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Characterization of Fracture Toughness Properties of Coir Fibre Reinforced Polypropylene Composites

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Abstract

This study investigates the production and assessment of fracture toughness in Polypropylene (PP) composites reinforced with different weight fractions of treated and untreated coconut coir fibres. The potential of natural fibres, especially those obtained from agricultural waste like coconut coir, to create lightweight, affordable, and environmentally friendly composite materials has drawn attention. In the study, coir fibres were cleaned and chemically treated with NaOH before being incorporated into PP using injection moulding and extrusion techniques. According to ASTM guidelines, composites with 10%, 20%, and 30% coir fibre concentrations underwent Single Edge Notched Bend (SENB) testing to determine their fracture toughness. The fracture toughness of composites containing 10% and 20% untreated coir fibres was found to be higher than that of pure PP, but composites containing 30% untreated and all treated coir fibres showed reduced fracture toughness. The best composite, with 20% untreated coir, showed the best mix of fibre content and material performance, emphasizing how chemical treatment hurt fibre brittleness and the composites' overall ability to support loads. The potential of untreated natural fibres to improve composite materials for industrial applications- particularly in the automotive industry- is highlighted by this study.

Keywords: *Biodegradable, Coir, Natural Fibre, Polypropylene*

1.0 Introduction

Composite materials are moulded of various materials that, when mixed, make one more material with credits that are not equivalent to the constituent materials. These materials ought to have broadly extraordinary manufactured or real properties. Normal fibres procured from agricultural waste have obtained significance in improving new sorts of composite materials. Right when these composite materials give a couple of advantages over made strands.

Supporting parts like strands, particles, chips, as well as fillers are coordinated into the framework material (polymers) to make material composites. The organization material stays aware of the fibres in reasonable shapes and conveys the heap among the strands, while the help material controls the composite's fortitude. The necessity for materials with pervasive execution in planning has extended lately, which has touched on the creation of new sorts of composites. Most of the composite materials made of late have found many purposes in the auto business[1]. Disintegration hindrance, a high fortitude to weight extent, in significant cost, and lightweight are two or three of the upsides of typical fibre-upheld composites. Composites offer a considerable number of utilizations because of these helpful characteristics.

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The attributes of the created composite are worked on with the help of the fibres in the organization material. Typical strands, which are quickly available in nature, go about as better supporting materials in the continuously unfeasible biological situation. Thus, they have emerged as a basic and supportive resource for the development of composites.

Provincial-based limitless materials have procured importance as supporting materials because of their sensibility, lightweight, eco-kind demeanor, receptiveness, and normal mindfulness. Models integrate rice straw waste, sugar stick bagasse, rice and wheat husk, rice straw, etc. Researchers are dynamically looking for new materials that are productive to human prosperity and the environment on account of extended regular concerns, unnatural weather conditions changes; waste-the-board hardships, and rising oil costs. Normal fibre composites have been used in various current regions all through ongoing years, particularly in the vehicle business for doorway sheets, seat backs, headliners, group plates, run sheets, and inside parts.

Jute/glass fibre crossover composites' mode 1 crack way of behaving was analyzed by Harikrishnan *et al.* in their review distributed[2]. The cracked way of behaving was found utilizing a SENB test. Fibre glass and jute pressure forming were utilized to make composites made of epoxy tar and fibre support. The discoveries exhibited that composites built up completely with glass fibre had the most elevated break strength. Composites made with 75% glass fibre 25% fibre half glass fibre and half jute fibre have break strength esteems that are the nearest to those of glass fibre composites. For the equivalent, limited component investigation was utilized. Nikita Agarwal and colleagues[3], Hand-layup procedure was utilized to make epoxy composites with carbon fibre support. The composite examples' carbon fibre content went from 20, 30, 40, and half by weight. The composite plates' mechanical and crack strength qualities were checked out. Higher crack sturdiness values were tracked down in the composite example with 50-weightper cent carbon fibre. The 50-weightper cent carbon fibre composite examples exhibited great hardness, flexural strength, and effect strength. The composite example with 40-weightper cent carbon fibre showed solid elastic properties.

