100 µm ve 200 µm KATMAN KALINLIĞI ile BASKI YÖNELİMİNİN 3B FDM POLİMERLERİNİN MEKANİK DAVRANIŞI ÜZERİNDEKİ ETKİSİ

Dr.Öğr. Üyesi, Murat ŞEN[1]/ Dr.Öğr. Üyesi, Emre AKIN[2]
[1]Marmara Üniversitesi, Teknoloji Fakültesi, Makine Mühendisliği, murat.sen@marmara.edu.tr, https://orcid.org/0000-0003-2216-245X
[2]Marmara Üniversitesi, Teknoloji Fakültesi, Metalurji ve Malzeme Mühendisliği, emre.akin@marmara.edu.tr, https://orcid.org/0000-0003-2067-1488

Özet

Bu çalışma, Katmanlı İmalat (Fused Deposition Modeling, FDM) yöntemiyle üretilen polimer malzemelerin çekme performansı üzerindeki katman kalınlığı ve baskı yöneliminin etkisini incelemektedir. ABS, ASA, PETG, Tough PLA ve Hyper PLA olmak üzere beş ticari filament, yatay yönde 100 µm ve 200 µm katman kalınlıklarında basılmıştır. Ayrıca, dikey yönde basılmış ek bir Tough PLA numunesi, baskı yöneliminin etkisini değerlendirmek amacıyla üretilmiştir. Sonuçlar, katman kalınlığının mekanik davranış üzerinde önemli bir etkiye sahip olduğunu göstermektedir. Genel olarak, 100 µm katman kalınlığında basılan numuneler, 200 µm kalınlıktaki numunelere göre daha yüksek nihai çekme dayanımı (UTS) sergilemiş ve bu durum daha güçlü katmanlar arası bağlanma ve gelişmiş filament kaynaşmasına işaret etmiştir. En yüksek çekme dayanımı, 100 µm Tough PLA numunesinde (52.8 MPa) elde edilmiş, bunu Hyper PLA ve PETG takip etmiştir; ABS ise en düşük değeri (34.7 MPa) göstermiştir. Dikkat çekici olarak, ABS malzemesinde ters bir eğilim gözlenmiş; 200 µm numunesi, daha iyi katman kaynaşması ve azalmış artık gerilmeler nedeniyle biraz daha yüksek dayanım göstermiştir. Dikey yönde basılan Tough PLA numunesinde ise belirgin bir dayanım düşüşü (18.3 MPa) meydana gelmiş, bu da katman arayüzlerine dik yükleme yönünün mekanik performans üzerinde olumsuz etkisini doğrulamıştır.

Anahtar Kelimeler: Katmanlı imalat, FDM 3B baskı, Katman kalınlığı, Baskı yönelimi, Çekme dayanımı

INFLUENCE of 100 µm AND 200 µm LAYER THICKNESS and PRINTING DIRECTION ON THE MECHANICAL BEHAVIOR OF 3D FDM POLYMERS

Assist. Prof, Murat ŞEN[1]/ Assist.Prof, Emre AKIN[2]
[1]Marmara University, Technology Faculty, Mechanical Engineering, murat.sen@marmara.edu.tr, https://orcid.org/0000-0003-2216-245X
[2]Marmara University, Technology Faculty, Metallurgical and Materials Engineering, emre.akin@marmara.edu.tr, https://orcid.org/0000-0003-2067-1488

