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PAPER

Investigation of oil palm fiber reinforced polylactic acid composite extruded filament quality

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Abstract

This study examines the quality of Polylactic Acid (PLA) filament reinforced with Oil Palm Fiber (OPF) for additive manufacturing applications. The research aims to create a composite filament that leverages the advantages of PLA, a biodegradable polymer, and OPF, a natural fiber from the oil palm tree, to enhance mechanical strength, dimensional stability, and printability. The methodology involves crushing the PLA filament and OPF to the desired size using a crusher machine, blending them in different ratios (e.g., 90:10 and 80:20 PLA to OPF), and using a hot-pressing process to bond the components. The resulting pelletized composites are then extruded into filaments using an extruder machine. The quality of the produced filament is assessed based on diameter consistency, surface smoothness, and printability, considering compatibility with 3D printers. The study reveals that composition ratios and processing parameters impact filament quality, leading to challenges such as diameter variations, rapid hardening, breakage, and extruder die clogs. Future recommendations were suggested to optimize compositions, refine processing, explore advanced extrusion, and investigate fiber distribution and bonding for improved filament properties. This research offers valuable insights for creating high-quality OPF-reinforced PLA filaments for additive manufacturing, advancing understanding of filament quality factors, and proposing ways to enhance composite filament performance across applications.

1. Introduction

Rapid prototyping implemented computer-aided design (CAD) for the first time in the 1980s. This technology has enabled users to realize their designs without mold or machining preparation. Since then, this technology has progressed exponentially, with the invention and development of numerous types of technology in tandem with various implementing materials. Due to the variety of available technologies, additive manufacturing (AM) is utilized more frequently than rapid prototyping. Even though there are limitations to this process, AM has been implemented for years and ushers in a new era of global manufacturing. By using CAD software to create a 3D model, which is then transferred to the slicing process format and incorporating the entire tool path for the AM printer, the AM printer begins the printing process to produce the final designed object [1].

This idea represented the earliest 3D printing technology known today as stereolithography (SLA). After the development of SLA, researchers took a keen interest in developing 3D printing technology to print objects with materials other than plastic, such as metal and ceramics. This resulted in the creation of alternative printing technologies such as fused deposition modeling (FDM), digital laser printing (DLP), selective laser sintering (SLS), material jetting (MJ), selective laser melting (SLM), and laminated object manufacturing (LOM) [2, 3].

Due to its low cost, simple printing mechanics, and wide selection of materials, FDM is one of the most popular types of 3D printing technology. These materials include acrylonitrile-butadiene-styrene (ABS), poly (ethylene terephthalate) (PET), polylactic acid (PLA), poly (carbonate) (PC), poly (vinyl alcohol) (PVA), thermoplastic elastomers (TPE). In FDM, a temperature-controlled print head is responsible for heating the filament material, transforming it into a molten or semi-molten state, and then extruding a pattern next to or on top of a previously extruded layer. Consequently, the layer-by-layer creation of an object is accomplished through the process of extrusion using the soft polymer. If separate nozzles are used for each type of printing material, FDM can create objects out of various printing materials simultaneously [4, 5].

PLA is a highly versatile, biodegradable, aliphatic polyester derived from 100% renewable resources, such as corn and sugar beets. PLA offers excellent promise in a wide range of commodity applications. Composite materials are created by combining multiple materials into a single structure. Most composites contain solid and rigid fibers in a matrix at a low density. PLA is a flexible polymer made from sustainable agricultural waste and fermented into carboxylic acid [6].

Oil Palm Fiber (OPF) comes from palm tree leaves, Empty Fruit bunches (EFB), fronds, and trunks. Its fundamental properties depend on post-processing and fire-harvesting location. OPF properties affect the final composite products with the desired application properties. Polymer composites are strengthened by OPF [7].

Natural fiber is also known for possessing biodegradable properties that adhere to the guidelines for eco-friendly materials. The issue that still requires attention when utilizing this composite type is that the adhesion bonding between reinforced and polymer matrix results in expensive consequences, such as wetting issues, swelling, and dimension instability [8].

