Effect of Water Absorption on Interface and Tensile Properties of Banana Fibre Reinforced Functionalized Polypropylene (BF/CFPP) Composites Developed by Palsule Process

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SUMMARY

Banana fiber (BF) reinforced chemically functionalized high density polypropylene (CFPP) composites (BF/CFPP) developed by Palsule process of using modified matrix, immersed in distilled water at room temperature for long duration, showed water absorption higher than that of the CFPP that increased with increasing fiber content in the composite compositions. Tensile modulus and tensile strength of the wet composite compositions was lower than that of the dry BF/CFPP composite compositions. Voids, capillary water transport and hydrogen bonds promote water absorption in BF/CFPP composites.

Keywords: Banana fiber/chemically functionalized polypropylene BF/CFPP composite, Palsule Process, Water absorption, Thickness swelling, Tensile properties, Fiber/Matrix interface, Voids, Capillary water transport, Hydrogen bonds

INTRODUCTION

There has been a growing interest in natural fiber reinforced polyolefin composites that are emerging as low cost engineering materials. Environmentally friendly natural fibers are now emerging as alternative reinforcers for glass and other synthetic and inorganic fibers in polymer matrix based engineering composites [1]. The techno-economic and environmental advantages of
natural fiber reinforced polyolefin composites include – constituents based on renewable and abundantly available raw materials, low density, acceptable mechanical properties, low cost, biodegradability, low energy consumption and several others [2]. However, natural fiber reinforced polymeric composite materials have some limitations [3] including, lower processing temperature that restricts the choice of matrix polyolefin material, limited applications at higher temperatures, high moisture absorption by the hydrophilic natural fibers, incompatibility of hydrophilic natural fibers with some hydrophobic polyolefin in the composites etc.

All polymeric composites absorb moisture in humid atmosphere, and also when immersed in water. However, natural fiber reinforced polyolefin composites are comparatively more susceptible to moisture absorption and the absorbed moisture adversely affects several of their physical and mechanical properties. All natural plant fibers are hydrophilic in nature with a moisture content of 8–13% due to the presence of cellulose in their cell structure [4]. Investigations of effects of moisture absorption by natural fiber/polymer composites have attracted attention of scientists and engineers. For example Jute fiber-reinforced polypropylene composites have been produced and characterized in order to investigate the influence of water on their mechanical properties by Karmaker et al. [5]. Girisha et al. [6] studied the water absorption behavior and its effect on the mechanical properties of natural fibers (sisal and coconut coir) reinforced epoxy composites. Water immersion tests have been performed by Dhakal et al. [7] on hemp fiber reinforced unsaturated polyester composites (HFRUPE) to evaluate the effects of water absorption on their mechanical properties.

Banana fiber obtained from the pseudo-stem of plant is a bast fiber. Banana belongs to the Musaceae family and is widely available in tropical and sub-tropical regions of the world [8-9]. High mechanical properties of banana fiber make it a suitable natural reinforcement for polymer composites. Studies of Pothan et al., [10] on water absorption by short banana fiber reinforced polyester composites indicated increasing water uptake with increasing amounts of reinforcing banana fibers in the composite compositions, and the composite samples soaked in water for about one month showed approximately 32% decrease in their tensile strength.

In presence of moisture or when immersed in water, reinforcing fibers of natural fiber reinforced polyolefin composite absorb moisture/water and swell. Polyolefin matrix, and natural fiber/polyolefin matrix interface in these composites develops voids that deteriorate the fiber-matrix interfacial adhesion, reduce the stress transfer from the matrix to the fiber, deteriorate mechanical properties and also dimensional stability. Moisture diffusion in polymeric composites has been shown to be governed by three different mechanisms [11, 12] – (i) diffusion of water molecules inside the micro gaps between
polymer chains, (ii) capillary transport of water into the gaps and flaws at the interfaces between fiber and the matrix, and (iii) transport of moisture through micro-ceracks in the matrix arising from the swelling of fibers, particularly in the case of natural fiber/polyolefin composites. In general moisture diffusion in a composite depends on several factors such as volume fraction of fiber, voids, viscosity of matrix, humidity and temperature [13].

