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FILAMENAS: SUSTAINABLE BIOCOMPOSITE FILAMENT FROM PINEAPPLE PEEL WASTE FOR 3D PRINTING

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ABSTRACT

Filamenas represents a pioneering sustainable innovation aimed at transforming the 3D printing domain by incorporating agricultural byproducts into a circular manufacturing paradigm. This initiative confronts the ecological challenges posed by the waste generated from pineapple (*Ananas comosus*) peels and the substantial carbon emissions associated with the utilization of virgin plastics through the fabrication of a hybrid-matrix biocomposite. The invention is characterized by a meticulously calibrated 50/50 amalgamation of recycled Polylactic Acid (rPLA) and virgin PLA (vPLA), augmented with 1 wt.% NaOH-treated pineapple fibers. Through the enhancement of the interfacial adhesion between the bio-fillers and the hybrid polymer matrix, Filamenas proficiently "upcycles" recycled materials, achieving a 5 wt.% fiber loading that successfully reinstates the mechanical properties diminished during the recycling process. The resultant filament exhibits enhanced tensile and flexural strength in comparison to conventional recycled feedstocks. This undertaking presents a commercially viable, environmentally sustainable alternative for FDM applications, thereby fostering a circular bioeconomy by mitigating the reliance on virgin plastics and valorizing biomass destined for landfill disposal.

KEYWORD

Additive manufacturing, recycled pla, pineapple peel waste, biocomposites, sustainable filaments, circular economy.

INTRODUCTION

The rapid progression of Additive Manufacturing (AM), particularly via the Fused Deposition Modelling (FDM) technique, has engendered a significant transformation in the utilization of this technology, transitioning from rapid prototyping to the production of functional, end-use components across the aerospace, automotive, and medical sectors (Horvath, 2014). Notwithstanding the intrinsic benefits of AM such as the capability to achieve geometric complexity and the minimization of subtractive waste. The additive manufacturing sector remains critically reliant on virgin thermoplastic feedstocks, specifically Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS), which underscores a persistent challenge in achieving material circularity. These standard raw materials present distinct ecological drawbacks. For instance, the synthesis and processing of petroleum-based ABS result in a high carbon footprint and toxic emissions (Zhang et al., 2019), while the sustainability of PLA is mitigated by its reliance on food-competing starch sources and the necessity for industrial-grade biodegradation environments (Kreiger & Pearce, 2012).

Simultaneously, there exists a rapidly expanding potential for the valorization of agricultural residues to mitigate these environmental challenges. As a leading global producer of Ananas comosus, Malaysia produces an estimated two million tonnes of lignocellulosic pineapple byproducts each year from a cultivation area surpassing 18,000 hectares of agricultural terrain (Tran et al., 2022). Lignocellulosic byproducts, particularly pineapple peels, represent approximately 30% to 50% of the total fruit mass and are presently underexploited, frequently being discarded in landfills or subjected to open-field incineration (Meena et al., 2021). Such disposal practices intensify environmental degradation through the emission of greenhouse gases and the leaching of high-chemical-oxygen-demand (COD) organic matter into surrounding ecosystems (Omar et al., 2023).

The incorporation of pineapple peel fibers (PPF) as bio-reinforcing agents within polymer matrices presents a strategic approach towards the establishment of a circular bioeconomy. By replacing a fraction of virgin polymer with processed agricultural waste, it becomes feasible to create sustainable, economically viable filaments that either preserve or enhance the mechanical properties of 3D-printed components. Nevertheless, a significant research gap persists concerning the optimization of fiber loading and the consequent thermomechanical characteristics of these biocomposites. This investigation aims to explore the viability of employing Malaysian pineapple peel waste as a sustainable substitute for traditional 3D printing reinforcements, thus minimizing the ecological impact of additive manufacturing while simultaneously offering a high-value industrial application for agricultural byproducts.

INNOVATION PIPELINE : FROM IDEATION TO PROTOTYPE

The advancement of Filamenas serves as a paradigmatic illustration of a methodical evolution from theoretical sustainability to concrete engineering, adhering to a stringent technical framework that converts agricultural byproducts into superior 3D printing substrates. The manufacturing procedure is carried out through four essential phases as illustrated in Figure 1.

