JPPIPA 12(3) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Processing and Characterization of Acrylonitrile Butadiene Styrene (ABS)-Based Biocomposite Filaments Reinforced with Oil Palm Empty Fruit Bunch

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Received: January 04, 2026
Revised: February 18, 2026
Accepted: March 25, 2026
Published: March 31, 2026

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DOI: 10.29303/jppipa.v12i3.14177

Abstract: The growing demand for sustainable materials in additive manufacturing has driven interest in biocomposite filaments reinforced with natural fillers. In this study, ABS-based biocomposite filaments reinforced with oil palm empty fruit bunch (OPEFB) microfibrillated cellulose were successfully fabricated using a single-screw extrusion process. The OPEFB cellulose content was varied from 0 to 30 wt.% to evaluate its effect on filament dimensional stability, morphology, and chemical structure. Filament extrusion was performed at a processing temperature of 220 °C and an extrusion speed of 850 to ensure stable melt flow and minimize thermal degradation. The results show that the filament diameter remained relatively stable within the range of 2.50-2.80 mm across all compositions, indicating good dimensional control during extrusion. This study highlights the novelty of successfully fabricating ABS-based biocomposite filaments reinforced with OPEFB microfibrillated cellulose using a simple process. SEM analysis revealed that low OPEFB content (2 wt.%) resulted in uniform filler dispersion and good interfacial bonding, while higher filler loadings led to increased porosity, agglomeration, and surface roughness, which may adversely affect filament quality and printability. The current findings demonstrate that OPEFB can enhance filament characteristics even at low composition scales. The presented results are comprehensive enough for initial filament characterization, including dimensional stability, morphology, and chemical structure, which adds to the interest of this study and has not been previously presented. FTIR analysis confirmed that no chemical modification occurred between the ABS matrix and OPEFB cellulose, with interactions dominated by physical bonding. Overall, the findings demonstrate that ABS-OPEFB biocomposite filaments with low to moderate cellulose content can be effectively produced and show potential for fused deposition modeling applications, offering a sustainable alternative to conventional ABS filaments.

Keywords: Acrylonitrile Butadiene Styrene (ABS); Oil Palm Empty Fruit Bunch (OPEFB); Biocomposite Filament; Microfibrillated Cellulose.

Introduction

The rapid development of additive manufacturing, particularly Fused Deposition Modeling (FDM), has increased the demand for polymer filaments with reliable mechanical performance, dimensional stability, and good processability. ABS remains a widely used material due to its balanced mechanical properties and ease of extrusion (Singh et al., 2015; Torrado et al., 2015); however, its non-biodegradable nature raises sustainability concerns. Natural fillers have been widely studied to enhance stiffness and reduce environmental impact (Kader et al., 2025; Faruk et al., 2012), but most studies focus on composites rather than FDM filaments.

How to Cite:
Rahmayanti, H. D., Pradipa, R. A., Akmalia, N., & Andayu, H. G. (2026). Processing and Characterization of Acrylonitrile Butadiene Styrene (ABS)-Based Biocomposite Filaments Reinforced with Oil Palm Empty Fruit Bunch. *Jurnal Penelitian Pendidikan IPA*, *12*(3), 524-534. https://doi.org/10.29303/jppipa.v12i3.14177

Consequently, the effects of fillers on filament quality such as homogeneity, diameter consistency, and extrudability which directly influence printing reliability, remain insufficiently understood. Moreover, characterization of filament morphology (surface and cross-section) and structure unitis still limited, despite being crucial for understanding matrix-filler interactions. Therefore, this study offers novelty by developing ABS-based FDM filaments with natural fillers, emphasizing the relationship between filament quality, morphological and structural characteristics, and printing reliability.

The utilization of Oil Palm Empty Fruit Bunches (OPEFB) as a reinforcing material in composites presents significant potential due to its abundance and high lignocellulosic content. Oil palm biomass has gained considerable attention for its ability to be converted into value-added products such as bioplastics, biosugars, nanocellulose, bioenergy, adsorbents, and polymer composites (Ilyas et al., 2020; Ilyas et al., 2020; Arifin et al., 2017; Norrahim et al., 2021; Sharip et al., 2020; Norrahim et al., 2021; Norrahim et al., 2020; Lawal et al., 2021; Zakaria et al., 2012; Ilyas et al., 2021; Asyraf et al., 2021). However, this potential is often not accompanied by a critical evaluation of its limitations. At a broader level, large-scale oil palm biomass production can lead to environmental issues, including waste accumulation, pollution, and contributions to global warming if not properly managed. Thus, OPEFB utilization should be viewed not only as a material opportunity but also as part of a sustainable biorefinery strategy that promotes biomass valorization into products such as biocomposites and biochemicals (Jalani & Zainal, 2024). While studies report increased stiffness in thermoplastic composites, these improvements are not always matched by enhanced tensile strength or impact toughness (Mahardika et al., 2024). Additionally, the incompatibility between hydrophilic OPEFB and hydrophobic polymer matrices remains a key challenge, reducing interfacial adhesion and overall composite performance (Asyraf et al., 2022). The need for mechanical, chemical, or thermochemical pretreatment further increases process complexity and cost, potentially limiting large-scale application. Therefore, a more comprehensive approach is needed, addressing not only material potential but also process efficiency, economic viability, and environmental sustainability to support a circular bioeconomy.

