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Research Article

Mechanical Properties of Arecanut and GFR Hybrid Polypropylene Composites

Yarrapragada K. S. S. Rao,[1] Ayaz Ahmad,[2] Sudheer Kumar Battula,[3] Reem Mohammed Alharbi,[4] Neveen Abdel-Raouf,[5] Ibraheem Borie M. Ibraheem,[6] Essam Nageh Sholkamy,[7] B. M. Bala,[8] and I. Jenish[9]

[1]*Department of Mechanical Engineering, Aditya College of Engineering, Surampalem, Andhra Pradesh 533437, India*
[2]*Department of Mathematics, National Institute of Technology, Patna, Bihar 800005, India*
[3]*Department of Mechanical Engineering, Lakireddy Bali Reddy College of Engineering, Mylavaram, Andhra Pradesh 521230, India*
[4]*Department of Biology, College of Science, University of Hafr Al-Batin, Hafar Al-Batin, Saudi Arabia*
[5]*Department of Biology, College of Science and Humanities, Prince Sattam Bin Abdulaziz University, AlKharj 11942, Saudi Arabia*
[6]*Department of Botany and Microbiology, Faculty of Science, Beni-Suef University, Beni-Suef-65211, Egypt*
[7]*Department of Botany and Microbiology, College of Science, King Saud University, Riyadh-11451, Saudi Arabia*
[8]*Department of Food Science, Sejong University, Republic of Korea*
[9]*Department of Applied Mechanics, Seenu Atoll School, Hulhumeedhoo, Addu City-19060, Maldives*

Correspondence should be addressed to I. Jenish; jenish@satollschool.edu.mv

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The mechanical characteristics of hybrid polypropylene composites may be enhanced by adjusting the fibre loading and ratio, according to this study. The hot press technique was utilised to generate a variety of composites with four different amounts of fibre loading. In addition, the fibre ratio in composites with a 20-weight-percent fibre loading was changed. The composites were characterised using Fourier transform infrared analysis as well as tensile, flexural, and hardness tests. In the composites that have been created, Fourier transform infrared examination showed that hemicelluloses, lignins, and moisture were present, all of which have the potential to reduce tensile strength. Fibre loading resulted in a decrease in tensile strength but an increase in Young's modulus. With increasing fibre loading, flexural modulus and hardness rose, whereas flexural strength declined. The best mechanical qualities were found in a composite made primarily of arecanut and glass fibres, with a weight ratio of 1 : 3.

1. Introduction

Design freedom is provided by hybrid fibre–polymer systems, which allow for the tailoring of composites and the attainment of qualities not possible in binary systems comprising the same fibre/filler in matrix [1]. In few cases, benefits of one fibre can outweigh the drawbacks of another. As a result, proper material design could bring about a performance-to-cost equilibrium [2, 3]. Automotive industry is the primary consumer of natural fibres because of their functional characteristics. Mirror frames, doors, windows, and other interior sections can all be made from composites, as can truck cabs, panels, shelves, and other trim components [4–6]. Composites are also popular in the production of brake shoes. Palm tree species (*Areca catechu*) bear the arecanut fruit (also known as the arecanut) and are found throughout Asia [7]. Fibres made from arecanuts are inexpensive. The fundamental issue with natural fibre composites is their incompatibility with polymer matrixes due to the hydrophobic nature of natural fibres [8–10].

Polymeric matrix composites commonly use glass fibres as reinforcement. Many applications benefit from its low cost, strong tensile strength, resistance to chemicals, and insulating properties [11, 12]. Among the most commonly

used types of fibres in fibre reinforced plastics, E and S glass are the most prevalent. E-glass fibres are the most commonly utilised reinforcing glass fibres in the fibre-reinforced plastic industry because of their low cost [13, 14]. It is possible to get the desired properties by combining fibres in the right way and orienting them in the right direction. Fibre composites are stiffer than aluminium and have a specific gravity one-fourth that of steel, but they have the same functional properties as steel [15]. In the nautical, automotive, and piping industries, glass fibre-reinforced composites (GFRCs) have become increasingly popular because of specific strength and stiffness, along with their resilience to corrosion and impact damage [16]. Fillers, on the other hand, enhanced the properties of composites while also lowering the overall cost of the final product. We see polymers in practically every facet of modern life, from high-tech devices like artificial hip and knee joints to single-use plastic utensils for food [17].

