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Fabrication and Characterization of Differently Laminated Jute Mat-PVC Composites

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***Abstract*- In this study, bleached and unbleached jute were used along with PVC to develop a strong, light and biodegradable composite. Jute mat-PVC composites were prepared by using hot press molding at temperature 150^{o}C and pressure 150KN. Series of experiments were conducted to find the best combination of composite. Physical, mechanical and thermal properties of prepared composites were studied by Universal Testing Machine, Rebound hardness tester, Micro hardness tester, TGA/DTA and TMA analyzer. Highest bulk density (0.98gm/cc) of composites obtained when ratio of jute mat: PVC was 1:2. When PVC remained in the both sides of the composite (PBP), maximum tensile strength (23.125 MPa) was noticed. Hardness of the bleached jute mat PVC composite at the ratio 1:2 was found 455.2. Thermal stability of bleached and unbleached jute mat-PVC composites at the ratio 1:2 was better than the ratio of 2:1. In X-ray diffraction studies, peaks were found at the 2θ value 22.20° for bleached jute mat and 17.94^{o} for PBP composite, where intensity of peaks of bleached jute mat-PVC composite at the ratio 1:2 decreased because of the presence of PVC on both sides of composite. Bleached jute mat-PVC composites showed higher thermal, mechanical and physical properties than unbleached composites.**

***Keywords*: jute mat, PVC, composite, hot press moulding, x-ray diffraction.**

I. Introduction

Currently environmental pollution is a huge threat for the world community. Therefore environmental friendly biodegradable materials are highly demanded. When it is thought about biodegradable composites, natural fiber comes first in consideration. Locally available natural fibers are easy to collect and store. Use of these fibers as reinforced materials increase biodegradability, reduces cost and decreases environmental pollution and hazard [1, 2]. The low density, high strength, excellent durability and design flexibility of fiber-reinforced polymers are the major reasons for their use in many structural components and other industries [3-5]. Composites are combination of two materials in which one of the materials, called the reinforcing phase, is in the form of fibers, sheets or particles and are embedded in the other materials called matrix phase. Typically reinforcing materials are strong with low densities while the matrix is usually a ductile or tough material. Fiber matrix interactions play a crucial role in determining the properties of their relative composites [6]. Composites are widely used in the brake-shoes, pads, tires and the diesel piston aircraft [7].

Natural polymers from renewable sources such as cellulose, wool, silk, jute, palm fiber etc. are of outmost importance for living systems [8]. The use of jute fiber as reinforcing fibers in both thermoplastic and thermosetting matrix composites provides positive benefit with respect to ultimate disposability and raw materials utilization [9].

The composites of polymers combined with natural components like wood, flax, hemp, jute, etc. are intensively investigated in recent times due to their environmental friendly nature and practical applications [10, 11]. Natural fibers such as jute, coir, palm, wood fiber, palm fiber, banana etc. are used as an alternative to synthetic fibers e.g. glass, aramid, carbon, etc. [12]. These fibers are used due to their renewable character, acceptable specific strength properties, low cost, enhanced energy recovery, biodegradability and CO_2 neutrality when they are incinerated [13]. The jute fiber can be used as reinforcing agent in thermoplastics like polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC) etc [14-16]. PVC-Jute fiber composites are low cost materials and may contribute to solving environmental problems considering that PVC is recyclable and have favorable mechanical properties while jute fiber is highly available and renewable [17-18].

One of the main factors that affect the mechanical properties of fiber reinforced material is the fiber-matrix interfacial adhesion; a weak interfacial region reduces the efficiency of stress transfer from the matrix to the reinforcement component and low properties can be anticipated [19]. However, the fiber-matrix incompatibility and the poor resistance to moisture can reduce the potential applications of the composites [20, 21]. The adhesion between the natural fiber and polymer matrix can be increased by modifying the fiber surface. A strong fiber-matrix interface bond is critical for high mechanical properties of composites. A good interfacial bond is required for effective stress transfer from the matrix to the fiber whereby maximum utilization of the fiber strength in the composite can be achieved [22, 23].

The present study emphasizes the effect of bleached and unbleached jute on the mechanical, physical and thermal properties of laminated jute mat- PVC composites. The objectives of the study are to fabricate and characterize laminated jute mat-PVC composites and to depict the mechanical, physical, thermal and structural properties among unbleached jute mat-PVC and bleached jute mat-PVC composites.

II. MATERIALS AND METHODS

The Chief raw materials used for the sample preparation are jute mat (unbleached and bleached) and PVC sheet. The two different types of composite specimen are then prepared by the following way-

A size of 31-21 cm was cut for single layer jute mat and single layer of PVC sheet. For fabrication of composites, PVC sheet and JM (unbleached & bleached) were laminated in the mold and heat pressed at 1500 C then hold for 10 minutes at the pressure 150 KN in the Hot Press (Poul-Otto Weber Press Machine). The ratio of PVC: JM in the composites were maintained as unbleached jute mat (UJM): PVC is 2:1(UPU) and 1:2(PUP) and bleached jute mat (BJM: PVC) is 2:1(BPB) and 1:2(PBP) where their weight ratio was maintained. After that temperature was fallen down that means after cooling the laminated JM-PVC composites of four types were prepared. Then the prepared composites were measured for measuring different properties like Bulk Density, Tensile properties, Flexural properties, Hardness, Thermal, Thermo-mechanical, Structural properties etc.

Bulk density was calculated using following formula (1),

$$D=Ws/V \qquad (1)$$

Where, D=Density of the specimen in kg/m^3, Ws=Weight of the specimen in kg and V=Volume of the specimen in m^3.

For Tensile strength, specimen was prepared according to ASTM-638M-91a.

