TENSILE, DURABILITY AND THERMAL CONDUCTIVITY ASSESSMENT OF JUTE/*TETRACARPIDIUM CONOPHORUM* REINFORCED POLYPROPYLENE COMPOSITES

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Received January 25, 2025

The use of natural fibers as a substitute for traditional synthetic fibers in various applications has attracted researchers due to their inherent characteristics and environmental friendliness, compared to the synthetic options. This study employed jute fiber and shell particles of African walnut (*Tetracarpidium conophorum*), in varying weight proportions of 5-30 wt% and 2-8 wt%, respectively, relative to the weight of polypropylene, in the presence of 2 wt% maleated polypropylene. The jute fibers were treated in a NaOH solution and used to produce the composites. All developed samples underwent various tests, and the microstructure of selected samples was examined using a scanning electron microscope (SEM). The analysis of ultimate tensile strength and tensile strength at break revealed that the sample reinforced with 4 wt% walnut shell particles (WSP) and 25 wt% jute fiber achieved optimum values, beyond which interference and agglomeration of the reinforcements became prominent. Both the tensile modulus and density were enhanced by adding jute fiber and WSP. Water absorption, both before and after soil burial, increased with higher filler content, while thermal conductivity rose with WSP addition. However, with increasing fiber content, the voids became more pronounced, resulting in lower thermal conductivity.

Keywords: polymer, jute fiber, tensile properties, *Tetracarpidium conophorum*, polypropylene, reinforced composites

INTRODUCTION

The recent trends in engineering and household applications show an increased use of composites compared to pure polymer materials. This shift is primarily due to the numerous advantages of low-density reinforcements, including light weight, reduced production costs, ease of fabrication, and improved mechanical and physical properties.[1-4] Reinforcements can be classified based on their origin as either natural or synthetic. Synthetic reinforcements, often referred to as artificial reinforcements, have gained popularity because they offer high specific strength and stiffness, thereby enhancing the properties of the final composite structure. These reinforcements can be fibers, such as carbon, ceramic, and glass fibers, or particulates, like graphite.[5-8] However, due to their high production costs, synthetic fibers are often limited to advanced applications. One advantage of

these fibers is their low water absorption characteristics, which promote strong interfacial bonds between the matrix and the reinforcements. This ensures good compatibility and improved load-carrying capacity.[9]

Nevertheless, recent research has shown that synthetic fibers can be harmful for human health and the environment, which contradicts the objectives of researchers aiming for eco-efficiency. These synthetic fibers are not easily recyclable, are non-biodegradable, and generate waste during production. This creates challenges for proper disposal after use, resulting in further environmental issues and prompting a shift toward natural fibers.[1,5] Natural fibers can be sourced from the environment by extraction from agricultural residues, including various types of biomass. Various natural fibers are available across different world regions, contributing to their widespread availability, promoting sustainable materials, and addressing environmental challenges when used as matrix reinforcements for automotive, aerospace, household, and construction applications. Natural fibers include sisal, coir, bagasse, bamboo, plantain, banana, hemp, cotton, kapok, abaca, flax, kenaf, jute, oil palm fiber, cow hair, chicken feathers *etc.*[10-14] Natural fibers can be classified into two main categories: plant fibers and animal fibers. Plant fibers can be categorized into bast, wood, straw, leaf, seed or fruit, and grass fibers. The properties of these fibers depend on their source, the extraction techniques used, and the chemical treatments they undergo.[12,15-16] Despite their potential benefits, natural fibers, often resulting as by-products of agriculture and other industries, are frequently disposed of improperly by being dumped in landfills, released into the environment, or incinerated. These waste disposal methods are detrimental to the environment. For example, environmental dumping leads to pollution, while burning these materials consumes energy and releases CO_2, contributing to ozone layer depletion and increasing global temperatures.[17] Instead, these fibers could be recycled, reprocessed, or reused as matrix reinforcements, adding economic value and benefiting the environment.

