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Regenerated Cellulose Fibers as Impact Modifier in Long Jute Fiber Reinforced Polypropylene Composites: Effect on Mechanical Properties, Morphology, and Fiber Breakage

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ABSTRACT: Polypropylene/jute fiber (PP-J) composites with various concentrations of viscose fibers (VF) as impact modifiers and maleated polypropylene (MAPP) as a compatibilizer have been studied. The composite materials were manufactured using direct long fiber thermoplastic (D-LFT) extrusion and compression molding. The effect of fiber length, after the extrusion process, on composites mechanical performance and toughness was investigated. The results showed that the incorporation of soft and tough VF on the PP-J improved the energy absorption of the composites. The higher impact strength was found with the addition of 10 wt % of the impact modifier, but the increased concentration of the impact modifier affected the tensile and flexural properties negatively. Similarly, HDT values were reduced with addition of viscose fibers whereas the addition of 2 wt % of maleated polypropylene significantly improved the overall composite properties. The microscopic analysis clearly demonstrated longer fiber pullouts on the optimized impact modified composite. © 2014 Wiley Periodicals, Inc. J. Appl. Polym. Sci. **2015**, *132*, 41301.

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INTRODUCTION

The primary research on direct long fiber thermoplastic (D-LFT) composites using hybrid fibers is to achieve better mechanical performance of the thermoplastic composites together with improved energy absorption. The incorporation of fibers in the form of continuous rovings using twin screw extruder will have a trend to retain higher fiber length and volume fraction.[1] Long fiber-reinforced thermoplastics (LFT) have excellent mechanical properties and stiffness-to-weight ratio, which is of great interest to the automotive industry.[2]

The weakness of natural fiber reinforced thermoplastic composites is poor resistance to impact strength due to the lack of plastic deformation mechanism. As the PP has low impact strength at low temperatures and the addition of fibers causes the reduction of matrix deformation, which leads to further lowering of fracture toughness.[3] An intrinsic cause of low fracture toughness of the composites is inherent brittleness of the fibers. Therefore, improving the toughness with better interfacial adhesion would lead to better performance of the composites. Various potential toughening approaches have been attempted to solve this problem for natural fiber reinforced thermoplastic composites. One efficient way of improving the impact energy-absorbing ability of composite materials is to add tough materials to the host composites, such as high strain-to-failure fibers.[4] Adekunle et al.[5] successfully used Lyocell fibers (regenerated cellulose fibers) as an impact modifier in jute fiber reinforced thermoset composite, and reported that the Lyocell fibers increases the impact resistance of the composites with longer pullout lengths. Graupner et al.[6] reported, that the thermoplastic composites prepared with a mixture of bast fibers such as hemp, kenaf, and cotton are suitable for various car components. The combination of hemp, kenaf with cotton

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Table I. Properties of Used Fibers

Materials	Tensile strength (MPa)	E-modulus (GPa)	Elongation at break (%)	Density (g/cm^3)	Fiber length (mm)	Fiber roving length (m)
Jute	517	118.6	0.6	1.45[a]	2–5[a]	1–2
Viscose[b]	340	12	11	1.3	38	Continuous

[a] Data from literature [21].
[b] Data from the manufacturer.

produced positive tensile characteristics of natural fibers with good impact properties of cotton.[6]

In fiber reinforced composites, fibers bridging the cracks in the matrix can provide resistance to crack propagation before these fibers break or are pulled out.[7] However, the extent of improvement toughness and energy absorption of the composites depends on factors such as: fiber content, aspect ratio, orientation, and interfacial adhesion between fiber and matrix.

The hypothesis of this study is that the combination of tough and strong fibers in the preparation of composites using direct long fiber thermoplastic (D-LFT) extrusion technique offers high fiber content, controlled aspect ratio and orientation. Thereby enhances energy absorption of the composites due to toughest fiber by providing longer fiber pullouts. Further the addition of maleated coupling agent increases the compatibility and improves the interfacial adhesion between the fibers and the matrix.

In this work, long and tough viscose fibers were used as an impact modifier in jute reinforced PP composites. The composites were manufactured through D-LFT process and the composites mechanical properties including impact strength and the energy absorption were investigated. In addition the microstructure and the extent of fiber breakage during the melt mixing process were studied using electron microscopy.

EXPERIMENTAL

Materials

Homopolymer polypropylene (PP) Propel 1350YG, extrusion grade, with MFI of 35 g/10 min (230°C, 2.16 kg) was purchased from Indian oil corporation Ltd., India used as matrix. A maleic anhydride grafted polypropylene, Epolene E-43, Sigma Aldrich, USA was used as a coupling agent. The jute fibers were procured from Chandra Prakash & Co. Pvt. Ltd., Jaipur, India. The fibers were used in the form of long fiber roving. The viscose fibers were supplied from Cheran Spinning Mills, Erode, India. They are derivative of wood pulp said to be regenerated cellulose processed by spinning method. The density of the fibers was 1.3 g/cm^3, and used in the form of continuous fibers.

Table I shows the properties of used fibers. Jute fibers are cheap raw material, having very good mechanical properties, the tensile strength, and moduli of the fibers were found to be 517 MPa and 118 GPa with a density of 1.4 g/cm^3 was used as reinforcement. They are available abundantly in India of various forms such as fiber roving, hessian cloth, yarn, etc. The present work has opted in the form of long fiber rovings having 1–2 m length with a fiber diameter ranging from 20 to 25 μm. The appearance of the fiber "rovings" is shown in Figure 1. The viscose fibers have tensile strength and modulus of 340 MPa and 12 GPa, respectively. They have good elongation at break of 12%, which act as impact modifier. Similar to jute fibers the viscose fibers were also used in the form of long roving and were twisted with the jute roving to make a mix of these fibers as shown in Figure 1.