Tensile strength = Applied load Cross sectional area of the load bearing area

$$\sigma = PA= PA \text{ in Pa} \qquad (2)$$

Tensile strain is calculated according to ASTM D-638M - 91a-

$$\varepsilon=l-lo/lo \qquad (3)$$

Where, lo = Original length of the sample, l = Length of the material after stretching

For Flexural strength, specimen was prepared according to ASTM D790M, 3 points loading.

The Flexural strength may be calculated for any point of the load deflection by means of the following formula (4),

$$S = 3PL / 2bd^2 \quad (4)$$

Where, S = stress in the outer fibers at mid span in MPa, P = load at a given point on the load – deflection curve in N, L = support span in mm, b = width of specimen tested in mm and d = depth of tested specimen in mm.

Flexural strain may be calculated for any deflection using (5),

$$\varepsilon f = 6Dd/L^2 \quad (5)$$

Where, εf = Main strain in the outer surface in mm/mm, D=Maximum deflection of the center of the beam in mm, L= Support span in mm, d= Depth in mm

Micro hardness of the samples was measured by using (6),

$$HV=1.854F/d^2 \text{ (approximately)} \quad (6)$$

Where, F= Load in Kg f, d = Arithmetic mean of the two diagonals, d1 and d2 in mm, HV= Vickers hardness

Leeb Rebound Hardness value is derived from the energy loss of a defined impact body after impacting on a metal sample, Similarly to the Shore scleroscope.

Thermal analysis of the specimen includes a group of techniques where some physical property of the sample is monitored under controlled conditions with variation of temperature at a programmed rate. When the mass change is monitored the results, which indicated chemical reactions, are called Thermo gravimetric (TG). When heat absorption monitored, the result indicate crystallization, phase change etc. as well as reactions. This is called Differential Thermal Analysis (DTA). Together, they are a powerful method of analysis [24].

X-ray diffraction technique is a family of non-destructive analytical techniques which reveal information about the crystal structure, chemical composition, and physical properties of materials and thin films. These techniques are based on observing the scattered intensity of an X-ray beam hitting a sample as a function of incident and scattered angle, polarization, and wavelength or energy. This analysis was carried out by using a D8 ADVANCE BRUKER.

Thermo-mechanical analyses of composites were carried out by using an S II-TMA/SS6300 analyzer [24].

III. RESULTS AND DISCUSSION

Distribution of sample as showing in the Table 1

TABLE 1. Sample Distribution

Sample composition	Sample no.
UJM : PVC= 2:1 (UPU)	1
UJM : PVC= 1:2 (PUP)	2
BJM : PVC= 2:1 (BPB)	3
BJM : PVC= 1:2 (PBP)	4

A. *Bulk Density:*

“Fig. 1” shows the variation in the density for both UJM and BJM - PVC composite. The density increases and the highest density is found where the ratios of bleached jute mat (BJM): PVC is 1: 2(PBP) and the value is 0.98gm/cc. Because PVC is both side of the jute mat though the density of PVC is higher than jute therefore the density of PBP composite is higher than other prepared composites and the lowest density found in UPU which is 0.8gm/cc.

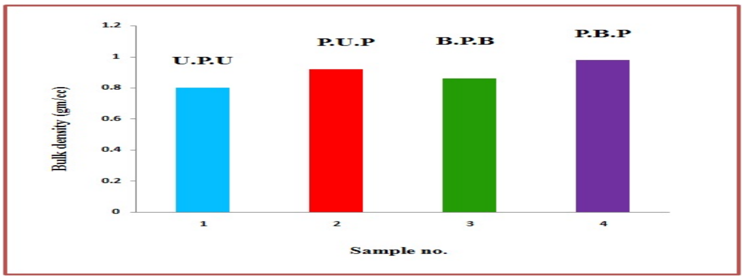

Figure 1. Bulk density of different composite samples

B. Percentage Elongation (%E)

"Fig. 2" shows the comparison graphs of %E for the prepared composites where their composition is shown in the Table 1.The maximum value of (%E) found for UPU which is 15.775 and the lowest value for PBP which is 6.585. Therefore the PBP is less ductile than UPU.

Figure 2. % Elongation different composite samples

C. Tensile Strength

"Fig. 3" shows the comparison graphs of tensile strength for the prepared composites where their composition is shown in the Table 1.The maximum value of the tensile strength found for PBP which is 23.125 MPa and the lowest value for UPU which is 8.313MPa.Therefore PBP has more strength than the other three types of composites.

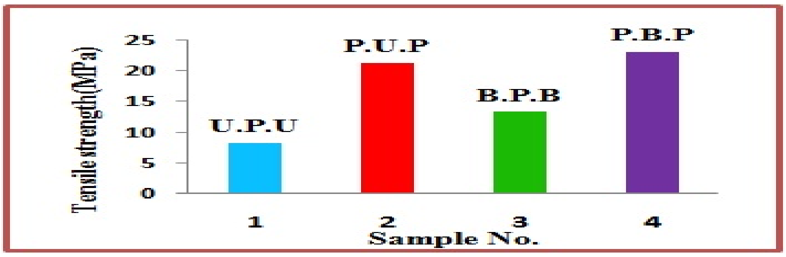

Figure 3. Tensile strength different composite samples

D. Flexural Strength

"Fig. 4" shows the comparison graphs of Flexural strength for the prepared composites where their composition is shown in the Table 1.The maximum value of the flexural strength for PBP which is 31.47 MPa and the lowest value found for UPU which is 8.62 MPa.Therefore PBP has more strength than other three types of prepared composite. Because this composite bonded strongly with resin and its matrix which is bleached jute mat, the composite also contains PVC in both side of the mat therefore more load is applied.