Several studies have explored the development of ABS-based composites reinforced with oil palm empty fruit bunch (OPEFB) or other lignocellulosic fillers, with particular attention given to systems employing recycled ABS matrices. Previous studies consistently report that the incorporation of natural fillers into ABS can enhance stiffness and dimensional stability due to the rigid nature of lignocellulosic components (Ilyas et al., 2022; Costa et al., 2023; Lamm et al., 2020; Mohan et al., 2021). However, a trade-off in mechanical performance is frequently observed, especially in terms of tensile and impact strength at elevated filler contents. Such behavior is commonly attributed to inadequate dispersion of the filler within the polymer matrix, the tendency of natural fibers or particles to form agglomerates, and limited interfacial compatibility between the hydrophilic filler and the hydrophobic ABS matrix.

In addition, differences in particle size distribution and processing conditions during melt compounding have been shown to significantly influence stress transfer efficiency and fracture behavior. These observations emphasize that careful control of formulation parameters including filler loading, particle morphology, and compounding strategy is essential to tailor the mechanical performance of ABS-OPEFB composite systems. Consequently, systematic investigations addressing both processing and structure property relationships are required to further optimize ABS-based biocomposites for advanced applications such as filament fabrication for additive manufacturing. When ABS-based biocomposites are intended for use as filaments in FDM applications, additional requirements must be considered. Filaments must exhibit consistent diameter, homogeneous material distribution, and stable melt flow behavior to ensure reliable extrusion and printing performance. Therefore, the processing route including filler preparation, compounding, and filament extrusion plays a crucial role in achieving high-quality biocomposite filaments with acceptable mechanical and physical properties (Tekinalp et al., 2014).

Comprehensive material characterization is essential to evaluate the suitability of ABS-OPEFB biocomposite filaments for engineering applications. Physical characterization provides insight into density, uniformity, and structural integrity of the filament, while mechanical testing, such as tensile strength and elastic modulus measurements, reflects the load-bearing capability of the material. Furthermore, morphological analysis using Scanning Electron Microscopy (SEM) offers valuable information regarding filler dispersion, interfacial bonding, and fracture mechanisms, which are directly correlated with the mechanical behavior of the composite (Essabir & Bouhfid, 2019; Junior et al., 2008).

Based on the above considerations, this study aims to present a systematic investigation of the processing and characterization of ABS-based biocomposite filaments reinforced with Oil Palm Empty Fruit Bunch (OPEFB). The study covers the formulation process, filament fabrication, and comprehensive characterization, including physical properties and morphological analysis using SEM. The findings of this research are expected to contribute to the development of sustainable, high-performance biocomposite filaments with potential applications in additive manufacturing and polymer-based industries.

Method

The fabrication of biocomposite filaments in this study was carried out using Acrylonitrile Butadiene Styrene (ABS) plastic pellets as the primary polymer matrix. Figure 1 was shown flowchart of the research method. The ABS pellets employed in the extrusion process possessed a particle size in the range of 2–3 mm, in accordance with the technical specifications provided in the data sheet summarized in Table 1. As a reinforcing phase, cellulose derived from oil palm empty fruit bunches (OPEFB) was utilized, specifically in the form of microfibrillated cellulose (MFC). The selected MFC fibers exhibited an average fiber size of less than 100 µm and a density of approximately 1.5 g/cm³, making them suitable for incorporation into the ABS matrix as a fine reinforcing filler.

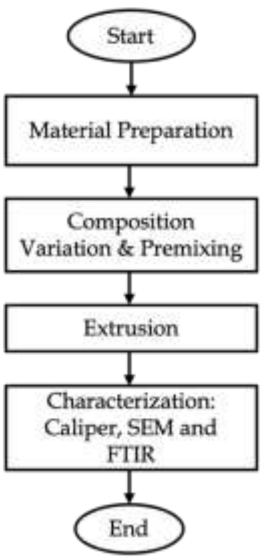

Figure 1. Flowchart of the research method

To investigate the effect of OPEFB cellulose content on filament characteristics, ABS pellets were blended with varying proportions of OPEFB fibers. The OPEFB content was systematically varied from 0 to 30 wt.%, with incremental additions of 2 wt.% cellulose to ensure a gradual and controlled variation in composite composition. Prior to the extrusion process, the ABS pellets and OPEFB MFC fibers were manually premixed to promote homogeneous distribution of the reinforcing fibers within the polymer matrix and to reduce the likelihood of agglomeration during processing.

