Influence of Fabrication Parameters on Thermo-Mechanical Characteristics of Zea Natural Fiber Reinforced Polymer Composites

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ABSTRACT: *Researchers have made remarkable achievements in natural fiber-reinforced polymer composite materials based on their superior properties over other materials for usage in engineering fields over the last four decades. Agricultural-based residues are primarily available in various countries; Nowadays, these residues are used to reinforce fiber material for preparing composites. Zea is one of the agricultural residues-based fibers. The present effort investigates the thermal property, hardness, water absorption property, and dynamic behavior of the composite material in the form of plates comprising polyester matrix reinforced with zea fibers. These properties are characterized by the composite plate possessing superior mechanical strength. The reinforcements are randomly oriented in the polyester matrix which is manufactured by compression molding technique. The experimental results showed that the composite plate exhibited superior mechanical and thermal properties.*

KEYWORDS: *Zea fiber; Polymer composite; Hardness; Water absorption; Thermal properties.*

INTRODUCTION

In recent years, researcher's interest has shifted to using natural plant fibers as efficient, economical, and easily producible additives for composite-based engineering and other applications. Natural cellulosic fibers are naturally derived from plants and trees that have been used from the last centuries and have become popular among end users [1]. The plant kingdom provides abundant potential resources for compound production. *Sathyanarayana et al.* [2] have examined the characteristics of the fibers in different structural parts of the Cocos nucifera, such as size, the chemical composition of fibers, mechanical properties, and elongation percentage. *Paramasivam T.* and *Abdul Kalam APJ.* [3] studied the tensile test of the sisal fiber-reinforced epoxy resin matrix. They proposed a more

comprehensive range of natural fiber-based composites for structural and other commercial applications. According to reports, the mechanical properties of the sisal-epoxy composite are almost half of the strength of the glass fiber-reinforced epoxy composites. Natural or biological fiber-reinforced polymers (called biobased composites) are viable alternatives to glass fiber-reinforced polymer composites. Researchers are analyzing the various possibilities of hybrid bio fibers such as stem fibers, leaf fibers, and grass fibers with a polymeric matrix in renewable and non-renewable resources to make natural fiber composites by *Sanadi et al.* [4]. Fibers extracted from

various portions of plants, and trees are called natural fibers. According to the plant parts from which they are extracted, these fibers are divided into the following categories. (i) Bast or stem fiber (jute, mesta, banana, etc.) (ii) Leaf fiber (sisal, corn, pineapple, spiral pine, etc.) (iii) Fruit fiber (coconut husk fiber, oil palm, cotton, etc.). Many plant fibers such as coconut, sisal, jute, banana, pineapple, hemp, etc., are utilized as industrial raw materials [5]. *Gunturu et al.* [6] studied the mechanical, thermal, and water absorption properties of banana/coir-reinforced polypropylene composites. They revealed that the coir fiber has more water absorption capability when compared to banana-reinforced PP composites, and it is found because of more lignin content in the coir fiber. Rice is a large class of grains that can be used to make husk fibers. Today, husk fibers are produced from wheat grains, corn stalks, rye, oats, and other cereal crops [7, 8]. *Ismail et al.* [9] studied the rice husk-filled polymer composites and reported that parameters such as fiber loading, coupling agent, processability, and damp heat aging impacted the properties of composites. *Shamsipur et al.* [10] studied the mechanical properties of two different-sized silica particle-added composites, the silica-added sulfur composites exhibited better mechanical properties. The mechanical properties of composites are highly influenced by the three critical factors: they are materials, fabrication methods, interaction properties between the matrix and reinforcement materials, the fiber length, fiber content, and fiber orientation under the material category. The fiber stacking sequence, fabrication temperature, and molding pressure are beneath the fabrication methods and the treatment process, impregnation of fillers, additives, and natural agro wastes are significantly enhancing the interaction properties between composites by *Nurazzi et al.* [11].

Ndazi et al. [12] stated that plant-based composite materials would be an alternative to polymer-based materials in the future in terms of their attractive special properties, lower cost, simple processing technology, eco-friendliness, and recyclability after the use of wood materials. The strength and performance of natural fiber-reinforced composite materials can be improved by executing appropriate engineering techniques, i.e., changing the fiber's physical, chemical, and thermal conditions or fabrication conditions [13]. Agricultural wastes are excellent alternatives to fibers extracted from

wood because they are diverse, widely distributed, and easily accessible. The economic, environmental, and technological advantages are emphasized based on the richness and renewability of agricultural residues [14]. *Panthapulakkal et al.* [15, 16] studied agro-based residues such as corn stalks, corn petals, and wheat straws and identified the corn cob reinforced high-density polyethylene composites as a suitable alternative to other natural fibers. The new variety of plant fibers such as Acacia nilotica, Vachellia farnesiana, and Eleusine Indica grass fiber was introduced by *Anish khan et al.* and *Vijay et al.* The basic physical and thermal characteristics of new fibers was analysed by using Fourier Transform- Infrared (FT-IR), X-Ray Diffraction (XRD), Thermo Gravimetric Analysis (TGA), Differential Scanning Calorimetric (DSC) techniques. The degradation temperature, glass transient temperature, crystallinity index, moisture content, and chemical composition of newly introduced fibers are illustrated by the above techniques [17-20].