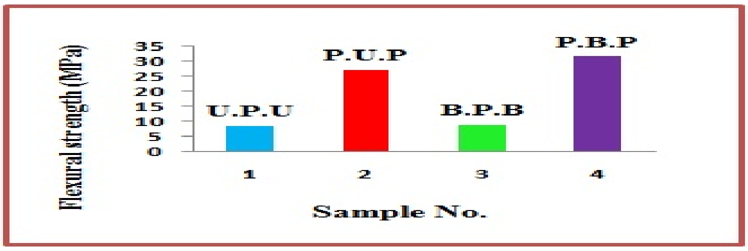

Figure 4. Flexural strength different composite samples

E. Elastic Modulus (EM)

The comparison graphs of EM are shown in "Fig. 5" for the prepared composites where their composition is shown in the Table [1]. The maximum value of EM found for PBP which is 929.75 MPa and the lowest found for BPB which value is 264.425 MPa. Therefore the bleached jute mat –PVC (1: 2) composite is stiffer than other three prepared composites.

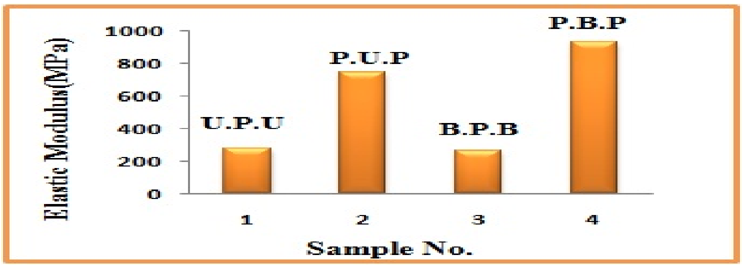

Figure 5. Elastic modulus different composite samples

F. Vicker's Hardness Test (HV)

The comparison graph of HV is shown in "Fig. 6" for the prepared composites where their composition is shown in the Table 1.The maximum value of HV found for PBP which is 197 and the lowest found prepared composites contains jute mat in both side and this is highly porous therefore indentation is not well recognized for PUP which is 80.2.Vicker's hardness of other to composites cannot found, because the prepared composites contains jute mat in both side and this is highly porous therefore indentation is not well recognized.

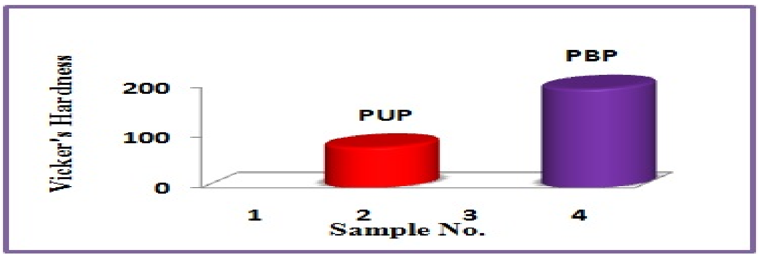

Figure 6. Vickers's hardness different composite samples

G. Leeb Rebound Hardness (HL):

"Fig. 7"shows the comparison graphs of HL for the prepared composites where their composition is shown in the Table 1.The maximum value of HL found for PBP which is 455.2 and the lowest found for BPB which is 379.4.This PBP composite shows maximum bulk density also that described in "Fig 1". It means that PBP has more energy absorption capacity of load than the other three.

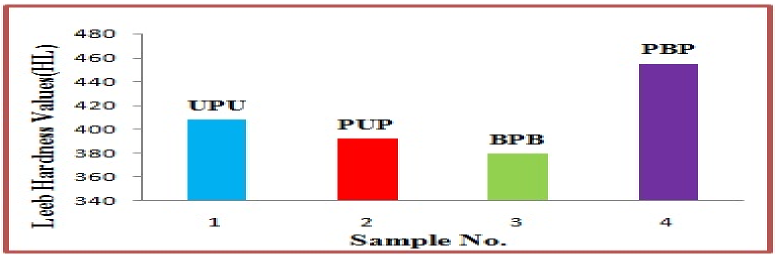

Figure 7. Leeb Rebound Hardness Value (HL) of different composite samples

In “Fig. 8”, the top one is the TG, Bottom one is the DTG and middle one is the DTA curves for UJM: PVC=2: 1(UPU) composite. The major degradation occurs in two stages. In first stage dechlorination occurred with the residue 59.2% and in second stage depolymerization occurred with the residue 12.2%.Weight loss occurs continuously. The lighter substances remove initially and then heavier material removed. Initially the composite losses 8.9% of its weight at 248.3°C.Then the TG curve reveals that the onset temperature, 50% degradation of unbleached jute mat-PVC (2: 1) composite occurs at 290.5°C, 306.8°C respectively and maximum slope at 309.6°C.87.5% mass loss was obtained remaining 28.3% residue. DTA yields two endothermic peaks at 307.9°C and 457.1^{0}C.This is due to the degradation of UPU composite. The DTG curve shows the maximum degradation rate was obtained at 309.6°C with the rate of 1.111 mg/min.