The premixed ABS-OPEFB blends were subsequently processed into filaments using a single-screw extruder of the SJ20 type. The blended materials were continuously fed into the hopper of the extruder to ensure stable material flow throughout the extrusion process. Filament extrusion was conducted at a controlled processing temperature of 220°C and an extrusion average speed of 850, parameters selected to provide sufficient melt flow of the ABS matrix while simultaneously minimizing the risk of thermal degradation of both the ABS polymer and the cellulose fibers. Throughout the extrusion process, careful control of key processing parameters, including temperature stability and screw rotation speed, was maintained in order to achieve continuous filament formation with a stable diameter. This control was also essential to prevent the formation of air bubbles, ensure uniform material dispersion, and produce filaments with consistent quality suitable for fused deposition modeling (FDM) applications.

The biocomposite filaments investigated in this study were fabricated using Acrylonitrile Butadiene Styrene (ABS) plastic pellets as the primary polymer matrix. The ABS pellets used for the extrusion process had a particle size in the range of 2–3 mm, in accordance with the technical specifications provided in the material data sheet, as summarized in Table 1. As the reinforcing phase, cellulose derived from oil palm empty fruit bunches (OPEFB) was employed in the form of microfibrillated cellulose (MFC). The selected OPEFB MFC fibers exhibited an average fiber size of less than 100 µm and a density of approximately 1.5 g/cm³, rendering them suitable as a fine reinforcing filler for thermoplastic composite fabrication. To evaluate the influence of OPEFB cellulose content on the properties of the resulting filaments, ABS pellets were blended with varying amounts of OPEFB MFC fibers. The cellulose content was systematically varied 0 wt.%; 2 wt.%; 4 wt.%; 6 wt.%; 10 wt.%; 15 wt.% and 30 wt.%, with to ensure a gradual and controlled modification of the composite formulation. Prior to extrusion, the ABS pellets and OPEFB MFC fibers were manually premixed to promote a more homogeneous distribution of the reinforcing phase within the polymer matrix and to reduce the likelihood of fiber agglomeration during subsequent melt processing.

The premixed ABS-OPEFB blends were processed into continuous filaments using a single-screw extruder (SJ20 type). The blended materials were continuously fed into the extruder hopper to maintain a stable and consistent material flow throughout the extrusion process. Filament extrusion was conducted at a processing temperature of 220 °C and an extrusion average speed of 850. These parameters were selected to ensure adequate melt flow of the ABS matrix while minimizing the risk of thermal degradation of both the polymer and the cellulose fibers. During extrusion, critical processing parameters, including temperature stability and screw rotation speed, were carefully controlled to achieve continuous filament formation with a stable diameter. Such control was essential to prevent the formation of air bubbles, promote uniform dispersion of the OPEFB fibers within the ABS matrix, and produce filaments with consistent quality suitable for fused deposition modeling (FDM) applications. The physical properties of the extruded biocomposite filaments were evaluated through diameter measurements.

Table 1. Data Sheet of Acrylonitrile Butadiene Styrene (ABS) Plastic Pellets.

Propertied	ASTM Test Method	Test Condition	Unit	General PA-757
Melt Flow Index	D1238	200°C, 5 Kg	g/10 min	1.6
		220°C, 10 Kg		-
Mass Density	D792	23°C	-	1.05
Hardness	D785	-	R Scale	116
Tensile Strength (Yield)	D638	6 mm/min	Kg/cm²	470
			lb/in²	6660
Tensile Elongation	D638	6 mm/min	%	25
Flexural Strength	D790	2.8 mm/min	Kg/cm²	790
			lb/in²	11660
Flexural Modulus	D790	2.8 mm/min	10^4 Kg/cm²	2.7
			10^5 lb/in²	3.8
IZOD (Izod Impact Strength)	D256 (Notched)	6.4 mm, 23°C	Kg-cm/cm	20
			ft-lb/in	3.7
		3.2 mm, 23°C	Kg-cm/cm	21
			ft-lb/in	3.9
Vicat Softening Temp.	D1525	1 Kg, 50°C/hr	°C	105
			°F	221
Heat Distortion Temp.	D648	1.8 Mpa Annealed	°C	95
			°F	203
		1.8 Mpa Unannealed	°C	85
			°F	186
UL Flammability	UL 94	-	-	1.5 mm HB

The filament diameter was measured at multiple locations along the filament length using a vernier caliper to assess dimensional consistency and uniformity. These measurements were performed to ensure that the produced filaments met the dimensional requirements for FDM processing.

