RESEARCH PAPER

# Experimental Investigation of Mechanical and Physical Properties of FDM-Printed Acrylonitrile Styrene Acrylate (ASA)

Dr.Captan Prabakaran A[1]*, Dr.Loganathan S[2], Dr.Raju P[3], Mr.Rajasekar K[4], Mr.Harishankar R[5] and Mr.Sri Nithish S P[6]

*[1]Department of Mechanical Engineering, V.S.B. Engineering College, Karur, Tamil Nadu, India*
*[2]Department of Mechanical Engineering, V.S.B College of Engineering Technical Campus, Coimbatore,Tamil Nadu, India*
*[3]Department of Mechanical Engineering, V.S.B College of Engineering Technical Campus, Coimbatore,Tamil Nadu, India*
*[4]Department of Mechanical Engineering, V.S.B. Engineering College, Karur, Tamil Nadu, India*
*[5]Department of Mechanical Engineering, V.S.B. Engineering College, Karur, Tamil Nadu, India*
*[6]Department of Mechanical Engineering, V.S.B. Engineering College, Karur, Tamil Nadu, India*
*[1]acprabakar@gmail.com, [2]srilogu66@gmail.com, [3]rajupmech@gmail.com, [4]rajavsbmech@gmail.com, [5]rrharishankar4646@gmail.com and [6]srnithishsp@outlook.com*
**Corresponding Author Information: Dr A. Captan Prabakaran (acprabakar@gmail.com)*
*ORCID: 0009-0005-5877-6412*

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## ABSTRACT

Fused Deposition Modelling (FDM) is a widely used additive manufacturing process that creates objects layer by layer from a CAD model using a feedstock plastic filament. ASA (acrylonitrile styrene acrylate) is a popular filament in 3D printing due to its favorable properties. This study examined the behavior of ASA specimens printed with varying infill densities (50%, 70%, and 90%) and layer thicknesses. The weight of the specimens is proportional to the infill density. The printed specimens were subjected to izod impact testing, surface roughness testing, and water absorption testing. The results showed that specimens with 90% infill density and 0.2mm layer thickness exhibited the highest impact strength. Conversely, specimens with 50% infill density and 0.4mm layer thickness had the highest surface roughness. Notably, the water absorption test revealed excellent water resistance, with minimal water absorption observed after testing. This property enables the printing of lower-weight components with high impact strength and controlled surface roughness, making ASA a versatile material for various applications.

**Keywords**: *Fused deposition modelling, Acrylonitrile styrene acrylate, Impact strength, Surface roughness, Water absorption.*

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## GRAPHICAL ABSTRACT

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*Author for Correspondence: acprabakar@gmail.com

## 1. INTRODUCTION

Additive Manufacturing (AM) has emerged as a transformative technology in modern engineering, enabling the fabrication of complex geometries directly from digital models with reduced material waste and minimal process steps [1]. Among various AM techniques, Fused Deposition Modeling (FDM) is one of the most extensively used methods due to its operational simplicity, economic feasibility, and adaptability to a wide range of thermoplastic materials [2]. In FDM, components are fabricated through the layer-by-layer deposition of molten polymer extruded through a heated nozzle, allowing the production of customized and intricate structures across diverse industrial sectors, including aerospace, automotive, biomedical, and consumer products [3]. Despite these advantages, FDM-fabricated components are often associated with inherent limitations such as anisotropic mechanical behavior, poor surface finish, and the presence of internal defects [4]. These issues primarily arise from weak interlayer bonding, void formation between adjacent rasters, and the staircase effect caused by discrete layer deposition [5]. Consequently, the mechanical and physical properties of FDM parts are highly dependent on processing parameters, including layer thickness, raster orientation, infill density, build orientation, and extrusion temperature [6]. A comprehensive understanding of these parameters is essential to improve part performance and ensure reliability in functional applications. In recent years, significant research efforts have focused on commonly used thermoplastics such as poly(lactic acid) (PLA) and acrylonitrile butadiene styrene (ABS) [7]. However, Acrylonitrile Styrene Acrylate (ASA), an advanced engineering thermoplastic, has received comparatively less attention despite its superior properties [8]. ASA is a terpolymer consisting of styrene-acrylonitrile (SAN) copolymer modified with an acrylic ester elastomer, which provides enhanced ultraviolet (UV) resistance, excellent weatherability, and improved thermal stability compared to ABS [9]. Furthermore, ASA demonstrates superior resistance to environmental stress cracking and retains its mechanical integrity under prolonged outdoor exposure, making it highly suitable for exterior and structural applications [10]. For instance, recent experimental investigations have demonstrated that process parameters such as infill density and build orientation significantly influence the tensile and flexural strength of ASA components [11]. Advanced studies using design of experiments (DOE) approaches have reported improvements in specific strength and structural performance of FDM-printed ASA parts [12]. Furthermore, comparative studies between fused filament fabricated and injection-molded ASA components have highlighted the critical role of process optimization in bridging the mechanical performance gap between additive and conventional manufacturing [13]. Recent research has also explored post-processing and predictive modeling approaches, including machine learning-based estimation of hardness and surface roughness in ASA components, indicating the growing integration of data-driven techniques in additive manufacturing [14]. Additionally, process optimization strategies addressing defects such as warpage, void formation, and poor interlayer adhesion have been proposed to enhance the overall quality and reliability of ASA-based FDM components [15]. These recent advancements underline the increasing industrial relevance of ASA and the need for further systematic investigations. Although ASA has been increasingly adopted in FDM processes, there exists a notable lack of comprehensive experimental studies investigating its mechanical and physical performance under varying process conditions. The influence of FDM parameters on critical properties such as tensile strength, hardness, impact resistance, surface roughness, and dimensional accuracy remains insufficiently explored.