Processing of Composite Material

Compounding. Prior to compounding, the jute fibers were washed and dried completely at 60°C for 48 hr until achieving a uniform weight at different intervals of time. Similarly, the viscose fibers were dried at 60°C for at least 2 hr. The composite materials were manufactured using direct long fiber thermoplastics (D-LFT) processing method, using a high performance co-rotating twin-screw extruder (ZE-25 model Berstorff Maschinenbau GmbH, D-3000 Hannover, Germany). The continuous

Figure 1. Handmade rovings of jute fibers, viscose fibers and a mix of jute, and viscose fibers. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

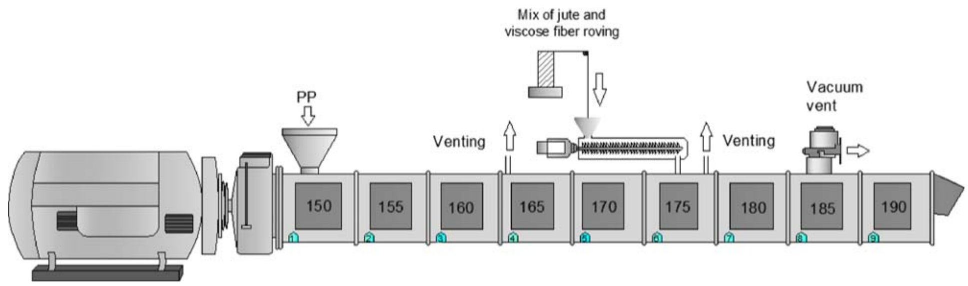

Figure 2. The schematic representation of the LFT extrusion process with processing parameters. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

roving was incorporated into a side feeder of the extruder, which feeds it direct into the polymer melt. The composites were prepared by varying the viscose fiber content ranging from 5 to 15 wt %, while the jute fiber content was kept constant at 30 wt %. The fiber weight fractions was controlled by the screw speed and it was calculated using targeted fiber content, the weight of the fiber roving per meter, the length per screw revolution and time. The compound was extruded in the form of profile and cut to the required lengths. The throughput was 5 kg/hr and the compositions of different materials and the processing setting along with the temperature profile are shown in Figure 2 and Table II. The compositions of the prepared using various concentration of impact modifier on PP-J materials is shown in Table III.

Compression Molding. Prior to compression molding, the cut profiles were dried at 60°C for 2 hr. Sheet size of 250 × 125 mm and 3 mm in thickness were prepared using a conventional compression molding press, Hindustan Hydraulics, India with a load capacity of 150 tons. The mold temperature was 170°C and the pressure was about 35 MPa. The samples for mechanical testing were cut from the sheets according to ASTM standards.

TESTING AND CHARACTERIZATION

Mechanical Testing

The tensile properties of the composites were performed according to ASTM D 638 using conventional tensile testing, Instron 3382, UK with a cross head speed of 3 mm/min. The tensile strength, tensile modulus, and elongation at break are calculated from the tensile test data. The flexural testing was performed according to ASTM D 790, with a support span of 16 times the sample thickness and strain rate of 5 mm/min using the same equipment. The flexural strength is determined using $F_s = (3P_{max} L)/(bh^2)$, where P_{max} is the maximum load at failure (N), L is the span (mm), b and h is the width and thickness of the specimen (mm), respectively. Flexural modulus was calculated from $F_m = (mL^3)/(4bh^3)$, where m is the initial slope of the load deflection curve. Impact testing was performed according to ASTM D 256 on notched Izod specimens using M/s. Tinius Olsen, Model IT 503, Germany. The impact was provided with built-in pendulum hammer. At least 10 specimens were tested for each set of samples and the mean values were reported. Toughness (energy absorption) of the composites was calculated from the tensile results. The tensile toughness is defined here as the area under the stress-strain curve up to the complete rupture of the sample.

Single Fiber Pullout Test

Single fiber pullout test was used to characterize the fiber-matrix interface. The bonding characteristics single fibers were investigated using pullout test. The samples were prepared by embedding a controlled length of the fiber in the PP matrix. The test was carried out using Instron 3382, Universal testing machine (UTM) tester, UK by pulling out the fiber from the resin block. The load and its extension were measured from the test in a force displacement. At least 25 samples were tested on each composition.

Table II. Material Formulations

Materials	PP (wt %)	Jute fiber (wt %)	Viscose fiber (wt %)	MAPP (wt %)
PP	100	0	0	0
PP-J	70	30	0	0
PP-J-M	68	30	0	2
PP-V	70	0	30	0
PP-V-M	68	0	30	2
PP-J-V5	65	30	5	0
PP-J-V10	60	30	10	0
PP-J-V15	55	30	15	0
PP-J-V10-M	58	30	10	2

Table III. Processing Parameters for the Materials Preparation Using a Twin Screw Extruder

Parameters	Settings
Screw speed (rpm)	100
Screw diameter (mm)	25
Screw L/D ratio	48 : 1
Temperature profile	(°C)
Zone 1	150
Zone 2	155
Zone 3	160
Zone 4	165
Zone 5	170
Zone 6	175
Zone 7	180
Zone 8	185
Zone 9	190

Table IV. Mechanical Properties of PP Composites Containing 30 wt % Jute Fibers Modified with Viscose Fibers and MAPP