Morphological characterization of the biocomposite filaments was carried out using a Phenom Pro X Desktop Scanning Electron Microscope (SEM) equipped with energy-dispersive X-ray spectroscopy (EDX). SEM analysis was performed to observe the surface morphology, fiber dispersion, and interfacial characteristics between the OPEFB cellulose fibers and the ABS matrix. The EDX system was employed to support elemental analysis and confirm the presence and distribution of cellulose within the composite structure.

The molecular structure and functional groups of the ABS- OPEFB biocomposite filaments were characterized using Fourier transform infrared spectroscopy (FTIR). FTIR measurements were performed using a PerkinElmer Spotlight 400 Frontier spectrometer. The spectra were recorded over a wavenumber range of 4000-400 cm^{-1} to identify characteristic absorption bands of PLA and cellulose components and to assess potential interactions between the polymer matrix and the reinforcing fibers.

Result and Discussion

The influence of OPEFB cellulose content on the diameter of ABS-based biocomposite filaments is presented in Table 2. The results show that the average filament diameter remained relatively stable across all compositions, ranging from 2.50 mm to 2.80 mm, despite the gradual increase in cellulose content from 0 to 30 wt.%. This behavior indicates that the extrusion process was well controlled and that the incorporation of microfibrillated cellulose did not cause severe dimensional instability during filament fabrication. For neat ABS filaments (0 wt.% OPEFB), an average diameter of 2.76 mm was obtained. The addition of low cellulose contents (2-6 wt.%) resulted in minor fluctuations in filament diameter. In particular, a slight reduction to 2.50 mm was observed at 4 wt.% OPEFB. Such variations may be associated with temporary changes in melt rheology, including improved filler wetting and localized alignment of cellulose microfibrils within the molten ABS matrix, which can influence die swell and draw-down behavior during extrusion (Banerjee & Ray, 2023; Faruk et al., 2012).

Table 2. Results of measuring the diameter of 3D printing filament from the extrusion process with ABS material and variations of oil empty palm fruit bunches cellulose.

Polymer Matrix	Variation OEPFB Cellulose	Average Diameter (mm)
ABS	0%	2.76
ABS	2%	2.76
ABS	4%	2.5
ABS	6%	2.56

Polymer Matrix	Variation OEPFB Cellulose	Average Diameter (mm)
ABS	10%	2.7
ABS	15 %	2.8
ABS	20%	2.72
ABS	30%	2.76

At higher cellulose loadings (10-30 wt.%), a modest increase in filament diameter was observed, reaching a maximum average value of 2.80 mm at 15 wt.% OPEFB. This trend can be attributed to an increase in melt viscosity resulting from higher filler content, which tends to reduce melt flowability and limit filament stretching after exiting the die. Similar effects have been reported in thermoplastic composites reinforced with natural fibers, where increased filler loading leads to higher resistance to flow and slight dimensional enlargement of extruded products (Ariel et al., 2016; Yap et al., 2024; Hao et al., 2021; Ahmad et al., 2006; Thomason & Rudeiros, 2018).

Nevertheless, the absence of a continuous or monotonic increase in diameter suggests that the selected processing parameters were effective in maintaining dimensional control throughout the extrusion process.

The relatively narrow variation in filament diameter across the entire composition range demonstrates that the ABS-OPEFB biocomposite system exhibited good dimensional stability. This observation indicates that the manual premixing step and controlled extrusion conditions promoted adequate dispersion of microfibrillated cellulose within the ABS matrix, thereby minimizing the formation of agglomerates that could otherwise disrupt melt flow and filament geometry. Previous studies have emphasized that uniform filler dispersion is a critical factor in achieving consistent filament dimensions in biocomposite extrusion (Angelopoulos et al., 2021; Mian et al., 2025; Tekinalp et al., 2014; Dananjaya et al., 2025).

Dimensional consistency is particularly important for filaments intended for fused deposition modeling (FDM), as fluctuations in filament diameter can lead to irregular material feeding, inconsistent extrusion rates, and defects in printed parts (Cardona et al., 2016; Chan et al., 2025; Ng et al., 2025). The results obtained in this study suggest that the incorporation of OPEFB cellulose up to 30 wt.% did not significantly compromise filament dimensional uniformity, supporting earlier findings that natural fiber-reinforced thermoplastic filaments can be successfully produced when appropriate processing conditions are applied.

