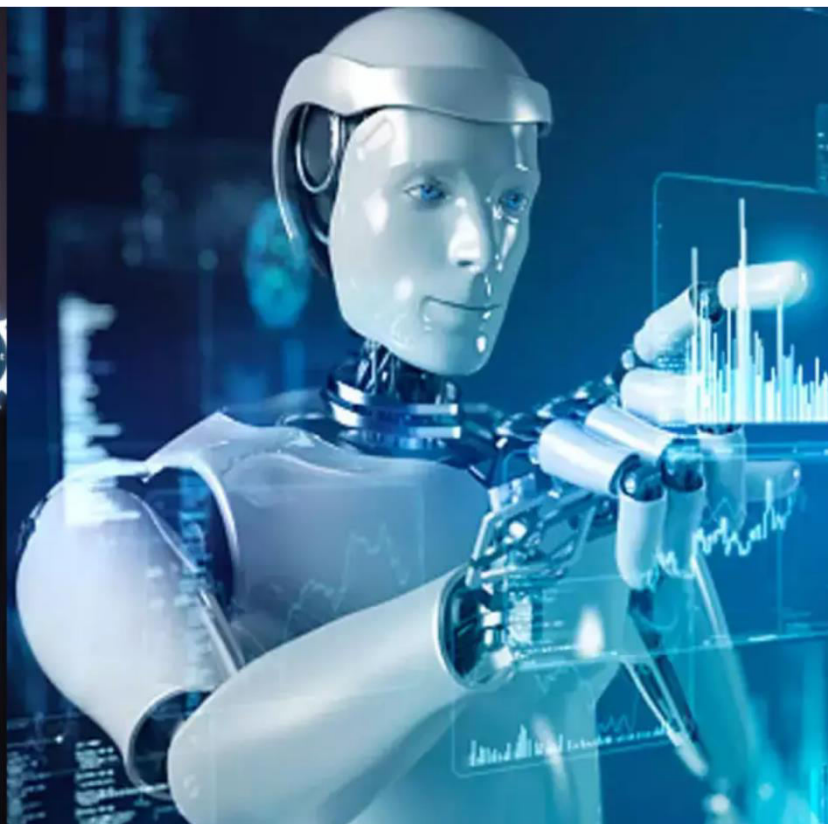




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Evaluation of Mechanical Characteristics and Thermal Stability of PLA-Based Composites Reinforced with Aluminium Oxide and Banana Fiber

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ABSTRACT : This project explores the development of a biodegradable composite using Polylactic Acid (PLA) as the matrix, reinforced with Aluminium Oxide (Al_2O_3) and banana fiber. The study focuses on fabricating the composite with varying compositions of Al_2O_3 and banana fiber, evaluating its mechanical strength, thermal stability through standardized tests. The inclusion of banana fiber aims to enhance the composite's flexibility, impact resistance, and biodegradability. The results will contribute to improving material performance, offering a sustainable alternative for applications in automotive, aerospace, and biomedical fields. This research builds upon previous studies, advancing the development of eco-friendly composite materials.

