DYNAMIC MECHANICAL ANALYSIS OF JUTE FIBER REINFORCED COMPOSITES WITH EFFECT OF PLA COATING AND ALKALI TREATMENT

Ch. Naveen Reddy [a], Dr. J. Suresh Kumar [b]

[1]Research Scholar, Department of Mechanical Engineering, Jawaharlal Nehru Technological University Hyderabad (JNTUH), Hyderabad - 500085, Telangana. India

[2]Professor, Department of Mechanical Engineering, Jawaharlal Nehru Technological University Hyderabad (JNTUH), Hyderabad - 500085, Telangana. India

---

Abstract: In this study, woven jute fibers were subjected to an eco-friendly NaOH treatment and polylactic acid (PLA) coating to improve adhesion with epoxy resins and improve composite performance. The treated and coated jute fiber reinforced epoxy composites were prepared by hand layup technique such that the fiber content in each composite was kept constant at 40 wt%. The dynamic mechanical properties of the prepared composites were determined using dynamic mechanical analysis (DMA) based on storage modulus (E'), loss modulus (E"), and damping coefficient (Tan δ) Tests are performed in three-point bending mode Experimental results show that NaOH-treated and PLA-coated jute composites perform best compared to untreated jute fiber reinforced composites indicates that Composites reinforced with NaOH-treated and PLA-coated jute fibers exhibited the highest values for storage modulus, loss modulus, and glass transition temperature.

Keywords – Jute fiber, Poly Lactic Acid, Dynamic Mechanical Analysis

---

I. INTRODUCTION

The fields of applications of composite materials have developed high-speed and have even identified new exchange. Composite materials consist of many materials used in refining applications. A material which has minimum of two macroscopically structure those materials combined work together to get good results. The Composite materials withhold separate chemical, physical, and mechanical properties. Composites are globally used in the aero industry and mechanical engine applications. Fibre Reinforced Polymer (FRP) composites have got various industrial and researchers' interest because of the type of behavior exhibited by the FRP materials [1-2].

Fibers are produced from the tress, animals and minerals are called natural fibers and the fibers which are made by humans with chemical synthesis are called as synthetic fibers. Organic fibers have lot of advantages compare to the conventional fibers like low weight, biodegradability, nontoxicity and renewability [6-7]. In the recent days the combination of natural fibers with synthetic fibers can greatly improve their mechanical properties to a large extent. Natural fibers are mainly used for reinforcement in the polymer composite [3-4]. Natural fibres which are draft from plants majorly consist of cellulose, hemi- cellulose, lignin, waxes and small amount of moisture content. The mechanical properties and with physical properties of natural fibers depend on the chemical and anatomical composition of the fiber [5]. The interconnected bonding between reinforced different natural fibers with various matrix materials will affect DMA like storage modulus (E′), loss modulus (E″), and damping factor (tan δ). Dynamic mechanical properties influenced main key factors like fiber contents, shape and sizes, orientations, and loading in the NFCs. Hence, it was proven that DMA is a perceptive tool in generate the DM parameters related to NFRCs to ensure the safety, drawing, and substitution of the many automobiles' spare parts and additional structural mechanism in the prospect applications [6]. Dynamic mechanical analysis of hemp nanofiber and epoxy composite were studied. Hand lay-up techniques were used to fabricate and nanofibers wt % are used in between the (1 – 5) %. DMA properties were studied are loss modulus ("E), storage modulus ('E), damping (Tanδ), glass transmitting temperature and thermal stability also analyzed using thermogravimetric analysis (TGA). Nano fiber 2 wt.%, dynamic mechanical properties were seen improved and thermal stability also increased due to incorporation of hemp nanofibers [7].

