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IMPACT OF PRINT SPEED ON STRENGTH OF SAMPLES PRINTED IN FDM TECHNOLOGY

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ABSTRACT

This paper presents research on the impact of printing speed on the strength of a manufactured object and is the next stage of the author's research on the impact of technological parameters of 3D printing on the strength of printed models. The tested universal specimens were printed using the FDM (Fused Deposition Modeling) method from PLA (polylactic acid, polylactide). The paper presents the maximum breaking force of the samples and the time of printing samples depending on the printing speed, which varied from 20 $mm \cdot s^{-1}$ to 100 $mm \cdot s^{-1}$. The research indicates that the strength of samples decreases with increasing speed. In the range of 50-80 $mm \cdot s^{-1}$, the strength of the specimens remined at a similar level, however, above 80 $mm \cdot s^{-1}$, it decreased significantly.

Introduction

Spatial printing is used in many fields of industry, including production of machinery for the agricultural industry. This article discusses the impact of printing speed on tensile strength of samples made on spatial printers using FDM (Fused Deposition Modeling) technology, which is warm modeling. The samples were printed from PLA (polylactic acid, polylactide).

Previous research of the author, presented in the form of articles (Miazio, 2015; 2016; 2017; 2018) addressed the tensile and bending strength of samples printed with different type and density of filling. Other authors also undertook similar research (Anithaa et al., 2001; Lee et al., 2005; Wimpenny et al., 2017), however the author identified no research on the impact of print on the strength of specimens manufactured in FDM technology.

Test method

The conditions and the method of conducting tensile tests of plastics are described in the PN-EN ISO 527:1998 standard: *Plastics. Determination of tensile properties.* The sample, referred to in the standard as the specimen, is flat and paddle-shaped. The dimensions of the sample should be as follows: thickness 4.0±0.2 mm, gauge width 10±0.2 mm and overall length over 150 mm. In the case of mechanically machined samples, the gauge is 60±0.5 mm long (type B1).

The shape, modeled using SolidWorks software was saved to a STL file (The StL Format, 2019). Based on the STL file, an executive code controlling the operation of the printer, the so-called Gcode, was created in the Cura program (Ultimaker Cura manual, 2019).

The samples were printed from PLA on the BIG Builder DUAL FEED printer by Builder 3D Printers HQ. The printer's nozzle is 0.4 mm in diameter. All specimens were printed flat along the Y-axis of the printer. The specimens were printed in series of five, with the following printing parameters:
– printing speed of the first layer: 20 mm·s^{-1},
– temperature of head: 215ºC,
– layer height: 0.2 mm,
– thickness of the bottom and top layers: 0.6 mm,
– thickness of side walls: 0.8 mm,
– degree of filling: 30%.

In addition, a heated table was used, with temperature set at 60 ± 5ºC. The adopted value of the degree of filling of the samples, i.e. 30% resulted from the author's previous research. It is a polyoptimum value in terms of print time and strength of the samples (Miazio, 2015). The fittings were printed with a 45° angle grid filling (Fig. 1) relative to the sample axis. The printing speed has been changed from 20 mm·s^{-1} to 100 mm·s^{-1}.

Figure 1. Cross-section of the sample with 30% grid filling

The results of the study were subjected to a statistical analysis using the Statistica v13 program using the descriptive statistics, parametric and non-parametric statistics modules. The consistency of obtained result distributions was checked against normal distribution using the Shapiro-Wilk test and the Brown-Forsythe variance homogeneity test. Since the assumptions were satisfied, a one-way analysis of ANOVA variance was applied (Rabiej, 2012). In the case of rejection of the null hypothesis (H_0: mean breaking force does not depend on printing speed), a Post-hoc Tukey test was applied. The calculations were carried out at the significance level of $\alpha = 0.05$.

Results

Table 1 presents the results obtained from the tensile tests of the specimens. The maximum tensile force was changed depending on the printing speed of the specimen. Additionally, Figure 2 presents the curves of the mean value of the maximum tensile force as a function of the sample print speed. On the other hand, Figure 3 presents the printing times of five samples depending on the printing speed.

Table 1.
Comparison of statistical analysis values

Printing speed (mm·s^{-1})	Group	Breaking force (kN)						Standard deviation S	Coefficient of variation V (%)
		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Mean		
20	A	0.7	0.78	0.75	0.72	0.74	0.74	0.030	4.11
30	B	0.64	0.66	0.67	0.61	0.66	0.65	0.024	3.68
40	C	0.61	0.61	0.62	0.6	0.62	0.61	0.008	1.37
50	D	0.58	0.53	0.58	0.57	0.55	0.56	0.022	3.86
60	E	0.57	0.55	0.58	0.59	0.56	0.57	0.016	2.77
70	F	0.48	0.54	0.59	0.55	0.57	0.55	0.042	7.62
80	G	0.52	0.62	0.61	0.51	0.48	0.55	0.063	11.50
90	H	0.45	0.4	0.57	0.52	0.53	0.49	0.068	13.77
100	I	0.55	0.35	0.5	0.55	0.45	0.48	0.084	17.43

Result of the variance analysis:
F=14.50; p=0.0000
Results of Tukey test:
A, B, C > H, I; A, B > F, G; A > C, D, E

Material strength distributions obtained for all the analyzed tensile speeds showed compliance with the normal distribution. The Brown-Forsythe test carried out did not show differences in homogeneity of variance, therefore a one-way analysis of variance was applied.

Upon analyzing the results of statistical analysis, the significance of differences and the coefficient of variation V, one can assume that due to the uniformity of strength results, the printing speed should range from 30 to 60 mm·s^{-1}. However, taking into account the criterion of the printing time of the samples, the speed of 60 mm·s^{-1} should be considered.

