

A Surface Roughness Analysis of 3D Printed Mold Inserts Using ABS-Like and TR300 Resins: An Evaluation of Printing Angles and Material Performance for Injection Molding Applications

Soontorn Weeradeachlikul

Faculty of Engineering, Thammasat School of Engineering, Thammasat University, Pathumthani, Thailand
soontorn@pttc.ac.th

Jak Chuanasa

Faculty of Engineering, Thammasat School of Engineering, Thammasat University, Pathumthani, Thailand
cjakkrap@engr.tu.ac.th (corresponding author)

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ABSTRACT

This research focuses on a comparative study of the surface roughness of parts fabricated using Stereolithography (SLA) 3D printing technology. The objective is to compare the surface roughness of printed parts at various build angles, ranging from 0° to 90°, using two types of resins: Acrylonitrile Butadiene Styrene (ABS)-like resin and TR300 resin. The study aims to determine whether the surface roughness trends are consistent between the two materials and to analyze the effect of printing angle on surface quality. This analysis will identify the optimal printing conditions for producing high-quality insert mold cavities used in plastic injection molding. The experimental results reveal that TR300 resin consistently provides a smoother surface finish than ABS-like resin across all printing angles. The lowest surface roughness was observed at a 0° printing angle with TR300 resin, showing values of $R_a = 0.175 \mu\text{m}$, $R_z = 1.123 \mu\text{m}$, and $R_t = 1.136 \mu\text{m}$. In comparison, the lowest surface roughness for ABS-like resin at the same angle was $R_a = 0.256 \mu\text{m}$, $R_z = 1.690 \mu\text{m}$, and $R_t = 2.170 \mu\text{m}$. These findings indicate that the most suitable condition for producing insert mold cavities for high-quality plastic injection molds is using TR300 resin printed at a 0° angle. This is due to the fact that the resulting surface roughness falls within the recommended range for mold cavities ($R_a = 0.2\text{--}1.6 \mu\text{m}$), making it ideal for precision applications in injection molding.

Keywords-3D printing; surface roughness; ABS-like resin; TR300 resin; injection molding; printing angle; surface finish

I. INTRODUCTION

Rapid advances in Additive Manufacturing (AM) have allowed the fabrication of complex geometries, overcoming the limitations of traditional methods [1]. Stereolithography (SLA) is a widely utilized 3D printing technology that employs Ultraviolet (UV) light to solidify photosensitive polymers. This technique is a rapid prototyping process that uses a high-intensity UV beam, typically generated by Light-Emitting Diodes (LEDs) with a wavelength of 405 nm, to selectively cure layers of liquid resin within a transparent-bottomed vat [2]. The process operates on a layer-by-layer basis, wherein the

UV light hardens the resin at specific points to form the desired three-dimensional structure. SLA printing typically offers two exposure methods: top-down or bottom-up UV projection, depending on the orientation. This configuration affects the adhesion properties and printing accuracy.

The conventional manufacturing of plastic injection molds typically involves Computer Numerical Control (CNC) machining, which follows a subtractive manufacturing approach [3, 4]. However, this method presents several drawbacks and challenges:

- Excessive material waste: A significant amount of raw material is removed during the machining process, leading to considerable material wastage.
- High skill requirement: CNC machining requires specialized knowledge, technical expertise, and experience to operate effectively.
- Expensive equipment and tools: The cost of CNC machines, cutting tools, and auxiliary equipment is relatively high, making it a substantial investment.
- Extended lead time: The production cycle for CNC-machined molds is often time-consuming, resulting in longer delivery times and increased production costs [5, 6].

These factors render CNC machining a less cost-effective solution for short-run production molds (shot-time molds), such as those used for product design iterations, pilot production, and prototyping applications [5]. Based on the advantages of 3D printing technology and the limitations of traditional subtractive manufacturing in the production of injection molds, this study explores the feasibility of using AM, specifically SLA 3D printing, to fabricate insert molds as an alternative to conventional CNC-machined molds. SLA-based insert molding offers several benefits, including lower production costs compared to CNC machining [6], reduced dependency on highly skilled labor, and a more predictable and faster production timeline. However, to achieve optimal results in SLA 3D printing, the orientation of the printed part must be carefully considered. In most cases, tilting the part at an angle relative to the build platform is necessary due to the following reasons:

- Support structures: SLA printing requires support structures to stabilize the part during fabrication, reducing the risk of print failure or detachment from the build platform.
- Resin drainage: Since SLA printing uses liquid resin that solidifies under laser exposure, horizontally printed parts may trap uncured resin in hard-to-drain areas. Angling the part allows excess resin to drain more efficiently, minimizing defects caused by residual liquid.
- Peel force reduction: During layer curing, forces are applied as the part separates from the resin vat's bottom film. Orienting the part at an angle distributes these peel forces more evenly, reducing stress concentration and minimizing the risk of delamination or detachment.
- Surface finish: Printing parts in a completely horizontal orientation can lead to visible layer lines and surface irregularities. By tilting the part, layer stacking is optimized, resulting in a smoother and higher-quality surface finish.

This research investigates the surface quality of SLA-printed parts at various printing angles to determine the optimal orientation for producing high-quality insert molds for plastic injection molding. It compares the surface roughness parameters (Ra, Rz, Rt) of parts made from two different resins to assess the feasibility of using SLA-printed parts as molds. The goal is to identify the printing angle that achieves surface

smoothness within industry standards (Ra: 0.2-1.6 μm , Rz: 2.5-16 μm).

II. EXPERIMENTAL PROCEDURE

The materials used for fabricating the test specimens were resins designed for SLA, Digital Light Processing (DLP), and Liquid Crystal Display (LCD) 3D printing technologies. This study compares two types of resin materials, Acrylonitrile Butadiene Styrene (ABS)-like and TR300.

A. ABS-Like Resin

ABS-like resin is a specialized resin formulated for SLA, DLP, and LCD 3D printing. It is designed to mimic the properties of ABS plastic, making it ideal for fabricating structural components and high-performance tools, particularly for drilling and tapping applications. This resin is a copolymer blend of Acrylonitrile, Butadiene, and Styrene, with a composition ratio of 20:30:50. The key material properties are as follows: density (1.17 g/cm^3), viscosity (160–250 MPa·s), surface hardness (80 Shore D), tensile stress at break (59.9 MPa), elongation at break (3.9%), tensile modulus (3443 MPa), notched Izod impact strength (20.2 J/m), glass transition temperature (T_g) (220 $^{\circ}\text{C}$) [7, 8].

B. Fabrication of Test Specimens

The test specimens used in this study were rectangular blocks with dimensions of $X = 12$ mm, $Y = 6$ mm, and $Z = 3$ mm. These specimens were fabricated using SLA 3D printing technology with the Phrozen Sonic Mega 8K S printer. The Phrozen Sonic Mega 8K S printer, which employs UV LCD projection technology, features a build volume of $330 \times 185 \times 300$ mm, and supports layer thicknesses ranging from 10 to 300 μm [9]. In this experiment, two resin materials were utilized: ABS-like resin and TR-300 resin. The UV-LCD 3D printing process was carried out with a UV wavelength range of 385 – 405 nm [7-9]. The printing code was generated using Chitobox software, and the specimens were printed at various orientations, including 0° , 3° , 5° , 15° , 30° , 45° , 60° , 75° , and 90° , as illustrated in Figure 1. The printing parameters used in this study are presented in Table I.

TABLE I. PRINTING PARAMETERS

Parameter	Value
Layer height	0.02 mm
Bottom layer count	6 layers
Exposure time	1.250 s
Bottom exposure time	12.50 s
Lifting distance	8 mm
Bottom lift distance	8 mm
Lifting speed	60 mm/min
Bottom lift speed	80 mm/min

C. Surface Roughness Principles

Measuring the surface roughness of a printed part is crucial for achieving high-quality components, as surface characteristics are not always visually discernible or detectable by touch [9]. In surface roughness measurement, four key factors influence the results [10-15]:

- Roughness: The fine irregularities present on the surface of the material.
- Waviness: The larger-scale deviations from the surface profile, typically caused by machining or printing inconsistencies.
- Lay: The predominant surface texture direction that results from the manufacturing process.
- Probe or stylus tip: The measuring instrument used to trace and quantify surface roughness values [10].

There are various surface roughness parameters, but the most commonly used include average roughness (Ra), determined roughness (Rz), maximum profile peak height (Rp), maximum profile valley depth (Rv), and maximum height of profile (Rt).