Linear hydrocarbon polymers such as polypropylene are widely utilised in textiles, lab equipment, and automobile parts. Polypropylene is available in densities varying from 0.91 to 0.97 g/cc and is completely linear [18]. Polypropylene composites offer good flowability, mechanical properties, weatherability, and chemical resistance and are cost-effective when compared to other materials. These composites are widely employed as a key raw material, particularly in vehicle parts. Natural fibres that have been hybridized with synthetic fibres have been the subject of extensive study. However, no studies have been done on the use of arecanut and glass fibres in a polypropylene matrix. It is so hoped that this paper may provide some light on the hybridization of arecanut and glass fibres with polypropylene [19, 20]. Because of its inexpensive price, polypropylene was selected as the matrix material. Our approach of making eco-friendly hybrid composites out of natural fibres is described in this publication [4, 21, 22]. The paper focuses on the interaction of arecanut fibres with glass and polypropylene in this application.

Hybrid fibre-based polymer composites are created all over the world to give designers greater creative freedom when creating composites and to provide features that cannot be achieved in binary systems using only a kind of fibre or filler discrete in the matrix [23, 24]. They provide balanced strength and stiffness, increased bending and mechanical characteristics, improved fatigue and impact resistance, improved fracture toughness and crack arresting qualities, and decreased weight and cost. Polymer-based composites have been used to tackle technological difficulties since the 1960s [22]. Fibre composites that combine two or more types of fibre can fill in the gaps left by the omissions in the original design. As a result, good material design allowed for a trade-off between performance and cost. To improve the composite's mechanical strength and other qualities, stronger synthetic or natural fibres can be hybridized with natural fibres [25]. The automotive sector prefers natural fibres because of their beneficial properties. Because of its biodegradable nature, natural fibre-reinforced composites are both low-cost and environmentally friendly. As an additional benefit, lignocellulose fibres are nonabrasive, light in weight, and easy to get. They also take less energy to process, decrease the density of finished products, and absorb carbon dioxide at the time of their growth. For composites, lignocellulose fibres can be blended with either thermosetting or thermoplastic polymers. However, thermosetting polymers show the composite to be extremely brittle, making it impossible to repair. Natural fibres, despite their amazing properties, have gained popularity due to their little impact on the environment [4]. This palm tree, known as the *Areca catechu*, produces the arecanut fruit, which is widely available and thrives throughout Asia [26]. Due to deficiency of compatibility between natural fibres and the hydrophobic qualities of polymer matrix, the fundamental impediment to using natural fibre composites is lower fibre–matrix interfacial bond.

Figure 1: Universal testing machine setup.

On the other hand, polymeric matrix composites are commonly reinforced with glass fibres. Because of their inexpensive price, strong tensile strength, good chemical resistance, and excellent insulation, these materials are often preferred over others [27]. Fibre-reinforced plastics commonly use S-glass and E-glass fibres. Commercially accessible reinforcing glass fibres are more expensive than E-glass fibres. These composites have been tested for their mechanical properties. Composites bonded with polyester and oil palm fibre/glass were made for research in another work [28]. The researchers also looked at flax/glass-reinforced composites, jute/glass-reinforced composites, and basalt/glass-reinforced composites. There are a lot of studies being done that use a combination of glass and a natural fibre.

This polymer is utilised in textiles, laboratory equipment, food packaging, and automobile components because of its low cost [29]. Polypropylene's density ranges from 0.91 g/cc to 0.97 g/cc depending on the materials' availability. Natural fibres that have been hybridized with synthetic fibres have previously been the subject of extensive study. It is, however, the first time that arecanut and glass fibres have been used in conjunction with a polypropylene matrix. Arecanut's hydrophilic characteristic causes moisture absorption and, as a result, product deformation when used as a