Natural fibers are highly renewable and tend to retain beneficial properties. Therefore, they have drawn significant research interest in the development of new materials for various engineering applications. Natural fibers that can be derived from industrial wastes can be crucial in producing sustainable materials.[12] However, it is essential to note the drawbacks of natural fibers, such as their hydrophilic characteristics and susceptibility to poor durability, which can accelerate their degradation during use. Various modification methods, including coating and chemical treatment, to modify or blocking these fibers' hydroxyl and polar groups, have decreased the degradation rate in cementitious and polymer matrices.[18-19] For instance, Adediran *et al*.[12] examined the effects of surface modification on the properties of jute fiber-reinforced cement composites for ceiling board applications. Their findings indicated that chemical treatment yielded improved performance, suggesting fiber degradation in cementitious and sand-based materials can be modified by treatment, as also noted by Machaka *et al*.[20] Further research has shown that the mechanical properties of yam peel and coir fiber-reinforced polypropylene (PP) composites can be enhanced through alkali treatment, with 1.5 M NaOH, demonstrating improvements in mechanical and wear properties.[21] Liu *et al*.[22] reported that coating flax fiber composites with acrylated epoxidized soybean oil enhances the water resistance and physical characteristics of the composite, without adversely affecting its color or mechanical properties. Studies by Haque *et al.* and Haydaruzzaman *et al*.[23-24] revealed that chemical treatment of coir, palm, calcium alginate, and abaca fibers used as reinforcements in PP matrices resulted in superior tensile and bending strength, compared to untreated fiber-reinforced PP composites.

Several research efforts have focused on methods to enhance the mechanical properties of polypropylene (PP). On the one hand, the development of composites, which involves using fibers and particulates, largely depends on the concentration of these reinforcements. This highlights the importance of understanding the impact of the concentration of each constituent and determining the optimal mix to achieve the desired properties. On the other hand, many fillers used for reinforcement in PP are polar, which can contribute to poor interfacial adhesion. To address this issue, the chemistry of polypropylene can be modified by attaching polar groups, such as acrylic acid and maleic anhydride, to its molecular structure. Maleated polypropylene (MAPP) is the most used polar group. These polar groups serve as coupling agents, enhancing adhesion at the fiber-matrix interface and facilitating efficient stress transfer from the matrix to the reinforcement

fibers. MAPP has demonstrated a tendency to effectively improve the mechanical properties of composites reinforced with natural and synthetic fibers.

With these considerations, the present study aims to investigate the properties of a hybrid composite made from jute fiber and walnut shell particles (WSP) in a PP matrix. The study will investigate the effects of chemical treatment and various weight fractions of jute and WSP on the properties of the PP composite.

EXPERIMENTAL

Processing of jute fiber and WSP

Jute fiber (JF) was obtained from the jute plant through soil-retting, after which the fermented stems were exhumed. The exhumed fibers were washed with detergent, rinsed with tap water, and oven-dried at 70 °C for 5 hours. This step was performed in accordance with the procedure described earlier in the literature.[25] The fibers were treated in a shaker water bath using a 1.2M NaOH solution for 4 hours at 50 °C temperature and washed with distilled and tap water until the removal of NaOH residue was assured. Afterward, the fiber was subjected to oven drying for 4 hours at 70 °C and cut to obtain a length of 8 mm.

Shells of *Tetracarpidium conophorum* walnut were collected, washed, and rinsed to eliminate foreign contaminants and impurities. They were then oven-dried at 90 °C for 7 hours before being treated in a 1.2M NaOH solution at 50 °C for 4 hours in a shaker water bath. Afterward, the walnut shells were oven-dried at 80 °C for 5 hours. The dried walnut shells were then pulverized and sieved using a sieve shaker (model 16155) to achieve a particle size of 45 µm. Then, WSP were combined with jute fiber to develop a PP-based composite.

The PP, jute fibre, and WSP have densities of 0.914 g/cm³, 1.3 g/cm³, and 0.689 g/cm³, respectively. The chemical composition of the raw materials used in this study has been explicitly reported in our previous study.[26]

Composite development process

Hybrid composites were developed using jute fiber, WSP, and PP matrix. The WSP and jute fibers used in the study are shown in Figure 1. The constituents were thoroughly mixed according to the mix proportion outlined in Table 1, before molding, to ensure an even distribution of the jute fibers and WSP. MAPP of 2 wt% was added to all mix ratios. The mixture was then poured into aluminum molds and carefully placed into the compression molding machine, operated at 170 °C for 8 minutes and a pressure of 0.25 kPa. Afterward, the samples were shredded into smaller fractions for approximately 2 minutes using the compounding machine and remoulded using the compression moulding parameters mentioned earlier.

