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OPTIMIZATION OF PINEAPPLE LEAF FIBER-REINFORCED ABS WASTE FILAMENTS FOR FDM: EFFECT OF MESH SIZE AND VOLUME FRACTION

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Abstract. Acrylonitrile Butadiene Styrene (ABS) plastic waste presents significant potential for upcycling into environmentally friendly materials, particularly as feedstock for 3D printing filaments in Fused Deposition Modeling (FDM). This study investigates the influence of pineapple leaf fiber (PALF) reinforcement at two weight fractions (3% and 5%) and two mesh sizes (200 and 300) on the dimensional stability, printability, and mechanical properties of ABS waste-based composite filaments. Comprehensive evaluations were conducted, including filament diameter consistency, surface morphology, and uniaxial tensile testing. The 5% fiber content with 300-mesh PALF yielded the most stable filament diameter (average 1.73 mm, CV 2%), while the same formulation also achieved the highest ultimate tensile strength (UTS) of 8.873 MPa and elongation at break of 0.197%. Interestingly, the highest Young's modulus (0.139 GPa) was observed in the 3%–300 mesh variant, although it exhibited more brittle behavior. Overall, the 5%–300 mesh formulation was identified as optimal, striking a favorable balance between tensile strength, flexibility, and dimensional consistency, thereby validating its suitability as a sustainable FDM filament derived from post-consumer ABS waste.

Keywords : 3D Printing, Composite Filament, Fused Deposition Modeling (FDM), Morphology, Pineapple Leaf Fiber, Printability, Recycled ABS, Tensile Test.

1. INTRODUCTION

Plastics are widely used across numerous industries, but this extensive use generates substantial waste [1]. The recycling process is a beneficial way to handle plastic waste. As technology improves, the processing of plastic waste is becoming increasingly common as a source of new materials. One of the most promising outcomes of this development is composite materials, which are already applied in many applications [2], [3]. The matrix and fibers are the two parts that make up composites. These parts impart composites benefits like being light, strong, and resistant to corrosion.

In composite processing, there are several common methods used, such as compression molding and additive manufacturing (3D printing) [4]. Compression molding, which uses a hot press, is a widely used method because it can produce high-quality composites in various volumes. However, in practice, this method has a weakness: its inability to form composites in more complex configurations [5]. Compared to hot pressing, 3D printing methods have advantages in producing more complex and economical composite products, thereby improving the efficiency of the production process [6].

The 3D printing process uses filament as the main material. Thermoplastic materials are used to create 3D printer prototypes [6], [7]. Acrylonitrile Butadiene Styrene, or ABS, is one of the two common types of polymer thermoplastics used as filaments. To enhance its mechanical properties and sustainability, natural fibers are often added as reinforcement. Pineapple leaf fiber (PALF), with a high cellulose content (70–80%), offers excellent stiffness and strength, making it a promising additive. PALF-reinforced ABS filaments are suitable for use in various industries, including construction, automotive, and aerospace [8], [9].

Muck et al. (2021) study colour fastness to various agents and dynamic mechanical characteristics of biocomposite filaments and 3d printed samples. The researcher used a matrix made of PLA with 5% wood and flax fibers added to it in the study [10]. The results showed that adding wood and flax fibers to PLA made it much rougher on the surface than pure PLA. The resulting filaments also changed size, going from 1.54 to 1.9 mm, which which in turn reduced filament uniformity. Previous research used ABS and PLA as the matrix materials, while flax fibers and rice husk served as the fillers. They use an extrusion temperature between 165 and 200°C for plastic pellets. With fiber mesh sizes of 75, 100, and 125 mesh, they found that particles larger than 100 mesh would cause clogging in the nozzle used. Therefore, the researchers used a larger nozzle size for fibers with particle sizes below 100 mesh. However, this will cause the filament results to decrease when extruded [11].

