Development of Coir Fiber Reinforced Polymer Reinforcing Bars for Concrete Structures

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ABSTRACT

At present, global warming increment and petroleum reserve depletion have been a major threat to the environment. These occur due to various human activities. Construction industry contributes 40 % for the global carbon emission. From that 10% is contributed from the manufacture of cement and the rest is contributed by the other requirements in the construction industry. Therefore, scientists are now more focused to involve bio-based products to minimize the emission of carbon. This resulted in, paying more attention towards the natural composite materials that can be used instead of artificial materials. Scientists are eager to find natural materials which are locally available. The structures built today, does not survive the entire service life of the structure. This is due to corrosion of steel, especially in coastal areas. So, in order to overcome this, use of a natural material which can provide the same tensile strength can be used. Over the past few decades engineering materials like composites, plastics, ceramics has dominated the engineering industry. There are new polymer materials introduced such as glass fiber, carbon fiber and aramid but they are not eco-friendly. The main problem associated with these is the high production cost. Therefore, new composites which are environmentally friendly should be found in order to replace other materials. Even though there has been much research published on different natural fiber composite materials, here an attempt has been made to use coir to produce reinforcement bars in order to combat corrosion

Keywords: *coir, composite, corrosion, petroleum, fiber glass, aramid*

1 INTRODUCTION

Structures exposed to extreme environmental conditions such as coastal structures, bridges etc deteriorate due to corrosion of steel. Reinforced concrete could be a durable method of construction until it gets the exposure of acidic environment. Alkaline environment of concrete helps the steel to form a dense gamma ferric oxide layer which could prevent the steel from corrosion. However, chloride ions and carbon dioxide penetrate the concrete cover and destroy the passive layer of the steel and accelerate expansive corrosion(Chung, 2000; Tharmarajah et al., 2015a, 2011a). It is important to develop new technologies which are environmentally friendly rather than developing materials or products which are insecure to the environment. Therefore, more attention is paid towards the natural fibers with the increase of environmental properties. at the moment, utilization of petroleum products is at a high rate. Due to this high usage, the depletion of petroleum reserves has increased. More number of harmful by-products are released to the atmosphere which are not eco-friendly. Scientists and environmentalist suggest that replacing these products with natural fiber (NF) materials will guide the world to a better place minimizing environmental pollution. Another, matter of the petroleum products is the

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expensiveness of the products due to their high production cost. (Ali and Chouw,2013). The introduced new materials to replace steel rebar include fiber glass, carbon fiber and aramid fibers. The main problem associated with these introduced materials is the high production cost. There are many NF materials available in the surrounding such as jute, coir, hemp, sisal etc. which can be locally produced. The main objective of this study is to use coir, to produce reinforcement bars as replacements for steel reinforcement. To do this coir itself cannot be used directly. Therefore, a composite material should be prepared with the inclusion of coir. Coir composite should be made into shapes of bars in order to be included as reinforcement therefore, a process like pultrusion should be involved.

There were studies(Archila et al., 2018; Chin et al., 2020; Ganesan et al., 2020; Haryanto et al., 2021; Mali and Datta, 2020, 2018; Muhtar, 2020; Muhtar et al., 2020; Puri et al., 2017; Ramaswamy and Mathew, 2019; Terai and Minami, 2012) investigated use of cut bamboo bars as a reinforcement in concrete structures. However, all these studies evaluated the use of bamboo strips directly taken from bamboo grass without any pre-engineering. Instead of using the natural fibers directly these fibers could be made into composite materials with the use of a resin such as polyester resin, epoxy resin etc. which will increase the mechanical properties of the fiber. There are several studies (Adeniyi et al.,2019; S. Kumar, Shamprasad M.S., Varadarajan Y.S., et al,2021;Ali et al.,2012) conducted which exhibits the potential of coir fiber's tensile behaviour related to the construction industry.