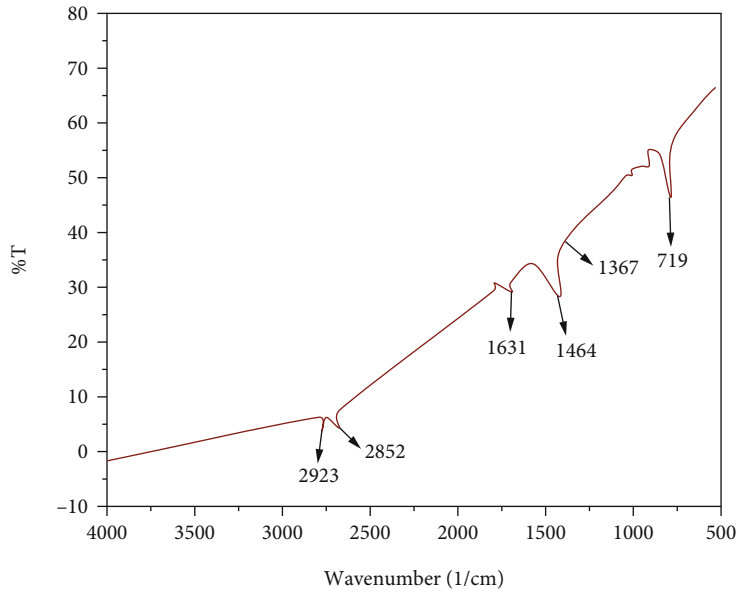

Figure 2: Fourier transform infrared spectrum of polypropylene.

fibre material. Fibre-matrix adhesion is critical to the strength of produced composites [30–32]. Fibre-polymer matrix interface bonding can be improved by modifying the fibre surface with alkaline treatment such as NaOH. NaOH solution was added to the arecanut fibres in order to improve their adherence. A major goal of this study is to create a composite containing raw and alkali-treated arecanut fibre, glass fibre, and polypropylene, as well as other materials [10]. Alkali treatment and fibre ratio have been shown to influence the mechanical and morphological properties of produced composites.

2. Methods and Materials

2.1. Materials. Polypropylene, arecanut, and glass fibre were all used in this experiment. The melting point of LDPE granular polypropylene was 140°C, and the material was white in colour. It was in granular form. The arecanut fibres were released by soaking it in water at room temperature for ten days. After that, nut was cracked open and the fibres of the arecanut extracted by hand.

2.2. Manufacturing of Composites. These hybrid composites are made using hot press process with several proportions of arecanut and glass fibre. The aluminium die has a 150 × 150 × 5 mm size. When the maximum load and temperature were both 35 kN, the hydraulic machine was used. The percentage of arecanut and glass fibres was altered from 5 to 20 wt percent, with a 1 : 1 ratio. Fibres with a diameter ranging from 3 to 5 mm were employed. A balance was used to determine the amount of fibre and polypropylene needed. The die was filled with the premixed mixture. The fibre–matrix mixture was pressed into the die with 30 kN of pressure. To begin with, the temperature was increased to 140°C and kept for around 18–20 minutes before being increased to 160°C. Depending on the thickness requirement, this is true. Cooling the die to room temperature was the next step. By relieving the pressure, the composites were removed from the die. This method was used to make all of the composites.

A spectrophotometer was used to record the FTIR spectra of arecanut–GFR hybrid composites in this study. To obtain the first powdered samples, a knife was used to scratch the composite. At a mortar pestle, the samples were mixed with potassium bromide (KBr) in a 1 : 1 ratio. Using a mechanical presser with an 8-ton pressure rating, the mixture was compressed into a pellet and deposited on a sample holder for spectroscopic analysis.

2.3. Mechanical Testing. Tests for tensile, flexural, and hardness were conducted. There were five samples analyzed and average values were presented for each. A head speed of 4 mm/min was applied on a UTM machine for the tensile test in accord with standard of ASTM D 638-01, and the setup is shown in Figure 1. The same testing machine was used to conduct static flexural tests in accordance with ASTM D 790. A durometer hardness tester set on Shore (A) scale was used to gauge the composite's hardness.

3. Results and Discussion

Figure 2 depicts the polypropylene FTIR spectrum. The most prevalent applications include identifying unknown materials and confirming manufacturing materials, as well as performing qualitative and quantitative analyses of organic molecules and determining the chemical structure. CH_2 (methylene) symmetrical strong stretch, methylene asymmetric stretch, bending deformation, medium wagging deformation, and the occurrence of water vapour in the air are all seen in the spectrum at 2923 cm. It can be seen in Figure 3 that the absorption highest point at 3477 cm^{-1} corresponds to a –OH group, while other peaks related to the

