CONTRIBUTION TO SURFACE TEXTURE CHARACTERIZATION OF 3D PRINTED PARTS

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Abstract

The paper deals with the evaluation of the surface texture of parts produced by material extrusion-based 3D printing technology (FDM/FFF). Samples from PETG material were used for evaluation. The surface texture was evaluated after printing and after the ironing process of the last printed layer. Ironing was carried out using ironing at an angle of 45° with different line spacing parameters. The parameters selected to evaluate the surface texture were the height parameter Ra (arithmetic mean height), Rz (maximum height), Rpt (maximum peak height), and Rvt (maximum pit depth). The selected surface texture parameters lead to the characterization of surface texture changes that occur after the ironing process (reduction of protrusion height, filling of depressions, reduction of surface roughness) and that affect its functional properties (reflectivity, adhesion). This paper presents one possible approach to evaluate stratified surfaces produced by 3D printing and subsequent post-processing, which leads to a significant change in surface texture.

Keywords: 3D printing, surface texture, PETG, ironing

1. INTRODUCTION

Additive manufacturing (AM), commonly known as 3D printing, constructs three-dimensional objects by incrementally adding materials layer by layer to achieve the desired form. 3D printing avoids the need for physical equipment alterations post-design, revolutionizing time-consuming and labor-intensive manufacturing processes. Additionally, AM reduces material waste compared to subtractive manufacturing approaches [1-3].

Fused Deposition Modelling (FDM) or Fused Filament Fabrication (FFF) is one of the most widely used 3D printing technologies due to its simplicity, affordability, and versatility [4-6]. Among the diverse materials available for FDM/FFF printing, one of the most commonly used materials in this printing technology is PETG which stands out as a prominent polymer in the realm of 3D printing materials due to its versatile properties. PETG offers a unique combination of attributes, including compatibility with lower printing temperatures, low tendency to shrinkage, and resistance to humidity and chemicals, which enhances its suitability for a wide range of applications [7].

Despite the numerous advantages of FDM/FFF technology, a common challenge is the surface quality of the printed objects. The layer-by-layer construction inherent in this technology often results in visible layer lines and surface roughness. These surface imperfections can affect the aesthetic appeal, mechanical performance, and functional properties of the printed parts, particularly in applications requiring smooth surfaces or tight tolerances [8-10].

To address the issue of surface roughness, ironing treatment is employed as an effective post-processing technique. Ironing involves the printer's hot end making additional passes over the top layers of the print, melting and smoothing the material to reduce the appearance of layer lines and enhance the surface finish. This method significantly improves the surface quality of 3D printed objects, making them more suitable for applications demanding higher aesthetic and functional standards [8-10].

Assessing and quantifying surface quality is crucial for ensuring consistency and meeting industry specifications. Among the various standards available, ISO 21920 is widely used for its comprehensive approach and numerous advantages. ISO 21920 provides clear guidelines for measuring and interpreting surface texture, ensuring that surface roughness measurements are consistent and comparable across different settings. This standard includes methods for capturing detailed surface profiles and evaluating key parameters, which help manufacturers maintain high quality and performance in their printed parts.

2. MATERIALS AND METHOD

In the present study, PETG purchased from Devil Design was employed. The Bambu Lab X1-Carbon 3D printer (Bambu Lab, Shenzhen, China) was used to manufacture simple square samples of (30×30×5) mm to analyse the effects of different ironing parameters. Bambu Studio was used to generate G-code files and to control all the process parameters. Two different ironing parameters ironing line spacing, and ironing flow were used. The chosen ironing pattern was rectilinear. Furthermore, the sample without the use of ironing was also manufactured to provide a comparison with the ironed samples. The extrusion temperature and bed temperature of all samples were set at 250°C and 80°C. Other printing parameters, such as layer thickness were set to 0.2 mm, the infill density was set at 100%, the infill direction 0º, the printing speed was set at 100 mm/s, and the ironing speed was set at 30 mm/s. The combinations of different ironing parameters used in this study are shown in **Table 1**.

