

Experimental Evaluations of the Tensile and Impact Characteristics of Polypropylene Composites Reinforced with Hybrid Fibers

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Abstract

In marine engineering design, polymeric composites reinforced with natural fibers are frequently used. Through hybridization, natural fiber plastic composites' mechanical properties can be improved. Assessing the performance of recycled newspaper fiber (rNF) and rNF/glass fiber (GF) hybrid polypropylene composites is the aim of the current experiment. Using maleic anhydride (MA) as a coupling agent, the effects of GF loading on the impact strength and tensile behavior of composite materials with 30 weight percent fiber were examined. The results suggest that the tensile strengths of the rNF/PP composites are increased by the addition of additional GF. Ten weight percent rNF and twenty weight percent GF are combined to create a hybrid composite with a tensile strength of 55.7 MPa and a tensile modulus of 1432.1 MPa. The impact strength of the rNF/PP composites steadily decreased as the GF % rose. By adding 2 weight percent of MA to the composite formulation, the mechanical characteristics and dimensional stability were significantly improved. Microstructure characterization of the broken surfaces of the modified composites demonstrated improved interfacial bonding. The strength and dimensional stability of the composites can be improved by adding a coupling agent or by increasing the amount of glass fiber. This investigation has shown that the composites treated with glass fiber and coupling agents will be preferred as building materials due to their improved stability and strength properties.

Keywords: Composites, PP, hybrid fibers, mechanical properties, water absorption

INTRODUCTION

For their prospective use in the fields of textiles, automotive, construction, and aerospace, a number of natural fibers, such as vetiver, calotropis gigantean, jute, banana, coir, and pineapple leaf fiber reinforced thermoplastic composites [1-6], are attracting increasing amounts of interest. The use of lignocellulosic fibers, such as wood and cellulose, in polymer composites has been the subject of numerous investigations [7]. A major source of lignocellulosic fibers or an equivalent feedstock can be

obtained through recycling fiber-based products including paper, waste wood, and agricultural byproducts. Newspaper is an excellent recycling fiber-based product since it contains lignocellulosic material as well as various inorganic fillers like printing inks and chemicals for process help [8]. Both can be used as alternatives to inorganic fillers such as clay, talc, calcium carbonate, silica, etc. in the production of polymer composites [9]. Inks and varnishes, for example, have no effect on composite materials but have detrimental effects on recycled paper. The main benefits of lignocellulosic fiber reinforced composites for commercial applications have been their low cost, ease of availability, low

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density, light weight, high strength to weight ratio, minimal wear and tear on processing gear, and environmentally friendly qualities. Although natural fiber reinforced composites have these advantages, their usage has been limited due to problems with moisture absorption, wettability, processing heat stability, and poor natural fiber adhesion to synthetic counterparts. To build composites with superior mechanical and environmental performance, it is essential to impart the hydrophobicity of the natural fiber. A wide range of fiber surface treatments have been discussed by numerous authors, including alkali/mercerization [10, 11], silane [12, 13], alkali and silane combined [12, 14], monomer grafting under UV radiation [15-17], and various other techniques including acetylation, benzyolation, etc. [18, 19]. The use of polar maleic anhydride grafted polypropylene (MAPP), which improves fiber dispersion and fiber/matrix interfacial interaction by creating hydrogen bonds between the hydroxyl groups of natural fibers and the carbonyl groups of the maleic anhydride segment of the MAPP, is another technique [20]. As a result, the rate of moisture absorption is slowed, and composites' mechanical strength is increased [21].

Used paper products and recycled newspapers are wonderful sources of fiber, and this fact is increasingly understood [22]. Newspapers are one of the materials that are collected the most frequently in the majority of local recycling systems. Recycled newspaper materials are made composed of lignocellulosic material and various inorganic fillers, which often include printing inks and other process aid elements. Recycled newspaper cellulose fiber-reinforced plastic composites could be used by the housing industry as structural components for load-bearing roof systems, framing components, and non-structural items like doors, furniture, and car interior components that resemble wood-based composites [23].

Newspapers can be recycled into fibers that can be utilized to build high-quality composite materials by compression molding or other dry, commonplace techniques. Researchers have used a variety of processing techniques to take use of the reinforcing properties of newspapers to produce thermoplastic and thermoset composites [24, 25]. Paper waste strengthened with Yuan et al. conducted study on PP. They found that when the amount of newspaper in the composite grew, its flexural strength quickly decreased after peaking at 30 weight percent of newspaper [26].