In view of poor fiber/matrix interfacial adhesion in natural fiber/polyolefin composites, following three processes have been used to improve fiber/matrix interfacial adhesion in these composites – (i) chemical and/or physical treatment of surface of natural fibers (ii) use of third components i.e.; compatibilizer (iii) Palsule process of modified polyolefin matrix. This study describes water absorption behavior and its effects on fiber/matrix interfacial adhesion and tensile properties of banana fiber reinforced chemically functionalized polypropylene (BF/CFPP) composites developed by Palsule process [14-16]. Details of development of BF/CFPP composites by Palsule process have been described in literature [16].

**EXPERIMENTAL**

**Materials**

Chemically functionalized maleic anhydride grafted polypropylene (CFPP), (with 2% maleic anhydride grafting) used as matrix for processing the composites for this study, was the commercially available as OPTIM P-425® obtained from Pluss Polymer Pvt. Ltd., India. It is available, commercially, as free flowing granules/pellets and is white to light yellow in appearance. It has a density of 0.91 g/ml, melting temperature (T_{m}) of 165°C and the melt flow index (MFI) is 110 (190°C, 2.16 Kg). The reinforcing banana fiber (BF) was obtained from Mushroom Welfare Association, Tripura. The percentage of cellulose and lignin content in banana fiber is 60-65% and 5-10% respectively [17]. Tensile strength, tensile modulus and density of banana fiber are approximately 675 MPa, 31 GPa and 1.3 g/cm³ respectively [18]. The reinforcing banana fibers, of 38-50 µm diameter, used in this study were cut to 1-3 mm length.

**Compounding and Processing**

Chemically functionalized maleic anhydride grafted polypropylene (CFPP), (with 2% maleic anhydride grafting) and 1-3 mm long banana fibers were pre dried in hot air oven at 40°C for one day, and then at 80°C for 2 hours to remove
moisture. Calculated amounts of BF and the CFPP were mixed manually with a view to finally obtain 10/90, 30/70 and 50/50 BF/CFPP composites. The mixtures were fed into the hopper of the co-rotating twin screw extruder (model JSW TEX 30α) having 30 mm screw diameter and L/D ratio of 36:1 and the screw speed was set at 145 rpm. There are nine different temperature zones in TEX 30α extruder and the temperature profile for these zones varies from 180°C to 195°C. The temperature profiles of the various zones of the extruder were - 180°C-185°C -185°C-190°C -190°C-193°C -193°C-195°C-195°C-195°C. The BF/CFPP mixtures with appropriate amounts of the constituents were compounded in the extruder, and extruded composite compositions, termed as 10/90, 30/70 and 50/50 BF/CFPP composites, were cooled in water. These were then pelletized in a pelletizer to obtain 3 mm long granules that were kept in hot air oven at 80°C for overnight and were then used to mold test specimens of 10/90, 30/70 and 50/50 BF/CFPP composites for tensile tests and water absorption studies using injection molding machine (Model JAD series, JSW Ltd. Japan).

Water Absorption Test

Water absorption tests were conducted in accordance with ASTM D570. Long-term water absorption tests for 4680 hours at room temperature were performed for three samples of the CFPP and three samples of each of the 10/90, 30/70 and 50/50 BF/CFPP composite compositions. The samples were placed in distilled water, in a container at room temperature, after conditioning, for which, the samples were dried in an oven at 80°C for 1 hour and were then allowed to cool to room temperature in desiccators. Samples were weighed to the nearest of 0.1 mg. The samples were then immersed in distilled water at room temperature for different time durations. The change in weight of each sample was measured periodically; and then the sample was again submerged in distilled water. Before taking weight, the sample was removed from water and all surface water was wiped off with a clean dry cloth. The weight of the sample was measured at various time intervals up to 4680 hours. The moisture absorption was calculated by the weight difference between weight of the specimen (g) at a given immersion time t and the conditioned weight of the specimen. The values of the water absorption in percentage were calculated using the following equation:

\[ W = \frac{W_t - W_0}{W_0} \times 100 \]

