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ORIGINAL ARTICLE

Characterization of banana fiber-reinforced polypropylene composites

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Abstract The present work deals with effect of coupling agent on banana fiber-reinforced polypropylene (PP) composites. Banana fiber-reinforced polypropylene composites were prepared using twin screw extruder with coupling agent and also without coupling agent. The mechanical properties of coupled composites like tensile, flexural and impact strength revealed significant enhancement compared to the uncoupled composites. The failure of uncoupled composites is mainly because of minimum stress development at the interface of composites due to the distribution of load transfer along the fiber. Thermal stability of the banana fiber, polypropylene and banana fiber-reinforced with PP composites was investigated using thermo-gravimetric analysis and found that degradation temperature of the fiber increased in coupled composites. Fourier transform infrared spectroscopy analysis of samples with and without coupling agent was performed to examine respective functional group present in the composites. The encapsulation of filler material by polymer matrix may be the probable reason for coupled composites to absorb moisture content as revealed from moisture studies. Morphological studies of tested samples were made using scanning electron microscope which indicates improved adhesion between banana fiber and polypropylene.

Keywords Banana fiber · Polypropylene (PP) · MAPP · Mechanical properties · TGA · FTIR · Moisture absorption · SEM

Introduction

Natural fibers are gaining importance because of increased environmental issues and its consciousness. This leads to gather attention from researchers and academicians to prepare a material which is biodegradable, eco-friendly and other important properties compared to synthetic fibers (Mohammad et al. 2015). Instead of synthetic materials like iron and steel, there are various materials that have been invented to be used in automotive, construction, etc., with the example like plastic. Presently, due to some uncertain circumstances in the availability, cost of petroleum and its byproducts are strenuous to accomplish the needs of the society. In recent years, the vegetable/plant fiber has proved itself as an alternative fiber to its counterpart. The natural fibers are cost effective, renewable, biodegradable and have no health hazards. In addition to these, natural-reinforced fibers are seen to have good potential compared to synthetic fibers (Venkateshwaran and Elayaperumal et al. 2010). Interest is warranted due to advantages of natural fiber composites being low cost and environmental-friendly. In addition to this, natural fiber composites (NFC) have low density, low machine wear and environmental-friendly (Pickering et al. 2015).

Natural fibers are sourced from plants or animals. The fibers obtained from plants are classified into bast fibers (jute, flax and ramie), seed fibers (cotton, coir), leaf fibers (sisal, pineapple and abaca), core fibers (hemp, kenaf and jute) grass and reed fibers. In tropical countries, fibrous plants are available in abundance and some of them like

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banana are agricultural crops (Srinivasan et al. 2014). Banana is a ligno-cellulosic bast fiber obtained from the pseudo-stem of the banana plant (Musa Sapientum) suitable for relatively good mechanical properties. Out of 300 species available, around 20 species are used for consumption. It is also reported that from the 130 banana cultivated countries, India is the largest producer of banana with 27% of world production. Karnataka is one of the major banana cultivated state in India. Banana is also cultivated in the various states including Maharashtra, Tamil Nadu, Andhra Pradesh, Kerala, Assam and Gujarat. Banana fibers are the waste product of its cultivation; hence, without any investment, the source can be obtained for industrial purpose. There has been lot of research on natural fibers for many applications for the reason that they are having appropriate stiffness, high disposability and renewability. Furthermore, they are recyclable and biodegradable. Plant fibers are hydrophilic in nature with moisture content of about 8–13% with the presence of cellulose in cell structure. In addition to cellulose, plant fibers consist of different natural substances such as lignin, hemicellulose, pectin and waxy substances. The plant fibers lignin content influences its structure, properties and morphology (Subramanya et al. 2016).

To fabricate natural synthetic polymers composites, one of the best potential routes is the reinforcing fibrous natural fiber with the thermoplastic polymer. A thermoplastic material consists of one or two molecular dimensions and it has the tendency to make softer at high temperature and roll back their properties after cooling (Ticoalu et al. 2016). The widely used thermoplastics for bio-fibers are polyethylene, polypropylene (PP) and polyvinyl chloride (PVC), whereas phenolic, epoxy resins and polyester are commonly used thermoset polymers. PP(C_3H_6)n is a class of thermoplastic engineering polymer, and it possesses several imperative and useful properties such as transparency, flexibility, dimensional stability, flame resistance, high heat distortion temperature, high impact strength suitable for filling, reinforcing and blending (Faruk 2012).