Ashori et al. [21-23] studied the global shortage of fiber materials, which persisted due to deforestation. They suggested new environmental policies that demanded the preparation of composite materials from various waste agro materials. Also, they proved agricultural waste residues as a reinforcement for thermoplastics composites instead of wood fiber. One such new variety zea lignocellulosic natural leaf fiber was extracted from the Zea mays plant, the cultivation of which has been carried out universally, especially in Asia. The manually extracted zea fiber has emphasized its significance over other natural fibers [24-27].

Wielage et al. [28] investigated flax and hemp fibers through TGA studies and DSC studies for the thermal behaviors of composites. The analysis proved that thermal stability is essential for the consolidation process of composite materials. The PANI/ZnO hybrid nanocomposite was prepared and studied by *Toumi et al.* [29, 30]. the composite adsorption characteristics were analyzed using XRD, FT-IR, TGA, and SEM analysis. The congo red and Methylene blue dyes have better adsorption performance in PANI/ZnO Composites. *Wollerdorfer* [31] identified that the rise in temperature influences the mechanical properties of composites with polymer degradation. *Joseph et al.* [32] studied the thermal and crystallization behavior of sisal/polypropylene composites. The addition of fibers to the Polypropylene matrix

improved the composite's crystallinity and crystallization temperature, confirmed by TGA and DSC Analysis. The hardness and thermal stability of recycled low-density polyethylene composites reinforced by corn husk fiber were studied by *Youssef et al.* [33]. The experimental study witnessed corn husk fiber is suitable for engineering applications such as engine guard, electrical panels, and sports goods based on the composite's crystallization peak temperature and melting temperature. The corn husk fiber-reinforced recycled low-density polyethylene composite material has a hardness value of 29.61 to 79.72 N/mm². The hardness value is associated with the yield strength and ultimate tensile strength of the material with respect to a function of the force and the size of the indentation, and the pressure used to create the indentation and the resulting stress [34, 35].

Kaymakci et al. [36] studied wood-filled wood-plastic composites for hardness and tensile strength. It is found that there is a strong correlation between the hardness and tensile strength of wood-plastic composites when the wood content is between 30 and 40 weight percent. *Anbukarasi et al.* [37] analyzed the significance of volume fraction on luffa-reinforced epoxy composites by mechanical properties, thermal behaviors, and water absorption behavior and suggested the utilization of luffa fibers is suitable for strengthening the polymer composites. *Saha et al.* [38, 39] used the Dynamic Mechanical Analysis (DMA) method to study polymer composites' thermal characterization. They reported the combination of jute fiber and unsaturated resin significantly reduced the tan δ peak height. The DMA of jute fiber-novolac-epoxy composite laminates was carried by *Chandan Datta et al.* [40, 41]. He found that novolac epoxy resin exhibits increased stiffness without sacrificing its ductility. Investigating composite material's thermal, hardness, water absorption, and mechanical properties under different fabrication conditions is essential to evaluate the capabilities of newly identified zea fiber. In the current investigation, the characterization of zea polyester composites based on better mechanical strength and better fabrication molding pressure was studied and discussed comprehensively. In addition, this research plan evaluates the use of cheap and highly available agricultural residues that may help reduce waste disposal and promote economic development through the transition from agricultural waste to engineering applications.

EXPERIMENTAL SECTION
Zea Fiber Materials
The zea fiber is extracted from the agricultural waste manure of corn petals, and the petals are collected from the harvesting areas of corn plants. The petals are immersed in water then the manual peeling process is performed. The essentially required zea fiber properties for making the composites are shown in Table 1. For enhancing the reaction of polyester resin, Methyl Ethyl Ketone Peroxide (MEKP) is used as the catalyst. For curing purposes, the cobalt octoate is used as an accelerator for zea polyester composites. The concentration of the cured matrix employed for this study is a 0.01 w/w ratio.