Pliable properties and break sturdiness of coconut shell fibre epoxy composites were overviewed by Abdul Hakim Abdulla *et al*[4]. The strands were first treated with a fundamental, silane plan that included both a solvent and a silane part. The instances of hand-layup composite improvement were truth-be-told sounds. Flexibility of strands treated with silane. Maximum fibre upheld composite showed more noticeable breaks in untreated models. The break durability direct of sisal-upheld epoxy composites was explored by Araya Abera, *et al*[5]. The Hardener (HY-951) and the cross section (AY-105) are both used. By using the hand-layup approach, composite models with various weight portions of fibre (15, 25, 30, 35, and wt%) were made. More imperative break toughness was displayed by the composite model with 30 wt% of fibre. Basappa, Hulugappa and accomplices[6] by using the hand-layup process and a hot press, glass surface upheld epoxy composites with a couple of fillers, including silicon carbide and graphite, were made. We looked at the materials' pliant, flexural, impact, and break strength. The composite model's glass fibre piece was set at 55 weight per cent. The filler part went from 5 to 10 weight per cent. Extraordinary malleable and flexural limits were shown by the composite model with a 10-weightper cent graphite filler. The composites that weren't stacked up with filler had more unmistakable impact resistance. Extended graphite filler stacking extended the composites' breaking strength. M Kullayappa and partners[7] Vinylester stick was used to develop groundnut shell and silicon carbide particles and composite plates were made using the hand-layup technique. Powdered groundnut shell immersed with a maleic anhydride.

V. Santhnam and others[8], the hand-layup strategy was utilized to make polyester sap composites supported with banana and glass fibre. The composite examples' shifting fibre contents 13.17 to 20.0% of the volume. Methyl ethyl ketone (2%), Branch of I and P Designing, NIE, Mysuru, used as a gas pedal and Bug. Impetus is made with 1% cobalt. Composites with banana fibre support showed fracture strength esteems that were more like those of composites with glass fibre support. In this way, in certain applications, composites built up with banana fibre can replace composites supported with glass fibre. Shivakumar Gouda and associates[9] Mode 1 Glass-carbon fibre supported half-breed polymer composite's break conduct was considered. Along and across the example's fibre direction, the example's break sturdiness was evaluated.

Z Khan *et al*.[10] Audit of the writing the investigation of bamboo fibre built-up epoxy composites' break conduct was panned. At first, 24 hours were enjoyed treating strands with 2, 6, and 10% NaOH arrangements. The composite examples were made utilizing strands that were 10, 20, and 25 mm long. The hand-layup approach was utilized to make composite examples. The discoveries showed that break durability values were higher in composite examples with filaments of 25 mm length and lower in composite examples with strands of 10 mm length. JC Man-caused cellulose strands that have been reinforced by Zarges *et al*[11]. Composites made of polypropylene were made utilizing the infusion shaping interaction. On the crack sturdiness, the impacts of fibre content were researched by a couple of specialists. The water ingestion, mechanical properties, and electrical properties of the coconut fibre-supported polypropylene composites were concentrated by Maria Virginia Gelfuso *et al*. Coconut strands were first precisely (utilizing an ultrasonic shockwave) and artificially (utilizing an alkalization cycle) treated, and afterwards, they were dried utilizing UV light. By utilizing infusion forming, composite examples with 5, 10, 15, and 20 vol% of treated and untreated coconut strands were made. In contrast with untreated and synthetically treated composite examples, composite examples containing 5 vol% of precisely treated filaments show higher elasticity values. Electrical following test and electrical resistivity results are best for composite examples having 10% precisely treated strands. The discoveries show that composite examples made with filaments that have gone through mechanical treatment are proper for electrical applications[12].

