Technological Restrictions at 3D Printing with Zortrax M200 3D Printer

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The aim of the research presented in this paper is to examine the accuracy (to what extent the 3D print fits to the 3D model) and the precision (which establishes the consistency of the measurements) for small-sized plastic parts printed on Zortrax M200 3D printer. One of the goals of the research is to find out how much the thickness of a wall (or of a bolt) can be reduced as it still to keep its stiffness and dimensional precision. A proper method for designing part couples was targeted. In order for a part to be correctly assembled with its pair, the deviation of the physical dimensions was taken into account. Also, the results of the experimental work on the capabilities and limitations of printing technology using this printer are presented in this paper. Several parameters such as surface quality and strength, layer shifting or misalignment are closely studied.

Key words: 3D printing, technological restrictions, fused deposition modeling, Zortrax M200, small-sized parts, technological restrictions

1. INTRODUCTION

Almost forty years into its development, additive manufacturing (AM), also known as 3D printing, has become a mainstream manufacturing process, already widely applied to many industries.

Additive manufacturing is a manufacturing method which builds up parts by depositing materials, such as plastic or metal, onto one another in layers based on a computerized 3D solid model. This model can dire-

ctly be transformed to a finished part without the use of additional machining or cutting tools [1, 2].

Complexity and design freedom, customization, efficiency and material waste minimization are the main benefits of 3D printing. As such, too much attention should not be paid to design for manufacturing and assembly (DFM/DFA) while designing the product, which is conducive to design innovation.

In order to take advantages of the above-mentioned benefits of 3D printing, it is necessary to consider the manufacturing limits and restrictions of this new technology. Although a considerable number of papers regarding additive manufacturing have been published over the past four decades, most of them were focused on different processing technologies.

The purpose of this paper is to assess the accuracy and the precision for small-sized parts printed on

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Zortrax M200 3D printer. Information is gathered, analyzed and summarized in order to draw conclusions regarding the capabilities and restrictions of the technology when printing small-sized parts. The study was carried out at the Department of Manufacturing Engineering of Transilvania University of Braşov.

2. ADDITIVE MANUFACTURING TECHNOLOGY

In order to obtain a part using additive manufacturing technology the following steps must be performed [2]:

1. A computerized 3D solid model must be produced. The most common method is computer-aided design (CAD), but reverse engineering can also be used to produce a digital model via 3D scanning. The 3D model will be converted into an STL (stereolithography) file format, which describes only the surface geometry of the 3D model, using polygons, without any other CAD attributes or into a recent additive manufacturing file format.

2. Once the STL file has been generated, it is sent to a slicer, a specialized computer software that allows manipulating the model in order to change (if needed) its position and orientation, or scaling it. Also, during this step the build parameters will be customized, such as support or layer height. Afterwards, the slicer creates a G-code file, which is sent to an additive manufacturing machine.

3. The part is built on the additive manufacturing machine using layer-by-layer fabrication technique.

There are several methods of 3D printing, but the most widely used for plastic materials is Fused Deposition Modeling (FDM), an additive manufacturing process that belongs to the material extrusion family.

In FDM, the object is built by extruding melted thermoplastic material from a movable FDM head and then selectively depositing it in ultra-thin layers onto a substrate. The material comes in a filament shape and is heated slightly above its melting point so that it solidifies almost immediately after extrusion and cold welds onto the previous layer [2].

As for any technology, 3D printing has some fundamental limitations and rules that need to be followed [3]. Before starting the manufacturing process, technological restrictions (in terms of size and geometry) must be considered, in order to determine whether a 3D model is suitable for 3D printing. These considerations apply to all CAD designs, from basic parts to more complex components.

Further on, the most important restrictions will be presented, which were taken into account in this study as well. The first one that should be taken into account is the physical size. It is impossible to 3D print thin

parts or sections of a design that are smaller than the minimum printable feature size for each technology. FDM recommends a minimum size of 0.8 mm. For larger parts, the model can be split into 2 or more parts that can be printed separately and later assembled. The second most important aspect is watertightness. The model should be completely watertight: without any gaps between faces and edges. Otherwise, inconsistent layers, holes or other errors may occur, making the object unprintable [4].

