Evolution in Polymer Technology Journal

Research Article *Volume 3 Issue 1*

Investigation of Fiber Loading on Physico-Mechanical and Thermal Properties of Jute-Mat Fiber Reinforced Recycled Polymer Composite

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Received Date: December 07, 2019; **Published Date:** January 09, 2020

Abstract

In Bangladesh, millions of waste high density polyethylene (HDPE) plastic containers have been thrown away annually in open places including rivers. In this work we investigate the feasibility of recycling and reusing HDPE plastics materials. This paper represents the preparation and characterization of jute-mat reinforced composites incorporated into recycled HDPE. The objective of this study was to determine the effects of Jute fibers addition on the performance of the fiber-reinforced composites. Composites consisting recycled HDPE and bleached jute-mat were prepared using hot compression molding at 145°C. The mechanical and physical properties of composites were measured as a function of fiber loading (up to 25 wt %) and compared. Tensile strength, young modulus, flexural strength, tangent modulus and hardness of the recycled HDPE composites increased with the increment of fiber addition but start to decrease after 20 wt % incorporation of jute-mat fiber. Thermal analysis of the composites revealed that the thermal stability of recycled HDPE/jute-mat composites is moderate.

Keywords: High density polyethylene; Recycling and reusing; Young modulus; Flexural strength; Tangent modulus

Abbreviations: HDPE: High Density Polyethylene; NFRP: Natural Fibers Reinforced Polymeric; UTM: Universal Testing Machine; TGA: Thermo Gravimetric Analyzer: TG: Thermal Gravimetry; DTG: Derivative Thermo-Gravimetry; DTA: Differential Thermal Analyzer; TGA: Thermo Gravimetric Analyzer

Introduction

Plastic has become one of the biggest threats to environmental safety due to its non-biodegradable behavior. This has led researchers to design new environment friendly materials leading to a recycling and reprocess approach. There has been a significant development of cellulosic natural fibers reinforced polymeric (NFRP) composites material, over the last few decades, because of its wide range of applications and their excellent sustainability, biodegradability, low density and non-toxicity [1-15]. This is the case of natural fibers particularly the lignocellulosic fibers that are currently being considered as reinforcement for composite materials [16-20]. Applications of lignocellulosic fiber composites help in the diversity of modern technological uses for these fibers, such as automobile components [3] that result in both societal and economic advantages including good incentives for the producers of such fibers. Some of the lignocellulosic fibers can be used in woven type (fabric/braided) as reinforcements in composites [21], thus providing further potential jobs, as well as the possible use as automobile parts, construction panels and furniture [3, 20-22]. In recent years, a variety of lignocellulosic fibers including jute, sisal,

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coir, flax, hemp and wood has been used as reinforcements in polymer matrices with relevant contribution to the world economy [22]. Due to its ecofriendly nature, comparable specific properties, durability and low cost, fiber-reinforced polymer composites resulted in more focus on the application of natural materials such as lignocellulosic (Jute) fibers. The natural fiber-reinforced polymer composites gain huge popularity due to their excellent properties, inexpensive preparation methods, excellent reusability and recyclability. These commercial and eco-friendly advantages makes natural fiber reinforced composites one of the vastly studied materials. For the survival of jute in competition with the synthetic fibers, scientists have attempted to modify its quality and characteristic properties. Owing to their high specific properties and biodegradability, as reported in numerous published literatures, jute fiber reinforced polymeric composites has been prepared using various polymer matrices [8,15,23-25]. On the contrary, weak non-covalent interfacial bonding with different phases of NFRC and high moisture uptake of the natural fiber content are the most notable disadvantages while considering any usage of natural fiber-reinforced composites [4,10,13,15,26-29].

This paper presents the preparation and characterization of bleached jute-mat incorporated, as isolated pieces up to 25 wt%, recycled high density polyethylene (HDPE) composites. The objective of this study was to determine the effects of Jute fibers on the performance of the fiber-reinforced composites. The mechanical and thermal properties of the composites were studied by universal testing machine (UTM) and thermo gravimetric analyzer (TGA) respectively. The mechanical properties (tensile properties, flexural properties) and physical properties (bulk density, water absorption) were measured for different wt% of jute-mat reinforced HDPE composites and compared.

Materials and Method

Raw materials

Waste material was employed in this investigation, viz., recycled HDPE as matrix and jute-mat fabric as reinforcement. Jute fiber from new jute-mat was obtained by sectioning out pieces from the mat. It should be noted that the new jute-mat was obtained from a Bangladesh textile industry. The recycled high-density polyethylene (HDPE) was obtained in the form of cleaned pellets from a city dump collecting factory operating in the district of Dhaka, Bangladesh. They were conventionally milled from large parts of post-used HDPE components. Accordingly, few stain marks was detected on these used HDPE pellets. Hence, these pellets were thoroughly cleaned with water and dried for at least 2 days under the sun in open air before they were used as composite matrix. Figure 1 shows square woven fabric of the new jute-mat, figure on the left, had a interlace space of about 1 mm between parallel fibers that were still integral parts.