Hybridization allows for the tailoring of composite properties to the desired structure under consideration [27]. In order to overcome the limitations of cellulosic fiber reinforced composites, glass fiber and cellulosic fiber can be combined. This creates hybrid composites with the required attributes, such as the best aspects of the two distinct composites combined with the best cost-performance ratio. An increasing number of hybrids are being intimately blended or combined. These materials' constituent fibers are mixed as randomly as possible to avoid any concentrations of any kind. There have already been numerous attempts to create various hybrid composites reinforced with synthetic fibers, such as carbon/glass [28] and UHMPE/glass [29]. By mixing cellulosic fiber with stronger, more corrosion-resistant synthetic fibers like carbon, aramid, glass, etc., the stiffness, strength, and moisture resistance of the composites can be improved. On the other hand, the literature on hybrid composites reinforced with synthetic and cellulosic fibers is scarce. In their investigation of the low-density polyethylene (LDPE) based short banana-glass fiber hybrid composite, Kalaprasad et al. [30] saw a notable improvement in the mechanical properties of the composites.

There don't seem to be many research that cover the loading rate sensitivity of hybrid fiber-reinforced polymer composites in the literature. These are of vital importance since composites are extending their range of applications and the material should be unaffected by the loading rate. This experimental study intends to examine how changing the loading rate affects composites made of recycled newspaper and glass fiber that have undergone various treatments. Inspected in order to further investigate the kind of failure under varied stress settings. In order to improve the robustness and mechanical properties of cellulosic fiber composites, the current work serves as a prerequisite.

EXPERIMENTAL

Ingredients

Isotactic polypropylene (Grade M110) from M/s Haldia Petrochemicals in Kolkata was used as the basic matrix for this work. It weighs 2.16 kg at 230°C, with an MFI of 11 g/10 min, and a density of 0.9 g/cm³. Recycled newspaper, especially from the Bangladeshi daily The Ittefaq, is used as the reinforcing cellulose fiber material. The recycled newsprint was periodically rinsed with distilled water after being immersed in a NaOH (10 wt%) solution for 24 hours at room temperature. Prior to being milled into a finer powder, the recycled newsprint was dried in a vacuum oven at 80°C for 24 hours to remove any last traces of moisture. The ground recycled newsprint was segregated using an Endecotts separator, and the Mastersizer Instrument (Type E) determined the particle size. The recycled newspaper fibers were typically 20 μm wide and 950 μm long on average. The short glass fibers used in this experiment were provided by Pongpana Co., Ltd. of Bangkok, Thailand. Glass fiber's original lengths ranged from 2 to 6 mm. Maleic anhydride (MA), a coupling agent provided by Merck (Frankfurt/Darmstadt, Germany), and dicumyl peroxide (DCP), an initiator provided by Hercules (Wilmington/Delaware). Irganox 1010 from Ciba was also utilized in the composite as a heat stabilizer.

Fabrication of Hybrid Composites

In order to combine the recycled newspaper fiber (rNF) particles with the chopped strand-glass fiber and PP compound, the rNF particles were heated in an oven at 80°C for 24 hours until their weight remained constant. Since it might have an adverse effect on the mechanical properties of the composites, any remaining moisture in the rNF particles had to be removed. GF, rNF, and PP were weighed and bagged based on the different fiber contents listed in Table 1 for each product. Also included were MA and DCP at 2% and 0.1% of the batch weight. Then, they were combined for 10 minutes at 180°C and 60 rpm using a co-rotating twin-screw extruder (Brabender Plasticorder, model: PLE-331). Prior to combining, the PP and rNF were manually blended. PP and rNF were combined for five minutes prior to charging the glass fiber. A heat stabilizer was applied to all samples at a weight percentage of 0.5% to reduce thermal degradation during compounding. Following that, the extruded materials were ground in a pilot-size grinder (WIESER, WGLS 200/200 model). Prior to the creation of the panel, the compounded pellets were dried at 80°C for two hours in order to remove any moisture that might have remained. The pellets were then created in an electrically heated platen press using an aluminum mold coated with a releasing agent made of dibutylether.

