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Mechanical, Electrical and Thermal Properties of Jute Fabric Reinforced Hybrid Matrix Composite: Impact of *Diospyros peregrina* Juice

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ABSTRACT

Jute fabrics were treated by *Diospyros peregrina* (1%, 3%, 5%, 10%, 20% formulations) juice at 25^{0}C for preparing composite to characterize the mechanical properties. The mechanical properties like tensile strength (TS) were increased 118% higher than virgin jute fiber composite. The thermal properties were observed by FT-IR and TGA where found changes in the fiber structure. The *Diospyros peregrina* treated cellulose-based reinforced PET+LLDPE composite had prepared by compression molding with the optimized (62%) jute content. The Tensile Strength (TS), Bending Strength (BS), Tensile Modulus (TM), and Bending Modulus (BM) of the composites were found 58, 36, 1440, and 1027 MPa which were higher than without *Diospyros peregrina* composite. The dielectric properties, water uptake, water, and soil degradation were performed as a significant improvement. The findings revealed that *Diospyros peregrina* juice treatment can lead to effective for the thermal and mechanical properties changes for the sustainable development of jute fiber-reinforced composite materials.

1. INTRODUCTION

The research interest of composite materials is increasing day by day for its potential applications in the field of aerospace, sports, industries, medical, and other mechanical and civil engineering sectors [1]. There are generally two parts that formed composite materials, one is polymer matrix and the other is a reinforcing agent. In recent years, composite materials based on thermoplastic resins are being attracted due to their very good processing features [2].

The natural fiber-reinforced composites have attracted substantial importance as a potential structural material in different applications. Natural fibers like jute, sisal, coir, and banana show various attractive features such as low cost, lightweight, high specific modulus, renewability, and biodegradability [3-7]. Among these fibers, jute is a particular interest because jute fibers have moderate tensile and flexural properties compared with other natural fibers [8]. However, the major drawbacks of jute are their poor mechanical properties and high moisture absorption [9]. The other issue is its hydrophilic nature that creates a harmful effect on almost all properties, including dimensional stability [10] and also it possesses poor adhesion with hydrophobic polymer matrix [11]. So, to overcome these problems, surface modification of jute is necessary by using a different chemical treatment like alkalization, bleaching, grafting, etc. These treatments not only decrease the water absorption capacity of the fiber but also ensure the better fiber-matrix interface adhesion. Many researchers are still working on jute fibers based composites to make better compatibility between fibers and polymer matrices. Khan *et.al* [12[used silane and acrylic monomers to improve the mechanical properties of jute-biopol composite and they found that tensile properties were increased up to 80%. According to the investigations on mechanical properties of jute-polyester composites by B. N. Dash and his co-workers [13], delignification (bleaching) brought better adhesion between fiber and polymer matrix. Joseph & co-workers [14-15] observed that permanganate treated sisal fiber-reinforced low-density polyethylene (LDPE) composites where an enhancement occurs in tensile properties due to the permanganate induced grafting. Researchers worked on jute fibers/polyolefin composites and reported improved physicomechanical properties of the composites [16-17]. The investigations of different chemical modifications including permanganate treatment on natural fiber-reinforced composites have been reviewed by Xue Li *et al*. [18] and found significant improvement of mechanical properties. The oxidation of cellulose was performed by different researchers with potassium dichromate-sulfuric acid, potassium dichromate-oxalic acid, potassium permanganate, sodium hypochlorite, etc. and

positive modifications were found [19–21]. Bleaching of jute fiber with sodium chlorite had carried out to decrease its hydrophilicity and bring better adhesion between fiber and polymer matrix [13]. Khan *et. al* [22-25] used vinyl monomers like 2-ethyl hexyacrylate (EHA) and 2-hydroxyethyl methacrylate (HEMA) as additives in jute plastic composites with enhanced mechanical properties.

The *Diospyros peregrina* fruit [local name: gaub] belongs to the Ebenaceae family locally called River ebony, Gaub, and/or Indian persimmon. *Diospyros peregrina* is a medium-sized evergreen tree that grows throughout Bangladesh. The extremely slimy pulp comes out of the fruit as gum exudates which mainly contained triterpenes, alkenes, flavonoids, and tannins [26-27] and had already shown it's antioxidant [28], antidiabetic [29-30], antidiarrhea, and antidysentery properties [31]. This plant has traditionally been used as an aphrodisiac, astringent, bactericide, and tonic, and for the treatment of many ailments, e.g., diarrhea, cholera, dysentery, fever, malaria, menorrhagia, and sore throat. Fruits content is mainly alkenes and triterpenes. The boatmen of this subcontinent usually rub the fruit-juice of *Diospyros peregrina* on the undersurface of boats and fishermen use the same in their fishing net to protect them from rotting. The aqueous extracts of *Diospyros peregrina* fruit have been used in the radiation vulcanized (0 to 20 kGy) natural rubber latex (RVNRL) films as a natural antioxidant to evaluate the mechanical properties after thermal aging at 100°C for 24 hr [28]. They found that the addition of different concentration of natural antioxidant into natural rubber latex improve the aging property of the film. Where optimized the decreasing in tensile strength of rubber film with 10 phr natural antioxidant and 15 kGy radiation dose.