The filament diameters produced in this study fall within a relatively narrow and controllable range, indicating that ABS-OPEFB biocomposite filaments with varying cellulose contents can be fabricated using a single-screw extrusion process without severe processing instability. Minor diameter fluctuations observed at specific filler loadings did not indicate issues such as excessive die swell, filament breakage, or void formation, which are commonly reported challenges in natural fiber reinforced filament production (Gupta et al., 2025; Khilji et al., 2023; Rajendran et al., 2021).

Furthermore, the stable filament diameter suggests that the selected extrusion temperature of 220 °C and extrusion speed of 850 were appropriate for balancing melt flow behavior and filler dispersion while limiting thermal degradation of both the ABS matrix and cellulose reinforcement. These findings demonstrate that OPEFB reinforced ABS filaments possess adequate dimensional characteristics for subsequent mechanical testing and potential application in FDM-based additive manufacturing.

The cross-sectional morphology of ABS filaments reinforced with oil palm empty fruit bunch (OPEFB) was investigated using Scanning Electron Microscopy (SEM) at magnifications of 260x and 1500x were shown in Figure 2. This analysis aimed to evaluate the influence of OPEFB weight fraction on the internal structure of the filaments, including filler dispersion, interfacial bonding, and the presence of defects such as voids or agglomerates. SEM images at 260x magnification (Figure 2 (a)) reveal that the ABS filament containing 2 wt.% OPEFB exhibits a relatively compact and homogeneous cross-sectional structure. The ABS matrix dominates the morphology, with OPEFB particles dispersed fairly uniformly throughout the polymer. Only a limited number of small voids are observed, indicating that the mixing and extrusion processes were effective at this low filler loading.

At a higher magnification of 1500x (Figure 2(b)), the interface between the ABS matrix and OPEFB particles appears continuous and well bonded. Most cellulose particles are fully embedded within the ABS matrix, with minimal interfacial gaps. This morphology suggests good interfacial adhesion, which is favorable for efficient stress transfer from the polymer matrix to the reinforcing phase. The relatively smooth fracture features further indicate that the incorporation of 2 wt.% OPEFB does not significantly compromise the structural integrity of the filament.

In contrast, SEM observations of the ABS filament containing 10 wt.% OPEFB at 260x magnification (Figure 2 (c)) show a noticeably rougher and more porous cross-sectional structure. A higher number of voids and larger cavities are evident, suggesting that the increased OPEFB content reduces the ability of the ABS matrix to adequately wet and encapsulate the filler particles. In addition, the distribution of OPEFB appears less uniform, indicating the onset of particle agglomeration.

Further examination at 1500× magnification (Figure 2 (d)) reveals a weakened interfacial region between the ABS matrix and the OPEFB particles. Several cellulose particles appear partially exposed, and signs of particle pull-out and microcracking are observed around the interfacial zones. These features indicate reduced interfacial compatibility at higher filler loadings, leading to poorer bonding and increased structural heterogeneity within the filament.

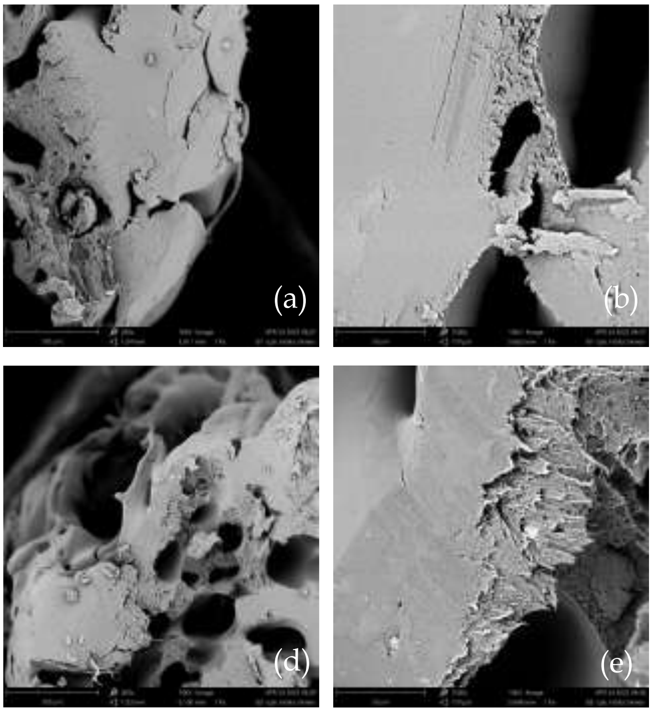

Figure 2. SEM micrographs of ABS-based filaments cross-sectional with varying oil palm empty fruit bunch (OPEFB) (a) 2% OPEFB magnifications 260x; (b) 2% OPEFB magnifications 1500x; (d) 10% OPEFB magnifications 260x; (e) 10% OPEFB magnifications 1500x.