It was heated to 200°C before to placing the mold with the pellets inside it on the bottom hot-press platen. The pellets were then hot-pressed for a further five minutes at ten MPa, and then for an additional five minutes at that same pressure. The panel and mold were then transferred to a cold press where they underwent a further 5 minutes of 10 MPa compression. The regulation of the panel thickness was achieved by using 3.2 mm spacers. The finished composite panel measures 150 by 120 by 3.2 mm³. The composite panels were condition for at least 24 hours in accordance with ASTM D618-99 at a temperature of 25 ± 2°C and a relative humidity of 50 ± 5%.

Table 1. Each composite's sample is identifiable.

Composite sample code	PP content (wt%)	Recycled newspaper fiber, rNF (wt%)	Glass fiber, GF (wt%)	Coupling agent (wt%)
PP	100	0	0	0
P30r	70	30	0	0
P30rC	68	30	0	2
P25r5GC	68	25	5	2
P20r10GC	68	20	10	2
P15r15GC	68	15	15	2
P10r20GC	68	10	20	2

All specimen content: 0.5% Irganox 1010 and 0.1% DCP.

CHARACTERIZATION AND TESTING

Mechanical Traits

Dog-bone-shaped specimens were made out of composite plates, and they were then tested in line with ASTM standard D-639. Specimens were put through a stress test until they failed using a Shimadzu UTM (Model AG-1, Japan) with a cross-head speed of 10 mm/min and a gauge length of 50 mm. For each test, a minimum of five samples were analyzed. The tensile strength and tensile modulus were reported. The Notched Izod impact strength was evaluated using a Testing Machines Inc. (TMI) 43-02-01 Monitor/Impact machine in compliance with ASTM D256. The experiment was conducted on the notched samples, and at least five samples of each composite were assessed in order to obtain a reliable average.

Dimensional Stability Tests

Water absorption tests (WA) and thickness swelling tests (TS), both in accordance with ASTM D570-98, were performed. Each sample's weight, width, and thickness were measured before the test, along with their length and width. Under the given circumstances, samples were soaked in distilled water at 25°C for two and twenty-four hours. Following the designated period of time, the samples were removed from the water, and all surfaces were wiped with a cloth before being weighed. Following the test, all of the specimens were oven-dried for 24 hours at 105°C in order to acquire the oven-dry weight needed to calculate the panel WA using the formula below:

$$WA(\%) = [(W_a - W_b)/W_b] \times 100 \quad (1)$$

where WA is the percentage of water absorption and W_b and W_a are the sample weights before and after soaking. The TS values in percentage were calculated using the subsequent equation (2).

$$TS(\%) = [(T_w - T_i)/T_i] \times 100 \quad (2)$$

where T_w represents the sample's wetted thickness and T_i represents the sample's original thickness.

Analyzing the Fracture Surface Microstructurally

Studies on the morphology of the tensile fracture surface of the composites were carried out using a scanning electron microscope (SEM; JEOL, Japan JSM-6360LV). The fracture ends of the specimens were mounted on aluminum stubs, and thin palladium films were sputter coated on them to avoid electrostatic charge while they were being inspected.

DISCUSSION OF THE RESULTS

Mechanical Characteristics of Composites

The Tensile Features

Figure 1 shows how changes in glass fiber concentration affect the tensile strength of rNF/glass fiber hybrid composites. The composite's overall fiber content was held constant at 30 wt%, but the glass fiber percentage varied from 0 to 20 wt%. All hybrid fiber composites contain a compatibilizer in the amount of 2 weight percent to increase the interfacial adhesion between the fiber and the matrix. The matrix reinforced with 30% weight rNF fiber has a tensile strength of 36.7 MPa, while the PP utilized has a tensile strength of 27.3 MPa. Strength levels are observed to increase even more with the inclusion of glass fibers. The inclusion of 20 weight percent glass fiber increased the tensile strength by 52%. Given that glass fiber is stronger and stiffer than natural fiber, as shown by prior investigations, it is anticipated that hybridization will increase the strength of the rNF/PP composite [31, 32]. As a result of the hybridization of sisal with a relatively tiny volume proportion of glass fiber, oriented sisal polyethylene composites' tensile strength, according to Kalaprasad et al. [32], improved by 80%. According to Mishra et al. [33], the tensile strength rose by 66% when pineapple leaf-reinforced polyester composites were hybridized with 8.6 wt% woven glass mat via press molding. The inclusion of 15% glass fiber content increased the tensile strength of 40% sisal/glass fiber reinforced polypropylene by 13%, according to Panthapulakkal and Sain [31]. The tensile strength and tensile