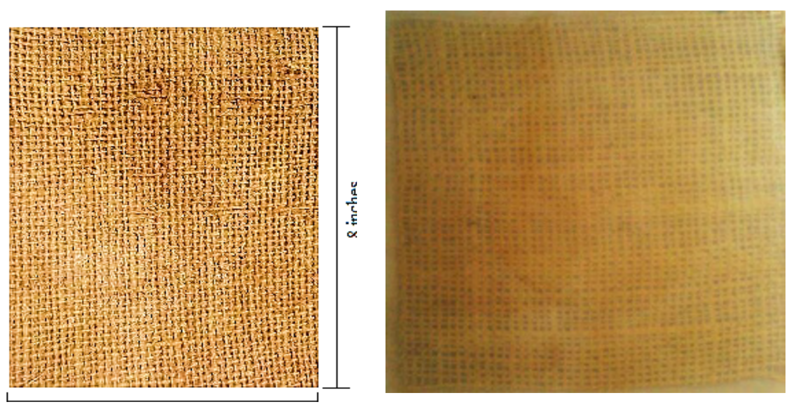

Figure 1: Jute-mat after cutting from sackcloth fabric (left) and Recycled HDPE/Jute-mat composite (right)

Composite preparation

Rectangular pieces of jute fabric taken from jute-mat were cleaned and dried in open air. Cleaned recycled HDPE pellets and fiber were dried in dryer at 50^0C for 24 hours. Composites for different ratio of HDPE and jute-mat fiber were made by Paul-Otto Weber Press machine. The jute-mat fabrics were cut into length of 8 inch and width of 6.5 inch with the aid of a scissor. An interlayer stacking with up to 25 wt. % of jute-mat fabric pieces was lay down in a 8 inch × 6.5 inch rectangular closed steel mold of 450KN Weber-press together with the HDPE pellets. The mold was then compressed with 100KN pressure at 145^0C for 20 min and allowed to cool to room temperature. The composition of composites samples are given in the table below:

Composites	Composition (weight %)	
	HDPE (wt. %)	Jute-mat (wt. %)
C1	100	0
C2	95	5
C3	90	10
C4	85	15
C5	80	20
C6	75	25

Table 1: Percentages of Jute-mat fiber and HDPE in composites.

After the hot press molding operation, the specimen was cut according to ASTM standard and characterized in terms of density, thermal, mechanical and flexural properties. The average dimension of composite samples is 20.32 cm×16.5 cm × 0.396 cm. The dimensions and geometric characteristics of the maximum amount of 25 wt. % jute fabric incorporated into the HDPE matrix did not allow the recommended standard specimen thickness to be used. Hence, possible and practically allowable thickness of the composite sample was employed. To measure bulk density and water uptake 1 inch x 1.5 inch samples were cut. For water-uptake, all the samples were heated at 50^0C for about 30 minute and then weighted at room temperature. A minimum of four specimens was tested for each investigated percentage of incorporated jute fabric to permit a limited statistical analysis. Tensile testing was carried out on HDPE/jute-mat composites using samples sizes as per ASTM D638 Standard and for the flexural properties, each specimen was subjected to bend test in an Instron universal testing machine partially following ASTM D790-03 standards used for reinforced plastics. The span-to-depth ratio was maintained at a constant value of 9 and the test speed was kept at 1 mm/min.

Thermal Gravimetry (TG) and Derivative Thermo-Gravimetry (DTG) were carried out by a coupled Differential thermal analyzer (DTA) and Thermo gravimetric analyzer (TGA) to investigate the thermal stability of the jute fiber, HDPE and composites. Composites were taken using a computer controlled to an EXSTAR 6000 STATION, Seiko Instrument Inc. Japan. The TG/DTA module uses a horizontal system balance machine. The specifications of the instruments are: Heating rate: 0.1 K/min. to 100.00 K/min, TGA measuring range: ±200 mg (0.2µg), DTA measuring range: ± 100µV (0.06 µV), Gas flow: ≤ 1000m/min. The sample weight as a function of temperature is recorded, the data indicate a number stages of thermal breakdown, weight loss of the material in each stage, etc.

Results and Discussion

Several composite systems were produced in this study under a set of specific fabrication procedures and with target constituent fractions. The composite systems fabricated for this study are all classified as bidirectional composite laminates, consisting of one to four degree layers. The composites were put through a rigorous characterization techniques including tensile, flexural, compressive and thermal testing. The results of these tests were analyzed to determine the potential of the systems for application as load bearing structural materials. Additionally, the test results were compared to results from similar studies on bio-composites found in the literature.

Bulk density

Before making the composite, the moisture absorption of jute fibers should be reduced as it is hydrophilic in nature. The effect of the variation of wt. % of jute-mat fabrics on the density of HDPE/Jute-mat composite is illustrated in Figure 2.