The DMA and water absorption characteristics parameters of hybrid sisal and jute fibre reinforced epoxy composite were studied. The maximum value of loss modulus and storage modulus absorbed in the H30 hybrid composites, and the lowest value of water absorption and sorption coefficient absorbed with H-30 composites [11]. Jute fibre reinforced hybrid composites fabricated hand lay-up techniques with different weight percentage (10, 20, 30 and 40) and investigated DMA of composites. 30% weight jute fibre shows better results in Tg and load bearing capacity. Frequency increases the storage modulus also increased and with increasing frequency Glass transition temperature/thermal stability reduced [9]. In this article properties of polyester-based hemp were studied with different treatments. Chemical treatments such as alkali, benzoylation and sodium bicarbonate on water absorption and mechanical and DMA hemp/polyester has been studied [12]. Hand lay-up method used for the fabrication and with 15% weight of hemp fiber. Treated hemp shows better results than untreated and benzoylation treat shows better results. HC-T3 shows better results in storage modulus, glass transition temperature and maximum water absorption resistance [10].

Now, it can be concluded that the limitations of the natural fibres were found to be significantly overcome resulting in enhanced properties by the various surface modification methods. Chemical and eco-friendly treatments are found to be useful to improve the properties of the natural fibres and its composites up to some extent. In the present work, to evaluate the dynamic mechanical analysis properties like storage modulus (E'), loss modulus (E"), damping factor (Tanδ) and compare the DMA properties of surface modified and untreated jute fiber reinforced composite laminate structures.

II. MATERIALS AND METHODS

Jute fiber

Jute is derived from the blood of the Taxaceae family, whose methodological term is Corchorus capsularis, an extract from Corchorus, a plant low in dietary fiber. Jute is used worldwide to create tones ranging in size from $2300x10^3$ to $2850x10^3$. Jute has a wide range of uses in industries such as construction, textiles and automobiles. Jute textile fibers were purchased from his Vruksha Composites & Services in Guntur, Andhra Pradesh.

Resin and hardener

Epoxy resin, a polymer material, has excellent properties such as excellent chemical, mechanical, easy processability, and corrosion resistance. Epoxy resin was chosen as the matrix material in this study due to its wide potential applications. Hardener additives act as catalysts to accelerate the curing process. The composite is manufactured using Aralidite LY556 epoxy resin and his HY951 hardener are provided by Alide Engineering Services.

Alkaline treatment on Jute fiber

In the current study, woven jute fibre is treated with 2% NaOH. Jute fibre was submerged in the alkaline solution for 4 hours at 30^0C. After that, the fibre was removed from the solution and repeatedly rinsed with floating water before being immersed in the HCL solution to remove the NaOH adhere from the fiber's exterior [8]. Once more, fibre washed in water and dried for 24 hours in an oven set at 60^0C.

$$\text{Fibre–OH} + \text{NaOH} \rightarrow \text{Fibre –O–Na+} + \text{H2O}$$

PLA coating on Jute fiber

First, the PLA pellets were soaked in the chloroform solution for 8 hours. The solution was then manually stirred and heated to 60°C to ensure uniform dispersion of the PLA in the chloroform solution. After creating the PLA solvent, the woven jute fibers were soaked and removed after soaking for 5 minutes [8]. Finally, the coated fibers were dried in a hot air oven at room temperature for 24 hours and then at 60°C for 4 hours. The physical and mechanical properties of PLA are shown in Table 1.

Table 1: Physical & Mechanical attributes of PLA.

Properties	Values
Tensile strength (MPa)	37
Density (g/cm^3)	1.29
Tensile modulus	27-16
Melting temperature(^{0}C)	173-178
$T_{g(}{}^0$C)	55-80
Impact strength (J/m^2)	13

Fabrication of Composite Laminates

The laminates of the required dimensions are made from hardened steel using rectangular molds. The dimensions of the mold used to manufacture the laminate are 300mm x 300mm and 4mm thick [13]. In this study, hand lay-up techniques were employed for the fabrication of composite laminates due to the flexibility and availability of material design. The jute fiber layer is marked and cut according to the mold dimensions. Calculate the amount of resin based on the GSM of the fabric. Add low temperature curing type epoxy resin LY-556 and curing agent HY-951 to epoxy resin in a ratio of 10:1% by weight and mix thoroughly using a vertical mixer, keeping the jute weight constant at 40%. The detailed fabrication process of composite laminates as shown in figure 1. The untreated, treated, coated, and treated and coated composite laminates of different compositions are designated JL1, JL2, JL3, and JL4 and are listed in Table 2. Finally, a jigsaw is used to cut the laminate to obtain specimens according to ASTM standards for characterization and testing. Jute fiber before treatment and after surface modification, as shown in figure 2.

