



## DEVELOPMENT OF ECO-FRIENDLY POLYESTER MATRIX COMPOSITE REINFORCED WITH DOUM PALM KERNEL POWDER FOR ADVANCED MOTORCYCLE LEG SHIELD DESIGN

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**Abstract:** *This study investigates the mechanical properties of polyester matrix composites reinforced with varying weight percentages of doum palm kernel powder (DPKP) aimed at motorcycle leg shield design. Four composite formulations with varying polyester-to-doum palm kernel powder ratios (90/10, 80/20, 70/30, and 60/40) were fabricated and subjected to mechanical and thermal testing to evaluate their suitability for structural applications. The mechanical properties were evaluated through tensile, compression, flexural, and impact tests, while the thermal performance was analyzed using dynamic mechanical analysis (DMA). The results indicated that the 90/10 composition exhibited the highest stiffness, strength, and energy dissipation capacity, making it the most suitable for applications requiring rigidity and impact resistance. In contrast, the 60/40 composition demonstrated increased flexibility and water absorption at the rate of 8.30% after four days, along with reduced mechanical strength (12.119 MPa) and thermal stability. DMA results further revealed that the 90/10 formulation retained its stiffness up to higher temperatures of 55.5°C indicating the onset of the material's transition from a glassy to a rubbery state. Overall, the work successfully demonstrated the potential of doum palm kernel powder as reinforcing filler in polyester composites for high-performance motorcycle leg shields due to its superior mechanical and thermal properties.*

**Key words:** Doum Palm Kernel; Composites; Polyester Matrix; Dynamic Mechanical Analysis

### 1. Introduction

In recent years, the demand for lightweight, durable, and high-performance materials in the automotive and motorcycle industries has significantly increased. This trend has led to the exploration of composite materials that offer enhanced mechanical properties while reducing overall weight. Conventional materials such as metals (e.g. steel and aluminum) and thermosetting plastics (e.g., fiberglass) have been widely used in manufacturing motorcycle components due to their proven mechanical strength and durability. However, these materials often contribute to increased weight and can limit design flexibility.

Polyester matrix composites, which consist of a polymer matrix reinforced with various fillers, have emerged as a promising alternative to conventional materials. These composites provide excellent mechanical strength, corrosion resistance, and design flexibility, making them suitable for a wide range of applications, including structural components in motorcycles. Natural fibers and fillers have garnered attention due to their environmentally friendly characteristics, low cost, and availability.

Doum palm kernel powder, derived from the seeds of the doum palm tree (*Hyphaene thebaica*), is a renewable resource that has been identified as a potential reinforcement material for polyester composites. Research has demonstrated that incorporating natural fillers into polyester matrices can improve mechanical properties such as impact resistance, tensile strength, and flexibility (Kumar *et al.*, 2017; Prasad *et al.*, 2019).

Motorcycle leg shields are comparable to Car bumpers in terms of mechanical properties and are pinnacle of lightweight performance. Their exceptional strength-to-weight ratio makes them significantly lighter than steel or aluminum, improving acceleration, handling, and fuel efficiency (Tushar *et al.*, 2024).

The use of doum palm kernel powder in polyester composites not only enhances their performance but also contributes to the use of local contents, job creation and sustainability by utilizing agricultural waste. As industries move towards eco-friendly practices, the exploration of natural materials for composite fabrication becomes increasingly important. Previous studies have highlighted the influence of filler content on the mechanical and thermal properties of composites, suggesting that optimizing the composition can lead to improved performance in specific applications (Akinlotan *et al.*, 2020).

In light of these considerations, this study aims to develop polyester matrix composites reinforced with varying percentages of doum palm kernel powder, specifically targeting their application in motorcycle leg shields. By analyzing the mechanical and thermal properties of these composites, the research seeks to identify the optimal formulation for enhanced impact resistance and stiffness, thereby contributing to the advancement of sustainable composite materials in the automotive sector.

## 2. Materials and Methods

### 2.1. Materials

The matrix material used was polyester resin, reinforced with doum palm kernel powder (DPKP), which was prepared through mechanical grinding of preheated doum palm kernels. The powder was sieved to obtain a particle size of 1 mm to ensure adequate

dispersion, better adhesion, uniform stress distribution within the matrix and improved surface smoothness while avoiding excessive agglomeration, consistent with previous studies on particulate-reinforced polymer composites (Hassan *et al.*, 2025).