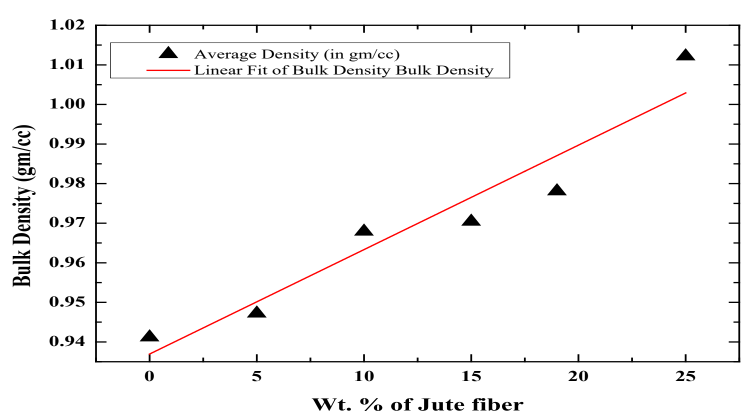

Figure 2: The effect of the variation of the amount of jute-mat (wt. %) on the density of HDPE/Jute-mat composite.

The bulk density of recycled HDPE/Jute-mat reinforced composite increases with Jute-mat fiber addition. This follows the mixture rule. The density increases from 0.94 gm. /cc to 0.99 gm. /cc when the amount of Jute-mat fiber increases from 0 to 25 wt. % respectively. That is quite compatible with the reported density of pure high-density polyethylene ranging from 0.94 to 0.96 g/cc [3].

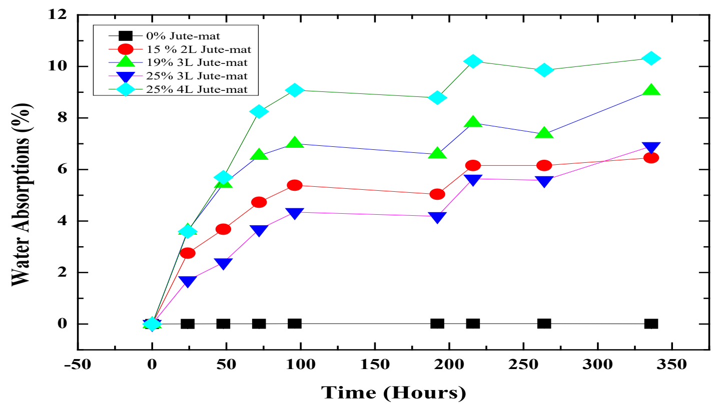

Figure 3: Effect of immersion time on water absorption of recycled HDPE/Jute-mat Composites.

Water absorption of composites

The water absorption of HDPE/Jute-mat fiber-based composites is presented in Figure 3 as a percentage of dry weight after 24 hour's immersion in water. The results show that the water absorption of the recycled HDPE/Jute-mat composites absorbed most of the water, suggesting that changes in surface chemistry have reduced the affinity of fibers to moisture. Strong intermolecular fiber-matrix bonding decreased the rate of moisture absorption in bio-composites [3]. The rate of water absorption with time tends to lower. In most of the cases of NFRC, the hydrophobic polymers and hydrophilic natural fibers makes poor interfacial bonding in natural fiber composites. Natural fibers also absorb moisture content due to its strong hydrophilic natures which in turns degrade the mechanical properties of natural fiber reinforced composite [22].

Mechanical Properties

Any chemical or morphological change has an effect on the mechanical properties of the fibers. Due to poor natural fiber-polymer bonding, lignocellulosic fillers have limited use in industrial practice in spite of its attractive properties [21]. Both the fiber and matrix bear the load and make resistance to slip as the case of hardening of metals.

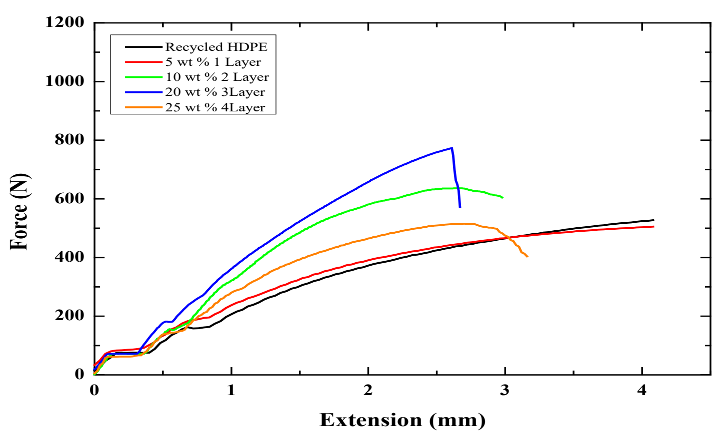

Figure 4: Load versus extension curves recycled HDPE/Jute-mat composites with different wt. % of fiber.