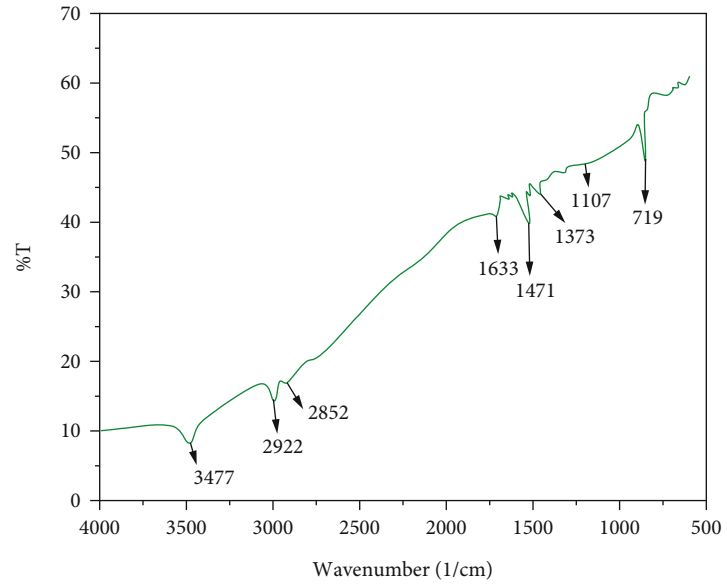

Figure 3: Fourier transform infrared spectrum of arecanut glass (1 : 3) 20 wt% fibre-reinforced composite.

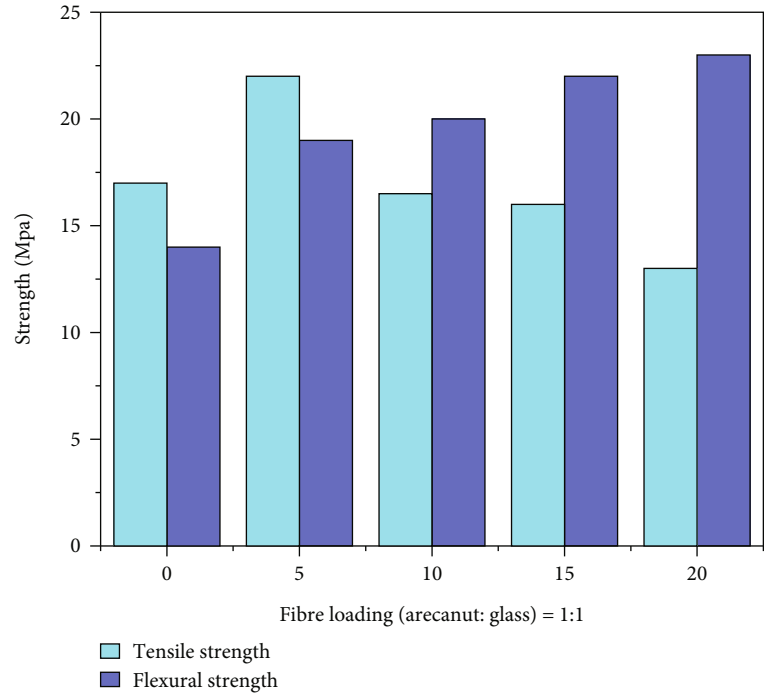

Figure 4: Variations in tensile and flexural strength with diverse fibre loadings.

aromatic C=C in-plane alkenes and C-H bond of the various components of the composite are depicted.

3.1. Tensile and Flexural Strength. Measurements were made with 5, 10, 15, and 20% fibre content. Tensile strength decreased with increasing fibre loading. Fibre loading was initially increased to 5%, but as fibre loading grew further, the interfacial bonding between the fibre and its matrices became less stable and hence lowered its mechanical properties over time and it is shown in Figure 4.

Composites with a fibre content of 5, 10, 15, and 20 wt percent had their flexural strength evaluated as well. Fibre loading enhanced the flexural strength of the material. It is possible to overcome weak fibre–matrix adhesion due to proper alignment of polypropylene chains with the fibre. Flexural strength is strengthened when fibre loading increases because of the increased likelihood of robust fibre–matrix adhesion, and it is shown in Figure 5.

