Fibers and Polymers 2021, Vol.22, No.11, 3183-3191
DOI 10.1007/s12221-021-0027-9

ISSN 1229-9197 (print version)
ISSN 1875-0052 (electronic version)

Characterization of Bamboo - Polypropylene Composites: Effect of Coupling Agent

Madhavi S[1], Raju N V[1]*, and Jobish Johns[2]

[1]*Department of Physics, Global Academy of Technology, Bangalore 560098, India*
[2]*Department of Physics, Rajarajeswari College of Engineering, Bangalore 560074, India*
(Received January 9, 2021; Revised February 9, 2021; Accepted February 22, 2021)

Abstract: Bamboo fibre reinforced polypropylene composites at various bamboo fibre loading levels (20 %, 30 %, 40 % and 50 %) with and without coupling agent Maleic Anhydride Polypropylene (MAPP) were prepared by extrusion and moulded in injection moulding machine. Moulded specimens were characterized by SEM, FTIR, thermal and mechanical properties. The fibre content of 50 % by weight has been proven to provide adequate reinforcement to increase the mechanical strength significantly. Thermal stability of bamboo, polypropylene and bamboo fibre reinforced polypropylene composite coupled with MAPP were analysed by using thermo gravimetric. SEM micrograph confirmed the proper interfacial adhesion between the wood fibre and PP matrix in the presence of coupling agent. Moisture absorption of coupled and uncoupled composites were compared and reported. These composites can be used in a variety of applications such as construction, automobiles, consumer goods etc. They are considered as suitable replacement for solid plastic products and materials.

Keywords: Bamboo fibre, Polypropylene, MAPP, Mechanical properties, Coupling agent

Introduction

Due to serious issues of environmental hazards and energy shortages, natural fibre reinforced composites have gained great attention [1]. Generally, natural fibers have been used to fill or reinforce thermoplastics especially polypropylene composites, have grasped greater attention due to their added advantage of recyclability [2]. Natural fibres used as reinforcing material which are polar bio-fillers and hydrophilic in nature. Polymers which are used as matrix are non-polar and are hydrophobic in nature. As a result, bio fillers do not disperse easily in thermoplastic polymers such as polypropylene. Lower compatibility and interfacial adhesion of these composites leads to reduce the mechanical properties of the final products [3]. Therefore, it is essential to improve the interfacial adhesion between bio filler and polymer. The resulting compatibilised materials can be used in industries and engineering applications.

Maleic anhydride polypropylene (MAPP) is a very effective and commonly used compatibilizer at the interface of natural fiber and polymer matrix [4]. The molecular structure of MAPP is shown in Figure 1.

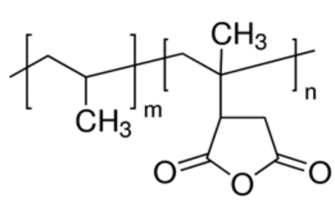

Figure 1. Molecular structure of MAPP.

*Corresponding author: raju_nv@gat.ac.in

In recent years, various physical and chemical treatments have been introduced to improve the interfacial adhesion between the bio-filler and polymer. Among those methods, coupling with MAPP is found to be the most successful method [5]. Nearly 40 coupling agents with different functional groups have been used in wood fibre-filled thermoplastic composite [6].

The poor wetting of bamboo fibre surfaces upon the incorporation of unmodified PP due to different surface energies between the hydrophilic fibre and hydrophobic PP matrix can be improved by the addition of MAPP. Formation of hydrogen bonds occurs at the interface between the -OH group of cellulose or lignin in bamboo fibre with the anhydride groups in the MAPP. MAPP crystalizes the bamboo surface and the bamboo fibre acts as a reinforcing agent as well as a nucleator for MAPP. This surface crystallization contributes to the better interfacial adhesion in Bamboo/PP/MAPP composite [7].

Polypropylene has many advantages when compared to other thermoplastic materials such as poly vinyl chloride, poly ethylene etc. Poly vinyl chloride products pollute the surrounding environment and causes problems during processing, use and disposal. Poly ethylene exhibits poor performance than PP in terms of mechanical strength and is more difficult to degrade. Some of the benefits of PP is that it has good mechanical properties, high temperature of thermal deformation, possess moderate dimensional stability, flame resistance and recyclability. The recovered PP showed lower porosity and water absorption property with high dimensional stability and high density. Composite materials based on PP shows excellent mechanical properties such as tensile, flexural and impact strength when compared to other thermoplastic materials. Hence it becomes an obvious choice for the researchers to use PP as polymer matrix in the natural fiber composite materials replacing other thermoplastic materials [8].

Some researchers also showed that alkali treatment process for the bamboo fibre reinforced epoxy resin composite improves the interface strength which intern increases the tensile strength of the composite. Bidirectional bamboo fibre/epoxy composites shows improved tensile strength in both the longitudinal and transverse direction when compared to unidirectional composites and pure epoxy [9].

It has been reported that bamboo fibre as an eco-friendly material can be used to replace the conventional fibres such as glass and carbon [10]. Addition of bamboo fibre to polypropylene causes an increase in the overall crystallization rate [7]. The new composites developed by bamboo/PP coupled with MAPP are water resistant, lighter, and cheaper. Its tensile strength is three times higher than that of the commercial product [11]. It has also been reported that the increase in fibre content after 50 % in weight decreases the tensile strength slightly. Hence, at 50 % loading level, bamboo fibre showed the maximum tensile strength [10].

