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Coir-carbon Fiber Hybrid Composite: Mechanical, Chemical Resistance, and Morphological Properties

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Abstract

The invention of novel materials is essential for present-day industry and society. These sectors are looking for not only strength and cost but also on environmental compliance issues. Synthetic fiber-reinforced composites (SFRC) are having enough strength but are not biodegradable and not environmentally friendly. Natural fiber reinforced composites (NFRC) have moderate strength but are environmentally friendly and biodegradable. The drawbacks in NFRC and SFRC composites were addressed by the hybridization of composite. The current research aims to investigate the performance of a hybrid composite plate made of coconut coir (CC), carbon-fiber (CF), and epoxy resin. The hand lay-up method was followed to fabricate the hybrid composite. Five samples were prepared, based on varying weight percentages in the following stacking order of 20CC, 15CC/5CF, 10CC/10CF, 5CC/15CF, and 20CF. Utilizing the universal testing machine (UTM - INSTRON 3369) and the Izod impact tester, the tensile, flexural, and impact strengths were determined. In contrast to other composites, the hybrid 10CC/10CF composite has high mechanical properties. The SEM (Scanning electron microscope) analysis revealed bonding between the CC, CF, and epoxy. The developed hybrid composite is useful in industries such as footwear, textiles, marine, military, and aerospace.

Keywords

Coir fiber, Carbon fiber, Mechanical Properties, Chemical Resistance, Morphology

Introduction

Nature is a great source of natural materials, such as wood, bamboo, bone, leather, and so on. People in ancient times relied on natural resources to sustain their lively hood, as well as to build their houses to protect themselves from the weather and wild animals [1]. To make ornaments for their survival, early humans invented and experimented with monolithic materials. Later, the use of monolithic materials increased dramatically due to their high strength and ease of manufacture, but they also have a few drawbacks, such as high weight and corrosiveness [2]. To address the aforementioned shortcomings, researchers developed synthetic fibers (man-made). Synthetic fibers are fibers that are produced via various man-made processes, such as carbon, Kevlar, glass, and so on [3]. CFs are produced by combining rayon, petroleum pitch, and polyacrylonitrile. CFs have wide applications due to their outstanding mechanical (high stiffness and high tensile strength) and thermal (high thermal conductivity and high-temperature

tolerance) properties [4]. CFs are commonly used in aerospace applications because of their low weight, high stiffness, high thermal conductivity, and high elastic modulus [5]. Due to their higher cost, non-biodegradability, and disposal issues, synthetic fiber's applicability in polymer composites is waning. In the area of polymer composites, the aforesaid issues can be easily overcome by utilizing natural fibers, but the resulting physical and mechanical qualities must be compromised [3]. One development in the production of composites is the reinforcement of polymers with nano-fillers and nano-fibers, which improves mechanical qualities.

Fibers that are obtained from natural sources, such as plants, animals, and minerals, are known as natural fibers. They are taken through the various parts, including the leaves, seed, stem, and bark of the plant [6]. Nano-fillers are being utilized in addition to fibers to suit current demands. To meet the needs of modern industry, many investigators glanced into the viability of using plant, fruit, vegetable, and wools fibers as strengthening elements in the thermosetting matrix [7, 8]. Coir fiber is an important fruit waste obtained from the husk of the coconut. Coconut is widely grown in tropical countries such as India, Thailand, Sri Lanka, etc. [9]. Coir fibers have a high lignin content, which makes them resilient to weather and water and allows for chemical modification. [10]. The foremost detriment of plant fibers is the low moisture resistance, which results in a tenuous contact between the fiber and matrix surface [11]. These detriments could be avoided by altering the fiber surface through chemical-based treatment processes like alkali treatment (NaOH), acetylation, chemical grafting, bleaching, delignification, etc. [12, 13]. Santafé et al. [14] extracted fiber reinforcements from the skin of the coconut fruits, then used these fibers as reinforcement along with a polyester matrix to fabricate the composite and tested its mechanical properties. SEM was used to investigate the factors that contributed to the composite's fracture.