Phase 1 : Fiber micro-refining

Raw fibers of Ananas comosus were precisely cut into segments measuring 2–3 cm in length and then subjected to high-velocity grinding to attain a homogeneous matrix dispersion. The resultant particulates underwent precision sieving to conform to a standardized particle size range of 125–250 µm, which was specifically designed to mitigate the risk of nozzle occlusion during high-resolution three-dimensional printing.

Phase 2 : Bio-chemical surface engineering

To mitigate the variance between hydrophilic fibers and the hydrophobic polylactic acid (PLA) matrix, a mercerization procedure utilizing a 1 wt.% sodium hydroxide (NaOH) solution was conducted for three hours. This treatment effectively removes non-cellulosic constituents such as hemicellulose and lignin, thereby significantly augmenting the available reactive surface area for bonding interactions. The fibers were subsequently neutralized and subjected to dehydration at a controlled temperature of 80°C for a period of 48 hours to eradicate moisture-induced hydrolytic degradation.

Phase 3 : Precision Hybrid Compounding

The treated fibers were incorporated into the polymer matrix at mass fractions of 1%, 3%, and 5%. Employing hot compression molding at a temperature of 160°C and a pressure of 10 MPa, the bio-fillers were thoroughly encapsulated within the molten polymer. The resultant composite material was then granulated into uniformly high-quality pellets, thereby ensuring a consistent feedstock for the subsequent stages of manufacturing.

Phase 4 : Filament Extrusion & Quality Validation

The final filament strands were produced using a single-screw extruder, which was optimized to achieve a standardized diameter of 1.75 mm. Comprehensive tensile and flexural testing confirmed the structural integrity of the filaments, designating the 5 wt.% loading as the "Gold Standard" for achieving optimal mechanical reinforcement and suitability for industrial printing applications.

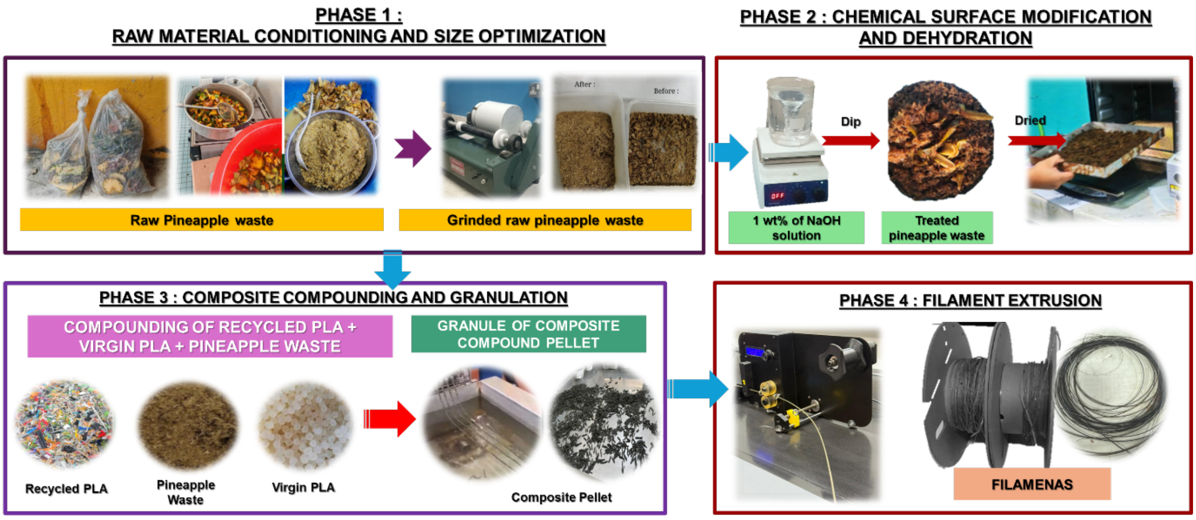

Figure 1: Research Methodology of production of Filamenas.