Compared with these studies, the present work focuses specifically on recycled ABS waste reinforced with PALF, with controlled variations in mesh size (200 and 300 mesh) and volume fraction (3 and 5 vol%). The recycled filament was extruded at 180°C . This study not only extends previous research by examining finer PALF particle sizes but also combine the practical issue of producing stable filaments from plastic waste, thereby supporting both material performance and sustainability objectives.

2. METHODS

This study used recycled ABS pellets (Polylac PA-757) as the matrix and pineapple leaf fibers (PALF) as reinforcement. The fibers were first cleaned using a wire brush to remove impurities and then treated with a 5% NaOH solution for 1 hour to eliminate non-cellulosic components. After rinsing with clean water, the fibers were oven-dried at 100°C for 2 hours and subsequently ground using a blender to produce fine powder. The resulting powder was sieved using 200 and 300 mesh screens to obtain the desired particle sizes. Both the ABS pellets and treated PALF were weighed using a digital scale to match the required fiber volume fractions of 3% and 5%. The schematic diagram mof filament preparation is shown in Figure 1.

The composite mixture of ABS pellets and pineapple leaf fiber (PALF) was homogenized and then processed using a WellZoom single-screw extruder at a temperature of 180°C. The filament exiting the 0.8 mm diameter nozzle is directed into a container of water for cooling to maintain dimensional stability and then wound onto a spool. During the extrusion process, parameters such as temperature, extrusion speed, and cooling rate are monitored to ensure filament consistency.

Filament dimension measurements were taken using a digital micrometer at several points along the filament to evaluate diameter uniformity, which is crucial for 3D printing performance. Measurement data were statistically analyzed by calculating the mean and coefficient of variation (CV) to assess dimensional stability. Additionally, the surface morphology of the filaments was observed using the same microscope to identify structural irregularities, fiber distribution, and the potential presence of voids, thus offering perspectives on the homogeneity and quality of the composite structure.

The extruded filaments from each variation were then cut into 10 cm lengths and was tensile tested according to the ASTM D3822 standard. Tensile testing was conducted using a Universal Testing Machine to obtain the maximum tensile strength (UTS), elongation at break, and Young's modulus values, thus enabling an evaluation of how the amount of pineapple leaf fiber and mesh size influence the mechanical performance of ABS waste-based composite filaments.