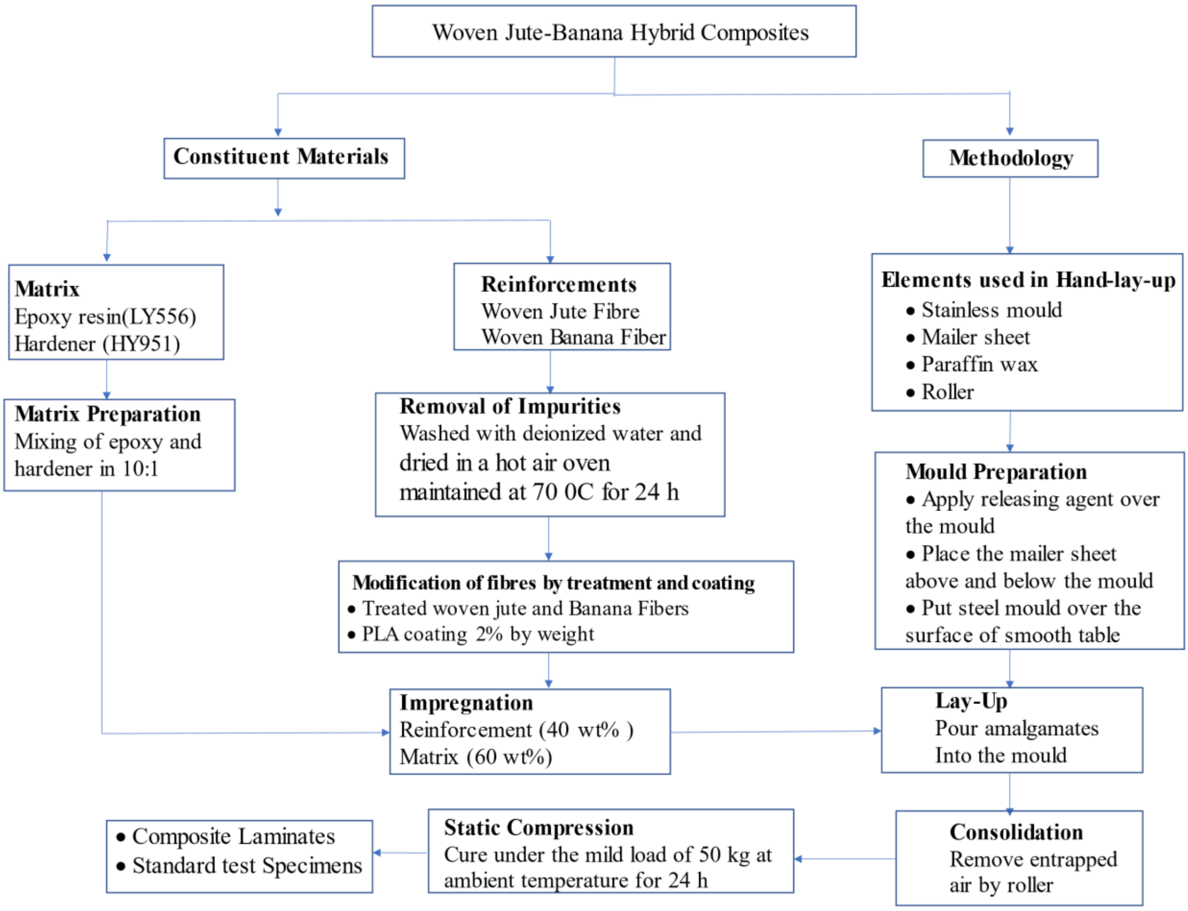

Figure1: Fabrication process of the composite laminates

Table 2: Nomenclature of composites.