From the above-mentioned literature, our aim of the present study is to investigate the influence of gummy *Diospyros peregrina* fruit extracts as a natural cross-linking agent on the mechanical, thermo-mechanical, thermal, crystallization, and swelling properties of Jute fiber reinforced polymer composites.

2. EXPERIMENTAL

2.1 Materials

Diospyros peregrina (Gaub) fruit was collected locally and cellulose-based Jute fibers were obtained from the Bangladesh Jute Research Institute (BJRI), Dhaka, Bangladesh. Poly-ethylene Terephthalate (PET) and Linear Low-Density Polyethylene (LLDPE) were purchased from MITSUIPET Company, Thailand, and Uniplast Company Saudi Arab respectively.

Methods:

2.2 Fiber Surface treatment

The concentrations of Gaub fruit extract (0.5-10%) were prepared in distilled water. The jute fabric was cut into (14 to 20 cm) and dried in an oven for one hour. It was treated by 0.5, 1, 3, 5 and 10% solution of gaub for 2 minutes. After that, the treated samples were dried by sunlight. The dried jute fabrics were stored in a sealed plastic bag to avoid atmospheric moisture contamination before thermal analysis and composite processing.

2.3 Composite Fabrication method

The matrix (10% PET in LLDPE) was prepared using a Twin Screw Extruder machine (Type-LTE 16-Lab Tech Engineering Company) by mixing PET and LLDPE granules. The PET+LLDPE matrix-based composites (10% PET) were made by compression molding. The treated jute fabric was cut into the desired size and recorded the weight of jute and hybrid sheet. Composites were prepared by sandwiching four layers of jute fabrics between five layers of hybrid sheets alternately. The fiber weight fraction of the composite was calculated as 62%.

2.4 Fourier transform infrared (FTIR)

IR spectra of bleached jute fiber and gaub treated jute fibers were recorded with an IR spectrometer using the KBr pellet technique.

2.5 Thermal Analysis of fiber

Thermogravimetric (TGA) measurements were performed under a nitrogen atmosphere (60ml/min) using a thermal gravimetric analyzer (TGA-Model, Universal V4.5A TA). For analysis 6 mg to 10 mg of fibers was taken. Fiber samples were heated between the temperatures 250C to 5000C at a rate of 100C/min.

2.6 Mechanical properties measurement test

The tensile properties of the composites were determined using a Universal testing machine (Model: H 50 KS-0404, Hounsfield Series S, UK) gauge length of 20 mm and crosshead speed 10 mm/min. The tensile properties were measured followed by DIN 53455 standard method and bending properties were measured followed by the ASTM D 790 standard method [32]. Dynamic Charpy impact tests were conducted on the unnoched mode of the composites

specimen according to ASTM D 6110-97 using an Impact tester (MT-3016, Pendulum type, Germany). Minimum five composites samples were tested to account for statistical scatter and to arrive at the mean values. The entire test was carried out at room temperature.

2.7 Electrical properties

The electrical properties of the composite were carried out by using the Wayne Keer Inductance analyzer (3255B). For electrical properties measurements, the rectangular-shaped samples were well polished to remove any roughness and the two surfaces of each sample were coated with silver paste as a contact material for electrical measurement. The dielectric properties, especially the dielectric constant and dielectric loss of both the treated and untreated composites were calculated from the measured capacitance of samples using the relation $\varepsilon = ct/\varepsilon A$, where C is the capacitance of the sample in a vacuum and $\varepsilon 0$ = Permittivity of air (8.85×10^{-12}), A= Area of a cross-section of the sample, t= Thickness of the sample.

2.8 Water uptake

Water uptake of the composites samples was carried out in deionized water at room temperature (25°C). This test was carried out up to70 minutes. Before immersion in water, the specimens were dried in an oven at 105°C and cooled in a desiccator using silica gel, and then weight was taken (Wdry). After certain periods, samples were taken out from the bath and wiped using tissue paper, then weighed (Wwet). Water uptake was determined followed by:

$$\text{Water uptake (\%)} = (W_{wet} - W_{dry})/ W_{dry} \times 100$$

2.9 Water and soil degradation

Water degradation tests of the composites were performed in deionized water at room temperature and carried out up to 70 mins. For aqueous degradation, after taking weight the specimens were placed into glass beakers containing 100 ml of deionized water. Setting point of time, samples were taken out to be dried for 6 hours at 1000c then reweighted for calculation.