Where, \( W \) is the percentage water absorption of the sample at time t, \( W_0 \) is the oven dried weight (g) (conditioned weight) and \( W_t \) is the weight of the specimen (g) at a given immersion time t.
**Tensile Testing**

The tensile properties of CFPP, the processed 10/90, 30/70 and 50/50 BF/CFPP composites and the 10/90, 30/70 and 50/50 BF/CFPP composites that had absorbed water after the water absorption tests were evaluated on a Universal Testing Machine, (Model 3382, Instron 25 Ton Capacity) in accordance with ASTM standards D 638 with cross head speed of 50 mm/min.

**RESULTS AND DISCUSSIONS**

**Effect of Fiber Loading on Water Absorption by Various BF/CFPP Composite Compositions**

*Figure 1* shows the water absorption by the CFPP matrix and various BF/CFPP composite compositions plotted as a function of time (hours). Water absorbed by the BF/CFPP composite compositions is much higher than water absorbed by the CFPP matrix and increases with increasing banana fiber content in composite compositions. The hydrophilic property of banana fiber is responsible for the water absorption by the BF/CFPP composites. The 50/50 BF/CFPP composite composition shows higher water absorption than 10/90 and 30/70 BF/CFPP composites due to higher amount of banana fibers in the 50/50 BF/CFPP composite composition. CFPP matrix, due to the presence of grafted maleic anhydride moiety, shows 0.6% water absorption after 2520 hr (105 days). The 10/90, 30/70 and 50/50 BF/CFPP composites show 2%, 6.5%...
and 11% moisture/water absorption after 4680 hrs (195 days), with minimum (approx 2%) water absorption by the 10/90 BF/CFPP composite with minimum amount of banana fiber, and maximum (almost 11%) water absorption by the 50/50 BF/CFPP composite with maximum amount of banana fiber.

The water uptake behavior of all BF/CFPP composite compositions is linear in the beginning and then slows down, but this behavior is not exhibited by the CFPP matrix. The initial rate of water absorption and the maximum water uptake increased for all composites with increasing fiber content in the BF/CFPP composite compositions.

**Effect of Moisture Absorption on Tensile Properties**

**Figure 2** represents the tensile strength of the dry and the wet CFPP matrix and the 10/90, 30/70 and 50/50 BF/CFPP composites. The tensile strengths of the dry CFPP and the dry 10/90, 30/70 and 50/50 BF/CFPP composites is recorded as 33.54 MPa, 38.20 MPa, 51.11 MPa and 60.17 MPa respectively. The absolute values of tensile strengths of the wet CFPP and the wet 10/90, 30/70 and 50/50 BF/CFPP composites have been recorded as 33.0 MPa, 35.17 MPa, 38.61 MPa and 42.92 MPa respectively. The tensile strength of the wet CFPP and 10 wt%, 30 wt% and 50 wt% BF/CFPP composites decreases by 1.5% and 9%, 32%, 40% respectively, as compared to that of the dry sample of the CFPP and of the same composite compositions.