## 2.2 Methods

### 2.2.1 Preparation of Doum Palm Kernel Powder

The outer layer of the doum palm fruit (Figure 1a) was carefully removed to expose the hard shell. To facilitate breaking, the shell was lightly warmed in a charcoal furnace. Special attention was given to controlling the temperature, as the shell itself is combustible. Care was taken to ensure the shell did not burn, as it could act as fuel at higher temperatures. After warming, the shell was broken using a hammer to access the kernel inside (Figure 1b). The kernels were then manually broken using a hammer to further reduce their size, making the material more manageable for the grinding process. The broken kernels were ground into a fine powder using a grinding machine (Figure 1c).



Figure 1(a): Doum palm



Figure (b): Doum palm kernel

(c) DPK powder

The grinding process was carefully monitored until the powder reached a desired consistency. The ground powder was sieved to obtain particles with a size of 1mm. This ensures consistency in the particle size for uniform reinforcement in the composite.

### 2.2.2 Composite production

A digital measuring scale was used to measure the exact quantities of both the polyester resin and the doum palm kernel powder in grams for each sample mixture. According to Jones (2010) and Gibson & Ashby (1997) who elucidated the selection of matrix and reinforcement materials, as well as manufacturing processes, to achieve desired mechanical properties, four compositions were prepared: 60/40, 70/30, 80/20, and 90/10 polyester to DPKP by weight; 0.5% Cobalt Octoate was used as accelerator while 1 wt % methyl ethyl ketone peroxide (MEKP) served as initiator for curing.

These percentages were chosen based on standard industry guidelines. Technical datasheets from Ashland and Reich hold recommend cobalt octoate in the range of 0.3% to 0.6%, with 0.5% being optimal for balanced curing times, while 1% MEKP is widely accepted for effective hardening.

Prior to casting, the molds were lined with a light polythene layer to prevent sticking, and a thin layer of Vaseline (petroleum jelly) was applied to both the mold and the polythene. This served as a releasing agent, ensuring easy removal of the composite samples after curing.

The prepared sample mixtures were poured into the molds, which had been designed to accommodate the specific test requirements in terms of pattern and shape. The molds containing the sample mixtures were left undisturbed for a period of 24 hrs at room temperature to allow curing and hardening of the resin.

### 2.2.3 Physical properties tests

After curing, the samples were carefully removed from the molds and prepared for subsequent testing. A total of 32 samples of different geometry were produced, four (4) for each experiment as shown in Figure 2.



**Figure 2: Sample production of the Composites Reinforced with Doum Palm Kernel Powder**

#### (a) Water Absorption Tests

The water absorption characteristics of the composite samples were evaluated in accordance with ASTM D5229/D5229M. In the method a glass measuring scale was used to measure the mass changes over a period of four days. A setup involving a horizontal stick, thread, and a bowl of water was used to ensure uniform immersion of the samples. After removing from the water, the samples were weighed, and then re-immersed at regular intervals from day 0 to day 4, with precise notes taken on the times of removal and re-immersion.

For the water absorption test, equation (1) was used (Hassan et al., 2025)

$$\text{Water Absorption (\%)} = \frac{\text{Wet mass} - \text{Dry mass}}{\text{Dry mass}} \times 100 \quad (1)$$

#### (b) Density test

The density of the composite materials was measured using a covered glass measuring scale and a 100mL test tube ( $\pm 1\text{mL}$ ) at a controlled temperature of  $20^\circ\text{C}$ . Each composite sample was carefully weighed, and its volume displacement was measured by immersing it

in the test tube filled with water. The density was calculated using the mass-to-volume ratio in equation (2) (Hassan et al., 2025)

$$\text{Density (g/ml)} = \frac{\text{Weight in Air}}{\text{volume of Water displaced}} \quad (2)$$

#### 2.2.4. Mechanical properties tests

##### (a) Impact test

The impact resistance of the composite samples was assessed using a Charpy impact testing machine (ASTM D6110 standard) serial number Charpy-412-07-15269C, model HD9 6QD, with an energy capacity of 15J/25J. Each sample was positioned horizontally in the machine, and the pendulum was released to strike the center of the sample, recording the energy absorbed during the fracture.