Hybridization is a process that involves the inclusion of multiple fibers (natural/natural fiber, natural/synthetic fiber, and natural and synthetic fibers/ nano-fillers) into a single-base matrix that improves the net quality of the composite [15]. The nano-fillers are nanoparticles that are made up of layered mineral silicates and nano-fibers. Due to hybridization, physical, mechanical, and thermal properties are positively impacted [16]. Hybridization lowers the overall manufacturing cost by adding natural fibers to synthetic fibers, but there is a chance of compromising the strength of the composite. According to several investigations, coir fibre composites have been hybridized with other natural fibers such as kenaf (*Hibiscus cannabinus*) [17], bamboo (*Bambusa vulgaris*) [18], and rice straws (paddy straw) [19]. Harish et al. created two types of composites, coir/epoxy and glass/epoxy, and investigated their mechanical properties and interfacial characteristics. Because coir/epoxy fibers have lower mechanical qualities than glass/epoxy composites, they are suitable for low load-bearing applications [20]. Bhagat et al. developed hybrid composites made from glass, coir, and epoxy resin. Eight composite samples were prepared by fixing the constant glass fiber content (20 wt.%) and varying the coir fiber content (5 wt.% and 10 wt.%) and fiber length (5 mm to 20 mm), as well as varying the epoxy weight content (70 wt.% and 75 wt.%), and their mechanical and water taking up characteristics of the hybrid composite were studied. The fibers with the highest mechanical properties have a length of 15 mm and content of 10 wt.%. The amount of water absorption rises when both fiber content (wt.%) and fiber span (mm) increase. The lowest water taking up is reported for composites with a fiber quantity of 5 wt.% and a fiber length of 5 mm [21].

Extensive study has previously been conducted on the hybrid epoxy composite made of glass fiber and coir. However, there is a gap in the literature on the investigation of CC/CF/epoxy resin hybrid composites. A proposal was undertaken to create a hybrid polymer composite by combining CF, CC, and epoxy resin using the hand lay-up process. In this study, the influence of CF on the performance of manufactured hybrid composite samples was studied. Mechanical, water absorption, and SEM morphological characterization were done on the aforementioned hybrid composites. In the future, natural nano-coir fibers will be combined with CF and reinforced with epoxy matrix and evaluated its mechanical properties.

Materials and Method

To develop any product, first select materials, fabrication techniques, mechanical properties, and characterization needed to commercialize or use the product in the industry.

Materials

The following reinforcements and resins have been chosen to fabricate the hybrid composite.

Natural fiber reinforcement: CC fiber

Coconut trees are commonly grown in coastal and other parts of Andhra Pradesh, India. Coconut is harvested from the coconut tree, and the outer protective husk of the coconut is separated from the coconut. To extract CC fiber from coconut husks, the traditional water retting technique is employed, followed by a mechanical beating. This technique yields high-quality white fiber, which can be used for weaving and spinning. The extracted high-quality long fibers were dried in the sunlight after washing, cleaning, and before being hackled and combed. These fibers were trimmed to the desired length of 15 cm, weighted, aligned to the mold size, and then compressed with weight to obtain the desired thickness as well as uniaxial fibers.

Synthetic fiber: CF

CFs are produced by combining rayon, petroleum pitch, and polyacrylonitrile. CF (unidirectional mat 200 gsm) was supplied by Ram Composite Products in Kakinada, Andhra Pradesh, India.

Epoxy resin

Epoxy resin (Grade: LY556), and hardener (Grade: HY 951) were supplied by Ram Composite Products in Hyderabad, Telangana, India.

Composite fabrication

A hybrid composite material made of CF, CC, and epoxy resin is fabricated using the hand lay-up process. Five different samples were fabricated by altering the weight percentages of

CC and CF in the stacking sequences of 20CC, 15CC/5CF, 10CC/10CF, 5CC/15CF, and 20CF, as shown in table 1. In a 100:10 weight ratio, epoxy resin and hardener were blended before placing them in the mold. Releasing gel was applied on the mold surface to prevent the damage of composite laminate during removal. The two fibers were then laid out uniformly; and resin mixture was introduced in between them to maintain the required thickness and adherence in the composite sample. Finally, the remaining resin mixture was distributed on top of the composite laminate and positioned on the overhead projector sheet to get the smooth surface. A compression machine was used to acquire the correct dimensions. Constant pressure was applied to the composite laminate for about 24 h to improve cure as detected by tactile touch. Figure 1 shows the fabricated hybrid composites using the hand lay-up method.