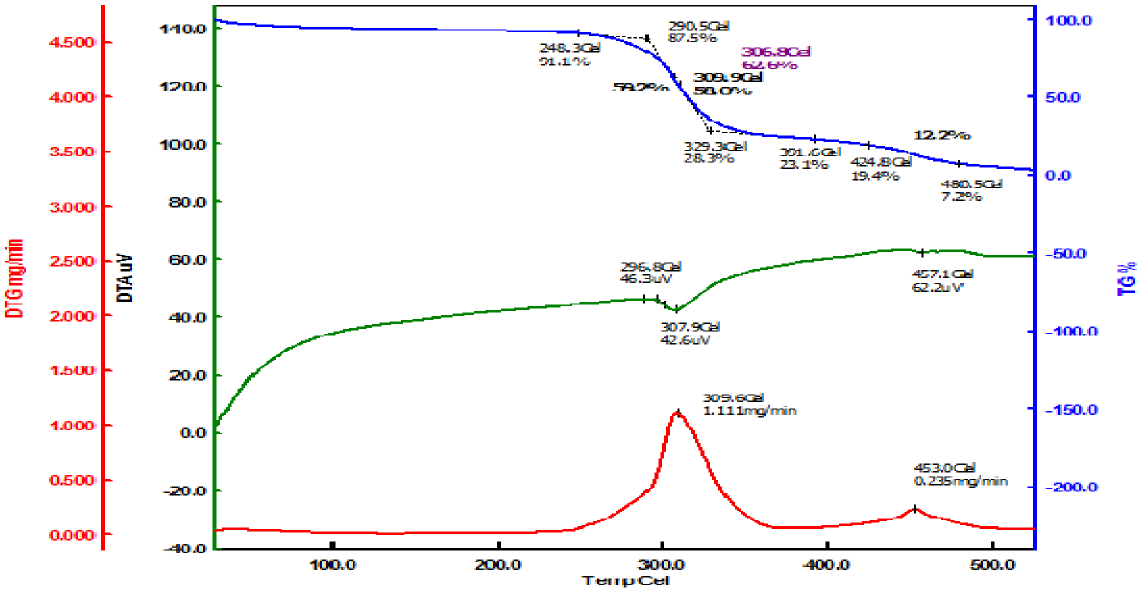

Figure 8. Thermal behavior of UPU analyzed by TG, DTG and DTA curves.

In “Fig. 9”, the top one is the TG, Bottom one is the DTG and middle is the DTA curves for unbleached jute mat-PVC (1:2) (PUP) composite. The major degradation occurs in two stages. In first stage dechlorination occurred with the residue 49.6% and in second stage depolymerization occurred with the residue 13.4%. The lighter substances remove initially and then heavier material removed. Initially the composite losses 11.3% of its weight at 252.1°C.Then the TG curve reveals that the onset temperature, , 50% degradation of unbleached jute mat-PVC (1: 2) composite occurs at 292.0°C, 301.7°C respectively and maximum slope at 303.1°C.49.6% mass loss was obtained remaining 35.4% residue.

DTA yields two endothermic peaks at 302.3^{0}C and 460.1°C.This is due to the degradation of unbleached jute mat-PVC (1: 2) composite. The DTG curve shows maximum degradation rate was obtained at 302.3°C with the rate of 2.00 mg/min.

