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Investigation of an Optimum Method of Biodegradation Process for Jute Polymer Composites

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Abstract: - Natural fiber reinforced polymer composites are currently being developed as an alternative for plastic material because of having some environmental benefits such as biodegradability, reduced dependence on non-renewable material, greenhouse gas emissions and enhanced energy recovery. This study focuses on the fabrication of jute polymer composites, biodegradation and the investigation of an optimum method of biodegradation. Polyethylene and Polypropylene were reinforced with 5%, 10% and 15% of fiber. Jute fiber of 1mm and 3mm fiber length were used to fabricate composites using compression molding. Degradation behavior of composites was studied in terms of percentage weight loss. Samples are kept in compost heap and in soil burial to observe the degradation of the specimens. In weather degradation the effect of natural phenomena were observed. The biodegradability of composites was enhanced in compost condition with respect to soil burial and weather degradation. Degradation rate were higher in compost condition considering natural weather and soil and higher fiber reinforced ratio shows higher degradation.

Keywords: - *Jute, Polymer, Composites, Biodegradation*

I. INTRODUCTION

Polymeric materials have gained a wide influence due to their structural versatility, excellent mechanical and thermal properties and high stability [1].

But the non-biodegradability of most commercially available plastic has caused many environmental problems associated with their waste pollution and disposal. These plastics are characteristically inert and resistant to microbial attack and therefore they remain in the nature without any degradation for every long time [2]. However their increasing accumulation in the environment has been a threat to the planet.

Since the end of the nineties, biodegradable polymers have begun to attract interest because of their potential to substitute traditional, non-biodegradable polymers [3]. Biopolymers offer environmental benefits such as biodegradability, greenhouse gas emissions and renewability of the base material [4]. The majority of biodegradable polymers are not widely used because they are too expensive and the range of the material selection suitable for various end-use products is limited [5].

For the purposes of this research, the term “composites” are materials that are comprised of strong load-carrying materials (known as reinforcement) imbedded in a weaker material (known as matrix). Reinforcement provides strength and rigidity, helping to support structural load. The matrix, or binder, maintains the position and orientation of the reinforcement and balance loads between the reinforcements. In this form, both fibers and matrix retain their physical and chemical identities, yet they produce a combination of that cannot be achieved with either of the constituents acting alone.

With the increasing environmental concerns, there has been a significant research interest in the area of natural fiber-based composites [6]. The use of natural fibers as reinforcing material in polymer matrix composites provides positive environmental benefits with respect to ultimate disposability [7]. Degradation tendency in these fiber reinforced composites is also a deciding factor in the use of these materials for various high performance applications and their ultimate disposal at the end of their life cycle [6].

Bangladesh is an agricultural based country and every year it produces a large amount of jute. Based on this, jute fibers have been used as a reinforcing material for composite fabrication in this work.

The improper disposal and treatment of solid waste is one of the gravest environmental problems faced by most of the countries. With the increasing globalization and modernization, generation of waste for disposal is likely to increase still further. Importantly, in many parts of the world proper waste disposal facilities do not exist and the wastes are simply discarded in the surrounding areas [8]. Ultimately, we have to depend on the nature for biodegradation of the materials.

Biodegradation of a polymeric material is chemical degradation brought by the action of naturally occurring microorganisms such as bacteria and fungi via enzymatic action into metabolic products of microorganisms [9]. Biodegradation of the jute polymer composites will encourage increased use in composites and hence capture ever growing market share, boost the agricultural based economy and help the world to make it more environmental friendly.

Yuksel Orhan et al [10] worked on biodegradation of plastic compost bags under controlled soil conditions. Degradation of plastics was determined by the weight loss of sample, tensile strength, carbon dioxide production, chemical changes measured in infrared spectrum and bacterial activity in soil.

Hee-Soo Kim et al [5] carried out experiments on the biodegradability of bio-flour filled biodegradable poly (butylene succinate) (PBS) bio-composites in natural and compost soil. The percentage weight loss and the reduction in mechanical properties of PBS and the bio-composites in the compost soil burial test were significantly greater than those in the natural soil burial test. The biodegradability was enhanced with increasing bio-flour content.

Sanjay K. Nayak [6] studied the degradation and flammability behavior of pp/banana and glass fiber-based composites. Further, BFPP composites exhibited higher degradation tendency as compared with the virgin polymer as well as the hybrid composites. Extent of biodegradation in the irradiated samples showed increased weight loss in the BFPP samples thus revealing effective interfacial adhesion upon hybridization with glass fibers.