Abstract

This study examines the influence of layer thickness and build orientation on the tensile performance of Fused Deposition Modeling (FDM) printed polymer materials. Five commercial filaments including ABS, ASA, PETG, Tough PLA, and Hyper PLA were printed at two layer thicknesses of 100 µm and 200 µm in the horizontal orientation. An additional Tough PLA specimen was printed vertically to evaluate the effect of build direction. The results show that layer thickness has a significant impact on mechanical behavior. In general, specimens printed with 100 µm layers exhibited higher ultimate tensile strength (UTS) than those printed with 200 µm layers, indicating stronger interlayer bonding and improved filament fusion. The highest tensile strength was achieved by the 100 µm Tough PLA specimen (52.8 MPa), followed by Hyper PLA and PETG, while ABS had the lowest value (34.7 MPa). Interestingly, ABS showed a reverse trend where the 200 µm sample had slightly higher strength due to better interlayer fusion and reduced residual stress. The vertically printed Tough PLA sample demonstrated a pronounced strength reduction (18.3 MPa), confirming the detrimental effect of loading perpendicular to the layer interfaces. Fracture surface analysis supported these observations, revealing more compact and interlocked morphologies for thin-layer specimens.

Key words: Additive manufacturing, FDM 3D printing, Layer thickness, Build orientation, Tensile strength

1. INTRODUCTION

Additive Manufacturing (AM), commonly known as three-dimensional (3D) printing, has revolutionized conventional production systems by enabling the fabrication of complex geometries directly from computer-aided design (CAD) models without the need for molds or extensive post-processing. Among the various AM techniques, Fused Deposition Modeling (FDM) has gained remarkable popularity because of its cost efficiency, material versatility, and ability to produce customized parts with minimal waste [1–3]. The technology allows rapid prototyping and low-volume production, offering significant design freedom for geometries that are difficult or impossible to achieve through traditional subtractive or molding-based methods. These advantages have expanded the use of FDM in numerous industrial sectors, including automotive, aerospace, biomedical, and consumer products, where lightweight, tailored, and cost-effective polymer components are in high demand [4, 5]. Moreover, the capability to fabricate parts without tooling and with minimal post-processing enables FDM to serve as a sustainable and flexible production route, especially for customized or small-batch manufacturing.

However, the mechanical performance of FDM-printed parts is highly sensitive to printing parameters, which control the degree of interlayer bonding, void formation, and anisotropy within the structure. Factors such as infill ratio, raster pattern, build orientation, and particularly layer thickness strongly affect the tensile strength, stiffness, and ductility of printed components [6–9]. Previous investigations have shown that thinner layer heights promote enhanced diffusion and bonding between adjacent filaments, leading to higher interlayer strength and improved mechanical performance [8]. In contrast, thicker layers reduce the total number of interfaces but may also increase internal voids and residual stresses, thereby decreasing mechanical reliability [9]. In addition, printing orientation exerts a pronounced influence on the anisotropic behavior of FDM specimens; vertically printed (Z-axis) specimens generally exhibit inferior mechanical properties compared to horizontally printed ones because tensile loads act perpendicular to the layer interfaces, promoting delamination and brittle fracture [10, 11].

In this study, the influence of layer thickness and printing orientation on the mechanical performance of five widely used thermoplastic filaments—ABS, Tough PLA, Hyper PLA, PETG, and ASA—was systematically evaluated. All specimens were fabricated using an FDM printer at two different layer thicknesses, 100 µm and 200 µm, in the horizontal orientation, and their ultimate tensile strength (UTS) and elongation at break values were compared. Additionally, the filament that exhibited the highest tensile strength, Tough PLA, was also printed in the vertical orientation to assess the effect of build direction. The results demonstrated that, for most materials, specimens printed with 100 µm layers exhibited higher UTS values than those printed with 200 µm, owing to stronger interlayer bonding. Interestingly, ABS showed the opposite trend, where 200 µm-layer specimens achieved greater tensile strength—likely due to reduced internal stress accumulation and improved thermal fusion between layers. As expected, vertically printed Tough PLA samples exhibited markedly lower strength and ductility than their horizontal counterparts because the applied load was perpendicular to the deposited layers, facilitating early delamination and failure. These findings highlight the critical role of layer height and build orientation in optimizing the mechanical performance of FDM-printed polymers and provide useful guidance for selecting process parameters in engineering applications requiring structural reliability.