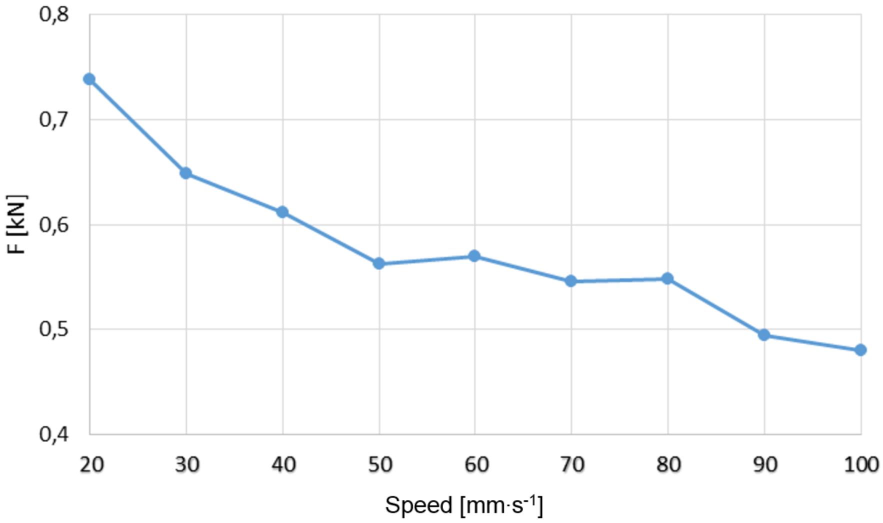

Figure 2. Graph of the mean value of the breaking force as a function of the printing speed

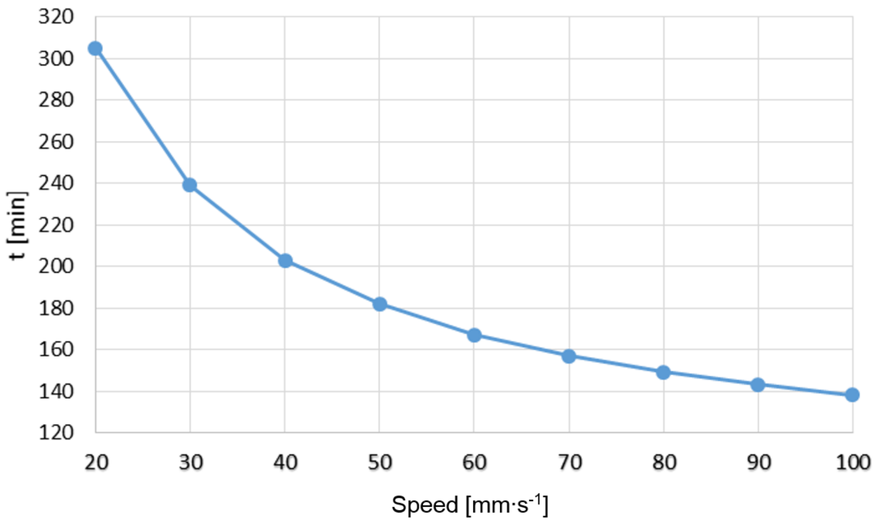

Figure 3. Printing time of the five specimens as a function of printing speed

Figure 4. Printing defects - printing speed 100 mm·s^{-1}

Summary

The research presented in this article shows that the strength of samples decreases with increasing speed. In the range of 50-80 mm·s^{-1}, the strength of the specimens was at a similar level. However, above 80 mm·s^{-1}, the strength decreases significantly. This is due to print defects (Figure 4), which are caused by the limited capacity of the print head. The time needed to plasticize the filament is too short. In turn, the printing time exponentially increases with a decrease in speed.

From the above, it can be concluded that in the case of the BIG Builder DUAL FEED printer by Builder 3D Printers HQ and PLA, the optimal print speed ranges between 30 and 60 mm·s^{-1}, due to the low value of the coefficient of variation. Based on the author's experience in working with the aforementioned printer, it appears that the polyoptimal printing speed is 60 mm·s^{-1}, due to its durability and printing time. At higher speeds, defects appear in the printed models due to the occurring wear of Teflon tubes in the print head, and the resulting insufficient quantity of the supplied material. This is the result of an increasing resistance of the filament passing through the head.

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WPŁYW PRĘDKOŚCI DRUKU NA WYTRZYMAŁOŚĆ PRÓBEK WYDRUKOWANYCH W TECHNOLOGII FDM

Streszczenie. W niniejszym artykule przedstawiono badania nad wpływem prędkości drukowania na wytrzymałość wytwarzanego obiektu. Badane kształtki uniwersalne wydrukowano metodą FDM (Fused Deposition Modeling) z tworzywa PLA (ang. polylactic acid, polylactide). Artykuł jest kolejnym etapem badan autora nad wpływem parametrów technologicznych druku 3D na wytrzymałość wydrukowanych modeli. W artykule przedstawiono maksymalne silę zrywającą próbki oraz czas wydruku próbek w zależności od prędkości drukowania. Prędkość drukowania zmieniano od 20 $mm \cdot s^{-1}$ do 100 $mm \cdot s^{-1}$. Z przedstawionych badań wynika, że wraz ze wzrostem prędkości maleje wytrzymałość próbek. W zakresie 50-80 $mm \cdot s^{-1}$ wytrzymałość kształtek była na porównywalnym poziomie. Natomiast powyżej prędkości 80 $mm \cdot s^{-1}$ wytrzymałość już znacząco spada.

Słowa kluczowe: inżynieria materiałowa, szybkie prototypowanie, druk 3D, PLA, FDM