In this case, Young's modulus rose as the fibre loading raises. Separate microspaces are formed when the interfacial

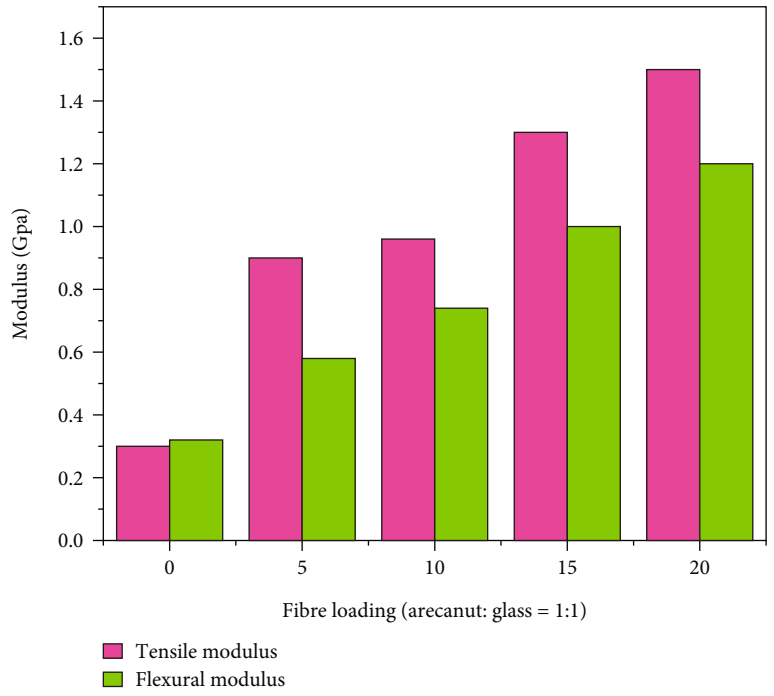

Figure 5: Variations in tensile and flexural modulus with unlike fibre loadings.

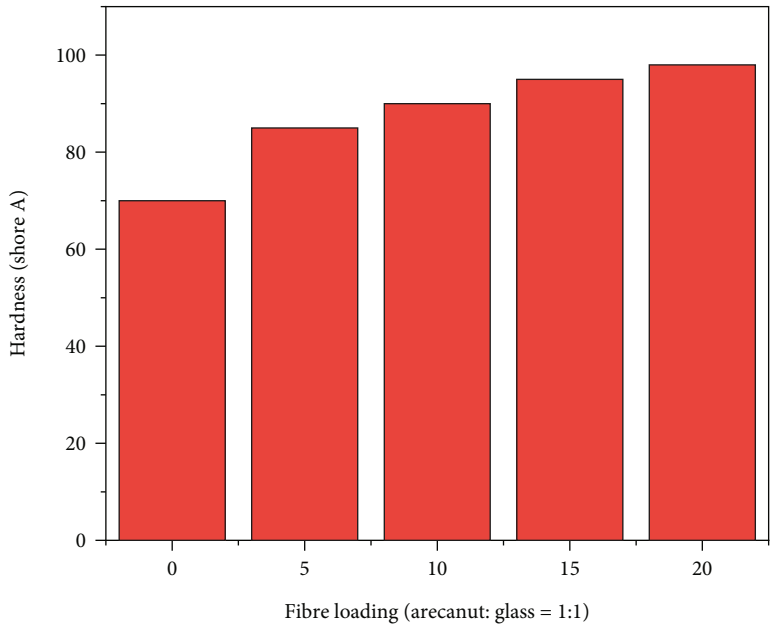

Figure 6: Different fibre loadings cause a change in hardness (Shore A).

connection among fibre and matrix becomes poor or weak. Increasing the fibre load, the obstruction to stress propagation becomes more severe, leading to an increase in stiffness. Adding fibre to the polymer matrix also reduces the mobility of the matrix, which in turn increases stiffness. High modulus materials include arecanut and glass. Increased fibre concentrations require a greater amount of stress in order to get the same deformation. Flexural modulus increased as fibre loading was applied, according to the findings. A possible explanation for these results is that the soft PE matrix was strengthened by the addition of hard glass fibres. As a result, the flexural modulus of the soft polypropylene matrix was raised by including high modulus fibres.

