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ANALYSIS OF THE INFLUENCE OF 3D PRINTING ON HARDNESS OF PARTS

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Original scientific paper
The principles of additive production are such that they enable the making of very complex product geometry. The hardness of printed parts is not increased proportionally to the increase of the infill of the parts themselves. Different ways of printing have a bigger impact on the hardness than the infill. The research conducted on the "solid" model samples established sufficient hardness of parts gained from 3D printing with less material use and shorter time of production due to correct selection of parameters and the way of printing.

Keywords: *3D print; ABS; deflection; infill*

Analiza utjecaja načina 3D printanja na krutost dijelova

Izvorni znanstveni članak
Načela aditivne proizvodnje su takva da omogućuju izradu vrlo komplicirane geometrije proizvoda. Krutost printanih dijelova ne raste proporcionalno povećanju ispuna samih dijelova. Načini printanja imaju veći utjecaj na krutost od same ispune. Provedenim ispitivanjima na uzorcima "punog" modela utvrđena je zadovoljavajuća krutost dijelova dobivenih 3D printanjem uz manje utrošenog materijala i kraće vrijeme izrade pravilnim izborom parametara i načina printanja.

Ključne riječi: *ABS; ispuna; progib; 3D print*

1 Introduction

Contemporary market demands impose strict conditions on the processes related to development and production. Besides demands regarding product quality and flexibility level, the market simultaneously imposes requests for reduction of costs and especially for reducing the time for development and production [1]. Emergence of 3D printers has facilitated the manufacture of complex geometries to numerous users unable to develop them using some other technologies. Improved possibilities of 3D printing will contribute to faster development of technological procedures in the future [2, 6, 7]. Due to lack of confirmed research regarding the characteristics of behaviour of materials used in 3D printing by means of using the equipment, according to [3÷5] it is not possible to adequately assess the "solid" model with reference to the "hollow" one. "Solid" models are more expensive to make, they require more material, the printing lasts longer and they have bigger mass, whereas "hollow" models are used for models which are not completely filled with material and have more complex construction requirements. The emphasis is placed on visuality, which contributes to qualitative integrity of the product. Simplified computer programmes adapted to 3D printing enable relatively quick comprehension of 3D printing with the infill ways of printing (Horizontal / Vertical), layer height (Layer Height), model shell (Shell) etc. In a few steps and adjusted parameters it is possible to carry out a 3D print of a certain model.

2 Method

Subject matter of this analysis is construction variants of products made by means of using 3D printers of low total costs [3]. Compared to the price of material, the influence of device price is significantly lower in total costs of production of parts [3, 4]. Used FDM technology of 3D printing, is described in [10, 11]. The samples on which measurements were made are the same shape as the sample described in [9].

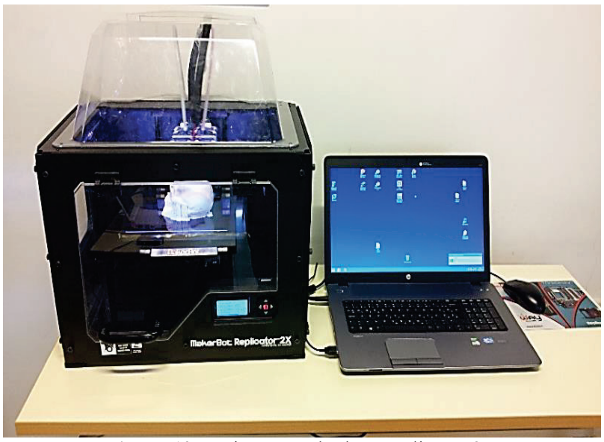

Figure 13D Printer - Makerbot Replicator 2X

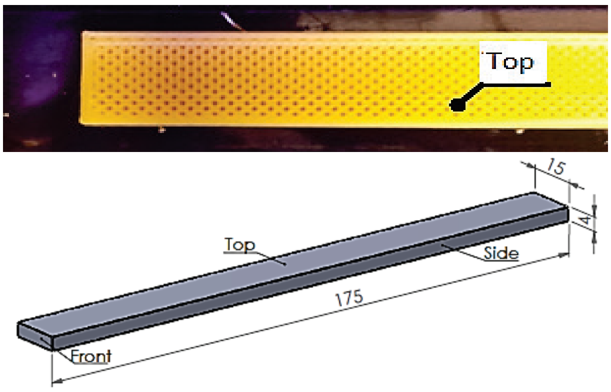

Figure 2 3D printed test sample and side naming

In order to obtain satisfactory construction solutions for the needs of small series production by means of using 3D print (in this case ABS, wire diameter 1,75 mm), rational selection of model infill combinations (Infill), ways of print (Horizontal / Vertical) [8], layer height

(Layer Height), model shells (Shell) etc. can result in significant reduction of costs.