The properties of jute polymer composites are studied and reported that addition of polymer leads to improvement in properties suitable for automotive industries throughout eco-design components (Al-oqla and Sapuan 2014). Incorporation of natural fiber with polymer would be helpful to increase tensile, flexural and impact parameters for the average strength applications. In recent years, extensive research has been carried in the field of various natural fiber composites and proved that natural fibers are excellent substitute for the potentially toxic synthetic materials (Zaman et al. 2013). Mechanical properties of pseudo-stem banana-reinforced epoxy composites are investigated and found that banana fiber composites exhibit ductile appearance with less plastic deformation (Maleque et al. 2007). Chemically treated and untreated banana nanofibers are examined and found that treated composites showed enhanced thermal properties suitable for making bio-renewable composites (Deepa et al. 2010). From the study of mechanical properties of banana-hemp-glass fiber-reinforced hybrid epoxy composites, it was revealed that these composites can be used as an alternative for synthetic fiber-reinforced composites (Bhoopathia et al. 2014). Composites prepared using polyvinyl alcohol with banana trunk fibers exhibited improvement in physical characteristics and reduction in the degree of swelling compared to unblended films (Sathasivam et al. 2010). Use of malic anhydride grafted polypropylene (MAPP) as coupling agent in the preparation of banana-glass fiber-reinforced polypropylene composites is cost effective and have enhanced the storage modulus, crystallization, thermal degradation temperature (Samal et al. 2009). There has been focus on the areas including environmental safety to mitigate the global scale pollution. The trend is to use locally available renewable resources that lead to value addition for the development of new innovative materials.

Experimental

Materials

In this study, banana fibers collected from Bangalore region are used for preparation of natural fiber composites (NFC). The polypropylene (H110MA) (melt flow index 11 g/10 min at 230 °C under 2.16 kg load) and malic anhydride polypropylene as received from local dealer in Bangalore are used as matrix and coupling agent, respectively.

Preparation of composites

The composites comprise both filler and matrix material. In the present work, banana fibers are filler and polypropylene are used as a matrix. Initially, residual form of banana fibers is pulverized with the help of liquid nitrogen to convert banana fibers into powder form. These are oven-dried for 48 h to remove moisture content. In this study, two sets of composites were prepared, one without coupling agent and another with coupling agent. Composites were prepared using different concentrations of banana fiber (20, 30, 40, and 50%) with polypropylene using malic anhydride grafted polypropylene (MAPP) as a coupling agent to enhance properties of composites. Coupling mechanism of PP with ligno-cellulosic fiber is as shown in Fig. 1 (Aggarwal et al. 2013). The mixture of desired amount of fiber content, polypropylene and 4% of MAPP is poured into twin screw extruder to produce a thin wire