##### (b) Hardness test

The hardness of the samples was determined using a Vickers hardness tester, model MV1-PC, serial number 07/2012-1329. The machine applied a specified load to the surface of the samples using a diamond indenter. The diagonal lengths of the resulting indentation were measured, and the hardness values were calculated based on the Vickers hardness formula.

##### (c) Flexural test

The most common flexural testing of plastics, polymer composites, and large fiber-reinforced plates involves three-point and four-point bend testing according to ASTM D 790 / ASTM D 6272 (Saba, et al., 2019). The flexural strength of the composite samples was measured using a Universal Materials Testing Machine (100kN). Each sample was subjected to a three-point bending test, where the machine applied force at the center of the sample while supporting it at both ends. The load at which the sample fractured was recorded.

The flexural strength can be calculated using equation (3) (Gandevika & Butala, 2020)

$$\text{Flexural Strength} = \frac{3 \cdot F \cdot L}{2 \cdot b \cdot h^2} \quad (3)$$

Where:

$F$  is the applied load (kN),

$L$  is the gauge length (mm),

$b$  is the width (mm),

$h$  is the thickness (mm).

##### (d) Tensile test

Tensile testing of composites is generally in the form of basic tension or flat-sandwich tension testing in accordance with ASTM D638 (Saba, et al., 2029). The tensile properties were evaluated using an Electronic Universal Testing Machine, model WDW-100kN, model number 190536, the samples were clamped between the machine grips, and a tensile load was applied until the sample fractured. The machine recorded the stress and strain, which were used to calculate tensile strength and modulus.

##### (e) Compression test

The compression strength of the samples (ASTM D695) was assessed using Electronic Universal Testing Machine, model WDW-100kN, model number 190536. Each sample was placed between two compression plates, and force was applied until the sample deformed or fractured. The machine recorded the compressive load at failure. It can also be calculated from equation (4) (Hassan et al., 2025)

$$\text{Compression test} = \frac{\text{force}}{\text{cross-sectional area}} = \frac{p}{A} \quad (4)$$

##### (f) Dynamic Mechanical Analysis

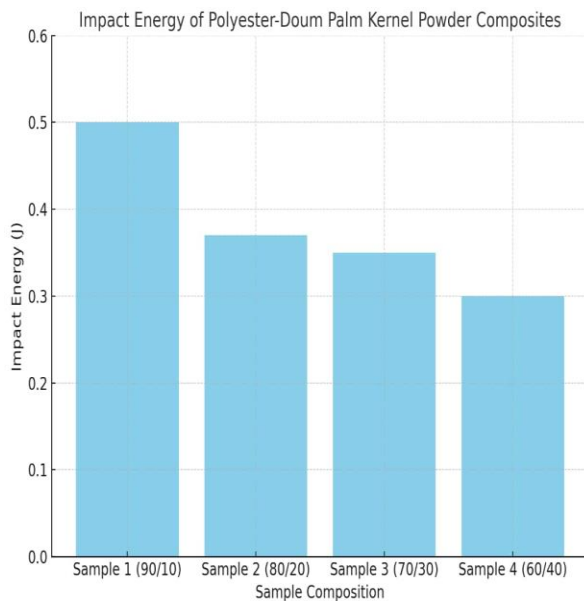
Dynamic mechanical properties were measured using a Dynamic Mechanical Analyzer, model DMA 242E Artemis, manufactured by NETZSH. The DMA provides key insights into the viscoelastic properties of the polyester matrix composites reinforced with doum palm kernel powder. The analysis reveals significant information about the storage modulus (elastic response), loss modulus (viscous response), and tan delta (damping behavior), which can be used to understand how the material responds under thermal conditions. Additionally, the change in length gives insight into the dimensional stability of the composites when subjected to temperature variations.

### 3. Results and Discussion

The findings of the experimental investigations are presented here highlighting the mechanical and physical properties of the developed composite material.