## *Mechanical Properties of Zea Polyester Composites*
The composite plates are fabricated using a compression molding machine (Make: ACE Automation) with two different molding pressures of 2.6 MPa and 5.2 MPa and a temperature range of 60ºC for 45 minutes. The fabrication process parameters like short fiber length (40 mm) and fiber content (40%) were used to fabricate the composite plates. The ASTM D3039-08, ASTM D 790-07, and ASTM D256-05 standards were adopted to prepare tensile test sample specimens, flexural test specimens, and impact test specimens, respectively. The samples, prepared at both the molding pressures (2.6 MPa, and 5.2 MPa), were used for the testing. The better tensile strength (29.50 MPa) and flexural strength (39.55 MPa) showed in 5.2 MPa composites. The notable impact strength of 50.75 kJ/m² is achieved from the 2.6 MPa composites, and the above results were justified with other existing fibers and pure polyester resin [24].

FT-IR Analysis
The chemical structure of the Zea fibers reinforced composite with polyester was determined using FT-IR spectroscopy. The surfaces of the zea composite were examined with NICOLET iS 10 model ATR mode FT-IR spectrometer. Fibers were grounded and embedded in KBr crystals before taking the spectra. As the infrared radiation passes through the substance, some wavelengths of the radiation are absorbed/ transmitted by the substance depending on the spectra derived. The resulting spectrum represents the molecular absorption/transmission and creates a molecular fingerprint of the samples. This makes infrared spectroscopy useful for chemical composition analysis of natural fibers like zea fiber.

Table 1: Zea fiber Properties.

Physical Properties	Zea
Cellulose content (%)	73 ± 2
Hemicellulos's content (%)	11.6 ± 2
Lignin content (%)	11.6 ± 2
Diameter (μm)	150 ± 5
Density (g/cc)	1.23
Tensile Strength (MPa)	301
Elongation at break (%)	4.97 ± 0.2
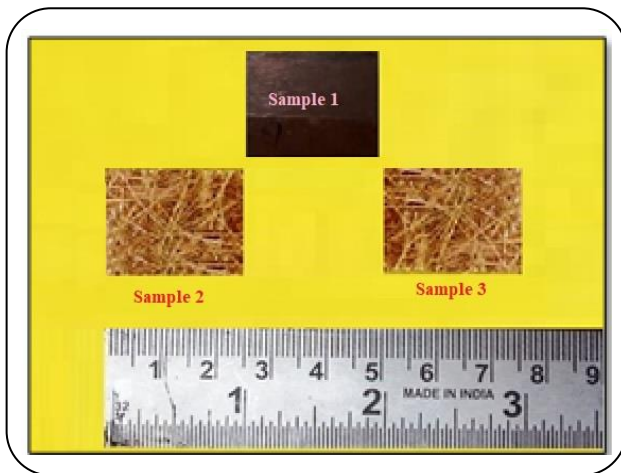
Fig. 1: *Hardness tested samples of pure polyester and zea-polyester composite specimen.*

Differential Scanning Calorimetry (DSC)

The DSC method conducts the thermoanalytical investigation, and the temperature transition occurs during the physical or chemical change in samples. The changes occur based on increasing the sample temperature relative to a locus temperature [42, 43]. Based on the above technique, the crystal temperature is studied to obtain the best results. The zea-polyester composites prepared with better fabrication conditions were grounded to fine powders. About 5 mg of composite powders were introduced in the DSC pan to identify the exothermic peak of the corresponding composite material. The obtained peak was used to measure the crystalline temperature of the zea polymer composites.

Hardness Study of Zea-Polyester Composites

The work utilizes the Brinell hardness tester to calculate the hardness of the composite material. The ASTM D 785 is used to prepare the samples with 25.4 mm

× 25.4 mm × 4 mm. The zea-polyester composites with better mechanical properties and pure polyester samples were selected to measure Brinell hardness. The 10 mm ball indenter was penetrated the specimen by an accurately controlled test force of 500 kg. The force is maintained for 10 seconds, after which the indenter was removed from the sample, and the indentation in the sample was measured for calculating the hardness number using Equation 1. The hardness tested samples are shown in Fig. 1.

$$HB = \frac{2 \times D}{\pi \times D \times (D - \sqrt{(D^2 - d^2)}} \tag{1}$$

Where, F - Force applied in the specimen
D – Diameter of the Indenter

$$HB = \frac{2 \times 500}{\pi \times 10 \times (10 - \sqrt{(10^2 - 4.8^2)}}$$

HB=25

Water Absorption Behaviours on Zea-Polyester Composites

The samples got altered into the desired size (76.2 mm × 25.4 mm × 3 mm) based on the ASTM D570 standard to measure the water absorption criteria of zea fiber-reinforced polyester composites. The samples were dehydrated in an oven at 45°C, then cooled at atmospheric temperature before evaluating, and then the weight of all samples was measured.

