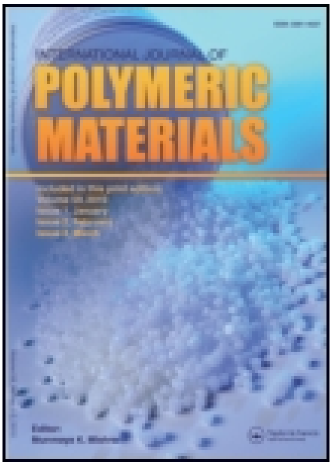

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Fabrication and Mechanical Characterization of Jute Fabrics: Reinforced Polyvinyl Chloride/ Polypropylene Hybrid Composites

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Jute fabrics such as reinforced polyvinyl chloride (PVC), polypropylene (PP), and a mixture of PVC and PP matrices-based composites (50 wt% fiber) were prepared by compression molding. Tensile strength (TS), bending strength (BS), tensile modulus (TM), and vbending modulus (BM) of jute fabrics' reinforced PVC composite (50 wt% fiber) were found to be 45 MPa, 52 MPa, 0.8 GPa, and 1.1 GPa, respectively. The effect of incorporation of PP on the mechanical properties of jute fabrics' reinforced PVC composites was studied. It was found that the mixture of 60% PP and 40% PVC matrices based composite showed the best performance. TS, BS, TM, and BM for this composite were found to be 65 MPa, 70 MPa, 1.42 GPa, and 1.8 GPa, respectively. Degradation

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tests of the composites for up to six months were performed in a soil medium. Thermo-mechanical properties of the composites were also studied.

Keywords hybrid composites, jute fabrics, polypropylene, polyvinyl chloride

INTRODUCTION

Having some extraordinary properties, composites are widely used all over the world. It is widely accepted that composite materials are the best choice for the numerous varieties of applications with desired properties. In the modern world, composite materials play a vital role in the fabrication of construction materials, automobiles, naval parts, and many more. Early work on composites chiefly emphasized the synthetic matrix and reinforcement [1–4]. It is well established that the synthetic materials are good in mechanical properties and durability. But due to increasing consciousness about the environment, these synthetic composites are considered with some due criticism as they are not easily biodegradable. Hence, in modern polymer technology, great concentration is given to invent environment-friendly composite materials to supplant synthetic composite matrixes and reinforcements like glass, carbon, aramid fiber, etc., with natural reinforcing fibers like jute, flax, hemp, etc. [5–8]. As a result, the term "bio-composite" has already found its place in the domain of composite materials. Some of these natural reinforcing fibers were successfully embedded into some other natural polymeric matrixes and even derivatives of natural polymers like cellulose, starch, and lactic acid were introduced to prepare bio-composites [9–11]. Lately, considering the environmental consciousness, desired properties in the material, and price, a compromise between the natural and synthetic polymers is being considered among polymer scientists. Keeping this view in consideration, some recent researchers have invented composites made of reinforcing natural fiber and synthetic polymeric matrixes to replace significant parts of synthetic and environmentally harmful materials [12–15].

Jute is the cheapest among all natural fibers. It could be the best choice for the above-mentioned purpose. In some of the earlier works, jute/plastic composites have been successfully prepared by different methods [16, 17]. Jute is an agricultural fiber grown mainly in South Asia. It has three principal constituents, namely α-cellulose, hemi-cellulose, and lignin. In addition, it contains minor constituents such as fats and waxes, inorganic and nitrogenous matters, and traces of pigments like β–carotene and xanthophylls. As it is inexpensive and available, jute can be used as the reinforcing agent for the manufacture of flat and complex-shaped components [18–22]. Jute was seen in many respects to be a potential composite reinforcement. The presence of -OH groups in the structure of jute fibers makes them susceptible toward moisture absorption from the surroundings. This hydrophilic nature lowers the compatibility and wetting behavior with the hydrophobic polymer matrix.