Composition	Flexural strength (MPa)	Flexural modulus (MPa)	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation to break (%)	Impact strength (J/m)
PP	33.2 (0.8)	867 (22)	27.6 (0.8)	634 (49)	–	28.0 (0.8)
PP-J	47.1(7.1)	5269 (482)	29.1 (1.1)	2700 (103)	3.3 (1.0)	24.4 (3.1)
PP-J-M	63.4 (4.2)	6329 (388)	32.3 (1.5)	2793 (184)	2.4 (0.4)	22.1 (3.4)
PP-V	38.8 (2.1)	2996 (71)	18.3 (0.6)	1426 (93)	8.9 (2.3)	84.3 (2.7)
PP-V-M	49.6 (7.1)	3446 (116)	19.1 (0.6)	1452 (68)	7.4 (0.6)	79.6 (4.0)
PP-J-V5	46.3 (5.5)	4969 (389)	26.4 (1.2)	2446 (171)	4.0 (0.7)	42.1 (2.3)
PP-J-V10	43.3 (5.9)	4819 (332)	25.1 (1.1)	2408 (53)	4.4 (0.4)	65.8 (3.4)
PP-J-V15	42.9 (6.5)	4260 (393)	24.5 (0.8)	2399 (191)	4.9 (0.4)	60.1 (3.2)
PP-J-V10-M	59.2 (8.1)	5908 (218)	30.4 (1.0)	2688 (95)	5.0 (0.1)	67.4 (2.7)

Softening Temperature

Heat deflection temperature (HDT) was measured by Ceast HDT apparatus, Italy. The testing was performed according to ASTM D 648 standard. The composites samples were tested at a rise in temperature of 2°C/min with a loading pressure of 0.455 MPa (66 psi). Five specimens were tested for each set of samples and the mean values were reported.

Electron Microscopy

Fractured surfaces of the impact test samples of the composites with jute and viscose fibers were analyzed using scanning electron microscopy (SEM) with a Tesan Vega3 SBU, Czech Republic. An acceleration voltage of 5 kV were used and the sample surfaces were sputter coated with gold prior to SEM observation to avoid charging.

Fiber Length Measurements

The fibers were extracted by dissolving the composites with boiling xylene. The fibers were manually separated without overlapping using water and observed using optical microscope. Length of the fibers was calculated automatically from the images through software.

RESULTS AND DISCUSSION

Tensile Properties

The mechanical properties of PP-J composites modified with various concentrations of VF and compatibilized with MAPP are shown in Table IV and Figure 3. The PP-J composite is used as reference for the comparison. The addition of jute fibers did not increase the tensile strength of the composites, which is an indication of poor adhesion between the jute fiber and the PP matrix.[8] This was also seen because an addition of MAPP on the PP-J composite exhibited a higher tensile strength than the uncompatibilized material. Thereby the stress is not transferred from the matrix to the stronger fibers.[9] The addition of viscose fibers showed a positive effect on the Izod impact strength but slightly decreased the tensile strength and modulus. The impact strength improved 73%, 170%, and 147% with an addition of 5, 10, and 15 wt % of the impact modifier, respectively, while the tensile strength decreased with 7%, 12%, and 14% as compared to PP-J composites. The decrease in the tensile strength is attributed to the lower mechanical properties of viscose fiber.[10,11] The lower mechanical properties of viscose fiber had a negative effect on the tensile properties of impact modified jute fiber reinforced PP system when compared to PP-J composites.

Generally, the addition of jute fibers increases the modulus of the composites. The modulus of the composites was progressively increased from 0.6 GPa of neat PP to 2.7 GPa for the composites with 30 wt % jute fibers, this is due to the high stiffness of these fibers. As expected the stiffness was reduced of all composites with impact modifiers which can be explained due to the low modulus of viscose fiber, whereas the addition of 2 wt % of MAPP significantly improved the tensile modulus of the composites. The PP-J-V10-M composites did not show much reduction in strength and stiffness compared to PP-J-M.

Figure 4 shows the elongation at break of PP-J composites modified with various concentrations of the impact modifier. The addition of viscose fibers on PP-J composites increased the strain to failure of the composites. Fu et al.[12] study showed the

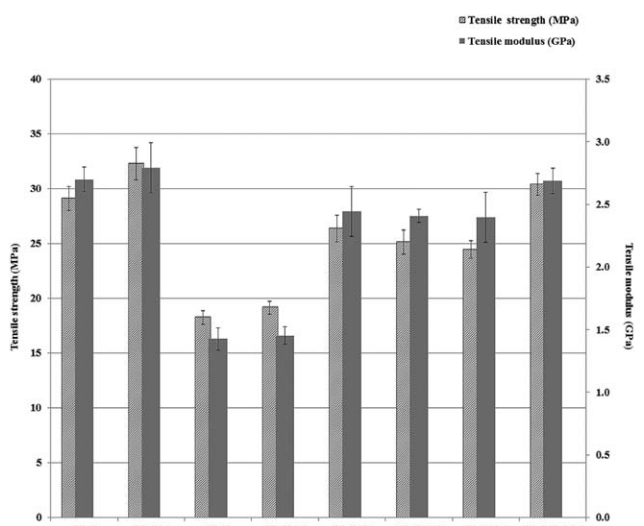

Figure 3. Tensile properties of jute fiber reinforced polypropylene composites modified with viscose fibers as impact modifier and MAPP.

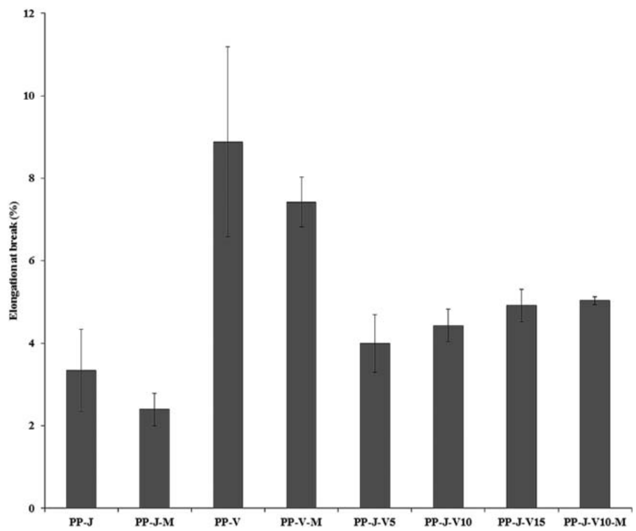

Figure 4. Elongation at break of jute fiber reinforced polypropylene composites modified with viscose fibers as impact modifier and MAPP.