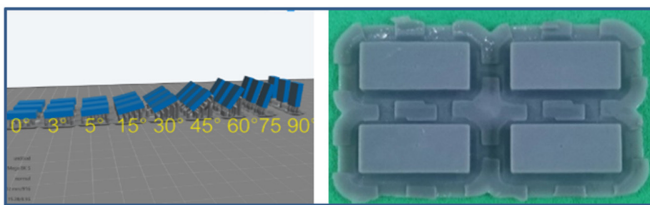


Fig. 1. Orientation of the test specimens at different printing angles.

1) Average Roughness

Average roughness (Ra) is defined as the arithmetic mean deviation of the surface profile from the mean line over a specified sampling length (lr). It represents the average absolute deviation of the measured roughness profile from the central reference line, providing a general indication of the surface texture [11, 16, 17].

2) Determined Roughness

Determined roughness (Rz) represents the average distance between the highest peak and the lowest valley within five sampling lengths (lr) of the measured surface profile. This parameter provides a more detailed evaluation of surface irregularities than Ra, particularly for surfaces with deeper valleys and higher peaks. This concept is described in [16, 17], where ln is the evaluation length and Rz1max is the maximum profile height, as defined in ISO 4287:1997 (i.e., the greatest Rz value from the five sampling lengths lr). Rt is the total profile height, defined as the distance between the highest peak and the deepest valley of the total evaluation length ln.

3) Maximum Height of Profile

Maximum height of profile (Rt) is defined as the vertical distance between the highest peak and the lowest valley within a given sampling length (ln). This parameter provides insight into the extreme variations in surface roughness, making it useful for applications requiring precise surface control. This concept is described in [11, 16, 17].

4) Selection of Surface Roughness for Injection Molds

The surface roughness requirements for injection molds are typically determined based on the DIN 140 standard, which

classifies roughness into 12 levels, ranging from N1 (the smoothest) to N12 (the roughest). This standard primarily considers two roughness measurement methods: average roughness (Ra) and determined roughness (Rz), according to [10, 11]. In most plastic injection molding applications, the surface roughness of mold inserts must be at a fine level, where surface irregularities are not visible to the naked eye. The recommended Ra values for mold surfaces typically range between 1.6, 0.8, 0.4, and 0.2 μm, whereas the corresponding Rz values range between 16, 6.3, 4, and 2.5 μm. Therefore, this study aims to investigate the feasibility of utilizing 3D printing technology for fabricating insert molds used in plastic injection molding applications. The experiment focuses on evaluating whether the surface roughness achieved through SLA 3D printing meets the required precision and determining the optimal printing angle that results in a surface roughness suitable for insert mold production.

III. EXPERIMENTAL RESULTS

A. Surface Roughness Results (Ra, Rz, and Rt) for ABS-Like and TR300 Resins

The average values of Ra, Rz, are summarized in Table II and Figure 2, which present the test results for specimens printed using ABS-like resin. Table III and Figure 3 display the corresponding results for specimens fabricated with TR-300 resin.

TABLE II. SURFACE ROUGHNESS VALUES FOR ABS-LIKE RESIN

Degrees (°)	ABS-like resin		
	Ra (μm)	Rz (μm)	Rt (μm)
0	0.256	1.690	2.170
3	3.574	14.382	15.337
5	3.379	15.439	16.457
15	2.819	14.480	17.540
30	4.002	19.989	23.080
45	4.441	24.292	25.050
60	6.471	29.402	36.775
75	9.421	38.813	39.750
90	0.997	7.162	9.997

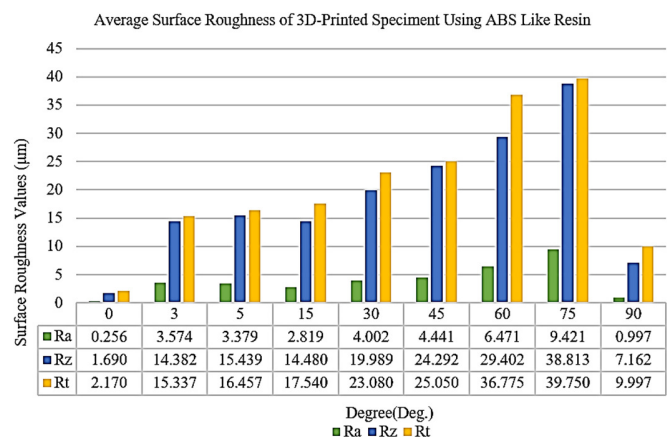


Fig. 2. Comparison of surface roughness values (Ra, Rz, and Rt) at different printing angles for ABS-like resin.