PVC has a linear structure similar to polyethylene. It is non-polar and density is 1.34 g/cm^3 (gram per cubic centimeter). PVC itself is hard and rigid but the addition of phthalate esters as plasticizers makes it soft and pliable and ideal for gloves, photographic dishes, and tubing. It is generally transparent with a bluish tint. It is attacked by many organic solvents but it has excellent resistance (no attack) to dilute and concentrated acids, alcohols, bases, aliphatic hydrocarbons, and mineral oils while it possesses a very good resistance (minor attack) to vegetable oils and oxidizing agents. It has a low permeability to gases. PVC exhibits greater tensile strength and high softening temperature (155°C). Throughout the world, more than 50% of PVC manufactured is used in the field of construction. It is cheap, durable, and easy to assemble as a building material. Its intrinsic properties make it demanding and suitable for numerous applications. In its rigid form PVC is available in sheets, which can readily be welded to produce tanks, trays, and troughs. PVC sheet is an excellent and very useful engineering plastic material. It is a very popular material and has many and varied uses within industry and fabrication applications. Almost all of the studies on PVC/wood-fiber composites have put emphasis on the improvement and up gradation of the fiber and plastic interface, the effect of the nature of the fibers, the impact of processing parameters, and the mechanical properties [23, 24].

Polypropylene (PP) is an amorphous thermoplastic polymer, made by the chemical industry and used in a wide variety of applications, including packaging, textiles (e.g., ropes, thermal underwear, and carpets), stationery, plastic parts and reusable containers of various types, laboratory equipment, loudspeakers, automotive components, and polymer banknotes. It is often opaque and/or colored using pigments. As a matrix material, PP is used in the current study because it has some excellent characteristics for composite fabrication. It has good resistance to fatigue and has a melting point of 170°C. Most commercial PP is isotactic and has an intermediate level of crystallinity between that of low density polyethylene (LDPE) and high density polyethylene (HDPE). PP is normally tough and flexible, especially when copolymerized with ethylene. Since it possesses several vital and useful properties such as dimensional stability, flame resistance, transparency, high heat distortion temperature, high mechanical strength, high impact strength, low moisture pickup and good dielectric properties, it is being used as engineering materials. In addition, polymers made from the monomer propylene are rugged and unusually resistant to many chemical solvents, bases, and acids. They also are used for filling, reinforcing, and blending purposes. PP with fibrous natural polymers of biomass origin is one of the most significant routes to create natural-synthetic polymer composites [25–30].

The objective of this work is to study the mechanical, thermo-mechanical, and degradation properties of Hessian cloth reinforced PVC and PP composites. For diversified industrial applications water uptake behavior of the resulting composites was also investigated.

EXPERIMENTAL

Materials

Bangladesh Jute Research Institute (BJRI), Dhaka, Bangladesh, was the main source of Hessian cloth (unbleached commercial grade, Tossa Jute). Polyvinyl chloride sheets and polypropylene pellets were procured from Polyolefin Company Ltd., Singapore.

Composites Fabrication

At 190°C granules of polymer PP were heat-pressed and made into thin sheets (0.20–.25 mm thickness) individually using a Carver Laboratory (USA Model 3856) press. After being cut into small pieces (15 cm × 12 cm), the polymer matrix sheets (PP and PVC) were kept in the desiccators until composite fabrication. To remove moisture, jute fabrics were dried in an oven at 105°C for 1 hr and then were cut into small pieces of dimension 15 cm × 12 cm. Composites were prepared by sandwiching four layers of jute fabrics (50%) between five layers of pre-weighted polymer matrix (PP, PVC, and a mixture of PP and PVC) and pressed at 190°C for 5 mins between two steel plates under a pressure of 5 tons. Afterwards, using another press (Carver, USA), the composite containing steel sheets was cooled to room temperature and then cut to the desired size.

Mechanical Properties of the Composites

According to DIN 53455 and DIN 53452 standard methods, the mechanical properties such as tensile strength (TS), bending strength (BS), tensile modulus (TM), and bending modulus (BM) were determined by a universal testing machine (INSTRON 1011) with a gauze length of 20 mm. The impact strength (IS) was measured according to DIN EN IS0179 standard in the flat-wise, un-notched mode using an impact tester (MT-3016). Hardness was determined by HPE Shore-A Hardness Tester (model 60578, Germany). All the results were taken as the average values of 10 samples.