KEYWORDS:Pla,Banana Fiber,Aluminum Oxide,Compression Moulding,Thermal Analysis

I. INTRODUCTION

Composite materials have become an integral part of modern engineering due to their superior mechanical properties, lightweight nature, and versatility. The increasing global emphasis on sustainability has driven extensive research into biodegradable and eco-friendly composites that reduce environmental impact while maintaining high performance. Among various biodegradable polymers, polylactic acid (PLA) has gained significant attention due to its renewability, biodegradability, and excellent mechanical properties. However, the inherent brittleness and limited thermal resistance of PLA restrict its widespread industrial applications. To overcome these limitations, the integration of reinforcing agents such as aluminum oxide (Al_2O_3) and natural fibers has been explored to enhance the mechanical strength, thermal stability, and overall durability of PLA-based composites. Aluminum oxide, a well-known ceramic reinforcement, improves the composite's hardness, wear resistance, and thermal stability, making it suitable for high-performance applications. Meanwhile, banana fiber, a naturally occurring lignocellulosic material, offers additional benefits such as enhanced impact resistance, reduced material density, and improved biodegradability, aligning with global sustainability goals. This study focuses on the development, fabrication, and characterization of a PLA-based composite reinforced with aluminum oxide and banana fiber. The research aims to investigate the synergistic effects of these reinforcements on the composite's mechanical performance, thermal behavior, and microstructural integrity. Standardized testing methodologies will be employed to assess the feasibility of this novel composite for potential applications in high-temperature environments, particularly in the automotive, aerospace, and biomedical sectors. By integrating sustainable natural fibers with advanced reinforcement materials, this research seeks to contribute to the development of next-generation eco-friendly composite materials with enhanced functional properties.

II. MATERIALS

The materials used in this experiment for fabrication are Polylactic acid, Aluminium oxide, Banana fiber. The banana fibers are collected in the form of residues from Kannur district, Kerala, India. The Polylactic acid pellets and aluminium oxide powder was purchased from Herenba instruments

2.2 Preparation of composites

The composite preparation process involved the hand lay-up method followed by compression molding. Uniform fiber mats were first prepared using banana fibers cut to a length of 1.5 inches. The composite consisted of three alternating layers, starting with dried and cut banana fiber, followed by PLA and aluminum oxide. This layering process was

repeated for three layers before undergoing compression molding at 172°C under a force of 40 kgf. Samples with varying compositions were then prepared for mechanical characterization and thermal analysis.

III. MECHANICAL TESTING

3.1 Tensile test

The specimen prepared is shaped into required dimensions using a hand cutter and the edges are polished using salt paper. It is prepared according to the ASTM D638 standard. The dimensions, gauge length and cross head speeds are chosen according to the ASTM D638 standard. The tensile test is performed on the Universal Testing Machine (UTM) Make FIE (Model: UTN 40, S. No. 11/98-2450). The process involves placing the test sample in the UTM and applying tension to it until the fracture of the material. Then the force is recorded as a function of the increase in gauge length. During the application of tension, the elongation of the gauge section is recorded against the applied force.

Table 1.Experimental tensile strength of the composite samples

Property	PLA-60 (25% Al ₂ O ₃ , 15% Fiber)	PLA-65 (20% Al ₂ O ₃ , 15% Fiber)
Tensile Strength (N/mm ²)	1.3663	1.3994
Elongation at Break (%)	0.8065	0.8665
Cross-Sectional Area (mm ²)	182.5	187.5
Breaking Load (N)	249.34	262.39

3.2. Flexural strength

The flexural specimens are prepared as per the ASTM D790 standards and the test has been carried out using the same UTM. The 3-point flexural test is the most common flexural test and used in this experiment for checking the bending strength of the composite materials. The testing process involves placing the test specimen in the UTM and applying force to it until it fractures and breaks.

Table 2.Experimental flexural strength of the composite samples

Property	PLA-60 (25% Al ₂ O ₃ , 15% Fiber)	PLA-65 (20% Al ₂ O ₃ , 15% Fiber)
Maximum Flexural Stress (N/mm ²)	0.0743	0.0564
Maximum Load (N)	26.0092	19.7470
Strain at Maximum Load (%)	1.7998	2.0198

3.3. Impact test

The impact test specimens are prepared according to the required dimension following the ASTM-A370 standard. During the testing process, the specimen must be loaded in the testing machine and allow the pendulum until it fractures or breaks. Using the impact test, the energy needed to break the material can be measured easily and can be used to measure the toughness of the material and the yield strength. The effect of strain rate on fracture and ductility of the material can be analyzed by using the impact test.

