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Dynamic Mechanical Analysis on Jute Fiber Reinforced Polymer Composites for Patella Implant

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Abstract

Natural fibres possess convincing properties when reinforced in polymers. In this study, JFRPs viscoelastic behaviour at low and elevated temperatures were explored. The present work focuses on the fabrication of jute reinforced polyester based polymer composites with different fiber compositions. Untreated long jute fibres and mat structured jute fibres were used for preparing the specimens. The Dynamic Mechanical Analysis (DMA) test was carried out on selected developed Polymer Matrix Composites (PMC). Density of selected PMCs are nearly equal to the bone density. So, PMC specimens are considered to carry out thermal analysis using DMA. In particular, by dynamic mechanical analysis experiments, properties such as storage modulus, loss modulus, tanδ and glass transition temperature were determined. It was found that the storage modulus (E') recorded above the glass transition temperature (Tg) varies with increase in temperature. Along with the previous research of material properties for possible bioimplantation, this Tg value is identified for possible implementation as patella bone implant. The loss modulus (E") and damping peaks (Tanδ) values were found to be reduced with increasing matrix loading and temperature.

Keywords: *Polymer composites, dynamic mechanical analysis, storage modulus, loss modulus, tan delta and glass transition temperature.*

1.0 Introduction

New techniques and developments are important in terms of natural fibres [1, 2]. Studying their mechanical and interfacing properties is an important phenomenon for identifying its interfacial bonding. Though the variety of materials has been added in polyester resin the research works are limited with fibers and nano reinforcements [3]. Other than mechanical properties, the composite material possesses unique properties with temperature which provides more insight to material behaviour in elevated temperatures. DMA can identify the Glass Transition Temperature. The Dynamic Mechanical Analysis (DMA) on a material provides information of material behaviour with respect to the modulus with the temperature. DMA test offers more insight on mechanical modulus and temperature dependant performance. The deformation which is applied on the sample in a cyclic manner and the DMA results are recorded in the form of graph. An oscillatory force is applied on the sample, the changes in stiffness and damping is identified. The

storage modulus, loss modulus and tan delta values provide details of modulus information, mechanical properties in frequency range [4]. The sensitive glass transition temperature is identified. It shows the curing reactions, effect of reinforcements and interaction of the fibers, fillers and matrix in various conditions[18].

2.0 Material and Methodology

2.1 Matrix-Polyester

The natural fibers like jute are considered as reinforcement fibers and polyester as base matrix in this present work also Al_2O_3 considered in the form of particulates to increase the density of composites. Methyl ethyl ketone peroxide (MEKP) an organic peroxide is used as a catalyst. MEKP is less sensitive to shock and temperature, more stable in storage. It initiates the crosslinking of unsaturated polyester resins. Catalyst cobalt is used for enabling hardening in resin as hardener. The catalyst and accelerator are used for 1% and 2% respectively in fabrication. The properties of the polyester are as shown in the Table 1.

2.2 Reinforcements: Natural Fibers and Alumina

Natural fibers are used to increase the density of the polyester and also to improve the mechanical properties of composite materials. Jute fibers are used as reinforcement materials in this research work. Figures 1 and 2 show the jute fiber and mat.

The stalks are tied into bundles and retted (soaked) in water for about 20 days. This process softens the tissues and permits the fibers to be separated. The fibers are stripped from the stalks in long strands and washed in water. Then they are dried. The fibers are white and may be brown. It can be 1-4 m long. It is completely bio-degradable and recyclable and thus environment friendly. Jute fiber has high tensile strength, low extensibility, low thermal conductivity properties. Jute long fiber and Mat fiber are shown in Figures 1 and 2. Properties of the jute fibers are as shown in the Table 2.

Figure 1: Jute long fiber

Figure 2: Jute mat fiber

Table 1: Properties of Polyester

Property	Density (kg/m^3)	Elastic Modulus (MPa)	Tensile Strength (MPa)	Compressive Strength (MPa)	Elongation (%)	Water absorption @24h (%)
Polyester	1200-1500	2000- 4500	40 - 90	90 - 250	2	0.1 - 0.3

Table 2: Properties of Jute fiber

Material	Density (Kg/m^3)	Elastic Modulus (MPa)	Tensile strength (MPa)	Stiffness KN/mm	Elongation (%)
Jute	1460	20-50	400-800	10-30	1.5-1.8

2.3 Aluminum oxide

Aluminum oxide commonly called Alumina is used as reinforcement. The properties of Al_2O_3 fiber are as shown in Table 3.