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

3. RESULT AND DISCUSSION

3.1 FT-IR analysis of the fiber

The FTIR spectra of jute fabric in Figure 1 showed a long and broad peak at 3406.29 cm^{-1} indicating the presence of H-bonded OH groups. A medium band observed at 2902.87 cm^{-1} indicates the presence of C-H stretching in the fabrics. A very short peak observed at 2129.41 cm-1 indicates the presence of –C≡C- bond stretching vibration. A small peak observed at 1730.16 cm-1 indicates the presence of C=O stretching of unsaturated aldehyde or ketones. Very small two peaks observed at 1629.85 cm^{-1} and 1597.06 cm^{-1} indicates the presence of –C=C- stretching and N-H bending respectively. The very short peak observed 1502.55 cm^{-1} provides the presence of C-C stretching in the ring. Other peaks observed at 1458.16, 1425.40, 1373.32, 1321.24, 1232.51, 1159.22, and 1111.00 cm^{-1} attributed to the presence of C-H bending, rocking, N-O symmetric stretching, C-N stretching, C-O stretching in the fabrics. A small and narrow peak observed at 896.90 cm-1 indicates C-H loop aromatics in the ring. In the FTIR spectra of Gaub treated jute also showed no massive difference with jute fabric. The FTIR spectra (Fig.2) of Gaub treated jute were also observed in almost the same region of the frequencies having similar intensities to jute fabric. The FTIR spectra of Gaub treated jute observed at 3421.72, 2900.94, 2127.48,1734.01, 1635.64, 1624.06, 1597.06, 1506.41, 1458.18, 1429.25, 1373.32, 1336.67, 1321.24,1236.37, 1111, 1060.85, 1035.77 cm^{-1} etc. which are identical like jute fabric. The findings revealed that no chemical reaction occurred between jute and Gaub compound but some physical modification is observed**.**