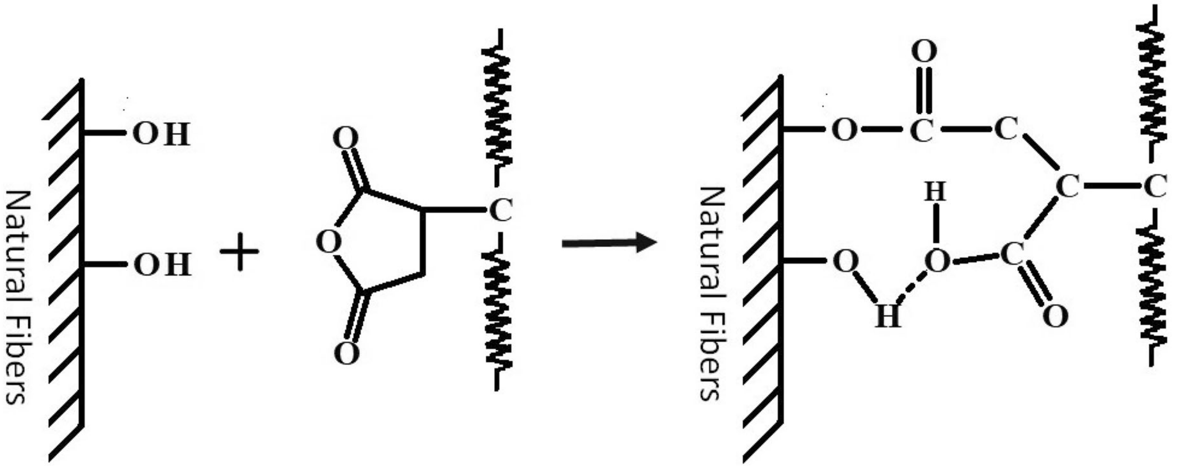

Fig. 1 Coupling mechanism of ligno-cellulosic fiber with polypropylene

shaped structure and later converted into a pellet form using chipper. The obtained pellet is oven-dried for 24 h to remove moisture content in composites. Later, the pellets were poured into injection molding apparatus to obtain composites according to American Standards for Testing Materials (ASTM). Different mechanical properties like tensile strength, tensile modulus, flexural strength, flexural modulus and impact strength for both notched and un-notched composites were determined using universal testing machine and impact apparatus. The values of both coupled and uncoupled composites were analyzed and compared to understand the effect of coupling agent added.

Mechanical testing

Tensile strength and modulus

Composites were prepared according to ASTM D638-94b standards (dimension 165 mm × 13.2 mm × 3.2 mm). The tensile strength and tensile modulus were measured using the universal testing machine (UTM). The experimental procedure involves that placing the composites on the sample holder in UTM and applying the stress on it until the sample get fractured. The average values of tensile modulus, elongation and strain were calculated from five different samples.

Flexural strength and modulus

To measure the flexural strength and modulus, samples were prepared according to ASTM D790 standards with dimension 127 mm × 13.2 mm × 6.4 mm. The test has been carried out for five different samples by placing samples in UTM. The process involves that placing sample in UTM and applying the force till it breaks, so that bending strength of composites is measured. The same procedure is followed for all other samples, and average values are tabulated.

Impact strength for notched and un-notched samples

For impact strength, specimens are prepared according to ASTM A256 standards. Experimental procedure involves placing the sample in the testing machine and allowing the pendulum to oscillate to get fractured. For notched and un-notched impact strengths, 1 J and 5.4 J hammers were used, respectively. This test was performed to determine energy needed to break the material and also to measure toughness of composites.

Thermal analysis

Thermo-gravimetric analysis of PP, banana fiber and banana fiber-reinforced with PP composites were carried out using thermal analyzer at Center for Nano and Soft Matter Sciences (CeNS), Bangalore. Ten grams of PP, fiber and WPC samples were scanned from 25 to 700 °C in a nitrogen atmosphere in which mass loss was measured as a function of temperature.

FTIR

Fourier transform infrared spectroscopy was performed to characterize both coupled and uncoupled composites using a Bruker make Tensor 27 model FT-IR spectrometer having 64 scans at a resolution of 4 cm^{-1}. Using FTIR spectroscopy, the functional groups present in composites were analyzed.

Scanning electron microscopy

The composite surface of tensile specimen was sputtered with gold and analyzed using environmental scanning electron microscope at an accelerating voltage of 10 kV at a working distance of approximately 14 mm. The surface of the specimen was gold coated to avoid electrical charging at the time of scanning.

Moisture absorption test

The impact of water absorption on the bio-composite materials was investigated for both coupled and uncoupled composites. The moisture absorption was calculated using the equation.

$$\Delta M(t) = \frac{m_t - m_0}{m_0} \times 100$$

where $\Delta M(t)$ is the moisture uptake at time t, m_t and m_0 are the mass of the wet weight and dry weight at time t, respectively.

Results and discussion

Tensile strength and modulus

The coupled and uncoupled banana fiber-reinforced with polypropylene and MAPP composites were prepared and tested using UTM. Tensile strength and tensile modulus with different values of fiber content are as shown in Figs. 2 and 3, respectively. The results revealed that in uncoupled composites the tensile strength decreased linearly with increase in filler content for 50%. The significant decrease in uncoupled composites is due to differences in surface morphology of fiber and matrix. It has been noticed that at 50% of banana fiber content and 50% PP with MAPP shows better performance than other concentrations of samples. This enhancement is due to the presence of compatibilizer like MAPP as a matrix which leads to improve the bonding internally.