Isiaka O and others[13], artificially treated coir fibre supported polypropylene composites' malleable and flexural attributes were considered. Coconut coir filaments go through compound handling. Utilizing potassium and sodium hydroxides. The composite examples' fibre content reaches from 2, 4, 6, 8, and 10 wt%. Pressure forming is utilized to make composite examples. Better ductile and flexural properties were found in examples that had been treated with KOH and NaOH, separately. Nadir and others[14], Polypropylene composite boards supported with coconut fibre were made utilizing the hot press process. The composite example has differing measures of fibre (40, 50, 60, and 70 wt%). As a coupling specialist, maleic anhydride united polypropylene powder (3 wt%) is used.

Research by Rajiv Kumar[15] focus has shifted from synthetic polymers to natural fibres due to the increased industry demand for sustainable materials. The difficulties and possibilities of using natural fibre-reinforced polymer composites in a range of industrial applications are covered in this paper. Given their biodegradability, low weight, affordability, and environmental friendliness, natural fibres make excellent candidates for use in contemporary industrial applications. It has been addressed how natural fibres are used in a variety of industries, with an emphasis on the furniture and automotive sectors. This document covers the common natural fibres used in polymer composites, such as jute, hemp, sisal, kenaf, bamboo, cotton, flax, abaca, and coir.

Given the availability and affordability of coconut coir as an agricultural waste product, the study emphasises the economic viability of using coir fibre and PP composites. Incorporating untreated coir fibres into PP lessens the need for more costly and non-sustainable synthetic fibres while also improving the material's qualities, such as fracture toughness. According to the study, composites containing 20% of untreated coir fibres performed at their best, showing that major advancements are possible even in the absence of pricey chemical treatments. This simplifies and lowers the cost of the production process. Additionally, using natural fibres like coir supports sustainable practices, which may reduce waste management expenses and environmental impact. Md. Nazrul Islam and others[16] physio-mechanical qualities of the polypropylene composite with coir fibre support were evaluated. O-hydroxybenzene diazonium salt is utilized to fix coir filaments. The composite example's fibre content reaches 10, 15, 20, and 25 weight per cent. By utilizing the infusion forming method, composite examples are produced using both untreated and treated coir strands. Synthetically modified examples showed work on mechanical characteristics. Anshu A S and others[17], Polypropylene composites built up with coconut fibre were made utilizing the infusion forming method and 2% maleic anhydride as the coupling specialist. The composite has shifting measures of fibre (5-10 wt%). Explored were the composites' tractable attributes. The discoveries uncovered that when contrasted with unadulterated PP, the composite made with 2% maleic anhydride would be wise to tractable attributes.

This study aims,

- To fabricate the coconut coir-reinforced Polypropylene composites with varied coir weight fractions.
- To conduct the fracture toughness test on the fabricated composites and to analyze the results.

2.0 Materials and Methods

2.1 Materials Used

The below table shows the list of materials used in the process.

Table 1. List of materials used in the process

Sl.No	Materials
1.	Polypropylene granules
2.	Coconut coir fibres
3.	Sodium Hydroxide (NaOH)

2.1.1 Coconut Coir Fibre

In Sri Lanka and India, coconut is a popular organic fibre that is easily obtainable. It acts as a fortifying element. The hard inner and outer layers of coconuts can be used to extract the fibre material known as coir. Aceraceae coconut fibre, or cocos nucifera, is the scientific name for this member of the palm plant family. Coconut fibre comes in two distinct brown varieties: white fibre and fibre. Mature coconuts were kept for their white fibres, whereas immature coconuts were kept for their brown fibres. Commercial coconut fibres come in three varieties: bristle (long fibres), mattress decorticated (mixed, relatively short fibres), and fibres.