This gap limits the effective utilization of ASA in high-performance engineering applications where both mechanical reliability and surface quality are crucial. Therefore, the present study aims to experimentally investigate the mechanical and physical properties of ASA polymer in FDM-printed components. The study systematically examines the influence of key process parameters on part performance and identifies optimal conditions to enhance mechanical strength and surface characteristics. The findings of this research are expected to contribute to the existing body of knowledge by providing a deeper understanding of ASA behavior in FDM processes and supporting its broader application in industrial and outdoor environments.

## 2. EXPERIMENTAL DETAILS

The experimental procedure involved selecting and preparing filament materials, utilizing Fused Deposition Modeling (FDM) to fabricate test specimens, and subsequently evaluating their mechanical properties

### 2.1. Filament material

FDM technology enables the printing of a wide range of thermoplastic filaments and their composite materials. In this research work, commercially available acrylonitrile styrene acrylate (ASA) filament is used for printing the samples. ASA is a modified copolymer of acrylonitrile butadiene styrene, designed to overcome ABS's limitations by enhancing its color stability, weather resistance, and overall durability. ASA comprises acrylic ester elastomer and n-butyl acrylate, which provide exceptional resistance to heat, oil, and ultraviolet irradiation, resulting in enhanced durability and chemical stability. Notably, ASA retains its properties after extensive exposure to UV radiation, outperforming ABS even with UV-resistant coatings. According to the falling dart impact test, ASA can withstand 85% of its impact resistance after 3 years of sunlight exposure, whereas a similar ABS sample with a UV-resistant coating can only withstand the same UV radiation for 3 weeks while retaining 85% of its impact resistance. The ASA polymer possesses high toughness, thermal stability, and resistance to aging, making it a suitable material for various industries due to its widespread applications.

### 2.2. Fabrication of specimens

The specimens were fabricated using ASA filament (WOL 3D, World of Lilliputs) with a diameter of 1.75 mm. The specimen models were designed in Solid Works, converted to STL file format, and sliced using Cura 4.3. A Prusa i3 MK 3D printer was used for fabrication, with printing conditions outlined in Table 1. The surface roughness and izod impact test specimens were designed according to ASTM D256 standards, with dimensions schematically illustrated in Figure 1.

**Table 1:** FDM parameters adopted for the printing of ASA specimens

| Parameters | Stage 1 | | | Stage 2 | | | Stage 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| **Sample** | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 |
| **Layer Thickness (mm)** | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 |
| **Infill density (%)** | 50 | 70 | 90 | 50 | 70 | 90 | 50 | 70 | 90 |
| **Raster angle** | 45° | 45° | 45° | 45° | 45° | 45° | 45° | 45° | 45° |