When bamboo surface is treated with MAPP, hydroxyl group of bamboo surface reacts with anhydride group of MAPP farming ester bonds. This esterification reaction modifies the bamboo surface. Hydrophilic anhydride groups of MAPP are prone to compatibilize with hydrophilic bamboo surface. This promotes the dispersion and surface wetting of bamboo particles in the PP. The efficient transfer of stress from PP to the stiffer bamboo leads to the improvement in the efficient chemical bonding between PP, MAPP and bamboo particles and thus enhance the mechanical strength. Thus MAPP played an effective role in improving the surface wettability of composites [12]. FTIR spectra clearly confirms the esterification between anhydride group of MAPP and hydroxyl group of bamboo surface [5].

Figure 2 shows the interaction of MAPP with natural fiber representing hydrogen bonding. Figure 2 illustrates how interfacial adhesion occurs when two different materials are mixed or combined or blended. SEM micrograph proves the interfacial adhesion among the phases.

Products developed from wood-polymer composite materials have several advantages as they are cost effective, environmentally friendly, recyclable, dimensionally stable, value addition to ligno cellulosic waste materials, superior strength and stiffer than plastics. Wood-polymer composite materials are used in various fields such as automobiles, construction, electronic components, aerospace, modern packaging system such as natural fibre reinforced wood polymer composite (WPC) pouches and wrapped to store food with free of contamination [13].

The present work deals with the effect of coupling agent (MAPP) on the properties of wood polymer composite. Bamboo fiber is used as the reinforcement in the polypropylene matrix to fabricate composites. Cellulose fibers aligned along its length provide maximum mechanical strength to bamboo [14]. Natural bamboo fibers are coarser and longer with high breaking tenacity and lower elongation were found to be good for some textile applications [15]. Therefore, bamboo fiber has been selected as the reinforcement in polypropylene. Water uptake is less when Polypropylene is used as matrix in composites compared to the other polymers such as polyethylene and polyvinyl chloride [16].

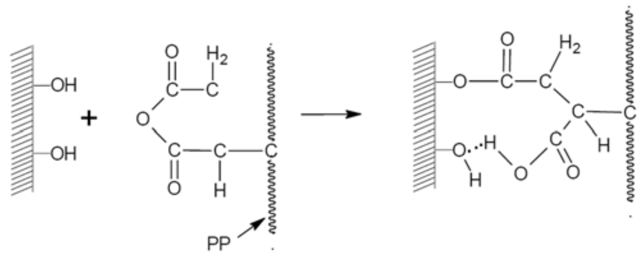

Figure 2. Interaction of MAPP with natural fibre representing hydrogen bonding [4].

Experimental

Polypropylene (H1110MA; melt flow index 11 g/10 m at 230 ^{o}C under 2,16 kg load) was purchased from Reliance industries Ltd. India and used as matrix polymer for composite. Bamboo was obtained from local source and MAPP was purchased from Sigma-Aldrich, Bangalore, India.

Bamboo fibre was initially powdered by using pulveriser and later it has been dried in oven at 105 ^{o}C for about 24 hours to remove the moisture content. The fibre content in polypropylene was varied at the loading levels of 20 %, 30 %, 40 % and 50 % in the presence of 5 % coupling agent (MAPP) of the fibre weight. The resulting mixture was then fed to the twin-screw extruder equipped with a side feeder and two volumetric feeders. The extrudate was then collected from steel belt and later it was cut into small pellets using cutter and these pellets were again kept in oven at 105 ^{o}C for about 2 days to remove the moisture content. The pellets were converted into the desired shapes with the help of De-Tech 60 LNC4-E (L&T) injection moulding machine with a load capacity of 60 Ton as per ASTM standards.

Determination of Mechanical Properties

Tensile, flexural and impact strength of samples were tested using Shimadzu universal testing machine (Model AGIS10, 10 kN). Tensile tests were carried out in accordance with ASTM D638-94b [17] with specimen dimension 165.0 mm×13.2 mm×3.2 mm at a cross head speed of 50 mm/min. The recorded value included tensile strength, tensile modulus, elongation and strain. Flexural strength was measured according to ASTM D790-92 [18] using a cross head speed of 2.8 mm/min using a support span of 100 mm

Figure 3. Composite samples to test tensile and flexural strength.

with dimension of 127.0 mm×13.2 mm× 6.4 mm. Impact strength was determined as per ASTM D256-93 [19] on a Ceast impact tester. For notched and un-notched impact strengths, 1.0 and 5.4 J hammers were used respectively. Five samples of composites were tested for each property.

Thermo Gravimetric Analysis (TGA)

Thermal stability of the material was evaluated using TGA. TGA model Q50 was used for thermal analysis in which the mass loss of the samples measured over time as the temperature changes. It was carried out in the atmosphere of nitrogen. About 5-8 mg of the composite sample was heated from 40 °C to 600 °C at a heating rate of 20 °C/minute. Prior to analysis, all samples were oven dried at 95 °C for 8 hours.

FTIR Spectroscopy and SEM

FTIR spectroscopy was used to characterize bamboo, PP, Bamboo-PP composite with and without coupling agent using a Bruker tensor 27 model FTIR spectrometer with co-addition of 64 scans at resolution of 4 cm^{-1}. SEM was characterized to know the state of adhesion between bamboo fibre and PP matrix in coupled and uncoupled composites.

Moisture Absorption

Diffusion of water molecules into the network of composites affects the mechanical properties. Specimens of the composites with and without MAPP of varying proportion were soaked in distilled water. During the conditioning time, the specimens were periodically removed for every 48 hours from the water and dried by tissue paper and weighed using an electrical balance accurate to 0.0001 g. The weight and time were recorded to calculate the moisture content. The final time at which the experiment was completed is for 1200 hrs i.e the experiment was carried out for 50 days.