Figure 1: Raw materials used for composite development: (a) walnut shell particles and (b) jute fiber

Table 1
Formulations of the developed composites (PP, jute fiber and WSP)

Group 1			Group 2			Group 3			Group 4		
PP/ MAPP (%)	JF (%)	WSP (%)	PP/ MAPP (%)	JF (%)	WSP (%)	PP/ MAPP (%)	JF (%)	WSP (%)	PP/ MAPP (%)	JF (%)	WSP (%)
93	5	2	91	5	4	89	5	6	87	5	8
88	10	2	86	10	4	84	10	6	82	10	8
83	15	2	81	15	4	79	15	6	77	15	8
78	20	2	76	20	4	74	20	6	72	20	8
73	25	2	71	25	4	69	25	6	67	25	8
68	30	2	66	30	4	64	30	6	62	30	8

Evaluation of samples

The properties evaluated in this study include tensile properties, relative density, water absorption, water absorption after soil burial, and thermal conductivity.

Tensile properties

The resistance of dumbbell-shaped samples to tensile stress was conducted in accordance with the ASTM D3039/D3039M-17 standard.[27] This was achieved by subjecting three identical samples, each with a dimension of 90 x 10 x 5 mm, to a tensional force using an Instron 3369 universal testing machine. Samples were fractured using a 10 kg load cell, a strain rate of 0.5 mm/min, and a gauge length of 30 mm. This was done to evaluate properties such as ultimate tensile strength, tensile strength at break, and tensile modulus.

Relative density

The relative density of the polymer composite samples was probed using an analytical weighing balance. Three samples of each formulation were weighed to evaluate this property, and Equation (1) was adopted to determine their densities:

$$RD = \frac{M}{V} \quad (1)$$

where RD is relative density, M is the mass of samples, and V is the volume of samples.

Water absorption

Water absorption was evaluated to determine the affinity of the composite samples to absorb water while in service. This property was appraised in accordance with ASTM D5529M-12.[28] The samples were placed in a beaker of water for 30 days. To determine their weight each day, samples were removed from the water, cleaned with a dry cloth, and weighed every day for 30 days using an analytical weighing balance. The total value of water absorption was computed using Equation (2):

$$(\%)W = \frac{W_f - W_0}{W_0} \times 100 \quad (2)$$

where W is water absorbed by the specimen; W_t is the final weight after immersion; and W_0 is the initial weight of samples before immersion.

Water absorption after soil burial

The water absorption tendency of the sample after exposure to soil was assessed by burying it in normal soil with a pH of 7.8 and a 30% moisture content at room temperature for a duration of three months. Following this period, the samples were dried at 100 °C for 4 hours, and their weights were recorded. Then, they were subjected to water absorption testing as described above. Water absorption measurements were conducted after 30 days. The calculation of water absorption percentage following soil exposure was performed using Equation (3):

$$(\%)W_s = \frac{W_e - W_i}{W_i} \times 100 \quad (3)$$

where W_s is the water absorption by the buried specimen, W_e is the final weight after water absorption, and W_i is the initial weight after oven drying.

Thermal conductivity

A modified Lee's disk apparatus was employed to evaluate the thermal conductivity of the PP hybrid composite. The tests were performed in conformity with ASTM E1530-19.[29] The test was done at a temperature of 50-85 °C, where no thermal degradation can occur of the reinforcing and matrix phases. The thermal conductivity value for each formulation was obtained by placing the samples between the upper and the lower disks of the apparatus. The time to achieve steady temperatures was measured, and the thermal conductivity was computed. Three similar samples of 50 mm diameter and 10 mm height were tested for thermal conductivity, and the average was used as a representative value.

RESULTS AND DISCUSSION

Ultimate tensile strength

It is considered that the soil-retting process minimizes induced stress in the fibers, which can occur during traditional fiber extraction methods. Thus, it was expected that the soil-retting would yield stronger fibers.

The tensile strength of a material indicates its ability to oppose stress applied in tension. In contrast, the tensile modulus underlines the stiffness exhibited by a material when tensional stress is applied.[30-31] Figure 2 shows the ultimate tensile strength of JF/WSP hybrid composites when the produced samples were subjected to tensile loading.