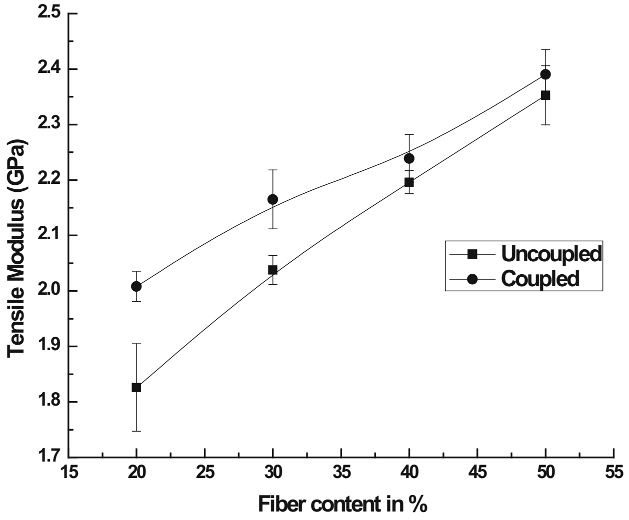

Fig. 3 Tensile modulus

Flexural strength and modulus

Flexural testing for coupled and uncoupled composites is analyzed using UTM apparatus. The variation of flexural strength and modulus with filler loading areas is shown in Figs. 4 and 5. The variation in flexural strength of composites with and without coupling agent is due to interfacial adhesion between banana fiber and polypropylene. It is a critical aspect in which effective load transfer from PP to

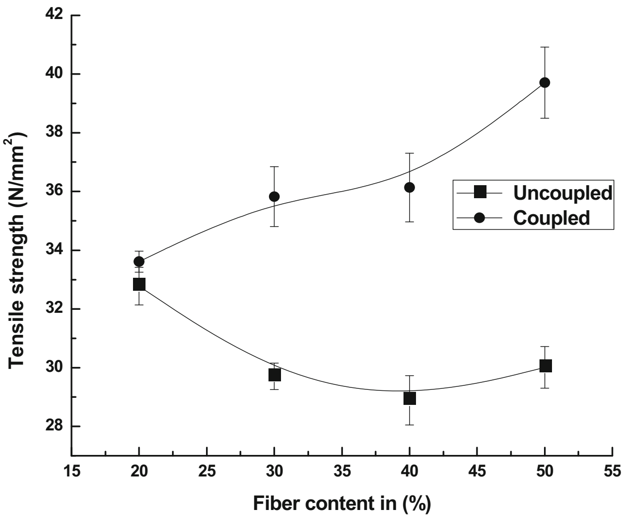

Fig. 2 Tensile strength

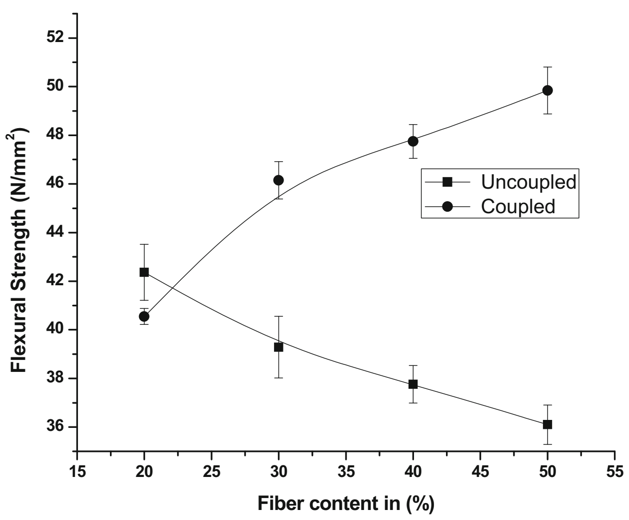

Fig. 4 Flexural strength

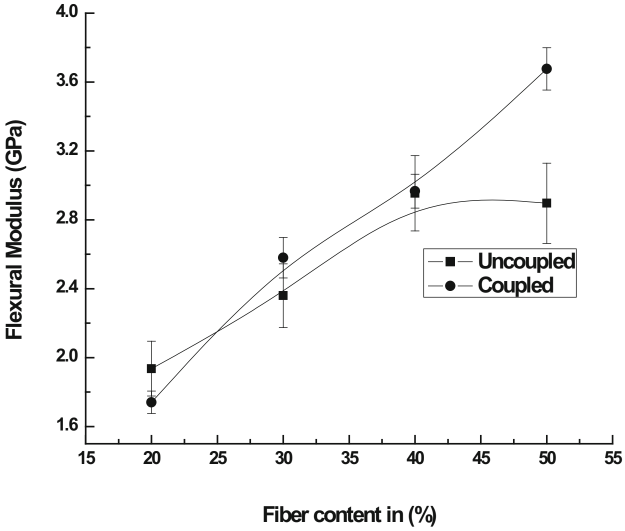

Fig. 5 Flexural modulus

fiber through this it affects the flexural strength. It was observed that improvement in properties is attributed to morphology of composites during the preparation. From the graph, it is clear that for 50% of polypropylene with MAPP composites perform better than other combination of composites.