Tab. 1 provides an outline of basic settings in usage of 3D printers.

Table 1 Parameters of 3D printed samples

Parameters	Number of samples							
	1	2	3	4	5	6	7	8
Infill / %	25	50	75	100	25	50	75	100
Number of shells	2	2	2	2	2	2	2	2
Layer height / mm	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
Extruding traveling speed / mm/s	120/ 150	120/ 150	120/ 150	120/ 150	120/ 150	120/ 150	120/ 150	120/ 150
Horizontal/Vertical print	Hor.	Hor.	Hor.	Hor.	Ver.	Ver.	Ver.	Ver.

Prior to production of samples, Fig. 2, 3D printer is calibrated according to the instructions of the manufacturer [3]. The samples were made by using a version of the software programme MakerWare 2.4.0.14, with 3D printer MakerBot Replicator 2X V7.5 drivers [3].

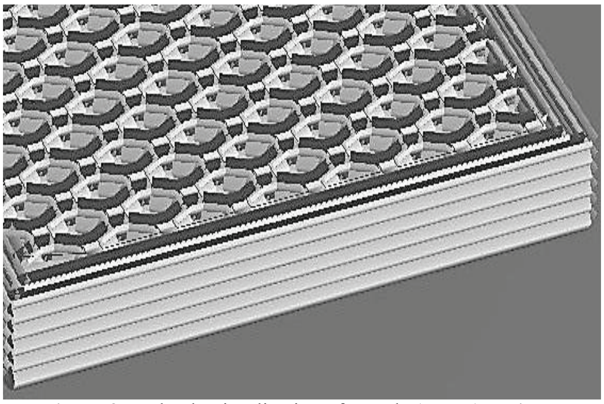

Figure 3 Toolpath Visualization of sample 175 × 15 × 4 mm (Horizontal print- Infill 75 %)

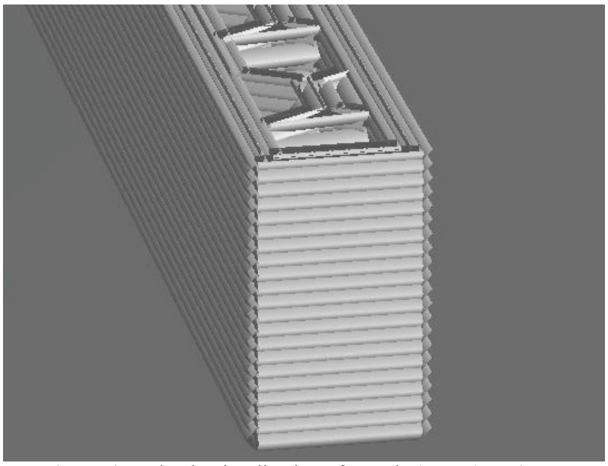

Figure 4 Toolpath Visualization of sample 175 × 15 × 4 mm (Vertical print- Infill 25 %)

Print time and quantity of material used, Figs. 3 and 4, vary according to the infills of the used samples [4].

Side 1 of the sample is always the one laying on the build plate, and side 2 is for all samples always the final layer, Fig. 5. Performance of a 3D printer is such that the build plate, on which the part being printed is located, is heated to 130 °C, and during testing it influences the sample quality.

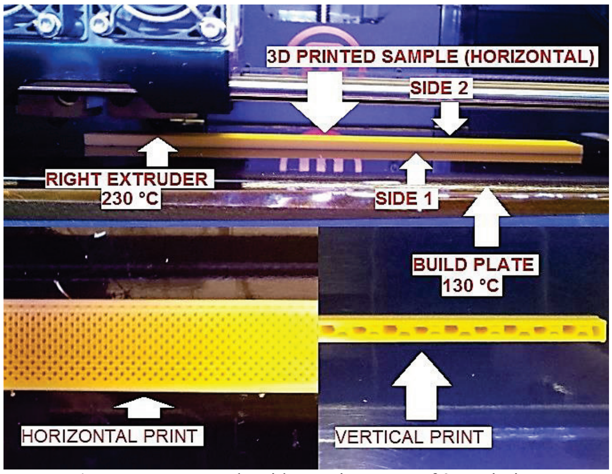

Figure 5 Test sample, side naming, type of 3D printing, description of 3D printer

3 Results

Samples on which research was conducted differ according to print direction, horizontally, vertically, as well as whether they were turned to side 1 or side 2 during measuring of deflection, and subsequently according to the percentage of the infill within the sample, Fig. 5. In the process of measuring the deflection we used equipment shown in Fig. 6. Precision weights were used which correspond to forces from 0,981 N and 1,962 N. To measure the deflection a comparator was used.

