundantly available and they are less in cost compared with steel reinforcement. Sisal fibre is solitary promising reinforcements in fibre-reinforced polymer composites because of increased in tensile strength. Traditionally sisal fibres were used to make ropes, due to these high tensile properties in the sisal fibre it can be molded into the form of a stirrup by using Pultrusion process and hand layup method, which leads to the replacement of steel stirrups. The beams were casted with steel stirrups and sisal fibre stirrups and tested. On comparison of the results sisal fibre stirrups showed slightly increase in flexural strength but crack width is more compared to beams with steel stirrups. Due to their superior corrosion resistance of SIFRP (Sisal fibre reinforced polymer), it increases the durability. But the brittleness of SIFRP and their inferior bonding performance with concrete needs to be addressed.

1. Introduction.

The steel produced for the construction purpose has its major disadvantages like discharge of greenhouse gases such as, CO2, N2O and methane. By using these steel in the field is not advisable for future due to its more emission and this will directly affect the environment by global warming. Instead of this steel reinforcement some fiber reinforcements have been introduced to rectify these environmental issues without compromising the strength aspects. In many structures the reinforcement used was steel for RC elements which has the lesser durability than the fiber reinforced composites. Fiber Reinforced Polymer (FRP) [1] is a combined material prepared with polymer matrix which is reinforced with fibers. The different types of fiber materials used for making main reinforcements and stirrup bars such as, Glass Fiber Reinforced Polymer (GFRP) [2-4], Basalt Fiber Reinforced Polymer (BFRP) [5-7], and Aramid Fiber Reinforced Polymer (AFRP) [8]. These fibers reinforced bars are introduced in the beams and columns for comparing its stiffness, ductility and crack pattern with the conventional steel reinforcements. The weariness life of fiber reinforced strengthened RC beams is predominately depending on reinforcements provided at the tensile portion and bond strength at the interface of FRP and concrete. This paper reveals that these FRP composite components can be recommended for improving the durability and insulation performance of the damaged and corroded beams [9]. Initially the natural FRP composites possess less strength when compared to synthetic fibers. These issues are overcoming by altering the fiber orientation, chemical composition, fiber length, and processing temperature, and tensile properties etc [10]. A hybrid of both FRP and steel bars will produce better performance when it is combined in the RC beams and columns than its replacing fully [11]. The improvement in flexural capacities have directly shows the higher withstanding ability of the BFRP rods which is introduced in the RC beams [12]. A hybridized basalt – steel rebar’s are produced to avoid the reinforcement from corrosion and to increase the elastic modulus of the bars [13]. Most of the test carried out in making the replacement of longitudinal steel bars...
with fiber reinforced bars. But, here the replacement is made in stirrups with GFRP materials. The result clearly shows that without stirrups the failure occurs in shear tension zone and with using stirrups the failure occurs in shear compression zone. This result is clearly evident in showing the high stiffness and flexural capacity factor of GFRP stirrups [14].

Natural fibers are fully biodegradable & less in weight than synthetic fibers. Due to the high possession of tensile strength, the sisal fiber is used as a reinforcement in FRP composite structures. The Presence of high tensile properties in the sisal fiber, it’s been molded into the form of a stirrup by using Pultrusion process [13]. Nowadays sisal fiber comprises a vital role in fabricating the both structural and non-structural elements with different polymer matrix. Some factors that are influencing the mechanical properties of the FRP composites such as, length of fiber, fiber orientations, mixing of fiber, treating with chemicals and hybridization with synthetic fibers and natural fibers [15-22]. Using the natural fiber instead of using synthetic fiber makes an economical way of construction.

2. MATERIALS AND METHODS.

2.1. Materials
The concrete cubes and RC beams are casted for this study in which the basic components for casting the concrete is ordinary Portland cement, M sand as fine aggregate and standard coarse aggregate of size 20mm. Here the RC beam is casted using M40 grade of concrete and steel bars as a main reinforcement. The replacement is done only in the stirrup bars as sisal fiber reinforced polymer Figure.1 instead of conventional steel stirrup bars. The main reinforcement of 12mm diameter bars are used and the stirrup of 8mm diameter bars are used. The SIFRP stirrup bar is also having the same diameter as the steel comprising.

![Figure 1. SIFRP Stirrup Bar.](image)

2.2. Fresh Concrete Properties
The M40 grade of concrete is preferred in this study for casting the RC beams. This concrete has been tested for the workability property to ensure the water cement ratio. The slump cone test is made for ensuring the water content to be added in the concrete.

2.3. Pultrusion Process
Pultrusion is the process used in the manufacturing of FRP’s like GFRP, BFRP, NFRP, and AFRP materials. These materials are coated with some epoxy substance on the surface of the fibers at all the surfaces. The Speed of Pultrusion process is 1 m per minute. This is a continuous process of making the FRP’s to increase its stiffness and flexural capacities. In this study the stirrups are also casted using this Pultrusion technique with the mould having the rings surfaces in it. Here the 8mm diameter of SIFRP
stirrup is casted by making it into two halves and then it is bonded together as shown in the Figure 2. In this SIFRP stirrup casting technique the epoxy resin and epoxy hardener are used for the polymer matrix. Resin is ly556 and hardener is hy951 is used in this process and its mix ratio is 1:4 where the hardener is 4 part and the resin is 1 part are added in this technique. By using this ratio, the polymer matrix is prepared and the Sisal fiber quantity is arrived by using the rule mixture followed in this study.

