JOURNAL OF PHYSICS AND TECHNOLOGY

Volume 6 (2025) Number 1, pp. 39-43

INVESTIGATION OF THE ROUGHNESS OF INCLINED SURFACES IN 3D PRINTING WITH DIFFERENT LAYER THICKNESS

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Keywords:

roughness,
inclined surfaces,
layer thickness

Submitted on:
16.12.2024

Accepted on:
04.08.2025

Abstract:

In this paper, a research is presented to determine the influence of surface inclination and layer thickness on the surface roughness of 3D printed parts. Test samples of PLA material with different tilt angles and layer thicknesses were prepared. Surface roughness was measured using a Mitutoyo SJ-210 instrument. The data obtained from the research can be used to optimize 3D printing processes. Different slopes and layer thicknesses have been shown to affect the roughness of 3D printed surfaces. Optimizing these parameters to the design and part finish requirements can significantly improve surface quality in 3D printing.

1. INTRODUCTION

3D printing, also known as additive manufacturing, has established itself as a versatile tool for creating complex geometries, prototypes and final products. One of the biggest challenges in achieving high-quality 3D printed products remains the control of surface roughness, a characteristic that affects both the aesthetic and functional properties of the printed part [2, 3]. Surface roughness depends on a number of factors, including the material, layer thickness, and slope of the printed surfaces. Understanding these interrelationships is key to optimizing the process and meeting specific design requirements [7, 10].

Inclined surfaces are a particular challenge in 3D printing. As the tilt angle increases, the interaction between the printer nozzle and the part surface changes, which significantly affects the final surface quality [4, 14]. In addition, layer thickness - a parameter that determines the height of each printed layer plays an important role in resolution and surface smoothness [1, 15]. Greater layer thickness results in faster production [9, 11, 12] but may compromise surface layer quality, while less thickness improves roughness but increases print time [6, 8].

The present study focuses on the influence of surface slope and layer thickness on the roughness of 3D printed articles [5] produced with polylactic acid (PLA) – a widely used thermoplastic in additive manufacturing [13]. By analyzing these variables, the research aims to offer guidelines for optimizing the 3D printing process, which will contribute to achieving better surface quality and functional characteristics of the printed components.

2. EXPERIMENTAL CONDITIONS AND METHODOLOGY

CAD models of test specimens were created for the present study. Each specimen was modeled to include a specific slope to the vertical axis, with slope values varying over a pre-set range in 10° increments, with a maximum value of 40°, **Fig. 1**. The values thus chosen provided maximum points for analyzing the relationship between slope and roughness.

The samples were made with a Creality KC1 printer, which is known for its high print speed of up to 600 mm/s and the stable CoreXY construction, ensuring precision and high accuracy in complex details. It is equipped with a "clog-free" extruder and a quick-change "Unicorn" tri-metal tip, which facilitates maintenance and makes working with different materials more productive. The built-in AI camera and automatic calibration further increase convenience and reliability by monitoring the print and optimizing settings. Supports printing with composite materials such as CF filaments suitable for industrial applications.

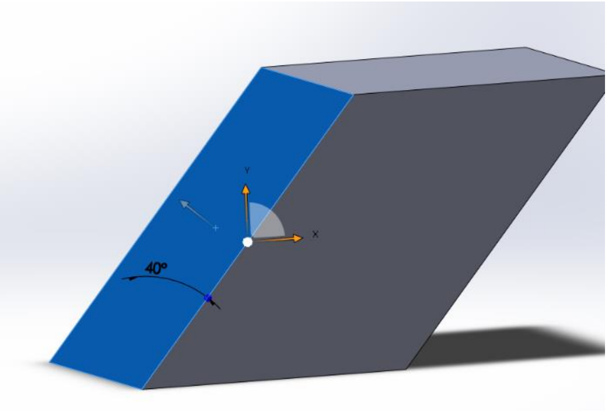

Fig. 1 CAD model of a specimen with a 40° deviation from the vertical axis.

Based on the created CAD models, samples were printed in four series, each with a different layer thickness of 0.08 mm, 0.16 mm, 0.20 mm and 0.24 mm, **Fig. 2**. This allows to simultaneously analyze the influence of layer thickness and surface slope on the roughness value.