The variation in the filler loading (JF and WSP) was observed to affect the tensile strength of the composite. At 2 wt% WSP, the ultimate tensile strength enhanced with increased fiber loading in the range of 5-30 wt%. The addition of 30 wt% JF led to the optimum improvement – of 40% – compared to pure PP at that weight percent. This increase may occur due to adequate stress transfer achieved, along with reduced interparticle spacing and strong interfacial characteristics, as further illustrated in Figure 8 (a and b) and Figure 9 (a and b), which may be responsible for the improved strength observed.[32] Embedding 4 wt% WSP resulted in an increase in ultimate tensile strength when accompanied by fiber loading of 5-25 wt%. Of all the hybrid composite samples developed, the one with 25 wt% fiber loading and 4 wt% WSP exhibited the best resistance to the tensile load. This may be linked to enhanced adhesion achieved due to the presence of treated JF and WSP, which

obstruct dislocation movement. The strengthening mechanisms governing the observed improved strength are molecular movement, chain sliding, and stress transfer.[33-34]

The presence of 4 wt% WSP helps appropriately fill the hybrid composite. However, when adding 30 wt% JF loading, a reduction in ultimate tensile stress was observed; this may result from insufficient fiber wetting, which eliminates the adequate stress transfer phenomenon dominant at 5-25 wt% fiber addition. The result presented confirms the findings of Oladele *et al*.[35] At 6 and 8 wt% WSP addition, the ultimate tensile strength increased for 15 and 10 wt% JF loading, respectively, after which a reduction in this property was recorded. 8 wt% WSP at 30 wt% JF loading revealed the lowest resistance to tensile stress. This underlines a 21.04% reduction when compared to 0 wt% JF/WSP sample. This observation may be explained by agglomeration and coarsening of WSP, which brought about increased interfacial debonding and reduced resistance to tensile load. This was confirmed by SEM analysis (Fig. 8 (e and f)), which revealed excessive agglomeration in these samples, which justifies the diminished strength reported. According to Daramola *et al*.,[36] the presence of reinforcement in the matrix improves the resistance of composite materials to plastic deformation, when stress is applied. The present study indicates that 4 wt% WSP is efficient in enhancing the strength of composites in the presence of jute fiber up to 25%. However, with increased WSP, a simultaneous decrease in ultimate tensile strength is inevitable due to particle agglomeration.

Tensile modulus

Tensile modulus indicates the stiffness exhibited by a material when stress is applied. The tensile modulus measures the resistance of a material to elastic deformation. The effect of treated jute fiber and WSP on the tensile modulus at various weight fractions was presented in Figure 3. The composites showed an increase in tensile modulus as the JF content increased up to 30 wt%, at 2, 4, 6, and 8 wt% WSP addition due to enhanced stiffness achieved based on JF and WSP addition. Nam *et al*.[37] reported that adding coir fiber to poly(butylene succinate) showed a similar result, where fiber improved the matrix's elastic modulus with optimum value achieved at 25 wt% coir fiber. In this study, 30 wt% jute fiber performed best in all combinations. This proved the effectiveness of JF in improving the stiffness of the composite.