Moisture absorption is calculated using the formula [20]

$$\text{Moisture absorption} = \frac{m_0 - m_t}{m_0} \times 100 \ (\%) \quad (1)$$

where m_0 is the initial mass of the sample and m_t is the mass of the sample at time t.

Results and Discussion

The tensile, flexural strength and stiffness are enhanced by inclusion of a compatibilizer, MAPP, in matrix material as a result of improved interfacial bonding [21]. Figure 4 shows the variation in tensile strength with fibre content for both coupled and uncoupled samples.

A significant improvement in tensile strength of bamboo fibre filled polypropylene has been observed with the addition of MAPP coupling agent. There is an increase of 35 % in the tensile strength of the coupled composite when compared with the uncoupled ones. The maximum tensile strength reached for coupled composite is 38.93 N/m^2 for 50 % fibre weight. The coupling agent MAPP helps to improve the interfacial adhesion between bamboo and Polypropylene. It acts as a crosslinking agent between bamboo and PP due to which there is an enormous increase in tensile strength of coupled composite when compared with uncoupled one.

In the present study the particle size of the bamboo maintained is 500 μm. Bamboo/PP/MAPP composites having bamboo fibers of different sizes < 500 μm, 500-850 μm, 850 μm to 1 mm and 2 mm shows different mechanical properties. On increasing the size of bamboo fibres, both tensile strength and modulus decreases considerably. At the same composition, smaller fibre has a relatively larger surface area which results in better contact between fibre and matrix [22].

In case of uncoupled composite rapid delamination of the matrix from filler occurs due to the lack of affinity or poor adhesion between PP and bamboo fiber. This makes the composite material to break sooner and thus the tensile strength of the uncoupled composite is less when compared to coupled composite. This problem doesn't exist in case of coupled composite since MAPP improves the affinity

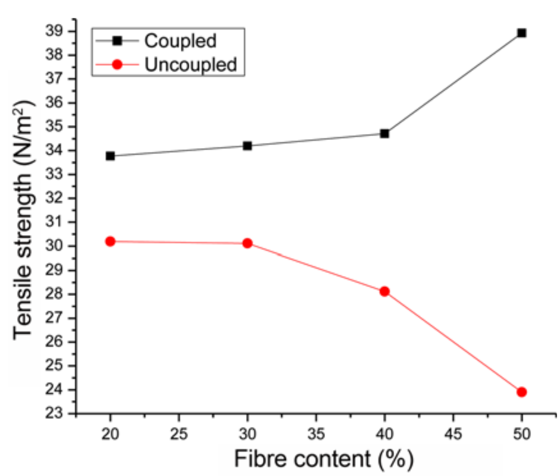

Figure 4. Variation of tensile strength with fibre content for both coupled and uncoupled sample.

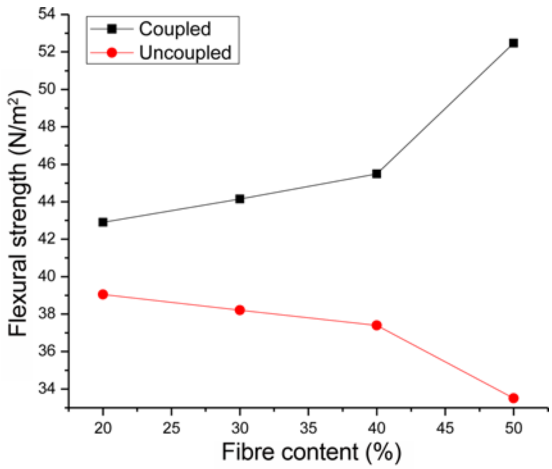

Figure 5. Variation of flexural strength with fibre content for both coupled and uncoupled samples.

between the PP and bamboo fiber. This makes the coupled composite to break slowly and hence its tensile strength is more [23].

Figure 5 shows the variation of flexural strength with fibre content for both coupled and uncoupled samples. There is an increase of 73 % in the flexural strength in case of coupled composite when compared to uncoupled composite. The optimum value of flexural strength for 50 % fibre weight in case of coupled composite is 52.47 N/m^2. The reason for significant increase in flexural strength is mainly due to the enhancement in the interfacial adhesion between fibre and matrix due to the inclusion of coupling agent (MAPP). The coupling agent also improves the interfacial chemical bonding between bamboo and polypropylene. Breakage mechanism for flexural testing method takes place due to the interlaminar fracture toughness of the composite [24].

Table 1 clearly summarizes the variation of tensile and flexural moduli with fibre content. A considerable enhancement in both the moduli values can be seen upon the addition of coupling agent. Higher modulus is observed in case of coupled composite when compared with the uncoupled composite. Enhancement in tensile and flexural modulus of coupled composite is mainly due to the better interfacial interaction between fibres and matrix upon the incorporation of coupling agent.

The values of Young's modulus provide better information about the change in tensile properties of the composites upon the addition of fillers. Table 1 clearly shows that the tensile or young's modulus increases with the increase in fiber content for both coupled and uncoupled composite. The increase in young's modulus values on increasing the fiber content shows that the filler reinforcement with the polymer matrix improves the tensile properties. More the percentage of fiber, a good filler reinforcement with the polymer matrix occurs due to which the mechanical properties of the composite increases.