Composites	Jute fiber (wt)%	Alkaline treatment (wt) %	PLA coating (wt) %
JL1	40%	-	-
JL2	40%	2%	-
JL3	40%	-	2%
JL4	40%	2%	2%

Figure 2: Jute fiber before surface modification and after surface modification

Dynamic Mechanical Analysis (DMA)

DMA is generally used to evaluate the temperature dependence properties like storage modulus, damping factor (tan δ) and loss modulus. SEIKO make Dynamic mechanical spectrometer Extar 6000 was employed for performing the experiments. The specimens are sectioned as per ASTM D4440 size of 20 × 10 × 4 mm3 for analysis. The laminates has undergone three point bend test under controlled condition of sinusoidal loading at 2 Hz frequency. The test was performed in the range of 310 C to 2100 C with a heating rate of 9^0 C/min). DMA is a non-destructive and sensitive technique for detection of interfacial region which measures two types of responses i.e damping (energy dissipation) and low-strain periodic deformation (stiffness). DMA is mainly used to determine whether the interfacial bond (weak, ideal and strong) in the composite. DMA is the most sensitive way to measure the subtle transitions in the composites. DMA technique characterizes the mechanical responses of the material by monitoring the property changes w.r.to the temperature and/or frequency of the oscillation. DMA generates the dynamic response of the material in to the two parts namely elastic part (E') and viscous (or) the damping coefficient (E''). Elastic process describes the energy stored in the system, viscous – energy dissipated during the process and mechanical loss factor (tan δ) is very much useful parameter for determining the occurrence of molecular mobility transitions, like glass transition temperature (Tq) i.e the dynamic deformation of material at different frequencies. Damping is sensitive indication for all types of molecular motion in the material. Molecular motion in the interfacial region generally shows damping in the material a part of the basic constituents. The estimation of damping magnitude at the interface s enables us to measure the bonding interface [12].

III. RESULTS AND DISCUSSION

The dynamic mechanical properties of the prepared composites were determined by storage modulus (E′), loss modulus (E″) and damping coefficient (Tan δ) using dynamic mechanical analysis (DMA). The test is performed in 3-point bending mode at a frequency of 1 Hz.

STORAGE MODULUS (E')

It is the amount of energy stored by a material during a vibration cycle and estimates the temperature-dependent stiffness behavior and load-bearing capacity of the material [8]. Figure 3 shows the change in loss modulus with temperature for untreated and modified jute composites at a frequency of 1 Hz. All of the treated and coated composites JL2, JL3, and JL4 were found to have higher storage modulus values than the untreated jute composite JL1 in the vitreous region. This may be due to the increased fiber stiffness of the composite after treatment and coating. In the glassy region, the order of increasing storage modulus values was JL4 > JL3 > JL2 > JL1. In the rubber range, the storage modulus of the composites saturated above 900 °C because the stiffness of the composites at very high temperatures cannot be controlled by treatments or coatings. It was also observed that the storage modulus of the composites did not show large variability between composites at very high temperatures. In JL4 Composite Laminate, stiffness is first increased by treatment and then by coating. JL4 has a high E' value at high temperatures, so it exhibits good bearing capacity.