Table 3. Experimental impact strength of the composite samples

Sample Type (Composite Strip)	Impact Strength in Joules			Avg
Banana + Aluminium oxide +PLA-60%	0.38	1.26	0.67	0.77
Banana + Aluminium oxide +PLA-65%	1.32	0.29	0.98	0.863

IV. RESULT AND ANALYSIS

The composite samples were tested using their respective testing machines to evaluate tensile, flexural, and impact properties. Each type of sample underwent two trials, and the average values were recorded.

4.1 Tensile strength analysis

The tensile test results of two composite samples, PLA-60 with 25% aluminum oxide and 15% fiber, and PLA-65 with 20% aluminum oxide and 15% fiber, were analyzed to determine their mechanical properties.

The first sample, PLA-60, exhibited a tensile strength of 1.3663 N/mm² with an elongation at break of 0.8065%. The cross-sectional area (C.S.A) was measured at 182.5 mm², and the breaking load recorded was 249.34 N. Conversely, the PLA-65 sample displayed a higher tensile strength of 1.3994 N/mm², with a slightly greater elongation at break of 0.8665%. This sample had a C.S.A of 187.5 mm² and a breaking load of 262.39 N.

The slight increase in tensile strength and elongation at break for the PLA-65 sample can be attributed to the reduced aluminum oxide content and the increased PLA matrix, leading to enhanced ductility and energy absorption capacity. Additionally, the improved fiber-matrix adhesion in the PLA-65 composition may have contributed to better stress distribution, resulting in higher tensile properties.

Fig 1. Pla 65% Aluminum oxide 20% banana fiber 15%

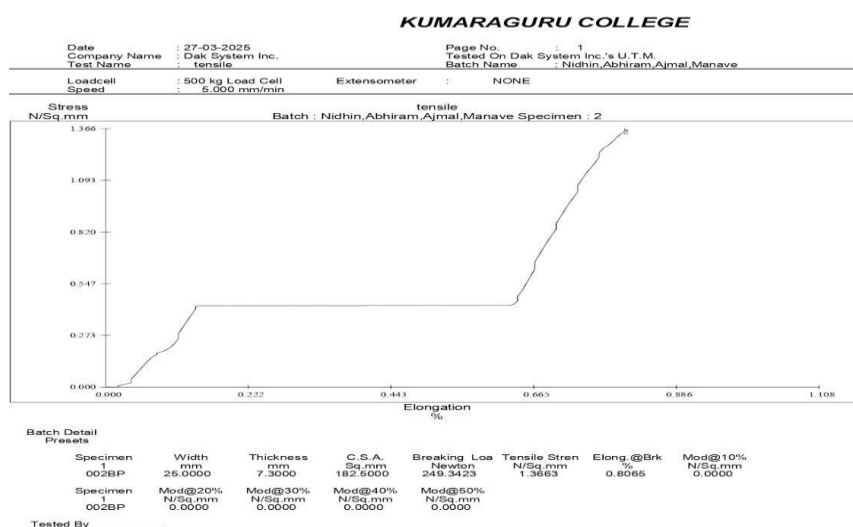
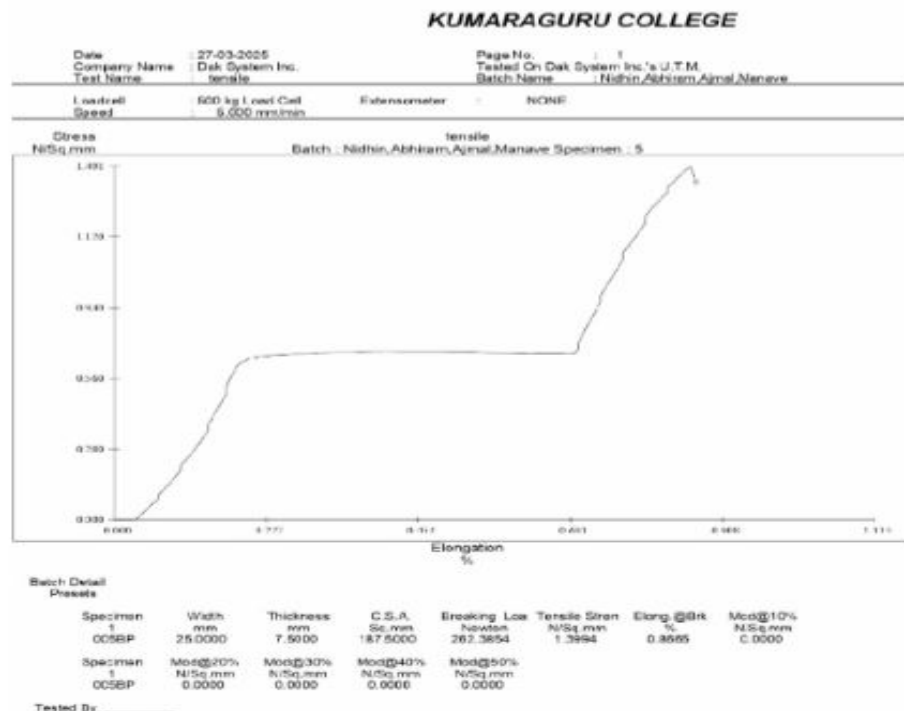