Table 1. Variation of tensile and flexural modulus with fibre content in case of both coupled and uncoupled composites

Fibre content (%)	Tensile modulus (N/m^2)		Flexural modulus (N/m^2)	
	Coupled	Uncoupled	Coupled	Uncoupled
20	2008.11	1669.45	2139.95	1732.62
30	2698.89	2357.11	3067.12	2499.96
40	2723.42	2458.31	3520.25	2976.88
50	2790.54	2641.68	3781.1	3659.25

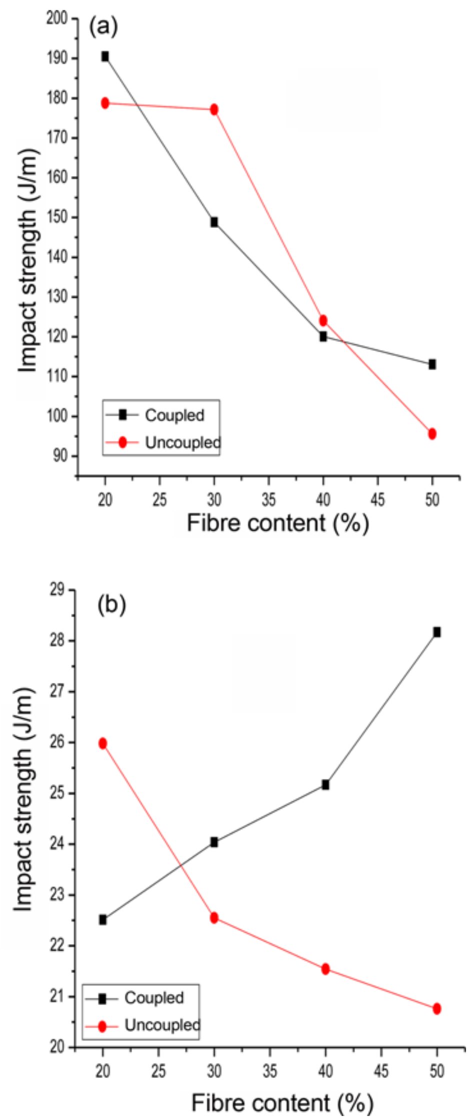

Figure 6. Variation of impact strength with fiber content for both coupled and uncoupled composites in case of (a) un-notched and (b) notched samples.

Figure 6(a) and 6(b) shows the variation in impact strength with fibre content for both coupled and uncoupled composites in case of un-notched and notched samples respectively.

Ability of the material to resist the fracture is termed as impact strength. Impact strength of the fibre reinforced composite depends on many factors such as fibre-matrix interface, fibre dispersion, nature of the constituent, test conditions and geometry of the composite. With increasing filler content, the impact strength of the un-notched sample decreases even in the presence of coupling agent. This is attributed to the presence of too many fibre ends which acts as point of crack initiation leading to the failure of the composite. Another reason for decrease in impact strength may be the stiffening of polymer chains due to bonding between fibre and matrix. However, the impact strength of the notched sample shows a slight increase in the case of coupled composite on increasing the fibre content. This is attributed by the higher energy need to be supplied to the fibre to pull out at higher filler content [25]. The maximum impact strength is obtained for the coupled composites with 50 % fibre and the value is found to be 28.17 J/m. The improvement in the mechanical properties is also attributed to the fact that cracks and irregular grooves induced by the modification of bamboo fibre facilitate the infiltration of PP into bamboo fibre due to the strong capillary effect [26].

As impact takes place, the failure initially occurs in the farm of micro cracks, as the stress concentration exceeds the polymer strength which later rapidly spread and eventually leads to macroscopic failure. Impact strength is sensitive to voids, particles etc. For uncoupled composite due to the poor interfacial adhesion between polymer and filler, impact leads to the formation of void around the filler particles. For this particular reason the impact strength of the uncoupled composite decreases for both notched and un-notched samples [27].

In case of notched samples, the specimen curvature increases which tend to increase the impact strength of the composite materials. Increasing notch radius will increase the impact strength of the material. This shows that the sample geometry, in particular, the curvature has a significant influence on the impact strength. As the specimen curvature increases in the notched samples, too many fiber ends which acts as point of crack initiations are avoided and results in the higher impact strength of the composite material. The influence of the specimen curvature on impact strength makes a difference in the values of notched and un-notched samples [27].

The composite properties not only depends on the fiber content, it also depends on many other parameters which can be varied to study the properties of the composite. Fiber type, concentration of coupling agent, fiber strength, fiber size, fiber species and age of the fiber are the factors that can be varied along with the fiber content to study the composite properties. It was reported in the literature that the concentration of coupling agent more than 9 % decreases the mechanical properties of the composite [12]. In the present study, 5 % of coupling agent (MAPP) is used.

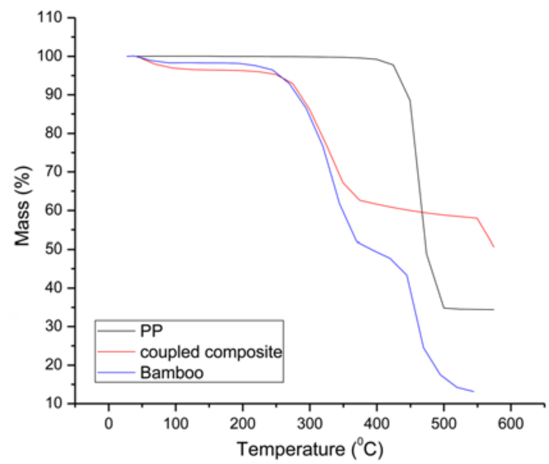

Figure 7. TGA of bamboo, PP and coupled composite.