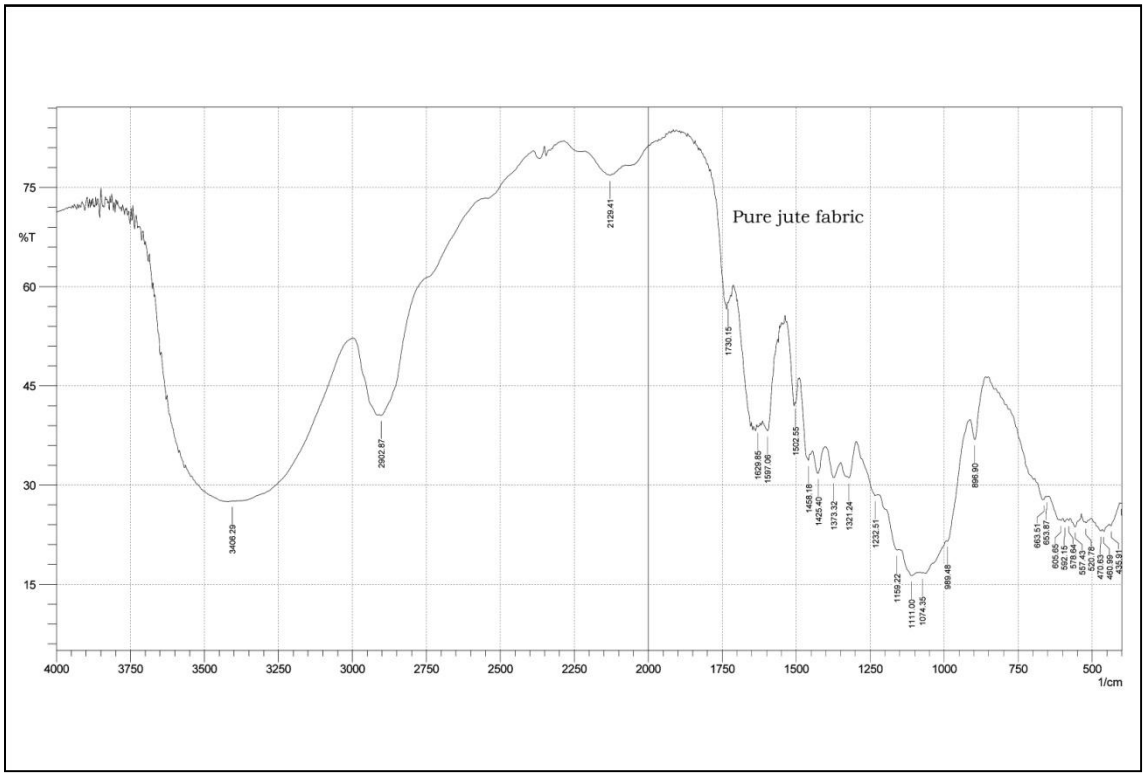

Figure No. 1: The FTIR study of pure Jute fiber

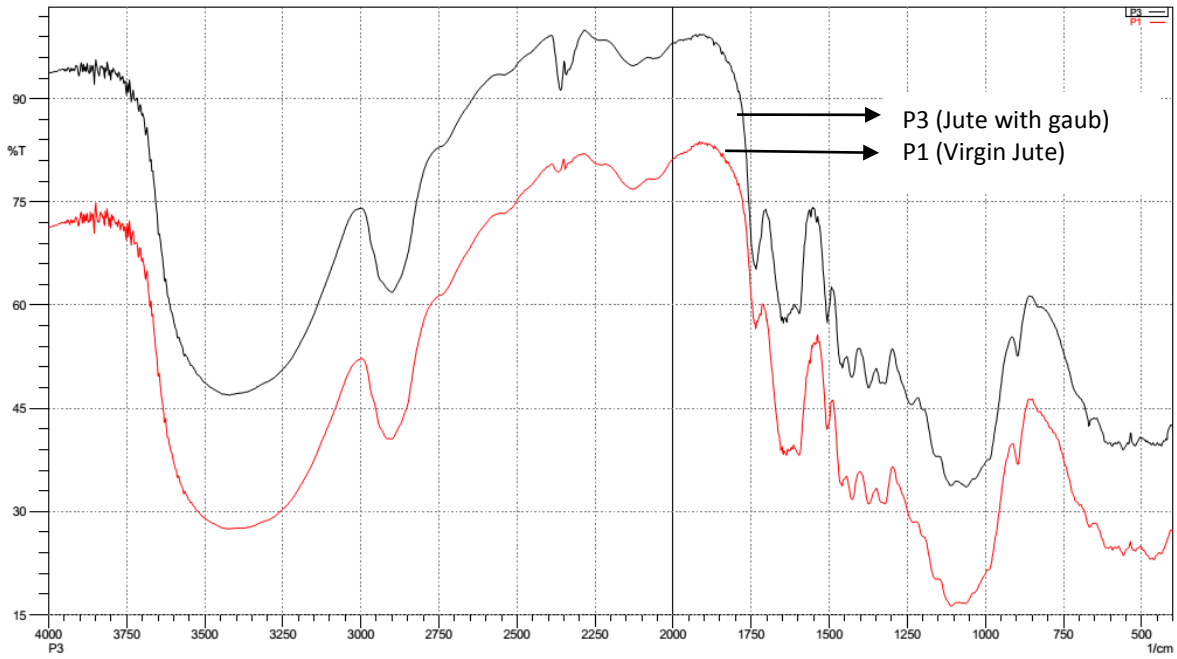

Figure No. 2: P1_P3: Comparative study of FTIR the virgin jute fiber and treated with gaub as a coupling agent

3.2 TGA analysis of the fiber

Thermal gravimetric analysis (TGA) was used to measure the weight loss of fibers as a function of rising temperature. The weight loss in fibers occurs due to the decomposition of cellulose, hemicelluloses, and lignin constituents during heating. Higher decomposition temperature gives greater thermal stability [33].

Figure 3 is stated three stages of weight loss increasing the temperature. The first stage of weight loss was observed between 25-200^{0}C, which was correspondence to the release of moisture content by the fiber. The second stage of weight loss occurred within the temperature between 254-348^{0}C that related to the degradation of lignin and hemicelluloses. The last stage of weight loss occurred at the temperature of 356-450 ^{0}C that indicated the degradation of cellulose and other cellulosic matters from the fiber [34]. The degradation process of untreated fiber is faster than treated fiber in the second stage which revealed that hemicelluloses and lignin constituents were partially removed from the treated fibers which enhance the thermal stability of fiber.

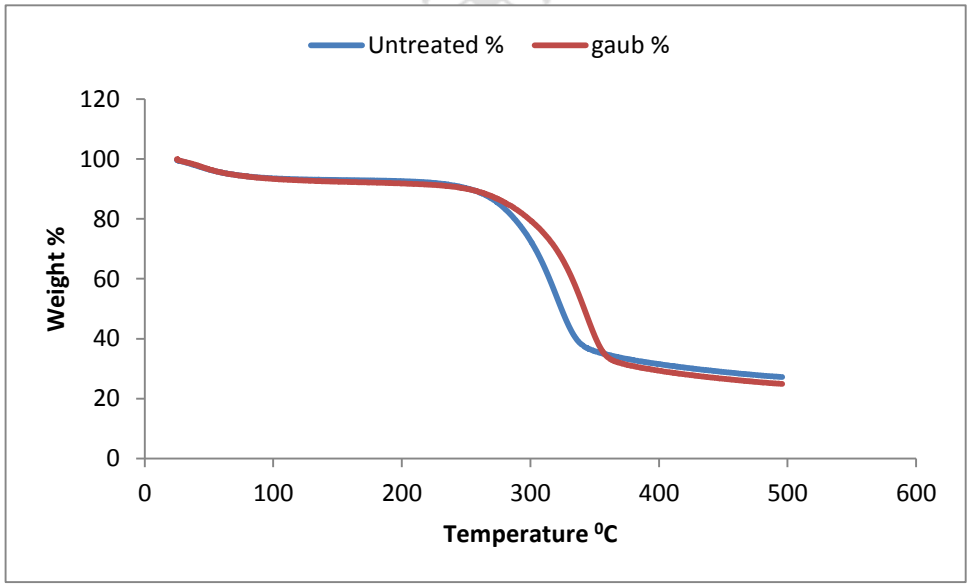

Figure No. 3: The weight loss by temperature (TGA)

3.3 Mechanical properties analysis of the fiber

Jute fabrics were soaked in the Gaub extract solution for different concentrations (0.5%-20%). The TS is higher of jute fabrics concerning different gaub concentrations are found from Figure 4 for 1% Gaub extract at 2 min. soaking time. Therefore TS of jute fabric decrease with the increase of concentration of Gaub extract. The highest TS (24 MPa) is obtained 1% gaub extract which is 118% higher compared to untreated jute fabric. This may be due to the physical changes of the fiber but FT-IR was observed no chemical modification.