Soil Degradation Tests of the Composites

Composites samples were buried in soil (having at least 25% moisture) for different periods of time. After a lapse of a certain period, samples were withdrawn carefully, washed with distilled water, dried at 105°C for 6 hr, kept at room temperature for 24 hr, and then measured for their mechanical properties.

Water Uptake of the Composites

Composite samples were immersed in the static water beaker at 25°C for different time periods up to 30 hours. Prior to immersion in the water, the weight of the samples was determined. After a certain period of time, samples were taken out from the beaker, wiped using tissue paper, and then the weight was taken. By subtracting the initial weight from the final weight, the water uptake (mass gained) was determined.

Thermal Properties

Evaluation of the thermal properties (onset, glass point, and offset of melting points) of the composites was performed using a thermo-mechanical analyzer (Linsesis TMA, L-77, USA).

RESULTS AND DISCUSSION

Comparative Studies of the Mechanical Properties of the Composites

Three types of composites were prepared based on jute fabrics, reinforced PP, PVC, and a mixture of PP and PVC hybrid matrices, and the mechanical properties were evaluated. The jute content in the composites was maintained at about 50% by weight. The mechanical properties, such as tensile, bending, impact, and hardness of the PVC sheet and jute/PVC composites (50 wt% fibers), were evaluated and the values are given in Tables 1 and 2. It was found that tensile strength (TS), bending strength (BS), tensile modulus (TM), bending modulus (BM), elongation at break (Eb%), impact strength (IS), and hardness of the PVC sheet were 39.3 MPa, 42.8 MPa, 0.676 GPa, 0.85 GPa, 16.4%, 4.94 kJ/m^2, and 98 Shore-A, respectively. Jute-based composites made of 50% fiber significantly improved the mechanical properties (TS, TM, BS, BM, and IS). Jute/PVC composites gained 14.5% increase in TS and

Table 1: Tensile properties of PVC sheet and jute/PVC composite (50 wt% fiber).

Materials	Strength (MPa)	Modulus (MPa)	Elongation at break (Eb%)
PVC sheet	39.3 ± 2	676 ± 45	16.4 ± 5
Jute composite/PVC	45 ± 2.5	800 ± 50	9.96 ± 4

Table 2: Bending, impact strength, and hardness of the PVC sheet and jute/PVC composite (50 wt% fiber).

Materials	Bending strength (MPa)	Bending modulus (MPa)	Impact strength (KJ/m^2)	Hardness (Shore-A)
PVC sheet	42.8 ± 2	850 ± 40	4.94 ± 0.5	98 ± 0.5
PVC/jute composite	52.2 ± 2.5	1100 ± 60	22 ± 1	97 ± 0.5

18.3% increase in TM over that of the matrix PVC sheet. It was also found that BS, BM, and IS were improved by 22, 29.4, and 345%, respectively, over that of the matrix material PVC. On the other hand, Eb% was reduced drastically because of low Eb% of the fibers compared to PVC. Shore hardness of the composites indicated that. due to incorporation of jute fibers inside PVC, the hardness of the composite did not reduce but had almost similar properties. From this investigation, it is clear that jute composites gained huge mechanical properties over the matrix material and thus indicated good fiber matrix adhesion.

The mechanical properties such as tensile, bending, impact, and hardness of the mixture of PP and PVC matrices based hybrid composites were evaluated. TS and BS of the composites with regard to PP content in the PVC are given in Figure 1. In the figure, 0% PP indicated jute/PVC composite and 100% denoted jute/PP composite. The figure shows that TS and BS values were increased gradually with the increase of PP content in PVC up to 60%, and with further addition of PP in PVC the values were gradually decreased. The TS and BS values of the jute fabrics reinforced PVC composites were found to be 45 and 52.2 MPa, respectively (indicated as 0% PP content in PVC in Figure 1). On the other hand, the TS and BS of jute/PP composites were found to be 50.5 and 55.9 MPa, respectively (indicated as 100% PP content in PVC in Figure 1). Incorporation of PP in jute/PVC composites improved the mechanical properties of the composites and mixture of PP and PVC matrix based composite containing 60% PP and 40% PVC performed the best results and reported that the TS and BS of 65 and 70 MPa, respectively. Tensile strength was found to be 51.87, 59.51, and 58.46 MPa for jute/(20% PP + 80% PVC), jute/(40% PP + 60% PVC) and jute/(80% PP + 20% PVC) composites, respectively, while BS values were found to be 57.42, 64.78, and 62.17 MPa, respectively. From this investigation, it is clear that the jute fabrics reinforced PP or PVC based composites possessed sufficiently lower values of TS and BS compared to that of the mixture of polymer matrix (PP + PVC) composites. The polymer matrix composite made of 60% PP + 40% PVC reinforced with jute was 44.4 and 28.7% higher TS than that of the PVC or PP based composites. Again, the BS values were found 34.1 and 25.2% higher compared to that of the PVC or PP matrix composites. The reason behind

