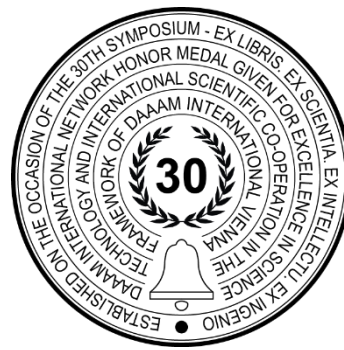


INFLUENCE OF THE INFILL ON THE TENSILE STRENGTH AND THE ECONOMIC FACTORS OF 3D PRINTING

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Abstract

This work deals with the infill of 3D printed parts. The goal of this work is to provide recommendations on how much a part should be filled. The recommendation is supported by experiment. The selected load is tensile. Therefore, the geometry of the samples was based on the standard ČSN EN ISO 527-2. Five densities of infill were selected to determine an infill rate from 0 to 100%. In addition to the tensile strength values for each sample, the work also considers economic factors. Characteristic graphs for this issue were constructed at the end of the work. They give an overview of how tensile strength, as well as time, and the cost of 3D printing, change with increasing densities of infill.

Keywords: 3D print; Tensile strength test; Fill density; Lattice structure

1. Introduction

The popularity of 3D printing is constantly increasing and the related amounts of 3D parts too. 3D printed parts can be described by mechanical properties. This experiment is focused on tensile strength. Every 3D printed part consists of a shell and an infill. The shell may be made from several walls. The infill is something that connects the walls. Then comes the question, how much should the part be filled. The density of infill is given in percent. What percent to choose? How much will it affect tensile strength? The experiment focuses on these questions. The percentage of infill and the effect of fill density on other properties will be researched for one type of infill.

For the experiment, the grid infill was selected. The possibility of filling the part is from 0 to 100 percent. The experiment is tries to cover this range with five infills. At the end of the work I also considered the costs of the consumed material and printing time.

2. Samples

The Ultimaker S5 printer was selected to print the part. This printer uses FDM (Fused Deposition Modelling) for printing. FDM is one of the most popular 3D printing methods. For this reason, it was chosen for this experiment. The principle of FDM is based on the application of molten plastic. The molten plastic is applied through a nozzle with an exact diameter. The first layer is deposited on the hot bed, the next layers on the previous plastic layers. This method is often called layer by layer printing. The direction of printing is from bottom to top. [2], [13]

Nowadays I can choose from a wide assortment of materials. The most commonly used material was selected for this experiment, PLA (Polylactic acid). In 2010, PLA had the second highest consumption volume of any bioplastic in the world. The material manufacturer was the same as for the 3D printer - Ultimaker. [6], [15]

The shape of the sample is shown in Fig. 1.

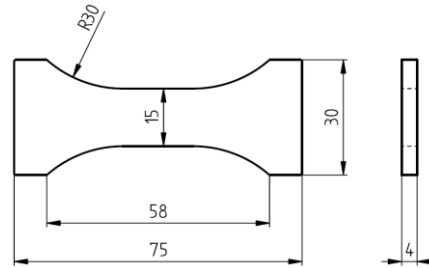


Fig. 1. Sample shape

The shape of the sample was based on ČSN EN ISO 527-2, type 1BA. The length of the sample is only 75 mm, still acceptable by the norm. Apart from the width, every other dimension was retained. The width was increased by three times. The reason is the transfer of the tensile load by more infill.

The tensile strength is also dependent on the deposition process of the layer. The deposition procedure can be seen in Fig. 2. The trajectory has not been changed from the default setting in the Cura slicer. [14]

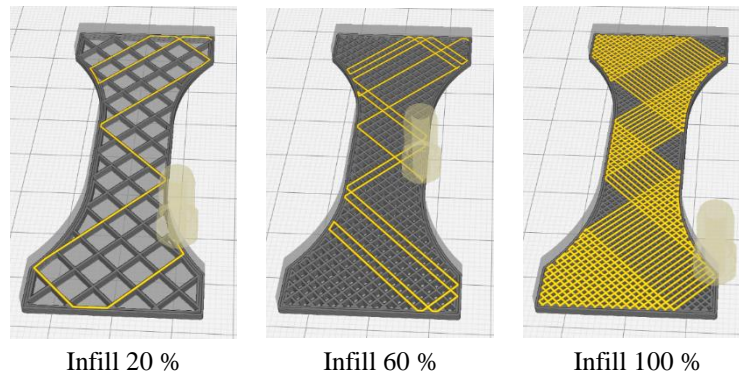


Fig. 2. Deposition of the infill

Other values of print settings are given in Table 1. Values in the table are the same for the initial layer and other layers.