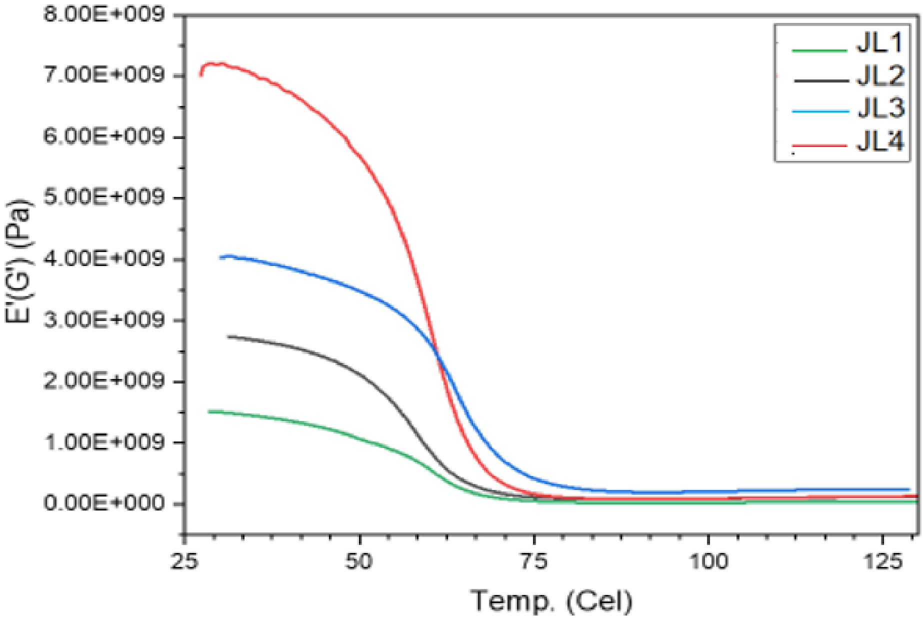

Figure 3: Storage Modulus of untreated and surface modified jute fiber composites.

LOSS MODULUS (E")

It is very useful in determining the glass transition temperature and represents the viscous response of the material. Figure 4 shows the change in loss modulus with temperature for untreated and modified jute composites at a frequency of 1 Hz. We found that with increasing temperature, the E″ values of all composites increased up to Tg and then decreased. Since then, the temperature corresponding to the highest peak of the E″ curve exhibits the Tg value. Corresponding composites. All treated and coated composites show higher E" values compared to the untreated composites. The E" curve peaks follow the order JL4 > JL3 > JL2 > JL1. JL4 incorporates alkaline treatment and a strong bonded jute weave PLA coating that absorbs the Tg and loss modulus and reduces epoxy mobility. The highest Tg value for JL4 indicates superior thermal stability compared to all other composites.