Impact strength

The impact strength of both notched and un-notched samples is measured using impact testing machine. From Figs. 6 and 7, it is observed that the composites having higher filler content exhibited low impact strength. Natural fibers are rigid in nature and offers sites for crack initiation. As the fiber content is increased, there is an increase in crack formation leading to a decrease in impact strength. Another factor for decrease in impact strength may be hardening of polymer chains because of bonding between fiber and PP. Impact strength of un-notched composites could be maintained up to some extent by the process of fracture initiation. In notched composites, impact nature is controlled to larger extent by factors influencing the propagation of fracture, caused due to stress variation at the notched end. It was observed that the impact strength in coupled composites exhibited better performance than the uncoupled one.

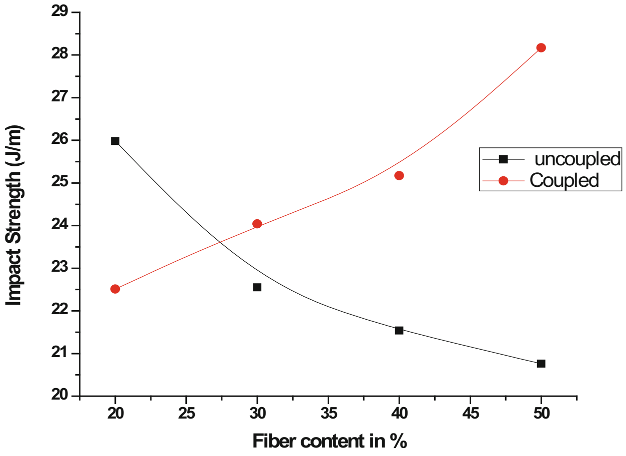

Fig. 6 Notched impact strength

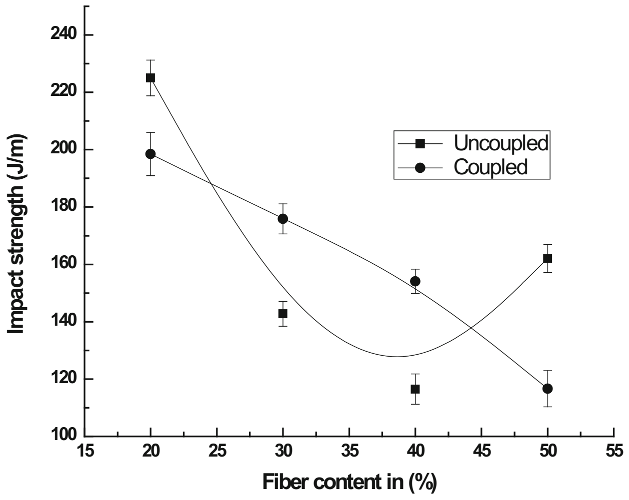

Fig. 7 Un-notched impact strength

Thermal analysis of wood polymer composites (WPC)

Figure 8 shows the thermal degradation behavior of PP, banana fiber and banana fiber-reinforced PP composites with MAPP as a coupling agent at 50% fiber loading,