enhancement of failure strain with the use of short glass fiber (SGF) in PP/short carbon fiber (SCF) composites, the work reported the increase of fracture toughness due to the positive hybrid (synergistic) effect. Our study observed the increase in the concentration of viscose fiber has continuously increased the percentage of elongation values of the composites, which indicates the decrease in the stiffness. Graupner et al.[6] study observed, the incorporation of Lyocell fiber onto the PLA-hemp composites has increased elongation from 1.2% to 1.9%. They found the regenerated cellulose fiber have linear elastic behavior in the first section and had higher elongation in the rest of the single fiber test. The addition of MAPP on the hybrid composites has accompanied the improvement in the ductility of the composites. Almost 50% of improvement in the elongation values was observed with PP-J-V10-M when compared with PP-J composites.

Flexural Properties

Figure 5 shows the flexural strength of PP-J composites compared with the composites of different concentration of impact modifier and MAPP. The study observed that the addition of 5 wt % impact modifier does not show much variation in the flexural stress, whereas the increase in the concentration of impact modifier to 10 and 15 wt % resulted in 8.5% and 10.5% reduction in the flexural strength of the composites in comparison to PP-J. However, the MAPP compatibilizer had a positive effect on the impact modified composites. The PP-J-V10-M composite has resulted with 28% higher flexural strength than PP-J composites but 6% lower than that of PP-J-M composites. The improved strength indicates the better stress transfer from matrix to fiber.

Table IV summarizes the flexural modulus of the jute reinforced PP composites modified with various concentrations of the impact modifier and compatibilizer. The results are also shown in Figure 5. The composite with highest flexural modulus was achieved with the combination of compatibilizer and PP-J composites, because of the higher fiber stiffness and strong interface.

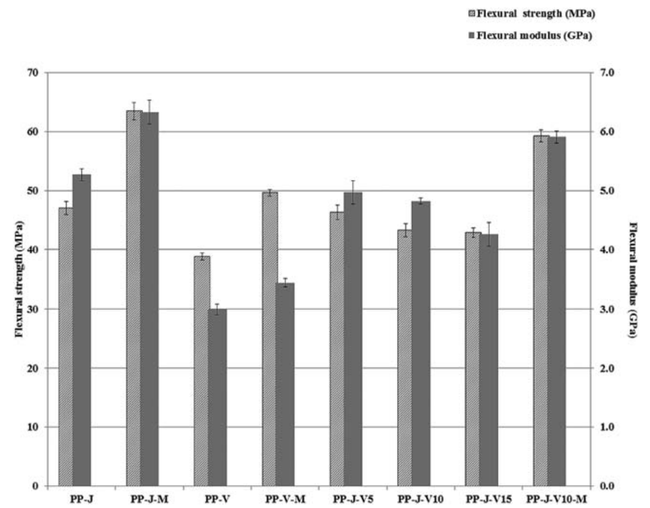

Figure 5. Flexural properties of jute fiber reinforced polypropylene composites modified with viscose fibers as impact modifier and MAPP.

The addition of impact modifier has significantly improved the flexible interphase between the fiber and matrix.[13] The study observed that the optimized interfacial adhesion was achieved with PP-J-V10-M component. The flexible interface attained has promoted the higher pullout of the fibers rather than the fiber breakage, which resulted with the efficient transfer of stress from matrix to fibers. Thereby the composites found to have improved the energy absorption without much sacrifice in the modulus.

Impact Strength

Figure 6 represents the notched Izod impact strength in turn the energy absorption of each compositions. The jute composites showed low impact strength of 24 J/m, which attributes to the presence of strong fiber reinforcement and poor fiber-matrix interface. The toughness of the composites is usually affected by the interfacial parameters and the mode of failure

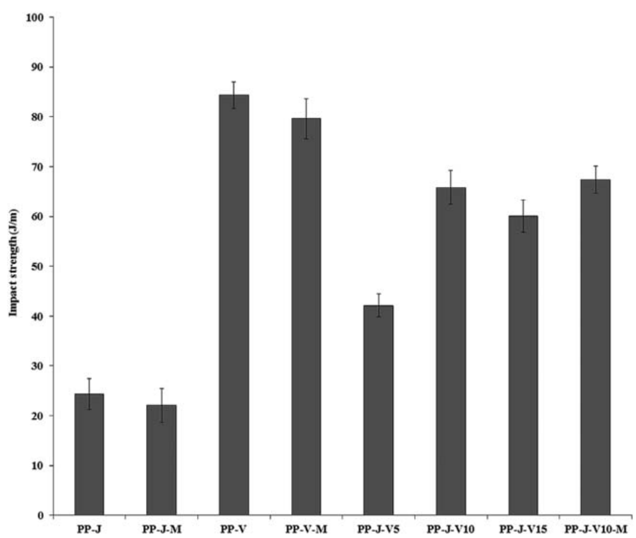

Figure 6. Izod impact strength of notched samples of jute fiber reinforced polypropylene composites modified with viscose fibers as impact modifier and MAPP.