J. Chlopec et al [11] studied on the influence of the environment on the degradation of polylactides and their composites. The degradation speed is dependent among others on the viscosity of the applied fluids and thus, their ability of penetration in the polymer’s structure and on the interfacial boundaries.

R. Kumar et al [8] carried out experiment on biodegradation of flax fiber reinforced poly lactic acid. Different amphiphilic additives can be added for delayed or accelerated biodegradability.

Prafulla K. Sahoo et al [12] investigated from the experiment on preparation, characterization, and biodegradability of jute-based natural fiber composites super absorbents that the water absorption of the grafted composites with SS was more than 35 times greater than that of the un grafted fiber. The biodegradability of the grafted crosslinked composite with sodium silicate (SS) was lower than the other samples due to dispersed silicate layers in the composite matrix.

II. MATERIALS AND METHODS

The middle parts of jute fibers were taken in this study and to prepare short fibers, the jute fibers were chopped into the lengths of approximately 1 mm and 3 mm. A commercial grade polypropylene (PP) and polyethylene (PE) was used in this study. Melting point of this polypropylene and polyethylene were measured and found to be 170°C and 125°C. In the literature it is mentioned that the melting point of commercial grade polypropylene lies in the range of 160°-170°C and polyethylene lies in the range of 115°-130°C.

2.1Composite fabrication

For the fabrication of the composites polypropylene/Polyethylene matrix and jute fibers were taken in different weight fractions for reinforcing fiber length of 1mm and 3mm (Table 2.1).

2.2 Preparation of composites by *compression* moulding

After loading the mould in the hot press machine (50±5%) KN pressure is applied to get the desired shape and possible homogeneity. *T*he temperature set points were (125°±10^0) C for PE and (170°±10^0) C for PP. About 30 to 40 min is required to reach the desired set points. When the temperature was raised at set points it was kept at those temperatures for 10 min to melt properly. After completion of heating when the pressure down to zero then pressure of (50±5%) KN was applied again to avoid the void and to have a desired thickness.

The composites get from the compression moulding, sized: 126mmx126mmx3mm. (Figure 2.1).

2.3 Biodegradation

Biodegradation is the chemical dissolution or breakdown of materials. It occurs with enzymatic action and involves living organisms (micro/macro). Molecular degradation is promoted by enzymes and can occur under aerobic and anaerobic conditions, leading to complete or partial removal from the environment. Linear polymers are generally more biodegradable than branched polymers. The biodegradability of jute polymer composite has been examined in various environments such as in the soil, compost and weather.

2.3.1 Degradation by Compost

Biodegradability of the samples was studied by weight loss over time in a compost condition. Compost degradation is carried out by following the ASTM D5338. The biodegradation of the specimen was checked after 15 days, 30 days and for 45 days on the compost heap. Samples are placed in 250ml Pyrex bottle containing compost. These bottles were placed in a temperature controlled water bath. To ensure homogeneity of temperature a stirrer was placed in that water bath to create water circulation. For the survival of microorganisms of the compost O_2, temperature and water are required. Water was poured in the bottles in every two days. Water bath provided the temperature. Air compressor was placed to ensure proper O_2 supply in the compost. First day the temperature of the water bath was ($35^0 \pm 5^0$) C. After that the temperature was maintained at ($58^0 \pm 5^0$) C for next 4 days. Consecutive 28 days water bath was set to ($50^0 \pm 5^0$) C and rest days water bath was set to ($35^0 \pm 5^0$) C. The samples were dug out at 15,30,45 days intervals throughout the time, washed with water, dried in a vacuum oven at 50±1ºC for 24 h before evaluation. The samples were then weighed to determine the weight loss.

2.3.2 Soil Burial Degradation

Soil burial is a traditional and standard method for degradation because of its similarity to actual conditions of waste disposal. Biodegradability of the samples was studied by weight loss over time in a soil environment. Samples were weighed (3.28gm) and then buried in the soil for up to 80 days. The soil was maintained at approximately 20% moisture by injecting water to keep the microorganisms active and samples were buried at a depth of 5 cm. The buried samples were dug out at 30, 60, 80 days intervals throughout the time, washed with water, dried in a vacuum oven at 50±1ºC for 24 h before evaluation. The samples were then weighed to determine the weight loss.

