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A Review on Mechanical Properties and Process Parameter Optimization of PLA and ABS Materials in Fused Filament Fabrication

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Abstract— Fused Filament Fabrication (FFF), also known as Fused Deposition Modeling (FDM), has become one of the most widely used additive manufacturing techniques for producing polymer-based components. Among the available thermoplastic materials, Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) are extensively used because of their favorable mechanical characteristics, ease of processing, and cost-effectiveness. However, the mechanical behavior and surface quality of FFF printed parts are strongly influenced by process parameters such as infill pattern, infill density, layer height, raster angle, printing speed, and extrusion temperature. This review paper summarizes recent research findings related to the influence of these parameters on PLA and ABS printed components. The paper discusses the effects of infill geometry, layer thickness, interlayer bonding, reinforcement techniques, and optimization approaches on tensile strength, stiffness, dimensional accuracy, and surface finish. Additionally, computational methods, finite element analysis, and AI-based optimization techniques used in modern additive manufacturing are reviewed. The literature consistently indicates that optimized infill patterns such as honeycomb, gyroid, and hexagonal structures, combined with infill densities between 80–90% and layer heights between 0.1–0.2 mm, provide improved mechanical performance and better structural integrity. The review also highlights future research opportunities in sustainable materials, hybrid reinforcement, and intelligent process optimization for FFF printed PLA and ABS structures.

Keywords— Fused Filament Fabrication(FFF), PLA, ABS, Infill Pattern, Infill Density, Layer Height, Mechanical Properties, Additive Manufacturing.

I. INTRODUCTION

Additive Manufacturing (AM) has revolutionized the manufacturing sector by enabling the production of complex geometries directly from digital models with minimal material waste. Among various AM technologies, Fused Filament Fabrication (FFF) has gained considerable popularity because of its affordability, simplicity, and capability to manufacture customized components. FFF technology works by melting thermoplastic filament materials and depositing them layer by layer to build three-dimensional structures.

Materials such as Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) are commonly used in FFF because of their excellent printability and versatile engineering applications. PLA is biodegradable, environmentally friendly, and provides high stiffness with good surface finish. ABS, on the other hand, offers superior toughness, impact resistance, and thermal stability, making it suitable for industrial and functional applications.

Although FFF offers significant advantages, the printed components often exhibit anisotropic mechanical behavior due to layer-wise deposition and weak interlayer bonding. The final properties of printed parts are influenced by multiple process parameters including layer height, infill density, infill pattern, raster angle, print speed, extrusion temperature, and material characteristics.

The main objective of this review paper is to analyse and summarize the influence of different process parameters on the mechanical properties and surface quality of PLA and ABS printed parts.

II. EFFECT OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES

The mechanical behaviour of FFF printed parts is highly dependent on process parameter selection. Researchers have investigated various combinations of parameters to improve tensile strength, flexural strength, dimensional accuracy, and surface finish.

Chacón et al. (2017) reported that raster orientation and layer thickness significantly affect the tensile behaviour of PLA structures. The study concluded that thinner layers improve bonding quality and dimensional accuracy, while unsuitable raster orientation weakens the structure due to anisotropic stress distribution.

Similarly, Ahn et al. (2002), one of the earliest studies on ABS materials, demonstrated that FDM printed ABS exhibits anisotropic mechanical behaviour because filaments are deposited directionally during printing. The bonding quality between adjacent layers was identified as a key factor controlling stiffness and tensile strength.

Recent work by Kumar et al. (2024) confirmed that tensile strength and elongation of PLA parts are highly influenced by layer thickness, infill density, and printing orientation. Ahmad et al. (2023) also emphasized that layer height and raster angle are dominant parameters affecting ABS mechanical performance and identified optimized conditions for minimizing anisotropic effects.

Hamoud et al. (2024) further demonstrated that optimized combinations of layer height, infill density, and printing speed significantly improve tensile and flexural properties in PLA composite structures.