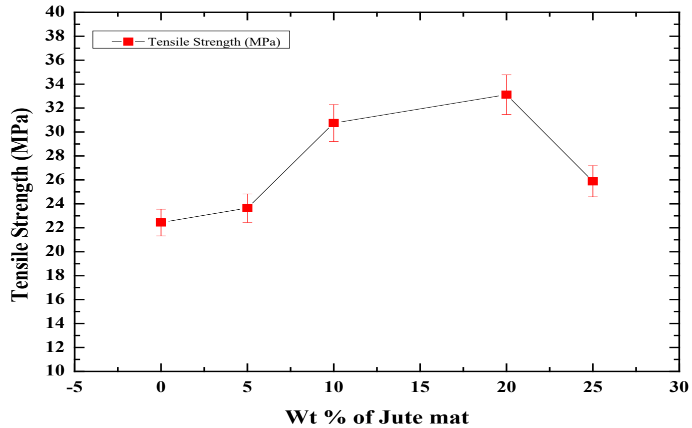

Figure 5: Tensile strength of recycled HDPE/Jute-mat composites with different wt. % of fiber.

Tensile strength

Figure 4 illustrates typical load versus extension curves obtained from biaxial tensile testing performed on composite specimens with different jute fabric compositions. All curves in this figure display some plastic extension before going through a maximum load value.

Figure 5 shows the tensile strength decreases with higher percentages of fiber. It can also be seen that the tensile strength (22.437 MPa) and tensile modulus (0.503 GPa) values of the pure HDPE waste obtained in this study are comparable with that reported in literature [30] for the tensile strength of high-density polyethylene. This indicates that the recycled HDPE used in the present work displays almost similar mechanical properties as that of the virgin resin.

Secondly, the jute-mat fabric produces initially a significant reinforcement effect in the used HDPE composite. The maximum value of the tensile strength of recycled HDPE/Jute-mat composites is found to be 33.12MPa for 20 wt. % jute mat fiber composite. In fact, for 20 wt. % incorporation of jute-mat fabric, the composite becomes more than 50% stronger (33.12 MPa) in relation to pure HDPE (22.43 MPa). This may be due to the fact that up to 20% the fibers are well distributed and the better interfacial bonding between the fiber and matrix. Previously, it was reported that the fibers disperses poorly when reinforced into thermoplastic matrices due to strong inter fiber hydrogen bonding which holds the fibers together [31]. However, above 20 wt. % a decrease is observed in the strength values, but these values are still higher than that of pure HDPE, indicating an effective reinforcement up to 25 wt. %. Indeed, in practice, the incorporations of jute fabric above 25–30 wt. % into the resin became increasingly difficult during the press-molding process [31].

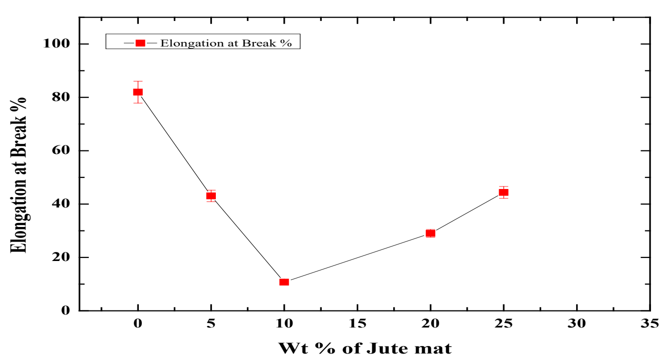

Figure 6: Effect of fiber addition on change of Eb (%) for recycled HDPE/Jute-mat composites.

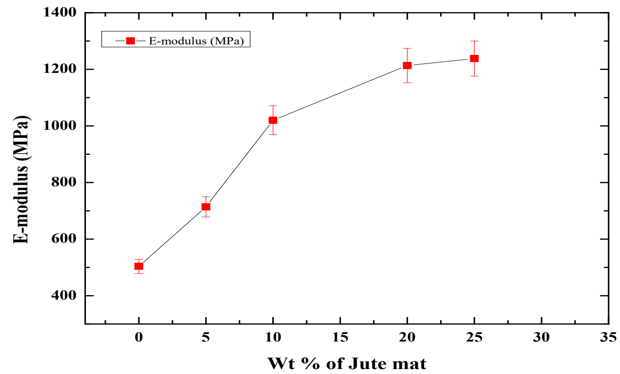

Figure 7: Young's modulus of recycled HDPE/Jute-mat composites as a function of the amount of jute-mat fabric reinforcement.

Elongation at break (Eb %)

Figure 6 shows the effect of addition of jute-mat fiber on the elongation at break (%) of recycled HDPE/Jute-mat composites. The value of elongation at break (%) for HDPE is 81.965%. It shows that the Eb (%) decreases when the amount of fiber increases from 0 to 10 wt. %. The increase in fiber loading limits the slip ensuing in lesser ductility [32] and consequently the % of strain decreases with the increase of fiber addition.

Young's modulus

Young's modulus of recycled HDPE/Jute-mat composites for different wt. % of jute-mat fiber is shown in Figure **7**. It reveals that the young's modulus increases with increase of fiber addition. The fiber and the polymer seems to be well dispersed for this increasing region. The Young's modulus is lower for pure recycled HDPE sheets than that of other composites. The Young's modulus is a measure of stiffness of a material. Thus, the stiffness of the HDPE/Jute-mat fiber composites increases with the increase of fiber addition. The increase in stiffness is a significant result shown by the HDPE/Jute-mat composite.