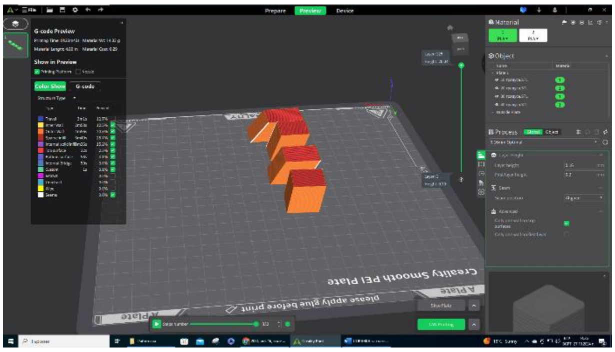

Fig. 2 Set print parameters.

To achieve uniform printing conditions, the parameters - nozzle temperature, printing speed and filling density are constant. This ensures uniformity in the printed samples within each run, creating a reliable basis for roughness analysis depending on the layer thickness and the slope of the surfaces. To eliminate material-related biases, the same PLA filament was used for all series of printed samples. This ensures that the values obtained in the roughness measurements are the result of the change in the printing parameters and not the differences in the material properties. PLA (polylactic acid) was chosen for the fabrication of the samples, which is biodegradable and due to its easy processing, low melting temperature and good mechanical properties is widely used in 3D printing.

The fabricated samples can be seen in **Fig. 3**.

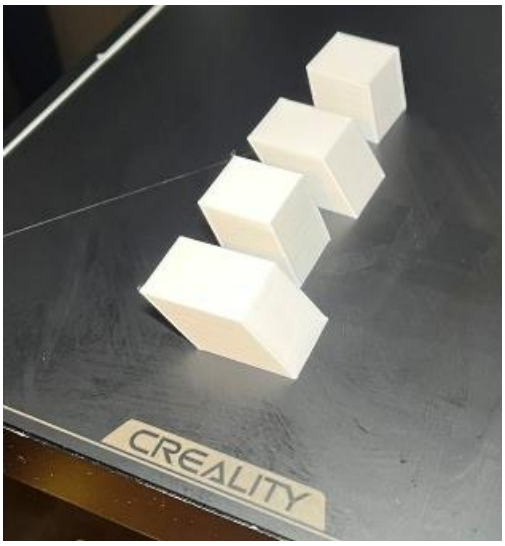

Fig. 3 Printed PLA samples.

A Mitutoyo Surftest SJ-210 roughness meter was used to measure the surface roughness of the printed samples, **Fig. 4**. It has a color LCD display providing a clear visualization of the results, works according to JIS, ISO, ANSI and VDA, which ensures compatibility with global requirements for measurements.

Fig. 4 Mitutoyo SJ 210 roughness tester.

For each series of samples, the parameters Ra, Rz and Rq were measured on the surfaces with dif-

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ferent slopes. Ra is the most commonly used roughness parameter and is defined as the arithmetic mean of the absolute deviations of the profile height from the midline within the gauge length. Rz describes the difference between the highest peak and the deepest valley within the measurement length. Rq is the statistical measure of the deviations of the surface from its mean line. It is used to characterize the texture of the surface and provides a more accurate estimate of its roughness compared to other parameters.

For each series of samples, five measurements were taken and the values were averaged.

3. RESULTS AND SUMMARIES

The averaged results of the conducted studies are presented in Table 1, and the graphical onesdependencies Ra, Rz and Rq of layer thickness at the investigated slope values is shown in **Fig. 5**, **Fig. 6**, **Fig. 7** and **Fig. 8**.

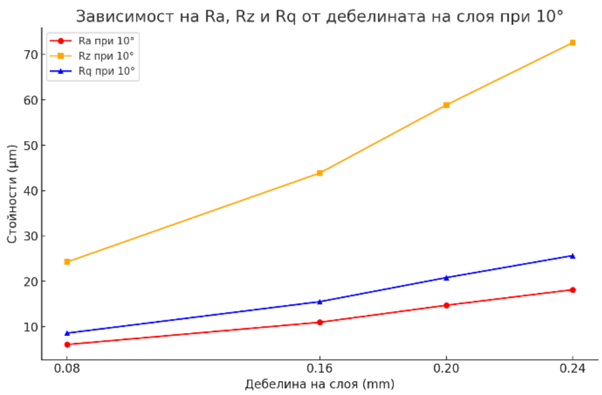

Fig. 5 Graphical dependency analysis Ra, Rz and Rq of layer thickness at 10° deviation from the vertical.