TABLE III. SURFACE ROUGHNESS VALUES FOR TR-300 RESIN

Degrees (°)	TR-300 resin		
	Ra (µm)	Rz (µm)	Rt (µm)
0	0.175	1.123	1.136
3	3.110	13.249	13.232
5	2.941	14.037	13.855
15	2.156	12.451	12.587
30	1.605	7.663	7.827
45	1.964	13.580	13.658
60	3.276	15.813	15.574
75	1.840	12.456	12.641
90	2.313	14.099	14.198

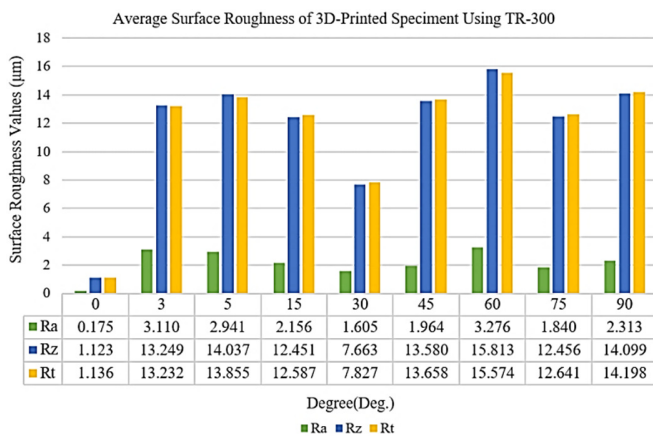


Fig. 3. Comparison of surface roughness values (Ra, Rz, and Rt) at different printing angles for TR-300 resin.

From Table II and Figure 2, it can be observed that 3D printing with ABS-like resin at 0° printing angle resulted in the smoothest surface finish, with surface roughness values of Ra = 0.256 µm, Rz = 1.690 µm, and Rt = 2.170 µm. The second smoothest result was obtained at 90°, with Ra = 0.997 µm, Rz = 7.16 µm, and Rt = 9.997 µm. Conversely, the highest surface roughness was observed at 75°, where Ra = 9.421 µm, Rz = 38.813 µm, and Rt = 39.750 µm.

From Table III and Figure 3, it can be observed that the 3D printing of TR-300 material at a 0° created the smoothest surface roughness, with measurements of Ra = 0.175 µm, Rz = 1.123 µm, and Rt = 1.136 µm. The second smoothest surface was achieved at a 30° printing angle, where Ra = 1.605 µm, Rz = 7.663 µm, and Rt = 7.782 µm. The roughest surface texture was recorded at a 60° printing angle, with Ra = 3.276 µm, Rz = 15.813 µm, and Rt = 15.574 µm. When considering the test specimens with Ra values within the recommended range for injection mold applications (0.2 to 1.6 µm), the following observations can be made: For ABS-like resin, the test specimens printed at 0° and 90° meet the recommended Ra range, with values of Ra = 0.256 µm and 0.997 µm, respectively. For TR-300 resin, the specimens printed at 0° and 30° fall within the Ra range, with values of Ra = 0.175 µm and 1.605 µm, respectively. Furthermore, given the range of Rz values recommended for mold applications (i.e., 2.5 to 16 µm), it is evident that for ABS-like resin the specimens printed at 0°, 3°, 5°, 15°, and 90° satisfy this criterion, with Rz values of 1.690 µm, 14.382 µm, 15.439 µm, 14.480 µm, and 7.162 µm,

respectively. For TR-300 resin, the specimens printed at 0°, 3°, 5°, 15°, 30°, 45°, 60°, 75°, and 90° meet this requirement, with Rz values of 1.123 µm, 13.249 µm, 14.037 µm, 12.451 µm, 7.663 µm, 13.580 µm, 15.813 µm, 12.456 µm, and 14.099 µm, respectively. These findings indicate that TR-300 resin provides a broader range of printing angles that yield acceptable surface roughness for injection mold applications compared to ABS-like resin.

B. Surface Roughness Profile Examination

In this experiment, the surface roughness profile was analyzed using a microscopic imaging technique to visualize the surface characteristics. An Olympus Inverter Metallurgical Microscope, Model GX 51, Serial 5K44107, was employed for this purpose. The microscope operated at 10x magnification with a resolution of 100x, enabling detailed examination of the surface texture of the printed specimens. The surface roughness evaluation focused on two key parameters: roughness height (Y), representing the peak-to-valley height of the roughness profile and roughness width (X), indicating the distance between adjacent roughness peaks [10, 11, 18]. These parameters were used to observe surface waviness, which plays a crucial role in determining the overall smoothness and quality of the printed surface. The experimental results are summarized in Table IV.