Fig 2. PLA 60% Aluminum oxide 25% banana fiber 15%



4.2 flexural strength analysis

The flexural test results of two composite samples, PLA-60 with 25% aluminum oxide and 15% fiber, and PLA-65 with 20% aluminum oxide and 15% fiber, were evaluated to assess their mechanical behavior under bending loads. The PLA-60 sample exhibited a maximum flexural stress of 0.0743 N/mm² with a maximum load of 26.0092 N. The strain at maximum load was recorded at 1.7998%, with a deflection length of 1.7998 mm. On the other hand, the PLA-65 sample showed a lower maximum flexural stress of 0.0564 N/mm², with a maximum load of 19.7470 N. However, it demonstrated a higher strain at maximum load of 2.0198% and a greater deflection length of 2.0198 mm. The decrease in flexural strength in the PLA-65 sample can be attributed to the reduction in aluminum oxide content, which affects the material's stiffness. However, the higher strain and deflection indicate improved ductility and energy absorption capacity, making it suitable for applications requiring flexibility. In contrast, the PLA-60 sample's higher flexural stress and lower strain suggest enhanced rigidity and load-bearing capability, which may be beneficial in structural applications.

In summary, PLA-60 is preferable for scenarios demanding higher stiffness and load resistance, while PLA-65 is more suitable for applications where flexibility and deformation tolerance are critical. This comparative analysis provides insights into selecting appropriate material compositions based on specific mechanical performance requirements.

Fig 4. PLA 65% Aluminum oxide 20% banana fiber 15%

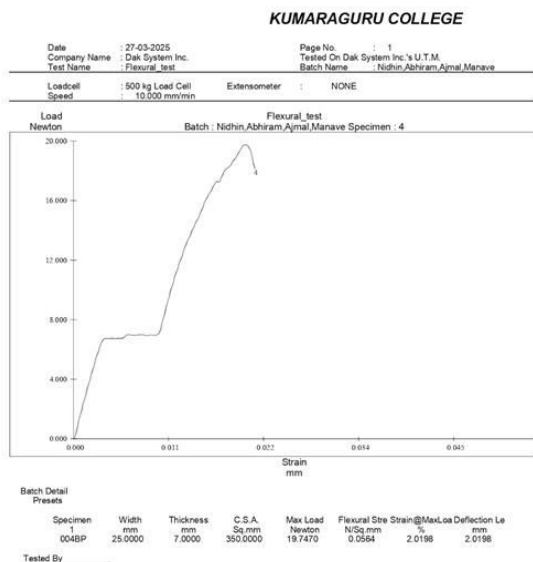
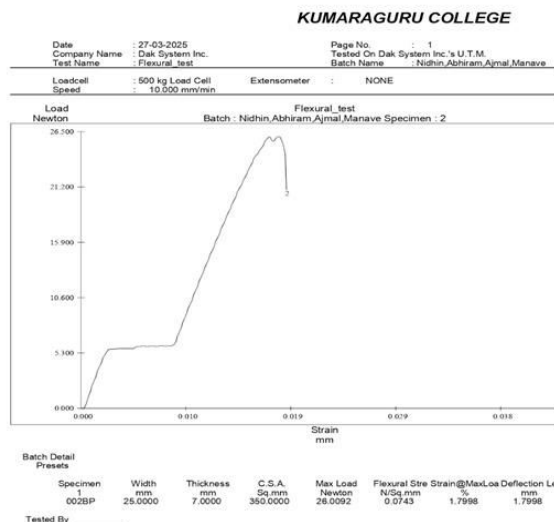