modulus of short bamboo fiber-reinforced PP composites increased by 7% and 12.5%, respectively, according to Thwe and Liao [34], who claimed that compressive molding followed by melt mixing improved these properties. The substantially different improvements in the rNF/glass fiber PP composites could be attributed to the processing technique and the type of glass fiber used. This shows that the benefit of hybridization cannot be fully realized unless the glass fiber breakage is decreased by changing the processing techniques. The hybrid effect of short glass fiber and rNF fiber on the tensile modulus of PP composite is shown in Figure 2. The tensile modulus of PP is increased from 590.5 MPa to 770.4 MPa by the reinforcement of 30 wt% rNF. As the amount of glass fiber grew, it was discovered that the rNF/PP composite's tensile strength and tensile modulus rose continuously. A 5–20 wt% increase in glass fiber content resulted in a 34–86% rise in tensile modulus.

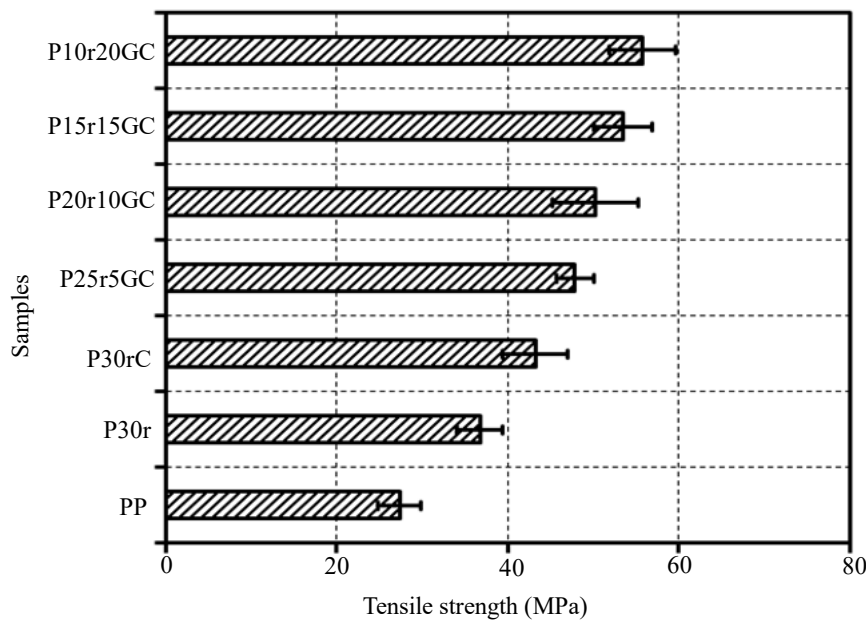


Figure 1. Tensile strength of rNF/glass fiber hybrid polypropylene composites is influenced by the glass fiber content.