The water absorption test involves immersing the entire sample in water at atmospheric room temperature for different times. After soaking for 24 hours, remove the sample from the water bath and then wipe it with a clean, dry cloth to remove the water. Then immediately re-weigh. Similarly, all samples were weighed regularly at the specified intervals of 1, 3, 6, 9, 12, and 15 days after exposure until the weight of the samples reached a constant level. The sample tested for water absorption is shown in Fig. 2.

The weight difference between before and after immersion in the water helped to evaluate the water absorption capacity of the composite samples. Percentage weight change after immersion is determined by Eq. (2).

$$\text{Weight change}, \% = \frac{RW - CW}{CW} \times 100 \tag{2}$$

Where,
RW= Water immersed specimen weight
CW = Actual specimen weight

Table 2: Fabrication Parameters and its better mechanical strength.

S.No	Sample	Fabrication parameters			Better values of mechanical strength		
		Molding Pressure (MPa)	Length of the Fiber (mm)	Fiber Content (%)	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Strength (kJ/m^2)
1	Sample 1	Nil	Nil	Nil	12	20	30
2	Sample 2	5.2	40	40	29.50	39.55	-
3	Sample 3	2.6	30	40	-	-	50.75
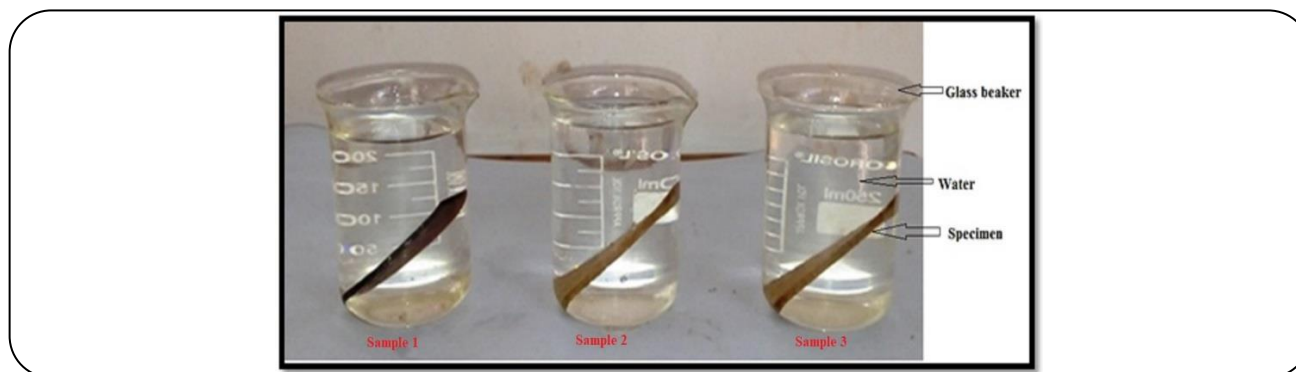
Fig. 2: The water absorption tested pure polyester and zea-polyester composite specimen.

Dynamic Mechanical Analysis of Zea-polyester Composites (DMA)

The viscoelastic behavior of zea fiber-reinforced polyester composites is characterized by Dynamic Mechanical Analyzer (DMS6100). The test involves exposing the samples at the temperature range and heating rate of 30 - 150ºC and 5°C/min, respectively, at 1 Hz. For the dynamic mechanical experiments, the zea fiber-reinforced polyester composites of 60 mm x 10 mm x 3 mm dimensions, were used.

RESULTS AND DISCUSSION

The result and discussion section focus on the thermal behaviour, hardness, water absorption, and dynamic mechanical characteristics of zea-polyester composites. The composites prepared with the desired combination of fabrication parameters demonstrated better tensile, flexural, and impact strength upon experimentation. Table 2. gives the fabrication parameters used to manufacture the composite samples.

FT-IR Analysis of zea fiber reinforced Polyester composites.

The FT-IR spectrum of zea fibers composite shown in Fig. 3. A sharp peak is obtained at 3346 cm^{-1} corresponding to the –NH stretching frequency of amino group present in the zea fiber composite.

The peak intensity for –NH group is as high as 0.154 indicating the amino functional group present in zea fibers and confirming the presence of cellulose bio-polymer backbone in the zea fibers. It is also seen that a peak obtained at 2917 cm^{-1} corresponds to the –CH symmetrical stretching frequency of -CH group present in the zea fibers. The peak intensity for –CH group is as high as 0.0849 indicating that the cellulose polymer and polyester C-H backbone are present in the zea fibers. Further, it is observed that a FT-IR peak is obtained at 1730 cm^{-1} corresponding to the –C=O symmetrical stretching frequency of –C=O group present in the polyester with the peak intensity of 0.0849 indicates that the reinforce material present in the zea fibers composite. It is also observed that a FT-IR peak is obtained at 1633 cm^{-1} corresponding to the –CH asymmetrical stretching frequency of –CH group present in the zea fibers with the peak intensity of 0.0553 indicates that the polymer chain present in the zea fibers.