2.4 Fabrication steps

1. Preparation of fibers and reinforcements to be free from moisture and contamination.
2. Prepare the matrix by mixing of polyester and hardener in the ratio of 10:1.
3. Prepare mold for designed dimension.
4. Apply the wax in mould.
5. Apply the mixed resin in mold.
6. Then keep the fiber mat as a first layer and roller be rolled properly on the mat.
7. Again apply the mixed matrix on the first layer of fiber and rolled properly.
8. Then second layer of fiber mats kept above the first layer and apply mixed
9. Matrix and again rolled properly.
10. Similarly the consecutive layer can be formed up to required thickness.
11. Then the laminates are allowed for curing in atmospheric condition for 2 days.

The Table 4 shows the composition of jute and polyester.

Post Curing

The resin in composites changes its properties when reinforced with fibers. It changes the form from liquid to brittle solid. At this position, post cure at higher temperature may need to be done. Post curing is done for 100° for 2 hrs. The purpose of the post cure is to increase Tg of the resin by complete cross-linking. The properties of the polyester resin are affected by the type and amount of reactant, catalyst and monomers as well as the curing temperature.

Table 3: Properties of Alumina

Property	Density (Kg/m^3)	Elastic Modulus (MPa)	Flexural strength (MPa)	Compressive strength (MPa)
Al_2O_3	3950	300000	379	2600

Table 4: Composites of Jute and polyester

Composites	Polyester Weight %	Jute LF Weight %	Jute Mat Weight %	Al_2O_3 Weight %
J1	90	10	-	-
J2	80	20	-	-
J3	70	30	-	
J4	90	-	10	-
J5	80	-	20	-
J6	70	-	30	-
J7	85	-	10	5
J8	75	-	20	5
J9	65	-	30	5