Cellulose is a naturally occurring polymer with a high strength and rigidity per weight used to construct long, fibrous cells. These cells are found in plants' stems, leaves, and seeds. There are three general types of natural fibers: plant, animal, and mineral. These three categories have numerous subcategories, including leaf, silk, and asbestos. The most abundant natural fibers are tree-based wood fibers [9].

Biobased fiber reinforcement in composites is becoming more popular. Natural fibers as reinforcing mediums have many advantages. Biodegradable features that make disposal easier, minimal investment, thermal recyclability, user-friendly circumstances, lightweight assemblies, and acceptable specific strength properties are just a few [10].

Due to its non-toxic and eco-friendly nature, PLA has been used as an additive material in 3D printing. Complex and branching chemical structures of lignin were utilized as a filler to improve the mechanical strength of PLA. Due to the availability of oil palm empty fruit bunches (OPEFB) in Malaysia, this material is a good source for lignin extraction [11].

Fiber-reinforced polymer composites, also known as fiber-reinforced polymer (FRP), are new materials introduced to replace the existing materials in global applications. It is also used in concrete and steel construction and building [12].

The production of environmentally friendly bio composites will involve using biodegradable polymers such as thermoplastic and a mixture of natural fibers. As biodegradable materials are combined, they can be used to create more items, such as automobile doors, sports equipment, and other everyday items. PLA is an example of a biodegradable polymer that has received significant attention due to its renewable source properties [13, 14].

This research assesses the quality of extruded filament made from Oil Palm fiber-reinforced PLA composite. Experimental investigations will be conducted to specifically analyze the surface condition, consistency of filament diameter, and various other factors related to filament quality. The research involves multiple steps to obtain the necessary materials, and the obtained results will be thoroughly discussed and analyzed.

1.1. Problem statement

Bio-composite filaments are a popular alternative to synthetic filaments due to their low price, wide availability, high strength-to-weight ratio, high aspect ratio, and high strength and elasticity modulus. In the case of bio-composite filaments, the strength of the printed product is dependent on the type of plant fiber, the aspect ratio (ratio of length to diameter), and the quality of the interface between the polymer matrix and the bio-reinforcements [15, 16].

Due to its renewability and biodegradability, Poly (lactic acid) (PLA), also known as polylactide, is widely used in fused deposition modeling (FDM) as a filament feedstock material. However, the most challenging aspect of FDM-printed composites is extrusion-induced defects, specifically porosity caused by inadequate interfacial bonding between fibers and matrices. This limitation degrades the mechanical properties of the printed composites, particularly at higher fiber contents [17].

The main concern, however, is the compatibility of natural fillers with hydrophobic polymers in composites. The interfacial adhesion between the filler and the matrix significantly impacts composite mechanical properties, and a strong interaction is required to provide good stress migration from the matrix to the fiber's surface. Through physical, chemical, and biological methods, OPF modification can improve matrix-fiber adhesion and reduce fiber hydrophilicity [18, 19].

Filament production is affected by various procedures, including sieving the fibers, drying, and mixing. These processes immediately affect the properties and suitability of the filaments produced. Drying and surface preparation are required for a strong bond between fibers and polymer matrices [20, 21].

Despite the utilization and optimization of 3D printing parameters for product fabrication, the inherent fragility of extruded filament poses a substantial barrier to the quality of 3D printed objects. In addition, the intricate relationship between multiple process parameters during extrusion directly impacts the product's durability and dimensions. This highlights the significant impact that product strength and size have on the characteristics and performance of 3D printing filament [22].

2. Methodology

These elements will then be mixed in the designated ratios of 80:20 and 90:10 using a hot press machine to produce a complicated mixture. Before being fed into the extruder, this mixture will be crushed into pellets. The result of the extrusion process will be considered when evaluating whether or not the filament produced is suitable for 3D printing.

This research evaluates the quality of extruded filament reinforced with Palm Oil Fiber and PLA. The purpose is to produce filament by feeding a mixture of Oil Palm Fiber and PLA through an extruder. Figure 1 shows the overall flowchart of this project, which begins with background research, defining the problem statement, establishing objectives, and stating the scope. Followed by a literature review about similar topics is performed. Then, sources for the PLA and Oil Palm Fiber materials will be identified. After obtaining both materials, the PLA filament will be crushed into pellets while the Oil Palm Fiber will be refined into smaller sizes.