Layer height	0.1	[mm]
Layer width	0.4	[mm]
Nozzle temperature	210	[°C]
Bed temperature	60	[°C]

Table 1. Printing setting

The width of the sample shell is 0.8 mm. It is equal to two walls. Samples of the same infill density were printed on the same bed. 25 samples were printed for the print setting parameters. One infill density was printed five times. Selected infill densities including properties are given in Table 2. [1]

Infill density	[%]	20	40	60	80	100
Sample weight	[g]	2	4	5	6	8
Consumption of material	[m]	0.29	0.47	0.64	0.82	0.99
Print time	[min]	21	30	39	49	59
Print time – infill	[min]	10	20	29	39	48
		52 [%]	67 [%]	75 [%]	79 [%]	82 [%]
Print time – wall	[min]	7	7	7	7	7
		35 [%]	24 [%]	18 [%]	15 [%]	13 [%]
Print time – others	[min]	2	2	2	2	2
		13 [%]	9 [%]	7 [%]	6 [%]	5 [%]

Table 2. Sample properties

Table 2 shows how the consumption of material and print time increases with increasing infill density.

3. Determination of tensile strength

This can be divided into two steps. Samples were analysed in the first step. During the measurement, it was found that the crack was not only at the narrowest place, as can be seen in Fig. 3. [10]

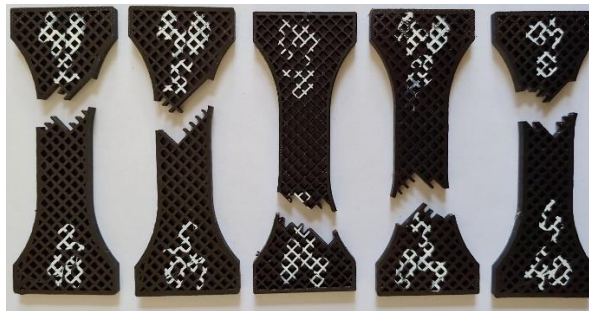


Fig. 3. Cracked samples with infill 40 %

The next part of the work was analysis of the crack. What affects the crack and where does it lead? The crack always goes through the infill and two walls. The crack probably starts in the infill, the smallest cross-section. It continues to the walls. Finally, the walls are torn too. The analysed cross-section is shown in Fig. 4. [9], [7]

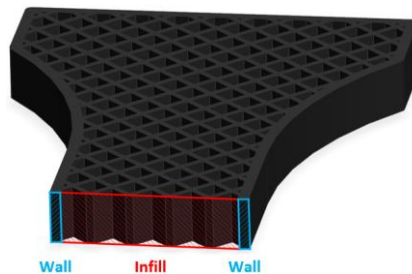


Fig. 4. Cross- section of sample

The second step investigates how much stress the walls can transfer. The wall samples were printed under the same printing conditions. The walls were printed from bottom to top. The material was deposited in the longitudinal direction. Five walls were printed. [3], [12]

The measurement conditions for the samples and the walls were the same. Samples were measured on a Zwick Roell Z250 and wall measurements on a Zwick / Roell Z005. The displacement and force were measured. All samples behaved as fragile materials. For this reason, the maximum force which the sample can transfer was selected. Tensile strength was calculated only for information purposes. The cross-section is the same as in Fig. 4. The measured values are shown in columns under the label – Sample in Table 3.

	Sample			Sample without walls	
	Displacement	Force	Stress	Force	Stress
	[mm]	[N]	[MPa]	[N]	[MPa]
Infill 20 [%]	0.49	369.3	6.0	143.7	2.2
Infill 40 [%]	0.51	497.9	8.6	272.2	4.8
Infill 60 [%]	0.53	729.9	12.5	504.2	8.7
Infill 80 [%]	0.52	1 130.9	18.9	905.2	15.1
Infill 100 [%]	0.43	1 736.8	28.9	1 511.2	25.1
Wall	2.18	112.8	1.88		