2 BACKGROUND

Corrosion of steel is a major problem influencing the long-term survival of a concrete structure. Corrosion of concrete normally occurs due to two main processes they are Carbonation and chlorination.in the presence of chloride, the steel protective passive layer is destroyed and unprotected steel areas dissolve. Steel corrosion is an electrochemical process in which iron (Fe) is removed from the corroding steel and dissolved into the surrounding solution, where it then appears as ferrous ions (Fe^{+})(Zhao and Jin, 2016). The ferrous ions typically react with hydroxide ions (OH^{-}) and dissolved oxygen molecules (O_2) to form rust, a solid by product of the corrosion reaction. The formation of corrosion products involves substantial volume increase this makes the volume of corrosion product greater than that of original steel bar. Therefore, expansive stresses are induced around corroded steel bars causing possible cracking, spalling of concrete cover and loss of bond between steel/concrete. (Ashour et al,2011).

There is a possibility to control the rate of corrosion by changing the resistivity, oxygen concentration and temperature. Better quality concrete, cathodic protection, corrosion inhibitor admixtures, and anti-corrosion coating are a few of the traditional measures used to combat the corrosion of reinforced concrete(Chung, 2000). Anti-corrosion chemicals provide only temporary protection. Cathodic protection is costly and has its own disadvantages, and repair processes frequently have short service lives and require frequent reinstallation. As a corrosion resistance technique, Coatings are applied on steel reinforcement to prevent the corrosion of steel re-bar. These consists of sacrificial coatings and epoxy coatings. Sacrificial coatings are coatings that are sacrificed for corrosion instead of the main metal. These include less noble metals such as Zinc and cadmium. Epoxy coatings are developed as resin material. For example, in the study (W. Fan, et al,2020) has used polyaniline (PANI) and cerium oxide (CeO2) to produce epoxy coating for steel rebar. But these coatings are exposed to damages when handling and placing which results in producing spots aiding corrosion to take place. therefore, this method is not competitive enough to prevent steel from corrosion. In contrast to non-sacrificial coatings, even if sacrificial coatings fail during production, transport, or service, the underlying metal remains protected.

Usage of composite materials have gained a lot of interest in the construction industry. Development of Fiber-reinforced plastics (FRP) is one result of the development of the usage of composite materials in the recent years due to the corrosion resistant nature of the materials. FRP bars demonstrate corrosion resistant nature, lightweight, and have a high tensile strength. Similarly, natural fibres such as coir and jute fibre demonstrate potential to be used in construction applications as a reinforcing material or as an additive to enhance properties of cement grout or concrete. Cor is one of the cheapest and mostly available materials in nature. Coir fibers are predominantly made of natural plant materials such as cellulose, lignin and Pectin. Coir fibers are strong, light in weight, highly durable and easily withstand heat and salt water. It is used o manufacture coir robes, mats, carpets, among other things. Typical properties of coir fiber is shown in table 1.

Table 1. Typical properties of jute fibre

Parameter	**Value**
Diameter	12–20 μm
Tenacity	10 g/Tex
Fibre length	13-29 mm
Density	1.4 g / cm^3
Moisture Regain	10 %
Modulus of elasticity	2-8 GPa
Breaking Elongation	30%
Tensile strength	95-118 Mpa (Romli, Alias, Rafie, & Majid, 2012)

There were several types of bonding agents such as polyester, epoxy, silicone resin, polyamide resin and alkyd resin that can be used for the production of bars. For the composite material, coir fiber was used as the reinforcing material and the polyester resin was used as the Binder. Polyester demonstrate adequate resistance to water and several chemicals, resilience to weathering and ageing, moderate temperature resistance (up to 80°C), good wetting to glass fibres, minimal shrinkage (4–8%) during curing, and linear thermal expansion (100– $200 \cdot 10^{-6}$ K^{-1}). Similarly epoxy demonstrate a good heat resistance, adhesion to a variety of substrates, low shrinkage during curing, corrosion resistance, high tensile, compression, and bend strengths. Considering properties of resins and economic feasibility, it was decided to use polyester resin for the research purpose.

3 METHODOLGY

It was decided to produce 12mm Coir Fiber Reinforced (CFR) bars of 1000mm in length according to ASTM standards. After a thorough investigation the polyester resin was taken as the binding material for the composite material. In this study, we decided to combine fibres and resin in the proportion shown in Table 2 to evaluate the strength of bars made of Coir fibres. For each proportion, 3 number of bars were produced and tested at lab for tensile strength and modulus of elasticity.