The FT-IR analysis also show a peak at 1371 cm^{-1} corresponding to the –CH wagging frequency of –CH group present in the polymer system with the peak intensity of 0.0607 indicates that the functional group present in the zea fibers. It is also observed that a FT-IR peak is obtained at 1633 cm^{-1} corresponding to the –CH asymmetrical stretching frequency of –CH group present in the developed system with the peak intensity of 0.0553

indicates that the polymer chain is present in the zea fibers. It is confirmed from the above FT-IR studies that the presence of hemicellulose polymer backbone in zea fibers reinforced composites with polyester.

Differential scanning calorimetric analysis

Fig. 4 shows the thermoanalytical peak of pure polyester resins and composites that exhibit better mechanical strength in the experiment. The heating curve of the pure polyester sample showed an exothermic peak at around 64°C, which could be related to the material's glass-transition temperature (Tg). The DSC curve shows the movement of the crystallization peak after the reinforcement of zea fiber with the polyester matrix in sample 2 and sample 3. The initiation of lignocellulosic materials degradation and water loss from the cellulose structure could be associated to the exothermic peak observed at roughly 73°C and 92°C. The crystallization temperature of pure polyester resin is lower at 64°C when compared with the composite material. The crystallization temperature of the composite material with a short fiber of 30 mm and a low weight content of 40% is 73°C. In addition, with the increase of fiber length and molding pressure (i.e., a composite material reinforced with 40 mm fiber length, 40% fiber content, and 5.2 MPa molding pressure), the crystallization temperature of the composite material increased by about 92°C. The difference in temperature between samples 2 and 3 is due to the increase in molding pressure from 2.6 MPa to 5.2 MPa, which is found due to the increases in the polymer chain mobility. Similar behavior was also noticed by *Spinace* and *da Luz et al.* [44-46] The composite plate has a tightly packed and rigid structure, thereby improving the temperature stability of the composite material. In addition, the increase in fiber length also supports the thermal stability of the composite.

Hardness Behaviour of Zea –Polyester Composites

The hardness behavior of polyester resin and zea-polyester composites with better strengths of the composites are plotted in Fig. 5.

The hardness of the polyester resin improved upon reinforcing the zea fibers with the polyester matrix. However, the hardness improvement of the composites is minimal because it is a surface behavior of the composites. The reinforcement of zea fiber in the polyester matrix enhanced the bulk properties, whereas the influence
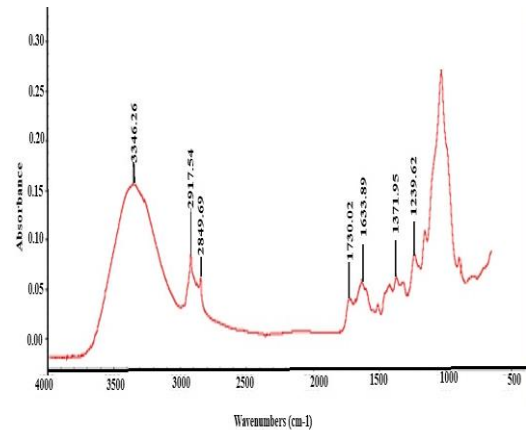

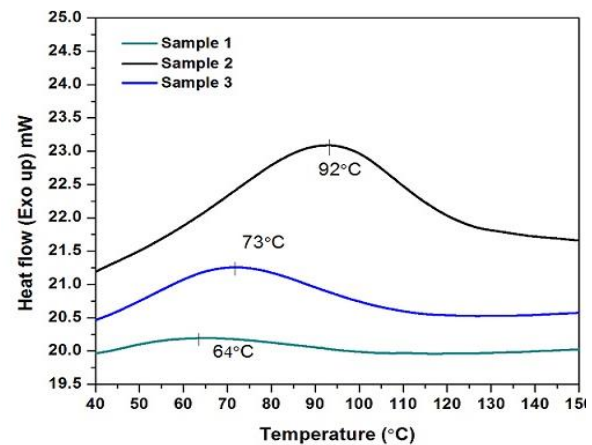*Fig. 3: FT-IR Spectrum of zea fiber polyester composite.*