Although as a printing technology FDM is very flexible, the manufacturing of parts is not limited by shape, but it is limited by dimension [5]. Therefore, this research is conducted to determine the precision and accuracy of small-sized parts using this technology.

3. MATERIAL AND METHOD

For this study twelve benchmark models of different sizes with various shapes (all in vertical position) are considered.

A good variety of materials can be used, but in this study the basic 3D printing filament Z-ABS (Z-Acrylonitrile butadiene styrene) was selected, due to its characteristics: high quality, easy post-processing and mat surface. The main technical properties of Z-ABS are presented in Table 1 [6].

Table 1. Technical properties of Z-ABS material [6]

Mechanical Properties	Metric
Tensile Strength	30.46 MPa
Breaking Stress	25.89 MPa
Elongation at max Tensile Stress	4.52%
Elongation at Break	11.08%
Bending Stress	46.30 MPa
Flexural Modulus	1.08 GPa
Izod Impact, Notched	8.93 kJ/m ²
Thermal Properties	Metric
Glass Transition Temperature	107.89 °C

The device used for manufacturing is a desktop 3D printer based on FDM technology, Zortrax M200 (Zortrax, Poland). The specifications are shown in Figure 1.

The set of parameters used for printing the parts is: layer thickness of 0.14 mm, high quality, auto fan speed, normal seam, 4 top and 4 bottom surface layers. Infill is a very important factor to a print's strength, weight and decorative properties. The term refers to the structure that is printed inside an object. The higher the infill percentage, the stronger the print. For this survey two infill percentages were considered: each part was printed twice, once with 60% infill and

secondly with 100% infill. Same parameters presented above were used for both infill percentages.

Figure 1 - Schematic presentation and the main technical details of Zortrax M200 3D printer [7]

The models considered for printing are presented below.

The model illustrated in Figure 2 a. is a cylindrical part which can be assembled with the part in Figure 2 b. It was printed for diameter e of 15 mm, height h of 16.5 mm, height l of 15 mm and diameter d of 12 mm, 11.9 mm, 11.8 mm and 11.7 mm.

The model presented in Figure 2 b. is a small tube printed for diameter f of 15 mm, diameter D of 12 mm and height h of 16.5 mm. The model shown in Figure 2 c. can be assembled with the part from Figure 2 d. It was printed for diameter d of 15 mm, height h of 16.5 mm and length l of 9 mm, 8.9 mm, 8.8 mm, 8.7 mm, 8.6 mm and 8.5 mm. The model pictured in Figure 2 d. was printed for diameter d of 15 mm, length f of 12.99 mm, length L of 8.99 mm and height h of 16.5 mm.

The two pairs mentioned above were closely studied in order to determine the way they can be correctly fitted. In this regard, for each part its pair was printed three times in order to find the optimal match between them. The model shown in Figure 2 e. is a cylindrical part which was printed in different sizes: diameters of 3 mm, 4 mm, 5 mm, 6 mm and lengths of 15 mm, 20 mm and 25 mm.

The model represented in Figure 2 f. was printed for length L of 15 mm, length L_1 of 5 mm and length L_2 of 7.68 mm, 8.64 mm, 9.66 mm and 10.77 mm.

The model presented in Figure 2 g. was printed for length L of 154 mm and 152 mm, length L_1 of 15 mm and thickness G of 1 mm or 2 mm.

The model illustrated in Figure 2 h. was printed for diameter D of 10 mm, diameter D_1 of 22 mm, length L of 17 mm and length L_1 of 15 mm.