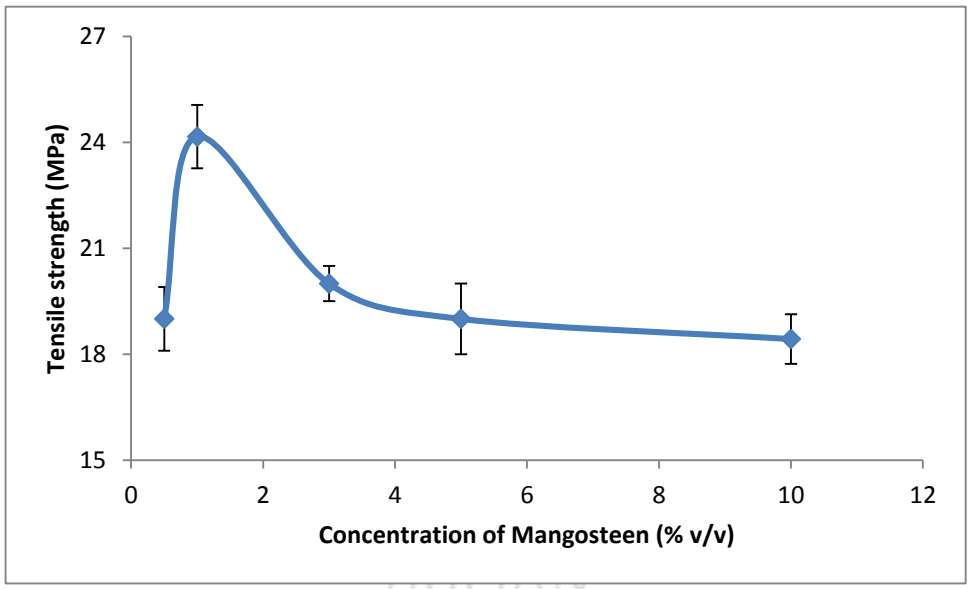

Figure No. 4: The tensile strength of the treated jute with the concentration of gaub

The mechanical properties of the treated jute fabrics based composites were found to be higher than those of the untreated jute fabrics based composites. Among all the formulations 1% Gaub treated jute fabrics based composite showed the highest mechanical properties. It was found (Fig: 5-7) that the maximum TS, BS, TM, BM, and EB (%) of jute-LLDPE+PET based composite were 58,36, 1440, and 1027 MPa and 21% for 1% Gaub solution for 2 min. soaking time. This may be due to the influence of the fruit extract of *Diospyros peregrina*. It is found from Figure 5-6 for a higher concentration of fruit extract TS, BS, TM, and BM decrease. It is probably due to the stiffing effect of fruit extract. For example, jute-LLDPE+PET based composite showed 38%, 64% increase in TS and BS compared to untreated jute-LLDPE+PET based composite.

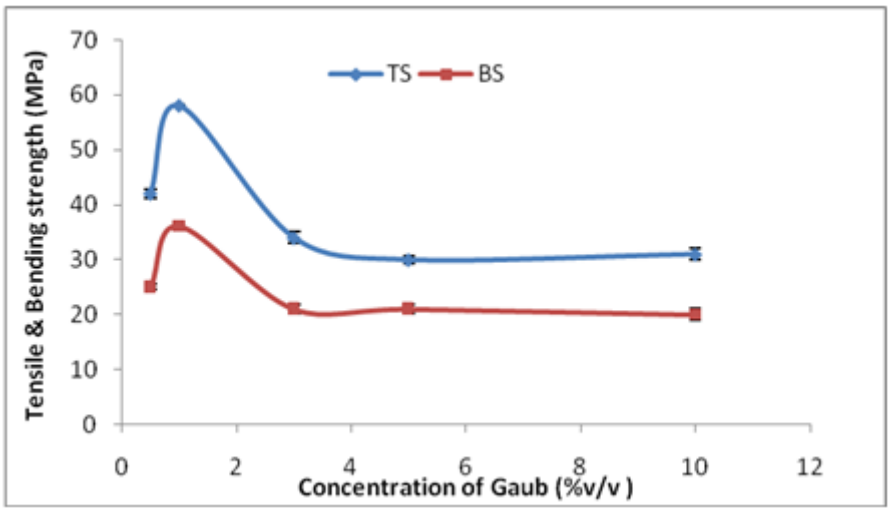

Figure No. 5: The tensile strength (TS) and Bending strength (BS) with the concentration of Gaub