Table 1 Ironing process parameters

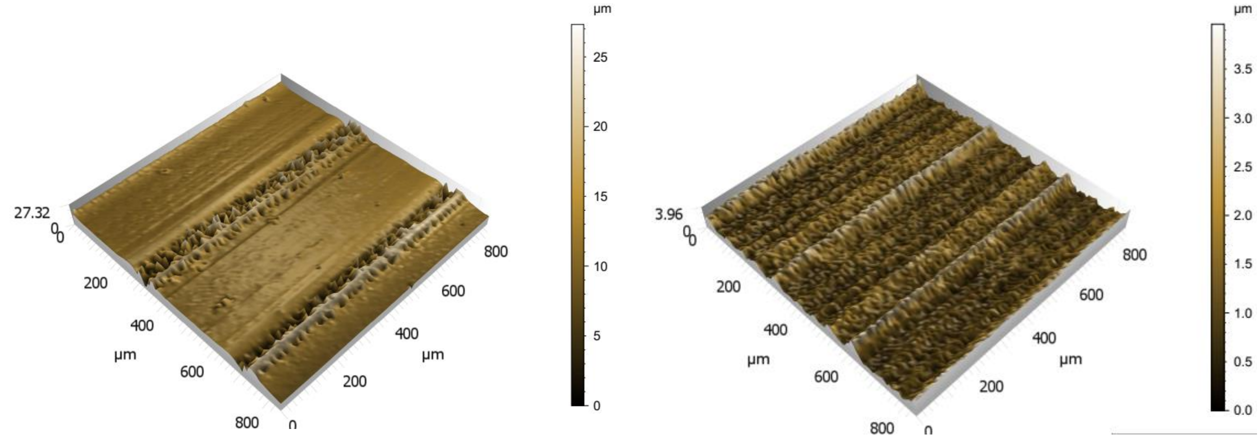
Sample	**Ironing flow** (%)	**Ironing line spacing** (mm)	**Sample**	**Ironing flow** (%)	**Ironing line spacing** (mm)
A1	10	0.05	B3	15	0.15
A2	10	0.10	C1	20	0.05
A3	10	0.15	C2	20	0.10
B1	15	0.05	C3	20	0.15
B2	15	0.10	D-Non-ironed	x	x

The surface texture analysis was conducted using a Talysurf CCI-Lite (Taylor Hobson, Leicester, UK) with 20 times magnification and a resolution of 0.1 nm. Several surface parameters of the samples were quantitatively measured at the micrometer level. These amplitude parameters include the height parameter Ra (arithmetic mean height), Rz (maximum height), Rpt (maximum peak height), and Rvt (maximum pit depth). These measurements were evaluated using Talysurf Platinum and Altimap (both from Digital Surf, Besancon, France) following the ISO 21920-1:2021, ISO 21920-2:2021 and ISO 21920-3:2021 standards. Other parameters to consider in the analysis of surface roughness include the size of the analyzed area (0.8 x 0.8) mm, the number of measured profiles (1024), the evaluation length (le) for the 2D roughness profile (0.8 mm), the section length (lsc) (0.25 mm). Measurements were filtered using the Gauss method with a nesting index (cut-off) of 0.25 mm.

3. RESULTS AND DISCUSSION

Figure 1 compares the PETG sample's surface texture with ironing and without ironing treatment. The use of ironing treatment has been observed to significantly reduce the surface roughness of PETG materials after 3D printing, as shown in **Figure 2**. There has been a considerable reduction in the product samples' *Rz* and *Ra* parameters.

Samples without ironing treatment exhibit significantly higher *Ra* and *Rz* values compared to samples treated with ironing. For instance, the *Rz* value of the non-ironed sample measures 13.95 µm, which is 229% higher than sample B1 with the largest *Rz* value among the ironing-treated samples, which has a value of 4.24 µm. Additionally, it is 6.5 times higher for sample A2, which has the smallest *Rz* value among the ironing-treated samples, measuring at 2.15 µm. Regarding the Ra parameter, sample C3 possesses the smallest *Ra* value among the ironing-treated samples, measuring at 0.37 µm, which is 170% smaller than the non-ironed sample with a *Ra* value of 1.17 µm.