Figure 2 – Models considered for printing

The model represented in Figure 2 i. has a parallelepiped shape and was printed for length L of 25 mm, length L_1 of 15 mm, length L_2 of 10 mm, length L_3 of 10 mm and length L_4 of 10 mm. The model shown in Figure 2 j. is a plate printed for height h of 15 mm and 30 mm and a thickness g of 0.5 mm, 0.75 mm, 1 mm, 1.25 mm, 1.5 mm, 1.75 mm, 2 mm, 2.25 mm and 2.5 mm. The model pictured in Figure 2 k. was printed for height h of 15 mm and thickness g of 0.5 mm, 0.75 mm, 1 mm, 1.25 mm, 1.5 mm, 1.75 mm and 2 mm. The model illustrated in Figure 2 l. is a small tube which was printed for height h of 15 mm and thickness g of 0.5 mm, 0.75 mm, 1 mm, 1.25 mm, 1.5 mm, 1.75 mm and 2 mm.

Table 2. Measurements results – Figure 2 a.

Infill 60%								
CAD				Measurements				Precision
d	e	h	l	d	e	h	l	
12	15	16,5	15	12,05	15,02	16,56	15,03	High
				11,97	15,04	16,55	15,04	High
11,9				11,88	15	16,6	15,04	High
11,8				11,78	15,01	16,58	15,02	High
11,7				11,64	15	16,55	15,05	High
Infill 100%								
CAD				Measurements				Precision
d	e	h	l	d	e	h	l	
12	15	16,5	15	11,98	15	16,52	15	High
				11,97	14,98	16,53	14,99	High
11,9				11,88	15,01	16,51	15,02	High
11,8				11,79	15	16,52	15,01	High
11,7				11,71	15,07	16,53	15,03	High

Table 3. Measurements results – Figure 2 b.

Infill 60%						
CAD			Measurements			Precision
f	D	h	f	D	h	
15	12	16,5	15,03	11,84	16,59	High
			15,02	11,83	16,6	High
Infill 100%						
CAD			Measurements			Precision
f	D	h	f	D	h	
15	12	16,5	15,08	11,65	16,51	High
			14,98	11,69	16,54	High

Table 4. Measurements results – Figure 2 c

Infill 60%						
CAD			Measurements			Precision
d	h	l	d	h	l	
15	16,5	9	15	16,58	9,12	High
		8,9	15,02	16,57	9,05	High
		8,8	14,99	16,56	8,97	High
		8,7	-	-	8,82	Low
		8,6	15,03	16,54	8,74	High
		8,5	-	16,58	8,63	Low
Infill 100%						
CAD			Measurements			Precision
d	h	l	d	h	l	
15	16,5	9	15,02	16,53	9,14	High
		8,9	15,04	16,52	9,07	High
		8,8	15,02	16,54	8,88	High
		8,7	15,05	16,54	8,76	High
		8,6	14,85	16,56	8,72	Low
		8,5	15,05	16,54	8,68	High

Table 5. Measurements results – Figure 2 d

Infill 60%								
CAD				Measurements				Precision
d	f	L	h	d	f	L	h	
15	12,99	8,99	16,5	15,04	13,08	8,82	16,59	High
				15,01	13,07	8,85	16,58	High
Infill 100%								
CAD				Measurements				Precision
d	f	L	h	d	f	L	h	
15	12,99	8,99	16,5	15,01	13,13	8,75	16,53	High
				15,03	13,12	8,74	16,51	High

From Table 2 it can be noticed that for the part presented in Figure 2 a. all values are accurate, for both infill percentages: 60% and 100%. The part represented in Figure 2 b, whose results are shown in Table 3, is not accurate for any infill percentages. The perfect fit between them, of 0,2 mm, was achieved for diameter d of 11,7mm and 11,8mm and diameter D of 12mm (both infill percentages). From Table 4 it can be seen that for the part illustrated in Figure 2 c. a good accuracy was obtained for diameter d of 15mm, length

l of 16,5mm and height h of 8,7mm. The measurements results of the part represented in Figure 2 d. are shown in Table 5: all of them are inaccurate for both infill percentages. The perfect fit between them, of 0,2mm, resulted for the pairs: length l of 8,5mm and 8,6mm with length L of 8,99mm (both infill percentages). For the part illustrated in Figure 2 e. it is noted a good dimensional accuracy for diameter D of 4mm and length L of 25mm, for diameter D of 5mm, all lengths (15mm, 20mm and 25mm) and for diameter D of 6mm

and length L of 25mm, all using 60% infill, while using 100% infill none of the parts were accurate.