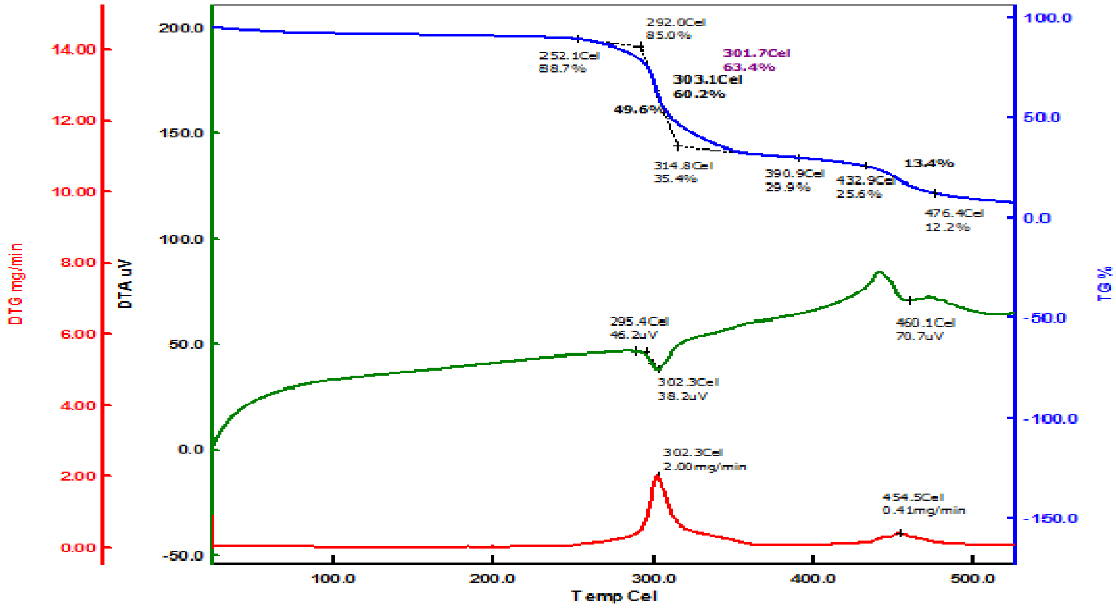

Figure 9. Thermal behavior of PUP analyzed by TG, DTG and DTA curves

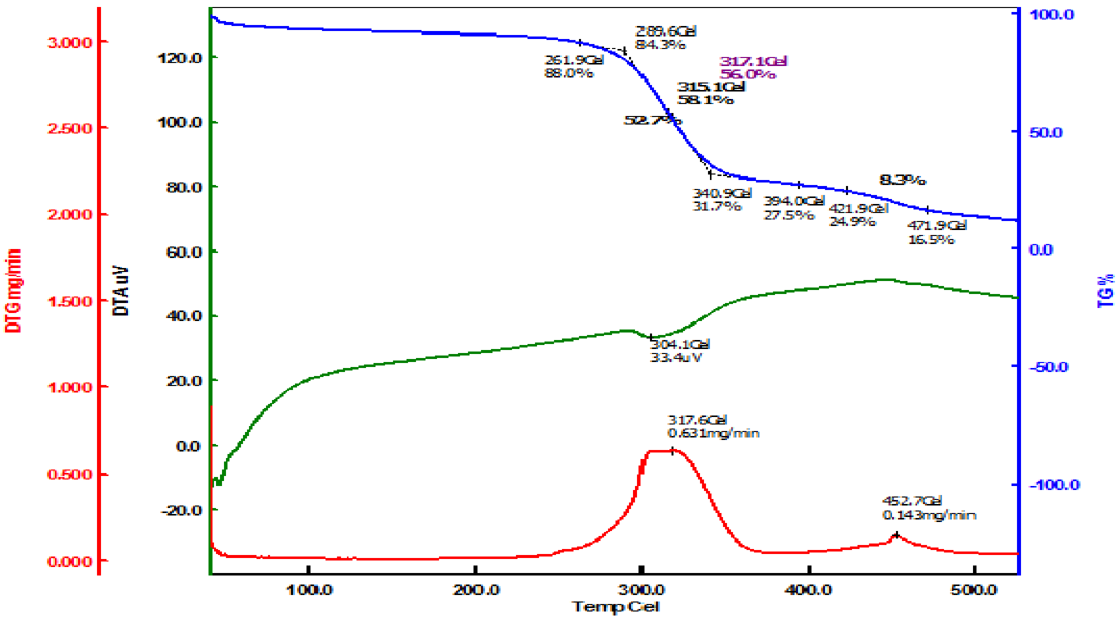

Figure 10. Thermal behavior of BPB analyzed by TG, DTG and DTA curves.

In “Fig.10”, the top one is the TG, Bottom one is the DTG and middle one is the DTA curves for bleached jute mat-PVC (2:1)(BPB) composite. The major degradation occurs in two stages. In first stage dechlorination occurred with the residue 52.7% and in second stage depolymerization occurred with the residue 8.3%. The lighter substances remove initially and then heavier material removed. The initial 12% weight loss occurred at 261.9^{0}C.

Then the TG curve reveals that the onset temperature, 50% degradation of bleached jute mat-PVC(2:1) (BPB)composite, occurs at 289.6°C, 317.1°C respectively and maximum slope at 315.1°C.52.7% mass loss was obtained remaining 31.7% residue. DTA yields one endothermic peak at 304.1°C. This is due to the degradation of bleached jute mat-PVC (2: 1) composite takes place in two stages. The DTG curve shows the maximum degradation rate was obtained at 317.6°C with the rate of 0.631 mg/min.

In “Fig. 11”, the top one is the TG, Bottom one is the DTG and middle one is the DTA curves for bleached jute mat-PVC (1: 2) (PBP) composite. The major degradation occurs in two stages. In first stage dechlorination occurred with the residue 51.9% and in second stage depolymerization occurred with the residue 12.6%. The lighter substances remove initially and then heavier material removed.

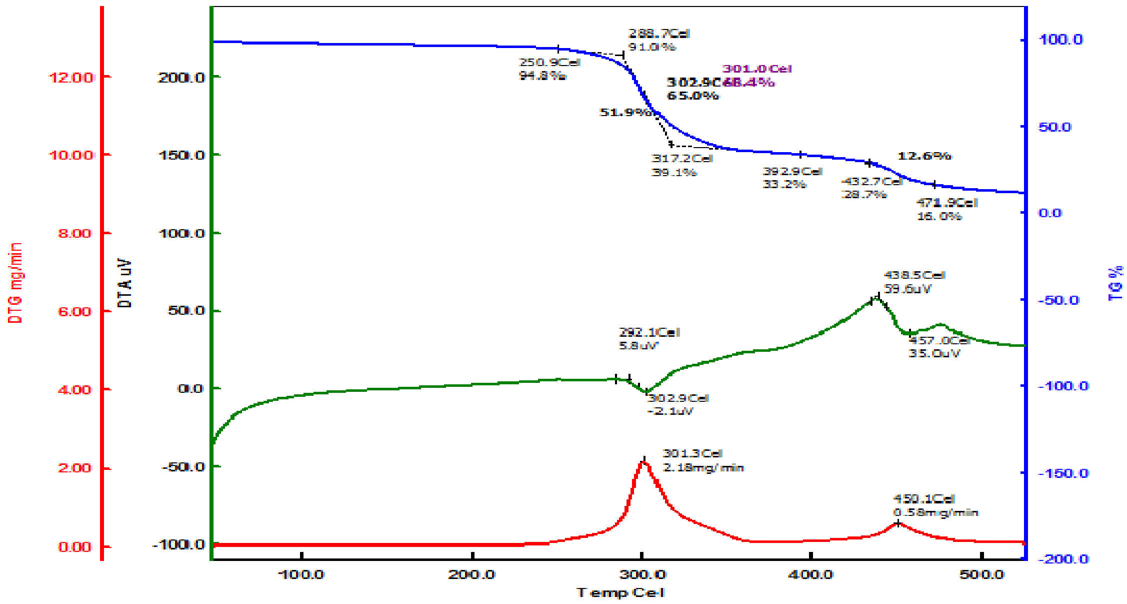

Figure 11. Thermal behavior of PBP analyzed by TG, DTG and DTA curves.

The initial 5.2% weight loss occurred at 250.9^{0}C. Then the TG curve reveals that the onset temperature, 50% degradation of bleached jute mat-PVC(1:2) composite, occurs at 288.7°C, 301.0°C respectively and maximum slope at 302.9°C.51.9% mass loss was obtained remaining 39.1% residue. DTA yields two endothermic peaks at 302.9°C and 457.0^{0}C. This is due to the degradation of bleached jute mat-PVC (1: 2) composite takes place in two stages. The DTG curve shows the maximum degradation rate was obtained at 301.3°C with the rate of 2.18 mg/min.