Table V. Interfacial Shear Strength of Jute and Viscose Fiber with PP and PP/MAPP Matrix, Toughness, and HDT of Composites Containing 30 wt % Jute Fiber Reinforced PP Modified with the Impact Modifier and MAPP

	Without MAPP			With MAPP		
Composition	Interfacial strength (MPa)	Toughness	HDT (°C)	Interfacial strength (MPa)	Toughness	HDT (°C)
PP-J	9.52 (0.3)	414.84	142 (1.4)	11.68 (0.6)	301.09	148 (0.8)
PP-V	1.91(0.2)	1636.52	118 (0.7)	3.05 (0.3)	831.29	123 (1.4)
PP-J-V10	–	710.67	140 (1.4)	–	720.10	145 (0.7)

that are observed between the matrix and the fiber, i.e., fiber fracture, debonding, and pullout. The improvement in impact strength values were observed in all composites modified with various concentration of impact modifier, i.e., the incorporation of higher strain to failure fiber has improved the impact strength values. The higher strain rate determines the amount of energy absorbed by a material during fracture.[14] The study depicts the addition of 5 wt % impact modifier had shown the improvement of 73%, the increase in the volume content of impact modifier to 10 wt % has again raised the impact strength from 42 to 66 J/m. The higher improvement of impact strength may be explained due to the longer fiber pullout length of viscose fiber. Benevolenski et al.[15] reported, that hybrid composites where flax fibers were partly replaced by Lyocell fibers improved the impact strength of the composites. The microscopy study confirmed longer fiber pullout lengths in hybrid composites compared than the flax fiber composites; they speculated that the high ductility of Lyocell fibers is responsible for the longer pullout lengths.[15] Hence, this study clearly indicated that the addition of viscose fiber changes the fracture behavior from brittle to ductile.

The crack propagation is the predominant toughening mechanism in the notched impact test.[16] The improvement of impact strength characterizes higher stress transfer from matrix to fiber and able to absorb energy effectively. The better explanation on positive effect on energy absorption in this case is also expected due to the fiber length and its orientation.[17] The longer the fiber will have effective energy dissipation; the tough fiber had a trend to maintain their fiber length and orientation after processing was the possible reason for improved toughness of the composite.

The compatibilized system had a significant impact on the impact strength of the composite. The addition of 2 wt % MAPP on PP-J and PP-V system has shown a negative effect, this may be due to the strong interface between the fiber and matrix, but the compatibilized PP-J-V-10 had positive effect. The reason for the drastic improvement in the impact strength is due to the weak interface, which dissipates more energy through stress transfer from matrix to fiber whereas in case of uncompatibilized composites the higher dissipation of energy occurs for fiber pullouts and debonding due to their very week interface. Hristov et al.[18] reported that the total fracture energy of unmodified PP/wood fiber composite slightly decreases compared to the virgin PP, while addition of the MAPP leads to about 20% increase of the absorbed total energy. Maleated polypropylene (MAPP) ensures better adhesion between the matrix and fibers leading to increased impact strength.

Toughness of Impact Modified Composites

The toughness values shown in the Table V are retrieved from the tensile stress-strain curves. Typical load–displacement curves of PP-J, PP-J-V10, and PP-J-V10-M are illustrated in Figure 8. The figure clearly shows the unmodified PP-J composite exhibit brittle fracture, characterized by a sharp drop immediately after reaching the maximum tensile strength, the plastic deformation of the unmodified composite seems to be much lower than the other composites. The low value of strain to failure has contributed to limited toughness of the composite,[14] which is probably due to the higher pullout of the fiber due to poor interfacial adhesion of fiber and matrix and higher stiffness of jute fibers. The system also exhibited with lower impact energy when tested in vertical direction along with a notch. The viscose fiber have a good strain to failure characteristic, the regenerated cellulose also have good fiber matrix adhesion than the natural fiber.[19] Thus as expected, the addition of viscose fiber to small wt % of about 10% have shown higher strain to failure without much decrease in the mechanical performance of the composites, thereby contributing to higher energy absorption.

Novak and DeCrescente,[20] stated in their report that the ability of the fibers within the composite to absorb large amounts of strain energy is a principal factor governing the amount of impact energy composite material can absorb. Present study,

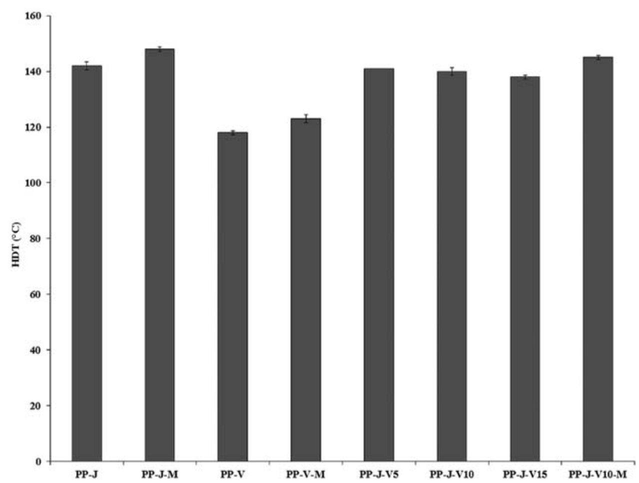

Figure 7. Heat deflection temperature of jute fiber reinforced polypropylene composites modified with viscose fiber as impact modifier and MAPP.

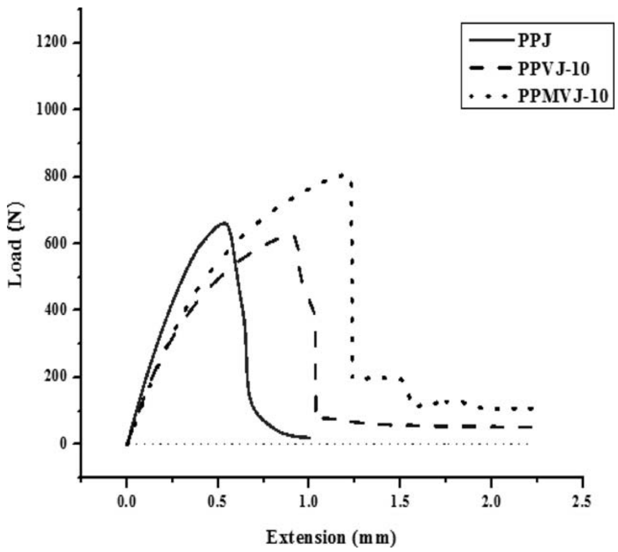

Figure 8. Toughness of PP-J, PP-J-V10, PP-J-V10-M composites.

observes that viscose fibers have greater ability to absorb the strain energy of the composites. The energy absorption behavior of the composites is not only affected by the properties of fiber and matrix but also with several parameters such as interfacial strength, fiber length after the extrusion and the failure mechanism of the composite such as matrix failure, fiber debonding and fiber pullout.