2.3.3 Degradation by weather

Weather testing of composites is the controlled polymer degradation and polymer coating degradation under lab or natural conditions. Just like erosion of rocks, natural phenomena can cause degradation in polymer systems. Both thermoplastics and natural fibers are susceptible to environmental stresses, including temperature, moisture, light [ultraviolet (UV) radiation], and chemical agents such as organic solvents, ozone, acids, and bases, though most polymers are primarily degraded by oxidative reactions. Outdoor weathering is a common case of oxidation enhanced by photochemical reaction, which is referred to as photo degradation. Photo degradation of some thermoplastics can result in changes to polymer morphology because of chemical cross linking or chain scission. Samples were weighed (3.23) and then buried in the natural weather for up to 80 days. The samples were weighed after 30, 60, 80 days to determine the weight loss.

2.4 Percentage Weight loss In Specimen after degradation

The time variation of percentage weight gain (wt) can be measured as:

$$wt = \frac{Wo - W(t)}{W} x\, 100$$

Here W(t) is the total weight after time t, W_o is the reference dry weight of the specimen before biodegradation.

III. RESULT AND DISCUSSION

3.1 Percentage weight loss of jute fiber reinforced polypropylene and polyethylene composites (as a function of fiber length and weight fraction) after biodegradation.

Figure 3.1(a) and (b) shows the variation of the percentage weight loss as a function of time for jute fiber reinforced polyethylene and polypropylene composites. The minimum value of % weight loss in weather condition is 0.65, for 5%, 1mm fiber reinforced PP composites after 30 days and the maximum value of % weight loss is 3.67, gain from 15%, 3mm fiber reinforced PE composites after 80 days.

Figure 3.2(a) and (b) shows the variation of the percentage weight loss as a function of time for jute fiber reinforced polyethylene and polypropylene composites. The minimum value of % weight loss in soil burial condition is 0.62, for 5%, 1mm fiber reinforced PP composites after 30 days and the maximum value of % weight loss is 2.21, gain from 15%, 3mm fiber reinforced PE composites after 80 days.

Figure 3.3(a) and (b) shows the variation of the percentage weight loss as a function of time for jute fiber reinforced polyethylene and polypropylene composites. The minimum value of % weight loss in compost condition is 0.89, for 5%, 1mm fiber reinforced PP composites after 15 days and the maximum value of % weight loss is 6.92, gain from 15%, 3mm fiber reinforced PE composites after 45 days.

Figure 3.4(a) and (b) shows the variation of the percentage weight loss as a function of biodegradation process for jute fiber reinforced polyethylene and polypropylene composites. The maximum degradation rate is 6.92 for compost degradation, 3.67 for weather degradation and 2.21 for soil burial degradation. In case of weight loss, degradation rate is maximum for compost condition. So compost condition enhances the biodegradation rate.

3.2 Optimum method of biodegradation process

- In this research work the degradation rate was observed in weather, compost and soil burial degradation methods in terms of % weight loss.
- Based on above figures degradation rate follows the sequence of:

Compost>Weather > Soil burial

- Compost show better degradation rate because of following reasons
- Microorganism accelerates the degradation process.
- Controlled environment.
- Temperature

IV. CONCLUSIONS

This study has covered the major concerns about the polymers, natural fiber reinforced polymer composites and biodegradability. In this work biodegradability of jute reinforced polymer composites were studied over time in compost, soil burial and weather condition. Degradation rate was designated in terms of weight loss. In the time scale of this study compost showed highest degradation rate and soil was the lowest. The biodegradability in compost condition was almost 60 percent higher considering soil which concludes compost condition as optimum degradation method. In compost condition rate of degradation was accelerated by factors like temperature, water and air. Pure polymers didn't lose their weight due to non biodegradable characteristics. Microorganisms mostly consume the fiber parts. Composites reinforced with larger fiber length showed higher degradation rate. Higher fiber loading gives microorganism's larger surfaces to consume and results higher degradation rate. Over time larger surfaces became smaller and became easier target for microorganisms. This explains reason of higher degradation rate in longer incubation time. Polyethylene showed slightly higher degradation rate concerning polypropylene but not significant.

This study concludes that the opportunities for Bangladesh grown jute fiber reinforced composites is enormous. The method and the rate of biodegradation will encourage increased use in composites and help the world to make it more environmental friendly.

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Table 2.1: Relative Amounts of Reinforcing Materials and Polymer Matrix by Weight Fraction.

