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QUALITY ASSESSMENT IN PETG 3D PRINTING

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Abstract

Nowadays, 3D printing has become more popular due to advancements in printing technology and materials. Nevertheless, it is necessary to continue expanding our understanding about it, as having a better comprehension of the relationship between printing parameters and part quality improves material use, energy consumption, and time efficiency. Furthermore, it can foster greater confidence in this manufacturing process. In this context, this study presents a quality assessment of PETG parts printed by Fused Filament Fabrication (FFF). The objective of this study is to contribute to this matter by describing the quality of PETG-printed parts produced with a cold bed printer under specific settings (temperature, speed, piece length, and infill percentage). It was identified that, under different conditions, warpage was the most prevalent defect in the experimental probes used. Qualitatively, it was observed that the surface finish was better at a lower speed (100 mm/min). In all conditions, parts with dimensions larger than the nominal dimensions were obtained. Comparatively, the smaller dimensions appear to be further away from the nominal value. The results observed imply that the CAD models must be adjusted to achieve a higher level of accuracy in the final dimensions of the product.

Keywords: 3D printing; defects; PETG; quality; FDM; FFF.

1. Introduction

At the present time, 3D printing is part of our life, as it has become more popular due to advancements in printing technology and materials. The market offers a wide range of prices for equipment and supplies, and there are technologies that do not require special installation or training for use. It is also worth noting that 3D printing has found applications in several different fields, including medicine, engineering, education [1] and more.

One of the most widely used technologies is Fused Deposition Modelling (FDM), a term trademarked by Stratasys [2], which is also known as Fused Filament Fabrication (FFF). This process entails passing a filament through an extruder, whereby the filament is softened to create the product layer by layer. The filament is typically composed of a polymeric material; however, composite filaments (fibre-reinforced polymers) are already commercially available.

Research has been done on different aspects of the FFF process. Some studies have explored mechanical properties such as tensile strength [3], hardness and flexural strength. In this respect, finding out how printing parameters affect these properties has been of particular interest [4], [5]. This has also included analysing post-processing operations [6], such as acetone chambering or heat treatment.

In addition to the mechanical properties of the product, it has also been relevant to evaluate the extent to which the final geometry aligns with the desired design specifications. Accuracy [2], and precision [7] are two variables that have been also deemed important.

Other studies have been conducted with the vision of identifying new applications for the 3D printing process. It has been discovered, for instance, that the process can be used to create laminates comprising different materials [8], or to print on a substrate [9].

Nevertheless, it is necessary to continue improving the understanding about it. Good comprehension of the printing process improves part quality, material use, energy consumption, and time efficiency. Furthermore, it can foster greater confidence in this manufacturing process.

Although the use of heated bed printers is recommended for printing PETG parts, certain circumstances may motivate the use of cold bed technology, such as the unavailability of heated bed printers or the need to print larger components. Additionally, based on prior empirical experience, quality issues can occur when using this technology to print large parts with the same printer settings that do not produce defects in smaller parts. Therefore, it is important to understand the quality of parts produced in this context. The objective of this study is to contribute to this matter by describing the quality of PETG-printed parts produced with a cold bed printer under specific settings (temperature, speed, piece length, and infill percentage). In the context of the study, quality was understood as the absence of visual defects—such as warping, delamination, and poor adhesion in the top layer—as well as compliance with the expected dimensions of the printed pieces.

2. Experimental Procedure

A part was designed and printed to observe defects and measure different dimensions (Fig. 1). Sixteen pieces were made setting eight treatments (eight combinations of temperature, speed, and infill, as detailed in Table 1). Layer height was a held-constant variable (0.15 mm). The material used was a PETG filament (diameter 1.75 mm) from Zhuhai Sunlu Industrial Co. A BQ Witbox 2 3D printer with cold plate was used. Printing trajectories were programmed using Ultimaker Cura v.5.7.1. The part was oriented at 45° measured from the x-axis to obtain the longest possible travels (Fig. 2) as previous experience had shown that long paths led to defects.

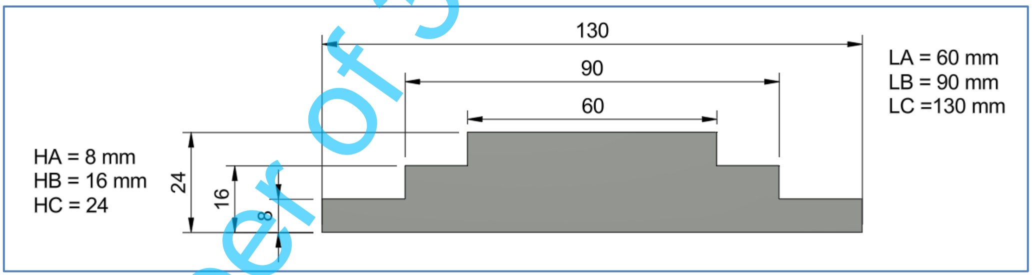

Fig. 1. Specimens dimensions.