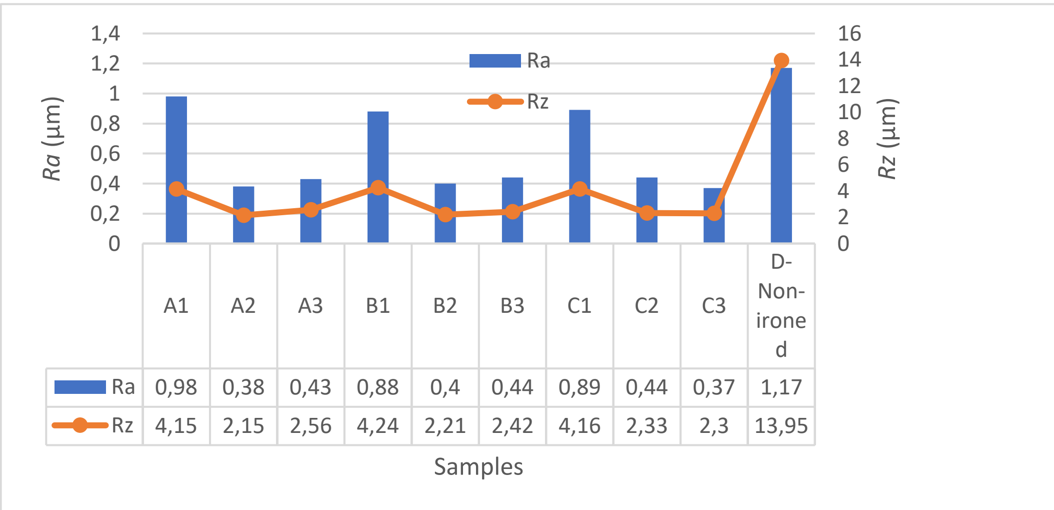


(a) (b)

Figure 1 3D surface texture of the samples (a) without ironing, (b) using ironing treatment

Figure 2 shows that the lowest surface roughness values of *Rz* and *Ra* parameters were observed for samples C3 which used a line spacing of 0.15 mm and an ironing flow of 20%. This suggests that the surface quality of 3D-printed objects can be significantly improved by optimizing these two parameters. The ironing flow refers to the amount of material that is supplied during the ironing process. With a higher ironing flow rate, more material is deposited onto the surface during the ironing process. This increased material flow helps to fill in gaps and irregularities, resulting in a more uniform surface texture and reduced roughness parameters.

Theironing line spacing, which refers to the distance between the ironing printed lines, also plays a crucial role in determining the surface quality. A larger ironing line spacing allows for smoother movements of the ironing tool over the printed surface. This process reduces irregularities and reduces the overall roughness of the surface, resulting in lower *Ra* and *Rz* values.



	A1	A2	A3	B1	B2	B3	C1	C2	C3	D-Non-ironed
Ra	0,98	0,38	0,43	0,88	0,4	0,44	0,89	0,44	0,37	1,17
Rz	4,15	2,15	2,56	4,24	2,21	2,42	4,16	2,33	2,3	13,95

Figure 2 Roughness surface

Furthermore, in assessing the effect of ironing line spacing on the *Ra* and *Rz* parameters, an increase in line spacing from 0.05 mm to 0.15 mm tends to result in a decrease in both *Ra* and *Rz* values. This phenomenon can be analysed based on several factors. Firstly, the increase in line spacing leads to a reduction in the density of surface features, resulting in fewer peaks and valleys per unit area. Consequently, this fosters a smoother overall surface profile, leading to lower Ra (average surface roughness) and *Rz* (maximum height) values. Secondly, wider line spacing diminishes the frequency of interactions between surface asperities, thereby reducing the prominence of height variations on the surface and contributing to lower *Ra* and *Rz* values. Additionally, the greater line spacing facilitates a more uniform redistribution of material during the ironing process, fostering surface evenness and minimizing extreme height variations that typically lead to higher *Ra* and *Rz* values.