Table 2. Composition of the bars

Name of the specimen	**fibre: Resin (V/V)**	**No. of bars**	**Resin Volume(ml)**
S-20	80:20	3	23.04 ml
S-30	70:30	3	34.56 ml
S-40	60:40	3	46.00 ml

For the production of the CFR bars, a rope manufacturing machine (Figure 1) was used. It was ideal to use a pultrusion method to produce the bars to achieve better strength and workmanship. However, the facility to produce bars using pultrusion method was not adopted. The fibers were separated to required size and was rolled into the machine to make the ropes for the required size.

Figure 1- Coir Rope making Machine

The twin spindle coir rope making machine (Figure 2) was used to make 10mm diameter coir ropes. Next these produced ropes were bath in a resin basin. This phenomenon is expected in the pultrusion process in this process the fiber ropes are sent through a resin bath and hardened.

Figure 2- Twin spindle coir rope machine

The coir rope was dipped inside the resin bath to bond the fibers together to form the shape of a bar. Coir and resin volume was calculated to obtain the compositions as presented in the table 2. The exact amount of resin was applied on the rope by tying the rope between two poles as figure 3. A hardener was used at 1:100 ratio to harden the bar after resin bath. During resin bath, the rope was rotated by 180 degrees to distribute the resin evenly across the rope to achieve well rounded bar. Finally, the resin coated jute fibre rope was sand coated before drying the resin. Sand coating is used in fibre reinforced polymer bars to enhance the bond strength between the bar and concrete (Figure 4).

Figure 3- Application of Resin

Figure 4- sand coated hardened Coir Bar

4 EXPERIMENTAL INVESTIGATION

4.1 Test Procedure

ASTM D7205 on Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars (ASTM D7205/D7205M-21, 2021) was used to carry out the tests on fabricated Coir fiber bars. The code recommends minimum anchorage length La of 300 mm was used to anchor the bars inside the wedges of the tensile testing machine. Free length (L) between anchors was maintained at 400 mm. The test method is developed to obtain longitudinal tensile strength and elongation data. By conducting a tension test, variety of data is obtained. The tensile properties of the bars depend on the following factors: constituent materials, void content, volume percent reinforcement, methods of fabrication and the architecture of fiber reinforcement. similar to that the results obtain from the tensile test depends on the specimen preparation, specimen conditioning, environment of testing, specimen condition, environment of testing, specimen alignment and Gripping. The apparatus must comply with the relevant standards according to the ASTM d702 standard. In respective of the sampling and test specimens, according to ASTM d702 standards at least 3 specimen samples should be tested. Otherwise, the procedures outlined in E122 should be consulted. The geometry of the specimens should also comply with the ASTM d702. According to the ASTM d702 the strain rate to be used 0.01 min^{-1} test environment temperature is normal Laboratory temperature of 27 ^{0}C.

Following the guidelines provided by ASTM D7205, the tests were carried out using a universal testing machine (Figure 5).

Figure 5- Testing the coir fiber using the Universal Testing machine

5 RESULTS AND DISCUSSION

This study mainly focused on developing an alternative bar using coir to replace the traditional steel reinforcement to reduce the corrosion risk. If it is possible to replace steel with natural fibre bars, it can enhance sustainability of reinforced concrete structures while preventing corrosion related problems. Figure 5 shows the stress vs strain behaviour of coir fibre bars with different composition.