Table 1: Shows sample code and fiber content (wt.%) in the hybrid composite.

Sample	Sample code	CC Wt.%	CF Wt.%	Epoxy resin Wt.%
S1	20CC	20	0	80
S2	15CC/5CF	15	5	80
S3	10CC/10CF	10	10	80
S4	5CC/15CF	5	15	80
S5	20CF	0	20	80

Mechanical testing and characterization

Tensile strength test

The tensile test was used to evaluate the response of the hybrid composite laminate when subjected to axial tensile load. By adopting the ASTM (ASTM: 3039) standard, these characteristics of hybrid composites were measured using a UTM.

Flexural strength test

The flexural test was used to evaluate how the composite hybrid laminate would behave under flexural load or transverse load. By adopting the ASTM D 760-03 standard, these characteristics of hybrid composites were measured using UTM. Utilizing the three-point bending technique, the strength of all created hybrid composite plates was evaluated.

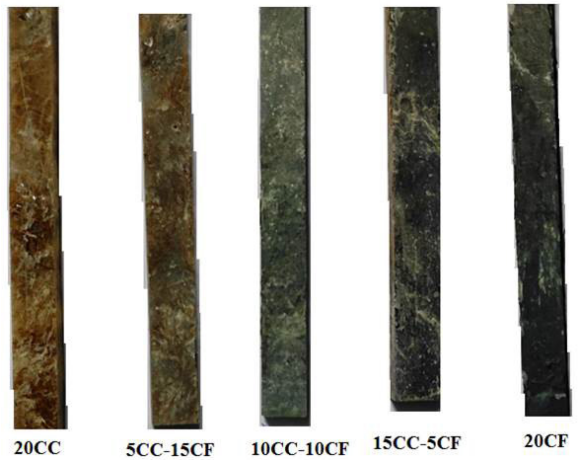


Figure 1: Shows the fabricated hybrid composites.

Impact strength test

This test is referred to as the quantity of energy engrossed in fracture when impact loads are applied. This was estimated by an Izod impact tester. Impact test samples were made using the as per ASTM D-256 standard, measuring 63.5 x 12.7 x 3 mm^3.

Characterization of water absorption

This characterization was performed to find out the capacity of water the hybrid composite sample can absorb under given weather conditions. The ASTM D570-98 guidelines were followed in the preparation of this test sample. These samples were initially dried out for a day at 105 °C in a hot oven before being cooled in desiccators. Through a digital weighing device, the cool down samples are weighed with 1 mg precision. These samples were submerged in distilled water for one day and noted down the time. Every day at the reported time, submerged samples were taken out and their surfaces cleaned out with an absorbent fabric before being weighed and the weight growth was then noted. For 240 h, this procedure was repeated.

$$\% \text{ of water absorption} = \frac{W_2 - W_1}{W_1}$$

Where, W_1 = Dried laminate weight in grams and W_2 = Wet laminate weight in grams.

Chemical resistance test

This test confirms whether hybrid composites will stay functional during their lifespan when exposed to chemicals or solvents. According to ASTM D-543-87 standards, chemical resistance tests on samples of hybrid composites were examined. The effects of acids, alkalis, organic compounds, and salt on hybrid samples were explored.

SEM morphology

A JEOL/EO SEM (Model-JSM-6390) was used to scan the morphology, structure, and interfacial bonding of the tested members. Before this characterization, the failed surfaces of composite members were gold coated with a fine coating of 3 µm, ensuring that the specimen conducts evenly.

Results and Discussion

Tensile strength test

Tensile properties, namely tensile strength, tensile modulus, and tensile strain of CC and CF strengthened epoxy hybrid composite measured and are displayed in table 2 with the findings plotted in figure 2, figure 3, and figure 4. According to figure 2, figure 3, and figure 4, hybrid composites (CC/CF) exhibit increased tensile properties in comparison to CC-reinforced composites (20CC). For 20CC composites, the tensile strength, tensile modulus, and tensile strain values are 30.57 MPa, 2377.16 MPa, and 0.02000 mm/mm, respectively. For 20CF composites, the maximum tensile strength, tensile modulus, and tensile strain values are 294.46 MPa, 10312.22 MPa, and 0.05699 mm/mm, respectively. It was found that increasing the CF content increased the tensile strength, ten-

Table 2: Tensile values of hybrid composites.