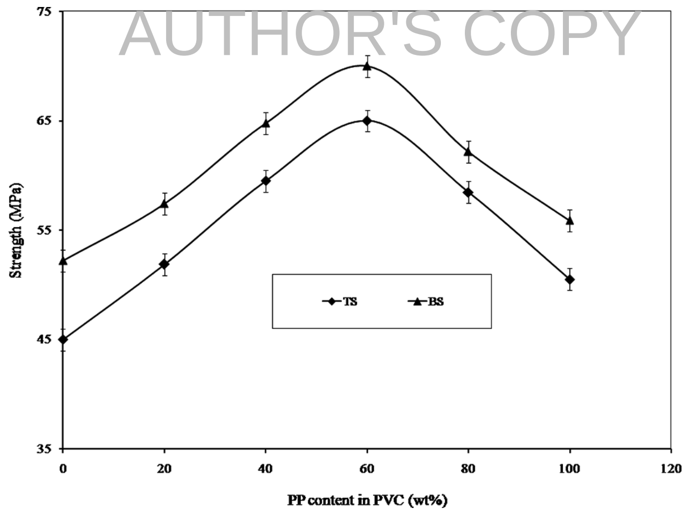

Figure 1: Tensile and bending strength of composites against PP content in PVC (wt%).

the increase of TS and BS for the mixture of PP + PVC composites may be explained on the basis of viscosity. During composite fabrication at higher temperature, the high viscous PP impregnated into the fiber and PVC caused better bonding. Though PP has lower TS and BS, several percentages of PP into the PVC can improve the TS and BS and thus indicates synergistic effect in the composites [25]. Actually, PP has a melting point of about 170°C but PVC has one of 155°C. The composites were fabricated at 190°C. At higher temperatures, the PP became too viscous and properly mixed with the jute and PVC. As a result, the composites containing 60% PP in the PVC performed the best.

The effect of incorporation of PP content in PVC on the tensile and bending modulus of the composites is plotted in Figure 2. From the figure, it is found that both tensile and bending modulus showed continuously increasing trends from 20 to 60% PP content in polymer matrixes such as TS and BS, and further increasing PP content decreased the values. The values of TM for PVC or PP based composites were found to be 800 and 1000 Mpa, respectively. On the other hand, the values of BM for PVC or PP based composites were found to be 1100 and 1270 MPa, respectively. The polymer matrix containing 60% PP showed 77.5 and 42% higher TM than that of PVC or PP based composites, respectively, and the value was found to be 1420 Mpa while the BM value was found 1800 Mpa, which was 63.64 and 41.73% higher than that of PVC or PP based composites, respectively. Tensile modulus was found to be 1050, 1250, and 1160 MPa for jute/(20% PP + 80% PVC), jute/(40% PP + 60% PVC), and jute/(80% PP + 20% PVC) composites, respectively, while BM values were found to be 1345, 1635, and 1535 MPa, respectively. The reason behind the decrease of mechanical properties above 60% PP content in