Temperature (ºC)	Print speed (mm /min)	Infill (%)
220	100	10
235	200	30

Table 1. Printing conditions

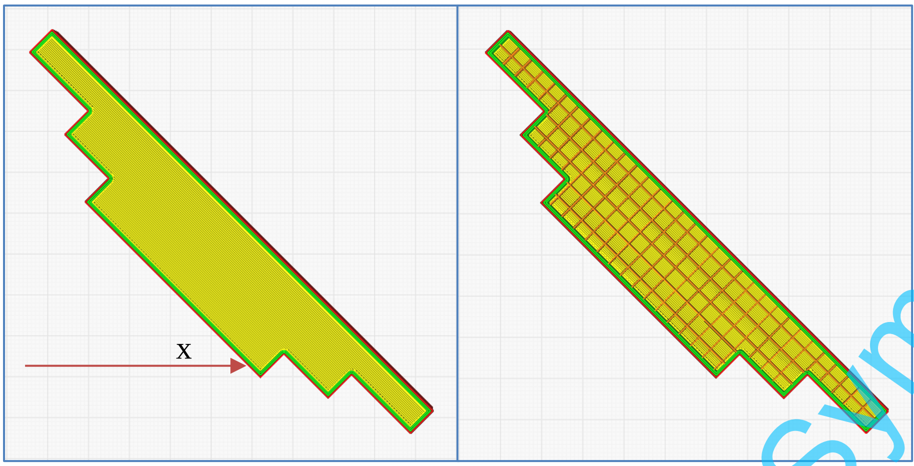

Fig. 2. Printing orientation and type of infill

The printed parts were checked for defects and measured. Three heights and three lengths were measured for each part. The heights and lengths were plotted to identify trends. One limiting condition experienced was maintaining a uniform working temperature in the equipment. This was issue was particularly observed when operating near the maximum configurable printer limit (240 °C).

3. Results and Discussion

3.1. Qualitative analysis

Each specimen was subjected to a visual inspection to identify any defects (Fig. 3). It is important to consider that the visual inspection used to assess defects may have limitations in sensitivity or accuracy. The most prevalent defects observed were warping and warpage. Less frequently, delamination was also noted. In a few instances, waviness of the layers was also observed. Warpage was observed in every piece (Fig. 4).

Fig. 3. Some defects identified: (A) warping, (B) delamination, and (C) waviness.

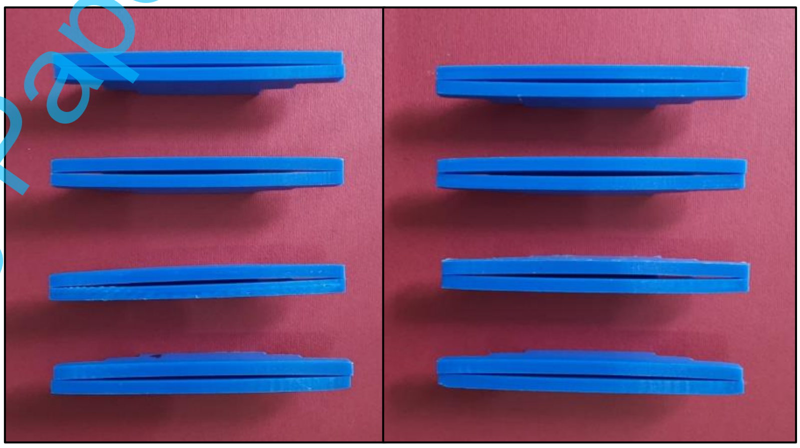

Fig. 4. Warpage in printed parts

Warpage is often attributed to residual stresses that are generated by different causes. In this instance, the deformation may be attributed to the discrepancy in cooling rates between the layers built on the bed and those deposited on top of other layers. In [10] the problem of these cooling rate differences is discussed extensively. In that study, it was observed that increasing the speed resulted in the bottom and top layers exhibiting a 15% and 13% decrease in residual stress, respectively; a drop-in warpage (~30%) was observed for both layers.