Flexural properties

Figure 8 illustrates typical load versus extension curves obtained from the three-point bend tests performed on discarded-after-use HDPE composite specimens with different jute-mat fabric compositions. Like **Figure 4**, all curves in this figure display the same plastic extension before going through a maximum load.

Flexural strength and modulus

Table 2 lists the flexural strength and modulus for the different compositions investigated in recycled HDPE composites reinforced with jute-mat fabrics. Figure 9 shows the variation of the flexural strength and flexural modulus for recycled HDPE composites with the amounts of jute-mat fabrics.

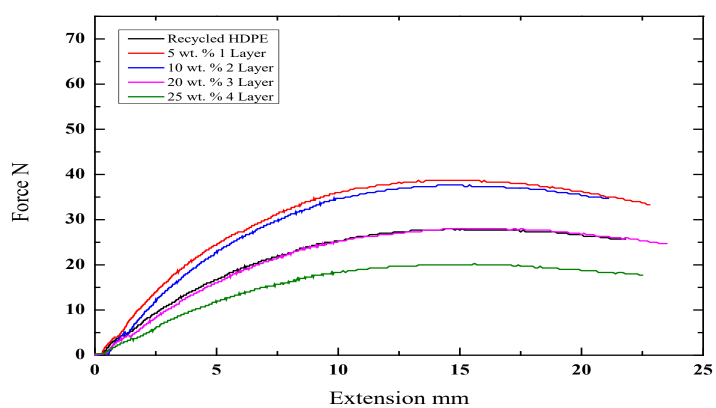

Figure 8: Load versus extension flexion curves for recycled HDPE/Jute-mat composites with different amounts of jute-mat fabrics.

Wt. % of Jute-mat	Flexural Strength (MPa)	Flexural modulus (MPa)
0	21.90	702.33
5	22.00	708.66
10	25.17	751.50
15	26.73	1117.00
20	24.69	794.33
25	26.26	994.66

Table 2: Flexural strength and flexural modulus for recycled HDPE composites reinforced with jute-mat fabric.

For pure used HDPE, the flexural strength is 21.90MPa and the modulus is 0.70GPa. It is clear from the figure that the flexural modulus and flexural strength shows significant reinforcement of the composite with the addition of jute-mat fiber content. Up to this composition (increasing region) the fiber and the polymer are well distributed.

Flexural strain

Figure 10 shows the effect of fiber addition on flexural strain of HDPE/jute-mat composites. For HDPE flexural strain is 12.14%. It reveals that the flexural strain of fabricated product decreases with the increase of fiber addition up to a certain limit then remains constant or decreasing slightly. It is apparent that the elongation decreases with the increasing of fiber addition.

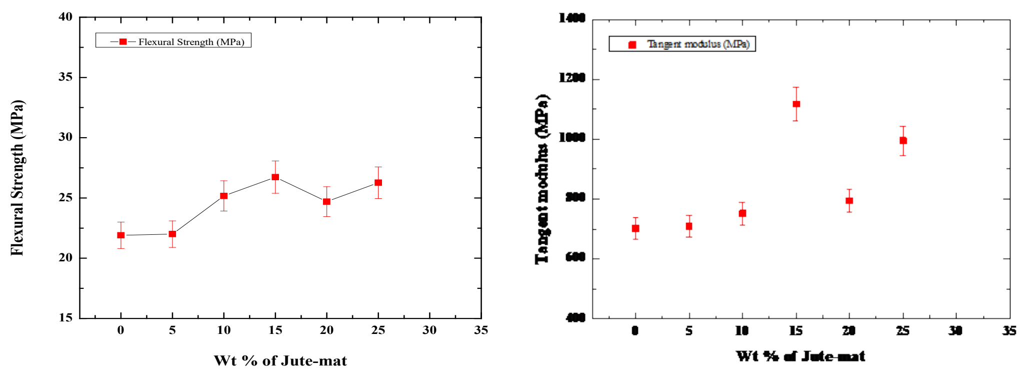

Figure 9: Effect of fiber addition on flexural strength and flexural modulus of recycled HDPE/Jute-mat composites.

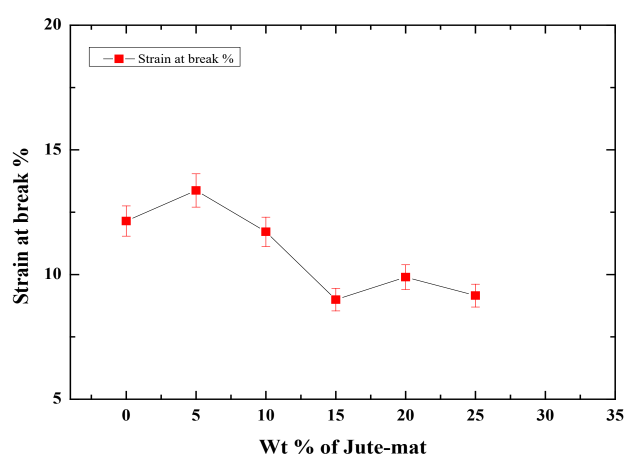

Figure 10: Variation of flexural strain of recycled HDPE/jute-mat composites with fiber addition.