Therefore, the DTG curve reveals that the maximum degradation rate of UPU, PUP, BPB and PBP composite is 1.111 mg/min at 309.6°C, 2.00 mg/min at 302.3°C & 0.631 mg/min at 317.6°C and 2.18 mg/min at 301.3^{0}C respectively which also means the bleached jute mat-PVC (1: 2) (PBP) composite is more thermally stable than the other three composites.

In “Fig. 12”, the top (green) one is for TMA, bottom (blue) one is for DTMA. The TMA curve shows that the initial contraction occurs in the range of 27.15 to 48.05°C, the value of which is 46.40μm. From DTMA curve there are three stages of contraction occurs at a rate of 2.328μm/°C at 36.88°C;1.548 μm/°C at 70.380C and at a rate of 0.575μm/°C at 62.65°C.

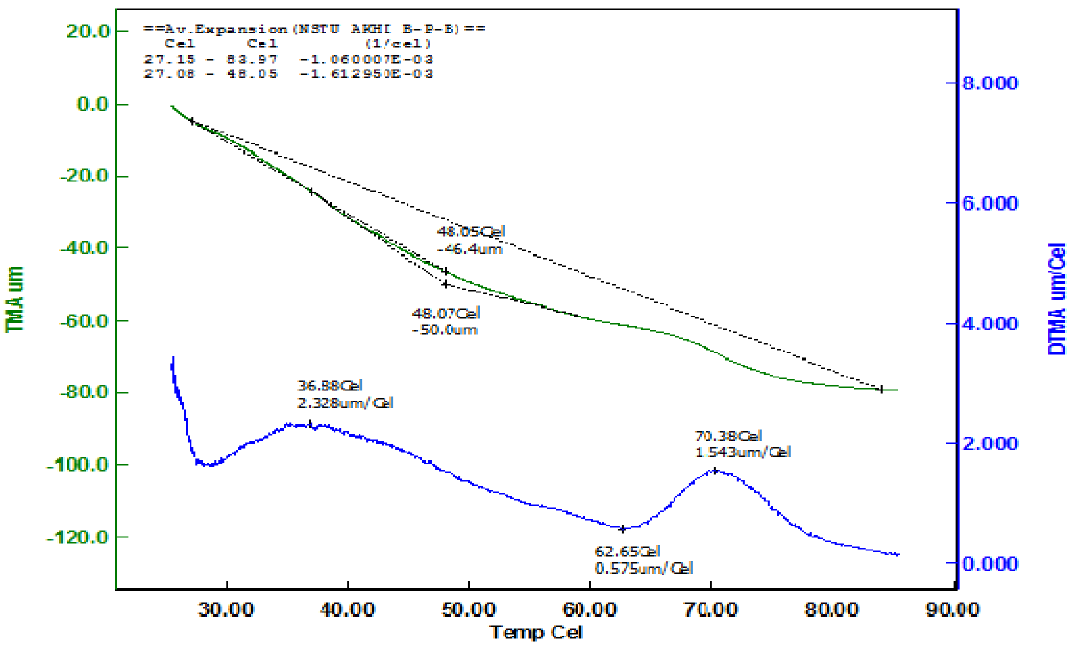

Figure 12. Thermo mechanical behavior of UPU composite analyzed by TMA & DTMA curves.

In "Fig. 13", the top one is for TMA, bottom one is for DTMA. The TMA curve shows that the initial contraction occurs in the range of 27.56 to 67.29°C, the value of which is 28.5µm and there is also a contraction occurs in the range of 67.29 to 74.90°Cthe value of which is 66.5µm. From DTMA curve there is two stage contractions occurs at a rate of 0.87µm/°C at 64.29°C and at a rate of 6.62 µm/°C at 70.73^{0}C.

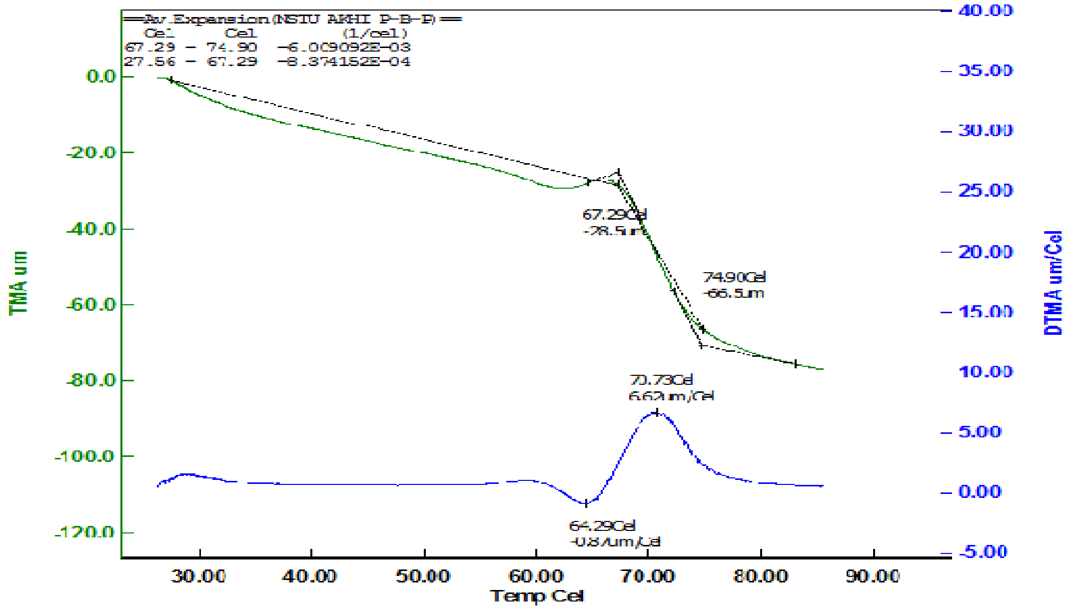

Figure 13. Thermo mechanical behavior of PUP composite analyzed by TMA & DTMA curves.