MILESTONE OF THE INNOVATION PROJECT

The initiative Filamenas emerged from a conceptual framework encapsulated in the "Waste to Wealth" paradigm, which aspires to metamorphose low-value agricultural byproducts into high-performance engineering composites. Initially derived from waste generated by pineapple food containers, the project underwent a comprehensive technical transformation into a specialized feedstock suitable for 3D printing applications. This innovative endeavor addresses the environmental challenges associated with the pineapple industry in Johor, Malaysia, by repurposing lignocellulosic biomass within a circular economy concept.

The technical advancement of Filamenas was realized through a collaborative framework involving the student and teachers from SMK Tan Sri Mohamad Rahmat, Johor, alongside the Social Innovation Team from the Faculty of Mechanical Engineering (FKM) at Universiti Teknologi Malaysia (UTM). The initiative evolved from a "Waste to Wealth" educational paradigm into a globally acknowledged engineering innovation. This advancement reached its apex at the 2025 Seoul International Invention Fair (SIIF) in South Korea, where the research team was conferred a Bronze Medal in an open category, effectively competing against distinguished university scholars and international academics. The innovation's transnational significance was further accentuated by Special Awards conferred by the Ministry of Education of Saudi Arabia and the Indonesia Invention & Innovation Association, subsequent to previous Gold Medal achievements at the Malaysia Technology Expo (MTE) and Penang International Invention, Innovation & Design (PIID). These accomplishments substantiate the industrial feasibility of the Filamenas as a commercially viable solution for sustainable additive manufacturing.

CONCLUSION

Filamenas initiative constructs a comprehensive technical framework for the "upcycling" of recycled plastics through the incorporation of Malaysian pineapple (*Ananas comosus*) peel waste into a high-performance 3D printing filament. By executing a precision-blending technique that combines a 50/50 hybrid matrix (comprising 50% recycled PLA and 50% virgin PLA) along with a 5 wt.% reinforcement of treated pineapple fibers, the initiative illustrates that agricultural byproducts can effectively recuperate the mechanical properties that are typically diminished during the plastic recycling process. This pioneering strategy—guided by the UTM Social Innovation Team and acknowledged internationally at the 2025 Seoul International Invention Fair (SIIF) which has successfully transformed a secondary school concept into a scalable engineering solution that adheres to international quality standards. Filamenas innovation project signifies a significant advancement in sustainable material science that empowers local communities to address global environmental issues, thereby demonstrating that strategic collaborations between universities and schools can propel the circular bioeconomy towards achieving a carbon-neutral future.

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REFERENCE

Horvath, J. (2014). Mastering 3D Printing. https://doi.org/10.1007/978-1-4842-0025-4

Kreiger, M., & Pearce, J. M. (2012, 2012/12/01). Environmental Impacts of Distributed Manufacturing from 3-D Printing of Polymer Components and Products. MRS Online Proceedings Library, 1492(1), 107-112. https://doi.org/10.1557/opl.2013.319

Meena, L., Neog, R., Sengar, A., & C K, S. (2021, 10/08). Pineapple processing waste (PPW): bioactive compounds, their extraction, and utilisation: a review. Journal of Food Science and Technology, 59. https://doi.org/10.1007/s13197-021-05271-6

Omar, S., Shafie, S., Hami, N., Othman, Z., & Djaohari, A. H. (2023, 06/01). Environmental Analysis of Power Generation from Pineapple Waste. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 105, 88-98. https://doi.org/10.37934/arfmts.105.2.8898

Tran, T., Nguyen, D., Nguyen, T., Nguyen, D. H., Mansur, A., Abdul Jalil, A., Nabgan, W., & Lee, T. (2022, 09/01). A critical review on pineapple (Ananas comosus) wastes for water treatment, challenges and future prospects towards circular economy. Science of The Total Environment, 856, 158817. https://doi.org/10.1016/j.scitotenv.2022.158817

Zhang, Q., Pardo, M., Rudich, Y., Kaplan-Ashiri, I., Wong, J. P. S., Davis, A. Y., Black, M. S., & Weber, R. J. (2019, 2019/10/15). Chemical Composition and Toxicity of Particles Emitted from a Consumer-Level 3D Printer Using Various Materials. Environmental Science & Technology, 53(20), 12054-12061. https://doi.org/10.1021/acs.est.9b04168