S. No.	Sample code	Tensile stress (MPa)	Tensile modulus (MPa)	Tensile strain (mm/mm)
1	20CC	30.57	2377.16	0.02000
2	15CC-5CF	45.96	2533.17	0.02267
3	10CC-10CF	189.56	4883.69	0.06650
4	5CC-15CF	211.78	6031.20	0.12500
5	20CF	294.46	10312.22	0.05699

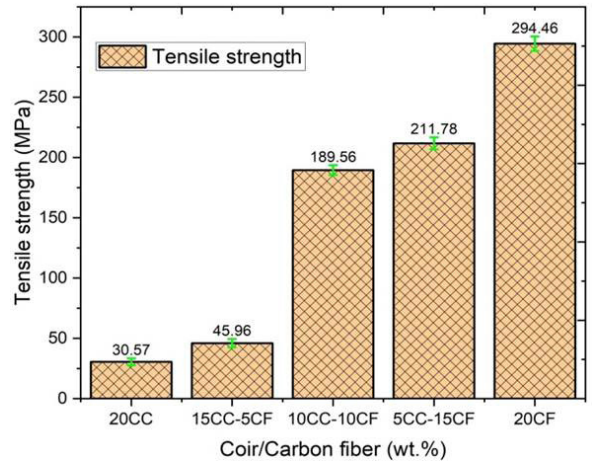


Figure 2: Tensile strength of CC/CF/epoxy hybrid composites.

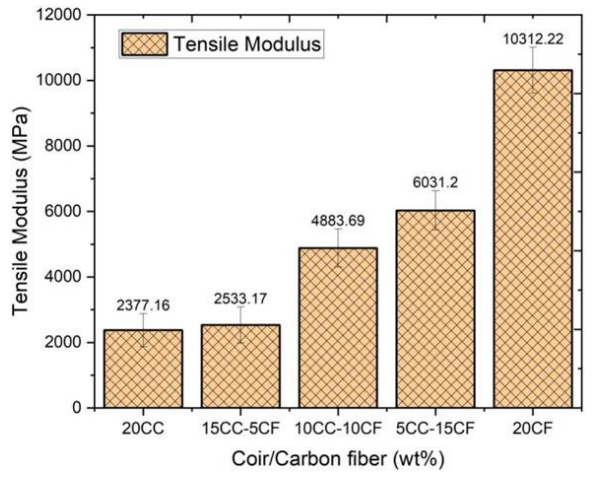


Figure 3: Tensile modulus of CC/CF/epoxy hybrid composites.

sile modulus, and tensile strain properties of the composite. In comparison to the 20CC composites, the hybrid (CC/CF) composites had an 86% increase in tensile strength, 61% rise in tensile modulus, and 84% increase in tensile strain values. This increase in tensile properties implies the formation of a significant interface interaction between the elements, namely CC, CF, and epoxy resin [22]. Another factor contributing to increased tensile properties is the use of stronger and stiffer CF in the hybrid composite [23]. Few researchers have proven that the combining of natural and manmade fibers in polymer composites has enabled the development of strength-enhancing composite materials [24, 25]. Similar kinds of outcomes have been seen when various fillers, such as carbon nanotubes, nanoparticles, and nano-fillers including clay, $CaCO_3$, etc. [26], are incorporated into epoxy composites. These inclusions aid to increase mechanical qualities Kumar et al. [27].

Flexural strength test

Flexural properties, namely flexural strength and flexural modulus of CC and CF reinforced epoxy hybrid composite were measured and are displayed in table 3 with the findings plotted in figure 5 and figure 6. According to figure 5 and figure 6, hybrid composites (CC/CP) exhibit increased flexural properties in comparison to CC-reinforced composites (20CC). For 20CC composites, flexural strength, and flexural modulus values are 30.87 MPa, and 2370.15 MPa, respectively. The maximum flexural strength and flexural strength values for 20CF composites are 146.84 MPa and 7000.56 MPa, respectively. It showed that adding the CF content increased the flexural strength and flexural modulus properties of the composite. In comparison to the 20CC composites, the hybrid (CC/CF) composites had a 61% increase in tensile strength, and a 36% rise in tensile modulus values. This increase in flexural properties implies the formation of a significant interface interaction between the elements, namely CC, CF, and epoxy resin [22]. Another factor contributing to increased flexural properties is the use of strong and stiffer CF in the hybrid composite [23]. Few researchers have proven that the combining of natural and manmade fibers in polymer composites has enabled the development of strength-enhancing composite materials [24, 25].