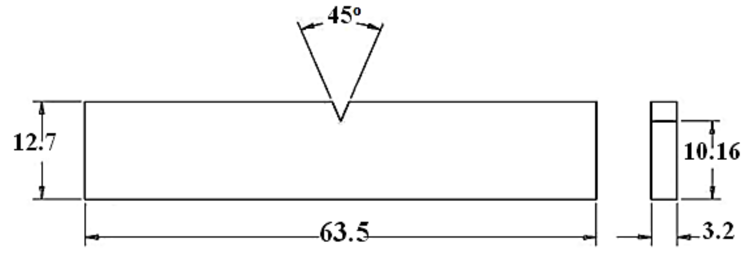

**Figure 1** Schematic representation of Izod impact specimen

## 3. MECHANICAL PROPERTIES

### 3.1 Surface roughness

Surface roughness measurements were conducted using a Zeiss Handy Surf E-35B contact-type surface roughness tester with a diamond stylus tip radius of 5 µm. Three consecutive measurements were taken for each ASA sample, evaluating parameters such as arithmetic mean deviation (Ra) and maximum height profile (Rz). The stylus traversed 12.5 mm across the specimen surface at 0.6 mm/s with a probing force of 4.5 mN.

### 3.2 Impact Test

The Izod impact test, conforming to ASTM D256 standards, was used to assess the toughness of ASA samples. A Tinius Olsen impact tester with a 2.75 J pendulum capacity was employed, featuring a 0.61 m drop height and 3.46 m/s impact velocity. The test measured the impact strength of V-notched samples in a cantilevered beam configuration, evaluating absorbed energy and notch sensitivity. Testing was conducted at ambient conditions (30°C, 40% ± 5% relative humidity), with three trials performed to analyze impact strength modifications.

### 3.3 Water absorption test

The water absorption test was conducted to evaluate the moisture absorption characteristics of the ASA samples. The test involved immersing the samples in distilled water at room temperature (30°C ± 2°C) for a specified period.

The samples were then removed, wiped dry, and weighed to determine the amount of water absorbed. The percentage of water absorption was calculated based on the initial and final weights of the samples. This test helps assess the material's susceptibility to moisture-induced degradation and its potential impact on mechanical properties.

## 4. RESULTS AND DISCUSSION

Layer thickness is one of the most influential process parameters in Fused Deposition Modeling (FDM), significantly affecting the mechanical performance and fracture characteristics of printed components. Figure 2 illustrates the fractured specimens fabricated with layer thicknesses of 0.2 mm, 0.3 mm, and 0.4 mm after mechanical testing.

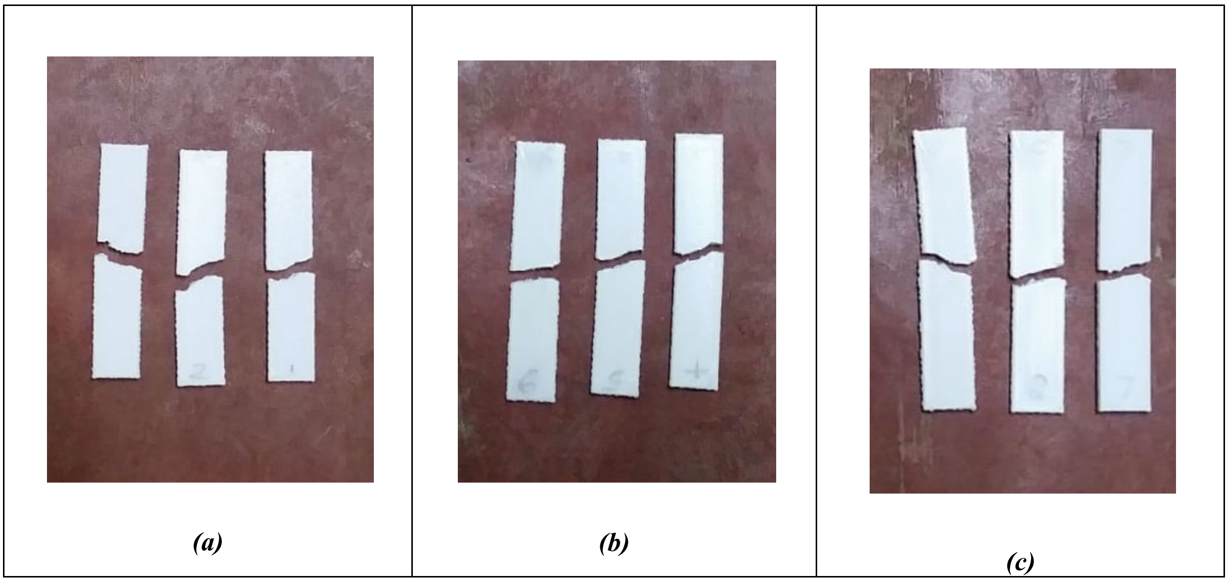
*(a)* *(b)* *(c)*

**Figure 2 (a)** Specimens with 0.2 mm thickness after Testing, (b) Specimens with 0.3 mm thickness after Testing, (c) Specimens with 0.4 mm thickness after Testing