![Figure 2. Tensile strength vs. fiber (wt%) of dry and wet specimens of BF/CFPP composites](image)

**Figure 3** represents the tensile modulus of the dry and the wet CFPP matrix and the 10/90, 30/70 and 50/50 BF/CFPP composites. The tensile modulus of the dry CFPP and the dry 10/90, 30/70 and 50/50 BF/CFPP composites is
recorded as 0.91 GPa, 1.19 GPa, 1.47 GPa and 1.87 GPa respectively. The absolute values of tensile modulus of the wet CFPP and the wet 10/90, 30/70 and 50/50 BF/CFPP composites have been recorded as 0.9 GPa, 1.11 GMPa, 1.27 GPa and 1.3 GPa respectively. A considerable decrease in tensile modulus of the wet samples compared to that of dry samples is observed. The percentage decrease in tensile modulus of wet samples compared to dry samples of CFPP and 10/90, 30/70 and 50/50 BF/CFPP composites are 1.1%, 7.2%, 15.7% and 44% respectively.

This study on effect of water absorption behavior on tensile properties of BF/CFPP composites shows that the tensile properties of the composites are adversely affected by moisture absorption and tend to decrease after water/moisture uptake. This may be due to the effect of water molecules on the components of the composites, which change the structure and properties of the fiber, matrix and the interface between them. This effect is particularly greater for the composites with higher fiber content, in which stress transfer from the matrix to the fiber is reduced due to moisture content.

Pothan et al. [10] have reported that water molecules act as a plasticizer by influencing the fibers, the matrix and the fiber-matrix interface simultaneously and thereby adversely affecting the mechanical integrity of the system; and water acts like a separating agent at the fiber-matrix interface [19]. When the natural fiber reinforced composite is exposed to moisture, due to the hydrophilic nature of banana fiber, these fibers swell. The high cellulose content in banana fiber further contributes to more water penetration into the interface through the micro cracks that are created by the swelling of fibers. As the composite cracks and gets damaged, transport of water through capillaries and via micro cracks becomes active. The capillary mechanism involves the diffusion and
flow of water molecules along fiber–matrix interfaces and through the bulk matrix. Water molecules promote de-bonding of the fiber and the matrix at the fiber/matrix interface.

The reaction mechanism scheme for effect of moisture absorption on in-situ fiber/matrix interfacial adhesion of BF/CFPP composites adversely affecting the mechanical properties of the composite is explained in Figure 4. Due to the presence of moisture or absorbed water molecules, new hydrogen bonds are established between cellulose molecules in the banana fiber and water molecules [4.1], or between maleic anhydride (of CFPP) and water molecules which results in formation of maleic acid [4.2]. This maleic acid (of CFPP), may further react with water molecules [4.3] or with cellulose molecules of banana fiber to establish hydrogen bonds [4.4] rather than the usual covalent ester bonds between hydroxyl groups of banana fiber and maleic anhydride group of CFPP. The presence of water, thus, reduces the interfacial bonding or adhesion between the banana fiber and the CFPP matrix, and decreases the tensile properties of the BF/CFPP composites.

CONCLUSIONS

Banana fiber (BF) reinforced chemically functionalized polypropylene (BF/CFPP) composites developed by Palsule process of using modified matrix absorb significant amount of water when immersed in distilled water at room temperature for a long duration. Water absorption by the composite compositions is higher than that of the CFPP matrix and increases with increasing fiber content in BF/CFPP composite compositions. Tensile modulus and tensile strength of the wet BF/CFPP composite compositions was lower than that of the dry BF/CFPP composite compositions. Voids and capillary facilitate water transport and hydrogen bonds between banana fibers, CFPP matrix and absorbed moisture promote water absorption in the composites that adversely affects fiber/matrix interface, stress and load transfer from matrix to fiber, tensile mechanical properties and dimensional stability of the composites.
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4.1 Hydrogen bonding between cellulose molecules of banana fiber and water

4.2 Hydration reaction of maleic anhydride to form maleic acid in CFPP

4.3 Hydrogen bond formation between maleic acid (of CFPP) and water

4.4 Hydrogen bond formation between maleic anhydride (of CFPP) with (–OH groups) of BF in the presence of water

Figure 4. Reaction mechanism scheme for effect of moisture absorption on in-situ fiber/matrix interfacial adhesion of BF/CFPP composite
REFERENCES