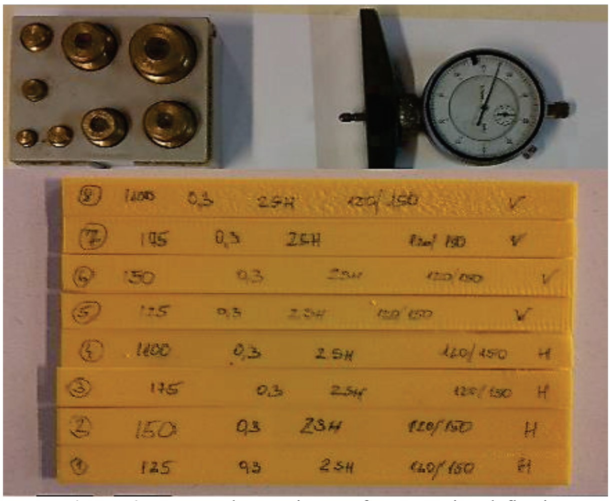

Figure 6 Test samples, equipment for measuring deflection

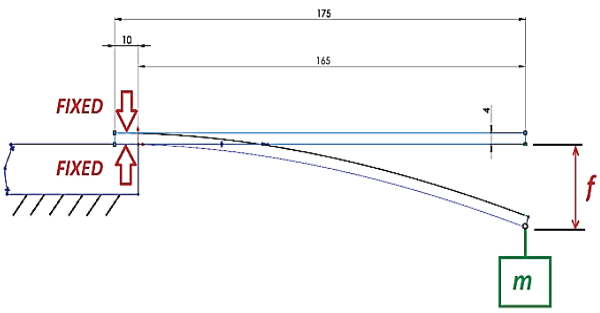

Figure 7 Method of measuring deflection

Method for measuring the deflection is illustrated in Fig. 7, and the results of measurements of deflection are presented graphically below.

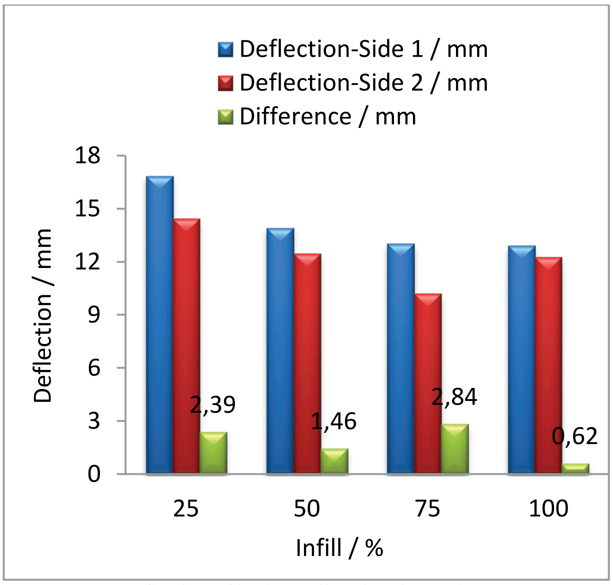

Figure 8 Deflection of horizontally printed sample (F = 0,981 N)

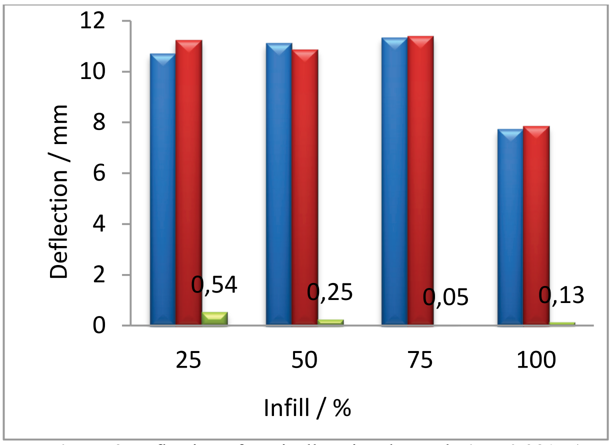

Figure 9 Deflection of vertically printed sample (F = 0,981 N)