Figure 3: Fabrication of composites

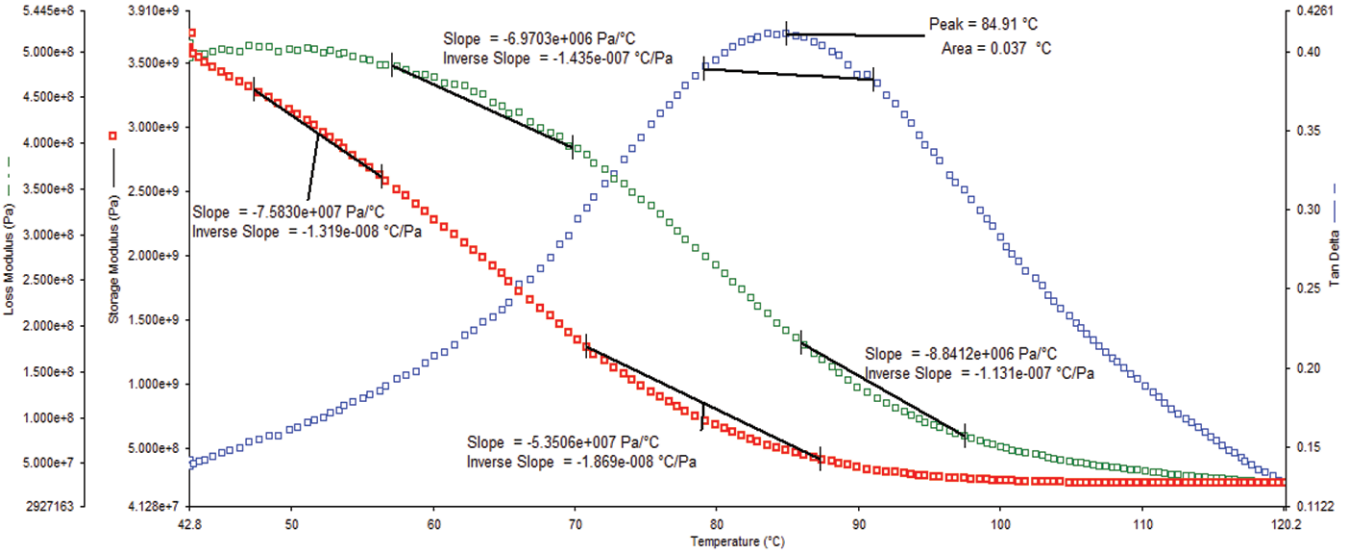

Figure 4: The DMA curve of J7

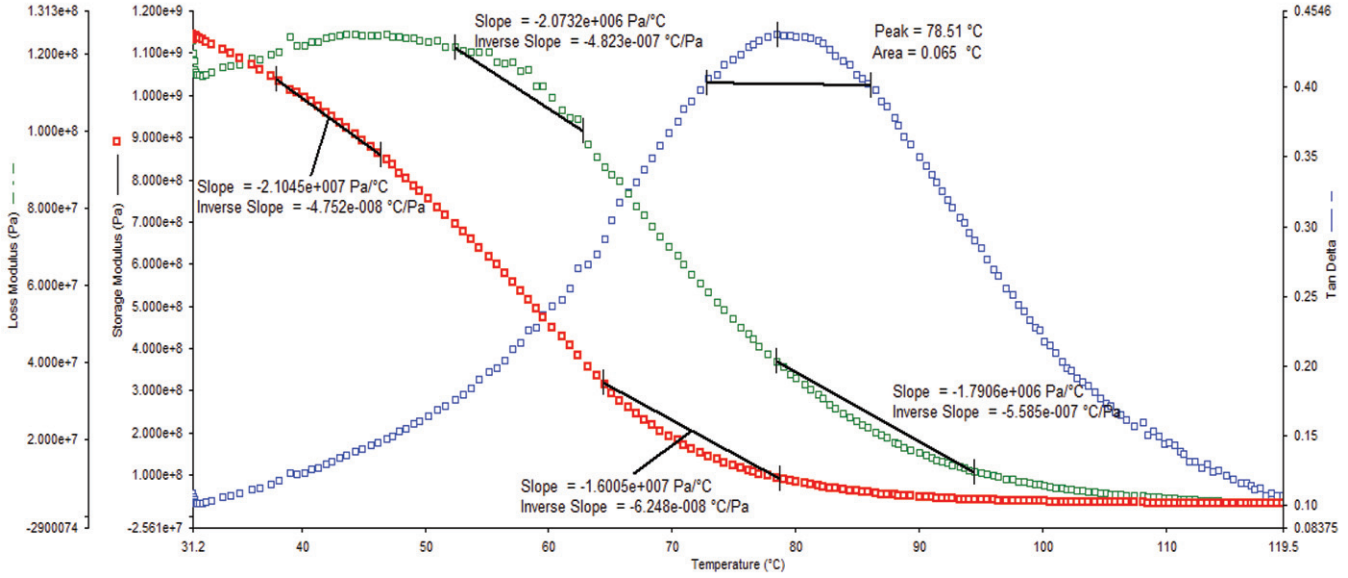

Figure 5: The DMA curve of J8

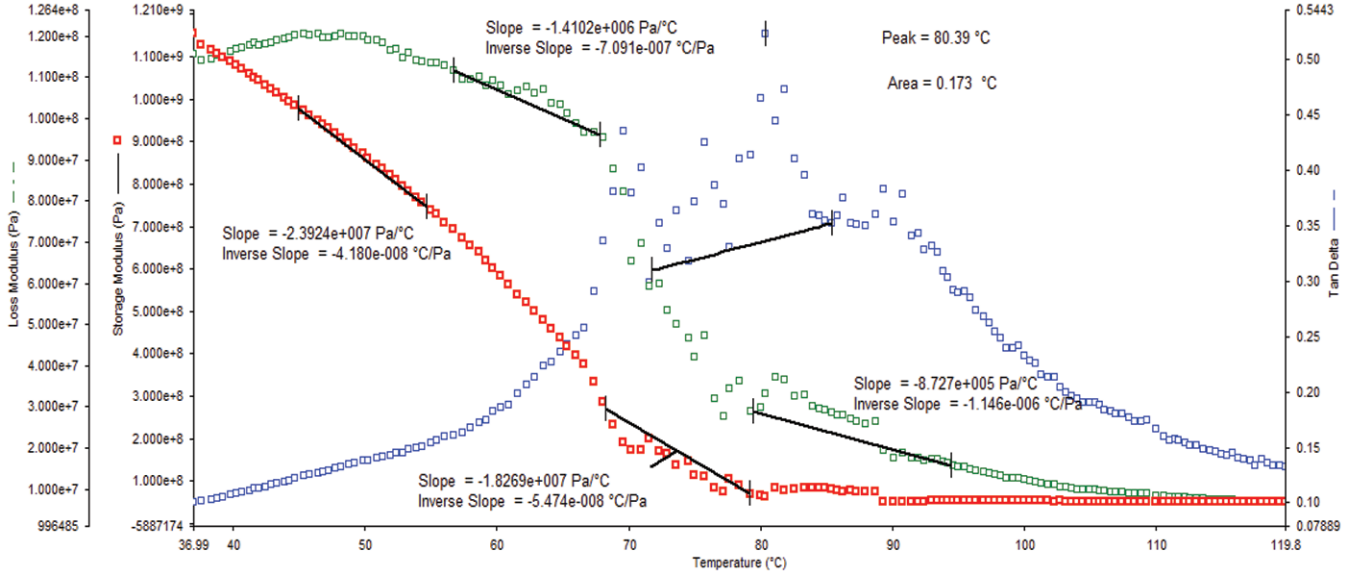

Figure 6: The DMA curve of J9

Testing

The material was then cut by water jet cutting for required dimensions according to ASTM standards for DMA, Apparatus: Dynamic Mechanical Analyser, Perkin Elmer 8000, ASTM standard Dimensions: 50mm×4mm×5mm. During testing for DMA, both procured and post cured samples were weighed before and after testing. First, before fixing the sample and soon immediately after cooling of DMA apparatus to room temperature. Two samples were tested and averages of two and best were considered for tabulation.

DMA Perkin Elmer 8000 machine settings:

1. Temperature: 25ºC to 150ºC
2. Frequency: 1Hz. (Also for 0.1 to 1, in intervals of 0.1Hz)
3. Static Force: 0.5N
4. Dynamic Force: 1N
5. Test conducted: Three point Bending Test

3.0 Results and Discussions

3.1 Dynamic Mechanical Analysis (DMA)

The DMA test was carried out for selected developed PMC based on the concept of density of developed PMC nearing to the density of bone. Therefore for J7, J8, J9, material specimen, thermal analysis was carried out using DMA. The results of DMA tests are shown in Figure 4 and discussed.

The Figure 4 shows Tan delta value peak is observed to be at around 85ºC and delta value approaches to zero, so material is said to be stable and elastic. The storage modulus values starts decreasing from $3e^9$ Pa to $5e^8$ Pa. After 98ºC it has maintained constant value. The decrease in slope value from slope 1 to slope 2 between 42.8ºC to 98ºC but within the 50ºC to 60ºC, material has maintained the stiff value. By observation of loss modulus curve, it can be concluded that material is not dissipating the energy up to 55ºC and material is stable and safe. The drop in storage modulus (E') and peak in damping factor (tan delta) between 85°C and 120°C is due to the glass transition temperature (Tg = 85º) of the polymer material. Above 120.2°C the sample begins to melt and flow, thus losing all mechanical integrity.