2. MATERIALS AND METHOD

In this study, five different thermoplastic filaments (ABS: Acrylonitrile Butadiene Styrene, Tough PLA: Polylactic Acid, Hyper PLA, PETG: Polyethylene Terephthalate Glycol, and ASA: Acrylonitrile Styrene Acrylate) were used to investigate the influence of layer thickness on the mechanical performance of FDM-printed parts. These commercial filaments were supplied by PORIMA 3D (Türkiye) and were selected because of their widespread industrial use and differing thermal and mechanical characteristics. The physical and mechanical properties of the filaments, as provided by the manufacturer, are summarized in Table 1.

Table 1. The properties of ASA, Tough PLA, Hyper PLA and PETG commerical filaments [12].

Material		ASA	Tough PLA	Hyper PLA	PETG	ABS
Physical properties	Density (g/cm^3)	1.06	1.22	1.23	1.28	1.03
	Melted flow index (g/10min)	22	17.3	17.3	20	5.2
Mechanical properties	Tensile Strength (MPa)	48	50	56	53	44
	Elastic Modulus (GPa)	2.1	2.4	2.85	3.0	2.1
	Elongation at Break (%)	12	50	7	30	40
	Impact strenght (kJ/m^2)	17	36	14.2	14.2	38
Thermal properties	Heat deflection temperature (°C)	95	58	55	80	95
	Transition temperature (°C)	100-105	55-65	55-60	80-85	95-105

Table 2. The printing process parameters for each filament type [12].

Parameter /Material	Nozzle Temperature (°C)	Bed Temperature (°C)	Print Speed (mm/s)	Cooling Fan Settings
ASA	260	100	200	Disabled
Tough PLA	235	60	200	100% after first layer
Hyper PLA	235	60	200	100% after first layer
PETG	240	80	200	20% after first layer
ABS	260	100	200	Disabled

2.1 Specimen Fabrication

Tensile test specimens were designed according to the ASTM D638 Type IV standard and modeled in SolidWorks 2023, then exported in STL format. The printing process was carried out using a Creality Ender 3 S1 Plus FDM printer equipped with a 0.4 mm brass nozzle. All samples were fabricated with 100% infill density and a linear raster pattern, ensuring consistent material deposition and avoiding internal porosity. Two different layer thicknesses, 0.10 mm (100 µm) and 0.20 mm (200 µm), were chosen as the primary process variables. Printing was performed in the horizontal orientation, where the loading direction is parallel to the deposited layers, providing the most favorable condition for interlayer bonding and thus the highest expected tensile strength. In addition to these horizontally printed specimens, an extra set of Tough PLA samples was fabricated in the vertical (Z-axis) orientation to evaluate the effect of build direction. Since the vertical configuration positions the printed layers perpendicular to the tensile loading axis, it represents the weakest structural arrangement due to the tendency of interlayer separation under tension. Tough PLA was specifically chosen for this comparison because it exhibited the highest tensile strength among all tested materials, and the vertical printing orientation was intended to reveal how much the strength deteriorates when the load acts across the layer interfaces rather than along them. Nozzle and bed temperatures for each filament were set to the average of the manufacturer's recommended range, and the printing process parameters for each filament type are summarized in Table 2 [12]. Printing speed and cooling-fan settings were optimized individually to obtain dimensionally accurate parts without warping or delamination. After printing, specimens were allowed to cool to room temperature on the heated bed to prevent thermal distortion. Minor surface irregularities were removed by gentle sanding to eliminate edge defects prior to mechanical testing.

2.2 Measurement

Mechanical characterization was only performed through tensile testing. All tests were conducted using a Zwick Z010 universal testing machine at room temperature under a crosshead speed of 5 mm/min, following the procedure defined in ASTM D638-10 [13]. For each material and layer-thickness condition, five specimens were tested to ensure repeatability and statistical reliability. During the test, the applied load and corresponding elongation were continuously recorded to obtain stress–strain curves, from which ultimate tensile strength (UTS) and elongation at break (ε_b) were determined. Fractured specimens were visually inspected after testing to assess typical failure modes associated with layer separation or interfacial debonding. All results were averaged and interpreted comparatively across materials and printing conditions to evaluate the influence of layer thickness and build orientation on tensile performance.