Then, using a hot press machine, these components will be combined in the specified ratios of 90:10 and 80:20 to create a complex mixture. This mixture will be crushed into pellets before being fed into the extruder. The outcome of the extrusion process will serve as a determining factor in assessing the suitability of the resulting filament for application in 3D printing or vice versa.

The quality of extruded filament reinforced with PLA and palm oil fiber is assessed in this experiment. The goal is to feed an extruder with a combination of PLA and oil palm fiber to create a filament. It starts with background information, defines the problem statement, sets goals, and specifies the scope. A review of the literature on related subjects is then conducted. Subsequently, the PLA and Oil Palm Fibre materials suppliers will be determined. After acquiring both resources, the Oil Palm Fibre will be refined into smaller diameters, and the PLA filament will be broken into pellets.

2.1. Experimental setup

Figure 2 shows the extruder machine and a conveyor stand positioned at the extruder's exit. The conveyor facilitated the pulling and guided the extruded filament as it fell onto the conveyor and indirectly fell to the floor. Varying the conveyor's speed settings helped form a new filament with a mixture of PLA and Oil Palm Fiber [23].

The hot press machine is an essential piece of equipment that will be utilized for this project. A complex mixture of Oil Palm Fiber and PLA is obtained or created using the hot press machine. This hot press machine applies pressure and heat to the mixture, which eventually causes the materials to combine and form a homogeneous material.

After separating the desired ratios of 90:10 and 80:20, Each ratio mixture will be loaded into the hot press machine. A hot press machine will subject the mixture to controlled heat and pressure. This controlled temperature and pressure refers to the literature review. The controlled heat and pressure will result in the PLA melting and flowing while promoting the bonding of Oil Palm Fiber within the polymer matrix.

A complete and uniform mixture will be produced by carefully and accurately adjusting the temperature and pressure settings of the hot press machine. Due to heat, PLA will soften and become malleable, effectively adhering to and wrapping Oil Palm Fiber. At the same time, the pressure helps to compress and merge the mixture, thereby strengthening their adhesion. Table 1 shows information on the conveyor speed applied throughout this research. The experiment setup was referred to in a few journals and articles.

2.2. Experimental parameter

The interface of the extrusion machine shows a few important parameters. M(Nm) stood for the screw speed that the extruder used or the torque that was given to the material in the extruder machine. There were four zones or temperatures: TS1, TS2, TS3, and TS-D1.

Because it aids in assessing the viscosity and flow characteristics of the PLA and Oil Palm Fiber mixture, it was essential to keep an eye on the torque being applied to the material in the extruder machine. Variations in torque revealed changes in the material and its characteristics or processing circumstances.