Vickers and leeb rebound hardness test

Figure 11 illustrates the effect of addition jute-mat on Vickers and Rebound Hardness of HDPE/Jute-mat composites. Results indicated that rebound hardness of recycled HDPE/jute-mat composite firstly decreased with the increase of jute-mat fabrics & from 20 wt. % composite it increases with the addition of jute-mat fiber. It measures the hardness of sample material and hardens material produce a higher rebound velocity than softer material. It can be seen that Vickers Hardness decreased with an increase of jute-mat fiber.

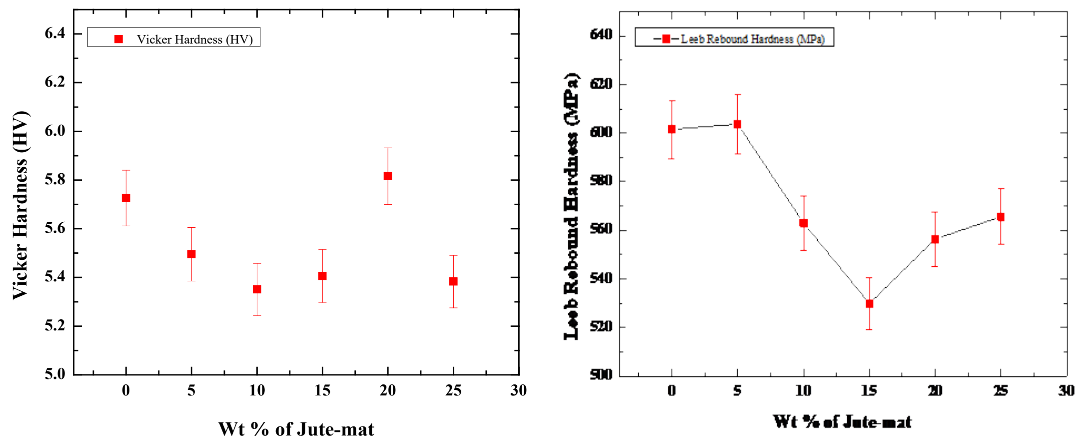

Figure 11: Effect of amount of Jute-mat fiber on Vickers and Rebound Hardness of recycled HDPE/Jute-mat composites.

Thermal Properties

TG, DTA and DTG of recycled HDPE pellets

The TGA was carried out to investigate the thermal stability of pure recycled HDPE and HDPE/Jute-mat composites samples. Figure 12 shows the TG, DTA and DTG curves for recycled HDPE pellets. The top (blue) one is the TG, bottom (red) one is the DTG and middle (green) one is the DTA curves for HDPE sheet under air environments. The onset temperatures which refer to the degradation of a sample are important in determining thermal stability of the composites. Table 3 summarizes the onset and decomposition temperatures and the residue of the pure recycled HDPE and HDPE/Jute-mat composites.

Thermal degradation of pure recycled HDPE shows similar features like the virgin HDPE pellet, as expected. We observed same endothermic peaks for all the composites. At maximum degradation temperature, the decomposition was faster owing to the increased thermal conductivity of the HDPE.

TGA Sample	Decomposition temperature (°C)	Onset temperature (°C)	*% Residue*
Pure recycled HDPE	489.4	462.7	100
HDPE/Jute-mat composites	494.0	475.2	27.9

Table 3: TGA decomposition temperature, onset temperature and the residue at maximum degradation temperature for pure recycled HDPE and its composites incorporating Jute-mat fiber evaluated in air.

The TG curve reveals that the onset temperature of recycled HDPE, 50% degradation occurs at 462.7°C, 483.7°C and maximum slope at 488.3°C. The total degradation loss is 100%. DTA yields the two endothermic peaks at 132.1°C and 490.4°C respectively. The first one is due to the melting and the second one is due to the degradation of polymer. The DTG curve shows the maximum degradation rate was obtained at 489.4°C with the rate of 2.32 mg/min. The maximum slope of TG (488.3°C), second peak of DTA (490.4°C) and the maximum degradation rate temp. (489.4°C) are closely related to the degradation of recycled HDPE.