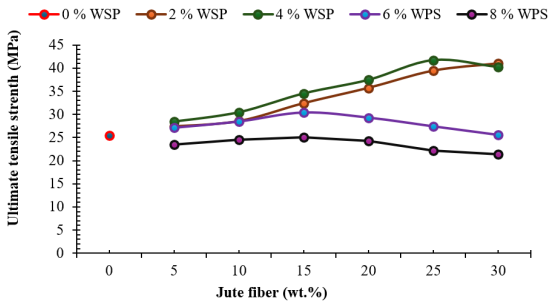

Figure 2: Variation in ultimate tensile strength of jute and WSP composites

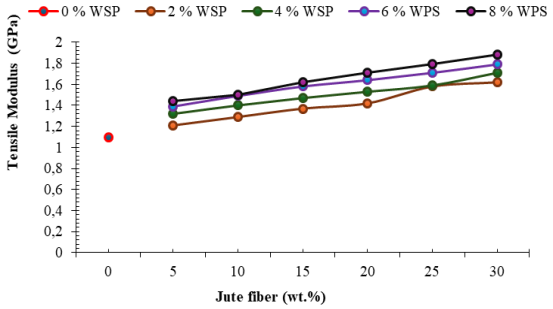

Figure 3: Variation in tensile modulus of jute and WSP composites

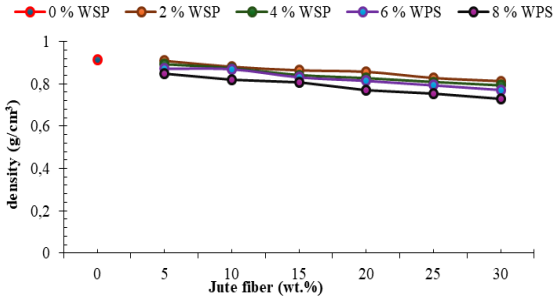

Figure 4: Variation in relative density of jute and WSP composites

Adding jute fiber and WSP as reinforcement acted as a barrier to the dislocation movement, ultimately increasing the stiffness of the composite. The enhancement in modulus may be linked to the composite's morphology, which plays a crucial role in determining its mechanical properties.[38] Thus, it was confirmed that as the filler content increases, the composite's stiffness also rises, resulting in an improved tensile modulus. A loading of 8 wt% WSP at 30% JF addition yielded an optimum value of 1.88 GPA. This showed an increase of 70.91% over that of pure PP and 1.11, 5.84, and 11.73% compared to other samples containing 30 wt% JF at 2, 4, and 6 wt% WSP, respectively. The result of this research confirms earlier studies,[35] which reported the maximum elastic modulus at 6 wt% cassava peel in the presence of palm kernel fiber. The findings of this study reveal that agricultural waste, such as jute fiber and WSP, can be used as promising fillers that enhance the tensile modulus of polymeric composites, confirming previous outcomes in the literature.[39]

Relative density

The relative density of the hybrid composite depends on the density of the matrix (PP) and the reinforcements used (JF and WSP). This property is one of the factors that affect the level of porosity in a composite sample. However, as reported by Adediran *et al*.,[11] chemical treatment given to reinforcements can lead to proper bonding, which infers reduced properties and increased density in treated fibers compared to untreated ones. Moreover, the presence of fiber in the treated or untreated state has a downtrend effect on the density of the polymeric matrix. This indicated that alkaline treatment restructures the surface of the reinforcement to yield adequate interfacial bonding and improved bond strength.

From Figure 4, the density of the composites developed was observed to vary with the presence of JF and WSP, compared to that of pure PP (control sample), which had a density of 0.914 g/cm^3. Thus, lower values were obtained as the weight fraction of WSP rose from 2 to 8 wt% at 5-30 wt% JF loading. This is likely explained by the fact that the density of the WSP and JF is lower than that of the PP material.[40] Singh[41] reported a reduction in the density of the epoxy composite when WSP was added, noting that WSP is lightweight, yet the particles occupy a significant amount of space. Obiukwo *et al*.[42] further confirmed this assertion when the properties of polyethylene reinforced with coconut shell particulate were assessed. This ratifies the findings of this study and underlines the efficiency of fibers and particulate reinforcements in reducing the composite's density, provided the reinforcement's density is lower than that of the polymer matrix. In the present study, density decreased with an increase in fiber content. The lowest density was observed for 8 wt% WSP at 30 wt% JF, representing a 25.03% reduction over that of pure PP. In modern applications, lightweight materials are deemed essential, and this study proves that adding agro-waste as additives to polymeric materials can produce a lightweight composite with improved transportation, fixing, and reduced labor costs.[43]

Water absorption

One of the drawbacks of natural fiber-reinforced polymer composites is their water absorption properties. This affects this composite's durability and limits its use in interior non-structural applications. The primary mechanism governing the transfer of water molecules in composites is diffusion, where water molecules are transported from regions of high concentration to those of low concentration.[44] Figure 5 illustrates the variation in water absorption characteristics of the JF/WSP composite. An upward trend was observed with an increase in the weight fraction of fibers and particulate loading due to the hydrophilic nature of these reinforcements.

Dhakal *et al*.[45] reported that polymeric composites containing natural fiber and particulates show water absorption characteristics that are dependent on the amount of fiber and particulates, the hydrophilic nature of each component, the level of particle dispersion, the orientation of fibers, void contents (porosity), the temperature of the water and the composite surface area exposed to water. In our case, all samples were fully immersed. At 2-6 wt% WSP loading, the water absorption displayed a linear upward trend for the JF loading of 5-30 wt%. However, the samples reinforced with 8 wt% WSP showed a linear progression for 5-30 wt% JF, but an exponential rise at 25-30 wt% JF addition. This further substantiates the assertion of Dhakal *et al*.,[45] as higher water content was observed at higher WSP and JF loading.