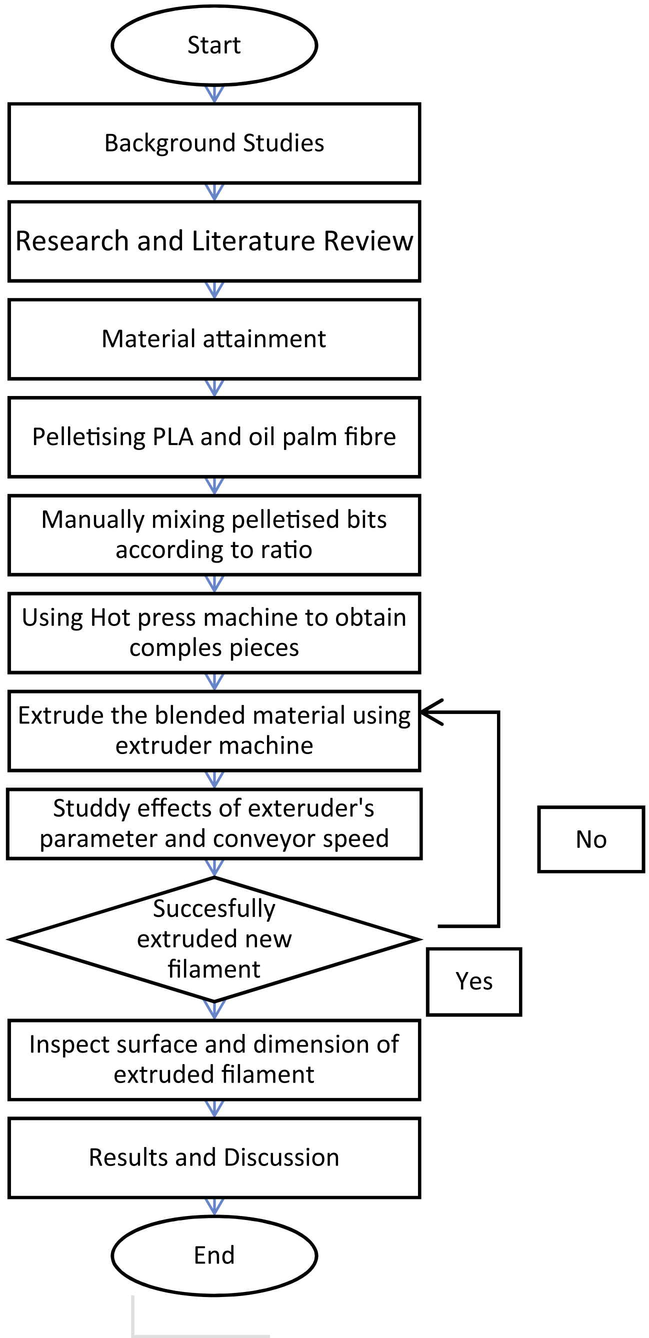


Figure 1. Flowchart for the study.

The TS1, TS2, and TS3 sensors monitored temperature. They were all located in different areas of the extruder barrel. The feed zone was usually home to TS1, the compression zone to TS2, and the metering zone to TS3. Die temperature sensor TS-D1. It was located at the die of the extruder.

To improve filament quality, it sensed the temperature at its exit point, where it was extruded, and monitored the die temperature to ensure it was adequately cooled and solidified [24].

The parameters listed in tables 1 and 2 below were applied to the Oil Palm Fiber and PLA extrusion mixture to produce a new filament. Furthermore, the characteristics of each of the given ratios varied. References from the literature review were used to determine the machine's temperature specifications and screw speed. Nonetheless, the ideal speed dictated the conveyor speed. This was because a conveyor was not used as an experimental setting in most of the references from the review of the pertinent literature.

Figure 2. The extruder machines.

Table 1. Machine parameter for 90:10 ratio.

Trial	Machine temp.	Screw speed	Conveyor speed
1	TS1: 160 TS2: 175 TS3: 190 TS-D1: 190	25	1.5
2	TS1: 180 TS2: 190 TS3: 170 TS-D1: 190	25	2.5
3	TS1: 165 TS2: 180 TS3: 180 TS-D1: 170	18	3
4	TS1: 170 TS2: 185 TS3: 190 TS-D1: 190	20	2

Table 2. Machine parameter for 80:20 ratio.

Trial	Machine temp.	Screw speed	Conveyor speed
1	TS1: 170 TS2: 185 TS3: 190 TS-D1: 210	30	2
2	TS1: 170 TS2: 190 TS3: 190 TS-D1: 210	25	1.2
3	TS1: 185 TS2: 195 TS3: 205 TS-D1: 220	18	3
4	TS1: 175 TS2: 190 TS3: 205 TS-D1: 220	20	4

Table 3. Parameter used in Hot Press Process.

Parameter	Values
Upper Mold	180 °C
Lower Mold	180 °C
Pressure	2 ton
Press Time	15s
Cooling Time	5s

3. Results and discussion

3.1. Fabrication of pelletized mixture comprising oil palm fiber and PLA

The main ingredients in this method were Oil Palm Fiber and PLA pellets, which underwent a rigorous processing sequence that included crushing and thorough mixing to produce the appropriate ratios of 80:20 and 90:10. After that, a 200 mm × 200 mm mold was used to apply a hot press process to the resulting mixture. Table 3 provides a detailed display of the hot press parameters used at this point. After the hot-pressing process, a solid PLA and oil palm fiber composite material was produced. A crusher was used to pelletize the solid composite.