Table 3. Sample values

Next, the force without walls was evaluated. The goal was to eliminate the influence of the walls. This evaluation is not totally accurate in terms of force effect. For the sample, the stress leads around the perimeter by the walls. For the wall samples, the force is in the axis. The force transmitted by the sample without the walls was determined as:

$$Force = Force\ transmitted\ by\ sample - 2 * Force\ in\ the\ wall \quad (1)$$

The calculated values are shown in columns under the label – sample without walls in Table 3. [8]

4. Evaluation

The printing time and cost of material were included in the total evaluation. Also, economic factors will have a decisive influence. They will decide if the technical parameters are acceptable

The filament in the spool is Ultimaker PLA – M0751 Black 750–211399, PLA plastic, 2.85 mm, 750 g. There is approximately 90 m of filament in one spool. The price of one spool is approximately 40 euros. From these values it is possible to calculate the price per 1 m of material.

$$price\ for\ 1\ [m]\ material = \frac{40\ [eur]}{90\ [m]} \cong 0.44\ [eur/m] \quad (2)$$

If the amount of consumed material per sample is known, it is possible to calculate the price per sample. How much the increasing force influences the printing time and the price can be seen in the graphs in Fig. 5. [4]

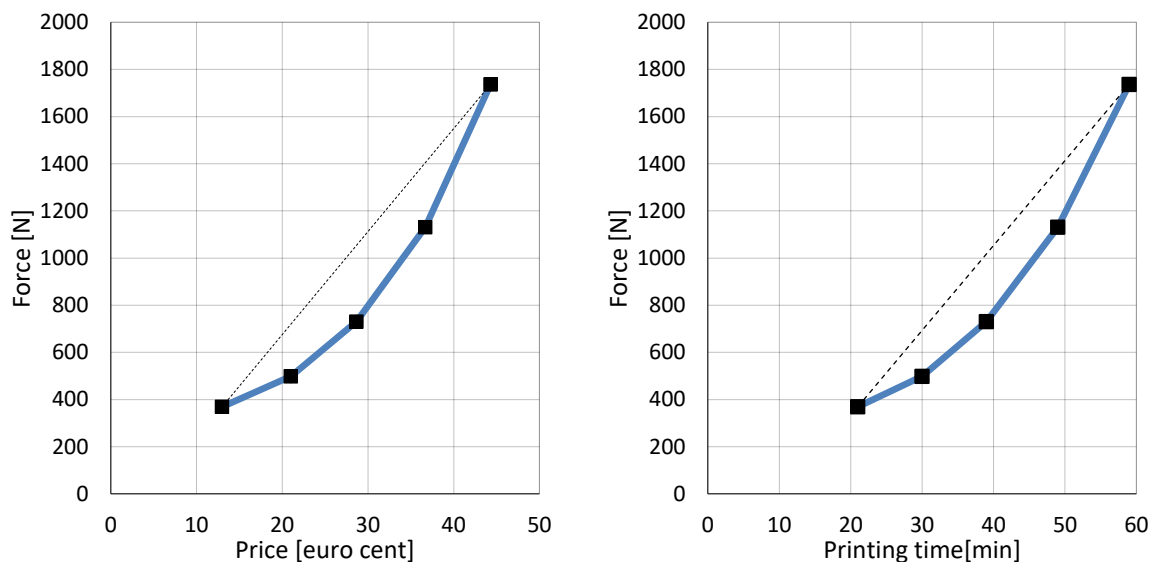


Fig. 5. Graphs of overall evaluation

The points gradually rise according to the sample infill percentage. The least force is in the 20% of infill and the highest in the 100% of infill. For better illustration, these points are connected by the line. The graphs in Fig. 5 show the exponential dependence between transferred tensile force and economic factors. At the start of the graphs, increasing the percent of the infill has a small effect on strength. Economic factors are growing faster. At the end of the graph in Fig. 5, the situation is reversed. Based on these properties, it is possible to say the following. If tensile strength is not required from the part, use only a little infill. Just enough necessary to print the highest layers. On the other hand, for high tensile strength it is good to use the largest possible percentage of infill. [5], [11]

5. Conclusion

The experiment deals with the influence of the infill on the tensile strength and the economic factors of 3D printing. The goal was achieved. Charts of recommendations for using 3D printing infill were presented.

The infill range was covered by 5 samples. The shape of the sample was based on the norm ČSN EN ISO 527-2. The shape of the sample was adjusted for analysing the infill. For analysing the force, it included the effect of the walls. Tensile strength was determined only for information purposes. The graphs at the end of this article describe the problem of 3D printing with infills.

6. Acknowledgments

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