A comparative analysis of the cross-sectional morphologies of ABS filaments containing 2 wt.% and 10 wt.% OPEFB demonstrates that increasing the filler content has a significant impact on the internal structure of the biocomposite filaments. At low OPEFB content (2 wt.%), the filler is well dispersed and adequately bonded to the ABS matrix, resulting in a dense and relatively uniform structure. Conversely, at higher OPEFB content (10 wt.%), intensified filler-filler interactions and limited matrix wetting lead to void formation, agglomeration, and interfacial debonding.

These morphological characteristics are closely associated with the mechanical performance and processability of the filaments in Fused Deposition Modeling (FDM). The porous structure and weak interfacial bonding observed in filaments with 10 wt.% OPEFB may adversely affect tensile strength, elongation, and extrusion stability during 3D printing. Therefore, the SEM results suggest that lower OPEFB loadings are more favorable for producing ABS-based biocomposite filaments with improved structural integrity and reliable performance in additive manufacturing applications.

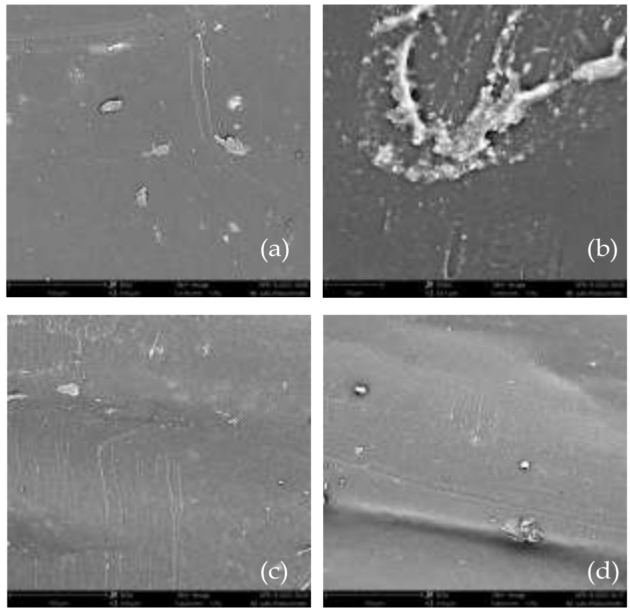

Figure 3. SEM micrographs of ABS-based filaments surface with varying oil palm empty fruit bunch (OPEFB) (a) 0% OPEFB magnifications 850x; (b) 0% OPEFB magnifications 5000x; (d) 30% OPEFB magnifications 850x; (e) 30% OPEFB magnifications 5000x.

The surface morphology of ABS filaments, both unreinforced and reinforced with oil palm empty fruit bunch (OPEFB), was examined using Scanning Electron Microscopy (SEM) at magnifications of 850x and 5000x were shown in Figure 3. This characterization was conducted to evaluate the influence of OPEFB incorporation on surface topography and its implications for filament quality and performance in Fused Deposition Modeling (FDM) applications. SEM images at 850x magnification (Figure 3(a)) show that the surface of the neat ABS filament (0 wt.% OPEFB) is relatively smooth and homogeneous. The surface is dominated by the ABS matrix without the presence of filler particles, and only minor surface irregularities, such as shallow grooves or scratches, are observed. These features are likely attributed to the extrusion and cooling processes rather than material inhomogeneity. The absence of agglomerates or foreign particles indicates stable melt flow during filament extrusion.

At 5000x magnification (Figure 3(b)), the neat ABS surface exhibits a more detailed yet still continuous and compact morphology. No significant microcracks or open pores are detected, confirming the good flowability and surface-forming ability of ABS. Such surface characteristics are essential for ensuring dimensional consistency and smooth feeding behavior during FDM processing.

In contrast, SEM images of the filament containing 30 wt.% OPEFB at 850x magnification (Figure 3(c)) reveal a rougher and less uniform surface. Pronounced surface undulations, protrusions, and depressions are evident, indicating that the high OPEFB loading significantly affects the melt flow behavior of the ABS matrix during extrusion. These surface irregularities suggest that the filament surface could not be formed optimally under high filler content.

Further observations at 5000x magnification (Figure 3 (d)) highlight the microstructural effects of excessive OPEFB incorporation. Exposed or near-surface OPEFB particles are clearly visible, along with layered surface textures and indications of microcracking. Some filler particles appear insufficiently encapsulated by the ABS matrix, reflecting limited matrix wetting and reduced interfacial compatibility at high OPEFB concentrations. The heterogeneous surface morphology also suggests the occurrence of filler agglomeration.