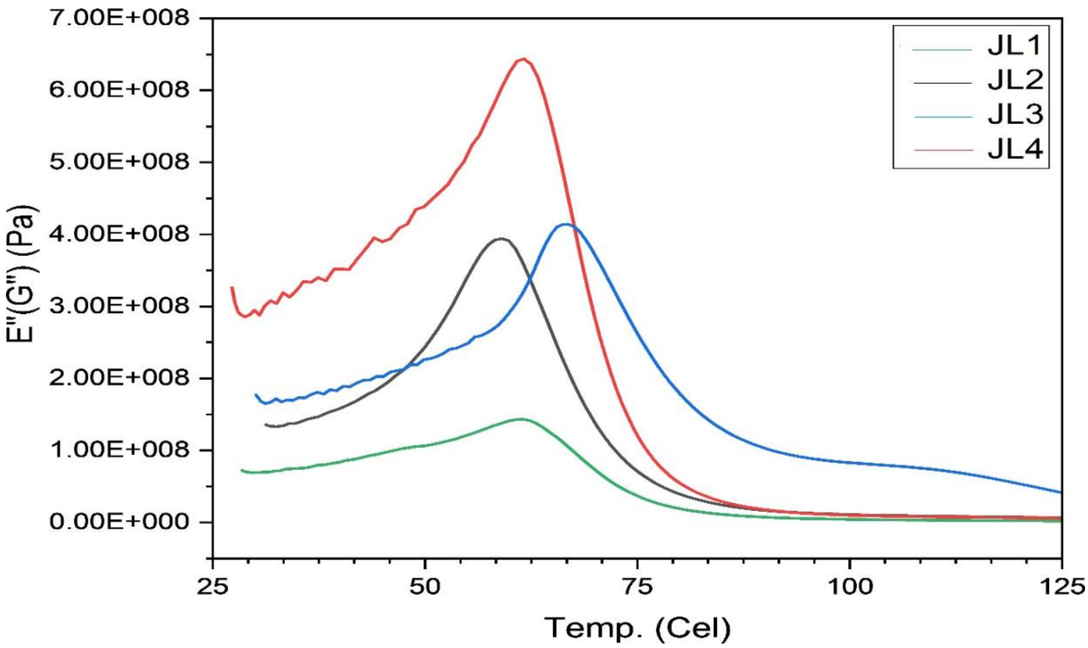

Figure 4: Loss Modulus of untreated and surface modified jute fiber composites.

DAMPING FACTOR (Tan δ)

It is the ratio of energy lost to energy stored during the vibration cycle and is determined by the bonding and stiffness of the fiber matrix. Cushioning is the ratio of E" and E' and indicates the impact resistance of the material. A positive value for Tan δ indicates good fracture toughness. Figure 5 shows the temperature variation of Tan δ at a frequency of 1 Hz for untreated and modified jute composites. Low values of Tan δ absorbed under strong bonding lead to poor polymer chain mobility. JL4 has the lowest peak lift capacity increase when Tan δ is low. Laminates JL1, JL2, JL4, and JL3 exhibit the highest peak Tan δ, similar to the loss modulus, and the damping also increases at the highest peak and decreases with temperature. Compared to other composites, JL4 shows a stronger transition to higher temperatures. For composites with strong bonds, low-energy laminate JL4 exhibits the highest peak Tg compared to weak bonds, followed by JL3, JL2, and JL1.

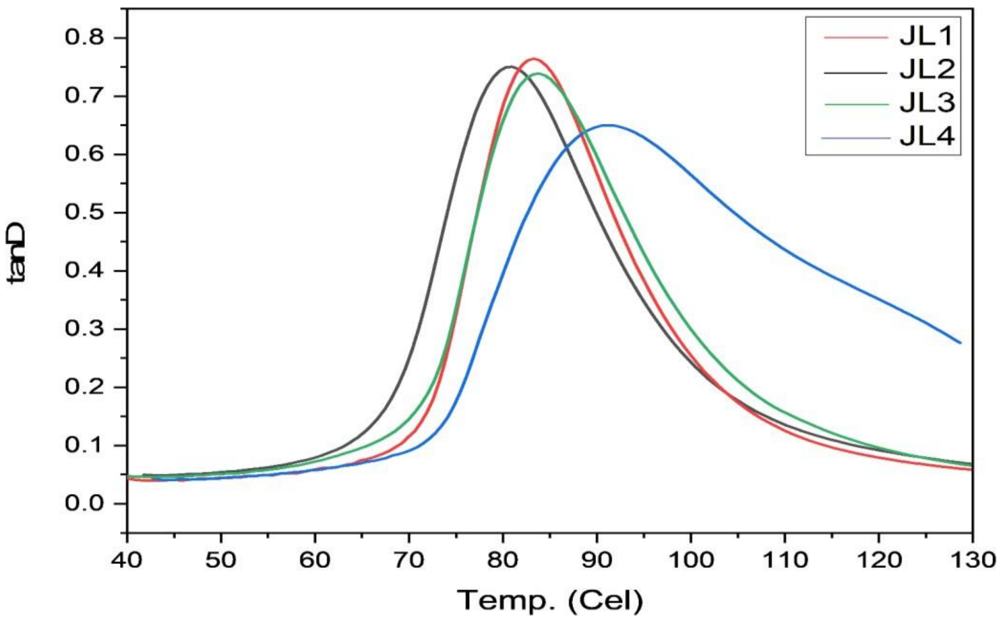

Figure 5: Damping factor of untreated and surface modified jute fiber composites.

IV. CONCLUTIONS

Based on the DMA results of this study, the following conclusions can be drawn.