2.1.2 Polypropylene

The thermoplastic PP is renowned for its affordability, resilience, and adaptability. Technically speaking, PP is ideal for a variety of applications, such as consumer goods, automotive components, packaging, and textiles. It also has a high melting point and exceptional fatigue resistance. It has a good strength-to-weight ratio and is comparatively light, making it useful for making strong but lightweight materials. PP offers manufacturing process flexibility since it can be treated through a variety of methods, including blow moulding, extrusion, and injection moulding. However, polypropylene's lack of biodegradability is a major disadvantage. Since PP is a petroleum-based plastic, it does not naturally break down and, if improperly handled, can contribute to long-term environmental damage. The goal is to reduce the environmental impact of PP while preserving its desirable technical qualities. This can be achieved by combining PP with biodegradable polymers or adding natural fibres.

2.2 Methodology for Fabrication of Composite

2.2.1 Washing with Water

The strands that were taken out are cleaned with water to eliminate any leftover residue and plant material. Strands are dried in daylight in the wake of washing with water to eliminate their dampness content. These dried filaments have sliced to an inexact length of 5 to 10 mm.

2.2.2 Compound Treatment of Fibre with NaOH (Sodium hydroxide)

Caustic soda, also referred to as sodium hydroxide, is an essential component in the chemical processing of natural fibres. This ionic compound, which has the chemical formula NaOH, is made up of ions that are hydroxide (OH) and sodium (Na). It has a density of 2.13 g/cm^3 and manifests as white flakes in its solid state. With a melting point of 318°C and a boiling temperature of 1388°C, sodium hydroxide is a remarkable substance. Because of its exceptional water solubility, it can be used in a wide range of industrial applications, most notably the processing of natural fibres. Because of its potent alkaline qualities, sodium hydroxide is widely used in industries to break down and alter the structure of natural fibres. It helps in cleaning, bleaching, and getting the fibres ready for dyeing or other treatments when applied to them. The fibres' overall quality and performance in textile applications are improved by the chemical treatment, which also increases the fibres' dye affinity and absorbency. Sodium hydroxide is widely used in many industries, which emphasises how crucial it is to preserve the efficacy and efficiency of fibre processing and other associated industrial processes.

One and a half litres of water are used to dissolve 250 grammes of sodium hydroxide (NaOH) to create a chemical solution for treating fibres. The purpose of the solution is to treat natural fibres synthetically. For a full day, the fibres are immersed in the NaOH solution so that the chemical can work on them. The fibres are completely rinsed with water to get rid of any remaining NaOH solution after this soaking time. The treated fibres are subsequently dried in the sun to remove any remaining moisture. This procedure guarantees that the fibres are adequately cleaned and devoid of surplus chemicals, preparing them for usage or processing in the future.

2.2.3 Composite Material's Structure

Utilizing the infusion forming process, composite material examples with differed weight rates of treated and untreated normal are made. The conformity of the composite materials manufactured is displayed in the table beneath.

2.2.3 Expelling Technique of Composite Example Pellets

The principal unimposing regular fibre and polypropylene are mixed in a ZV-20, a twin screw extruder machine, situated at the (CPET) Kochi found Kerala. While joining the combination of normal fibre and polypropylene. The engine speed was set to 90 RPM, and the dissolving temperature was set at 210°C. There were 5 to 14 bars of soft pressure.

2.2.4 Explicit twin screw extruder machine particulars

- Screw measurement: 21 mm
- Yield: 10 Kg/hr (wt. %)
- Engine: 5.5 KW 10 (untreated)
- LD proportion: 40:1 20 (untreated)
- Warming burden: 5 KW

The twin extruder machine produces strands of the composite material made of polypropylene and rice straw fibre. These expelled strands went through the water shower since they were warmed. To make composite pellets, these expelled strands are sent into the processor machine. The expelled strands take a little amount of water happily with them as they go through the water shower. To limit the dampness content, these composite pellets were dried in daylight.