A comparison between the surface morphologies of neat ABS (0 wt.% OPEFB) and ABS reinforced with 30 wt.% OPEFB demonstrates that increasing the OPEFB content markedly alters the surface characteristics of the filaments. While neat ABS produces a smooth and uniform surface, the addition of OPEFB at 30 wt.% results in increased surface roughness, heterogeneity, and the emergence of filler particles at the surface.

These morphological changes may adversely affect filament quality and 3D printing performance, particularly in terms of filament feeding stability, interlayer adhesion, and surface finish of printed parts. Excessive surface roughness and exposed fillers can increase friction during extrusion and compromise printing consistency. Therefore, the SEM surface analysis indicates that very high OPEFB loadings are unfavorable for producing ABS-based biocomposite filaments with optimal surface quality for additive manufacturing applications.

Fourier Transform Infrared (FTIR) spectroscopy was employed to investigate the chemical structure and functional group interactions (Kacem et al., 2025; Berthomieu & Hienerwadel., 2009) of the ABS-based biocomposite filaments reinforced with varying contents of OPEFB microfibrillated cellulose (MFC). FTIR analysis was conducted to evaluate the effect of OPEFB cellulose incorporation on the molecular characteristics of the ABS matrix and to identify possible interactions between the polymer and the lignocellulosic reinforcement. The FTIR spectrum are shown in Figure 4.

The FTIR spectrum of the neat ABS filament (0 wt.% OPEFB) exhibits characteristic absorption bands corresponding to the chemical structure of ABS (Figure 4(a)). The absorption peak observed at approximately 2235 cm^{-1} is attributed to the stretching vibration of the nitrile group (C≡N) originating from the acrylonitrile component, which is a distinctive feature of ABS polymers. Peaks located around 2920–2850 cm^{-1} correspond to aliphatic C–H stretching vibrations from the butadiene phase, while the bands near 1600 cm^{-1} and 1490 cm^{-1} are associated with aromatic C=C stretching of the styrene units. Additionally, out-of-plane bending vibrations of aromatic C–H groups appear in the region of 700–760 cm^{-1}. These absorption bands confirm the chemical integrity of the ABS matrix prior to reinforcement.

Upon the incorporation of 2 wt.% OPEFB MFC fibers, the FTIR spectrum (Figure 4(b)) reveals the appearance of a broad absorption band in the region of 3300–3400 cm^{-1}, which is assigned to the O–H stretching vibration characteristic of hydroxyl groups present in cellulose. This indicates the successful introduction of lignocellulosic material into the ABS matrix. The characteristic ABS peaks, particularly the nitrile band at ~2235 cm^{-1}, remain clearly visible, suggesting that the polymer backbone remains chemically stable. A slight increase in intensity in the 1000–1150 cm^{-1} region, associated with C–O stretching vibrations of cellulose, is also observed.

At an OPEFB content of 10 wt.%, the FTIR spectrum (Figure 4(c)) shows a more pronounced and broadened O–H stretching band, indicating an increased contribution of cellulose within the composite structure. The absorption bands corresponding to C–O and C–O–C stretching vibrations in the region of 1000–1150 cm^{-1} become more intense, reflecting the higher concentration of polysaccharide components derived from OPEFB fibers. Meanwhile, the relative intensity of ABS characteristic peaks, such as the C–H and C≡N vibrations, slightly decreases due to the increased presence of cellulose. This suggests enhanced physical interaction, such as hydrogen bonding, between the hydroxyl groups of cellulose and the ABS matrix.

For the biocomposite filament containing 30 wt.% OPEFB cellulose, the FTIR spectrum (Figure 4(d)) is dominated by absorption bands associated with lignocellulosic materials. The broad O-H stretching band becomes significantly more intense, while the C-O stretching vibrations are strongly pronounced. The characteristic ABS peaks are still detectable but appear relatively weaker due to the high cellulose content. Importantly, no new absorption bands are observed across the spectra, indicating that no chemical reactions or covalent bond formation occurred between the ABS matrix and the OPEFB fibers during the extrusion process.

The FTIR results confirm that the incorporation of OPEFB microfibrillated cellulose into the ABS matrix does not alter the fundamental chemical structure of the polymer. The absence of new functional groups suggests that the interaction between ABS and OPEFB fibers is primarily physical in nature, dominated by hydrogen bonding and interfacial interactions rather than chemical bonding. The gradual increase in hydroxyl- and cellulose-related absorption bands with increasing OPEFB content demonstrates the successful and controlled incorporation of the natural reinforcement into the biocomposite filaments.