Natural fibers are composed mainly of lignin, hemicelluloses and cellulose. Lignin is a nonreactive part of the fiber; it is hydrophobic and contains a low ratio of hydroxyl groups (OH) to

carbon. The primary fiber component is cellulose, and it has a relatively high hydroxyl group (OH) ratio to carbon.[11] In contrast, hemicelluloses feature an even greater OH-to-carbon ratio. Both are considered amorphous fiber constituents and have a strong affinity for water, readily absorbing water molecules. Hemicelluloses tend to swell quickly, as water molecules can readily penetrate and occupy the spaces between microfibrils.[26,46-47] The fibers are treated to effectively reduce the hemicellulose and lignin content, while modifying the cellulose to enhance adhesion between the fibers and the matrix.

Water absorption after soil burial

Natural fibers tend to degrade during service, which can ultimately lead to catastrophic failure. To predict the developed composite's decomposition behaviour, the samples produced were subjected to biological degradation during soil burial and their water absorption abilities were then measured. Figure 6 reveals the response of various samples to water absorption after soil burial. The trend observed was similar to that of normal water absorption.

Various factors may come into play here, such as microorganisms, changes in temperature, and the duration of soil burial of the specimen. Jumaidin *et al.*[48] stated that an increase in the hygroscopic characteristic of a material intensifies the growth of microorganisms. This led to enhanced degradation characteristics and weight loss. In the present study, water absorption after soil exposure was observed to increase as the WSP content rose from 2 to 8 wt%. Additionally, the degree of water absorption after soil exposure increased with higher JF loading. The peak value was displayed by samples containing 8 wt% WSP and 30 wt% JF. This may be due to the reduced hydrophobicity of the polymeric material and the increased hydrophilicity of the natural fibers.

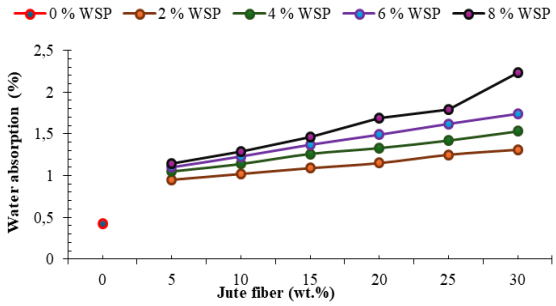

Figure 5: Variation in water absorption of jute and WSP composites

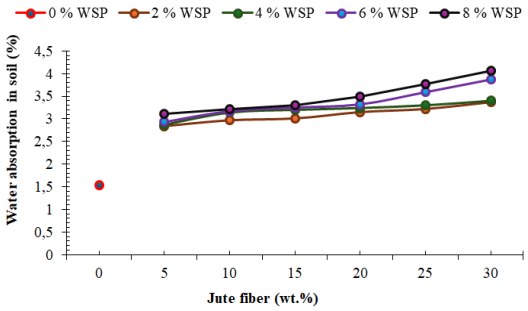

Figure 6: Variation in water absorption of jute and WSP composites after soil burial

According to earlier research,[49-50] the hemicellulose content of the fiber is responsible for biological degradation and water absorption. This underlies the reason why the fibers used in this study are treated to lower the hemicellulose content.[11] Alkaline treatment blocks the hydroxyl and polar groups on fiber surfaces, which leads to improved adhesion with the matrix, reduces interfacial strength loss, and enhances the fiber's resistance to biological degradation.[51] The results corroborate with those reported in the literature.[52] Additionally, the need for using biodegradable materials, such as fibers and particulates, as reinforcement in composites is further strengthened by the current research trend, which focuses on reducing dependency on petroleum products and ensuring safe methods for disposing of polymeric products and agricultural waste.[53]

Thermal conductivity and morphological study

The thermal conductivity of any material depends on the rate at which heat flows across the material through uniform thickness when the material experiences temperature change.[54] A material with high thermal conductivity signifies poor thermal insulation characteristics. Generally, polymeric materials have low thermal conductivity due to their isolated individual chains, leading to discontinuity in conduction in each polymer chain. For a composite material, thermal conductivity depends on the characteristics of the reinforcement, the matrix, and the porosity level within the composite.[52] Figure 7 presents the variation in thermal conductivity of the PP matrix reinforced with WSP and JF. It may be noted that the presence of WSP increases thermal

conductivity as the weight fraction of WSP rises from 2 to 8 wt%.