The part shown in Figure 2 f. is not accurate for any of the values considered; neither 60% infill nor 100% infill.

The part presented in Figure 2 g. is not accurate as well; the results of the measurements are beyond the CAD model for both infill percentages.

The part pictured in Figure 2 h. is inaccurate for 60% infill because of the length L , whose value is well beyond the designed one. For 100% infill, apart from the length L also the length L_I was out of dimensional tolerance, which lead to inaccuracy of the part.

The results of the measurements for the part represented in Figure 2 i. revealed the fact that this is not accurate for the dimensions considered, because of the lengths L_2 and L_3 , in both cases (infill 60% and infill 100%).

For part in Figure 2 j. eighteen variants were considered, each of them printed three times for both infill percentages, but none of them was accurate. The parts with thickness smaller than 0,5mm could not be printed (for none of the infill percentages) and the ones with thickness bigger than 1mm exceeded the value from the CAD model.

All the forms printed for the model presented in Figure 2 k. are inaccurate, for both infill percentages, all because of exceed values.

For the model in Figure 2 l. only the part having the diameter g of 2mm and the height h of 15mm has proved to be dimensional accurate, using 60% infill, all the other diameters under this value exceeding the CAD dimensions for both infill percentages.

5. CONCLUSIONS

The main advantages of 3D printing are single step manufacture, low cost, complexity freedom and design freedom. There are several methods of 3D printing, but the most widely used for plastic materials is Fused Deposition Modeling (FDM). Although FDM is very flexible, the manufacturing of parts is limited by dimension.

The purpose of this paper is to assess the accuracy and the precision for small-sized parts printed on Zortrax M200 3D printer in order to determine the manufacturing limits and restrictions of this technology. In this regard, twelve benchmark models of different sizes with various shapes were considered for this study, which was carried out at the Department of Manufacturing Engineering of the Transilvania University of Braşov.

Keeping a high surface quality and strength and avoiding layer shifting or misalignment, the minimum

diameter of the bolt that could be printed was of 3mm and the minimum value of the wall thickness was of 0,5 mm for a certain design.

Regarding the two pairs studied in order to determine the best match between them, after many trials, the value of 0,2mm was considered optimal in both cases.

In some cases the results obtained after measuring were the same for both infill percentage (60% and 100%), leading to the conclusion that infill percentage influences print weight, material usage and productivity.

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REZIME

TEHNOLOŠKE RESTRIKCIJE 3D ŠTAMPE ZORTRAX M200 3D PRINTER

Cilj istraživanja bio je da se utvrdi tačnost (do kog nivoa 3D štampa odgovara 3D modelu) i preciznost (koja ustanovljava konstantnost merenja) malih plastičnih delova odštampanih na Zortrax M200 3D štapača. Jedan od ciljeva istraživanja bio je i da se utvrdi koliko debljina zida može biti smanjena a da se zadrže tvrdoća i dimenzionalna preciznost. Odgovarajući metod dizajniranja jednog para delova je bio targetiran. Da bi odštampan deo bio odgovarajuće uklopljen sa svojim parom, devijacija fizickih dimenzija je uzeta u obzir. Isto tako, rezultati eksperimentalnog rada na mogućnostima i ograničenjima ove tehnologije štampanja koristeći ovoj štampač su prezentovane u ovom radu. Nekoliko parametara kao što su površinski kvalitet i jačina, menjanje slojeva i neporavnanja su posebno istražena.

Ključne reči: 3D štampanje, modeliranje taloženih depozita, Zortrax M200, minijturni delovi, tehnološke restrikcije