3. RESULTS AND DISCUSSION

The tensile stress–strain behavior is presented in Figure 1, and their corresponding mechanical properties are summarized in Table 3. The results clearly demonstrate that layer thickness has a significant influence on the tensile performance of FDM-printed polymers. In general, the specimens printed with a 100 µm layer thickness exhibited higher ultimate tensile strength (UTS) values than those printed with 200 µm layers, indicating improved interlayer adhesion and enhanced bonding strength at smaller layer heights. This behavior is consistent with literature reports stating that thinner layers promote greater molecular diffusion and a larger effective contact area between successive extrusions, which contribute to stronger interfacial bonding [4,6,8]. The only exception was observed in ABS, where the 200 µm specimens showed higher tensile strength than the 100 µm ones. This opposite trend can be attributed to the thermal characteristics of ABS; thicker layers allow longer cooling times between successive deposits, which helps reduce residual stress accumulation and promotes better filament fusion at the bead interfaces [9]. Consequently, while the majority of materials followed the expected relationship between layer thickness and strength, ABS behaved differently due to its distinct rheological and cooling properties during deposition, as well as the relatively high printing speed used for this material, which may have further influenced interlayer bonding and stress relaxation.

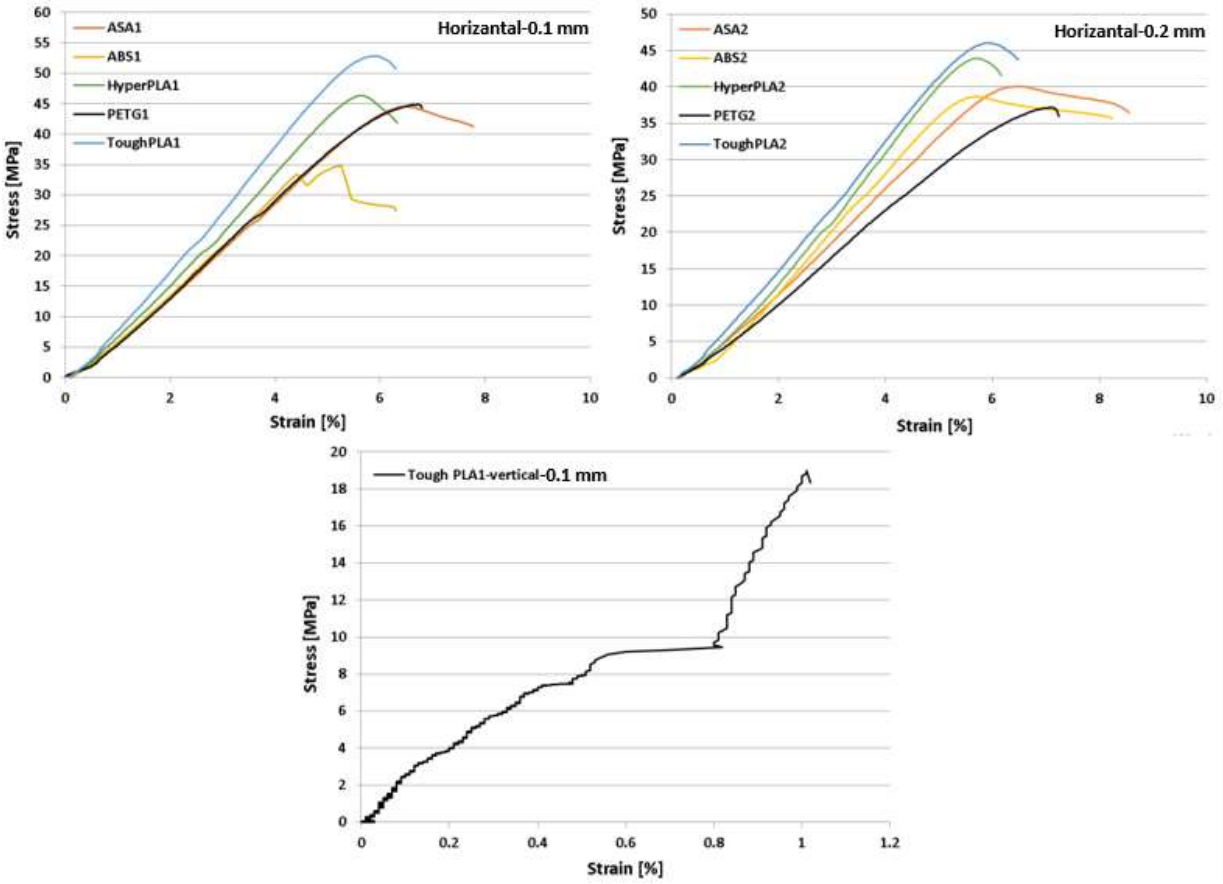

Figure 1. Tensile stress-strain curves of the samples.

Table 3. Mechanical properties of the samples.

Samples	Layer thickness (micron)	Ultimate Tensile Strength (MPa)	Elongation at Break (%)
Tough PLA1	100	52.8	6.29
Tough PLA2	200	46.0	6.48
Hyper PLA1	100	46.3	6.31
Hyper PLA2	200	43.8	6.16
ASA1	100	44.5	7.77
ASA2	200	40.0	8.55
PETG1	100	44.8	6.79