TABLE IV. AVERAGE INTERSECTING POINTS OF THE ROUGHNESS PROFILE FOR ABS-LIKE RESIN AND TR-300 RESIN

Degrees (°)	ABS-like resin		TR-300 resin	
	X (µm)	Y (µm)	X (µm)	Y (µm)
0	0.06	0.002	-	-
3	0.394	0.012	0.356	0.015
5	0.204	0.013	0.246	0.009
15	0.125	0.011	0.148	0.009
30	0.196	0.017	0.043	0.006
45	0.062	0.006	0.069	0.005
60	0.096	0.020	0.074	0.007
75	0.168	0.034	0.057	0.008
90	0.058	0.003	0.058	0.005

As illustrated in Figures 4 and 5, the results from the magnified surface images of the specimens printed with both materials at nine different printing angles reveal distinct surface characteristics. These surface profiles, observed under a microscope, exhibit the following features. The surface of the specimen printed with ABS-like resin at a 0° angle exhibits a smoother texture compared to those printed at other angles, as shown in Figure 3(a). In contrast, specimens printed at non-zero angles demonstrate noticeably rougher surfaces, as illustrated in Figures 3(b-i). The magnified images reveal that the surface characteristics align with the roughness measurement results obtained in Table IV. From Figure 5(a), it can be observed that the surface of the specimens printed with TR-300 resin at a 0° angle exhibits a smoother texture compared to prints at other angles. In contrast, specimens printed at non-zero angles display noticeably rougher surfaces, as illustrated in Figures 5(b-i).

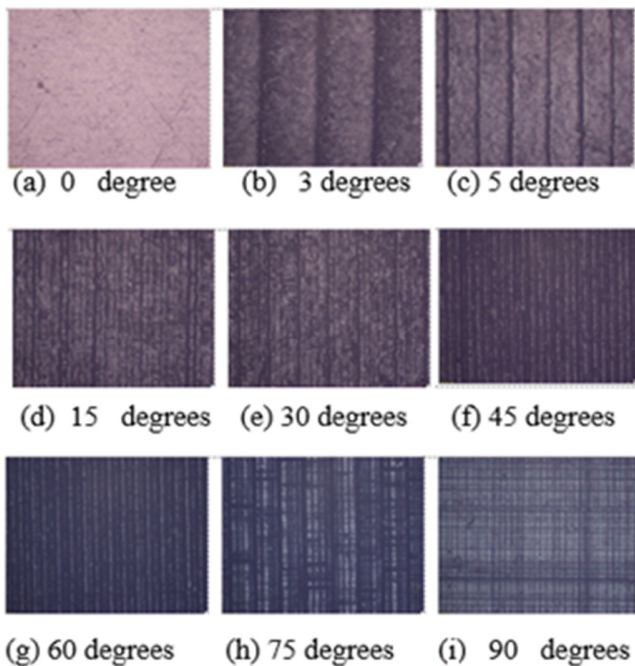


Fig. 4. Surface profiles of specimens printed with ABS-like resin at different angles.

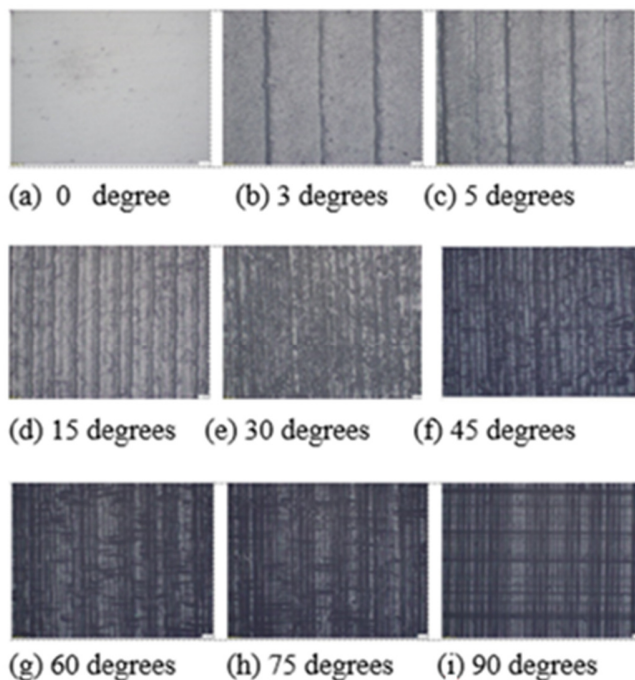


Fig. 5. Surface profiles of specimens printed with TR-300 resin at different angles.