The size of the bamboo fiber varies between 1-2.5 cm in length and 0.24-0.4 mm in diameter when it is separated from bamboo body by mechanical method [28]. Some researchers attempted to vary the size of the bamboo and study mechanical properties of the resulting composite. As the length of the bamboo fiber increases, the tensile strength of the composite decreases, whereas tensile modulus increases [29].

Figure 7 shows the thermo gravimetric analysis (TGA) of bamboo fibre, PP and coupled composite. The nature of decomposition in case of pure components and its composite is different. TGA curve of bamboo fibre exhibits weight loss in two steps. The weight loss occurs up to 240 ^{o}C may be attributed to gradual evaporation of absorbed moisture and decomposition of volatile compounds. The second step of weight loss in the temperature range 240 ^{o}C to 385 ^{o}C is due to the decomposition of major constituents of the bamboo fibre such as cellulose, hemicellulose and lignin [30]. Lignocellulose fibres are chemically active and decompose thermo-chemically between 200 ^{o}C and 400 ^{o}C. The degradation of PP occurred between 415 ^{o}C and 500 ^{o}C in a single step process. TGA curve of bamboo-PP composite with MAPP coupling agent exhibits two major steps of weight loss. The first step is of bamboo at 240 ^{o}C and the second step corresponds to the decomposition of PP at 415 ^{o}C. It is noticed that, the TGA curve of coupled composite in the initial stage of weight loss lies in between both the constituents. Therefore, it can be confirmed that the addition of bamboo fibres into PP increases the thermal stability when compared to bamboo alone.

Table 2 shows some of the major mass loss that takes place at different temperature in case of bamboo fiber, polypropylene and MAPP coupled bamboo fiber reinforced polypropylene composite. The weight loss of bamboo fiber

Table 2. Variation of change in temperature and mass loss in case of bamboo fiber, polypropylene and MAPP coupled composite

Sample	Temperature at different weight loss (°C)				
	T_{10}	T_{20}	T_{30}	T_{40}	T_{50}
Bamboo fiber	276.44	308.58	326.75	348.79	392.88
Polypropylene	451.27	459.18	461.20	469.27	475.33
MAPP coupled composite	286.53	320.69	344.75	441.17	571.51

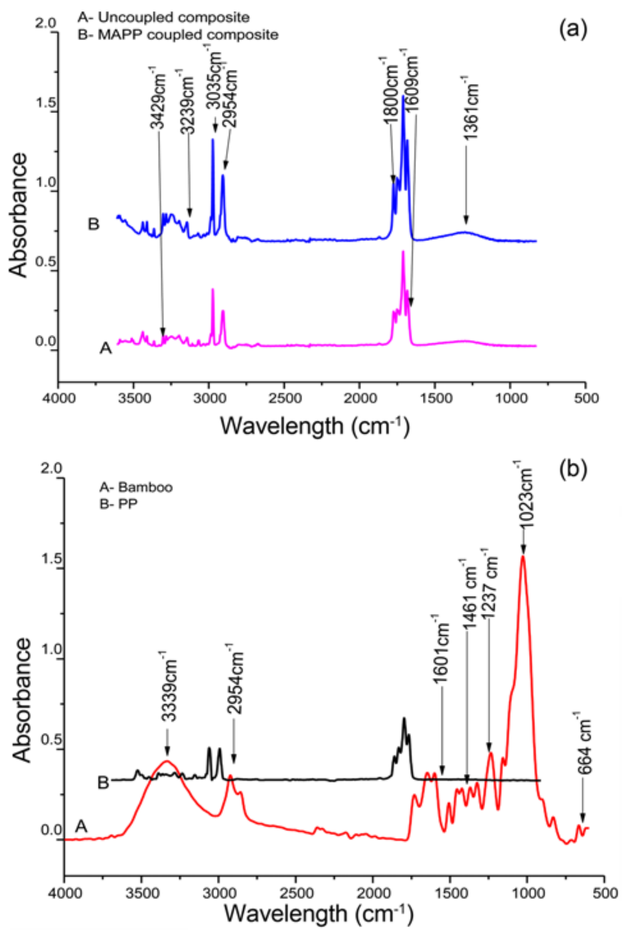

Figure 8. FTIR spectra of (a) uncoupled and MAPP coupled composite and (b) bamboo and PP.

occurs in the range of 240 °C to 320 °C, 320 °C to 350 °C and 350 °C to 430 °C are mainly due to the decomposition of hemicellulose, cellulose and lignin respectively. The most difficult component of the bamboo to decompose is lignin. When 5 % of MAPP is coupled for bamboo/PP composite, MAPP dissolves some of the lignin in fiber which makes it thermally stable.

From the Table 2, it is clear that the temperature required for different weight losses is more in case of coupled composite when compared with the bamboo fiber. This confirms that the coupled composite is thermally stable when compared to bamboo fiber alone. Good thermal stability of bamboo fiber/PP/MAPP composite have potential for engineering application [1].

Figure 8(a) shows the FTIR spectra of uncoupled and MAPP coupled composite. Figure 8(b) represents the FTIR spectra of bamboo and PP. FTIR spectra confirmed the typical functional group of bamboo fibre and PP. The spectra of reaction product of PP, MAPP and the bamboo fibre provided evidence of chemical coupling between bamboo and PP.