PETG2	200	37.1	7.24
ABS1	100	34.7	6.29
ABS2	200	38.6	8.24
Tough PLA1-vertical (z axis)	100	18.3	1.0

Compared to their 200 µm counterparts, the 100 µm samples of Tough PLA, Hyper PLA, ASA, and PETG showed tensile strength increases of approximately 14.8 %, 5.7 %, 11.3 %, and 20.7 %, respectively, whereas ABS exhibited an inverse behavior with a 10.1 % decrease. Regarding elongation at break, which represents the

ductility of the material, the differences between the two layer thicknesses were less pronounced. Nevertheless, slight variations were recorded, with the 200 µm specimens of Tough PLA, ASA, PETG, and ABS showing marginally higher elongation values of 3.0 %, 10.0 %, 6.6 %, and 31.0 %, respectively, while Hyper PLA demonstrated a small decrease of 2.4 %. Among all the tested materials, the highest tensile strength was obtained from the 100 µm Tough PLA specimen, reaching 52.8 MPa, while the lowest was measured for ABS with 34.7 MPa. The Tough PLA specimen printed in the vertical (Z-axis) orientation exhibited a drastic decrease in mechanical performance, with a UTS of 18.3 MPa, corresponding to nearly 65 % lower strength compared to its horizontally printed counterpart. This considerable reduction highlights the critical effect of build orientation, as tensile loads acting perpendicular to the layer interfaces promote interfacial delamination and premature failure, a phenomenon also reported in previous studies [6,10]. When the most durable material, Tough PLA, is compared with others, its 200 µm specimen, having a UTS of 46.0 MPa, still performed better than all 200 µm counterparts and remained approximately 3.7 % higher than Hyper PLA printed at 100 µm and 2.8 % higher than PETG printed at 100 µm. This indicates that even at higher layer thickness, Tough PLA maintains superior interlayer bonding and stiffness, attributed to its balanced viscoelastic properties and good flow behavior during extrusion.