2.2.5 Development of Composite Plate

In an infusion forming machine, the composite example is made utilizing the expelled pellets. The temperature at which expelled pellets are dried in an oven is 70°C for three hours before being supplied into the infusion shaping machine's container to dispose of any leftover dampness. The establishment forming machine, JIT 80, is utilized to make composite materials. This gear is presented at the CIPET in Mysore, Karnataka state. The machine of infusion forming the various prerequisites for the infusion shaping machine incorporates 32mm screw

Table 2. Composition of composite materials

Composite name	PP weight%	Coir Fibre weight%	Total weight%
PURE PP	100	00	100
U-10-S	90	10	100
U-20-S	80	20	100
U-30-S	70	30	100
T-10-S	90	10	100
T-20-S	80	20	100
T-30-S	70	30	100

measurement; 129 grams of shot limit: Power limit is 13.5 Kw at 1810 kg/cm of infusion pressure.

The infusion-forming machine has four unmistakable warming zones. The infusion forming machine's temperature zones are kept at 1stZone - 180°C, second Zone - 190°C, 3rdZone - 200°C, and 4thZone - 210°C with the goal that the plastic materials taken care of from the container dissolve in each zone and stream uninhibitedly into the bite the dust depression. The tension is kept at 60, 50, 47, and 45 bars in every one of the various zones, correspondingly. The infusion forming process is utilized to make composite plates with aspects of 100 X 90 x 5 mm. As per ASTM rules, test examples are obtained from these composite material plates that are produced.

3.0 Material Characterization

A Single Edge Notched Bend (SENB) test is carried out in compliance with ASTM D-5045 to ascertain the initial mode fracture toughness (KIC) of a plastic material. In this test, a room-temperature Universal Testing Machine (UTM) is used to load a pre-cracked specimen under stress. The initial 0.5 mm crack was made with a knife.

To propagate the initial crack, a tensile force is applied to the specimen during the test. The critical stress intensity factor (KIC), a measure of fracture toughness, is computed using the greatest load that the material can bear. The resistance of the material to fracture under stress is measured by this factor. The applicable equation from ASTM D-5045 standards is used to compute the critical stress intensity factor, taking into consideration both the applied load and the specimen's dimensions and geometry. In this research, we assessed mode-I fracture in the specimen.

Toughness test.

$$K_{IC} = \frac{P}{B\sqrt{W}} f(x)$$

$$f(x) = \frac{6\sqrt{x}\,[1.99 - x(1-x)(2.15 - 3.93x + 2.7x^2)]}{(1+2x)(1-x)^{3/2}}$$

Where,
B= Specimen thickness,
W= Specimen width,

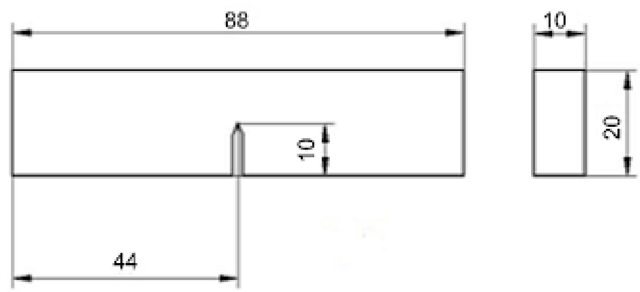

Figure 1. ASTM standard specimen for SENB.

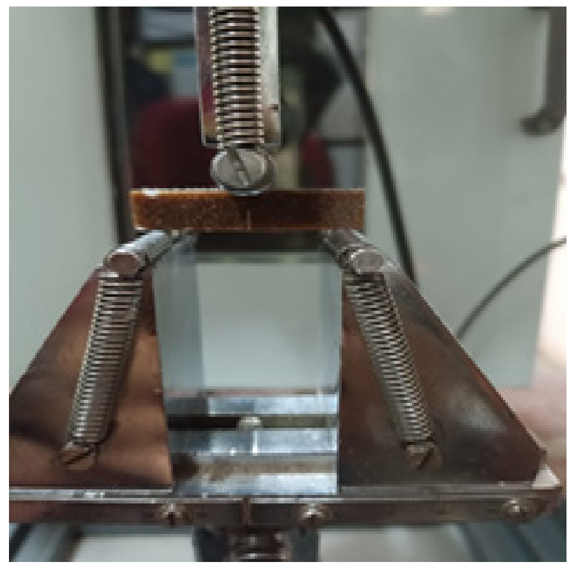

Figure 2. SENB test.

a = Crack length,
P= Extreme load supported by the specimen,
(a/w) = Geometric factor

Trial specimen dimensions are according to the American Society of Testing and Materials standards. The constructed SENB test specimen is depicted in Figures 1 and 2.