Fig. 4: DSC curves of pure polyester and zea-polyester composites.
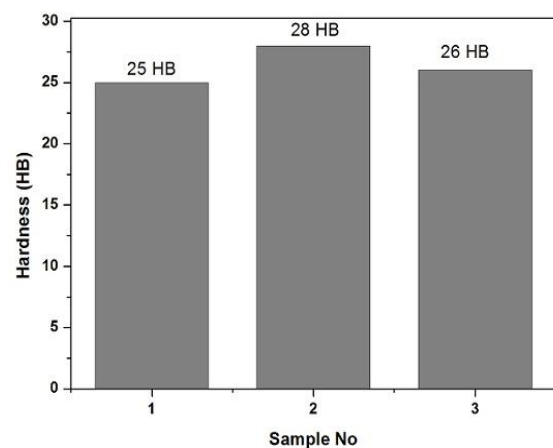

Fig. 5: Hardness properties of pure polyester and zea- polyester composites.

of hardness is insignificant due to the fabrication process parameters. Since, it had not affected the surface properties such as hardness in this case noticeably. Generally, more matrix material (60%) in composites exhibited the lower value of hardness. However, due to greater fiber dispersion in the polyester matrix and stronger interfacial bonding between the fiber matrix the hardness seems larger [47].

Water Absorption Behaviour of Zea –Polyester Composites

The water absorption behaviour of the zea-polyester composites with better strength is shown in Fig. 6. From Fig. 6, the observation made that the water absorption for sample 1 (polyester resin) was less due to the absence of cellulosic natural fibers, which usually is the reason to absorb water. But polyester composite reinforced with zea fibers exhibited a higher rate of water absorption due to cellulosic fibers. The sample 2 and sample 3 having different fabrication molding pressure of 2.6 MPa and 5.2MPa respectively both samples having good absorbing capacity of water due to the presence of lignin content. But, the high-pressure molding (5.2MPa) composite decreased the water absorption rate due to the tight packing of zea fibers in the polyester matrix, which restricted the exposure of zea fibers to moisture. On the other side, the increase in duration beyond 12 days did not report significant changes in the water absorption percentage; this is because the cellulose fibers start swelling after a certain point of time instead of absorbing moisture [48].

Dynamic mechanical analysis of Zea-polyester composites

Dynamic Mechanical Analysis (DMA) comprises characterizing the viscoelasticity of zea-polyester composites. Sinusoidal stress is applied and examined the deformation of the composites to find out the loss modulus, storage modulus, and tan δ values of the composites. The composite material's temperature and the applied stress frequency continue to change until the composite material breaks. The measurement of the glass transient temperature of the material assisted in identifying transitions of molecular motion due to continuous stress in the materials. The temperature-related tensile storage, loss moduli, and phase angle (tan δ) for the polyester resin and better mechanical properties samples are presented in Figs. 7, 8, and 9, respectively. The storage modulus curve defines the energy stored in the composite materials, which is a degree of the reversible elasticity of the composite materials.
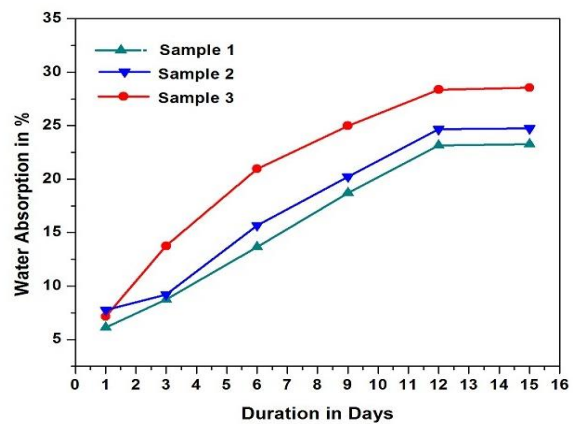

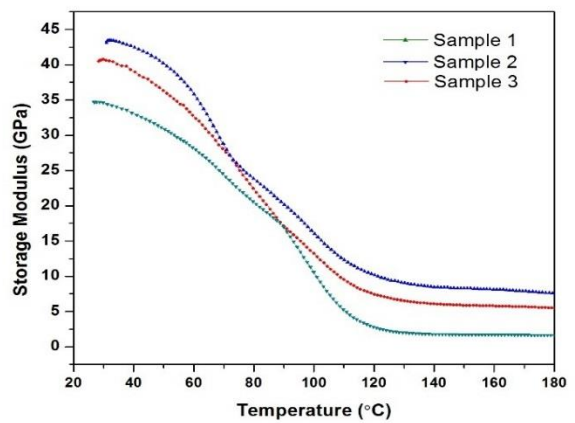*Fig. 6: Water absorption behaviours of pure polyester and zea-polyester composites.*