It is clear from Figure 8(a) that the intensity of -OH stretching in case of uncoupled composite is at 3429 cm^{-1} and whereas in case of coupled composite it decreased and shifted to 3239 cm^{-1}. The intensity of C-O stretching in case of uncoupled composite is at 1609 cm^{-1}. Whereas in case of coupled composite it increased and shifted to 1800 cm^{-1}. This confirms the esterification reaction between hydroxyl groups of bamboo fiber and the anhydride group of MAPP. This formation of ester bonds on the surfaces increases the interfacial adhesion among the surfaces. The peaks at 2954 cm^{-1}, 3035 cm^{-1}, and 1361 cm^{-1} were attributed to asymmetric, symmetric and scissor modes of -CH stretching respectively [12].

It can be observed from Figure 8(b) that the FTIR spectrum of bamboo fiber showed the presence of bands at 1601 cm^{-1} and 1461 cm^{-1} for C=C aromatic ring [12]. IR peak at around 3339 cm^{-1} is attributed to OH stretching of alcoholic group or it may be due to OH stretching of moisture content. Peak at 2954 cm^{-1} is due to C-H stretching. Two small peaks at 1461 cm^{-1} and 1237 cm^{-1} indicate the presence of C=O group. Peaks from (600-1000) cm^{-1} is due to carbon impurities. It is clear from the FTIR spectra that, the interfacial adhesion between bamboo fibre and PP can be improved by using MAPP as coupling agent [30].

Figure 9(a) and 9(b) shows the variation of moisture absorption with time for both coupled and uncoupled composites respectively. It is clear from the figure that, the moisture absorption in case of coupled composite is less than that of uncoupled composite. Moisture absorption in case of coupled composite is around 4 %, whereas, in case of uncoupled it is found to be around 8.5 %. It is observed that the moisture absorption in case of uncoupled composite is almost twice that of coupled composite. The reason for such an increase in the moisture absorption of uncoupled composite may be attributed to the fact that bamboo fibre consists of cellulose which absorbs water. Initially, water saturates the cell wall of the fibre and further occupies the void spaces. Therefore higher filler content may generate more possibility for water to diffuse into the composite. The presence of MAPP reduces cellular exposure to water as a result of better wetting of filler by matrix [31].

Less moisture absorption in coupled composite is more beneficial in many applications. It is also observed that in both coupled and uncoupled composites with the increase in

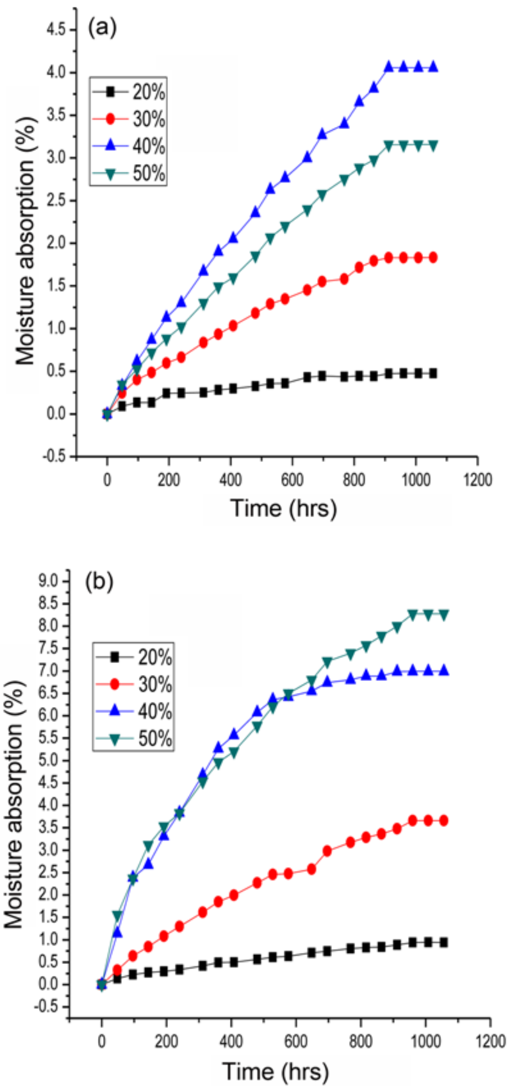

Figure 9. Variation of moisture absorption with time for the coupled composites (a) and uncoupled composite (b).

fibre content, the moisture absorption increases. For coupled composite, the moisture absorption in 20 % fibre content is found to be 0.5 % and that for 50 % fibre content is found to be 4 %. Effective wetting and encapsulation of bamboo fibre prevents fibre from forming a continuous network and does not allow penetration of water into the fibre. Even in uncoupled, water uptake is restricted even though there is no strong wetting or interfacial adhesion between fibre-matrix interfaces. This is due to the fact that fibre is surrounded by hydrophobic PP but the use of coupling agent will further restrict the water absorption of bamboo- PP composites [32].

Study on the moisture absorption is very essential to use the resulting composite material for outdoor applications. Moisture uptake effects the mechanical properties of the composite. Moisture absorption of the composites results in the swelling of natural fiber which is due to the filling up of the gaps between fiber and the matrix and thus leads to the failure of the composite. Both tensile and flexural modulus and strength decreases after moisture absorption in the composite. This less moisture absorption of the coupled composite makes it to be used potentially in the outdoor application such as in constructions and buildings where there is a continuous exposure to water. Reduced moisture uptake of the coupled composite prevents swelling of the composite material. This helps to retain the quality of a material in spite of its continuous exposure to moisture for a longer period [33].