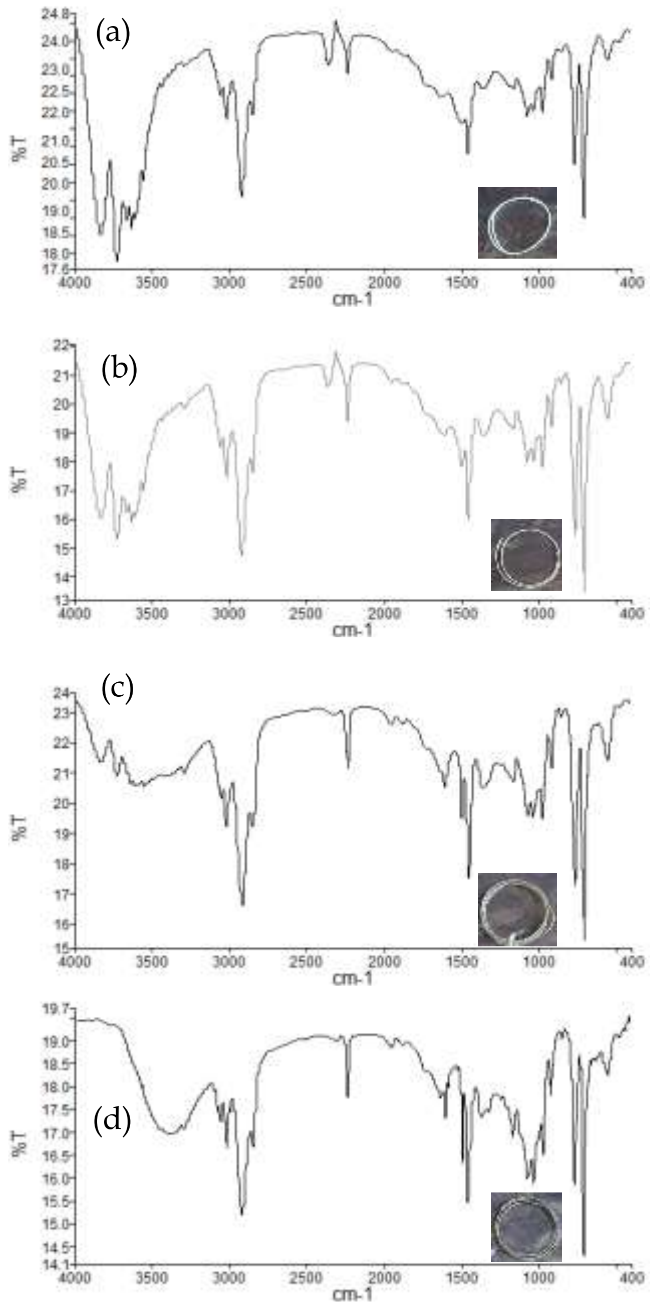

Figure 4. FTIR spectra of filaments fabricated from ABS reinforced with oil palm empty fruit bunch (OPEFB) fibers at contents of(a) 0%; (b) 2%; (c) 10% and (d) 30%.

Overall, the FTIR analysis supports the effectiveness of the selected processing parameters namely extrusion at 220 °C using a single-screw extruder in preserving the chemical integrity of both ABS and OPEFB cellulose, while enabling the fabrication of biocomposite filaments suitable for fused deposition modeling (FDM) applications.

Conclusion

This study confirms that ABS-based biocomposite filaments reinforced with OPEFB microfibrillated cellulose can be successfully fabricated via single-screw extrusion, maintaining stable and controllable dimensions up to 30 wt.% filler content. However, optimal performance is achieved at low to moderate OPEFB loadings, where uniform dispersion and strong interfacial bonding produce dense, homogeneous filaments. Higher filler contents lead to agglomeration, increased porosity, and surface roughness, which may reduce filament quality and FDM processability. FTIR results indicate that interactions between ABS and OPEFB are primarily physical. Overall, OPEFB cellulose shows strong potential as a sustainable reinforcing material when incorporated at appropriate concentrations.

Acknowledgments
Thank you for the Grant Riset Sawit research grant from the Plantation Fund Management Agency (BPDP), Republic of Indonesia No. Contract PRJ-142/DPKS/2024

Author Contributions
Handika Dany Rahmayanti contributed to the conceptualization, methodology development, formal analysis, supervision, and project administration of the study. Rakha Amanta Pradipa was responsible for conducting the experimental work, data curation, visualization, and preparation of the original draft manuscript. Nurul Akmalia contributed to result validation as well as manuscript review and editing to enhance clarity and communication quality. Haryasena Gusti Andayu contributed from an industrial practitioner perspective by providing insights related to industrial relevance, practical feasibility, and application considerations of the developed biocomposite filaments. All authors have read and agreed to the published version of the manuscript.

Funding
This research was funded by Plantation Fund Management Agency (BPDP), Republic of Indonesia No. Contract PRJ-142/DPKS/2024.

Conflicts of Interest
The authors declare no conflict of interest.

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