The effect of the compatibilizer on the composite was also examined and shown in Figure 8. The addition of 2 wt % of MAPP not only improved ductility, toughness but also the overall mechanical performance of the composites. It is believed due to the better interface, which allowed greater debonding and pullout of the fibers.

Interfacial Strength Through Single Fiber Pullout Test

The interfacial shear strength of the composites was determined from fiber pullout test. The load-extension characteristics of jute viscose fiber bundle are shown in Figure 9(a,b). Single fiber reinforced PP composites were prepared by placing single filament of fiber between two films of PP, 5 mm of fiber is embedded with matrix. Figure 9(a), shows curves of IFSS and work of adhesion between single jute fiber in PP and PP/MAPP matrix. The adhesion bond strength between the fiber and the matrix was characterized by the values of the apparent interfacial shear strength (τ_{app}).[9] The interfacial shear strength between the jute fiber and the PP matrix was measured to 9.5 MPa. It is seen that the jute fibers debonded more easily from matrix and pulled out from the PP matrix. The SEM micrograph study had also shown a partial adhesion of fibers with matrix; whereas the interfacial shear strength of single jute fiber embedded PP/MAPP is much higher than that of unmodified PP matrix, shown an improvement of 24%. This reveals and improved interaction between the fiber and the matrix and consecutively load transfer ability in the interface. The curve resembles a very strongly bonded interphase, i.e., the interface fails immediately after fiber extraction, as reported by De'sarmont et al.[21] Our study also observed enhancement of load along with the modulus reveals the improved work of adhesion between the jute fiber and PP matrix, this clearly indicates the chemical interaction. Figure 9(b), shows curves of IFSS between the viscose fiber bundle reinforced PP composite and MAPP modified PPV fiber bundle reinforced composites. The trend observed with viscose fiber pullout was a linear-elastic region in the first section followed by higher elongation at break. The curve clearly indicates weakly bonded interphase; once the interphase has failed, the fiber can be extracted in a controlled way and friction was measured until the fiber was completely pulled-out.[22] The higher fineness and the specific bonding area might be the reason behind the lower IFSS of the viscose fiber. But the SEM micrographs of viscose modified composites observed to have less and fiber pullouts than the PP-J composites. So, highest Izod impact strength values were also found in PP-V composite with almost 85 J/m.

Thermal Analysis

The heat deflection/distortion temperature of all the composites as a function of fiber content is represented in Figure 7 and Table V. The incorporation of jute on neat resin has shifted the

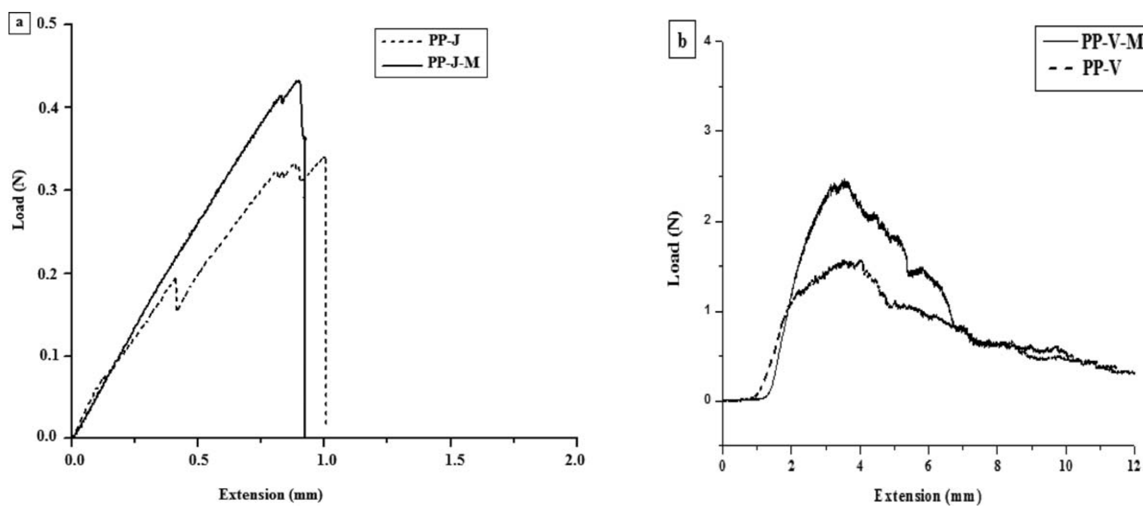

Figure 9. Typical single fiber pullout test load-extension curves for jute and viscose fiber bundle reinforced PP and MAPP modified composites.