In terms of surface finish, printing speed appears to be a key parameter. A better finish on the top layer was observed for parts produced at a lower speed (100 mm/min). This contrasts with the findings of the [11] study, which indicate that higher speeds (150 m/min) result in superior surface quality. It should be noted that in the case of [11], the material was PLA, whereas in the current study, it is PETG, and printing speed is considerably higher than it would be typically used for this material. It may be necessary to operate at this high speed to reduce the time required for printing and to exploit the properties of PETG. It is important to note that the decision to proceed under these conditions will inevitably result in a compromise of surface quality.

3.2. Quantitative analysis

To perform a quantitative assessment, the difference between the measured value and the nominal was calculated. Fig. 5 illustrates the magnitude of each discrepancy. The measured dimensions were larger than the nominal dimensions in all cases. It can also be seen that, with a few exceptions, the smaller dimensions (HA, HB, HC) are further away from their respective nominal values.

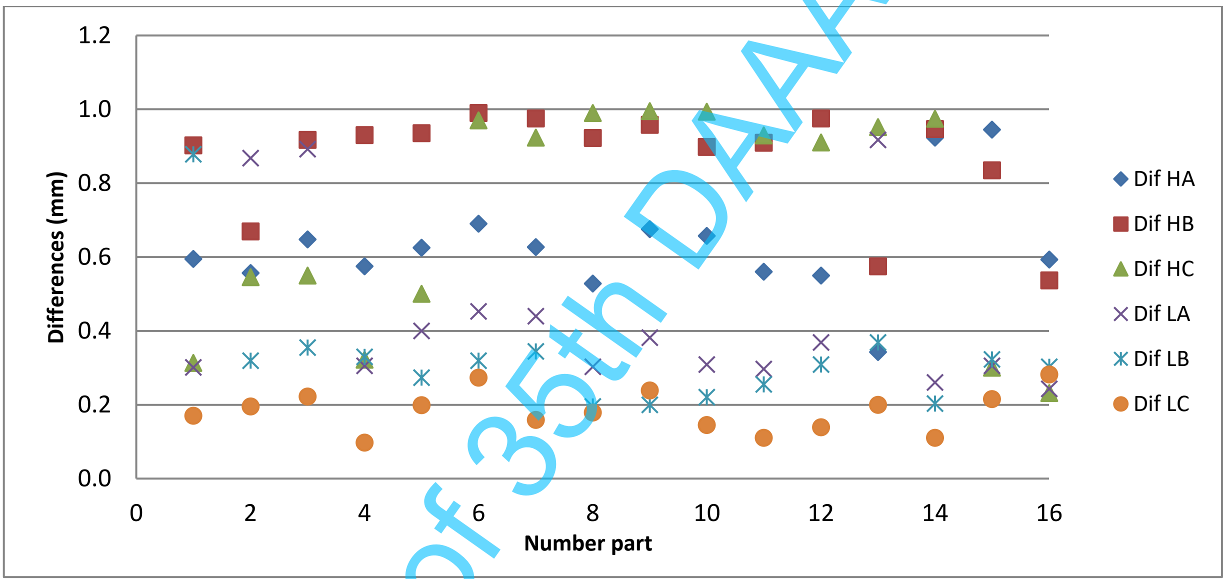

Fig. 5. Calculated deviations from nominal dimensions

5. Conclusions

This paper presents a quality assessment of 3D printed PETG parts under specific printing settings using cold bed technology in terms of the defects predominantly observed and conformance to designed dimensions. The results suggest that:

1. The most prevalent defects observed were warping and warpage. Less frequently, delamination was also noted. In a few instances, waviness of the layers was also observed.
2. Better surface finish was observed at the low printing speed (100 mm/min). It is possible to utilise a higher speed; however, this would have a detrimental impact on the quality of the workpiece.
3. In all instances, the dimensions exceed the nominal values of the model. This must be considered when generating three-dimensional models using computer-aided design (CAD) software. The largest discrepancies appear to occur for the smallest dimensions.
4. The results observed imply that the CAD models must be adjusted to achieve a higher level of accuracy in the final dimensions of the product, considering that under the analysed conditions, the process produces parts larger than expected.
5. Lack of adhesion was not a significant issue under the studied conditions, which would prevent the total rejection of the part as opposed to the effects of the other defects that occurred in the study.

This study reinforces the need to conduct further experimental research in order to have a better understanding of the factors that influence both the presence of visual defects and conformance to specified dimensions, considering the potential association between both quality issues. These efforts could also include the development of multiple regression models to estimate the dimensions of the 3D designs, with the objective of reducing the deviations from the nominal value along with the presence of shape defects. Other lines of research could include quality assessments regarding other dimensional characteristics of relevance based on the potential applications of the parts fabricated.

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