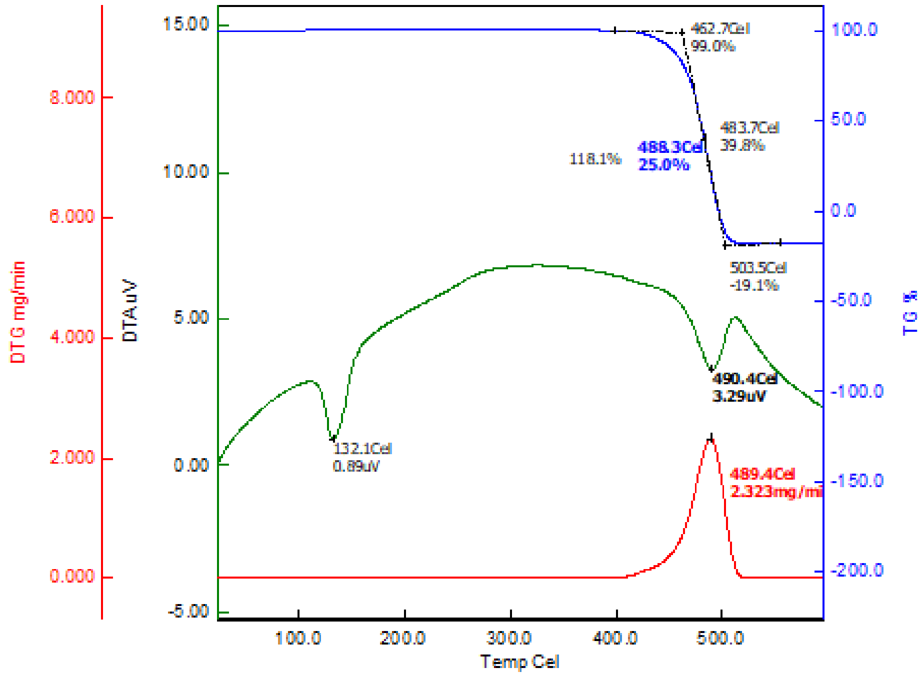

Figure 12: TG, DTA and DTG curves for recycled HDPE pellets.

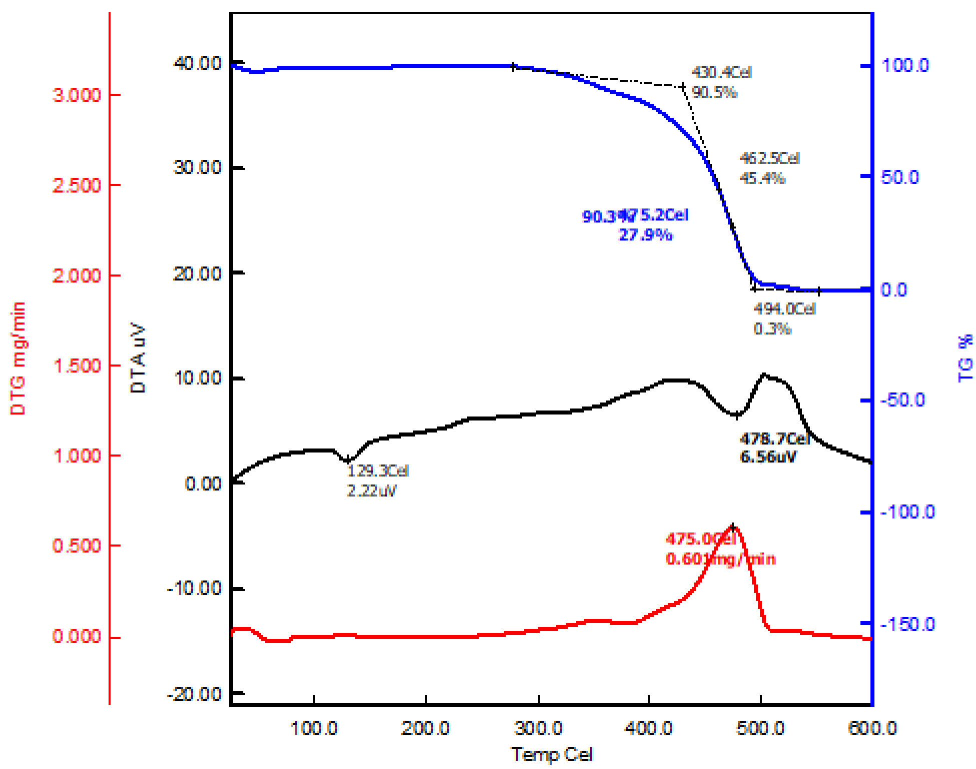

Figure 13: TG, DTA and DTG of recycled HDPE/Jute-mat Fiber composites.