This implies reduced pore size and enhanced cohesion in the polymer matrix, resulting in decreased interparticle spacing and interaction. The reduction in thermal conductivity was observed with an increase in JF, even in the treated state. The study of Liu *et al*.[55] and Aziz and Ansell[56] noted that chemical treatment reduces the effective diameter of natural fiber, thereby increasing the aspect ratio of fibers. This is caused by the dissolution of hemicelluloses and lignin, which results in reduced inter-fibrillar rigidity and, subsequently, the rearrangement of fibrils.[56-57] Hence, the thermal conductivity of the fiber is improved..

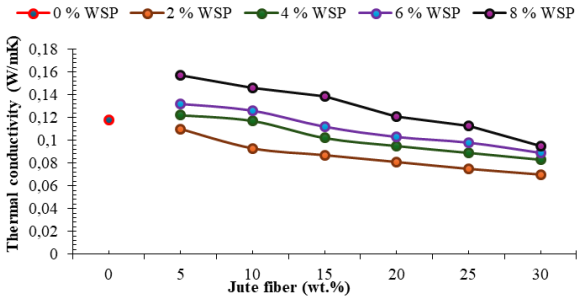

Figure 7: Variation in thermal conductivity of jute and WSP composites

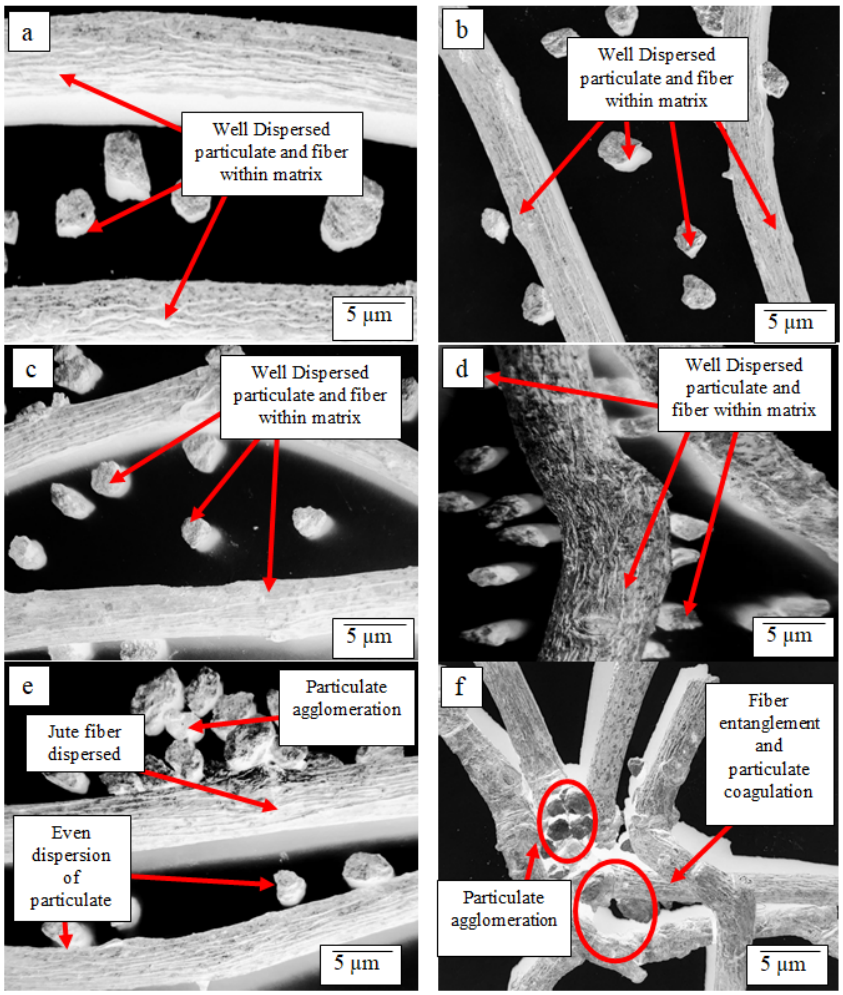

Figure 8: High fluorescence microscopy images (5000x) of (a) 15/2 wt% JF/WSP, (b) 25/2 wt% JF/WSP, (c) 5/4 wt% JF/WSP, (d) 25/4 wt% JF/WSP, (e) 15/8 wt% JF/WSP and (f) 30/8 wt% JF/WSP[24]