Table 3: Flexural values of hybrid composites.

S. No.	Sample code	Flexural strength (MPa)	Flexural modulus (MPa)
1	20CC	30.87	2370.15
2	15CC-5CF	60.09	3183.86
3	10CC-10CF	73.78	3911.21
4	5CC-15CF	78.90	3664.93
5	20CF	146.84	7000.56

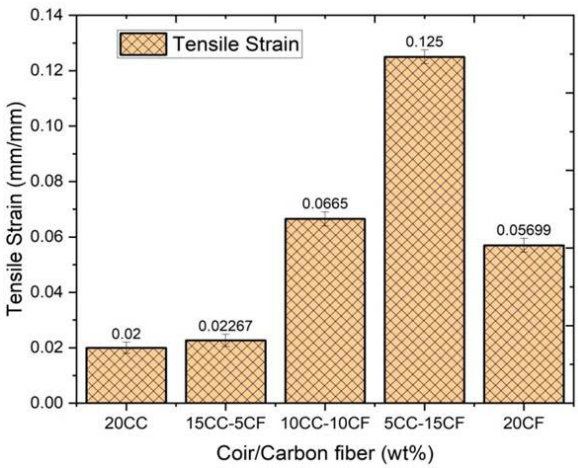


Figure 4: The tensile strain of hybrid composites.

Impact strength test

The impact strength of CC and CF reinforced epoxy hybrid composite were measured and are displayed in table 4 with the findings plotted in figure 7. According to figure 7,

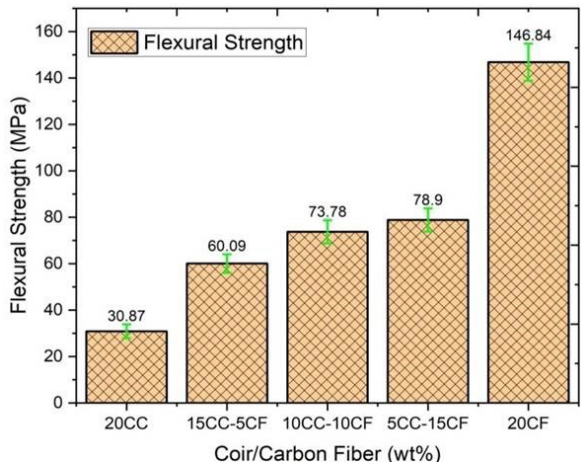


Figure 5: Flexural strength of hybrid composites.

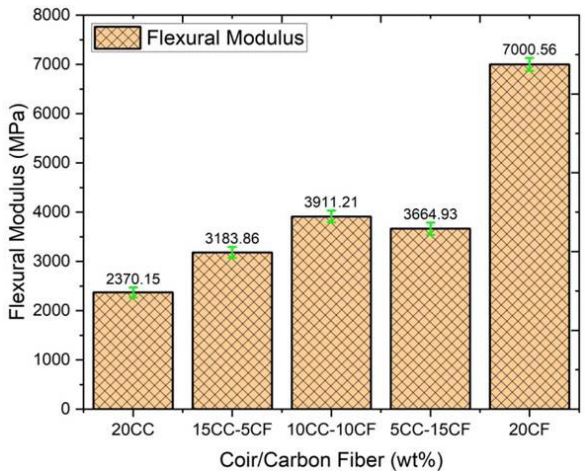


Figure 6: Flexural modulus of hybrid composites.

hybrid composites (CC/CP) exhibit increased impact strength in comparison to CC strengthened composites (20CC). For 20CC composites, the impact strength value is 21 kJ/m^2. For 20CF composites, the impact strength value is 110 kJ/m^2. It demonstrated that adding the CF content increased the impact strength of the composite. In comparison to the 20CC composites, the hybrid (CC/CF) composite has 76% increases