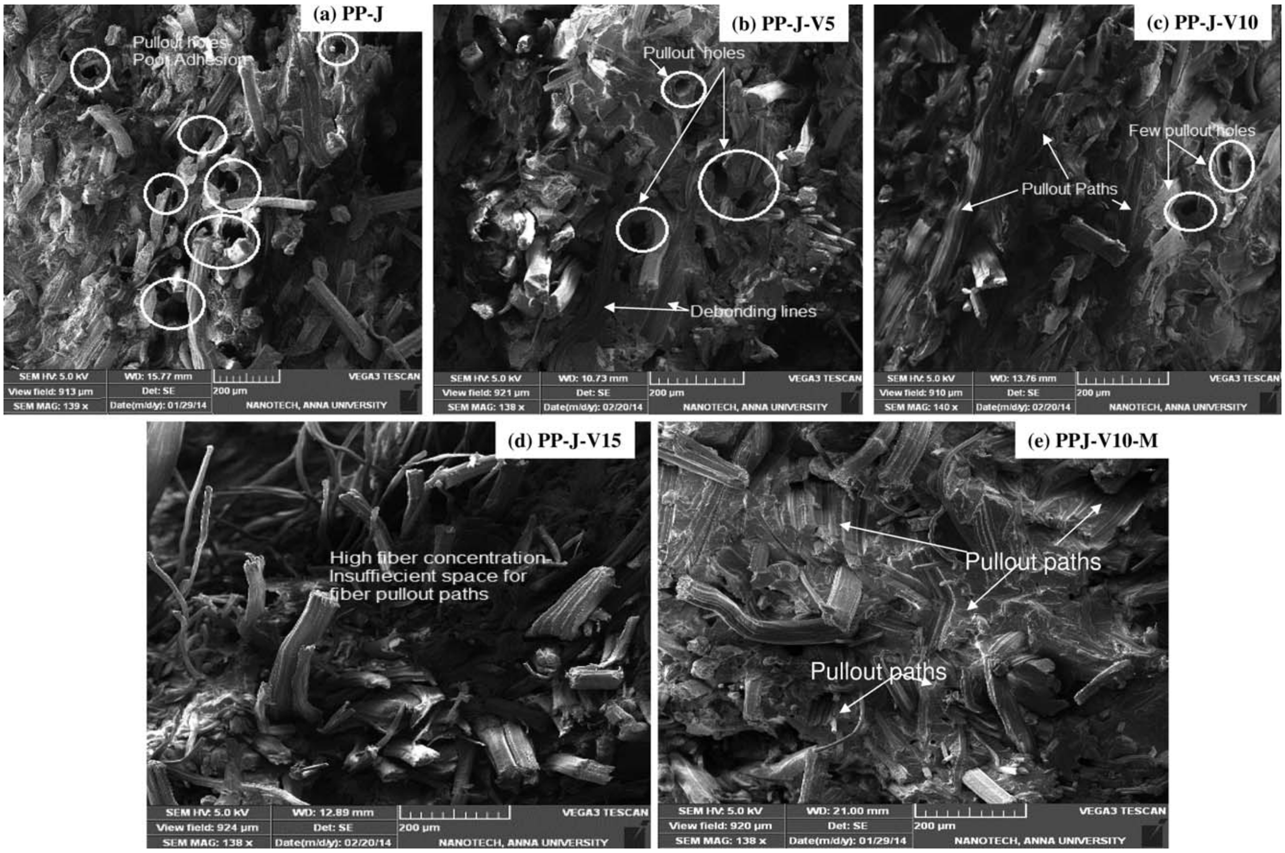

Figure 10. SEM micrograph of fractured specimen shows jute fiber–polypropylene composites with viscose fibers as impact modifier and MAPP has compatibilizer.

HDT value from 90°C to 140°C, with the loss in the impact strength about 4%. The compatibilized PP-J composite had shown the higher HDT values due to the higher stiffness of the jute fibers. The HDT values were observed to decrease slightly with the addition of impact modifier. The tabulation clearly indicates the moduli/stiffness of the composites is reduced with the addition of low moduli fiber. But when the concentration of impact modifier is increased to 10 wt % much reduction of HDT values was not observed. The incorporation of 2 wt % of MAPP on PPJ-V10 has gained the HDT of the composites are increased with the stiffness of the composites, indicates the volume fraction of reinforcement and impact modifier shows better dimensional stability of the composites. However, further increase of impact modifier, shows fall in the HDT values along

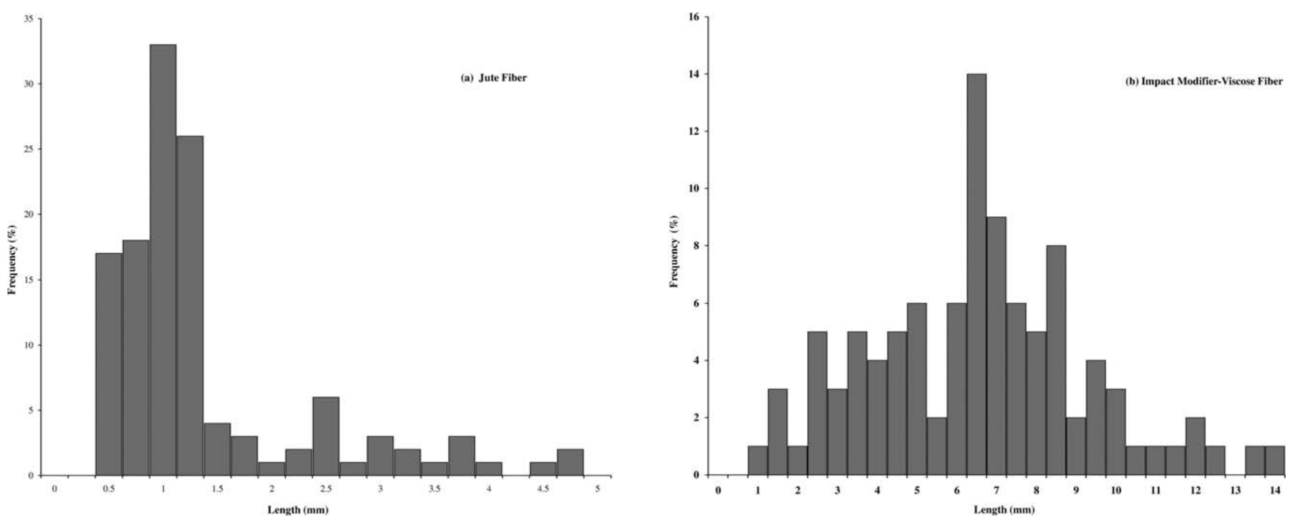

Figure 11. Fiber length measurements (a) jute fibers and (b) impact modifier-viscose fibers.

with impact strength. This is certainly due to the improper distribution and the dispersion of fibers and the insufficient amount of resin to properly wet the fiber are strongly decreased the properties of the composites.