Figure 2. SIFRP Stirrup Bar casting.

2.4. Casting and testing of Beams
The fresh concrete properties are tested and the proper workability have been measured. The hardened concrete is then testes for its characteristic compressive strength which is taken for this issue. The cubes having the dimensions of 150 x 150 mm is tested in compression testing machine. Then the grade of concrete which is having the proper compressive strength is taken for the casting of beam Figure 3.

Figure 3. Flexural Beams Casting.
third case is fully replacing the steel stirrup with the SIFRP. The main reinforcement used in for casting the RC beam is 12mm diameter bars. These beam is tested for the flexural strength by two-point loading which is shown clearly in Figure.4.

![Figure 4. Flexural Beams Testing.](image)

3. Results and Discussion

3.1. Basic Properties of materials
The materials that are taken for this research has undergone for some basic tests and the obtained test results are discussed. The normal consistency for cement content used here is around 28% with the specific gravity of 3.08. Then the same cement content is tested for the binding property is setting time test and the result obtained for initial and final setting time is 32 min and 305 min respectively. This proper result is due to the fineness of the cement content as 3.4%. The specific gravity is also tested for fine aggregate and coarse aggregate and its values are measured as 2.6 and 2.7 respectively.

3.2. Compression test on cubes
The compression test for the concrete cube which is casted using 150mm cube and tested as per the IS 516-1959 provisions Figure.5. Nine specimens are casted for 3 average specimen for 3 different curing days. The grade of concrete is M40 and the test results also shows the characteristic compressive strength is satisfied which is evident in Table.1. So, this concrete has been taken for the further casting of flexural Beams.

![Figure 5. Concrete Cube.](image)
### Table 1. Compressive Strength of Concrete.

| Grade of concrete | Sample         | 7th day   | 14th day  | 28th day  |
|-------------------|----------------|-----------|-----------|-----------|
| M40               | Specimen 1     | 21 N/mm²  | 36 N/mm²  | 44 N/mm²  |
| M40               | Specimen 2     | 20.8 N/mm²| 34 N/mm²  | 42.5 N/mm²|
| M40               | Specimen 3     | 22 N/mm²  | 36.5 N/mm²| 44 N/mm²  |

#### 3.3. Flexural Test on Beams

In this flexural test all the four specimens are exposed to two-point loading. The load at starting point is noted, then the load at initial crack is noted and the load at final crack is noted. The deflection, crack width and crack length is also measured in beam at respective cracks. When comparing the result of four different compositions of beams we are about to know that the conventional beams possess the moderate result when comparing to Fully replaced SIFRP stirrups and Phase replacement of stirrups.

### Table 2. Flexural Strength Test.

| Sample                          | Load (KN) | Stages  | Deflection (mm) | Crack width (mm) | Crack length (mm) |
|---------------------------------|-----------|---------|-----------------|------------------|-------------------|
| Conventional                    | 05        | starting| 0.46            | 0                | -                 |
|                                 | 40        | Initial crack | 1.64           | 0.002            | 35                |
|                                 | 135       | Final crack  | 9.32            | 2.6              | 120               |
| Fully replaced SIFRP stirrups   | 05        | starting| 0.50            | 0                | -                 |
|                                 | 35        | Initial crack | 2.31           | 0.05             | 30                |
|                                 | 130       | Final crack  | 12.31           | 3.5              | 110               |
| Alternate replacement of Stirrups| 05        | starting| 0.40            | 0                | -                 |
|                                 | 40        | Initial crack | 1.91           | 0.008            | 30                |
| Phase replacement of stirrups   | 140       | Final crack  | 10.25           | 3.2              | 130               |
|                                 | 05        | starting| 0.45            | 0                | -                 |
|                                 | 30        | Initial crack | 1.80           | 0.01             | 35                |
|                                 | 135       | Final crack  | 10.80           | 3.5              | 140               |

But, when compare the Alternate replacement of Stirrups beams with conventional beams the alternate stirrup beams possess higher stability than conventional beams. Figure.6 shows clearly that deflection is also higher than all the other specimens and the crack width and crack length is also measured and noted in the Table.2.
4. Conclusion

The study has provided many valuable insights about the fiber reinforced polymers, mainly the SIFRP (sisal fiber reinforced polymer) stirrups possess high strength to weight ratio, less weight, high anti corrosion resistance. The SIFRP stirrups gives same strength as steel stirrups and SIFRP stirrups has an advantage of anti-corrosion resistance. Due to the presence of anti-corrosion resistance in natural fibers, maintenance cost of the structure will be reduced. The weight of SIFRP stirrup and steel stirrups are 38gm & 245gm respectively. Dead load of a structure will decrease by using of SIFRP stirrups.

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