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A Review on Mechanical and Process Characteristics of PETG and ASA Materials in FDM 3D Printing

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Abstract: ***Fused Deposition Modeling (FDM) has emerged as one of the most widely used additive manufacturing technologies due to its cost-effectiveness, material versatility, and ease of operation. The mechanical performance of FDM printed parts is strongly influenced by process parameters such as infill density, infill pattern, raster angle, layer thickness, printing orientation, and post-processing conditions. This review paper presents a comprehensive analysis of recent studies focusing on the tensile, flexural, compressive, and fatigue behavior of commonly used thermoplastic materials including PLA, PETG, ASA, and carbon-fiber reinforced PETG. The review emphasizes the influence of infill geometry, layer height, and material combinations on anisotropy, strength, and structural integrity of printed components. Comparative findings from experimental investigations and finite element simulations are summarized to identify optimal process conditions for enhanced mechanical performance. The paper also highlights current research gaps and future directions in multi-material printing, reinforcement strategies, and parameter optimization.***

Keywords: FDM, PETG, ASA, additive manufacturing, infill density, raster angle, mechanical properties, process optimization.

I. INTRODUCTION

Additive Manufacturing (AM), commonly known as 3D printing, has revolutionized modern manufacturing by enabling rapid prototyping and customized product development. Among various AM technologies, Fused Deposition Modeling (FDM) is the most popular due to its affordability, ease of operation, and accessibility in industrial as well as academic applications. The FDM process builds components layer by layer through controlled extrusion of thermoplastic filaments, allowing the production of complex geometries with reduced material waste and shorter manufacturing time. This capability has made FDM a widely adopted technique in automotive, aerospace, medical, and consumer product sectors.

PETG and ASA are increasingly preferred in engineering applications because they offer improved mechanical strength, environmental resistance, and dimensional stability compared to traditional PLA materials. PETG provides excellent toughness, flexibility, and chemical resistance, making it suitable for functional components requiring durability and impact resistance. ASA exhibits superior UV resistance, weather stability, and thermal performance, which makes it highly suitable for outdoor and high-temperature applications. Due to these advantages, both materials are gaining attention for the production of lightweight and high-performance engineering components.

Several researchers have investigated how process parameters influence the performance of PETG and ASA printed parts. Parameters such as infill density, raster angle, layer thickness, nozzle temperature, bed temperature, print speed, and printing orientation directly affect bonding quality and internal structure. These parameters significantly influence mechanical properties such as tensile strength, impact strength, hardness, surface finish, and dimensional accuracy. Improper parameter selection may lead to poor layer adhesion, internal void formation, and reduced part strength. Therefore, optimization of process parameters is essential to achieve reliable and repeatable product quality.

Recent studies also highlight the importance of comparing different infill patterns and thermal conditions to improve mechanical performance and minimize material consumption. Researchers have applied statistical methods such as Taguchi analysis and Response Surface Methodology (RSM) to identify optimal parameter combinations. Such optimization techniques help in reducing experimental trials while improving printing efficiency and product performance. This review aims to summarize the recent developments in PETG and ASA-based FDM printing and provide a comparative understanding of their mechanical and structural behaviour. The findings of this review can support future research in selecting suitable materials and process parameters for engineering applications using FDM technology.

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Overview of PETG and ASA Materials

1) PETG Material

PETG is a glycol-modified polyester material widely used in FDM printing because of its:
High impact strength
Good layer adhesion
Excellent chemical resistance
Low shrinkage
Better flexibility than PLA
PETG is suitable for functional prototypes, medical devices, and mechanical components.

2) ASA Material

ASA is a thermoplastic polymer similar to ABS but with improved weather resistance. Important characteristics include:
High UV resistance
Better outdoor durability
Good thermal stability
Improved surface finish
High impact resistance
ASA is commonly used in automotive, outdoor, and industrial applications.

II. INFLUENCE OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES

1) Infill Density

Infill density significantly affects the strength and stiffness of FDM printed parts. Abdelilah El Omari et al. (2024) reported that increasing infill density improves tensile and compressive properties due to reduced internal voids. Adnan Pandžić and Damir Hodžić (2022) observed that higher infill density enhances tensile strength in PLA, PETG, and ASA specimens. However, increased density also increases printing time and material consumption. Kumar et al. (2025) demonstrated that PETG specimens printed with 100% infill density exhibited superior fatigue resistance and hardness compared to lower densities.