Overall, the literature clearly indicates that process parameter optimization is essential for improving the mechanical reliability and dimensional stability of FFF printed parts.

III. EFFECT OF INFILL PATTERN ON MECHANICAL PROPERTIES

Among all process parameters, infill pattern plays a critical role in controlling stress distribution, stiffness, load transfer, and anisotropic behaviour in printed structures.

Bonada et al. (2021) observed that grid and linear raster configurations often produce anisotropic mechanical properties because of directional filament deposition. However, using a 45° raster orientation improves isotropy and distributes stresses more uniformly throughout the structure.

Ganeshkumar et al. (2022) reported that hexagonal infill patterns provide superior tensile strength due to efficient stress distribution characteristics. Moradi et al. (2021) similarly confirmed that triangular and honeycomb structures enhance tensile strength and stiffness in PLA components.

Several recent studies have highlighted the advantages of advanced infill geometries. Patel et al. (2024) compared different infill patterns in PLA and ABS parts and concluded that honeycomb and gyroid structures provide better structural stability and energy absorption than simple line patterns. Wang et al. (2023) also demonstrated that gyroid and honeycomb patterns reduce stress concentration and improve load distribution.

Maskery et al. (2023) studied gyroid lattice structures and reported superior stiffness-to-weight ratio compared to conventional infill patterns. Turaka et al. (2024) extended these findings to carbon fiber reinforced ABS composites and showed that honeycomb infill at 80% density significantly improves tensile, compressive, and flexural strength because of enhanced interlayer bonding and reduced porosity.

Yankin et al. (2023) applied Taguchi optimization techniques and identified that a tri-hexagonal infill pattern with 100% infill density and 65 mm/s printing speed produced maximum tensile strength in ABS specimens.

Hybrid infill approaches have also attracted attention. Lalegani Dezaki and Ariffin (2020) demonstrated that combining honeycomb and grid structures improves tensile behavior and surface quality beyond what can be achieved using a single infill geometry.

Collectively, these studies suggest that honeycomb, gyroid, hexagonal, concentric, and hybrid infill patterns are among the most effective structures for achieving improved mechanical strength and structural stability.

TABLE 1
COMPARISON OF INFILL PATTERNS

Infill Pattern	Mechanical Behaviour	Advantages	Limitations
Line Pattern	Directional strength	Simple and fast printing	High anisotropy
Grid Pattern	Moderate stiffness	Easy manufacturing	Uneven stress distribution
Honeycomb Pattern	High strength and stiffness	Excellent load distribution	Slightly longer print time

IV. INFLUENCE OF INFILL DENSITY

Infill density directly controls the internal material distribution of FFF printed parts and strongly influences tensile strength, stiffness, load-bearing capacity, printing time, and material consumption.

Karad et al. (2023) experimentally showed that increasing ABS infill density from 25% to fully solid improved tensile and flexural strength by nearly 40–70%. The study also indicated that triangular and line patterns outperform several conventional geometries in terms of load-bearing capability.

Agrawal et al. (2023) reported that an 80% concentric infill pattern combined with a 100 µm layer height significantly enhanced tensile and impact resistance in ABS specimens. Similarly, Mayandi et al. (2024) concluded that increasing infill density reduces internal voids and improves stress transfer in PLA composites.

Singh et al. (2022) investigated lightweight FDM structures and observed that mechanical strength increases rapidly up to approximately 80% infill density. Beyond this level, the improvement becomes comparatively smaller relative to the additional material consumption and print time.

Racz and Dudescu (2022) used finite element analysis to study tensile behavior at different infill densities ranging from 20% to 100%. Their model predicted substantial increases in stiffness and strength up to nearly 80% density, after which the improvements became marginal.

Karkalos et al. (2024) confirmed through FEM simulations that higher infill densities improve load-bearing capability while maintaining relatively low structural weight in honeycomb ASA structures. Turaka et al. (2024) also concluded that approximately 80% infill density provides the best balance between strength and material efficiency for ABS and CF-ABS composites.