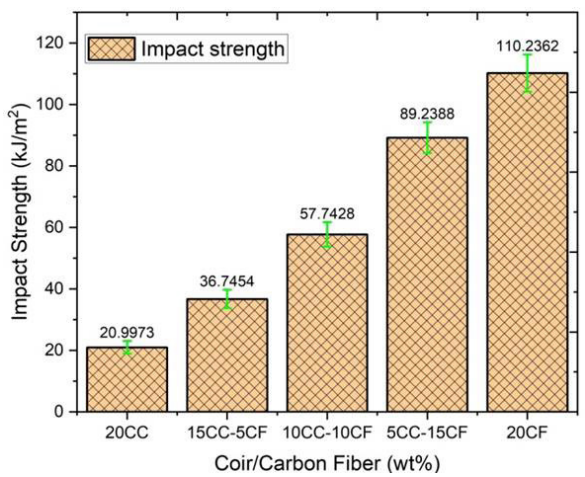


Figure 7: Impact strength of CC/CF hybrid composites.

Table 4: For impact strength of hybrid composites.

S. No.	Sample code	Impact energy (J)	Impact strength (kJ/m^2)	Impact strength (J/m)
1	20CC	0.8	20.9973	62.9921
2	15CC-5CF	1.4	36.7454	110.2362
3	10CC-10CF	2.2	57.7428	173.2283
4	5CC-15CF	3.4	89.2388	267.7165
5	20CF	4.2	110.2362	330.7086

in impact strength values. This increase in impact strength implies the formation of a significant interface interaction between the elements, namely CC, CF, and epoxy resin [22]. Another factor contributing to increased impact strength is the use of strong and stiffer CF in the hybrid composite [23]. Few researchers have proven that the combining of natural and manmade fibers in polymer composites has enabled the development of strength-enhancing composite materials [24, 25].

Characterization of water absorption

This characterization was essential to estimate the quantity of water the CC and CF hybrid composite will absorb every 24 h for 10 days of submersion. The extent to which a composite absorbs water depends on several factors, including its matrix, natural and synthetic fiber composition, manufacturing process, and environmental conditions. Figure 8 shows the percentage of water assimilation of CC/CF hybrid composite. Composites made with CC and CC/CF reinforced composites have a higher affinity for water absorption than CF composites. The fibers contain the hydroxyl (-OH) group, which absorbs water by hydrogen bonding [26].

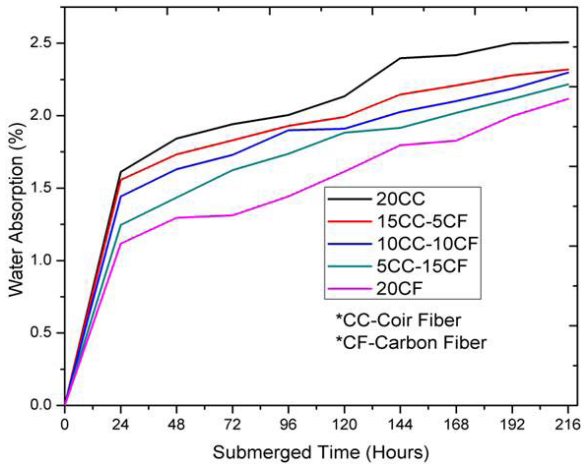


Figure 8: Characterization of water absorption in hybrid composites.

Chemical resistance test

This test was conducted to determine whether the developed hybrid composites would resist when interacting with various chemicals. Table 5 shows the percentage weight rise (+) or loss (-) that occurs when hybrid composite samples were immersed in acids, alkalis, solvents or organic compounds, and salts. Table 5 demonstrates the weight gain found in every sample after dousing in various chemicals. The weight of hybrid composites has increased due to more fibers being exposed to chemicals. However, weight drop was seen

Table 5: Chemical resistance of CC/CF hybrid composites for different chemicals.

Chemicals used	Hybrid composite samples of CC, CF, and epoxy resin				
	20CC	15CC-5CF	10CC-10CF	5CC-15CF	20CF
HCl (10%)	0.535	0.634	0.479	0.684	0.341
HNO_3 (40%)	0.706	0.637	0.708	0.886	0.581
CH_3COOH (8%)	0.278	1.460	0.805	0.585	0.476
NaOH (10%)	1.939	3.724	0.082	2.812	1.356
NH_4OH (10%)	0.438	1.745	2.979	3.385	2.096
Na_2CO_3 (20%)	0.341	0.726	0.465	0.164	0.197
C_6H_6	0.429	0.065	4.539	5.036	3.834
CCl_4	-0.336	-0.158	-0.713	-0.395	-0.345

when immersed in carbon tetrachloride since chlorinated hydrocarbons are quickly attracted to cross-linked polyesters.