Higher infill density improves the internal bonding between deposited layers, resulting in better load transfer throughout the printed component. This enhanced bonding reduces the possibility of crack initiation and improves resistance to deformation under mechanical loading. In addition to tensile and compressive strength, infill density also contributes to better impact performance and dimensional stability of printed parts. Components manufactured with lower infill percentages may show reduced weight and lower material cost, but they often experience greater internal porosity and lower structural integrity. The selection of an appropriate infill density therefore becomes important in balancing mechanical performance with production efficiency. For engineering and functional applications where high strength and durability are required, medium to high infill densities are generally preferred. Recent studies also indicate that the influence of infill density can vary depending on the material type and infill pattern used during printing, making it an important parameter for process optimization in FDM manufacturing.

TABLE I
EFFECT OF INFILL DENSITY ON MECHANICAL PROPERTIES

Author	Material	Infill Density	Major Findings
El Omari et al. (2024)	PLA/PETG	20–100%	Strength increases with density
Pandžić & Hodžić	PLA, PETG, ASA	Variable	Improved tensile properties at higher density
Kumar et al. (2025)	PETG	Multiple	Better fatigue and hardness at high density
Daly et al. (2024)	CF-PETG	25–100%	Increased stiffness with density

2) Infill Pattern

The internal geometry strongly influences stress distribution and load transfer.

Kumaresan et al. (2025) investigated concentric and cubic infill patterns in PETG and found that concentric structures provided improved tensile strength due to continuous load paths.

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Taresh et al. (2023) compared grid, octet, triangle, and hexagon infill patterns and concluded that hexagonal and octet structures achieved superior tensile performance.

Lopes et al. (2023) evaluated twelve infill geometries and reported that gyroid and honeycomb structures offered improved mechanical efficiency with reduced weight.

TABLE II
COMPARISON OF DIFFERENT INFILL PATTERNS

Infill Pattern	Mechanical Properties	Key Characteristics
Grid	Moderate strength	Simple structure
Honeycomb	High strength-to-weight ratio	Good energy absorption
Gyroid	Uniform stress distribution	Lightweight
Concentric	Improved tensile behavior	Continuous load path
Hexagon	High stiffness	Efficient load transfer
Cubic	Balanced isotropic properties	Suitable for general

3) Layer Thickness

Layer thickness affects surface finish, interlayer bonding, and anisotropy in FDM printed parts. Stojković et al. (2023) observed that lower layer heights improve tensile strength because of stronger interlayer adhesion. Similar observations were reported by Massimo Lanzotti et al. (2015). Nanche and Ladgaonkar (2025) found that reducing layer thickness from 0.3 mm to 0.1 mm significantly improved tensile properties in PLA and PETG.

Lower layer thickness allows better fusion between adjacent layers and reduces the formation of voids within the printed structure. It also improves surface finish and dimensional accuracy due to finer material deposition during the printing process. However, decreasing layer thickness increases printing time and may reduce production efficiency for larger components. Therefore, proper selection of layer thickness is essential to achieve an effective balance between mechanical strength, surface quality, and manufacturing time in FDM printed parts.

TABLE III
INFLUENCE OF LAYER THICKNESS

Layer Thickness	Effect on Mechanical Properties
Lower Thickness (0.1 mm)	Better bonding and tensile strength
Medium Thickness (0.2 mm)	Balanced print quality and speed
Higher Thickness (0.3 mm)	Faster printing but reduced strength

4) Raster Angle and Build Orientation

Raster angle determines the direction of filament deposition and strongly influences anisotropic behavior.

Ratiu (2022) reported that 45° raster orientation provides better isotropic mechanical properties compared to 0° and 90° orientations. Kumaresan et al. (2025) confirmed that alternating raster angles improved load distribution and reduced crack propagation in PETG specimens.

Yap et al. (2019) used finite element analysis to predict anisotropic behavior in ASA structures and validated the influence of print orientation on load-bearing performance.

III. FINITE ELEMENT ANALYSIS IN FDM STUDIES

Finite Element Modeling (FEM) has become an important tool for predicting the behavior of FDM printed structures.

Karkalos et al. (2024) performed FEM-based compression analysis on ASA honeycomb structures and demonstrated accurate prediction of deformation behaviour.

Yap et al. (2019) developed anisotropic FEM models for ASA materials and validated them experimentally.

These studies indicate that FEM can effectively reduce experimental cost and optimize process parameters before fabrication.