In FDM, parts are built through the successive deposition of semi-molten filaments, where bonding between adjacent layers occurs primarily through thermal diffusion and polymer chain entanglement. At lower layer thicknesses (e.g., 0.2 mm), each deposited layer experiences better thermal contact with the previously deposited layer, promoting enhanced interlayer adhesion. This results in improved stress transfer across layers, leading to higher tensile strength and more uniform deformation before failure. Consequently, specimens with smaller layer thickness typically exhibit ductile fracture behavior with relatively smoother fracture surfaces. As the layer thickness increases to 0.3 mm, the bonding between layers becomes comparatively weaker due to reduced heat transfer and insufficient polymer diffusion across the interfaces. This leads to the formation of microvoids and interlayer discontinuities, which act as stress concentration sites. As a result, the specimens exhibit moderate mechanical strength with mixed-mode fracture behavior, combining both ductile and brittle characteristics. At higher layer thicknesses (e.g., 0.4 mm), the reduction in interlayer bonding becomes more pronounced. The larger volume of extruded material per layer results in inadequate fusion between adjacent layers and increased porosity within the structure. These defects significantly impair load transfer efficiency and accelerate crack initiation and propagation along the layer interfaces. Consequently, specimens fabricated with higher layer thickness tend to exhibit brittle fracture behavior, characterized by rough and irregular fracture surfaces and reduced elongation at break. Furthermore, increased layer thickness contributes to a more prominent staircase effect, which not only affects surface quality but also introduces geometric inconsistencies that further influence mechanical performance. The anisotropic nature of FDM parts becomes more evident at higher layer thicknesses, where failure predominantly occurs along the interlayer boundaries rather than through the bulk material. Overall, the observations from Figure 2 indicate that decreasing layer thickness enhances interlayer bonding and mechanical performance, whereas increasing layer thickness leads to weaker structural integrity and premature failure. Therefore, optimizing layer thickness is crucial for achieving a balance between mechanical strength, surface quality, and production efficiency in FDM-printed ASA components. Table 2 presents the experimental results for various tests.

**Table 2** Experimental results of surface roughness and impact strength of FDM-printed ASA specimens at different layer thicknesses and infill densities

| S.No | Specimen | Layer thickness (mm) | Infill density (%) | Surface roughness (µm) | Impact strength(J/m) |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| 1 | S1 | 0.2 | 50 | 3.801 | 662.18 |
| 2 | S2 | 0.2 | 70 | 3.546 | 678.12 |
| 3 | S3 | 0.2 | 90 | 3.154 | 719.37 |
| 4 | S4 | 0.3 | 50 | 4.897 | 570.93 |
| 5 | S5 | 0.3 | 70 | 4.358 | 579.06 |
| 6 | S6 | 0.3 | 90 | 4.124 | 586.87 |
| 7 | S7 | 0.4 | 50 | 6.854 | 486.56 |
| 8 | S8 | 0.4 | 70 | 6.541 | 507.06 |
| 9 | S9 | 0.4 | 90 | 5.875 | 582.81 |

### 4.1 Analysis of Surface roughness

The surface roughness of FDM-printed ASA polymer samples exhibits a notable dependence on the interplay between layer thickness and infill density. Specifically, as the infill density increases, the surface roughness decreases, attributable to the formation of a more solid and cohesive structure that minimizes voids and irregularities. Conversely, an increase in layer thickness is accompanied by an escalation in surface roughness, primarily due to the exacerbated layer adhesion effects that yield a more pronounced topography. The most favourable surface finish, characterized by a surface roughness value of 3.154 µm, is achieved under the printing conditions of a 0.2 mm layer thickness and a 90% infill density. This underscores the significance of optimizing printing parameters to attain the desired surface quality in FDM-printed ASA components, where judicious selection of layer thickness and infill density can substantially mitigate surface roughness and enhance the overall finish. Surface roughness variation of FDM-printed ASA specimens under different process conditions is shown in Fig. 3.