3.2. Hardness Analysis. When the matrix is more flexible, it has a lesser hardness, like raw polypropylene. The degree to which the fibres are evenly dispersed throughout the matrix affects the composite's hardness. According to this

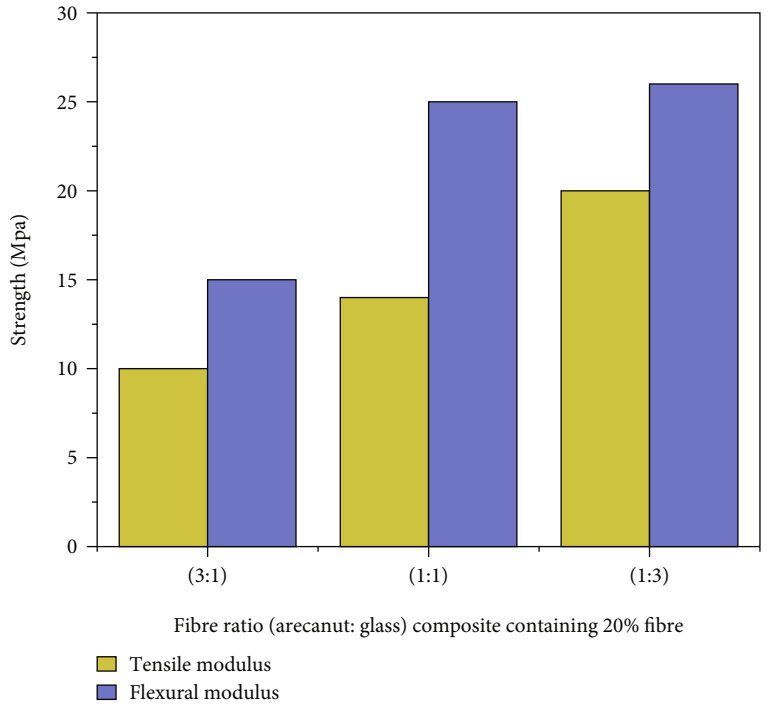

Figure 7: Variation in tensile and flexural strength for 20 wt% fibre loading at various fibre ratios.

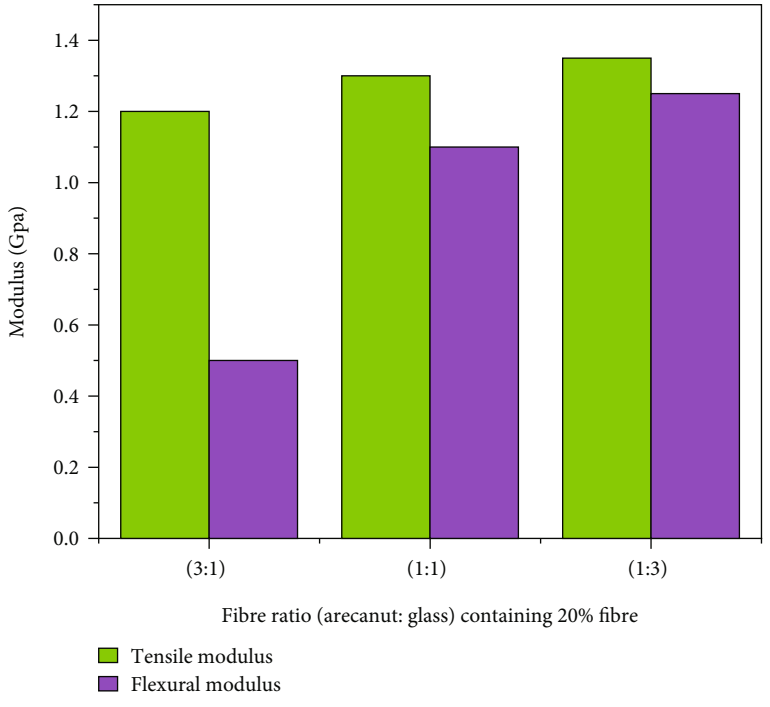

Figure 8: Tensile and flexural modulus variations with a 20 percent fibre load for varied fibre ratios.

study, raw polypropylene's hardness rises to around 90 when the fibre level exceeds 15% by weight. The hardness of the material was improved by reducing the number of spaces among the matrix and fibre. Polypropylene becomes more difficult to work with when more fibres are included into the resin. Figure 6 depicts the change in hardness as a function of fibre loading.