Figure 6, which includes a 100 μm scale bar, presents a comparison of the surface textures of specimens printed using ABS-like resin and TR-300 resin at the same inclination angles across nine different levels. It is evident that TR-300 resin exhibits a smoother surface texture at almost every printing angle. This is particularly noticeable at the 0° angle, as shown

in Figure 6(a), where the TR-300 resin produces a significantly smoother surface compared to the ABS-like resin. The comparison results indicate that the surface roughness trends align with the findings in Table IV, confirming the consistency of roughness variations across different printing angles.

IV. DISCUSSION

In this experiment, the surface roughness values (R_a , R_z , R_t) of specimens printed using ABS-like resin and TR-300 resin at different printing angles were analyzed. The test results revealed a clear distinction between the two materials and demonstrated the significant influence of the printing angle on surface roughness.

A. Comparison of ABS-Like Resin and TR-300 Resin

A comparison of the R_a values for both materials reveals that TR-300 resin consistently exhibited lower surface roughness than ABS-like resin at nearly all printing angles, particularly at 0° and 30°, which resulted in the smoothest surfaces. Additionally, TR-300 resin displayed less variation in surface roughness across different printing angles, indicating more consistent print quality than ABS-like resin. The R_a values for TR-300 resin ranged from 0.175 to 3.276 μm , whereas those for ABS-like resin ranged from 0.256 to 9.421 μm . These results indicate that TR-300 resin generally produces smoother surfaces than ABS-like resin.

B. Application Based on Appropriate Surface Roughness

Based on the previously discussed recommendations for selecting surface roughness in mold manufacturing, for applications requiring high precision, such as mold production, printing with TR-300 resin at a 0° or 30° angle is most suitable. This is due to its lower R_a values, which fall within the recommended range. Similarly, ABS-like resin printed at 0° and 90° can also be used for high-precision applications; however, it exhibits higher surface roughness compared to TR-300.

C. Evaluation of Surface Smoothness

Microscopic inspection revealed the surface characteristics of both materials, supporting the measured surface roughness values. The surfaces obtained from printing at 0° exhibited the highest smoothness for both materials. TR-300 resin demonstrated a significantly smoother surface compared to ABS-like resin, particularly at printing angles greater than 30°.

D. Analysis of the Effects of Different Printing Angles on Surface Smoothness

The variation in surface smoothness at different printing angles is primarily due to factors related to the material layering process in 3D printing. The key factors affecting surface roughness at different angles are as follows:

1) Layer Deposition Direction

- At lower printing angles, material layers are deposited more uniformly in a horizontal manner, leading to a smoother surface by reducing layer line formation.
- At higher printing angles, the layers are deposited in an inclined or vertical manner, increasing the visibility of layer overlaps and making surface roughness more pronounced.