#### 3.1 Impact test:

The impact energy from Figure 3 shows that 90:10 composition has the highest average impact energy (0.50 J), indicating better impact resistance and within the range of 0.5-1.5 J required for car bumpers (Tushar *et al.*, 2024). The graph also indicated that impact energy decreases as the doum palm kernel powder increases. This trend aligns with the findings of Shaker *et al.* (2025) who obtained a maximum impact strength at 5% filler content and suggested that further increase in the filler content can make the composite less ductile, thereby reducing its ability to absorb impact energy.



**Figure 3: Impact test graph of polyester–DPKP composites at different filler contents.**

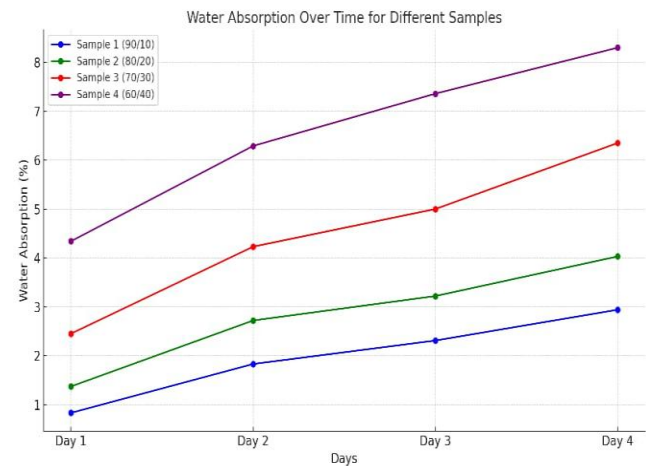
#### 3.2 Density test

The density of the composite materials increased with increasing doum palm kernel powder up to 30% (70:30), with a maximum of 1.320 g/mL. However, further increase in the kernel powder to 40%, resulted in the decrease in density (1.214 g/mL). This trend suggests that the addition of doum palm kernel

powder up to 30% enhances the packing efficiency of the composite material, leading to increased density. Beyond 30%, the doum palm kernel powder begins to be porous which reduces the material's compactness, causing a decrease in density (Shaker *et al.*, 2025). The density values obtained are within the range of typical polymer matrix composites, indicating potential suitability for motorcycle leg shield applications.

#### 3.3 Water Absorption

Figure 4 shows that the water absorption increases as the percentage of doum palm kernel powder increase. This is expected since natural fillers tend to absorb more water compared to polymer matrices.



**Figure 4: Water Absorption Graph of polyester–DPKP composites at different filler contents.**

As expected, the samples with higher amounts of doum palm kernel powder (Sample 3 and Sample 4) absorbed more water over time compared to others.

#### 3.4 Hardness test

The average hardness values on Figure 5 show that it increases with the increase in doum palm kernel powder content in the polyester matrix. Sample 4 (40% DPK) has the highest hardness value (81.41 HV) correlates with the findings of (Melese *et al.*, 2024) who obtained a maximum hardness value of 86.42 HV at 60/40 composition.

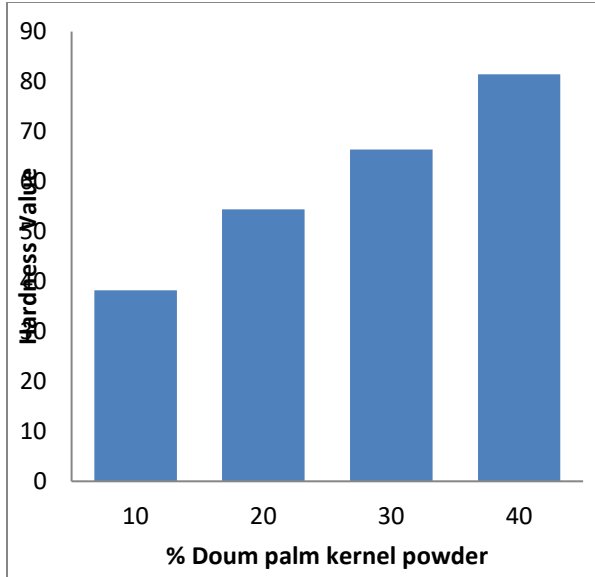


Figure 5: The graph of Hardness Value of polyester-*DPKP* composites at different filler contents.

The progressive increase in hardness with more reinforcement suggests that the doum palm kernel powder effectively enhances the hardness of the composite.