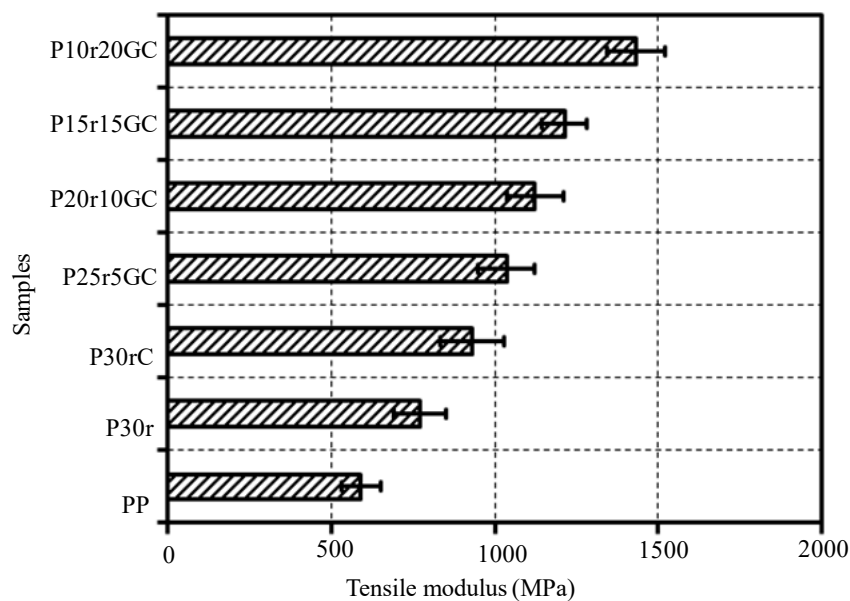


Figure 2. Tensile modulus of rNF/glass fiber hybrid polypropylene composites is influenced by the glass fiber content.

Impact Strength

The toughness and ability to absorb applied energy of a composite are inversely related to its impact strength, which is a measurement of the material's resistance to fracture failure under high-speed stress. The impact resistance of fiber-reinforced composites depends on the fibers since they interact with fracture development and act as a channel for stress transfer. The effects of fiber content and glass fiber variation on the Izod impact strength of the hybrid composite are shown in Figure 3. Virgin PP (26 J/m) exhibits high impact strength. The impact strength was lowered by 70% with the addition of 30% rNF fiber. However, when MA was utilized as a coupling agent between rNF and PP, as shown in Figure 3, the impact strength was somewhat reduced. This was anticipated, as noted by earlier scholars [32]. By forming chemical bonds and reducing the frictional force that results in fiber withdrawal, MA improved the interface between the fiber and matrix, as shown above. Even while the primary effects of surface treatment on composite properties improve the inter-laminar shear strength and flexural and tensile strengths [35], reports claim that surface-treated glass fiber often experiences a reduction in impact fracture toughness or notched tensile strength. The treated hybrid composite's impact strength dropped as the amount of glass fiber increased, as seen in Figure 3. As the percentage of glass fibers in the composite rose, its impact strength decreased by 26% between 0 and 20 weight percent. This could be as a result of the weakening effect of the fragile glass fiber. This indicates how the glass fiber composition has a significant impact on the impact properties.

Studies Using Scanning Electron Microscopy

It is widely believed that the orientations and distributions of glass fibers in polymer composites have a significant impact on the mechanical properties of the majority of glass fiber-filled polymer composites [35]. In this study, we examined, for instance, the distributions and orientations of glass fibers in hybrid composites using the SEM technique. In the matrix of hybrid composites (Figures 4,a and 4,b), recycled rNF and short glass fibers are extensively mixed, but are easily distinguished by their varied diameters. It was found that the fiber concentration had no effect on how the glass fibers were distributed or oriented in rNF/PP composites. SEM micrographs of the fracture surfaces of a hybrid composite consisting of 20% recycled rNF fiber and 10% glass fiber are shown in Figure 4(a). The regenerated rNFs in the PP matrix seem to have a good distribution. The strength of the composite is influenced by the features of the crack's initiation and propagation through the matrix. This depends on the form and direction of the reinforcements in the matrix. When the composites are loaded, cracks are more prone to form because short fiber fractions produce more fiber ends and stress-concentrating zones.

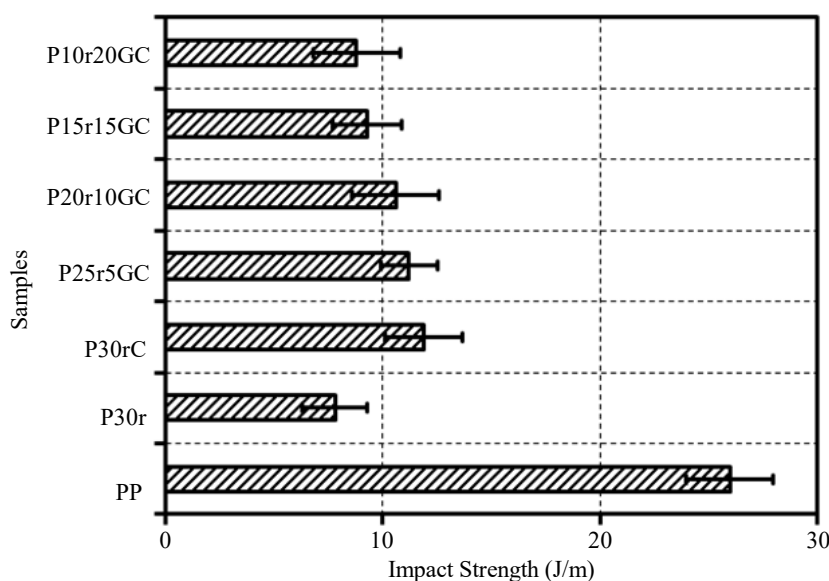


Figure 3. Impact strength of rNF/glass fiber hybrid polypropylene composites is influenced by the glass fiber content.