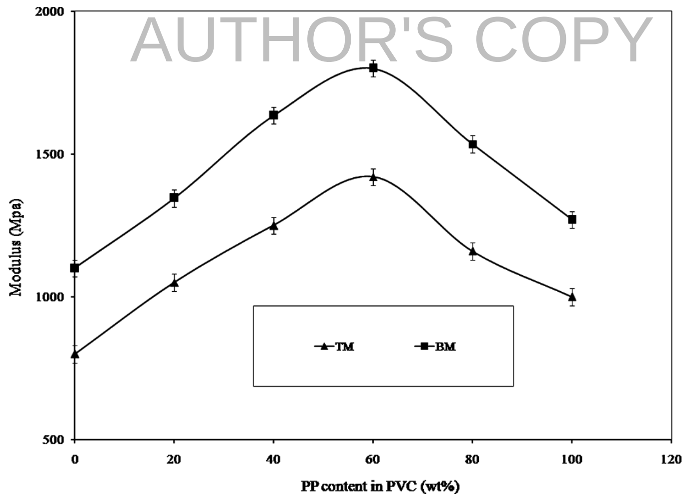

Figure 2: Tensile and bending modulus of composites against PP content in PVC (wt%).

polymer matrix is due to the high melt flow rate of PP. From this investigation, it is clear that jute fabrics reinforced PP or PVC based composites possessed sufficiently lower values of TS and BS compared to that of the mixture of polymer matrix (PP + PVC) composites.

The values of impact strength and hardness are depicted in Table 3. From the table, it is observed that the jute/(60% PP + 40% PVC) composite showed the highest impact strength and the value was found to be 24 kJ/m^2. From Table 3 it was also found that the hardness of the composites for all composition remained almost the same as the hardness of the PP and PVC sheet.

Relative Degradation of the Mechanical Properties of the Composites

Degradation tests of the composites (jute fiber/PP, jute fiber/PVC, and jute fiber/PP + PVC were performed in a soil medium at ambient conditions

Table 3: Impact strength and hardness of composites (50 wt% fiber).

Materials	Impact strength (KJ/m^2)	Hardness (Shore-A)
Jute fiber/PVC composite	22 ± 1	97 ± 0.5
Jute/20% PP + 80% PVC composite	22 ± 1	97 ± 0.5
Jute/40% PP + 60% PVC composite	23 ± 1	97 ± 0.5
Jute/60% PP + 40% PVC composite	24 ± 1	98 ± 0.5
Jute/80% PP + 20% PVC composite	21 ± 1	96 ± 0.5
Jute/PP composite	19 ± 1	96 ± 0.5

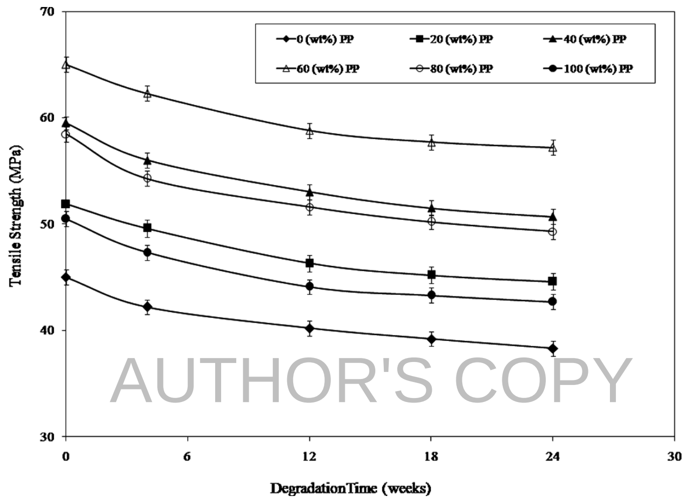

Figure 3: Variation of tensile strength (TS) with soil degradation time of different composites.

for up to 24 weeks. TS and TM values are plotted against degradation time and are shown in Figures 3 and 4. It was found that for jute/PVC and jute/PP composites, both TS and TM decreased slowly with time. After 24 weeks of soil degradation, the losses of TS values for jute/PVC and jute/PP composites were found to be 13 and 15%, respectively, and losses of TM were 19 and 20%, respectively. On the other hand, 15.2, 14.8, 12, and 15.7% losses of