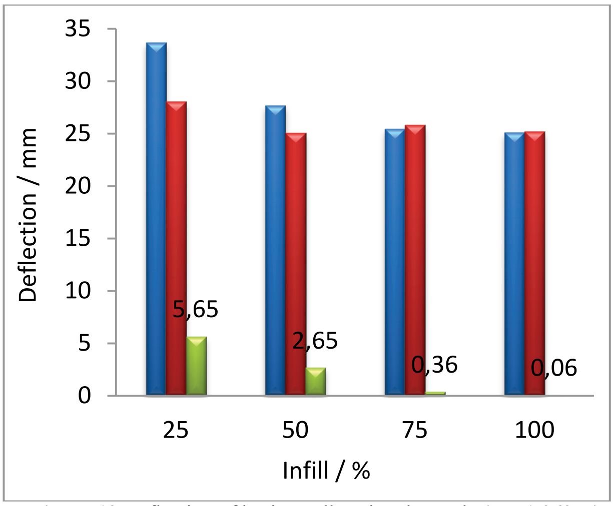

Figure 10 Deflection of horizontally printed sample (F = 1,962 N)

Assessment of deflection indicated significant differences outlined in charts in Figs. 8 ÷ 11. Computer simulation of deflection assessment for loads of 0,981 N and 1,962 N was made for the sample used in testing, whose dimensions were 175 × 15 × 4 mm, Fig. 12. The length of the side exposed to force was 165 mm. The sample was fixtured on the length of 10 mm, Fig. 12. Programming tool Solidworks, module Simulation was used. Fixture and load of sample sized 175 × 15 × 4 mm are depicted in Fig. 12.

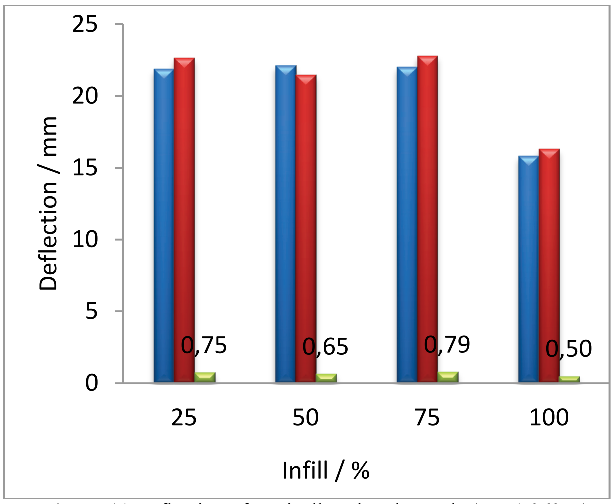

Figure 11 Deflection of vertically printed sample (F = 1,962 N)

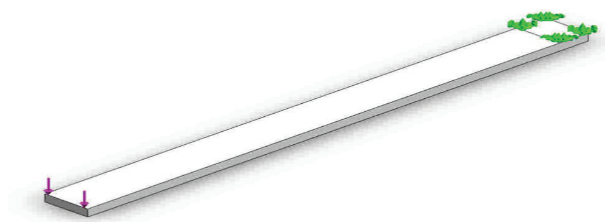

Figure 12 Fixture and Load-sample 175 × 15 × 4 mm

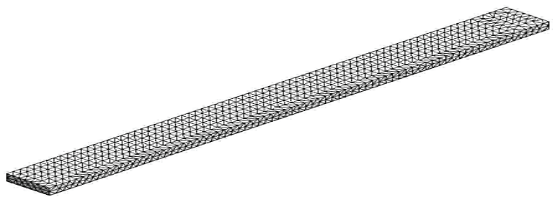

Figure 13 Mesh - sample 175 × 15 × 4 mm

Table 2 Material Properties - SW Simulation

Name:	ABS
Model type:	Linear Elastic Isotropic
Tensile strength:	30 MPa
Elastic modulus:	2×10^3 MPa
Poisson's ratio:	0,394
Mass density:	1020 kg/m^3
Shear modulus:	$0{,}319\times10^3$ MPa

Table 3 Mesh Information - SW Simulation

Mesh type	Solid Mesh 2
Mesher used	Standard mesh
Element size	2,3597 mm
Mesh quality	High
Total nodes	11075
Total elements	6352
Time to complete mesh (hh:mm:ss)	00:00:03

Properties of material used for simulations are defined in programming tool SolidWorks, and are located in the library of the module Simulation, and displayed in Tab. 2.

Properties of final elements of the mesh are displayed Tab. 3.

Response results of computer simulation of deflection assessment for load force of 0,981 N are displayed in Fig. 14, whereas Fig. 15 displays response results of computer simulation of deflection assessment for load force of 1,962 N.