### 3.5 Flexural test

The bar graph (Figure 6) represents the flexural strength for all the samples. The graph shows that it decreases as the percentage of doum palm kernel powder increases, indicating that higher filler content reduces the material's ability to withstand bending forces.

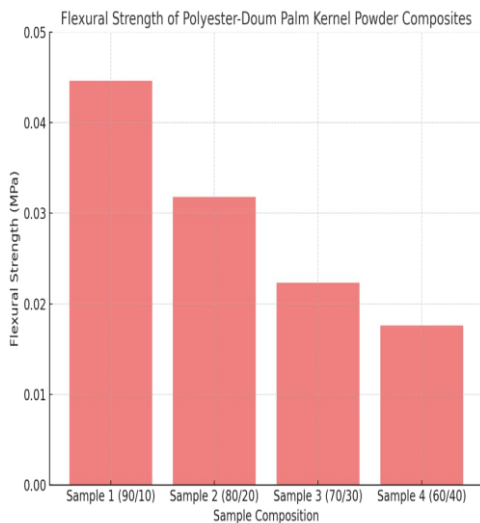


Figure 6: Flexural Test Graph of polyester-*DPKP* composites at different filler contents.

### 3.6 Tensile test

The tensile test results on Figure 7 highlights the influence of filler content on the mechanical properties of polyester matrix composites. As the filler content decreases, tensile strength and yield strength improve, while total elongation and plastic strain decrease. Among the four tested samples, 90/10 composition demonstrates the highest tensile performance (30 Mpa), with superior strength and moderate plastic strain. It is the best candidate for applications where high strength and resistance to tensile forces are crucial, even though lower than the given range for motorcycle leg shields as indicated (50-200 MPa for Natural fibers) by Tushar *et al.*, 2024. However, 70/30 composition provides a good balance between tensile strength, flexibility, and plastic strain capacity, making it a suitable alternative for applications requiring both strength and some degree of ductility. On the other hand, 80/20 and 60/40 compositions exhibit lower tensile strengths and higher susceptibility to plastic deformation, with the 60/40 sample being the least ideal for high-stress applications due to its lower total elongation and tensile strength.

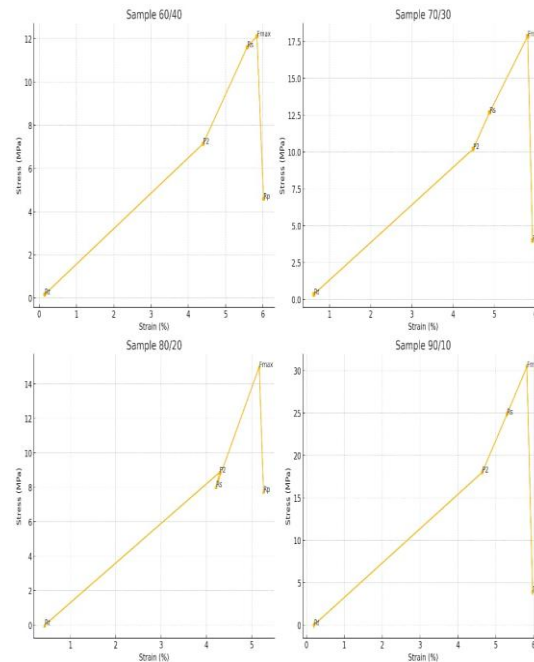


Figure 7: Tensile Test Graph of polyester–DPKP composites at different filler contents.

### 3.7 Compression Test

The compression test data on Figure 8 for the four samples were analyzed based on their stress-strain behavior. The key parameters (Rt, P2, Rs, Rp, and Fmax) were plotted, and the trends were observed for each composition. The compression test results show that the 70/30 polyester to doum palm kernel powder composition offers the best combination of strength, flexibility, and load-bearing capacity, making it ideal for motorcycle leg shield applications. While the 90/10 composition exhibits the highest initial and maximum stresses, its rapid stress drop after the initial peak suggests brittleness, which may not be ideal for impact-prone applications. The Rt, P2, and Rs values confirm that the 70/30 composition handles stress distribution more efficiently and offers better durability for long-term applications.