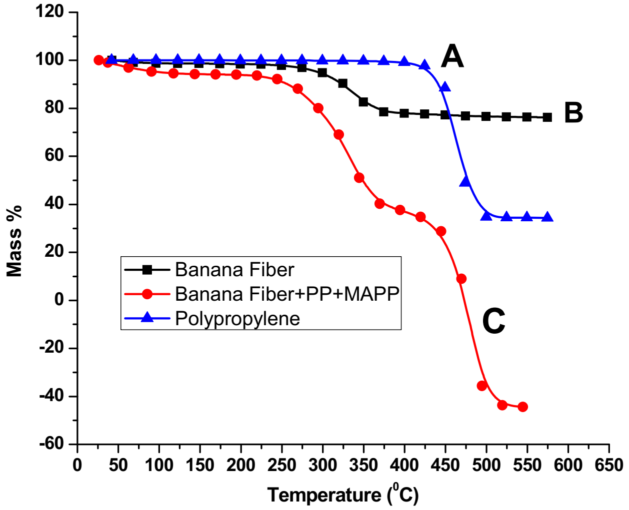

Fig. 8 Thermo-gravimetric analysis of **a** polypropylene (PP), **b** banana fiber, **c** banana fiber + PP + MAPP

respectively. The materials were analyzed under nitrogen atmosphere with the temperature from 50 to 700 °C. Thermal degradation of PP occurred between the ranges 400–450 °C. In banana, fiber mass loss is mainly due to decomposition of its components like cellulose, lignin and hemicellulose. The ligno-cellulosic fibers are chemically good and decay thermo chemically between 180 and 400 °C. The maximum degradation temperature of the materials is attributed to the presence of organics such as phenolic and esters in banana fibers. Thermo-gravimetric curve of banana-reinforced PP composites with MAPP shows two mass loss steps. The initial mass loss of WPC occurs slowly below 400 °C and increases suddenly after this temperature and continues till around 540 °C. However, blending of banana fiber and PP with MAPP as a coupling agent leads to improve thermal stability of the composites.

Fourier Transform Infrared Spectroscopy (FTIR)

FTIR spectroscopy of banana fiber, PP, and both coupled and uncoupled composites is as shown in Fig. 9. Broad peak at around 3436 cm^{-1} is due to the presence of OH stretching alcoholic group. The presence of band at 2914 cm^{-1} is due to C–H stretching. In addition to this there are two small peaks around 1740–1618 cm^{-1} is attributed to the presence of C=O functional group. The bands from 800 to 1454 cm^{-1} indicate that the carbon impurities are present, leading to increase in the strength of composites.

Moisture absorption studies

To carryout moisture absorption studies, the coupled and uncoupled composites were immersed in distilled water for 48 h. These were taken out from water and dried. Using the digital balance of accuracy about 1E−4 weight of all the specimens were recorded with respect to time. From the standard equation $\Delta M(t) = \frac{m_t - m_0}{m_0} \times 100$, the moisture absorption values were calculated. The variation of moisture content and time for both coupled and uncoupled specimens is as shown in Figs. 10 and 11, respectively. These plots report moisture absorption as a function of exposure time for coupled and uncoupled composites. Composites prepared without coupling agent absorbed 0.45% at 20% and 4.95% at 50% loading, respectively. Coupled composites absorbed 0.4% at 20% and 3.25% at 50% loading. This study revealed that higher filler content absorbs more moisture in both coupled and uncoupled composites. Also from the graphs it was observed that moisture absorption content in coupled composites is less compared to uncoupled composites. This is due to encapsulation of the filler by matrix material, and furthermore, the degree of encapsulation is greater for filler loadings.

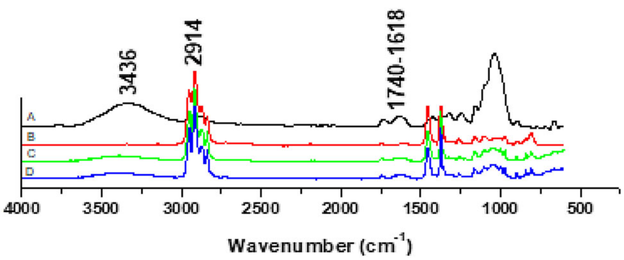

Fig. 9 FTIR spectra of **a** banana fiber, **b** PP, **c** banana fiber + PP, **d** banana fiber + PP + MAPP