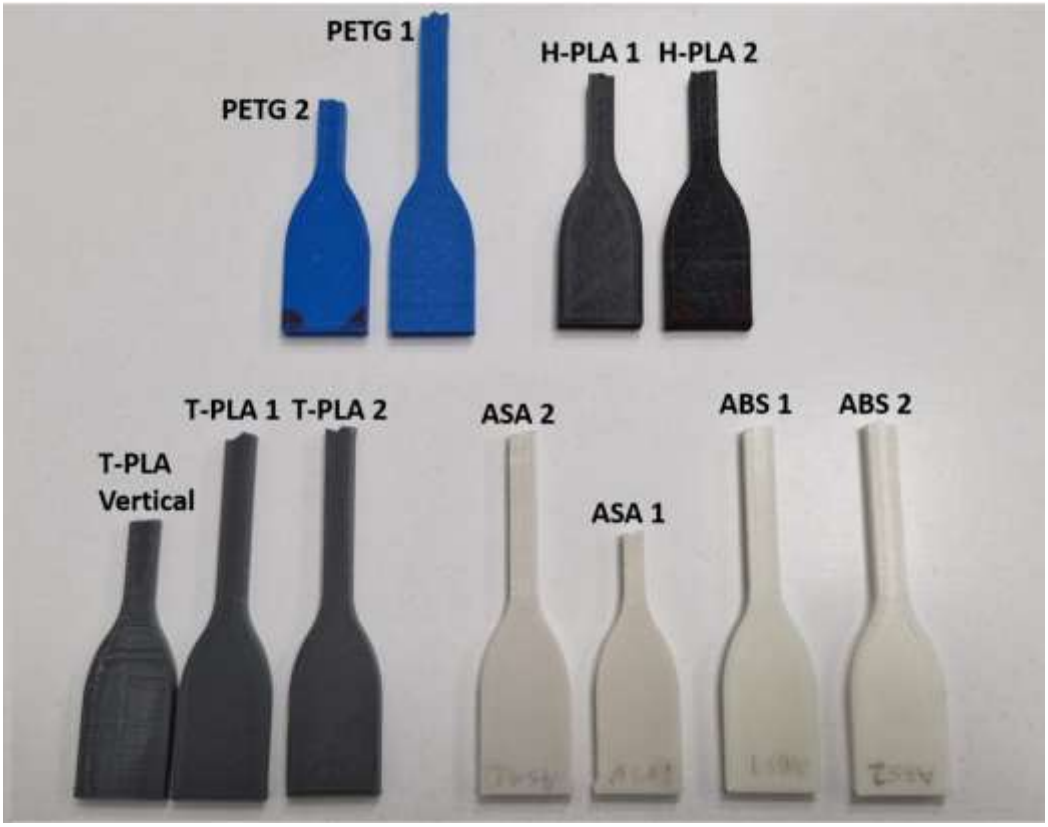

Figure 2. Tensile specimens of ABS, ASA, PETG, Tough PLA, and Hyper PLA after tensile testing, printed at two different layer thicknesses (100 µm and 200 µm), including an additional Tough PLA sample in vertical (Z-axis) orientation for comparison.

Fractographic observations after tensile testing, as illustrated in Figure 2, revealed evident differences in layer bonding and failure morphology among the materials. The 100 µm samples generally displayed rougher and more cohesive fracture surfaces, suggesting stronger interlayer bonding and effective filament fusion. The fracture surfaces appeared compact and interlocked, indicating sufficient thermal diffusion between successive extruded layers, which correlates well with the higher UTS values obtained in Table 3. In contrast, ABS presented a distinct fracture morphology. As seen in Figure 3, the 200 µm ABS specimen exhibited more uniform filament coalescence and fewer interfacial voids, whereas the 100 µm ABS sample showed partial layer separation and

visible micro-gaps. These morphological differences support the mechanical data and explain why ABS demonstrated higher tensile strength at greater layer thickness.