Microscopy Analysis

Scanning electron microscope images of impact fracture surface of PP-J and PP-J composites modified various concentrations of viscose fibers and MAPP are shown in Figure 10. The SEM images of all the composites observed having perfect fiber dispersion without local concentration. In Figure 10(a), it can be clearly seen that the fracture surface are rough and more traces of jute fiber pullout holes in the matrix indicating lack of interfacial adhesion between the fibers and the polypropylene. This leads to easy fiber pullout during the impact.[23] The Figure 10(b,c) fracture surface image evident the traces of both fiber pullouts are quite low with addition of viscose fiber. Some fiber debonding lines are also observed on the fracture surface image, which indicates the fiber matrix adhesion is comparatively higher in case of 5 and 10 wt % of viscose fiber. Johnson et al.[24] study reported on PP/wood/Lyocell fiber reinforced hybrid composite, they found that the regenerated cellulose has less-pullouts during failure. Kim et al.[15] study also reported a better adhesion between the PP matrix and rayon surface was observed than PP and pineapple fibers. The study of Adekunle et al.[5] observed that, good fiber–matrix adhesion, as it was very difficult to see the fiber pull-outs with Lyocell reinforced composites. They believed that the fibers were well-embedded in the matrix due to their microstructure. The Figure 10(d) seems to have higher fiber loading and observed to have insufficient space for pullout paths. This reveals poor fiber wetting of the fiber occurs due to insufficient matrix material and fiber travelling gap, resulting in lowering impact strength. Figure 10(e), fracture surface observed to have excellent fiber matrix adhesion. In image both the fibers jute and impact modifier are visible, they are covered with the polymeric matrix demonstrating the effectiveness of the coupling agent. The micrograph also indicates no voids around the fibers surface and found to have clear fiber debonding and pullout paths of both natural fiber and the viscose fiber. As reported by Oksman et al.,[25] the improvement in almost all mechanical properties with pronounced deformation in presence of MAPP is evident, for the good interfacial adhesion between the hydrophilic fibers and hygroscopic matrix.

Fiber Content and Length Measurements After Extrusion

The fibers were extracted from the composites by dissolving PP in hot xylene using Soxhlet extraction apparatus. The fiber images are taken with M/s. OPUS vision measuring machine with a 0.75X–4.5X observing magnification. A sufficient number of extracted fibers are characterized; the length and the area of the fibers are calculated automatically from the images through software. At most care has been taken to avoid the duplicates.

Figure 11(a,b) shows the fiber length measurements of jute and viscose fibers, respectively. The typical average fiber length values of jute and viscose fiber lengths are 1–1.2 mm and 6.8–7.3 mm, respectively. The mechanical performance of the composites and the microscopic analysis of fiber length clearly demonstrate, that the viscose fiber acts as an impact modifier by bridging the cracks in the matrix and provides resistances to crack propagation and crack opening. Thereby fracture toughness of the composites is enhanced by larger deformation before complete pullout of fibers. Ganster et al.[26] reported the fiber length distribution determines the mechanical performance of the composite; their study observed unnotched charpy strength at room temperature were roughly doubled and notched impact strength increased almost five times from rayon reinforced PA 6.10 composites. They believed the drastic improvement energy absorption of the composite was due to their higher average fiber length in the final composites.

CONCLUSION

This study confirms that the impact strength of PP-J composites can be increased with viscose fibers as impact modifier. An increased viscose fiber concentration did slightly decrease the composites strength and stiffness as expected. The maximum improvement in the impact strength, toughness and elongation to break was found with 10 wt % addition of viscose fibers. This is an effect of the low strength and modulus with high elongation of the used viscose fibers.

The addition of a MAPP had negative effect on impact strength and elongation at break and positive effect on tensile and flexural properties for PP-J and PP-V. But it was found that the addition of MAPP had a positive effect on all mechanical performance including impact strength when it was used in the hybrid composite of PP-J-V. This is believed due to weak interface achieved with the composite, which dissipates more energy through stress transfer from matrix to fiber, allowing the fiber debonding with higher energy absorption with longer pullout lengths.

The IFSS of MAPP modified single jute and viscose fiber composites have improved to 11.6 and 3.0 MPa from 9.6 and 1.9 MPa, respectively, due the better interaction between the fiber and the matrix.

The electron microscopy images of fracture surfaces of the composites showed that PP-J composites had poor fiber matrix adhesion compared to those of impact modified composites. This is due to the ingredients that are presents in the fibers. The viscose fibers are chemically regenerated cellulose connected by hydrogen bonding, which can be wetted out with PP molecules, whereas the volatiles present in the jute fibers such as lignin and other extractible may restrict the adhesion with the PP.

The fiber length measurements after the extrusion process showed that the length of jute fibers were reduced to an average length of 1.0–1.2 mm while the viscose fiber length was around 6.8–7.3 mm. The higher fiber length after the extrusion indicates less sensitive fibers for the shear forces and higher toughness. The addition of viscose fibers influenced the impact strength due to the increased energy dissipation along the length of fiber. Thus, revealing the long fiber carry significantly higher fraction of load compared to short fibers.

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