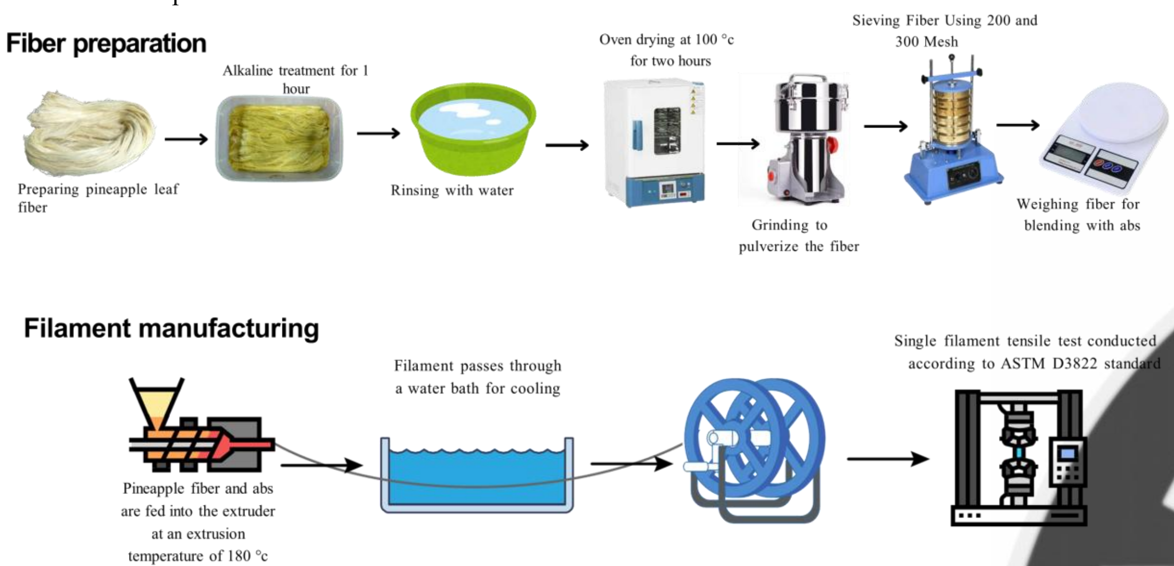


Figure 1. The sequential process of fiber preparation and filament manufacturing

Table 1. Summary of Experimental Variables Used

	Variable	Description / Levels
Matrix Material	ABS	Recycled ABS (Polylac PA-757) pellets
Reinforcement	Pineapple Leaf Fiber (PALF)	Cleaned, alkaline treated, ground, and sieved
Fiber Mesh Size	Mesh size	200 mesh and 300 mesh
Fiber Volume Fraction	vol%	3% and 5%
Extrusion Temperature	°C	180°C
Extruder Type	—	Single-screw WellZoom extruder
Nozzle Diameter	mm	0.8 mm
Cooling Method	—	Water bath during filament take-up
Measured Printability Parameters	Diameter uniformity	Mean diameter, coefficient of variation (CV)
	Surface morphology	Optical microscopy (roughness, fiber distribution, voids)
Mechanical Testing Parameters	Tensile properties	UTS, elongation at break, Young's modulus (ASTM D3822)
Sample Preparation	Filament length	10 cm samples for tensile testing

3. RESULTS AND DISCUSSION

3.1 Filament Morphology Analysis

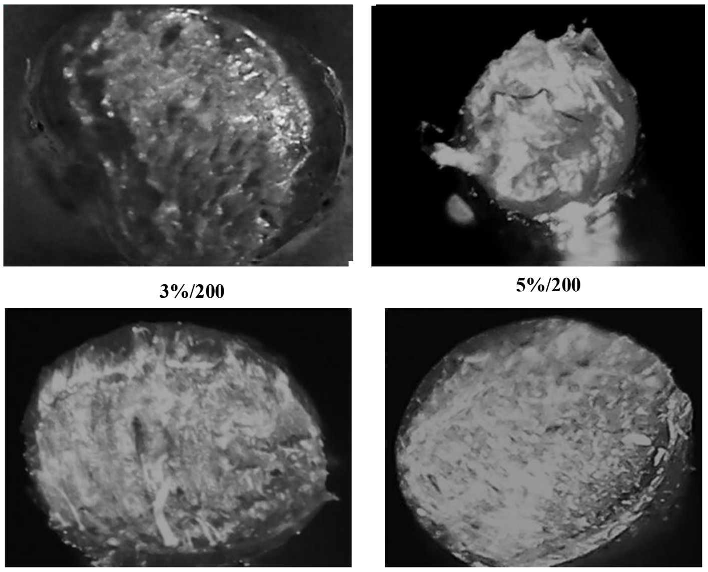
Dimensional measurements were conducted using a digital micrometer with a resolution of 0.01 mm. For each filament sample, measurements were taken every 5 cm along a 100 cm segment, resulting in 20 data points per variation. As listed in table 2, the recorded average diameters for each formulation were as follows: 1.66 mm for 3% fiber content with 200 µm mesh, 1.73 mm for 5% with 200 µm mesh, 1.72 mm for 3% with 300 µm mesh, and 1.73 mm for 5% with 300 µm mesh. In research conducted by Cardona et al. [12], the tolerance for filaments for 3D printing was explained to be ±0.02 mm. Therefore, only the filament with 5% pineapple fiber content (for both 200 and 300 mesh) met the ISO 5425:2023 required the diameter 1.75 with the tolerance standard of ±0.02 mm and was deemed suitable for FDM-based 3D printing. The filament with 5% PALF had more stable diameters because the greater fiber content let the ABS–fiber combination melt more easily and flow more smoothly during extrusion. The higher fiber content at 5% made the composite flow more even and continuous, which reduced die swell variance and helped the extrudate keep its shape as it cooled in water. This makes the filament less likely to become bigger or thinner. Only the 5% PALF formulations met the ISO 5425:2023-dimensional criterion for a 1.75 mm filament (±0.02 mm). Thus, the data obtained showed that filaments with a volume fraction variation of 3% and 200 and 300 µm mesh did not meet the standard for the 3D printing process because the filament dimensional size exceeded the tolerance limit of ±0.02 mm. Filaments with a volume fraction of 5% and mesh sizes of 200 and 300 µm met the standard because their diameters were within the specified tolerance limits. This reasoning is supported by research conducted by Lendvai et al., which explains that deviations of more than ±0.02 mm cause unstable printing and deformation in the final printed product [13], [14].