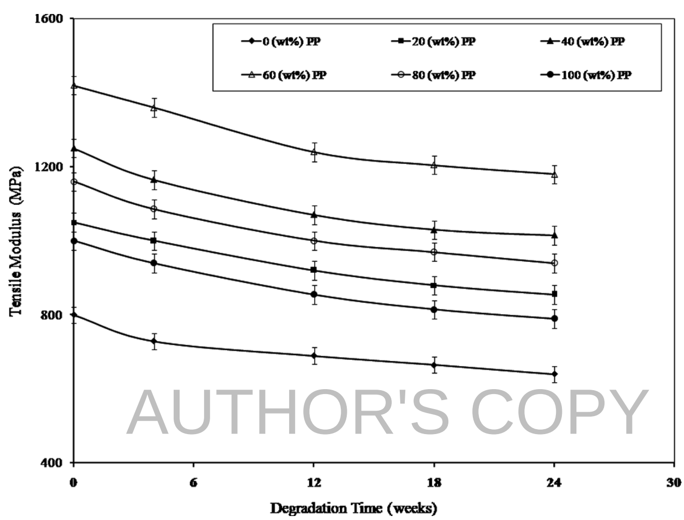

Figure 4: Variation of tensile modulus (TM) with soil degradation time of different composites.

TS were found for 20, 40, 60, and 80% PP based composites, respectively, and the losses of TM were found to be 18.6, 19, 17, and 19%, respectively. The above results revealed that both degradation values of TS and TM for jute/60% PP + 40% PVC composite were lesser than that of jute/PVC, jute/PP, and other jute/PP + PVC hybrid composites. Jute is a natural biodegradable fiber and because this fiber is cellulose based, it absorbs water within a couple of minutes, indicating its strong hydrophilic character, and becomes saturated with water. After the saturation point, moisture exists as free water in the void structure, which leads to delamination and void formation [9]. Cellulose has a strong tendency to degrade when buried in soil. Water penetrates from the cutting edges of the composites in jute-based samples and degradation of cellulose occurs in jute during a degradation test; as a result, the mechanical properties of the composites decreased significantly [6].

Similarly, BS and BM values were also decreased over degradation time and the results are depicted in Figures 5 and 6. It was found that the BS values were 16, 15.7, 15.4, 13, 15.2, and 16% decreased from their initial values for 0, 20, 40, 60, 80, and 100% PP content in PVC matrix based composites, respectively. On the other hand, the BM values that were 23, 22, 20, 18, 21, and 22% decreased for 0, 20, 40, 60, 80, and 100% PP content in PVC matrix based composites, respectively. From the above results it is clear that the reduction of BS and BM of jute/60% PP + 40% PVC composite were lower than that of jute/PVC, jute/PP, and other jute/PP + PVC hybrid composites. More than 80% of the strength of the jute/60% PP + 40% PVC composite was retained after 24 weeks of degradation in a soil medium.

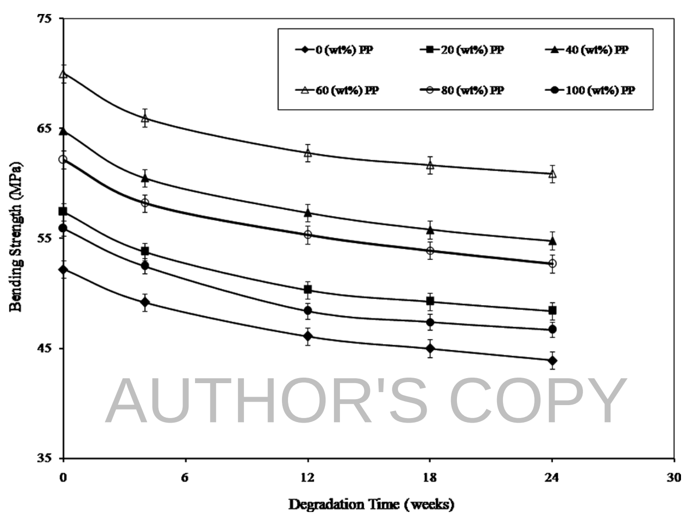

Figure 5: Variation of bending strength (BS) with soil degradation time of different composites.