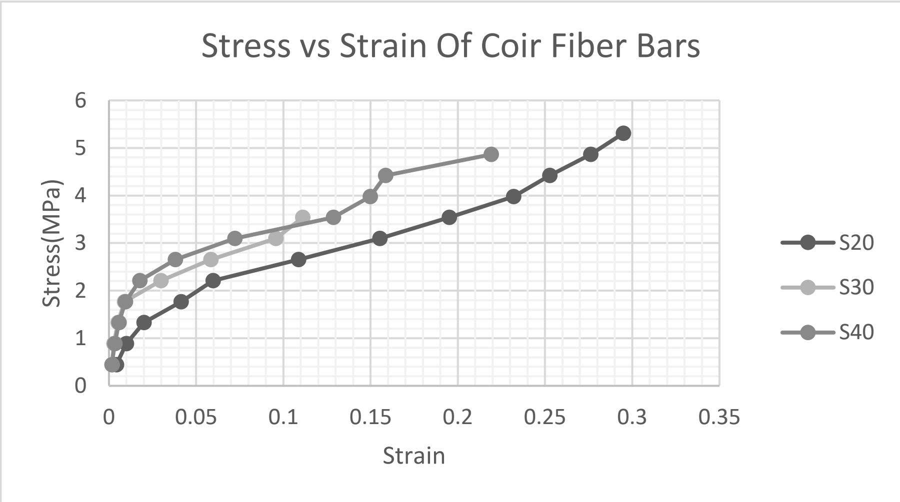

Figure 6: Stress vs strain behaviour of Coir fibre bars

It can be observed that the bar with highest fibre content demonstrates higher tensile stress. Literature on FRP reinforced materials show that with the increase in fibre content, tensile strength of the bars increases. However, this requires a considerably a higher number of specimens tested for each composition. Therefore, three specimens were tested for each composition and the average stress, strain and modulus of elasticity is reported in Table 3.

Table 3. Average Stress strain values

Sample		Max stress (MPa)	Max strain	Average Stress (MPa)	Average Strain
S20	01	5.31	0.225	4.72	0.277
	02	4.42	0.285		
	03	4.42	0.290		
S30	01	4.86	0.226	3.98	0.155
	02	3.54	0.130		
	03	3.53	0.109		
S40	01	3.54	0.148	4.13	0.186
	02	3.98	0.191		
	03	4.86	0.219		

Unlike steel, natural fibres can show a greater variation (Figure 6) when it comes to mechanical and physical characteristics. A similar observation was made in the experimental investigation. Continuously testing bars made of fibres from different sources and increasing the number of bars tested can help to obtain an acceptable tensile strength. Modulus of elasticity obtained from stress strain behaviour indicate a modulus of elasticity of 17.04 N/mm^2 for 80% fibre and 25.68 N/mm^2 for 70% fibre and 22.20 N/mm^2 for 60% fibre. The modulus of elasticity obtained indicate that the bars made of Coir fibre possess a much lower modulus of elasticity than steel (1/7000). This indicates that the modulus of elasticity values are really very low values.

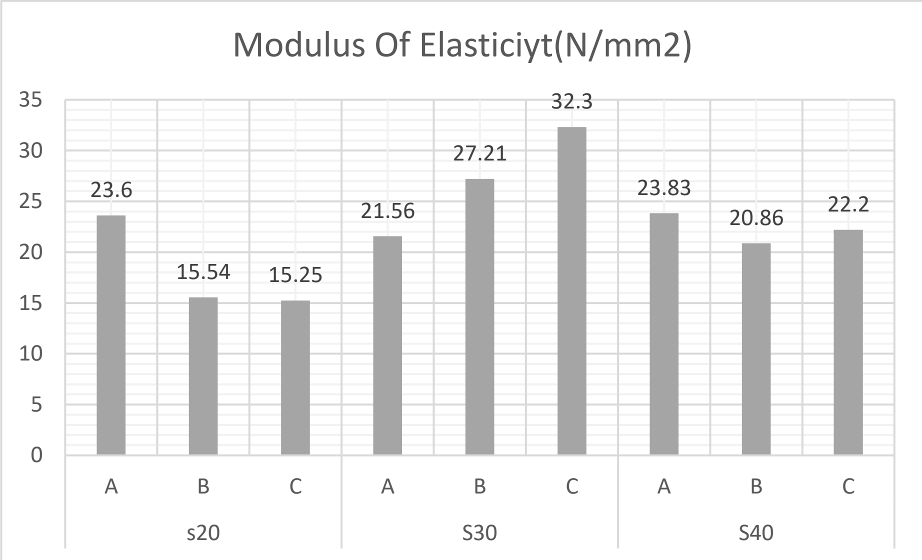

Figure 7: Variation of modulus of elasticity

In the manufacturing process of the coir bars the fibers were randomly placed along the length of the bar, this showed a tensile strength of 3.98 -4.78 Mpa for uniaxial tensile test. Romli et.al, (2012) tested the tensile strength of a coir-based composite made of coir and epoxy resin of 15% of the fiber weight. In this Research a factorial study was conducted varying the curing time, coir fiber volume and compression loading. The specimen was tested according to the ASTM D638 Type I standard. The test element was fabricated by placing fibres pre-impregnated with the matrix on top of each other. Untreated Coir fibre plates demonstrated a strength of 55 MPa. Therefore, it is possible to achieve a greater strength with coir fibres. However, the challenge remains having the fibre arrangement and fibre overlapping in an appropriate level to achieve a much more desirable strength. this could be achieved at to some extent by following a manufacturing method such as Pultrusion.