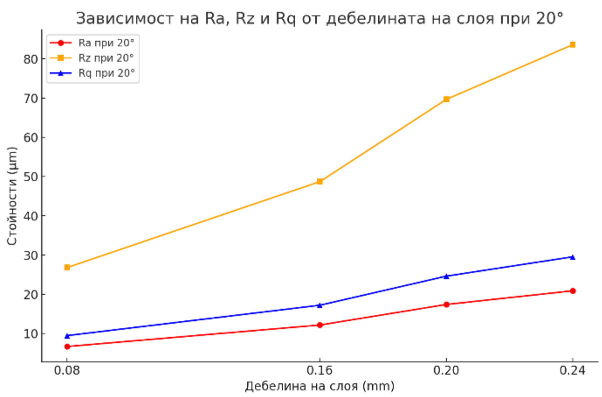

Fig. 6 Graphical dependency analysis Ra, Rz and Rq of layer thickness at 20° deviation from the vertical.

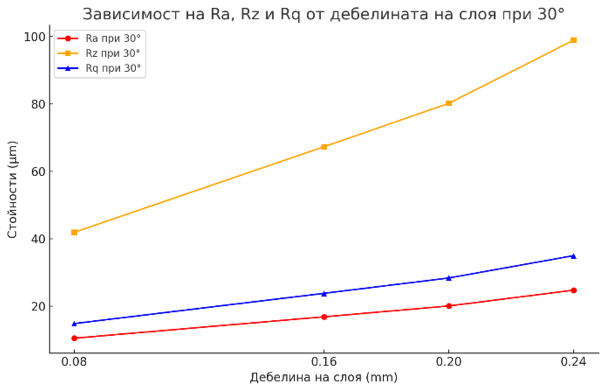

Fig. 7 Graphical dependency analysis Ra, Rz and Rq of layer thickness at 30° deviation from the vertical.

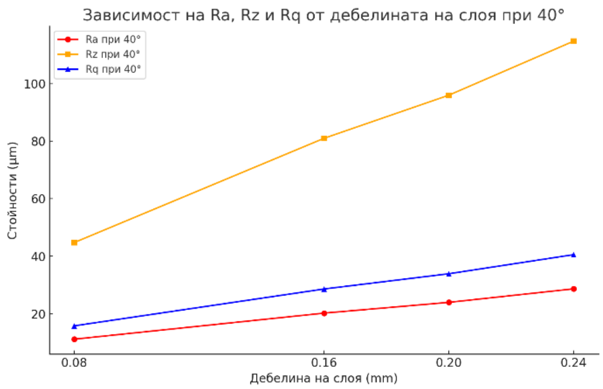

Fig. 8 Graphical dependency analysis Ra, Rz and Rq of layer thickness at 40° deviation from the vertical.

Analyzing the data, it is evident that the increase in thickness leads to a significant increase at all investigated tilt angles. For the smallest layer thickness (0.08 mm) the values of Ra vary between 6.07 µm and 11.19 µm, while at 0.24 mm they reach 18.15 µm to 28.67 µm. The analysis shows that Rz and Rq follow a similar trend, Rz reaches maximum values of 118.99 µm at 0.24mm and an angle of 40°, while Rq for the same parameters it has a value of 33.79 µm.

Table 1. Average values of the roughness in the conducted studies.

Layer thickness, mm	**Values of the slope of the surface relative to the vertical axis, µm**											
	10°			20°			30°			40°		
	Ra	Rz	Rq	Ra	Rz	Rq	Ra	Rz	Rq	Ra	Rz	Rq
0.08	6.07	33.81	7.43	6.70	37.72	8.19	10.48	61.43	12.84	11.19	62.38	13.62
0.16	10.97	52.94	13.20	12.18	58.93	14.54	16.82	86.55	20.33	20.23	87.46	23.55
0.20	14.72	70.08	17.62	17.41	80.95	20.72	20.05	90.95	23.72	23.98	100.58	27.92
0.24	18.15	80.64	21.58	20.90	94.12	24.83	24.74	108.18	29.17	28.67	118.99	33.79

Research results prove that different slopes and layer thicknesses affect the roughness of surfaces in 3D printing. At smaller slopes (10° and 20°), the roughness remains relatively low, even as the layer thickness increases. Optimizing these parameters to the design and part finish requirements can significantly improve surface quality in 3D printing.

4. CONCLUSION

Current research shows the influence of surface slope and layer thickness on surface roughness in 3D printing with PLA material. Research data can be used to optimize 3D printing processes. Different slopes and layer thicknesses have been shown to affect the roughness of 3D printed surfaces. Optimizing these parameters to the design and part finish requirements can significantly improve surface quality in 3D printing.

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