Overall, most researchers recommend infill densities between 80–90% for achieving an effective compromise between mechanical performance, material usage, and printing efficiency.

TABLE II
EFFECT OF INFILL DENSITY ON MECHANICAL PROPERTIES

Study	Material	Infill Density	Outcome
Karad et al. (2023)	ABS	25–100%	Strength increased by 40–70%
Agrawal et al. (2023)	ABS	80%	Improved tensile and impact strength
Mayandi et al. (2024)	PLA	Increased	Reduced voids and improved strength
Racz and Dudescu	ABS	20–100%	Stiffness increased up to 80% density
Turaka et al. (2024)	CF-ABS	80%	Maximum tensile and compressive

V. EFFECT OF LAYER HEIGHT AND INTERLAYER BONDING

Layer height significantly affects interlayer adhesion, surface finish, dimensional accuracy, thermal diffusion, and anisotropic behaviour in FFF printed parts.

Chacón et al. (2017) found that thinner layers improve bonding quality and dimensional precision in PLA structures. Bonada et al. (2021) and Ganeshkumar et al. (2022) similarly observed that reduced layer height decreases anisotropic behaviour and improves structural uniformity.

Mazlan et al. (2023) experimentally verified that lower layer heights combined with higher wall counts improve structural strength and surface quality. Akin et al. (2025) investigated the combined effects of layer height, infill density, and epoxy infiltration and reported that the highest tensile strength was achieved at a 0.1 mm layer height.

Foundational work by Bellehumeur et al. (2004) demonstrated that proper thermal diffusion between polymer filaments is essential for achieving strong interlayer bonding. Their model explained how insufficient heat transfer weakens adhesion between adjacent layers and reduces overall mechanical integrity.

Torrado Perez et al. (2014) analysed fracture surfaces of ABS specimens and reported that poor interlayer fusion and internal void formation are major reasons for crack initiation and premature failure.

Zhang et al. (2023) reviewed anisotropy and interlayer bonding in FDM printed structures and concluded that weak layer adhesion remains one of the primary limitations of FFF technology. The study emphasized the importance of optimizing raster angle, extrusion temperature, and layer thickness to minimize anisotropic effects.

Most literature therefore recommends layer heights between 0.1–0.2 mm for achieving an effective balance between mechanical strength, surface quality, and printing efficiency.

TABLE III
EFFECT OF LAYER HEIGHT ON MECHANICAL PROPERTIEs

	Material	Layer Height	Major Observation
Chacón et al. (2017)	PLA	0.1–0.3 mm	Lower layer height improved bonding and accuracy
Akin et al. (2025)	ABS	0.1 mm	Maximum tensile strength observed
Mazlan et al. (2023)	PLA/ABS	Reduced layer	Improved structural uniformity
Ahmad et al. (2023)	ABS	Variable	Layer height strongly influenced tensile strength

VI. CONCLUSION

The reviewed literature clearly demonstrates that the mechanical performance and surface quality of PLA and ABS parts manufactured using Fused Filament Fabrication are strongly influenced by process parameters such as infill pattern, infill density, layer height, raster orientation, and material selection.

Honeycomb, gyroid, concentric, hexagonal, and hybrid infill patterns consistently provide superior stress distribution, stiffness, and tensile strength compared to conventional line patterns. Increasing infill density generally improves load-bearing capability and structural integrity, with most studies recommending densities between 80–90% for optimal performance.

Similarly, thinner layer heights improve dimensional accuracy, interlayer bonding, and surface finish, although proper thermal fusion between adjacent layers remains essential for achieving high mechanical strength. Reinforcement techniques such as fiber embedding, epoxy infiltration, and multi-material printing further enhance structural reliability and toughness.

Recent developments involving finite element modelling, AI-based optimization, and computational prediction methods are helping researchers identify optimal process conditions while reducing experimental cost and testing time. Future research should focus on hybrid reinforcement strategies, sustainable material development, and intelligent optimization systems for achieving lightweight, high-strength, and reliable FFF printed structures using PLA and ABS materials.