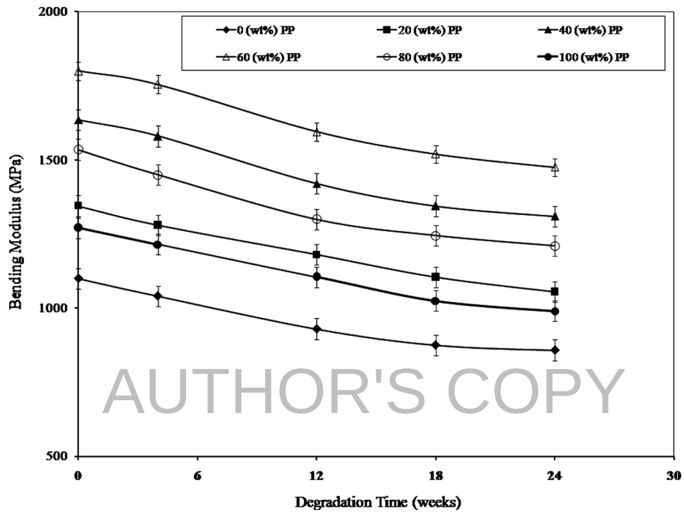

Figure 6: Variation of bending modulus (BM) with soil degradation time of different composites.

Weight Loss (wt %)

After 24 weeks of degradation of the composites, the weight loss was calculated and is shown in Figure 7. The weight loss of the composites was increased slowly with the extent of degradation time. After 24 weeks of degradation, the weight loss of the jute/PVC, jute /PP, jute/(20% PP + 80% PVC), jute/(40% PP + 60% PVC), and jute/(80% PP + 20% PVC) composites were

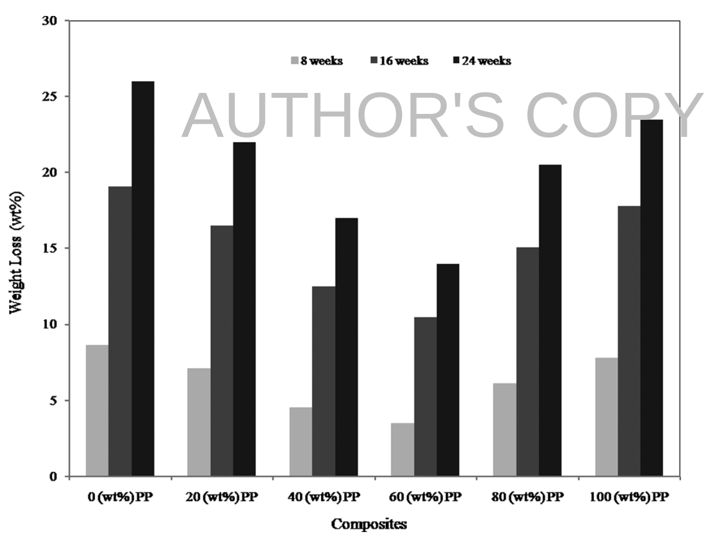

Figure 7: Weight loss (wt%) of various composites at different soil degradation times.

found to be 22.5, 19.32, 19.21, 18.35, and 18.54%, respectively. On the other hand, for the composite of jute/(60% PP + 40% PVC) weight loss was found to be 17.53%, which is lesser than jute/PVC, jute/PP, and other jute/PP + PVC composites. The reduction of the mass from the composites is attributed from the loss of the degradable fibers. PP and PVC are strongly hydrophobic and the hydrophilic fibers are incorporated inside PP and PVC. As a result, the hydrophilic nature of the fibers decreased drastically because of the coating of PP and PVC on the fibers inside the composites. During burial of the composites in the soil medium, microbial degradation took place and water might have entered from the edges of the composites and thus degraded the fibers slowly inside the composite [1].