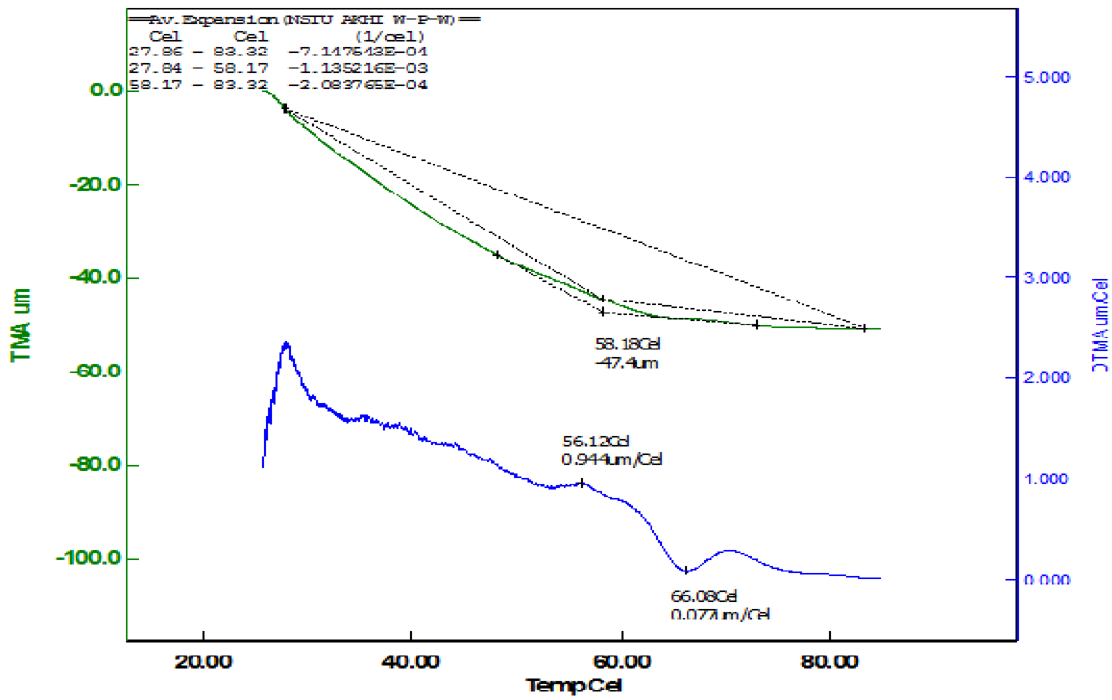

Figure 14. Thermo mechanical behavior of BPB composite analyzed by TMA & DTMA curves.

In “Fig. 14”, the top one is for TMA, bottom one is for DTMA. The TMA curve shows that the initial contraction occurs in the range of 27.84 to 58.18°C, the value of which is 47.4μm. From DTMA curve there is two stage contractions occurs at a rate of 0.944μm/°C at 56.12°C and at a rate of 0.077 μm/°C at 66.08^{0}C.

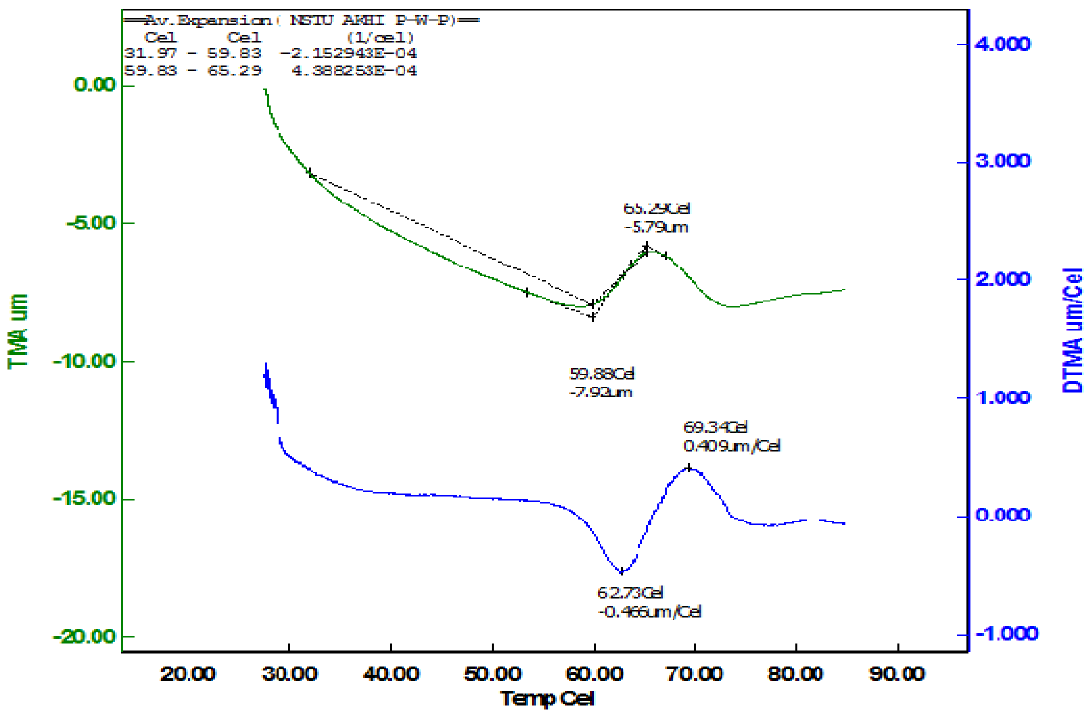

Figure 15. Thermo mechanical behavior of PBP composite analyzed by TMA & DTMA curves.