Table 2. Coefficient of Variation (CV) of Filament Diameter

Fiber Volume Fraction	Mesh Size	Average Diameter (mm)	CV (%)
3%	200	1.66	11
5%	200	1.73	8
3%	300	1.72	5
5%	300	1.73	2

As shown in Table 2, the filament with 3% fiber content and 200 µm mesh exhibited the highest CV value of 11%, indicating significant dimensional inconsistency and poor homogeneity. This variation does not meet the threshold for acceptable printability (CV <10%). Meanwhile, the 5%/200 µm, 3%/300 µm, and 5%/300 µm variations achieved CV values of 8%, 5%, and 2%, respectively demonstrating better extrusion stability and fiber dispersion. The 5%/300 µm variant, with the lowest CV of 2%, meets the criteria for high dimensional precision and is the most suitable for FDM 3D printing applications.

Based on digital microscope analysis at 100× magnification (Figure 2), the surface morphology of the filaments shows significant variation across different combinations of pineapple fiber content and mesh size. Filaments with 3% fiber content and a 200 µm mesh size, exhibit a rough surface, high ovality, and dominant porosity due to uneven fiber distribution and particle clumping, potentially leading to nozzle clogging during extrusion. The 5% variation with a 200 µm mesh shows similar symptoms to the addition of air bubbles, indicating high moisture content, which, according to Hamrol et al.[15], can affect viscosity and dimensional stability, as well as reduce print quality. Increasing the mesh size to 300 µm yielded better results, as seen in the 3%–300 µm variation, with the cross-sectional shape being closer to a circle, fiber distribution more even, and a reduction in the number of pores. Meanwhile, the 5%–300 µm variation showed the best morphology: a perfect circular cross-section, smooth surface, minimal porosity, and no indication of clogging, making it the most optimal formulation for FDM-based 3D printing. These results confirm that printability performance is highly influenced by dimensional uniformity, surface condition, particle size, moisture content, and extrusion process parameters, as previous research [16].



3%/200 5%/200

3%/300 5%/300

Figure 2. Surface morphology of filament with 3% /200, 5% /200, 3% /300, 5% /300 mesh size (100x maginification)

3.2 Tensile Properties of Filaments

Figure 4 and Table 3 show the results of tensile testing on the filament, the analyzed parameters such as Ultimate Tensile Strength (UTS), Yield Strength (YS), Young's Modulus, and Strain, each of which plays an important role in determining the performance of the composite material. The test results show that at a 5% variation and 300 mesh, this variation has the best mechanical performance compared to the other variations. This is indicated by the highest Yield Strength (YS) value of 8.873 MPa. This characteristic is highly advantageous for 3D printing applications that require high load resistance while maintaining dimensional stability, such as in 3D-printed structural components that need precise dimensions [17]. There was an increase in the variation of UTS (MPa), yield strength (MPa), Young's modulus (GPa), and strain (mm/mm) for the 5%/200, 3%/200, 5%/300, and 3%/300 mesh variations. The higher UTS and yield strength values for the 300-mesh variation are due to increasing the contact area between the fibers and the matrix, making load transfer from the matrix to the fibers more effective. The effect of increasing UTS and yield strength values will impact the filaments, making them stiffer and stronger even though the strain value obtained is relatively low. This is in line with research conducted by Wang et al., which explains that a significant increase in fiber fraction will add tensile strength and yield limit if the fibers are evenly dispersed [18], [19]. However, variation 5% /300mesh results the strain value was smaller, at 0.197. This can be explained by the fact that stiffness increases with a larger volume fraction of fibers, but although increasing the variation in fiber fraction further increases stiffness, the strain effectiveness of the filaments decreases. This can happen because of uneven fiber distribution, which creates weak zones in the material's binding structure [20]. Based on the evaluation of the tensile testing results on the filaments, the 5% addition of pineapple fiber with a mesh size of 300 is the most optimal variation, yielding the highest UTS value of 8.873 MPa and a strain value of 0.197. The balanced strain and UTS values make this variation a highly optimal combination. Naseer et al. explain that the optimal combination of strain and strength is crucial to avoid delamination during the extrusion process in the printing machine and to produce highly precise and durable prints[21].