Water Uptake of Composites

Water uptake (%) of the composites was plotted against different soaking time and is shown in Figure 8. For jute/PVC, jute/PP, jute/(20% PP + 80% PVC), jute/(40% PP + 60% PVC), and jute/(80% PP + 20% PVC) composites water uptake was found to be 13, 12.4, 11.8, 10.1, and 11.1%, respectively. On the other hand, for the composite of jute/(60% PP + 40% PVC) water uptake was found to be only 9.4%, which is lower than that of jute/PVC, jute/PP, and other jute/PP + PVC composites. These indicated that incorporation of 60% PP in PVC matrix composite showed better adhesion. It is known that jute is strongly hydrophilic. The hydroxyl (–OH) group is one of the important functional groups in jute fiber, which causes hydration in aqueous media and increment of the water uptake of the composites [25].

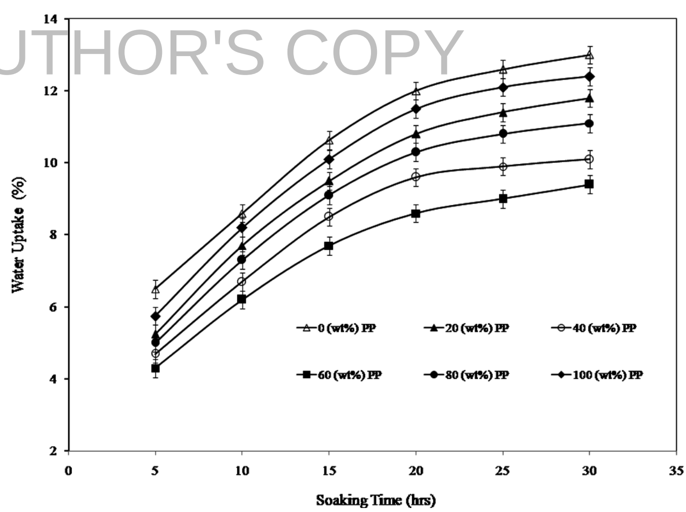

Figure 8: Water uptake of various composites against soaking time.

Table 4: Thermal properties of the composites (50 wt% fiber).

Materials	Onset of melting (°C)	Glass point (°C)	Offset of melting point (°C)
Jute/PVC composite	164	171	177
Jute/20% PP + 80% PVC composite	167	174	180
Jute/40% PP + 60% PVC composite	172	177	183
Jute/60% PP + 40% PVC composite	174	178	184
Jute/80% PP + 20% PVC composite	170	175	182
Jute/PP composite	165	172	178

Thermal Properties

Using a thermo-mechanical analyzer, the thermal properties (onset, glass point, and offset of melting points) of the composites were evaluated. The onset, glass point, and the offset of melting points of the composites are given in Table 4. The onset and offset of melting temperatures for the jute fiber/PVC were found to be 164°C and 177°C, respectively, while for fiber/PP composites the values were 165°C and 178°C, respectively. On the other hand, the onset and offset of melting temperatures for the jute/(60% PP + 40% PVC) composite were found to be 174°C and 184°C, respectively An important thermal property, glass point temperature for the jute/PVC, jute/PP, and jute/(60% PP + 40% PVC) composites, was found to be 171°C, 172°C, and 178°C, respectively. This investigation revealed that the thermal stability of jute/(60% PP + 40% PVC) composites was improved compared to that of the jute/PVC, jute/PP, and other jute/PP + PVC hybrid composites.

CONCLUSION

Hessian cloth (jute fabrics) reinforced polyvinyl chloride (PVC), polypropylene (PP), and mixtures of PP and PVC matrix based composites (50 wt% fiber) were prepared by compression molding and the mechanical properties were evaluated. It was found that 60% PP + 40% PVC based composite performed the best. TS, BS, TM, and BM of jute/PVC composite were found to be 45 MPa, 52.2 MPa, 0.8 GPa, and 1.1 GPa, respectively, and for jute/PP composite the values were found to be 50.5 MPa, 55.9 MPa, 1.0 GPa, and 1.27 GPa, respectively. On the other hand, TS, BS, TM, and BM for the mixture of 60% PP + 40% PVC based hybrid composite were found to be 65 MPa, 70 MPa, 1.42 GPa, and 1.8 GPa, respectively. From this comparative study, it was found that the jute/(60% PP + 40% PVC) based hybrid composite showed better mechanical and thermal properties compared to that of the jute/PVC, jute/PP, and other jute/PP + PVC hybrid composites.

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