The Figure 5 shows Tan delta value peak is observed to be at around 78ºC and delta value approaches to zero, so material is said to be stable and elastic. The storage modulus values starts decreasing from $1.1e^9$ to $3e^8$ Pa. After 80ºC it has maintained constant value. The decrease in slope value from slope 1 to slope 2 between 31ºC and 80ºC but within the 50ºC to 60ºC, material has maintained the stiff value. By observation of loss modulus curve, it can be concluded that material is not dissipating the energy up to 55ºC and material is stable and safe. The drop in storage modulus (E') and peak in damping factor (tan delta) between 80°C and 119.5°C is due to the glass transition temperature (Tg=79ºC) of the polymer material. Above 119.5°C the sample begins to melt and flow, thus losing all mechanical integrity.

The Figure 6 shows Tan delta value peak is observed to be at around 80ºC and delta value approaches to zero, so material is said to be stable and elastic. The storage modulus values starts decreasing from 36.99ºC to 99ºC. After 99ºC it has maintained constant value. The decrease in slope value from slope 1 to slope 2 between 36.99ºC and 99ºC but within the 50ºC to 60ºC, material has maintained the stiff value. By observation of loss modulus curve, it can be concluded that material is not dissipating the energy up to 55ºC and material is stable and safe. The drop in storage modulus (E') and peak in damping factor (tan delta) between 85°C and 119.8°C is due to the glass transition temperature (Tg=80ºC) of the polymer material. Above 119.8°C the sample begins to melt and flow, thus losing all mechanical integrity. Many distortions in graph is observed which may be due to sample impurity or agglomeration of particles.

4.0 Conclusion

By observation of curves, it can be concluded that material is not dissipating the energy up to 55ºC and material is stable and safe. Tan delta value peak is observed to be at around 78-85ºC and delta value approaches to zero, so material is also said to be stable and elastic. The storage modulus values varies with temperature. After 98ºC it has maintained constant value. The material has maintained the stiff value. The properties of composites vary because of the bonding between the fibers and resin. The additional variation in temperature is observed with the inclusion of alumina particles and the surface interaction between the particles and resin provides additional thermal properties enhanced. The surface area of particles and its chemical bonding provides more contact surface which increases the properties of composite. This may be used for human body temperature range for implants with further tests conducted.

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