In "Fig. 15", the top one is for TMA, bottom one is for DTMA. The TMA curve shows that the initial contraction occurs in the range of 31.97 to 59.88°C, the value of which is 7.92μm and there is also a contraction occurred in the range of 59.83 to 65.29^{0}C the value of which is 5.79 μm. From DTMA curve there is two stage contractions occurs at a rate of 0.466μm/°C at 62.73°C and at a rate of 0.409 μm/°C at 69.34^{0}C.

Therefore the TMA curve shows that for PBP,BPB, PUP and UPU composite, the onset of contraction occurs at 31.97°C,27.84°C, 27.56°C and 27.15°C respectively, the value of which is 7.92μm, 47.4μm,28.5 μm and 46.4μm respectively which means that PBP is thermo mechanically stable than the other three composites.

The "Fig. 16" shows the XRD pattern of BJM, PBP and PVC**.** The crystallinity of PBP composite and PVC are almost similar. But the crystallinity of bleached jute mat is higher than other two. Therefore when PVC is added in both sides with the bleached jute mat intensity of peak is decreased and then crystallinity of PBP composite becomes similar to PVC. The X-ray diffraction peak of intensity of PVC is very low due to that the only syndiotactic isomer is crystalline. [16]. BJM exhibits a sharp peak at 2θ = 22.20°, but with the addition of PVC in both sides with BJM, the intensity of peak of PBP composite decreases gradually. One diffraction peak at 2θ=17.94^o is observed.

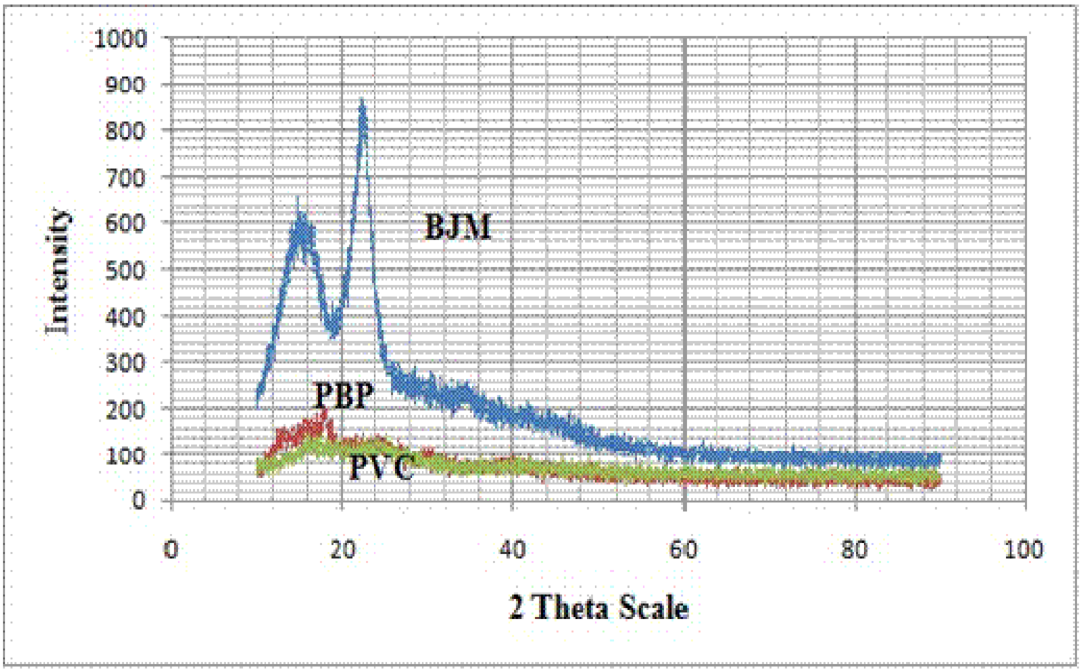

Figure 16. Comparison of the XRD pattern of PVC, BJM and PBP composites.

IV. CONCLUSIONS

Composites with higher physico-mechanical properties were successfully developed by using bleached jute mat as matrix and PVC on the both sides of the composites. The bleached jute mat-PVC (PBP) composite showed highest density 0.98gm/cc at the ratio of BJM: PVC=1:2 and highest tensile strength was found 23.125 MPa. Lower % elongation (6.585) denoted the rigid nature of the composite. High young modulus (929.75MPa) of this composite (PBP) revealed its better stiffness than the other three prepared composites. Flexural strength (31.47 MPa) was highest for PBP composite.

Higher Vickers hardness value (455.2) and Leeb rebound hardness (HL) value (197) was found for PBP which implies the composite possess more load bearing capacity than the other three prepared composites.

From the thermal behavior of composites the DTG curve revealed that the maximum degradation rate of UPU, PUP, BPB and PBP composite was 1.111 mg/min at 309.6°C, 2.00 mg/min at 302.3°C, 0.631 mg/min at 317.6°C and 2.18 mg/min at 301.3^{0}C respectively which indicates that the bleached jute mat-PVC (1: 2) (PBP) composite is more thermally stable than the other three prepared composites.

To ensure the successful application as well as to establish the commercial viability of laminated Jute Mat-PVC composites still much work has to be done for the development of physical, mechanical and thermal properties.

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