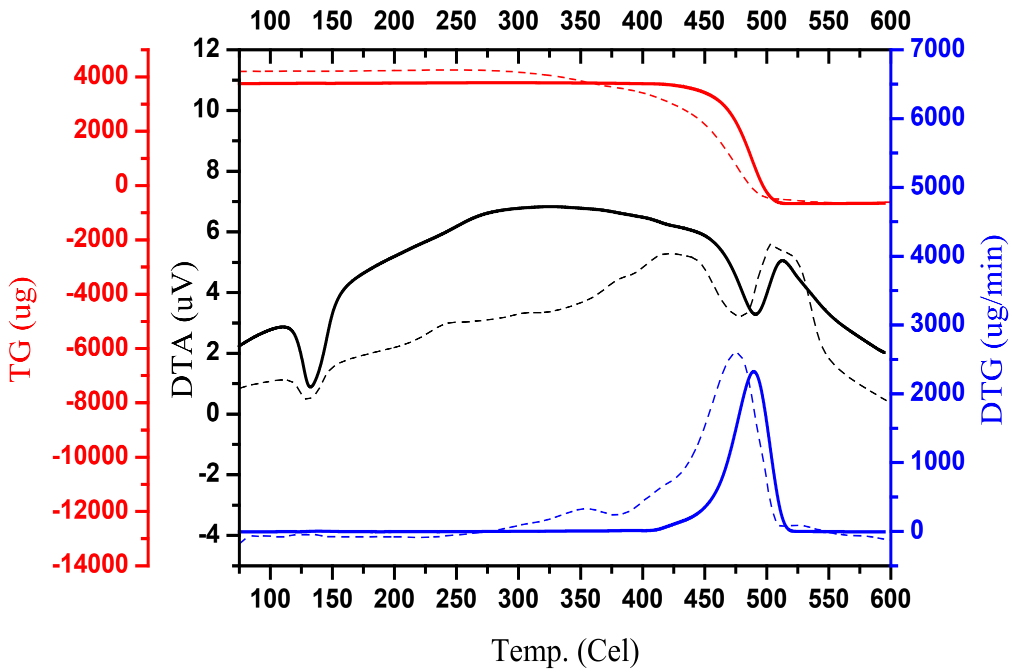

Figure 14: TG, DTA and DTG curve of recycled HDPE/Jute-mat composites (dotted line) and recycled HDPE (solid line).

TG, DTA and DTG of recycled HDPE/Jute-mat Composite

From Figure 13, the TG curve shows the major degradation occurs at two steps for jute-HDPE composites, first one is related to fiber degradation and the 2nd one is related to polymer degradation. The onset temperature i.e., 50% degradation temperature and maximum slope are at 475.2°C and 494.0°C. The total degradation loss is 27.9%. The DTA curve shows the two endothermic peaks 478.7°C and 129.3°C which are due to removal of moisture and thermal degradation respectively. The DTG curve also reveals that there are three peaks at the temperature of 66.0°C, 373.9°C and 487.9°C. DTG curve of jute-HDPE composites depicts a predominant peak at 475.0°C where maximum degradation rate is 0.601mg/min which corresponds to heavier material.

Comparison: TG, DTA and DTG of recycled HDPE and HDPE/Jute-mat Composites

Figure 14 shows the TG, DTA and DTG curves of recycled HDPE and HDPE/ Jute-mat composites. The dotted curves are for recycled HDPE/ Jute-mat composites and the solid curves are for recycled HDPE. From this figure it is clear that, with the addition of jute-mat fabrics the recycled HDPE matrix shows the lower thermal stability as the initial losses of recycled HDPE are slightly higher than HDPE/jute-mat composites.

Conclusion

The performance of an engineering material is essential for selecting the proper material in a given application as well as for designing a composite structure with the selected material. The objective of this work was to fabricate and study the effect of addition of Jute fiber in composites with recycled high-density polyethylene matrix reinforced with different amounts of jute fabric pieces, sectioned out from bleached new jute-mat, with a view to examine the possibility for the use of recycled plastic and jute fabric. This research studies the effect of fiber addition on the performance of composites focused on three properties, namely, mechanical, physical and thermal property. Composites consisting of high-density polyethylene (HDPE) and bleached jute-mat were prepared using compression molding at 145°C. Temperature is an important parameter to obtain a good product. It has found that best samples have been obtained at 145°C. The fiber found to burn out for higher temperature, and polymerization has not been completed for lower temperature. The incompleteness of polymerization has recognized by granule structure of samples. Considering all the factors associated with this fabrication process, a temperature of 145°C and pressure of 50 KN has been taken as the optimum parameters. Varying the amount of matrix and jute fiber is the most important parameter of this fabricated process. In this fabricated process it is seen that with the increase of fiber addition the density increases and follows the mixture rule. The density of the HDPE product without addition of fiber was found 0.94 gm/cc. Water absorption of the jute fiber reinforced composites was higher than that of glass fiber composites.

Tensile strength, young modulus, flexural strength and tangent modulus of both composites were found to be increased with increasing fiber addition but increases up to certain limit then decrease. Inclusion of fiber in HDPE/Jute improved the load bearing capacity (tensile strength) and the ability to withstand bending (flexural strength) of the composites. But at the same time with the incorporation of jute-mat fabrics, the tensile strengths of the composites are found to be decreasing in some of the cases. This decline in strength may be attributed to the presence of pores at the interface between the jute-mat fibers and the matrix; the interfacial adhesion may be too weak to transfer the tensile stress. It was also revealed that HDPE/Jute-mat composites had moderate mechanical properties (such as tensile strength, young modulus, flexural strength, and tangent modulus). The study shows that standard plastic like HDPE can be reinforced by adding jute-mat fibers with improved mechanical strength up to 25 wt. % incorporation.

Thermal analysis of the composites revealed that the thermal stability of jute fiber-HDPE composites is reasonable. The thermal stability of recycled HDPE/Jute-mat fiber composites is lower than that of jute fiber and recycled HDPE pellets. Compared to the conventional glass reinforced thermoplastics this reinforced thermoplastic has the major advantage of recyclability which represent a new spectrum of recyclable polymer composites. Additionally, studies on the durability, biodegradation, and long term behavior of the composites are necessary if they are to be used in load bearing applications. It would be nice to produce the samples by using injection molding machine instead of hot press machine. Because in hot press machine made samples presence of air bubbles are almost inevitable.

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