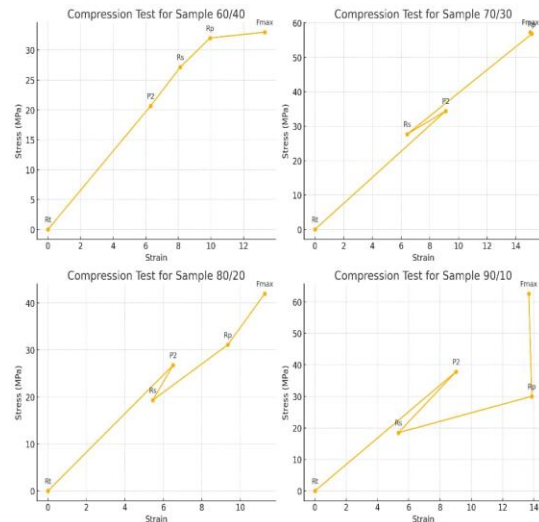


Figure 8: Compression test graph of polyester–DPKP composites at different filler contents.

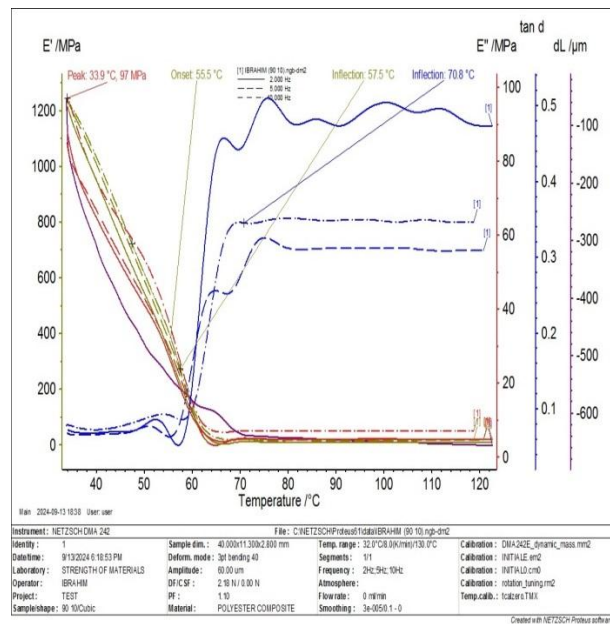
### 3.8 Dynamic Mechanical Analysis (DMA) Test

From the DMA graphs (Figure 9) generated for the four samples, 90/10 composition exhibits the highest stiffness, retaining its structural integrity up to 55.5°C. As the filler content increases, the stiffness decreases, with the 60/40 composition losing its rigidity the fastest. This trend suggests that increasing the amount

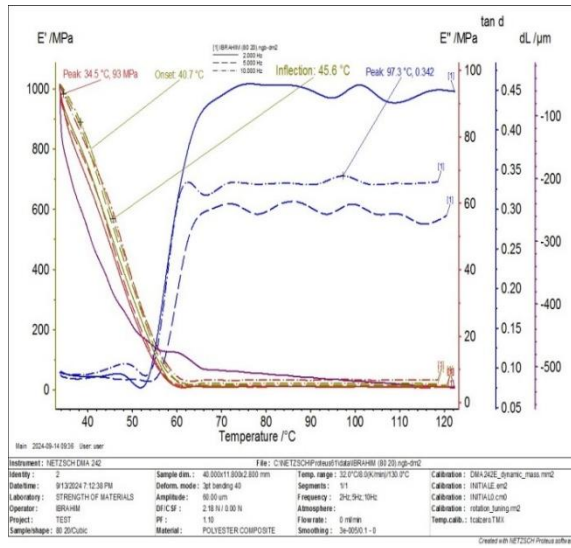
of doum palm kernel powder results in materials that are less stiff and transition to the rubbery state at lower temperatures.

The 90/10 composition has the highest energy dissipation capacity, making it suitable for applications where vibration damping is required. As the filler content increases, the loss modulus decreases, resulting in materials that are less capable of dissipating energy. The 60/40 composition is the least efficient in terms of damping and energy absorption.