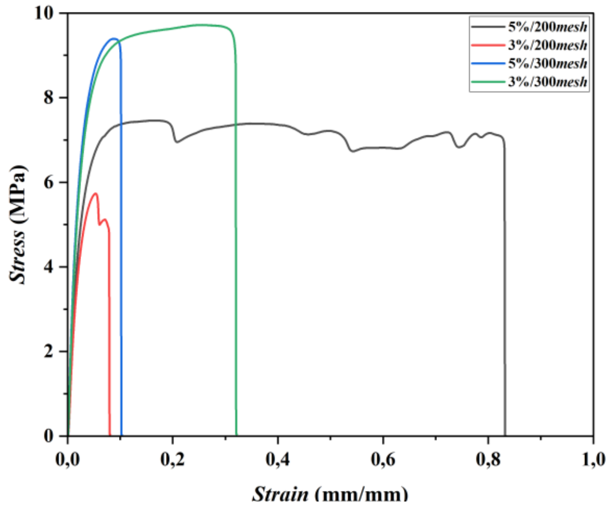


Figure 4. Graph of tensile properties of ABS-PALF Composite Filaments with different fiber volume fractions and mesh sizes.

Table 3. Tensile Properties of ABS-PALF Composite Filaments

Variation	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	Young's Modulus (GPa)	Strain (mm/mm)
5% / 200mesh	6.964 ± 0.63	6.584 ± 0.69	0.070 ± 0.04	0.650 ± 0.17
3% / 200mesh	5.063 ± 0.61	4.933 ± 0.65	0.077 ± 0.05	0.319 ± 0.15
5% / 300mesh	8.873 ± 0.52	8.873 ± 0.52	0.098 ± 0.04	0.197 ± 0.07
3% / 300mesh	7.795 ± 1.66	7.582 ± 1.76	0.139 ± 0.10	0.169 ± 0.14

4. CONCLUSION

Based on the research findings, it can be concluded that the volume fraction of pineapple leaf fibers and the fiber mesh size significantly influence the physical properties, surface morphology, and mechanical strength of composite filaments based on ABS waste. Increasing the fiber volume fraction from 3% to 5% was proven to improve dimensional stability, particle distribution homogeneity, and filament mechanical strength, particularly at the 5% variation with a 300 µm mesh size, which showed the most optimal performance. Conversely, a lower fiber volume fraction leads to fiber distribution irregularities, increases surface defects, and reduces tensile strength. On the other hand, the fiber mesh size also plays a key role in controlling morphological quality. Using smaller mesh-sized fibers (300 µm) results in a smoother filament surface, minimal porosity, and a more uniform cross-sectional shape, which directly impacts increased tensile strength. Thus, a combination of 5% volume fraction and 300 µm mesh size is recommended as the best formulation for producing viable and optimally usable ABS–PALF composite filaments in FDM-based 3D printing applications. Future investigations may examine fiber volume fractions ranging from 1% to 10%, various mesh sizes, and the implementation of hybrid fiber systems to expand the material design space. Variations in extrusion temperatures, screw speeds, and cooling methods can reveal correlations between processing and structure.

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