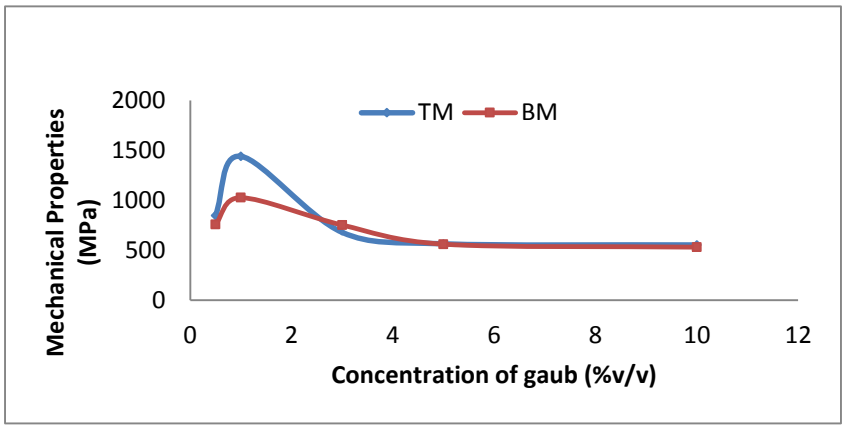

Figure No. 6: The modulus with the concentration of Gaub

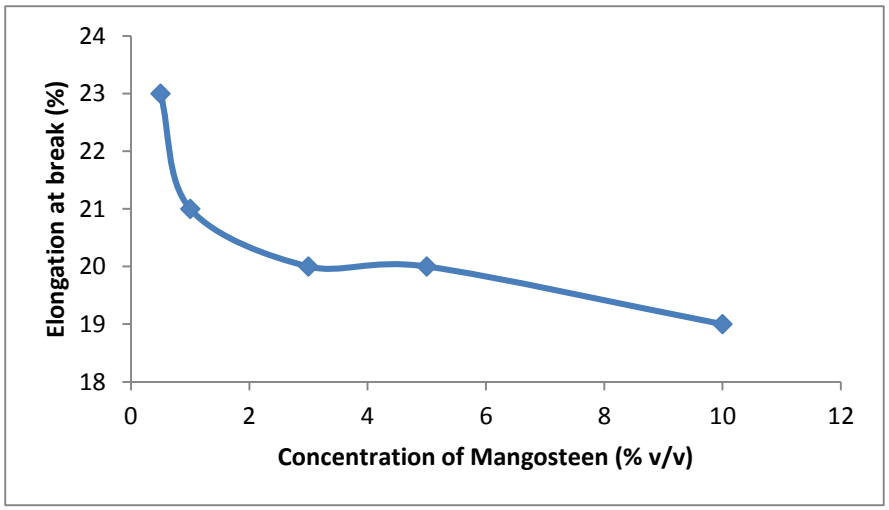

Figure No. 7: The elongation (%EB) with the concentration of Gaub

3.4 Electrical properties measurement of the composite

The dielectric constant depends upon the polarization of the materials. The greater polarizability of the molecule shows a high dielectric constant. The dielectric constant of polymeric materials depends on interfacial, dipole, electronic and atomic polarization. Dielectric constant varies between 1750 to 50000 frequency and finally become constant. The highest dielectric constant has been observed 15 and it has decreased with an increase in frequency. The increase is higher at low and medium frequencies and lowers at high frequencies, which has been explained by considering the orientation polarization and interfacial polarization. From the results of the experiment, it has been stated that the dielectric constant decrease with increasing frequency and finally becomes constant. This was because, at high frequencies, the rotational motion of polar molecules of the dielectric is not sufficiently rapid for attain of equilibrium with the field. Again it has been observed that dielectric loss factor decreased with an increase of frequency at a fixed temperature. At higher frequencies, the dielectric loss factor is low and remained more or less constant with increasing frequency because the orientation polarization due to chain motion of polymer cannot keep phase with rapidly oscillating electric field [35].