A research study (Zaman & Beg, 2013) that evaluated mechanical and physical characteristics of Coir fiber–reinforced polypropylene-based unidirectional composites that were prepared by compression molding. Based on fiber loading, 30 wt% fiber-reinforced composites had the optimum set of mechanical properties. Treatment of the coir fiber with tetra methoxy orthosilicate after the alkali pre-treatment enhanced the mechanical properties and water desorption of the resultant composites, resulting from the improved adhesion between the coir fiber and polypropylene matrix. According to this study the coir fibers were subjected to a pre-treatment process before the manufacturing of the composites.in the manufacturing of the composite 6g of polypropylene granules had been used and the fibers had been placed unidirectionally. Tensile strength and tensile modulus of the coir fiber composite was measured according to ASTM D 638-03 procedure using a Shimadzu Universal Testing Machine. The untreated coir fiber resulted in giving a tensile stress about 35 MPa while the treated coir composite gave a tensile stress about 40 Mpa. Deterioration in tensile strength at higher fiber content is a direct consequence of poor fiber/matrix adhesion, which leads to micro-crack formation at the interface under loading and non-uniform stress transfer due to the fiber agglomeration in the matrix. Therefore, it can be observed that a significant difference between tensile strength and flexural test can be obtained in FRP elements.

Considering 55 MPa observed for 15% polyester resin reinforced coir fibers, the coir fibre reinforced bars tested by authors show a strength of 4.72 MPa. The huge difference can be attributed to the method adopted when manufacturing the coir fiber bar. Therefore, the below mentioned modifications could help to achieve higher tensile stress values for the coir fiber bars

(i) Adopting a better manufacturing process such as Pultrusion
(ii) Development of a technique to lay fiber arrangements with higher level of resin impregnation between fibers
(iii) Enhance the lapping arrangement of the Fibers

(iv) Use different types of resin matrixes to identify the resin that provides better tensile stress.

With further experimental investigation there is huge potential to improve the coir fiber bars to replace steel rebar. Additionally, novel manufacturing processes and surface modification methods can increase the mechanical properties of the bar making it a next level construction material in the future. These CFR bars have the potential to be the next generation materials for structural applications in the construction industry, hence allowing the structures to sustain up to their designed life expectancy without requiring for renovation within the building service life

6 CONCLUSION

The main objective of the study was to produce a reinforcement with the use of coir to replace the steel reinforcement in concrete structures which are subjected to corrosion. For this purpose, it was decided to prepare coir fiber reinforced bars with use of coir and a resin matrix. Coir fibers were combined with polyester resins to make a composite bar with fiber volume percentage of 80%,70% and 60%. Uniaxial tensile test was performed on coir fiber reinforced bars according to the ASTM standard helped to achieve the following conclusions

- Coir fiber reinforced polymer bars were tested using the universal testing machine for showed an average tensile stress of 4.72 Mpa for 80% by volume, 3.98 MPa for 70% by volume, 4.13 Mpa for 60% by volume. As reported for other FRP bars, strength should increase with the increase of fibre content. Therefore, the fluctuation in strength between 70% fibre and 60% fibre indicate that there is a possible increase in strength with the addition of fiber volume, further studies with a larger number of samples should be carried out to achieve consistent results.
- The tests carried out in this study and the literature demonstrated, indicate the possibility of using coir fiber reinforced polymer bars instead of steel reinforcement in concrete structures. Implementation of natural materials in the construction industry modifies and develops the sustainability of the construction industry. Moreover, limits the emission of Co2 gases that leads to global warming potential.
- It is also observed that through this study that the coir fiber bars need a huge improvement in the manufacturing process of the bars. Furthermore, these coir fiber bars require an investigation to improve the strength of the bar through proper arrangement of the fibers and enhanced resin impregnation between the fibers.

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