Table 3 shows the f(a/w) values for the above test for different values of a/w.

The following procedures have been followed to perform the SENB fracture toughness test on natural fibre-reinforced polymer composites we started by precisely measuring the composite specimens by ASTM guidelines, making sure that each sample has a pre-notch in the centre. After that, the specimens ought to be brought up to standard humidity and temperature levels. Place the specimen, notched side down, in a universal testing machine's three-point bending fixture. Apply a

Table 3. The f(a/w) values for SENB test

a/w	f(a/w) for SENB test
0.450	2.286
0.460	2.354
0.470	2.426
0.480	2.501
0.490	2.580
0.500	2.663
0.510	2.749
0.520	2.840
0.530	2.936
0.540	3.036
0.550	3.142

load gradually while maintaining a constant crosshead speed until the specimen fractures; during the test, record the load and displacement data. Applying the specimen dimensions, notch geometry, and peak load, compute the fracture toughness.

4.0 Result and Discussions

Fracture toughness of coconut coir-reinforced PP composites

Fracture toughness (SENB) test:

Figure 3 shows the stress intensity factor values for pure PP and coir fibre-reinforced PP composites. In the above graph, it is observed that for untreated 10 wt% and 20 wt% fibre-reinforced PP composites the fracture toughness values, i.e. stress intensity factor values are higher as compared to that of pure PP composites. However, untreated 30 wt% coconut coir fibre reinforced PP composites demonstrate a lesser value of fracture toughness or stress intensity factor as compared to that of pure PP. Similarly, in the above graph, it is observed that treated 10 wt%, 20 wt% and 30 wt% coconut coir fibre reinforced PP composites show detrimental values of fracture toughness or stress intensity factor as compared to that of pure PP.

By Figure 3 we can also derive that as compared to treated fibre specimen untreated one shows better values of fracture toughness hence good load bearing capacity. By comparing untreated 10, 20 and 30 wt% fibre-reinforced PP composites among themselves they show an ascending pattern of fracture toughness parallel to increasing weight fraction with slight decrements in 30 wt% composites. Similarly, by comparing treated 10, 20 and 30 wt% fibre-reinforced PP composites among themselves they show a descending pattern of fracture toughness parallel to increasing weight fraction. By this we can conclude that chemical treatment of the fibre affects the strength of the fibre and makes the fibre brittle; hence increase in fibre content in treated fibre-reinforced composites fails to carry the load.