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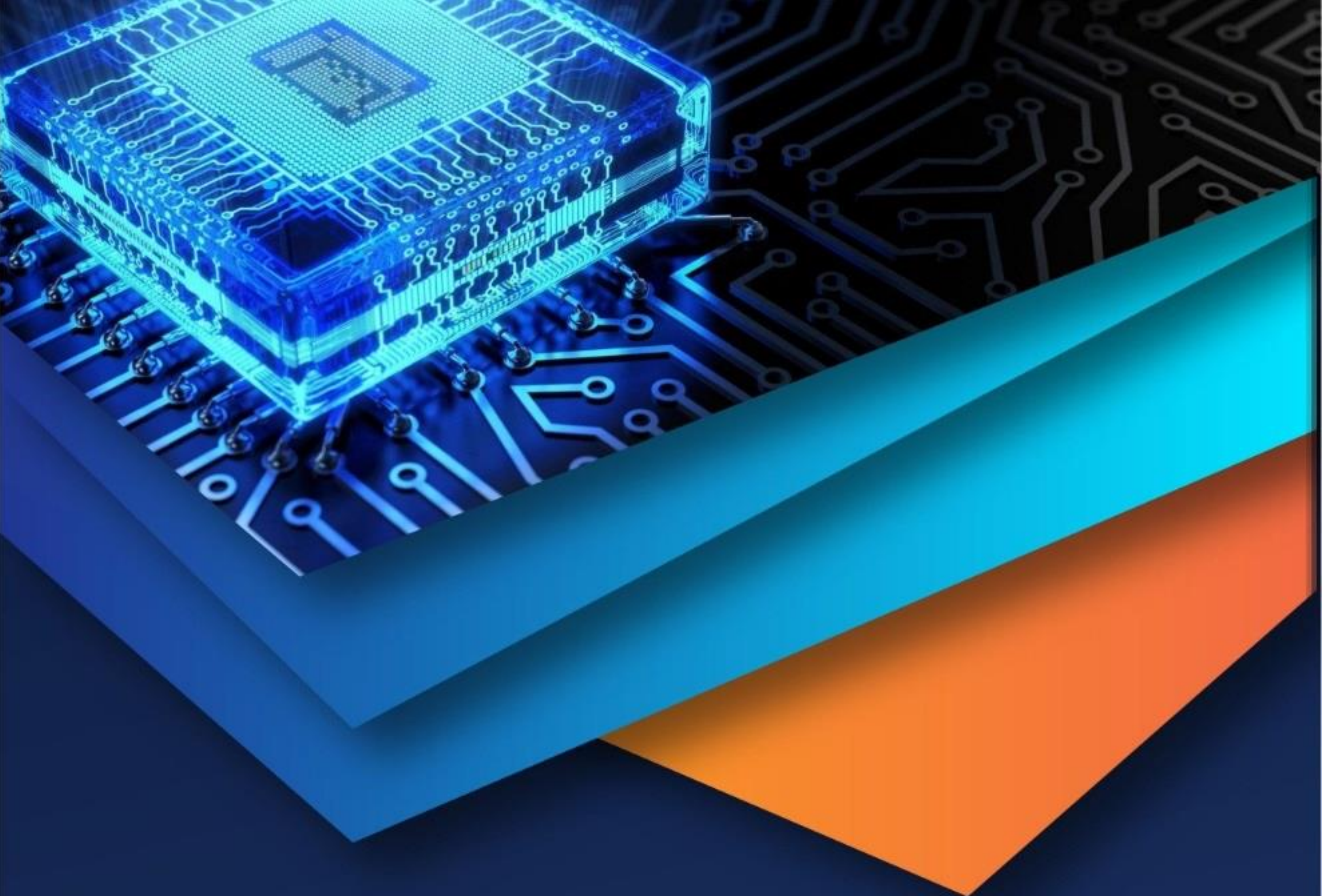

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