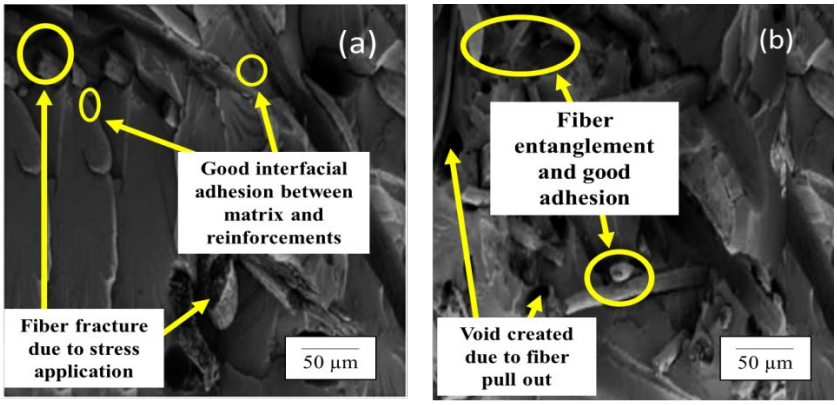

Figure 9: SEM images of the fractured surface of (a) 5/2 wt% JF/WSP and (b) 30/2 wt% JF/WSP[24]

However, incorporating fiber as reinforcement engenders increased porosity within the composite. Air, being a good thermal insulator, has a more pronounced effect on the composite's thermal conductivity than chemical treatment.[55] The resultant effect of voids and pores is most significant in determining thermal conductivity, as there is a greater distance between the components of the composite, which can affect thermal transmission. From Figure 7, as the JF increased from 5 to 30 wt%, a reduction in thermal conductivity was noted in all WSP variations. The highest thermal conductivity value was obtained for 8 wt% WSP and 5 wt% JF, underlying an increase in thermal conductivity over that of pure PP. Nevertheless, the composite with 2 wt% WSP and 30 wt% JF loading gave the best thermal insulation characteristics due to high fiber agglomeration and possible void formation. This finding upholds the research work of Liu *et al*.,[55] who reported lower thermal conductivity with an increase in abaca fiber due to the void created as the weight fraction of fiber increases.

Figures 8 and 9 reveal the microstructure of the developed JF and WSP-reinforced PP composites. Figure 8 (a-d) highlights the good dispersion of WSP, suggesting that these sets of composites are free from agglomeration. Figure 8 (e and f) shows the presence of agglomeration, which reduces tensile strength due to stress concentration at the agglomeration sites. This led to a loss of mechanical properties and high water absorption capabilities. Good adhesion was exemplified in Figures 8 (a-d) and 9, which explains the good tensile strength reported for composites developed at lower weight fractions of WSP and higher weight fractions of JF.

CONCLUSION

Jute fiber and WSP were incorporated into the PP matrix to develop PP-based composites using the compression molding machine. The samples were tested for tensile properties, relative density, water absorption, before and after soil burial, and thermal conductivity. The results demonstrated that the addition of these reinforcements significantly enhanced the mechanical, physical, and thermal performance of the PP matrix. The incorporation of WSP notably improved tensile performance, with 4% being identified as the optimal level; any further increase led to noticeable agglomeration, which adversely affected performance. Jute fiber contributed to increased stiffness and enhanced tensile modulus, with its effectiveness being contingent upon fiber loading. Additionally, the composites showed improved density but reduced durability, as water absorption (both before and after soil burial) increased due to the hydrophilic nature of the fiber and walnut shell particles, where 2 wt% WSP loading exhibited the lowest water uptake among the developed composites. Meanwhile, thermal conductivity was reduced with the addition of walnut shells and jute fiber due to the formation of voids. Overall, the analyzed results indicated that the use of jute fiber and WSP enhanced the properties of PP, making the developed lightweight composite a suitable and environmentally friendly alternative solution for applications in the automobile sector.

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