Investigation on the Influence of Alumina Trihydrate Additive on the Mechanical Properties of Banana Fibre Reinforced Polyester Composite

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***Abstract*— Incorporating alumina trihydrate (ATH) as an additive into banana fibre reinforced polyester composites enhances both flame retardancy and mechanical integrity. Varying concentrations of ATH were blended into the matrix, and the resulting composites were tested for tensile strength, flexural strength, and impact resistance. Optimal ATH loading improved mechanical performance while also increasing thermal stability. The natural banana fibres contributed to weight reduction and sustainability, while ATH acted as an effective flame retardant. The synergistic effect between ATH and the fibre-polyester matrix suggests strong potential for developing eco-friendly composites for structural and automotive applications.**

Index Terms*— Banana fibre, Alumina trihydrate, Polyester composite, Mechanical properties, Flame resistance, Bio-composite, Sustainable materials, Fibre reinforcement.

I. INTRODUCTION

Natural fibre-reinforced polymer composites have become a focus of research due to their ecological benefits, cost efficiency, and mechanical advantages. Among natural fibres, banana fibre is particularly attractive owing to its high tensile strength, flexibility, and availability as agricultural waste. However, natural fibres pose challenges in terms of hydrophilicity and flammability, which limit their broader industrial application. To address these issues, composite formulations are often modified with fillers or additives that can improve specific properties.

One of the most effective additives for improving flame resistance is alumina trihydrate (ATH), a halogen-free, non-toxic compound. ATH decomposes endothermically when exposed to heat, releasing water vapor that dilutes flammable gases and cools the material surface. This not only enhances flame retardancy but may also impact the mechanical characteristics of the composite, depending on its dispersion and concentration. By incorporating ATH into a banana fibre–polyester matrix, this research aims to explore a holistic improvement in mechanical strength and thermal performance.
The objective of this investigation is to identify the optimal loading of ATH that enhances composite performance without compromising its structural integrity. This study contributes to the development of sustainable, fire-resistant materials suitable for automotive, construction, and household applications.

II. LITERATURE REVIEW

Several studies have explored the mechanical behaviour of natural fibre composites, particularly using flax, jute, and banana fibres. The integration of fillers like ATH has been reported to improve flame retardancy in synthetic and natural polymer systems. For instance, prior work on jute-polypropylene systems has shown that ATH improves limiting oxygen index (LOI) values, though excess loading leads to reduced tensile strength. Research by Salim et al. (2019) demonstrated that the use of mineral additives can tune both thermal and mechanical properties of bio-based composites when used within optimal limits.
However, literature specific to banana fibre reinforced composites remains limited, especially regarding the synergistic use of ATH. Studies by Harinarayan et al. (2021) showed that chemical treatment of banana fibres significantly improves fibre–matrix adhesion, but integration with ATH for

multifunctional enhancement has not been adequately explored. This research aims to bridge that gap by systematically evaluating the dual role of ATH in both mechanical and thermal enhancement in banana fibre composites.
Furthermore, gaps remain in understanding how ATH affects impact resistance, fibre wettability, and microstructural integrity, especially in hand lay-up processes common in small- to medium-scale fabrication settings. This project addresses these under-explored aspects.

III. MATERIALS AND METHODS

The primary materials used in this research include banana fibres extracted from pseudo-stems of matured banana plants, unsaturated polyester resin as the matrix, and commercial-grade alumina trihydrate (ATH) as the flame-retardant filler. Banana fibres were mechanically retted and treated with 5% NaOH to remove lignin and hemicellulose, which improves surface roughness and interfacial bonding. ATH was dried and pulverized to a fine powder before mixing.
Composites were fabricated using the hand lay-up technique followed by compression moulding. ATH was added at 0%, 10%, 20%, and 30% weight fractions relative to the total matrix content. Fibre-to-matrix ratios were held constant at 30:70 to maintain comparability across samples. Curing was done at room temperature for 24 hours followed by post-curing at 60°C for 3 hours.
Mechanical testing included tensile strength (ASTM D638), flexural strength (ASTM D790), and impact strength (ASTM D256). Thermal properties were assessed using Thermogravimetric Analysis (TGA), and flame resistance was evaluated using the UL-94 vertical burning test. Scanning Electron Microscopy (SEM) was used to observe the fracture surfaces and evaluate fibre dispersion and filler–matrix interfacial bonding.

IV. EXPERIMENTAL RESULTS

Tensile testing revealed that composites with 10% ATH showed a 17% improvement in strength compared to the control, attributed to better filler distribution and stress transfer. At 20% ATH, the strength plateaued, while 30% ATH composites exhibited a 10% reduction, likely due to particle agglomeration creating stress concentrators. Flexural strength followed a similar trend, with a maximum at 10% ATH.
Impact strength increased slightly at 10% ATH due to crack deflection mechanisms induced by filler particles. However, higher ATH content reduced impact resistance, suggesting a brittle behaviour due to compromised matrix flexibility. SEM analysis confirmed good dispersion at low ATH levels but showed clear signs of clustering at higher concentrations.
Thermal stability increased consistently with ATH content. TGA showed that the decomposition temperature shifted from 360°C (0% ATH) to 405°C (30% ATH), indicating improved heat resistance. The UL-94 test rated the 30% ATH sample as V-0, with self-extinguishing behaviour and minimal dripping, validating ATH's flame-retardant efficacy.

V. DISCUSSION

The mechanical performance of the composite depends on the balance between matrix continuity, fibre adhesion, and filler dispersion. Low to moderate ATH additions improve interfacial interactions by enhancing the stiffness of the matrix, allowing better stress transfer to the fibres. This results in higher tensile and flexural strength. However, higher ATH concentrations disrupt matrix homogeneity, leading to voids and poor bonding, which deteriorate mechanical performance.

From a thermal perspective, ATH improves fire retardancy through a well-established endothermic decomposition mechanism. However, this benefit comes at the cost of decreased ductility and increased brittleness, as evidenced in the impact testing results. SEM micrographs highlighted a clear transition in matrix morphology, from uniform interfaces to fractured, clustered regions.

Hence, the ideal ATH content lies between 10% and 15%, where the composite benefits from enhanced mechanical and thermal properties without the drawbacks of overloading. These findings are consistent with similar studies involving other natural fibres, indicating that the trend may be generalizable across bio-composites.

VI. CONCLUSION

This research successfully demonstrates that incorporating alumina trihydrate into banana fibre reinforced polyester composites significantly improves thermal resistance and flame retardancy. Mechanical properties are enhanced at optimal filler levels (10–15% ATH), with maximum tensile and flexural strength observed in this range. Beyond this, filler agglomeration leads to a decline in performance due to poor interfacial bonding.

The composite developed in this study represents a sustainable, cost-effective alternative to traditional synthetic materials, particularly for applications where both lightweight and flame retardant properties are critical. The outcomes suggest strong potential in automotive panels, partition boards, and low-load structural components.

VII. FUTURE WORK

Future studies can explore the use of surface-modified ATH to improve dispersion and compatibility with the polyester matrix, potentially overcoming the limitations associated with higher filler loading. Advanced manufacturing techniques like vacuum infusion or resin transfer moulding could also be employed to enhance uniformity and reduce porosity.

Additionally, further investigations into hybrid filler systems—combining ATH with nanoclays or other synergistic additives—could offer tailored property enhancement. Long-term durability, biodegradability assessments, and weathering resistance under real-world conditions should also be part of future evaluations to validate industrial viability.

Finally, exploring the use of other natural fibres such as jute or hemp in a similar matrix system can provide comparative insights and broader applicability for eco-friendly, flame-resistant composite development.

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