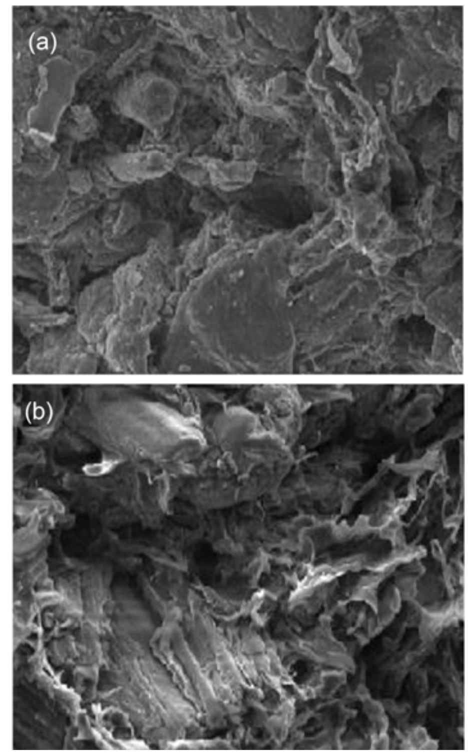

Figure 10. SEM images of coupled (a) and uncoupled composite (b) with SEM magnification 1.5kx.

Figure 10(a) and 10(b) shows the SEM images of coupled and uncoupled composites respectively with SEM magnification of 1.5kx. Figure 11(a) and 11(b) shows the SEM images of coupled and uncoupled composites respectively with SEM magnification of 1.00kx. In case of uncoupled composite, the recovery of fibre in the matrix is low, indicating a weak bonding. The fibre/matrix affinity is low, and the primary mechanism of rupture is fibre pull-out. However, the SEM images of the coupled composite showed a good fibre-matrix adhesion. Once again, these observations provide the evidence for the results obtained from the mechanical test. In the absence of MAPP, there are many detached fibres and voids. Interestingly in the presence of MAPP, the fibres are strongly bonded to PP matrix due to which there is a significant increase in the mechanical

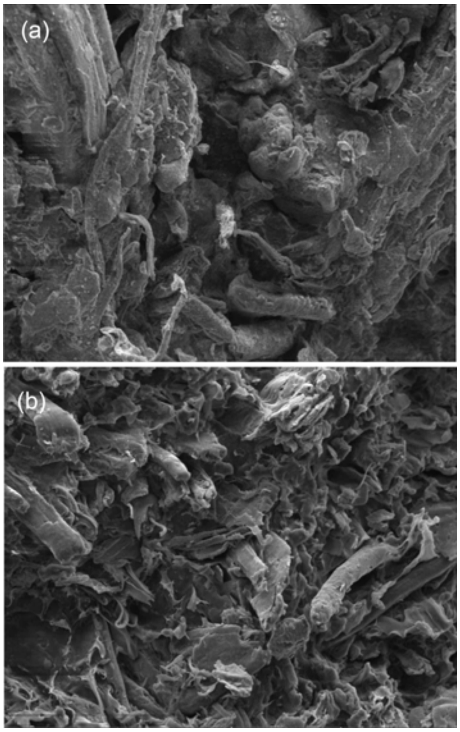

Figure 11. SEM images of (a) coupled and (b) uncoupled composite with SEM magnification 1.00kx.

performance of the coupled composite when compared with uncoupled composite. This is attributed to good dispersion and the adhesion between bamboo fibre and PP in the presence of coupling agent MAPP [34].

The composites without MAPP showed surfaces with deeper fractures, while the composites with MAPP showed shallower fractures. MAPP coupled composite shows less erosion when compared to uncoupled composite. This is attributed to better contact and encapsulation of PP with bamboo fiber. The fractures present on the surface of the composite are the very minute or microscopic changes confirms the loss of tensile properties in case of uncoupled composite [35].

Conclusion

Composite without the use of coupling agent (MAPP) showed a lower strength, lower stiffness and higher water absorption than the coupled ones. MAPP coupled bamboo fibre filled polypropylene composite exhibits superior tensile and flexural strength than uncoupled composite which is attributed to the proper interfacial adhesion between the filler and the matrix. The notched sample shows slight increase in the impact strength of the coupled composite due to the fibre pull out effect. Thermal stability of Bamboo-PP composite coupled with MAPP improved when compared to bamboo alone which indicates better adhesion between MAPP coupled bamboo-PP composite. Coupled composites show less moisture absorption than uncoupled samples so that it can be used in many applications where moisture absorption is expected to be minimum. SEM micrographs confirmed the good interfacial adhesion and chemical bonding of wood fibre with PP matrix in the presence of coupling agent. FTIR spectrum revealed that MAPP acts as an effective coupling agent for bamboo with PP. It is envisaged that bamboo could be used as an eco-friendly reinforcement to develop new age composite materials with PP. With a view of minimising environmental pollution rather than imparting bamboo as a strong reinforcing effect, the bamboo-PP composite had reasonably better properties.

Acknowledgement

Dr N V Raju and Madhavi S would like to thank the management and Principal of Global Academy of technology for constant encouragement and support. Authors would also like to thank Director, IWST, Malleshwaram, 18th cross, Bangalore for the lab facility provided for carrying out the preparation of composite and their mechanical characterization and BMS college of Engineering, Bangalore for SEM and Nano and soft matter sciences, Bangalore for TGA.