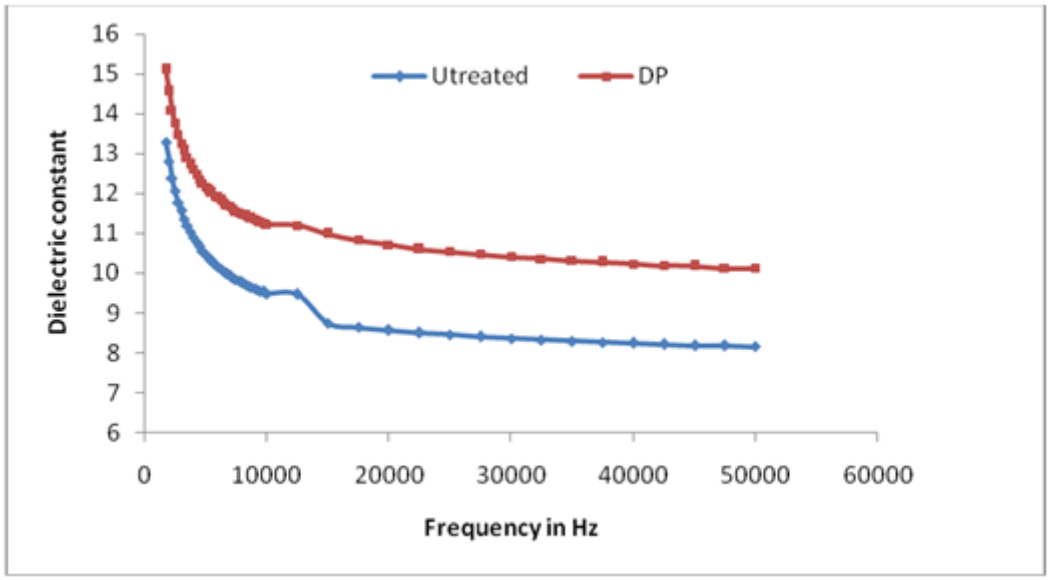

Figure No. 8: The dielectric constant of the composite material

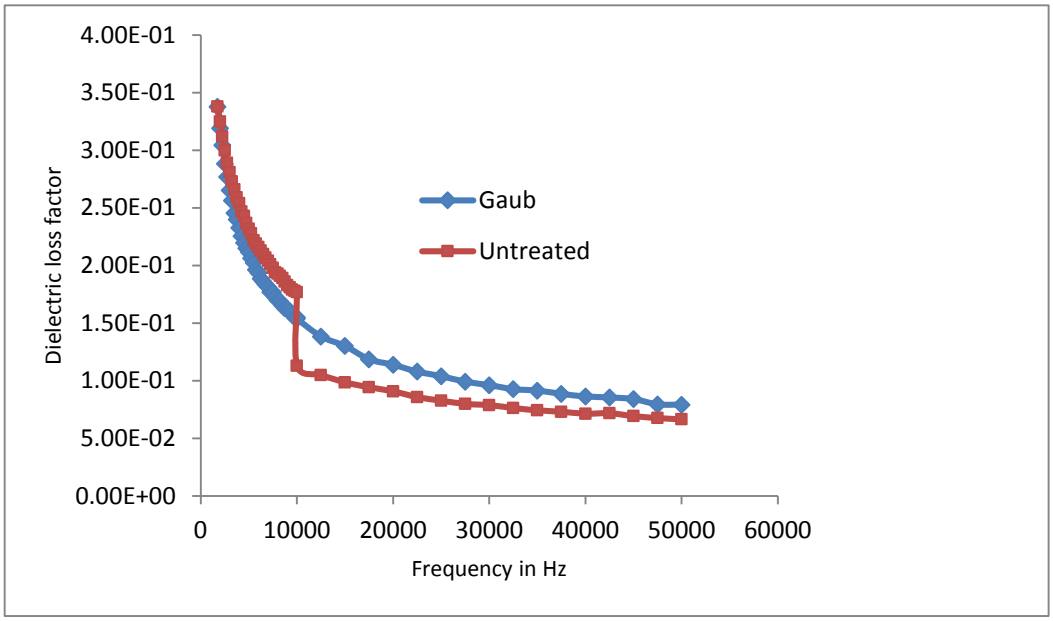

Figure No. 9: Dielectric loss factor of the composite sample

3.5 Water uptake of the treated composite

Water uptake of the composite (jute/ Gaub grafted LLDPE+PET) was investigated up to 70 min. The results have been shown in Figure 9. Initially, the composite absorbs water slowly. The initial water absorptions of the composite were 10%, 17%, and 27% for 10, 20, and 30 mins respectively. Water uptake reached 36% after 70 mins. Gaub grafted jute fabric may be hydrophobic in nature and the upper and lower layers of the composites were LLDPE+PET which is also hydrophobic, so only water can penetrate through the cutting edge. Because of this, the percentage of water uptake of the composite was so low to a value.

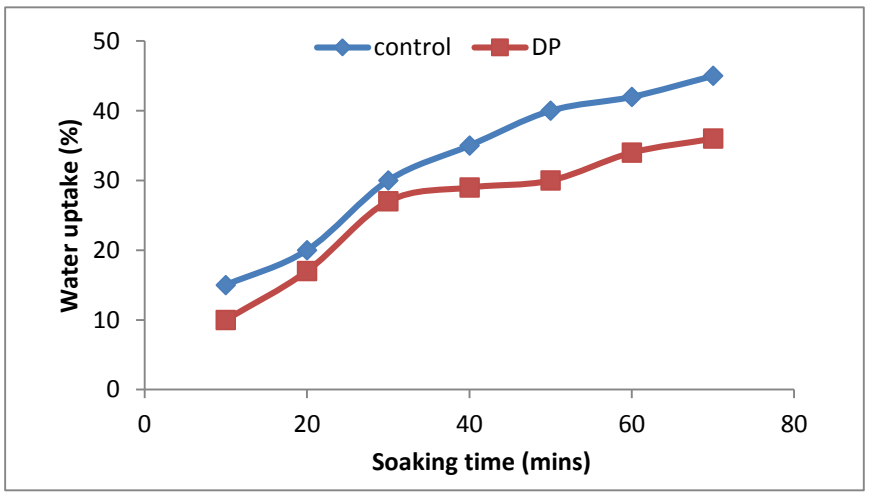

Figure No. 10: Water uptake with the composite

3.6 Degradation in water

The control and Gaub treated jute fabric-LLDPE+PET composite samples were immersed in a water bath in a static glass beaker at room temperature for a maximum period of 70 min. for studying the effect of environmental conditions on the degradability of the sample. The loss of TS of treated and untreated composite samples was periodically measured concerning their degradation time and the results are shown in Figure 5. It is found that the loss of TS of the composites increases with the increase in degradation time. But the loss is higher for the treated sample than that of the untreated sample. The loss of TS of the treated sample within the maximum period of observation is about 53% where is for an untreated sample is 35%. During water aging, water penetrates the cutting edges of the jute based composites, and degradation occurs only for jute fabrics.