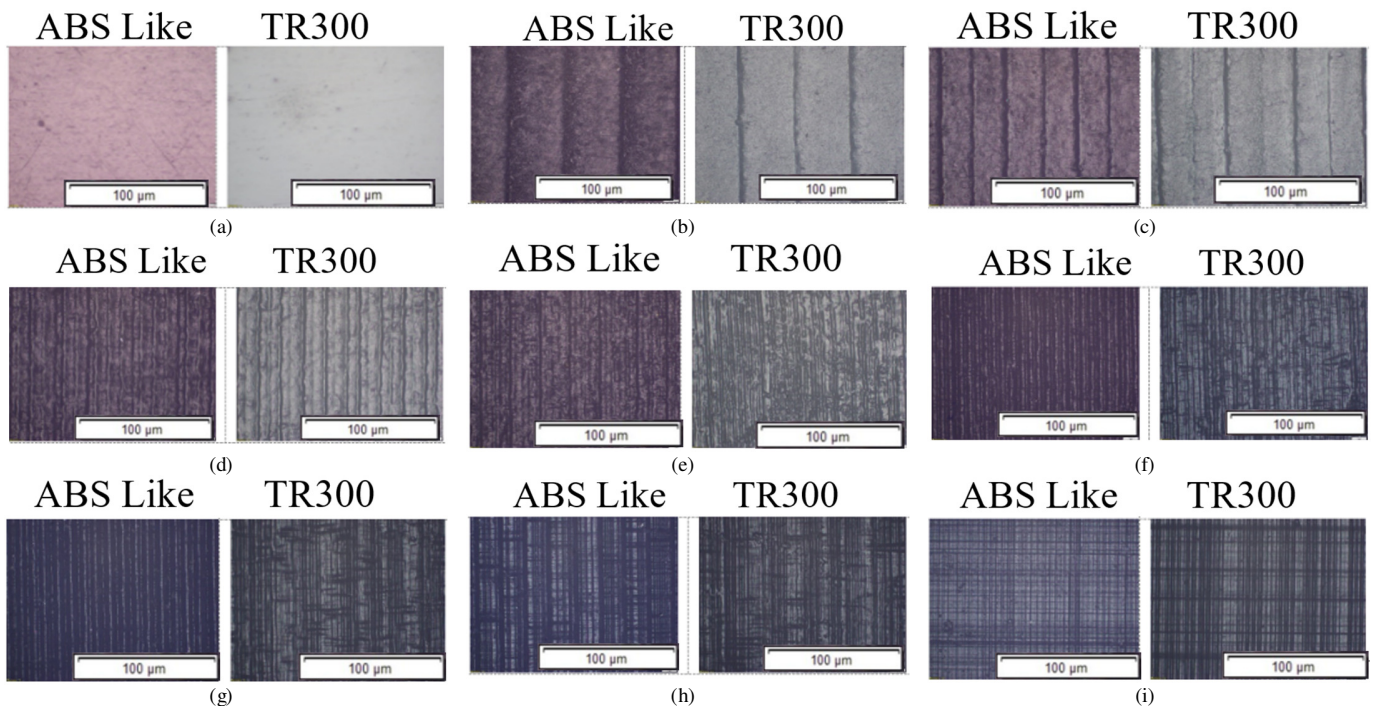


Fig. 6. Surface texture comparison of specimens printed using ABS-like resin and TR-300 resin at identical inclination angles across nine levels: (a) 0°, (b) 3°, (c) 5°, (d) 15°, (e) 30°, (f) 60°, (g) 75°, (h) 90°.

2) Resolution of Printed Objects

- Lower printing angles allow for finer layer placement, improving surface resolution, especially on the top surface of the printed object.
- Higher printing angles result in steeper material deposition, potentially causing a loss of detail and increased surface roughness due to the inability of the printer to align the material smoothly at an inclined angle.

3) Accumulation of Layering Errors

Layering errors refer to imperfections or inconsistencies that occur between successive layers during the 3D printing process. These errors can significantly affect the surface quality and dimensional accuracy of printed parts. In SLA printing, such errors are often caused by misalignment of layers due to mechanical inaccuracies or vibrations in the build platform. Inconsistent resin curing at layer interfaces, particularly in cases where exposure time or UV intensity exhibits variations, is a significant concern. In addition, peel forces are generated during layer separation from the vat's transparent bottom, potentially resulting in layer shifts or partial delamination. The presence of uneven resin flow between layers has been observed to result in the formation of trapped air bubbles or surface waves. The phenomenon of bulging or incomplete curing at layer edges is indicative of overexposure or underexposure of specific regions.

These layering errors often manifest as visible layer lines or inconsistent roughness on the surface, particularly at steeper print angles. The impact of layering errors becomes more

pronounced when printing at high angles, where the layer stacking direction is not perpendicular to the surface, increasing the stair-stepping effect and leading to higher roughness values (R_a , R_z , R_t). Therefore, optimizing the printing orientation and process parameters is critical to minimizing layering errors and achieving high surface quality:

- At lower angles, layering errors are minimized due to more compact and uniform material deposition, ensuring strong inter-layer adhesion and a smoother surface.
- At higher angles, accumulated errors between layers become more evident, leading to uneven material deposition and increased surface roughness.

4) Shrinkage and Adhesion

- Lower printing angles improve inter-layer adhesion as materials are laid down in a nearly horizontal manner, reducing the risk of uneven shrinkage or cracks between layers.
- At higher angles, differential shrinkage across layers can lead to poor adhesion, causing rougher surfaces at inter-layer junctions.