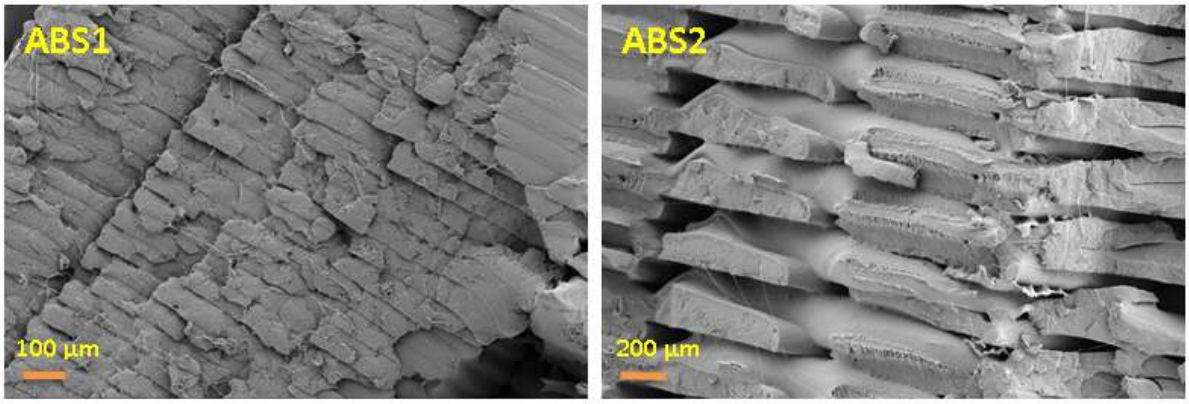

Figure 3. SEM images of fractured ABS specimens printed with different layer thicknesses after tensile test.

Overall, the experimental findings confirm that the mechanical performance of FDM-printed thermoplastics is highly dependent on both layer thickness and build orientation. For most materials, thinner layers enhance bonding strength due to improved diffusion and adhesion between filaments, while thicker layers tend to reduce bonding efficiency. However, material-dependent rheological behavior, as observed in ABS, can reverse this trend by influencing heat transfer and interlayer fusion. In the case of ABS, printing parameters such as the relatively high printing speed may also have affected its performance by altering the cooling rate and layer adhesion quality. The results highlight the necessity of optimizing both layer height and printing orientation based on material characteristics and process settings to achieve the desired mechanical integrity and performance in FDM-fabricated polymer components.

4. CONCLUSION

This study systematically examined the influence of layer thickness and build orientation on the tensile behavior of FDM-printed thermoplastic polymers, including ABS, ASA, PETG, Tough PLA, and Hyper PLA. The experimental findings clearly demonstrated that layer thickness plays a decisive role in determining the interlayer bonding quality and overall mechanical integrity of printed specimens. In most materials, the 100 µm layer thickness produced stronger interlayer fusion, resulting in higher ultimate tensile strength (UTS) compared to 200 µm layers. The maximum UTS value of 52.8 MPa was obtained for Tough PLA printed with 100 µm layers. In contrast, ABS exhibited an unusual trend where the 200 µm specimens achieved slightly higher tensile strength (38.6 MPa) than the 100 µm ones, likely due to improved filament fusion and reduced residual stress during printing at higher layer heights. This deviation may also have been influenced by the relatively high printing speed used for ABS, which can alter the heat transfer rate and cooling dynamics, thereby affecting interlayer bonding efficiency. The vertically printed Tough PLA sample showed a dramatic decrease in UTS (18.3 MPa) and elongation (1%), emphasizing the detrimental effect of build direction when the applied load acts perpendicular to layer interfaces. Fractographic observations supported these mechanical trends, revealing more compact and interlocked failure surfaces for thin-layer specimens, whereas thicker or vertically printed parts exhibited distinct interlayer separations and voids. Overall, the results confirm that reducing layer thickness enhances mechanical strength through better polymer chain diffusion and interfacial bonding, though this comes at the cost of longer print times. Future research should explore the optimization of process parameters such as raster angle, extrusion temperature, printing speed, and infill pattern to further improve interlayer adhesion without compromising productivity.

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