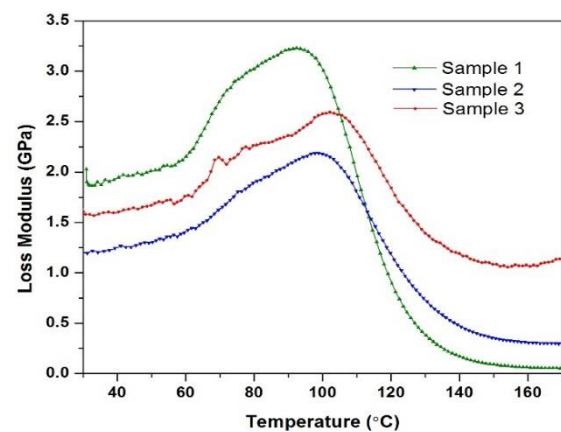*Fig. 7: Storage modulus of pure polyester and zea- polyester composites.*

Fig. 8: Loss modulus of pure polyester and zea-polyester composites.
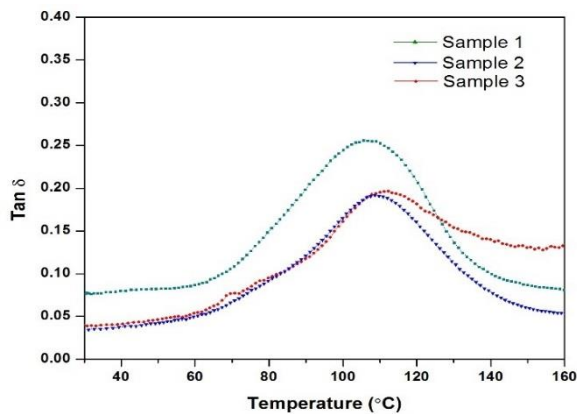
Fig. 9: *Loss factor curve for pure polyester and zea- polyester composites.*

The composite's glass transition temperature (Tg) is very close to that of the neat polyester matrix material. Similar observations were obtained by *Marcovich et al.* and *Mwaikambo et al.* [49, 50]. The prominence of the tan δ peak in the laminate is lower than in pure polyester resin. The addition of fiber causes this alteration because it obstructs the molecular mobility of the pure polyester matrix. The addition of fibers to the polymer enhances the resistance of the material, the storage modulus of samples 2 and 3 is higher than that of the pure polyester matrix. It should also be noted that, when the temperature rises, the variation in storage modulus between composite material and pure polyester matrix increases. Fig. 6 depicts the changes in tan δ as a function of temperature for different samples. The storage modulus increased significantly for the composite materials prepared at a molding pressure of 2.6 MPa. However, the zea fiber material reinforced in the polyester matrix allows more tremendous stress to be transferred at the interface under a fabrication pressure of 5.2 MPa and leads to increased stiffness. Under the fabrication pressure of 5.2 MPa, the increase in storage modulus indicates that the stiffness of the zea-polyester composite has increased. This is consistent with the tensile and flexural results that greatly influence the elastic properties of the composite material. Due to the softening of the zea-polyester composite material, the storage modulus decreases with increasing temperature. The storage modulus value dropped during the temperature range of 45-60°C, which corresponds to the glass transition temperature zone.

Fig. 7 shows the loss modulus plot for zea-polyester composites. DMA (Dynamic Mechanical Analysis) revealed the relaxation peaks in all the studied samples. The composite material with a fiber length of 40 mm, which consists of 40% fiber content, was manufactured under the pressure of 5.2 MPa, and the composite material with a fiber length of 30 mm manufactured under the pressure of 2.6 MPa with a fiber content of 40% have the peak loss modulus respectively. Similar viscoelastic characteristics were studied by *Etaati et al.* [51]. Up to 40% fiber content, there was a significant improvement in storage modulus in hemp fiber-reinforced polypropylene composites. This is due to an epoxy chain limitation caused by the dense packing of the treated coir fibers. It is 99°C and 102°C. This was due to the close packing of the components under the molding pressure of 5.2 MPa and the migration of molecules between the matrix and the fiber surface is prevented.

The impact of manufacturing parameters on the mechanical loss factor of zea composites is shown in Fig. 8. The tan δ curve shows a glass transition temperature (Tg) corresponding to the transition peak. The temperature of each component, which can be observed in all composites, indicates the incompatibility and immiscibility between the phases. The graph of tan δ versus temperature can be used to detect molecular transitions, and the peak of tan δ was interpreted as T_g. Obviously, under the molding pressure of 5.2 MPa and 2.6 MPa, the tan δ peak of the zea-polyester composite material was around 100°-120°, and there was no notable movement in the composite material, indicating that the presence of fibers will not affect the strength of the fibers.

When a load was applied to a composite material, a portion of the given load was dissolute through an energy dissipation mechanism (such as segmented movement), while the remaining load was stored in the material, which will be released after the load was removed (such as the spring flexible response).