Fig 5. PLA 60% Aluminum oxide 25% banana fiber 15%



4.3 impact strength analysis

The impact strength of two composite samples, **PLA-60** with **25% aluminum oxide** and **15% banana fiber**, and **PLA-65** with **20% aluminum oxide** and **15% banana fiber**, was evaluated using the **Charpy Impact Test** according to the **ASTM D-256** standard to assess their resistance to sudden impacts.

The **PLA-60** sample exhibited an average impact strength of **0.77 J**, with recorded values ranging from **0.38 J** to **1.26 J**. In comparison, the **PLA-65** sample demonstrated a slightly higher average impact strength of **0.863 J**, with values between **0.29 J** and **1.32 J**.

The increase in PLA content in the **PLA-65** sample contributed to its enhanced impact resistance by providing improved energy absorption capacity. However, the reduction in aluminum oxide content reduced the stiffness of the material, allowing greater plastic deformation during impact. On the other hand, the **PLA-60** sample exhibited a comparatively lower impact strength, indicating increased brittleness due to the higher aluminum oxide content, which restricted energy absorption.

This variation in impact strength highlights the trade-off between strength and ductility. **PLA-60** is preferable for applications requiring higher stiffness and load resistance, where the material is less likely to deform under impact. In contrast, **PLA-65** is more suitable for applications demanding improved energy absorption and flexibility, making it ideal for scenarios involving dynamic or unpredictable loading conditions.

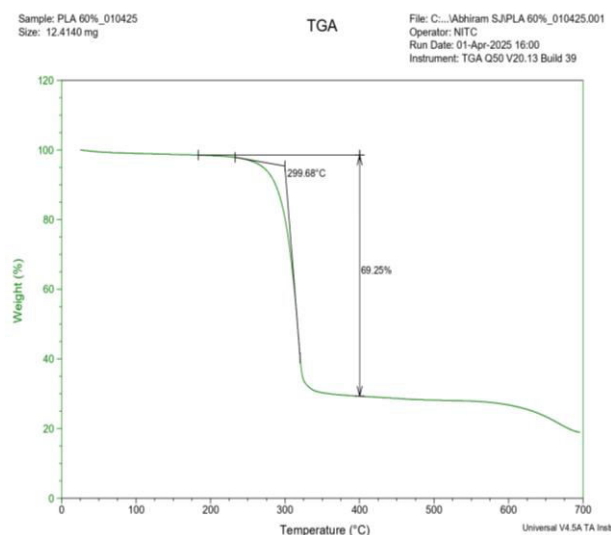
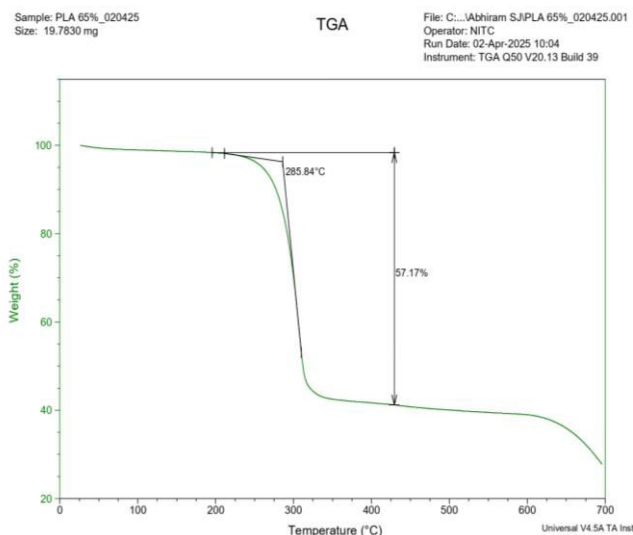
V. THERMAL ANALYSIS