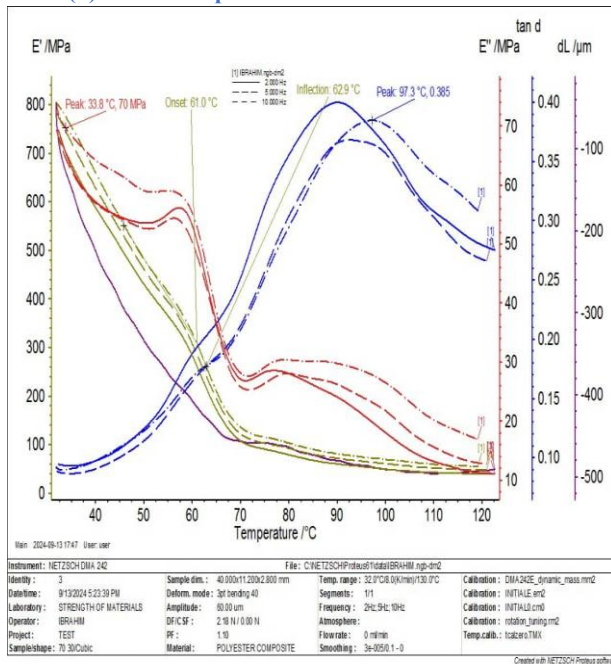
The tan delta peaks earlier as the filler content increases, meaning the glass transition temperature (Tg) decreases with higher filler content. The 90/10, 80/20 and 70/30 composition exhibits the best damping properties, while the 60/40 composition is the least capable of absorbing and dissipating energy.



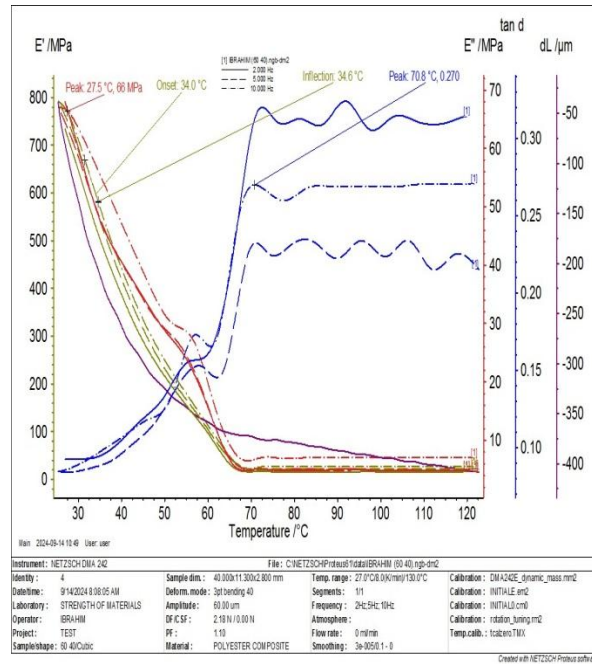
(a) 90:10 Composition



(b) 80:20 Composition



(c) 70:30 Composition



(d) 60:40 Composition

Figure 9: The DMA graph of polyester–DPKP composites at different filler contents.

### Conclusion

The primary aim of this study was to develop an eco-friendly polyester matrix composite reinforced with doum palm kernel powder for motorcycle leg shields design. This has been achieved through the systematic preparation and characterization of four distinct composite formulations (90/10, 80/20, 70/30, and 60/40 polyester to doum palm kernel powder ratios). The comprehensive investigation involved mechanical testing and DMA to evaluate the thermal and mechanical properties of the composites.

The mechanical tests revealed significant variations in the properties of the composites based on the filler content. 90/10 composition

exhibited the highest stiffness and energy dissipation capacity, making it the most suitable for structural applications where rigidity and impact resistance are required. The DMA results demonstrated that the 90/10 composition had the highest storage modulus (E') and tan delta (tan d) values, indicating superior stiffness retention at higher temperatures compared to other compositions.

The mechanical properties of the composites varied significantly with changes in filler content, suggesting

that by adjusting the ratio of doum palm kernel powder to polyester, it is possible to tailor the balance between mechanical strength, energy absorption, and flexibility for specific applications. This study lays a solid foundation for future research and exploration in the development of natural-fiber-reinforced composites.

For future research, the composites, especially the 90/10 composition, should be subjected to real-world testing, including exposure to environmental factors such as UV radiation, humidity, and temperature fluctuations, to validate their performance for long-term outdoor use.

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