The sample's micrograph demonstrates that the glass fiber was insufficiently moistened by the PP matrix. Figure 4(b) shows that glass fibers in hybrid composites displayed multiple fiber pull outs, in contrast to rNF fiber composite (note the pulled out fibers and the pull-out holes). Glass fibers are shattered and forced out of the polymer matrix during crack propagation, as evidenced by the fact that glass fibers were visible outside the fractured surfaces. The morphologies of the broken surface of these polymeric composites, which display fractured characteristics and serve as the reasons of the changing mechanical properties, are what determine their mechanical properties.

Water Consumption

Water absorption coefficients based on Equation (1) were also produced in order to examine the relative water absorption capabilities of the rNF/glass fiber hybrid composites using PP matrix. The water absorption of lignocellulosic fiber composites is a critical physical property that influences the uses for these materials. The mechanical and thermal properties of composite materials may be affected by water absorption, which is crucial to consider when considering their applications. Due to water absorption, the mechanical properties of the hybrid composite for both tensile and bending loading types reduced [31]. It is challenging to totally prevent moisture from seeping in the composite without expensive surface barriers being installed on the composite surface. Water absorption in rNF-based composites can lead to moisture accumulating in the lignocellulosic fibers' cell walls and at the rNF-matrix interface. The buildup of moisture in the cellular wall could result in fiber swelling and jeopardize the dimensional stability. On days when it rains, these rNF-based composites might occasionally be in constant contact with water and be subjected to conditions of extremely high relative humidity. Table 2 further demonstrates how the water uptake and TS of rNF/glass hybrid PP composites are impacted by the glass fiber content at 25°C. It is found that the density of the composites ranges from 1137 kg/m³ for the hybrid composite panels with 20% glass fiber and 10% rNF and 2% MA to 910 kg/m³ for the totally PP panel. Due to their higher density and decreased porosity, composites manufactured with MA have greater dispersion and interfacial strength when compared to composites made without the coupling agent [36]. The amount of water absorbed increases with the addition of rNF to the PP for both the 2 h and the 24 h water immersion studies. Table 2 shows that after a 24-hour immersion, the water absorption, however, practically doubles. How the plastic to rNF ratio impacts water absorption can be demonstrated by comparing the differences in water absorption between rNF and plastic. The main factors that contribute to moisture absorption in composites include the presence of lumens, microscopic holes, and hydrogen bonding sites in the rNF, as well as gaps and flaws at the interfaces and microcracks that were formed in the matrix during compounding [37]. Due to the presence of hydroxyl and other polar groups in certain rNF constituents, which increased the water absorption, the hydrophilic rNF and the hydrophobic polymers did not mix well. Because the number of free hydroxyl groups in cellulose and hemicelluloses determines how much water they can absorb, water can reach the amorphous areas. Plastics, in contrast, are water-repellent and have a much lower capacity to absorb water than cellulose.

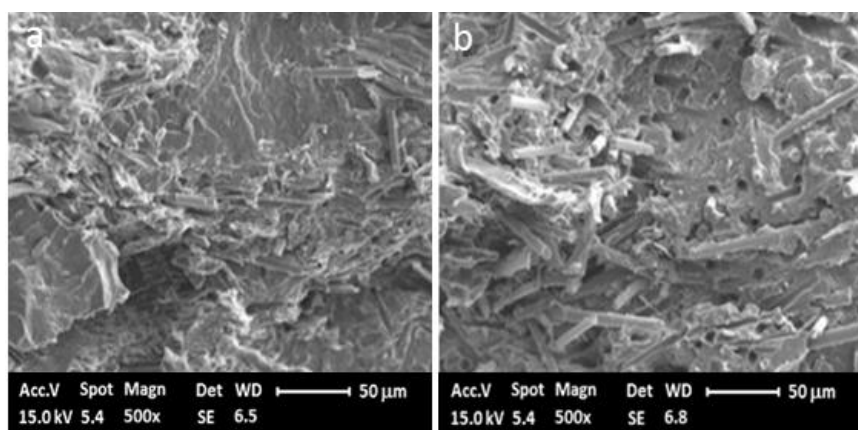


Figure 4. SEM micrograph of hybrid rNF/PP and GF (70/30), with (a) 10% GF and (b) 20% GF.

