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THE INFLUENCE OF LAYER HEIGHT ON THE TENSILE STRENGTH OF SPECIMENS PRINTED IN THE FDM TECHNOLOGY

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Abstract

This article analyzes the influence of layer height on the tensile strength of PLA specimens printed in the Fused Deposition Modeling (FDM) technology. The maximum breaking force of specimens with 30% and 100% infill density was determined at layer height of 0.05 mm, 0.1 mm, 0.2 mm and 0.3 mm. In the case of 30% infill, the highest value of the force was obtained for a layer with a height of 0.05 mm (which corresponds to 22.7 MPa), and for a 100% infill for a layer of 0.2 (which corresponds to 40 MPa). Over this layer height of 0.2 mm is the most poly-optimal due to the time prints and strength (which corresponds to 19.7 MPa).

Introduction

Rapid prototyping technologies, including 3D printing, enable the verification of CAD models in a short time and at a low cost. One of the most important parameters of 3D printing is the layer height. It affects the accuracy of the print as well as the printing time. On the other hand, this article analyzes the

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influence of layer height on the tensile strength of specimens printed in the Fused Deposition Modeling (FDM) technology. The article will check whether increasing the layer height will have a negative impact on the strength of the printed samples. The paper is a continuation of the author's previous research into the strength of specimens printed in the FDM process. Previous studies (MIAZIO 2015, 2016, 2017, 2018) explored the tensile and bending strength of printed specimens with different infill density and different infill patterns. The effects exerted by printing speed (MIAZIO 2019) and the specimens' compressive strength (MIAZIO 2020) were also analyzed. These problems have also been investigated by other authors (LUZANIN et al. 2019, KIŃSKI, PIETKIEWICZ 2019). Moreover, they also dealt with the search for polyoptimal printing parameters in their research (RANEY et al. 2017, SATY, RAJEEV 2020, TORRES et al. 2015, WANKHEDE et al. 2020). The aim of the present study was to determine the influnce of layer height on the tensile strength of the printed model and printing time. The filament material for 3D printing was polylactic acid (PLA).

Materials and Methods

The specimen (Fig. 1) for the tensile test was modeled in the SolidWorks program. The model was saved in an STL file. The G-code file for executing the 3D printing program was generated based on the STL file in the Cura program (Ultimaker Cura, online).

The parameters and procedures for conducting tensile tests in plastics are described by standard PN-EN ISO 527:1998: *Plastics. Determination of mechanical properties during static tensile tests*. The dimensions of the analyzed specimen (type B1) are presented in Table 1.

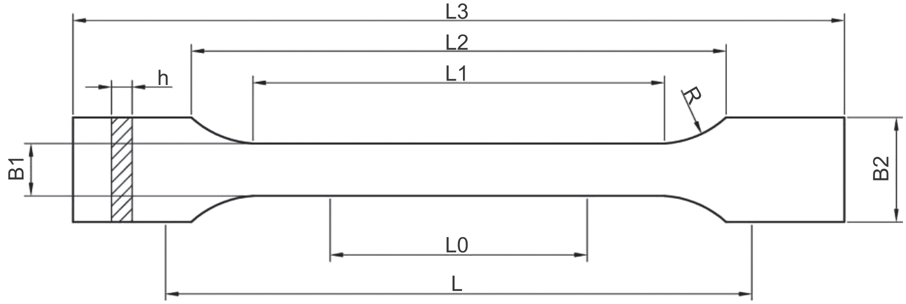

Fig. 1. Universal specimen

Table 1

Specimen dimensions

Specimen dimensions	Type B1 [mm]
L3 – total length	150
L1 – length of the segment limited by lines	40
R – radius	60
L2 – distance between wide parallel segments located at both ends of the specimen	106
B2 – width of each wide segment	20
B1 – width of the narrow segment	10
h – recommended thickness	4
L0 – measured length	50
L – initial distance between holders	115

The specimens were printed with the use of PLA filament in the BIG Builder DUAL FEED printer (Builder 3D Printers HQ) with a 0.4 mm nozzle. All specimens were printed flat, along the Y-axis of the printer. They were printed in batches of five specimens each. The following printing parameters were applied:

– printing speed of the first layer: 20 mm/s,
– printing speed of successive layers: 60 mm/s,
– head temperature: 215°C,
– thickness of the top and bottom layer: 0.6 mm,

Fig. 2. Cross-section of a printed specimen with a grid infill pattern and 30% infill density

The printed specimens were subjected to a quasi-static uniaxial tensile test based on standard PN-EN ISO 527:1998, with a strain rate of 2 mm/min. The test was conducted in five replicates for each layer height and infill density.

Results and Discussion

The results of tensile tests and the maximum breaking force values for each analyzed layer height in specimens with 30% and 100% infill density are presented in Tables 2 and 3, respectively. Curves representing the mean values of the maximum breaking force vs. layer height are presented in Figure 3. The printing times of specimens with different layer height are presented in Table 4 and Figure 4.

The data in Figure 3 indicate that in specimens with 30% infill density, the highest tensile strength was achieved at 0.05 mm layer height. In these specimens, tensile strength decreased with an increase in layer height. In specimens with 100% infill density, tensile strength was highest at 0.2 mm layer height, and it decreased considerably at 0.3 mm layer height.