SEM morphology

The surface morphology of the CC/epoxy and CC/CF hybrid composite was examined using SEM. These images are exhibited in figure 9 and figure 10. Figure 9 shows CC, epoxy, and good bonding between fibers and resin voids caused by fiber pullout, and fiber pullout. Figure 10 shows the failed surface of the hybrid composite, which includes strong fiber-to-matrix bonding, aligned fiber orientation, and a small number of unfilled regions.

Conclusion

A hybrid composite made up of CC, CF, and epoxy was successfully manufactured using the hand lay-up technique, and the results were evaluated. By adjusting different weight ratios, the mechanical (tensile, flexural, and impact) properties of the fabricated hybrid composites were examined. It has been found that increasing the CF content in hybrid composites improves the mechanical properties. The SEM morphology demonstrated that the CC and epoxy matrix had strong interfacial adhesion and fewer pullouts. The positioning of natural and manmade fibers in a single composite, as well as proper alignment and epoxy infusion between the fibers, lead to a hybrid composite with few flaws and minute spaces. The investigation on water absorption and chemical resistance makes it obvious that all chemicals, except for carbon tetrachloride, are substantially resistant to coir and hybrid composites. In future, nano-fillers like MMT clay and reinforced nanotubes will be added to composites to increase their suitability for use in a variety of industries.

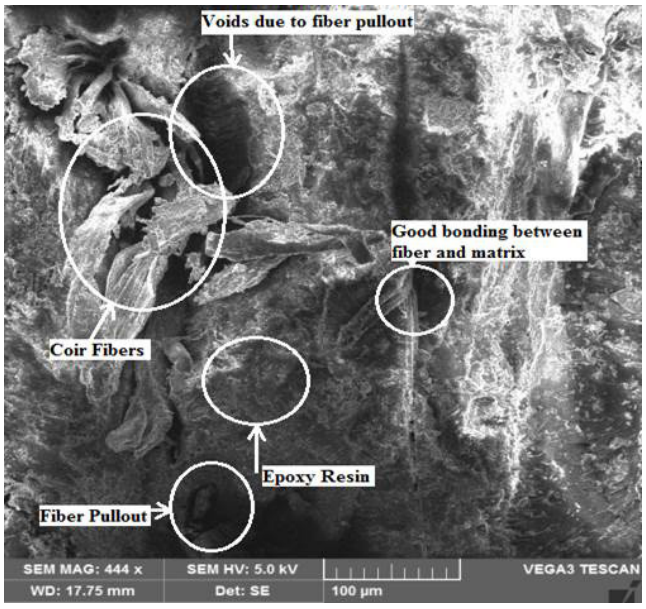


Figure 9: SEM image of CC/epoxy (20CC) composites.

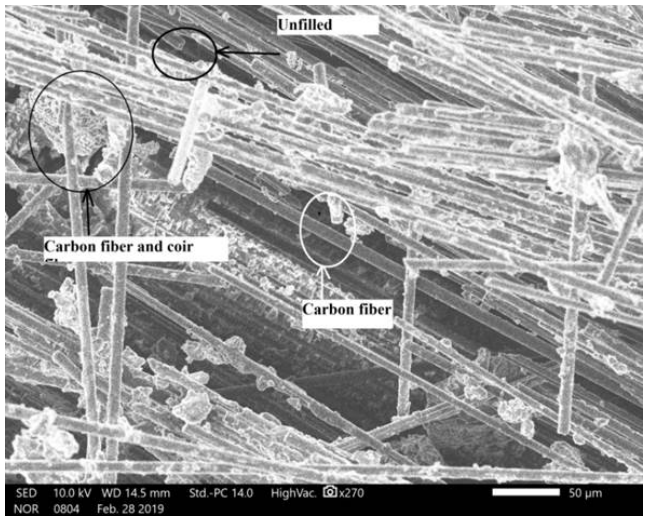


Figure 10: SEM image of CC/CF hybrid composites.

Acknowledgements

None.

Conflict of Interest

None.

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