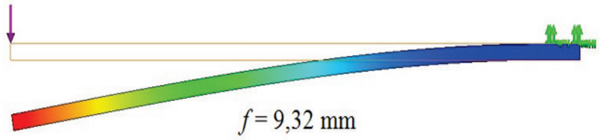

Figure 14 Simulation assessment of sample deflection loaded with mass of 0,1 kg (corresponds to 3D printed sample with 100 % infill)

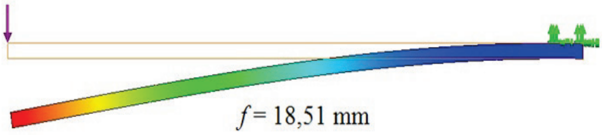

Figure 15 Simulation assessment of sample deflection loaded with mass of 0,2 kg (corresponds to 3D printed sample with 100 % infill)

By means of using computer numeric simulations it was established that double load results in approximately twice as large deflection of the tested sample, Figs. 14, 15. Sample dimensions displayed in Figs. 2, 7, 12 were used for analytic calculation of deflection.

$$f = \frac{F \cdot l^3}{3EI}, \quad (1)$$

$$I = \frac{b \cdot h^3}{12}. \quad (2)$$

In formula (1) the following sizes were used for analytic calculation of deflection: f - deflection (mm), F – force loading the sample (N), l – the side exposed to the force F (mm), E – Young's module of elasticity (MPa), I - moment of inertia of the console cross-section (mm^4), whereas (2) b and h represent dimensions of sample cross-sections (mm). Response results of computer simulation of deflection assessment for load force of 0,981 N and 1,962 N, amount to 9,32 mm and 18,51 mm, whereas according to analytic calculations deflection values amount to 9,18 mm for the force of 0,981 N, and 18,36 mm for the force of 1,962 N.

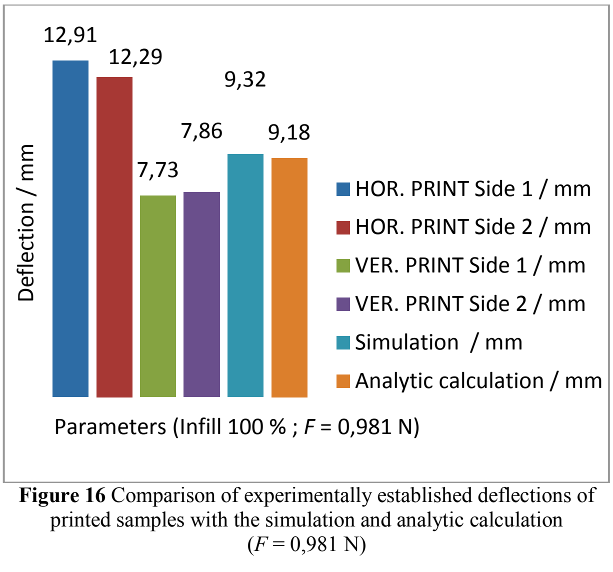

Figure 16 Comparison of experimentally established deflections of printed samples with the simulation and analytic calculation (F = 0,981 N)

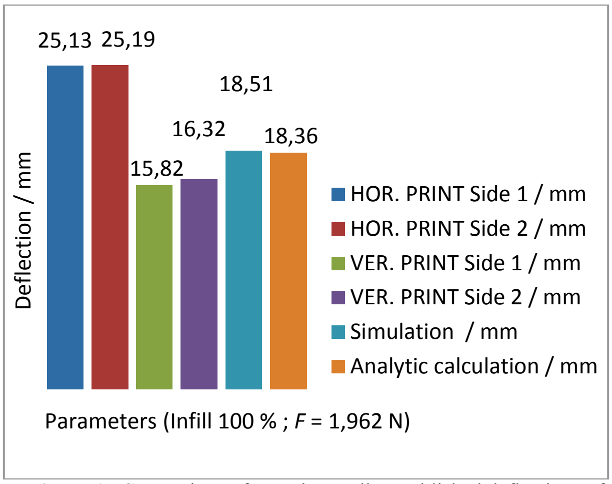

Figure 17 Comparison of experimentally established deflections of printed samples with the simulation and analytic calculation (F = 1,962 N)

4 Discussion

Conducted research established small discrepancies of deflection values of the tested samples between computer simulations and analytic calculations for the "solid" model (Figs. 16, 17). Significant differences were observed with experimental testing related to different ways of 3D printing (horizontally, vertically, side 1, side 2), with reference to analytic calculation and simulation.

5 Conclusion

Lack of knowledge related to accurate characteristics of the used ABS filament (cheap material and 3D printer) influences the values observed with different procedures. Print direction (horizontally, vertically) has a bigger influence on sample hardness than the infill of the model. Analytic calculations and computer simulations indicated small discrepancies of deflection values of tested sample related to the "solid" model.

6 References

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