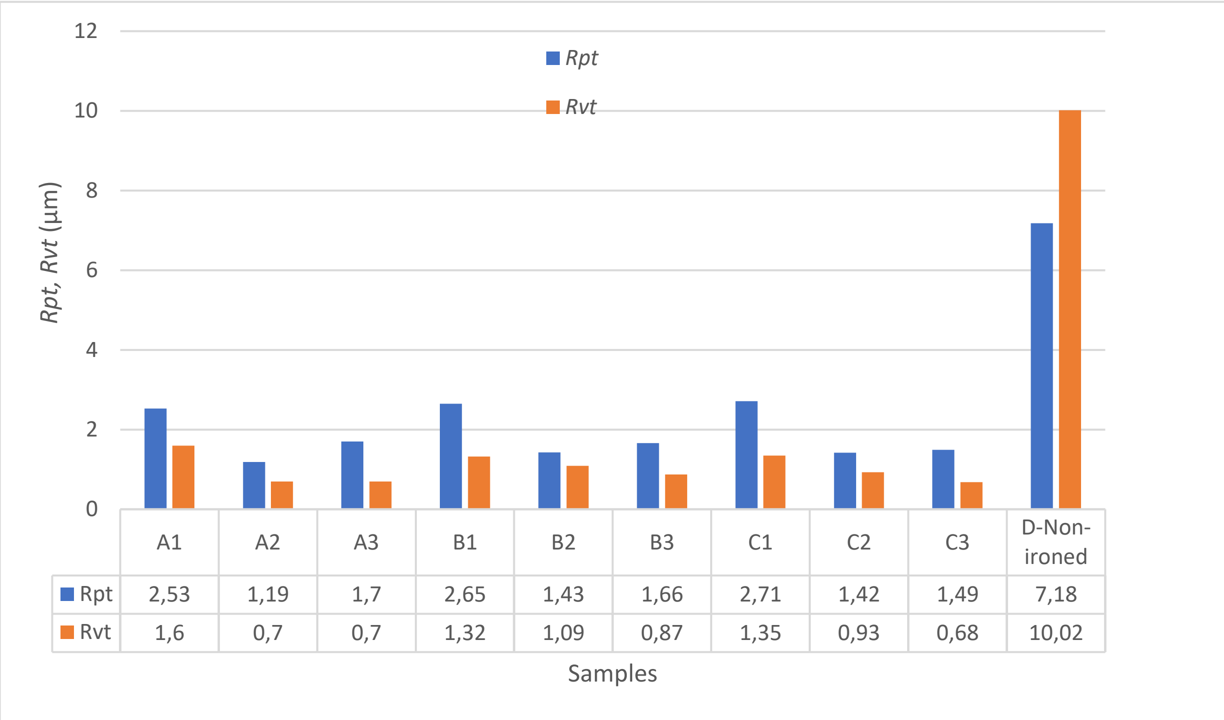


Figure 3 *Rpt*, *Rvt* assessment

Figure 3 shows the comparison of *Rpt* (maximum peak height) and *Rvt* (maximum pit depth) of different samples. The decreasing trend of *Rpt* and *Rvt* roughness values as ironing line spacing increases from 0.05 to 0.15 mm aligns with previous observations. The impact of ironing line spacing on *Rpt* and *Rvt* mirrors that of *Ra* and *Rz*, as discussed earlier.

However, analysing the effect of ironing flow on *Rpt* and *Rvt* demonstrates a notable difference. Specifically, as ironing flow increases from 10% to 20%, *Rpt* tends to increase while *Rvt* tends to decrease. The *Rpt* values for samples A1, B1, and C1 gradually increased to 2.53 µm, 2.65 µm, and 2.71 µm, respectively, with ironing flow at 10%, 15%, and 20%, respectively. Conversely, the *Rvt* value decreased from 1.6 µm for sample A1 to 1.32 µm for sample B1 and 1.35 µm for sample C1.

The effect of ironing flow on *Rpt* (maximum peak height) can be observed. An increase in ironing flow leads to a higher deposition rate of material onto the surface. This heightened material accumulation can result in the formation of more pronounced peaks on the surface, thereby increasing *Rpt*. Essentially, a greater ironing flow may contribute to the build-up of material, resulting in elevated peak heights.

Conversely, an increase in ironing flow facilitates more efficient material distribution and filling of surface dales and pits. This enhanced material flow helps to mitigate the depth of pits and irregularities on the surface, leading to a reduction in *Rvt*. As more material is deposited, it fills in the depressions, resulting in shallower pits and decreased *Rvt* values.

In summary, while the trend of decreasing *Rpt* and *Rvt* values with increasing ironing line spacing is consistent, the effect of ironing flow on these parameters presents a distinct pattern. As ironing flow increases, Rpt tends to rise due to increased material deposition, while *Rvt* tends to decrease as more material fills in surface irregularities, resulting in shallower pits.

4. CONCLUSIONS

In conclusion, the analysis of surface roughness parameters, including *Ra*, *Rz*, *Rpt* and *Rvt* in relation to ironing line spacing and ironing flow, reveals several significant findings.

Firstly, an increase in ironing line spacing from 0.05 mm to 0.15 mm leads to a consistent decrease in both *Ra* and *Rz* values. This trend indicates that wider line spacing results in smoother surfaces with reduced average roughness and maximum height variations.

Furthermore, the effect of ironing flow on surface roughness parameters differs. While Rpt tends to increase with higher ironing flow rates, *Rvt* tends to decrease. This indicates that elevated material deposition rates contribute to increased peak heights (*Rpt*) but shallower pit depths (*Rvt*), resulting in a nuanced impact on surface texture.

Additionally, the comparison between samples with and without ironing treatment underscores the effectiveness of ironing in improving surface quality. Samples subjected to ironing treatment consistently exhibit lower *Ra* and *Rz* values compared to untreated samples, emphasizing the importance of ironing in enhancing surface smoothness and uniformity.

Overall, optimizing ironing parameters, including line spacing and flow rate, plays a crucial role in achieving desired surface characteristics in 3D-printed objects. Understanding the nuanced effects of these parameters on surface roughness parameters enables informed decision-making for improved surface quality and performance in various applications.

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