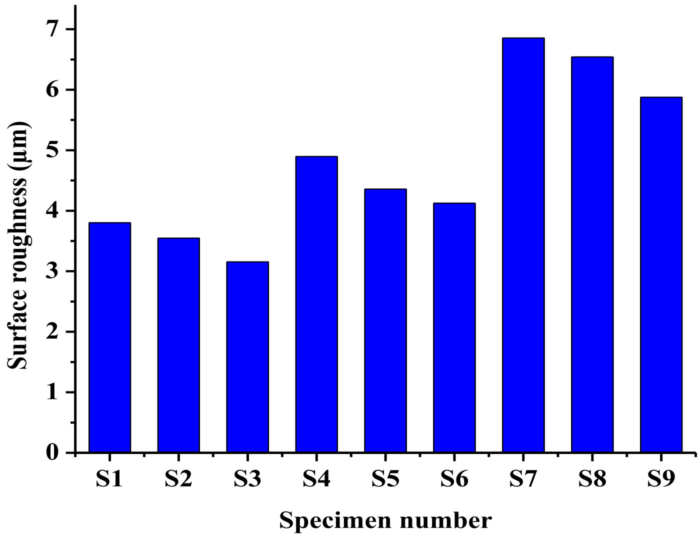

***Figure 3*** Surface Roughness Variations of FDM-Printed ASA Specimens at Different Process Conditions

The surface roughness values range from a minimum of 3.154 µm (achieved with 0.2 mm layer thickness and 90% infill density) to a maximum of 6.854 µm (observed with 0.4 mm layer thickness and 50% infill density). This indicates a significant impact of layer thickness and infill density on surface roughness, with optimal parameters yielding smoother surfaces.

### 4.2 Analysis of Impact strength

The impact strength of FDM-printed ASA polymer samples exhibits a notable dependence on layer thickness and infill density. Specifically, decreasing the layer thickness and increasing the infill density lead to improved impact strength. The highest impact strength of 719.375 J/m is achieved with a layer thickness of 0.2 mm and an infill density of 90%. This improvement can be attributed to the stronger interlayer bonding and more solid structure formed under these conditions, enabling the material to absorb more energy during impact. Conversely, thicker layers and lower infill densities result in reduced impact strength due to weaker interlayer bonding and increased porosity. Therefore, optimizing printing parameters is crucial for enhancing the impact resistance of FDM-printed ASA components. Impact strength variation of FDM-printed ASA specimens under different process conditions is shown in Fig. 3.

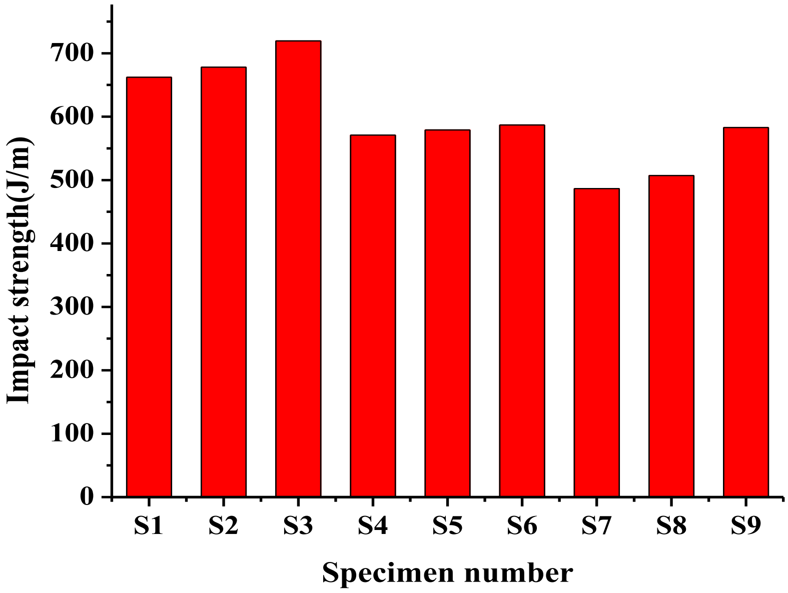

**Figure 3** Impact strength Variations of FDM-Printed ASA Specimens at Different Process Conditions

The impact strength of FDM-printed ASA samples ranges from a maximum of 719.37 J/m (achieved with 0.2 mm layer thickness and 90% infill density) to a minimum of 486.56 J/m (observed with 0.4 mm layer thickness and 50% infill density). This indicates a significant influence of layer thickness and infill density on impact strength, with optimal parameters yielding enhanced impact resistance.