IV. CONCLUSION

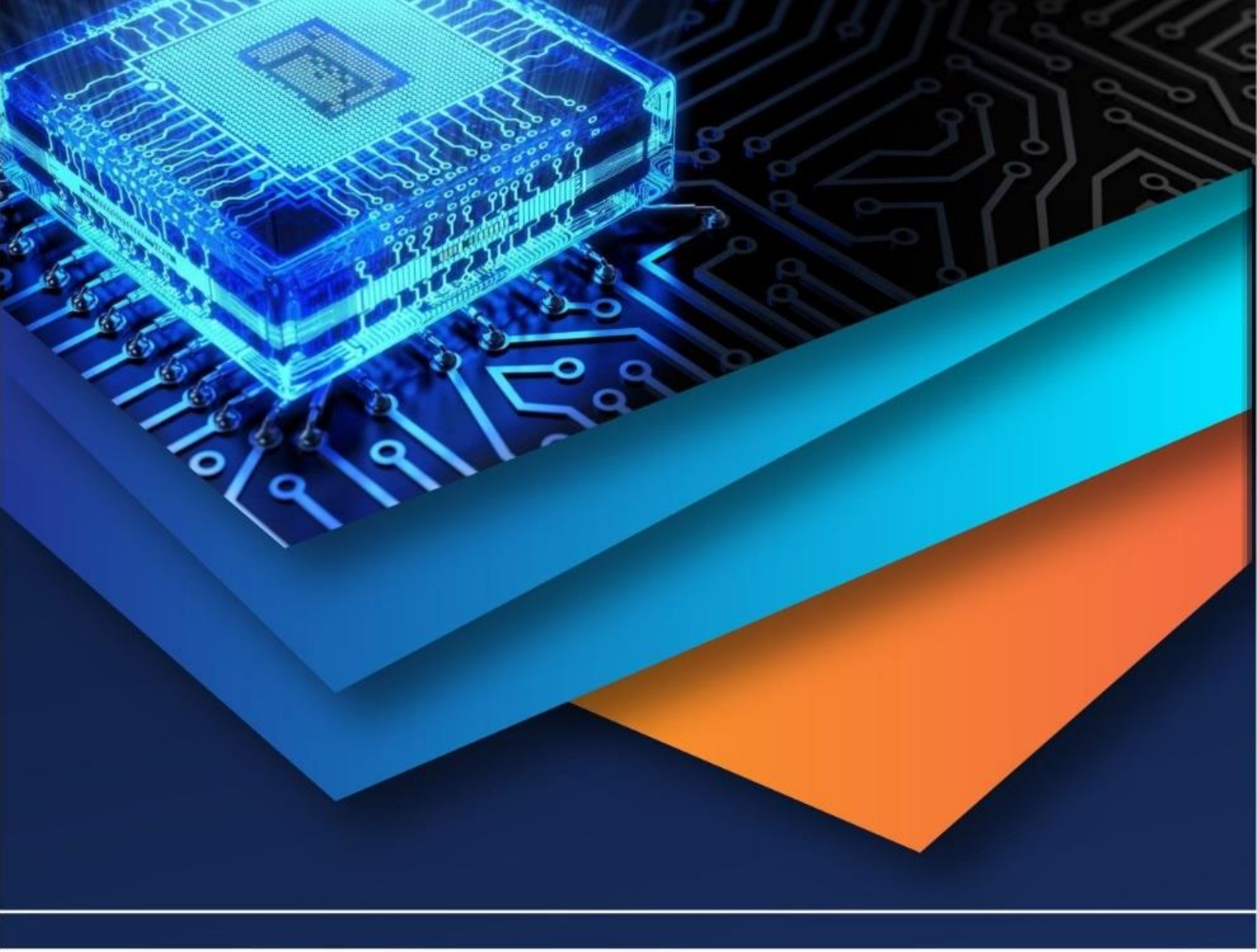
The mechanical properties of FDM printed components are strongly dependent on process parameters such as infill density, infill pattern, raster angle, layer thickness, and printing orientation. Higher infill density generally improves strength and stiffness but increases printing time and material usage. Honeycomb, gyroid, and concentric infill structures demonstrate superior stress distribution and mechanical efficiency. Lower layer thickness enhances interlayer adhesion and tensile strength.

Among the reviewed materials, PETG offers balanced mechanical performance and printability, while ASA provides superior environmental resistance. Carbon-fiber reinforced PETG significantly improves stiffness and structural stability for engineering applications.

Finite element analysis has emerged as an effective tool for predicting anisotropic behavior and optimizing FDM structures. Future work should focus on multi-material printing, fatigue analysis, machine learning-based optimization, and sustainable composite development to further improve the performance of FDM printed components.

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