● The increase in tan δ value indicates that the material has more significant energy dissipation potential. Therefore, the more excellent tan δ value shows, the greater the dissipative properties of the composite material.

● The decrease in tan δ indicates the material has greater elasticity, and by applying a load, it was more likely to store the load instead of dissipating it.

For polymer composites, increasing the fiber content will reduce the tan δ value because the fiber particles impose restrictions on the molecular motion of the polymer chains (due to the adsorption of the polymer chains on the surface of the fiber) in more material elasticity response. When studying the DMA of zea-polyester composites, similar inferences were observed.

Application of Zea –Polyester Composites

The agro residues-based fiber as an alternative reinforcement material comes from its high strength and stiffness, easy availability, and biodegradable. The tensile, flexural, impact, hardness, and water absorption properties of zea-polyester composites suit the fabrication of engineering and commercial products such as transmission gear, hockey sticks, and table bushes, as shown in Fig. 10. Generally, gears are used for the transmission of power from one shaft to another shaft with varying speed and uniform torque. The gears are made up of grey cast iron. The low-speed and low-power transmissions do not require high-strength metals. In this case, the zea-polyester composite materials can be used for manufacturing gears.

Generally, hockey sticks are made of wood, especially mulberry wood. The development of the hockey game, the improvement of technology and the trend of playing on sand and water-based artificial surfaces have firmly established a place. Many other materials have been introduced into the manufacture of hockey sticks. Composite hockey sticks have undergone a rapid evolution from a rather bulky start to almost the same profile and weight as traditional hockey sticks. The present invention relates to an improved sports stick, and more specifically, a sports stick made of zea fiber-reinforced polyester composite materials. The zea fiber composites have better mechanical properties; it was used to fabricate a sports stick. Zea fiber in composites will help to produce a new generation of eco-friendly appliances that are biodegradable.

CONCLUSIONS

The thermal, hardness, water absorption, and dynamic mechanical behavior of zea-polyester composites were studied for the composites prepared with the combination of fabrication parameters which demonstrated better mechanical properties upon experimentation. The thermal,
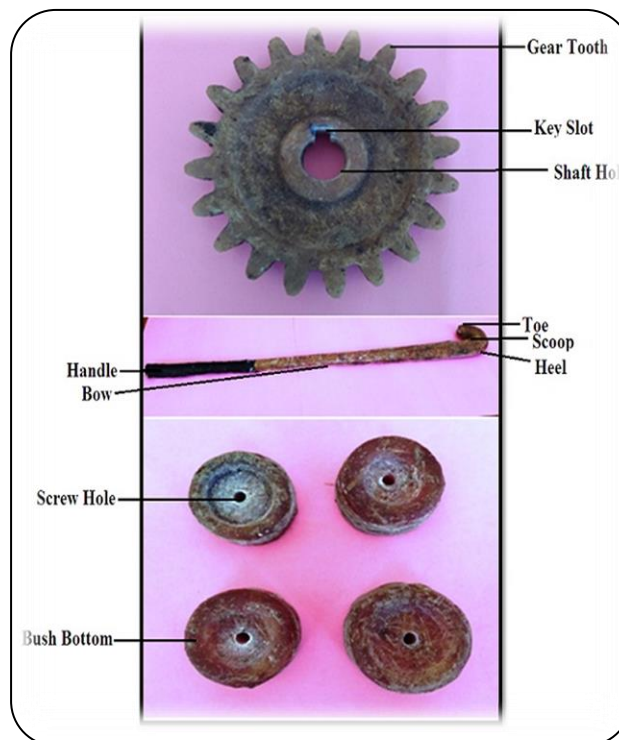

Fig. 10: Fabricated transmission gear, hockey stick, and table bushes using zea-polyester composites.

hardness, water absorption, and dynamic mechanical behavior of zea-polyester composites are satisfactory and can be used for engineering applications. The following conclusions are drawn from the present study.

● The DSC curve illustrates the better crystallization peak after the reinforcement of zea fiber with the polyester matrix and the difference in the molding pressure between the loaded samples are observed because of better fabrication conditions.

● The variation in the hardness found insignificant, however the change in the hardness (in pure polyester, 5.2 MPa sample and 2.6 MPa sample) results may be due to the dispersion of fibers in composites.

● The water absorption in pure polyester was found to be minimal because of the absence of lignin content. The 2.6 MPa molding pressure sample absorb more amount of water due to light packing between the fibers and matrix when it was compared with 5.2 MPa molding pressure sample.

● Increasing the fiber content will reduce the tan δ value because the fiber particles impose restrictions on the molecular motion of the polymer chains in more material elasticity response.

Acknowledgments

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