References

1. K. Zhang, F. Wang, W. Liang, Z. Wang, Z. Duan, and B. Yang, *Polymers,* **10**, 608 (2018).
2. S. V. Joshi, L. T. Drzal, A. K. Mohanty, and S. Arora, *Compos. Part A Appl. Sci. Manuf.*, **35**, 371 (2004).
3. H. S. Kim, B. H. Lee, S. W. Choi, S. Kim, and H. J. Kim, *Compos. Part A Appl. Sci. Manuf.*, **38**, 1473 (2007).
4. L. Techawinyutham, A. Frick, and S. Siengchin, *Adv. Mech. Eng.*, doi: 10.1177/1687814016645446 (2016).
5. K. L. Pickering, A. M. G. Efendy, and T. M. Le, *Compos. Part A Appl. Sci. Manuf.,* **83**, 98 (2015).
6. I. D. Ibrahim, T. Jamiru, E. S. Rotimi, W. K. Kupolati, A. C. Stephen, and G. Ekundayo, *J. Reinf. Plast. Compos.,* **34**, 1347 (2015).
7. M. Yongli, C. Xiaoya, and G. Qipeng, *J. Appl. Polym. Sci.,* **64**, 1267 (1998).
8. T. G. Y. Gowda, M. R. Sanjay, K. S. Bhat, P. Madhu, P. S. Kannan, and B. Yogesha, *Cogent Eng.*, doi: 10.1080/23311916.2018.1446667 (2018).
9. H. H. Chiu and W. B. Young, *Fiber. Polym.,* **21**, 2938 (2020).
10. S. L. K. Harry, W. Hao, N. Pattarachaiyakoop, and T. Mohan, *Compos. Part B-Eng.,* **42**, 856 (2011).
11. C. Xiaoya, G. Qipeng, and M. Yongli, *J. Appl. Polym. Sci.*, **69**, 1891 (1998).
12. X. Zhou, Y. Yu, Q. Lin, and L. Chen, *Bio Res.*, **8**, 6263 (2013).

13. P. K. Aggarwal, S. Chauhan, N. Raghu, S. Karmarkar, and G. M. Shashidhar, *J. Reinf. Plast. Compos.,* **32**, 1722 (2013).
14. S. Surisetty and C. A. Reddy, *Int. J. Eng. Res.,* **3**, 187 (2014).
15. B. P. Rocky and A. J. Thompson, *Fiber. Polym.,* **21**, 2740 (2020).
16. E. Bari, A. Sistani, H. R. Taghiyari, J. J. Morell, and J. Cappellazzi, *Maderas Cienc Tecnol.,* **19**, 455 (2017).
17. ASTM D 638-94b, "Standard Test Method for Tensile Properties of Plastics", ASTM International, West Conshohocken, PA, USA, 1995.
18. ASTM D 790-92, "Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials", ASTM International, West Conshohocken, PA, USA, 1995.
19. ASTM D 256-93, "Standard Test Method for Impact Resistance of Plastics and Electrical Insulating Materials", ASTM International, West Conshohocken, PA, USA, 1995.
20. S. M. Yadav and K. B. Yusoh, "Mechanical and Physical Properties of Wood-plastic Composite Made of Polypropylene, Wood Flour and Nano Clay", Proceeding Kuala Lumpur International Agriculture, Forestry and Plantation September 12-13, Hotel Putra, Kuala Lumpur, Malaysia, 2015.
21. K. Rassiah and M. M. M. H. Ahmad, *Aust. J. Basic Appl. Sci.,* **7**, 247 (2013).
22. C. Navin and F. Mohammed, "Tribology of Natural Fiber Polymer Composites", A Volume in Woodhead Publication Series in Composites Science and Engineering, pp.162-179, 2008.
23. B. P. Panda, S. Mohanty, and S. K. Nayak, *Chin. J. Eng.*, **2013**, 245718 (2013).
24. M. Tanoglu and A. T. Seyhan, *Int. J. Adhes. Adhes.,* **23**, 1 (2008).
25. K. Okubo, F. Toru, and Y. Yuzo, *Compos. Part A Appl. Sci. Manuf.*, **35**, 377 (2004).
26. L. Haibo, W. Zhiqiang, D. Qianqian, S. Yuting, Z. Wuyi, L. Ying, Z. Chaoqun, and D. Xianming, *Polym. Eng. Sci.,* **59**, E247 (2018).
27. N. Graupner, N. Kuhn, and J. Mussig, *Polym. Test.*, **93**, 106864 (2021).
28. D. T. Tran, M. D. Nguyen, N. C. H. Thuc, and T. T. Dang, *Compos. Interfaces*, **20**, 343 (2013).
29. A. U. Md Shah, T. H. Mohammed Sultan, M. Jawaid, F. Cardona, and A. R. A. Talib, *Bio Res.*, **11**, 10654 (2016).
30. N. Raghu, A. Kale, S. Chauhan, and P. K. Aggarwal, *J. Indian Acad Wood Sci.,* **15**, 96 (2018).
31. A. F. Osman and N. S. R. Akma, *J. Eng. Educ.,* **5**, 41 (2008).
32. P. K. Aggarwal, N. Raghu, A. Karmarkar, and S. Chuahan, *Mater. Des.,* **43**, 112 (2013).
33. E. Munoz and J. A. Garia-Manrique, *Int. J. Polym. Sci.,* **2015**, 390275 (2015).
34. I. Naghmouchi, F. X. Espinach, M. Pere, and B. Sami, *Mater. Des.,* **65**, 454 (2015).
35. L. P. Fajardo Cabrera de Lima, R. M. C. Santana, and C. D. C. Rodríguez, *Polymers*, **12**, 929 (2020).