Thermogravimetric Analysis (TGA) is a crucial thermal characterization technique used to evaluate the thermal stability and decomposition behavior of composite materials. By measuring the weight loss of a sample as a function of temperature under a controlled atmosphere, TGA provides insights into the thermal degradation temperature, composition, and filler-matrix interactions. This analysis helps in assessing the suitability of composites for high-temperature applications and optimizing their formulation for enhanced performance.

fiber 15% The thermal stability of two composite samples, PLA-60 with 25% aluminum oxide and 15% banana fiber, and PLA-65 with 20% aluminum oxide and 15% banana fiber, was analyzed using Thermogravimetric Analysis (TGA).

Fig 6. PLA 65% Aluminum oxide 20% banana fiber 15%

Fig 7. PLA 60% Aluminum oxide 25% banana



The first sample, PLA-65 sample, displayed an onset decomposition temperature of 285.84°C, with a lower weight retention of 57.17%. The increase in PLA content and reduction in aluminum oxide resulted in a slightly lower thermal stability, as PLA decomposes within the 250-300°C range. The lower aluminum oxide content in PLA-65 led to a reduced heat resistance, contributing to earlier decomposition.

Conversely, the PLA-60, exhibited an onset decomposition temperature of 299.68°C, retaining 69.25% of its weight at this stage. The higher aluminum oxide content in this composition contributed to enhanced thermal stability, as aluminum oxide remains intact at elevated temperatures, reducing overall material degradation.

The difference in decomposition behavior between the two samples highlights the role of aluminum oxide in enhancing thermal stability. PLA-60, with its higher aluminum oxide content, demonstrated superior thermal resistance, making it more suitable for applications requiring high-temperature durability. However, PLA-65 may still be preferred for applications that prioritize a balance between mechanical properties and moderate thermal stability, given its increased PLA content, which can improve ductility and processability.

VI.CONCLUSION

The comparative analysis of PLA-60 and PLA-65 composites provides insights into their thermal and mechanical properties, highlighting the impact of aluminum oxide and PLA content. Thermogravimetric Analysis (TGA) showed that PLA-60, with higher aluminum oxide content, had superior thermal stability (onset decomposition at 299.68°C, 69.25% weight retention), whereas PLA-65 exhibited lower heat resistance (285.84°C, 57.17% weight retention). Impact testing revealed that PLA-65 had a higher impact strength (0.863 J) due to increased PLA content, improving flexibility, while PLA-60, with greater stiffness, showed lower impact resistance (0.77 J). Tensile testing indicated a marginally higher tensile strength (1.3994 N/mm²) and elongation (0.8665%) for PLA-65, enhancing ductility, whereas PLA-60 exhibited higher stiffness. Flexural testing confirmed PLA-60's superior rigidity (0.0743 N/mm², 26.0092 N load), while PLA-65 demonstrated greater flexibility (0.0564 N/mm², 19.7470 N load). In conclusion, PLA-60 is ideal for applications requiring high thermal stability and stiffness, while PLA-65 is preferable for flexibility and impact resistance, emphasizing the role of composition in optimizing composite performance.

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