3.2. Quality of extruded filaments

The filament quality successfully extruded was comprehensively outlined in tables 4 and 5, and the simultaneous photographs demonstrated the unique features of every filament sample. The assessment of filament quality encompassed multiple elements, such as surface smoothness, elasticity, and dimensional accuracy. The efficiency of the chosen parameters in obtaining the intended filament qualities might be ascertained by looking closely at these crucial features. The outcomes provided insight into the extruded filament's appropriateness for various uses, including 3D printing and other industrial procedures.

The pictures showing the experimental results made it clear that the extruded filament did not fulfill the required quality criteria after closely reviewing and evaluating the supplied tables. Notably, the only acceptable filament—with potential for improvement—was the one produced during the third attempt for the 90:10 and 80:20 ratios. However, the filaments obtained from the first, second, and fourth tests showed several notable faults, such as variable diameter, pronounced brittleness, excessive hardness, and poor surface conditions. There could be several reasons for these limits. Thus, a careful examination and in-depth study are required to understand the underlying causes better.

Due to the majority of extruded filaments' poor quality, a careful investigation was carried out to pinpoint and resolve the main issues influencing their effectiveness. By carefully addressing these challenges, significant gains in the functionality and quality of the extruded filament might be made. The discussion section expounded upon these aspects elucidated the challenges, and delineated prospective pathways for future refinement and optimization.

3.3. Discussion

Extruding a PLA and Oil Palm Fiber blend to make a novel filament has presented several noteworthy difficulties and discoveries. At first, a significant percentage of the extruded filaments were highly fragile, suggesting they were not flexible or resilient enough to be used in various applications.

The problem of brittleness is caused by things like the oil palm fiber's moisture content. To remedy this issue, the fiber must be well-dried before processing. The connection of the fibers with the PLA matrix during hot pressing is improved by controlling the moisture levels throughout the drying process. Uniform fiber response to pressure and heat is ensured by consistent moisture levels, which results in uniform filament bonding and mechanical qualities.

Furthermore, variations in filament diameter during extrusion were noted, which could influence further processes such as 3D printing and ultimately affect the quality of the final product. To address this, parameters like the extrusion temperature and material feeding rate need to be carefully monitored and controlled. Adjusting these factors can result in a more consistent filament diameter, increasing the accuracy and caliber of printed goods [25].

It was also observed that extruded filaments quickly hardened during the extrusion procedure. This quick hardening limits the filament's malleability and future modification potential. This problem may be traced back to the experimental setup's improper conveyor speed, which resulted in uneven material flow and insufficient

Table 4. Result of Extruded Filament for 90:10 ratio.

Trial	Result
1	
2	
3	
4	

cooling. Maintaining constant filament diameter and avoiding fast hardening can be achieved by modifying and optimizing conveyor speed and other processing parameters [26].

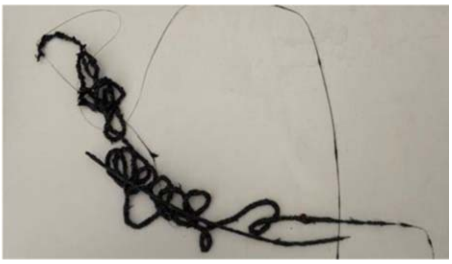
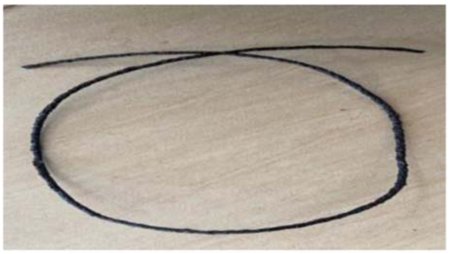
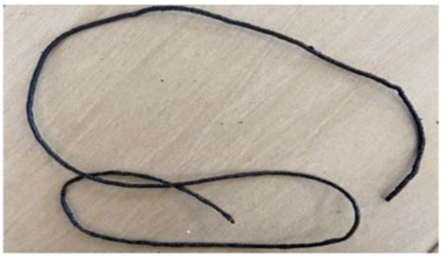
Intermittent filament breaking during extrusion was another problem that was noticed; this could have interfered with printing procedures and decreased the quality of the finished product. Comparably, material clogging at the extruder die's end impeded material flow and necessitated research to find and fix the root reasons, which may have to do with die design and temperature management [27, 28].