- The positive effects of his NaOH treatment and PLA coating on jute fibers were observed in terms of significantly improving the thermal properties of the composites.
- JL4 exhibits the highest E' values due to good bonding between fibers and surface modified matrix material. When the fibers are coated, the storage modulus increases as the stiffness increases.
- Incorporating alkaline treatment and a strong bonded jute weave PLA coating, JL4 absorbs Tg and loss modulus, making the epoxy less flexible. The highest Tg value for JL4 indicates superior thermal stability compared to all other composites.
- JL4 shows the lowest peak value when Tan δ of capacity increase is low. Laminates JL1, JL2, JL4 and JL3 offer the highest Tan δ. For composites with strong bonds, low-energy laminate JL4 exhibits the highest peak Tg compared to weak bonds, followed by JL3, JL2, and JL1.
- PLA coating of treated fibers is considered an effective approach to improve the performance of composites for automotive applications.

REFERENCES

[1] Singh, Harpreet, Jai Inder Preet Singh, Sehijpal Singh, Vikas Dhawan, and Sunil Kumar Tiwari (2018) "A brief review of jute fibre and its composites." Materials Today: Proceedings 5, no. 14: 28427-28437.

[2] Thakur, V.K., Singha, A.S. and Thakur, M.K, 2011 "Green Composites from Natural Cellulosic Fibers, Germany: GmbH & Co. KG, 2011.

[3] Bajpai PK, Singh I, Madaan J. Comparative studies of mechanical and morphological properties of polylactic acid and polypropylene based natural fiber composites. Journal of Reinforced Plastics and Composites. 2012 Dec;31(24):1712-24.

[4] Pramendra Kumar Bajpai, Inderdeep Singh and Jitendra Madaan, 2014, "Development and characterization of PLA-based green composites: A review", Journal of Thermoplastic Composite Materials, 27, pp.52-81.

[5] Omar Faruk, Andrzej K Bledzki, Hans-Peter Fink, Mohini Sain, 2012," Biocomposites reinforced with natural fibers:2000-2010", Progress in Polymer Science, 37, pp.1552–1596.

[6] R. Kozlowski, B. Mieleniak, M. Helwig, A. Przepiera, 1999," Flame resistant lignocellulosic-mineral composite particleboards" ,Polym Degrad Stabil, 64, pp.523-528.

[7] C Sareena, MP Sreejith, MT Ramesan and E Purushothaman, 2014" Biodegradation behaviour of natural rubber composites reinforced with natural resource fillers – monitoring by soil burial test," Journal of Reinforced Plastics and Composites, 33, pp.412–429.

[8] ArunYadav, and M. K. Gupta 2019 "Development and characterization of jute composites for sustainable product: effect of chemical treatments and polymer coating." Materials Research Express 7, no. 1: 015306.

[9] Jandas, P. J., S. Mohanty, S. K. Nayak, and H. Srivastava (2011) "Effect of surface treatments of banana fiber on mechanical, thermal, and biodegradability properties of PLA/banana fiber bio composites." Polymer Composites 32, no. 11: 1689-1700.

[10] Sahu Parul, and M. K. Gupta. "A review on the properties of natural fibres and its bio-composites: Effect of alkali treatment." Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications 234, no. 1 (2020): 198-217.

[11] Gupta, Manoj K., R. K. Gond, and Ajaya Bharti. "Effects of treatments on the properties of polyester-based hemp composite." Indian Journal of Fibre & Textile Research (IJFTR) 43, no. 3 (2018): 313-319.

[12] Gupta, M. K. "Investigations on jute fibre-reinforced polyester composites: effect of alkali treatment and poly (lactic acid) coating." Journal of Industrial Textiles 49, no. 7 (2020): 923-942.

[13] Sagar, P. N., CH, N. R., & Malyadri, T. (2022). Enhancement of Mechanical Properties Alkali-Treatment and Polylactic Acid Coated Woven Jute Fiber Reinforced Composites. In Recent Advances in Manufacturing Processes and Systems (pp. 403-413). Springer, Singapore.