Reinforcing fiber (Jute) weight fraction (%)	**Polymer matrix (Polypropylene/Polyethylene) weight fraction (%)**	**Composites (Jute : PP/PE)**
None	100	100
05	95	05: 95
10	90	10: 90
15	85	15 : 85

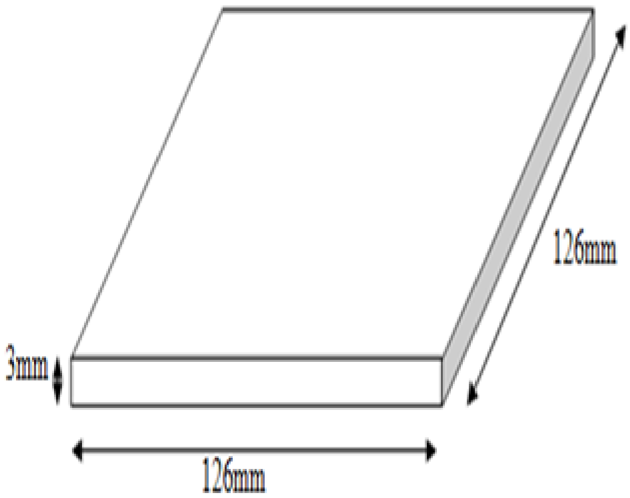
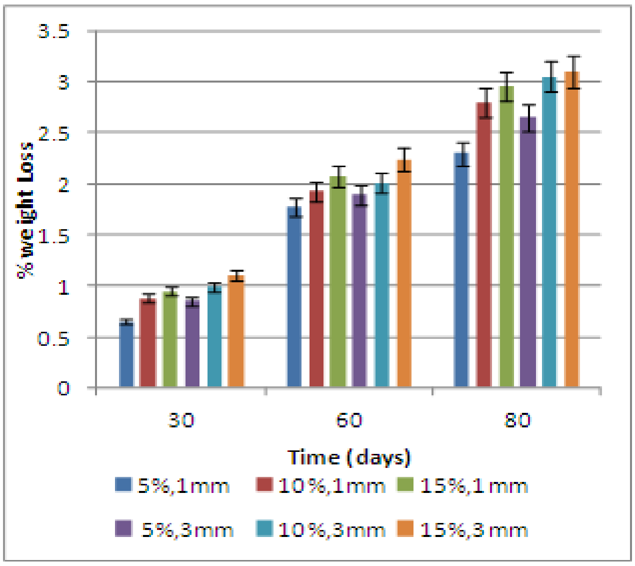
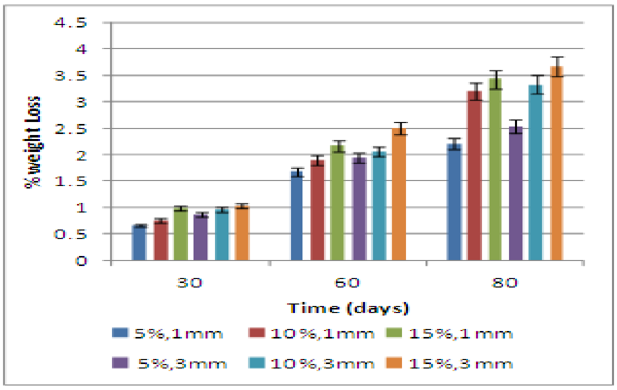


Figure 2.1: Composite after demoulding

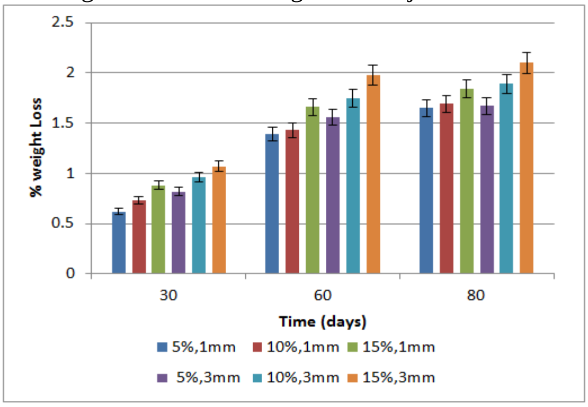


(a)



(b)

Figure 3.1: Effect of weather degradation on % weight loss of jute reinforced PP(a) & PE(b) composites