Table 2. Water absorption and thickness swelling of PP-rNF/GF composites.

Sample code	Density (kg/m ³)	Moisture absorption (%)		Thickness swelling (%)	
		2 h	24 h	2 h	24 h
PP	910	0.019	0.053	0.083	1.234
P30r	929	1.539	3.876	0.694	1.793
P30rC	941	1.295	2.586	0.536	1.439
P25r5GC	983	0.897	2.134	0.498	0.873
P20r10GC	1035	0.585	1.421	0.317	0.624
P15r15GC	1087	0.494	1.162	0.296	0.595
P10r20GC	1137	0.357	0.897	0.235	0.397

The glass fiber in the composite replaced the hydrophilic natural fiber, and as a result, the amount of water that the rNF/PP composites absorbed was significantly reduced. When 5 wt% of glass fiber were added to the composite, the water absorption was decreased by 31%, and this reduction persisted as more glass fiber was added. The composites' capacity to absorb water is reduced by 72% when 20% glass fiber content is added. PP absorbs the least water, whereas rNF composites take up the most. The hydrophilic property of natural fibers accounts for the fact that the amount of water absorbed was unaffected by the matrix. A large water uptake was indicated by the composite's considerable natural fiber content. As the glass fiber content increases, fewer water resident sites exist, resulting in less water absorption. Composites having a higher proportion of glass fiber, on the other hand, have fewer sites for water absorption and hence absorb less water. PP barely absorbs 0.019% and 0.053% of water after 2 hours and 24 hours, respectively, of immersion in water. The water absorption of materials with 30 wt% rNF and 2 wt% MA is 1.295% after 2 hours of immersion and 2.586% after 24 hours, which are significantly lower than the values of 0.357 and 0.897% for composites with 20 wt% glass fibers and 10% rNF content. In addition, it is well recognized that MA can significantly reduce water absorption. The composites comprising 30 weight percent of rNF and 2 weight percent of MA for the 24-hour immersion tests reduce the water absorption from 3.876 to 2.586%. The coupling agent can enhance bonding in natural fiber because it increases the compatibility of the polymer with the rNF particles, resulting in a greater amount of rNF surface areas being covered by the polymer during compounding. By adding the coupling agent, the ester linkages between the hydroxyl groups of cellulose and the anhydride component of MA are strengthened [36]. Less free OH- is present in the cellulose of the wood as a result of some of them reacting with maleic anhydride. These modifications lead to a relatively lower increase in water absorption as compared to the composite formulation without MA. The TS of PP/rNF composites increases with water absorption and follows a similar trend to water absorption (Table 2) in terms of the impacts of newspaper to plastics ratio and coupling agent. After a 24-hour immersion, the TS values rise to 0.397 to 1.793%, ranging from 0.235 to 0.694% during a 2-hour immersion. Higher glass fiber content samples have lower TS. However, samples that have been exposed to MA show that TS is reduced at the same level of rNF.

CONCLUSIONS

In terms of their mechanical properties, hybridization can be advantageous for natural fiber plastic composites. The results of the present study show that these properties can be enhanced by adding glass fiber to rNF plastic composites. When glass fibers were added to the rNF/PP composites system, the tensile strength and modulus increased, but the impact strength decreased. Because there is a considerable amount of rNF fiber present, the composite shows a high water uptake and thickness swelling. When the coupling agent (MA) is applied, these features are significantly reduced. Moisture absorption is further decreased with additional glass fiber present. Composite materials can acquire mechanical properties, such as dimensional stability, by adding coupling agents or more glass fiber. The coupling agent is essential because the fiber-matrix interphase area significantly affects the mechanical properties and water absorption of a composites system. Our research has shown that natural fiber composites treated with coupling agents and glass fiber will be the most advantageous as building materials due to their increased stability and mechanical properties.

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