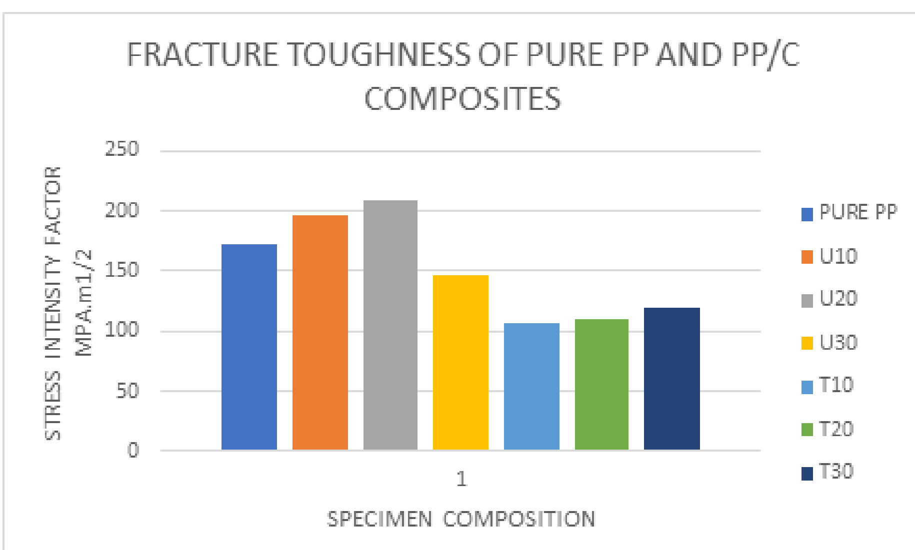

Figure 3. Fracture toughness of PP and PP/C composites.

Table 4.T Fracture toughness values of coir fibre-reinforced PP composites and rice straw fibre-reinforced PLA composites

Specimen composition	K_{IC} values of coir fibre-reinforced PP composites	K_{IC} values of rice straw fibre-reinforced PLA composites
PURE	170.32	120.19
U-10	193.02	127.96
U-20	210.65	128.81
U-30	148.63	105.86
T-10	106.23	139.29
T-20	113.46	124.38
T-30	122.28	73.24

The graph shows the stress intensity factor (MPa·m$^{1/2}$) for fracture toughness of various PP composites reinforced with coir fibres as well as pure PP. The labels on the specimens read T10, T20, T30, U10, U20, and PURE PP. It is clear from the data that the PP composites' fracture toughness is impacted by the inclusion of coir fibres. In comparison to composites, pure PP shows a modest level of fracture toughness. The composite with the highest fracture toughness among the others is U20 (20% untreated coir), suggesting that this composition provides the greatest improvement in resistance to crack propagation.

On the other hand, specimens with treated coir (T10, T20, and T30) and 10% and 30% untreated coir (U10 and U30) typically have lower fracture toughness than U20. This implies that, in this instance, a coir fibre content of about 20% is the ideal amount to increase the fracture toughness of PP composites. Since the values of T10, T20, and T30 treatments are lower than U20 and more akin to pure PP, it appears that these treatments do not affect coir fibres' fracture toughness. This suggests that the kind and amount of fibre may have a significant impact on how successful reinforcing is, with 20% of coir that has not been treated being especially effective.

The above table compares the fracture toughness values of coir fibre-reinforced PP composites and rice straw fibre-reinforced PLA composites[26]. As a result, coir fibre-reinforced PP composites are more resistant to cracks and chips than rice straw fibre-reinforced PLA composites. This difference may be caused by the fact that coir fibres are stronger than rice straw fibres and have better interfacial adhesion with PP resin. In summary, coir fibre-reinforced PP composites have a higher fracture toughness than rice straw fibre-reinforced PLA composites.

5.0 Conclusion

- Natural fibre composites, like coconut coir, are becoming more and more popular because of their lightweight, affordable, and environmentally friendly qualities. These attributes make them ideal for a variety of industrial uses, particularly in the automobile industry.
- To make composites, polypropylene granules and coconut coir fibres are utilised. To improve the coir fibres' performance and compatibility in the composite, they are cleaned and chemically treated with NaOH.
- The composites are made by an injection moulding and extrusion technique that yields samples with varying weight percentages of treated and untreated coir fibres (10%, 20%, and 30%).
- Using a Universal Testing Machine (UTM) and adhering to ASTM guidelines, SENB tests are performed on the composite samples to determine their fracture toughness.
- Compared to pure polypropylene, untreated 10% and 20% coir fibre-reinforced composites have higher fracture toughness but treated fibre

composites and untreated 30% coir composites have lower fracture toughness.

- The research indicates that the polypropylene composite with 20% untreated coir fibre content has the highest fracture toughness, indicating the ideal compromise between material performance and fibre content.
- Coir fibres that have been chemically treated often have less fracture toughness than untreated fibres, which makes them more brittle and less useful for increasing the load-bearing capacity of the composite.

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