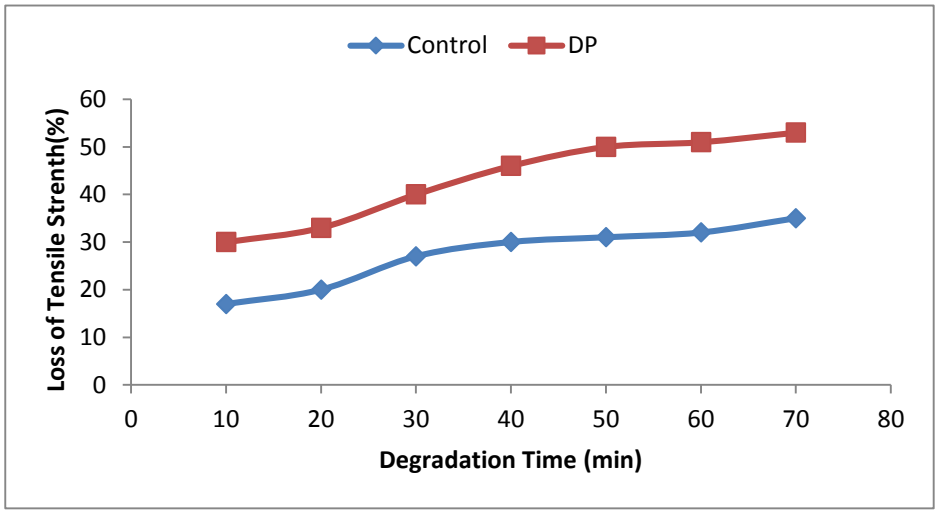

Figure No. 11: Water degradation

3.7 Degradation in soil

Both untreated and Gaub treated jute fabric-LLDPE+PET composite samples were buried in the soil (with 25% moisture) for up to 30 days to study the effect of an environmental condition on the degradability of the samples. The loss of TS of the treated and control composite sample was periodically measured concerning their degradation time and the results are shown in Figure 6. It is found that for control-treated composite the loss of TS increases gradually with increasing time of soil burial. After 30 days of soil degradation, the loss of treated composite is 77% whereas for untreated composite 59%. Jute is a natural biodegradable fiber and has a strong tendency to degrade when it is buried in soil [36]. During soil degradation test, water

penetrates from the cutting edges of the composites in jute based samples and degradation of cellulose occurred in jute, as a result, the TS of the composite decreased significantly. So the coupling agent "gaub solution" enhanced the degradability.

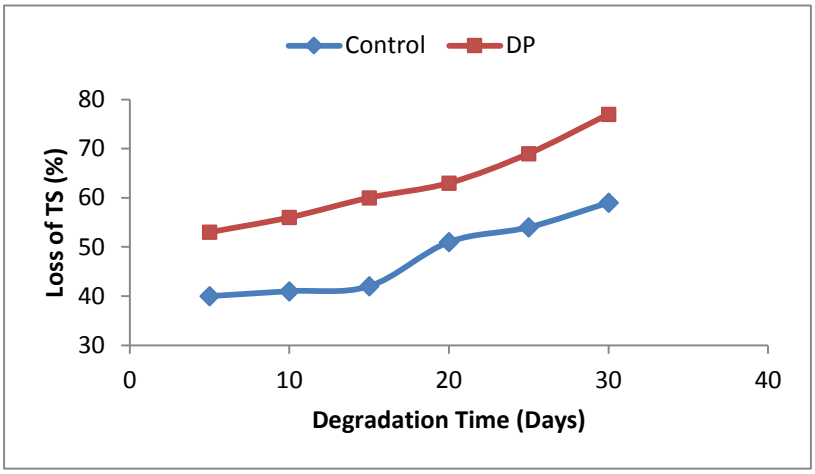

Figure No. 12: Soil degradation

4. CONCLUSION

The Jute fabrics treated with Gaub concentration (1%-20%) were confirmed by FT-IR spectra that no chemical modifications take place. The changes in fiber structure after treatment were investigated by thermogravimetric analysis. The mechanical properties of the treated jute fabrics like tensile strength (TS) which is 118% higher than untreated jute fiber. The bending strength (BS), tensile modulus (TM), and bending modulus (BM) are higher than the untreated composite and it was remarkable increased. The dielectric constant and loss factor decrease with increasing frequency.

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