### 4.3 Analysis of Water absorption behaviour

The water absorption test results for FDM-printed ASA polymer samples reveal low absorption rates, ranging from 0.21% to 0.44%. Notably, samples with higher infill densities exhibit lower water absorption, indicating that increased material density reduces water ingress. Additionally, layer thickness has a slight impact, with thicker layers resulting in marginally higher absorption rates. The sample with 0.2 mm layer thickness and 90% infill density demonstrates the lowest water absorption rate of 0.21%, suggesting that optimizing infill density and layer thickness can further minimize water absorption in FDM-printed ASA parts. *Table 3 presents the water absorption results under various conditions.* Percentage w*ater absorption* variation of FDM-printed ASA specimens under different process conditions is shown in Fig. 4.

**Table 3** Water absorption test results with all samples

| S.No | Specimen | Layer thickness (mm) | Infill density (%) | Specimen weight(grams) | | % of absorption |
|---|---|---|---|---|---|---|
| | | | | Before | After | |
| 1 | S1 | 0.2 | 50 | 2.040 | 2.048 | 0.39 |
| 2 | S2 | 0.2 | 70 | 2.420 | 2.428 | 0.33 |
| 3 | S3 | 0.2 | 90 | 2.830 | 2.836 | 0.21 |
| 4 | S4 | 0.3 | 50 | 2.240 | 2.249 | 0.40 |
| 5 | S5 | 0.3 | 70 | 2.580 | 2.590 | 0.38 |
| 6 | S6 | 0.3 | 90 | 2.890 | 2.897 | 0.27 |
| 7 | S7 | 0.4 | 50 | 2.450 | 2.461 | 0.44 |
| 8 | S8 | 0.4 | 70 | 2.700 | 2.709 | 0.33 |
| 9 | S9 | 0.4 | 90 | 3.020 | 3.030 | 0.29 |

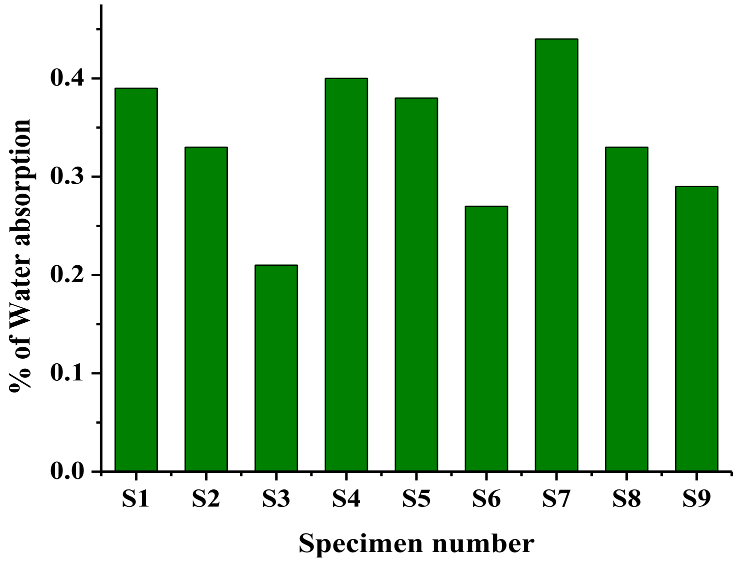

**Figure 4** Water absorption test *FDM-Printed ASA Specimens at Different Process Conditions*

## 5. CONCLUSIONS

This study investigated the effects of process parameters on surface roughness, impact strength, and water absorption of FDM-printed ASA polymer samples. The results revealed that lower layer thickness yields improved surface roughness, with the smoothest surface achieved at 0.2 mm layer thickness. Similarly, impact strength was highest at lower layer thickness, with a maximum value of 719.37 J/m recorded for the 0.2 mm layer thickness samples. Water absorption tests showed that the samples exhibited relatively low absorption rates, indicating good resistance to water. Overall, the study concludes that optimizing process parameters, particularly layer thickness, significantly influences the properties of FDM-printed ASA parts.

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