Temperature regulation affects and is influenced by these issues. Maintaining the appropriate filament flexibility and avoiding fast hardening depends heavily on temperature control. The quality and utility of filaments can be impacted by inadequate temperature management, which can lead to incorrect material melting, insufficient adhesion, and poor flow properties [29].

It will take a thorough effort to overcome these obstacles. This involves balancing Oil Palm Fiber and PLA in the material mix to maximize reinforcing effects without compromising processability [30].

Overall, this research underscores the intricate nature of extruding composite materials like Oil Palm Fiber and PLA. A thorough composition, processing parameters, and equipment design analysis are essential to

Table 5. Result of Extruded Filament for 80:20 ratio.

Trial	Result
1	
2	
3	
4	

enhance filament quality. The research aims to provide valuable insights and recommendations for improving the extrusion process and achieving high-quality filaments by addressing these factors.

4. Conclusion

This study investigated the quality of extruded filament made from an Oil Palm Fiber and Polylactic Acid (PLA) composite material. All essential experimental procedures included crushing machines to prepare the materials, hot press machines to pelletize the mixture and an extruder machine for filament extrusion. The experiments resulted in several significant discoveries. First, the extruded filaments exhibited varying diameters, which could result in difficulties feeding the filament into 3D printers or other manufacturing processes, thus affecting the quality and precision of the printed objects. This inconsistency may result from improper material blending during crushing and mixing or improper control of extrusion parameters. In addition, shortly after extrusion, the filaments exhibited a phenomenon of rapid hardening. This rapid hardening may cause complications during post-processing and handling, reducing the filament's malleability and preventing further modifications or adjustments. Fragmentation of filaments has been observed intermittently, suggesting filament structural defects. This issue could cause printing process interruptions or defects, resulting in lost time and resources and a degraded final product. In addition, it was observed that the material adhered to the end of the extruder die, impeding the filament's flow. This issue could be influenced by variables such as temperature distribution, die design, or the presence of contaminants.

The study found that the experimental setup's conveyor speed may have contributed to these issues. Inadequate conveyor speed may result in uneven material flow, insufficient cooling, and excessive hardening, negatively affecting the quality of the filament. Temperature regulation emerged as an essential aspect of the extrusion procedure, necessitating adjustments and fine-tuning temperature parameters for optimal extrusion outcomes. Inadequate temperature regulation can result in improper material melting, inadequate adhesion between components, and inadequate flow characteristics, all contributing to the observed problems. This research has accomplished all its stated goals. The first objective was determining the optimal ratio of PLA to Oil Palm Fiber by thoroughly reviewing the relevant literature. Based on the findings, two compositions, 90:10 and 80:20, were suitable for the mixture.

The effect of these parameters on filament quality was analyzed by meticulously adjusting and configuring the extruder machine's parameters after a review of the pertinent literature. The final objective of evaluating the extruded filament's quality, compatibility, and printability was met by conducting exhaustive tests of its physical properties and performance characteristics. The results revealed certain limitations, such as brittleness and inconsistent diameter during the extrusion process, indicating that additional improvements are required to produce a filament with the desired quality. In conclusion, the Oil Palm Fiber Reinforced Polylactic Acid (PLA) Composite Extruded Filament Quality study revealed the complexities and limitations of this method. It emphasized the significance of considering multiple factors, such as material composition, processing parameters, equipment design, and temperature regulation, to enhance filament quality. Future research and optimization efforts can enhance extruded filament's consistency, strength, and applicability for various applications by addressing these factors.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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