5) Effects of Gravity

- At lower angles, gravity has a minimal impact since material layers are deposited in alignment with the movement of the print head, ensuring smooth and uniform material placement.
- At higher angles, gravitational forces may pull the material in unintended directions, leading to layer misalignment,

overhang issues, or warping, which contributes to increased surface roughness.

Printing angles significantly impact the surface roughness of 3D-printed parts. It is difficult to formulate a single, precise mathematical equation that describes the relationship between printing angle and surface roughness due to the many other factors involved (e.g., material, printing technology, layer thickness). Nevertheless, the relationship between printing angle (θ) and surface roughness values (Ra, Rz, Rt) can be expressed in a general form as follows.

For TR-300 resin:

$$Ra(\theta) = -0.00013\theta^2 + 0.01579\theta + 1.89161 \quad (1)$$

$$R^2 = 0.0375$$

$$Rz(\theta) = -0.00097\theta^2 + 0.14253\theta + 8.70542 \quad (2)$$

$$R^2 = 0.2289$$

$$Rt(\theta) = -0.00098\theta^2 + 0.144\theta + 8.6901 \quad (3)$$

$$R^2 = 0.2407$$

For ABS-like resin:

$$Ra(\theta) = -0.00175\theta^2 + 0.18185\theta + 1.38837 \quad (4)$$

$$R^2 = 0.4215$$

$$Rz(\theta) = -0.00869\theta^2 + 0.89115\theta + 6.23219 \quad (5)$$

$$R^2 = 0.5823$$

$$Rt(\theta) = -0.00968\theta^2 + 0.99788\theta + 6.91877 \quad (6)$$

$$R^2 = 0.6510$$

where:

- $Ra(\theta)$, $Rz(\theta)$, and $Rt(\theta)$: Mathematical functions that represent the surface roughness values Ra, Rz, and Rt, respectively, as a function of the printing angle (θ). Substituting a value for the angle (θ) into the equation results in the predicted surface roughness value at that angle.
- θ : Variable representing the printing angle (in degrees).
- -0.00013, 0.01579, and 1.89161: These are the constants or coefficients of (1), derived from statistical analysis (quadratic regression) to make this quadratic equation "best fit" the data measured in the laboratory. The constants for the remaining equations have been determined in a similar manner.
- R^2 (coefficient of determination): This is a value that indicates how well the mathematical equation explains the variance in the data. An R^2 value close to 1 indicates that the equation explains the data very well. An R^2 value close to 0 indicates that the equation does not explain the data well.

The R^2 values in these equations are notably low, indicating that the data may have high variability, or the relationship between the angle and surface roughness may not be a clear

parabola. In other words, these equations may not be the best representation of the true relationship.

In conclusion, it is evident that the printing significantly impacts the layering process and the resulting surface texture. This is due to various factors, including material distribution, adhesion between layers, error accumulation, and gravitational effects. Selecting the appropriate printing angle is essential to controlling surface roughness and achieving the desired level of surface precision for specific applications.

V. CONCLUSION

The present study demonstrates that, when utilized with appropriate printing parameters, Stereolithography (SLA) 3D printing technology is capable of producing insert molds for plastic injection molding, resulting in surface roughness that is suitable for the intended application. The study revealed that TR300 resin consistently provides a smoother surface finish compared to Acrylonitrile Butadiene Styrene (ABS)-like resin across all printing angles. The optimal surface finish was achieved using TR300 resin at a 0° printing angle, resulting in roughness values of $Ra = 0.175 \mu\text{m}$, $Rz = 1.123 \mu\text{m}$, and $Rt = 1.136 \mu\text{m}$. For ABS-like resin, the smoothest surface was also obtained at a 0° printing angle, with the following surface roughness parameters: $Ra = 0.256 \mu\text{m}$, $Rz = 1.690 \mu\text{m}$, and $Rt = 2.170 \mu\text{m}$.

These findings suggest that TR300 resin printed at a 0° angle is the most suitable condition for producing high-quality insert mold cavities for plastic injection molds, as the surface roughness falls within the recommended range ($Ra = 0.2\text{-}1.6 \mu\text{m}$) for precision applications in injection molding. In future work, this research can be used to optimize 3D printing parameters for various materials and applications, enhancing the utilization of Additive Manufacturing (AM) in producing high-quality components with specific surface finish requirements.

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