3.3. Effect of Fibre Ratio. The orientation and architecture of fibres have a big impact on the impregnation surrounding them. A larger fibre volume fraction usually means the composite has superior mechanical characteristics. There is a noticeable difference in performance between arecanut and glass fibre-reinforced composites, as demonstrated in Figures 7–9. With increasing glass fibre loading, the tensile

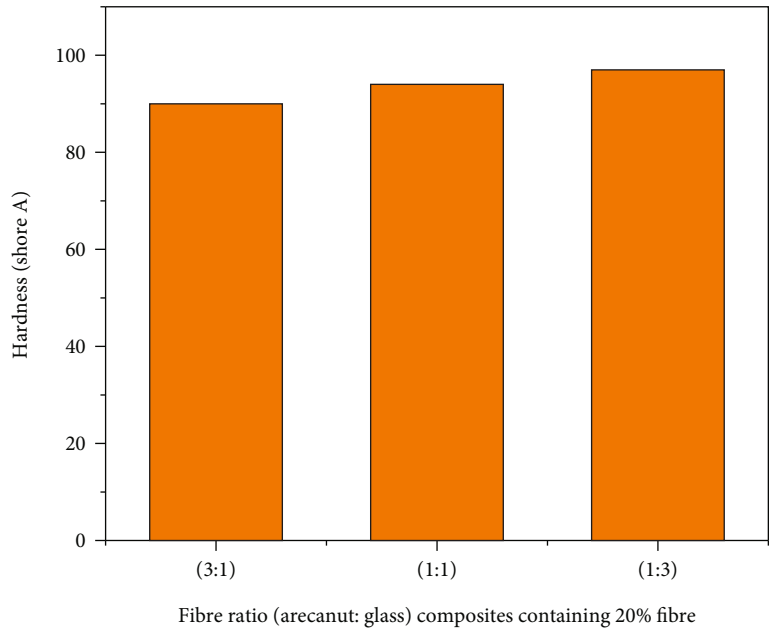

Figure 9: Variation in hardness (Shore A) for 20 wt percent fibre loading at various fibre ratios.

and flexural strengths also rose. Tensile strength of a fibre is determined by its chemical composition and internal structure. A 1 : 3 ratio of arecanut to high-strength glass fibres (2.0 GPa) improved tensile strength compared to arecanut (166.03 MPa), as illustrated in Figure 7. Bending and shearing were the causes of failure in a three-point flexure test. When glass fibres were incorporated into the hybrid composites, they boosted the composites' flexural strength due to the greater resistance to shearing.

There can be shown in Figure 8 that with increasing glass fibre content, the tensile and flexural modulus rose. As a result, the composite's tensile and flexural modulus is increased. Because glass fibres are stiffer than arecanuts, a higher percentage of glass fibres in the composite raises the modulus. In order to improve flexural modulus, the glass fibre ratio was increased from one to three and it is seen in Figure 8. Figure 9 indicates that the hardness increased from 90.23 Shore A to 96.7 Shore A by increasing glass fibre ratio from 1 to 3.

Fibre aggregation is seen on the fracture surface of the composites comprising 20% arecanut and glass fibres with a 1 : 1 ratio. Tensile strength decreased because of insufficient interfacial bond among the fibre and polymer matrix. Composite with a 20 wt% fibre content and a 1 : 3 arecanut/glass fibre ratio demonstrated strong fibre dispersion and bonding properties. This composite had a higher tensile strength as at last. However, the tensile strength of the composite was lowered due to deboning and agglomeration of the arecanut and glass fibres in a 3 : 1 ratio. As a result, this increased interfacial area was undesirable.

4. Conclusions

According to the results of this investigation, polypropylene composites can be successfully used with arecanut and glass fibre as reinforcing fibres. The following outcomes have been taken from the experiments:

(i) The mechanical characteristics of the composite comprising 20% fibres at a ratio of 1 : 3 in arecanut and glass were the best

(ii) The interfacial fibre–polypropylene interaction in the 1 : 3 ratio arecanut–glass fibre composite was excellent

(iii) FTIR spectroscopy indicated the presence of hemicelluloses, lignin, and –OH groups in the arecanut; there was evidence of weak interfacial bonding in the composites

(iv) Glass fibre ratios of 1 to 3 result in maximum flexural strength of 24.13 MPa and maximum flexural modulus of 1.17 GPa

(v) The produced composites' tensile strength reduced, while their Young's modulus rose, as the fibre loading rose. From this, 19.36 MPa maximum tensile strength and 1.23 GPa maximum Young's modulus are found

(vi) Compared to polypropylene, the composite has a maximum hardness of 96.7 (Shore A)

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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