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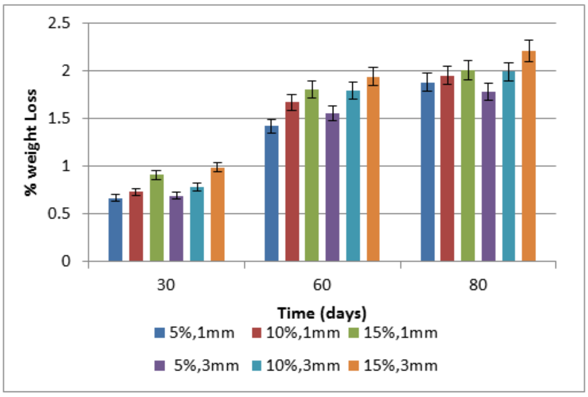
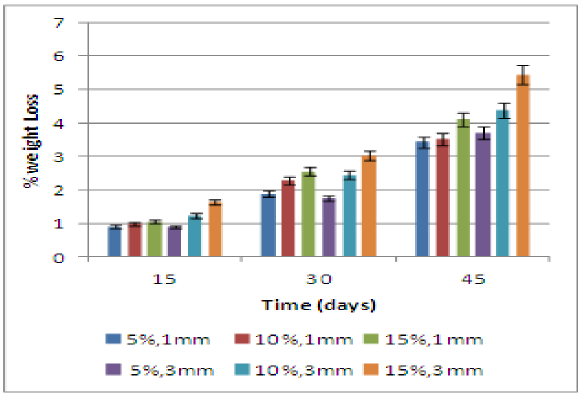


(b)

Figure 3.2: Effect of soil degradation on % weight loss of jute reinforced PP(a) & PE(b) composites



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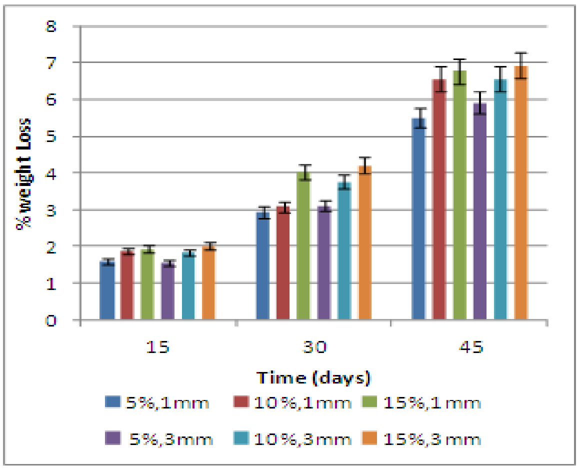
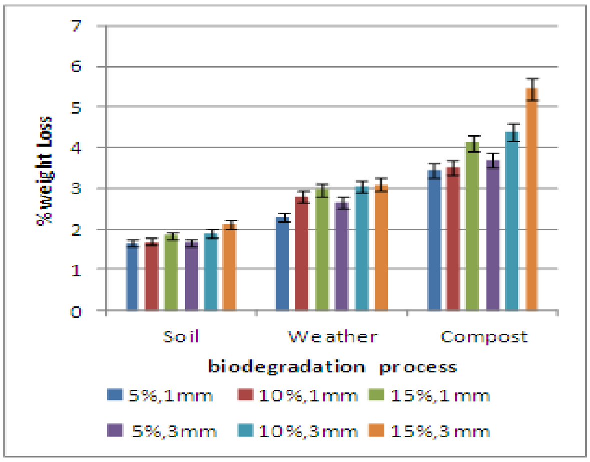
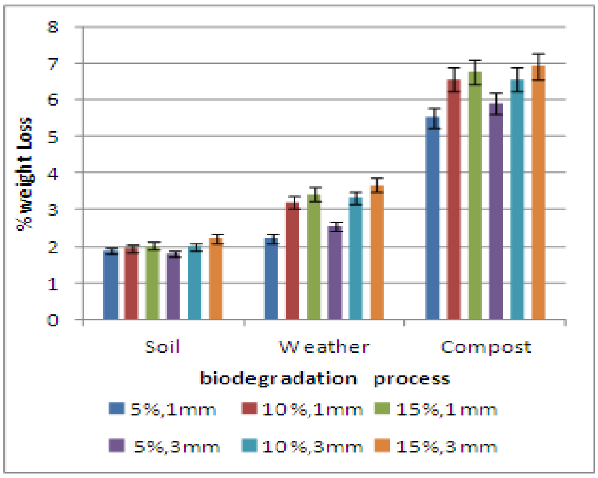


(b)

Figure 3.3: Effect of compost degradation on % weight loss of jute reinforced PP(a) & PE(b) composites



(a)



(b)

Figure 3.4: Effect of natural resources (soil, weather & compost) on the biodegradation rate of jute reinforced PP(a) & PE(b) composites in terms of % weight loss