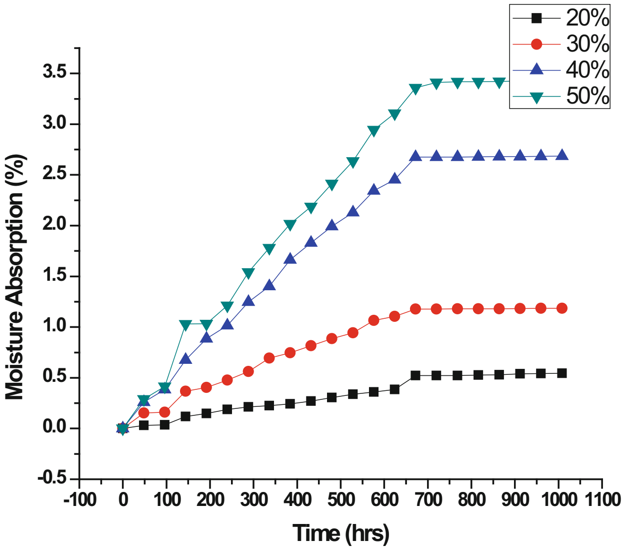

Fig. 10 Coupled composites

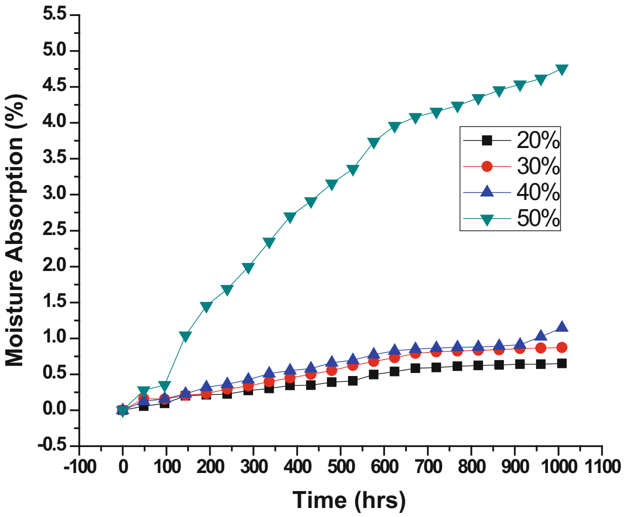

Fig. 11 Uncoupled composites

SEM

The scanning electron microscope images of uncoupled fracture surface of the composites are as shown in Fig. 12a, b. It is observed that in uncoupled composites, the adhesion is poor and when the stress is applied fibers are easily pulled out and holes are formed. Also in uncoupled composites, fibers and matrix de-bonding are evident because fiber is not well bonded with matrix. Uncoupled composites exhibited a rough morphology and non-uniform as observed from the presence of pores between fiber and PP. The SEM images of MAPP coupled fracture surface composites are shown in Fig. 13a, b. The coupling agent MAPP improves the reinforcement of banana fiber with polypropylene and also reduce the void size. It makes the surface better compared to uncoupled composites.

Conclusion

Increase in tensile strength, flexural strength, tensile and flexural modulus of coupled composites with different fiber is interpreted in graphs. The enhancement is attributed to sufficient adhesion between the fiber and matrix. The un-notched impact strength decreased steadily with increase in fiber content due to higher energy requirement for fiber to pull out at higher filler content. However, notched impact strength increased due to higher energy requirement for the fiber to pull out at higher filler content.

- The maximum tensile strength and tensile modulus are 39.70 (MPa) and 2.39 (GPa), respectively, for 50% banana-polypropylene composites.