Table 2

Breaking force values for specimens with 30% infill density

Layer height [mm]	Breaking force [kN]					
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Mean
0.05	0.9	0.91	0.91	0.92	0.9	0.9
0.1	0.84	0.83	0.84	0.83	0.82	0.84
0.2	0.8	0.81	0.76	0.77	0.8	0.8
0.3	0.71	0.71	0.73	0.74	0.71	0.71

Table 3

Breaking force values for specimens with 100% infill density

Layer height [mm]	Breaking force [kN]					
	Specimen 1	Specimen 2	Specimen 3	Specimen 4	Specimen 5	Specimen
0.05	1.44	1.45	1.43	1.45	1.43	1.44
0.1	1.55	1.56	1.58	1.57	1.58	1.55
0.2	1.62	1.59	1.61	1.6	1.63	1.62
0.3	1.27	1.3	1.25	1.25	1.24	1.27

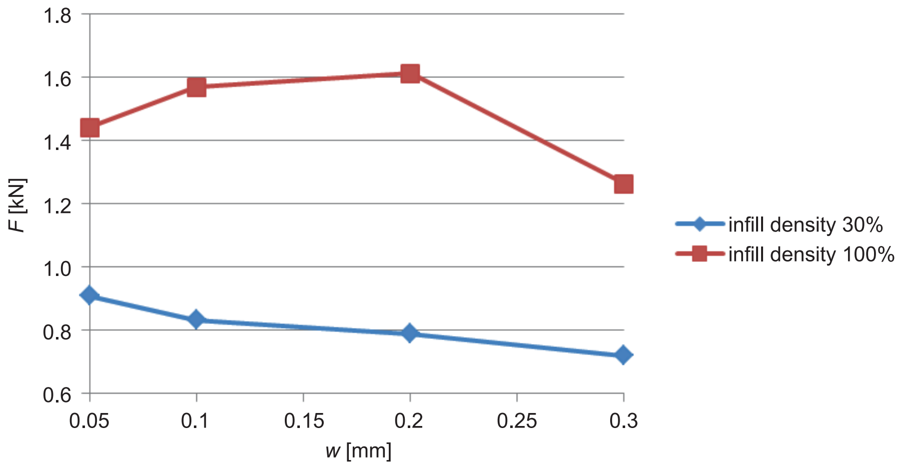

Fig. 3. Mean breaking force values vs. layer height

Table 4

Printing time of a batch of five specimens

Layer height [mm]	Printing time [min]	
	30% infill density	100% infill density
0.05	506	655
0.1	273	348
0.2	150	196
0.3	106	142

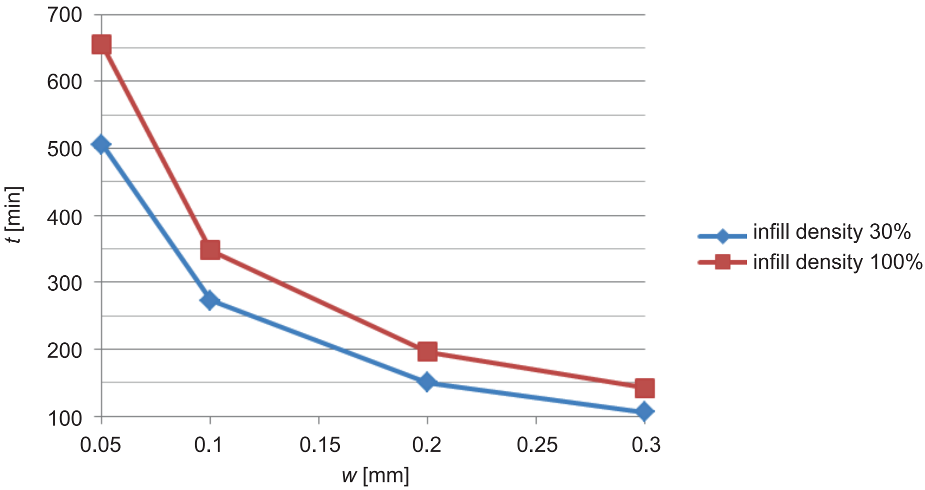

Fig. 4. Printing time of a batch of five specimens vs. layer height

An analysis of Figure 4 clearly indicates that printing time decreased significantly with an increase in layer height. Printing time was reduced by around 50% when layer height increased two-fold.

Conclusions

The results of this experiment indicate that specimens with 0.2 mm layer height were characterized by the highest tensile strength and the shortest printing time. Taking into account the specimen cross-section 10×4 mm, the stress at break for 30% infill density was 19.7 MPa, and for 100% infill density it was 40.2 MPa. The printing time of the specimens with 0.2 mm layer height was more than three times shorter in comparison with specimens with 0.05 mm layer height. The tensile strength of the specimens with 0.2 mm layer height and 100% infill density was higher, and it was only somewhat lower (by 11%) in specimens with 30% infill density. The decrease in strength at a layer height of 0.3 mm is caused by weaker plasticization of the filament and weaker gluing of the layers. Previous research by the author has shown problems with the plasticization of the filament at higher flow rates through the printer nozzle.

The present findings should be regarded as qualitative data. Quantitative data can differ considerably, depending on the type of filament material and the applied program for generating G-code files.

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