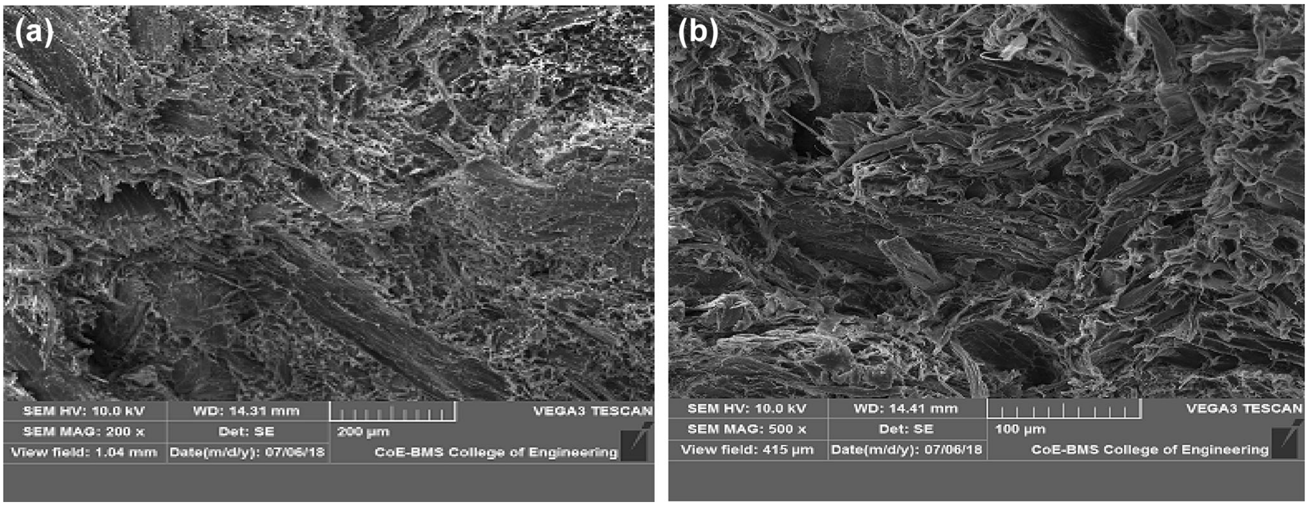

Fig. 12 **a**, **b** SEM of uncoupled composites

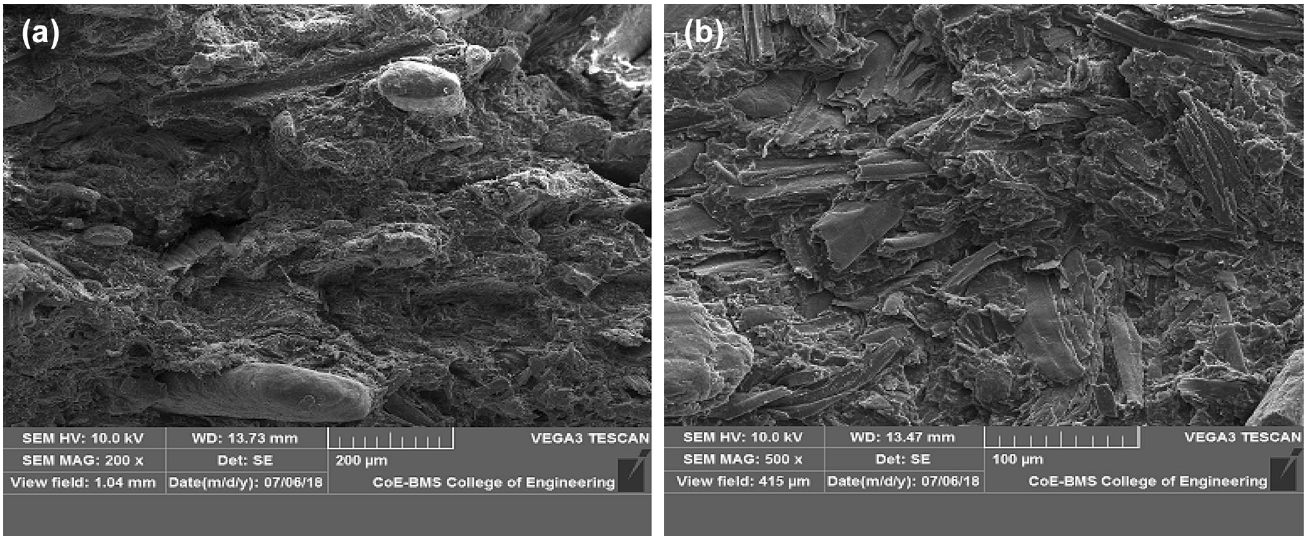

Fig. 13 **a**, **b** SEM of coupled composites

- The maximum flexural strength and flexural modulus are 49.8455 (MPa) and 3.670,539 (GPa), respectively, for 50% banana-polypropylene composites.
- The maximum impact strength observed in notched composites is 32.15 (J/m) for 50% banana-polypropylene composites.
- From the experimental study, it can be suggested that, the 50% banana fiber and 50% polypropylene composite materials can withstand the higher loads when compared to the other combinations and can be used as an alternate materials for conventional fiber-reinforced polymer composites.
- Thermo-gravimetric analysis (TGA) revealed the degradation temperature of PP, fiber and wood polymer composites which helps to analyze the temperature behavior of materials.
- Moisture absorption studies suggested that the coupled composites having low moisture absorption content compared to uncoupled composites.
- Morphology of the coupled composites clearly indicated that due to the presence of coupling agent the mechanical properties like tensile, flexural and impact strength have increased.

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