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Effect of Different FFF 3D Printing Materials on Surface Roughness, Dimensional and Mass Accuracy

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Abstract

3D printing is becoming more accessible every day, although it is still lagging behind conventional methods in terms of material properties and production time. The influence of different printing parameters on the characteristics of FFF printed parts has been the subject of research in many studies. Since each material behaves differently during printing, it is important to identify how the selection of the same printing parameters reflects on some of the important characteristics of parts made of different materials and how some of them (in this case mass) fits with the software predictions.

ABS, PLA and PLA+Carbon materials were used for comparison in this paper. The output parameters taken into consideration are surface roughness, dimensional accuracy and mass difference. The obtained values of these parameters, measured on the printed parts, were compared and analysed. The parts are made of the mentioned materials with similar printing settings (only the material specific settings where changed: printing temperature, build plate temperature, etc.) For each material 3 specimens were printed on the same FFF printer to determine which dimension accuracy can be expected (to scale the future designs of parts accordingly). This was also done to ascertain what properties of surface roughness can be achieved with these materials and settings. Finally, based on this procedure it is possible to determine what amount of material is going to be needed when compared to software predictions.

Key words

ABS;
PLA;
PLA+Carbon;
3D printing;
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1. Introduction

Since 3D printing becomes widely available and is used more frequently in daily life, it is essential to know the characteristics and behaviour of various materials. FFF (Fused Filament Fabrication) printing technology is utilized in this study, where three-dimensional parts are made layer by layer by the extrusion of plastic material in the form of filament. Numerous studies have examined the effects of various printing parameters on the properties of FFF printed items. Since each material behaves differently, it is critical to understand how the choice of the same printing parameters affects some of the key traits of parts created of various materials. Also, to see how certain characteristics align with software expectations. Surface roughness, dimensional accuracy, and mass accuracy were the three characteristics that were examined in this study. The materials were compered, and it is determined how each of them performs. Three materials were used, ABS, PLA, and PLA + Carbon.

2. Method

2.1. Printing settings and software

For each of 3 materials used, 3 specimens were printed on the same FFF 3D printer, in this case the Wanhao Duplicator I3 plus, using the Ultimaker Cura software. The reason for choosing this 3D printer is its affordable price while Ultimaker Cura is an opensource software that makes it very popular and, therefore, our results useful to a number of users of this technology. The printing settings used here were Cura's draft 0.2 mm general settings, except for some materials related that needed to be changed. These changed settings are shown in table 1[3]. Printing time for each specimen was 1:28:59s. The build plate for our printer is made of glass so in order for the first layer to stick to the bed, glue was applied. For PLA and PLA + Carbon, hair spray was used and for ABS, a mixture of acetone and ABS crumbs. Some of the important characteristics of Wanhao Duplicator I3 Plus are shown in the Table 2 [1].

Table 1 - changed parameters in Cura's draft 0.2mm settings

Changed parameters	ABS	PLA, PLA + Carbon
Printing temperature [°C]	240	220
Build plate temperature [°C]	80	70
Top/Bottom thickness [mm]	1.6	1.6
Print speed [mm/s]	40	40
Build plate adhesion	None	None
Cooling	Off	On

Table 2 - Some of the important characteristics of Wanhao Duplicator I3 Plus

Number of extruders	1
Print speed	10-100 mm/s
Layer resolution	0.1-0.4 mm
Nozzle size	0.4 mm
Precision tolerance (XY)	12 um
Precision tolerance (Z)	4 um
Material Dimensions (R)	1.75 mm

2.2. Measuring methods

After printing all specimens, they were measured and analyzed for dimensional accuracy, surface roughness and mass accuracy.

For measuring dimensional accuracy, a caliper is used. Each part is measured for length (x), width (y) and height (z). Due to the configuration of the part, the height was measured at 3 points and then the mean value was taken as a result. The width was also measured at 3 points, but each result was considered unique until a percentage deviation was calculated after which it was possible to find the mean value of the percentage deviation. All of the measuring points are shown in Figure 1 below, where a represents the length, b1, c, b2 width and d1, d2, d3 height.

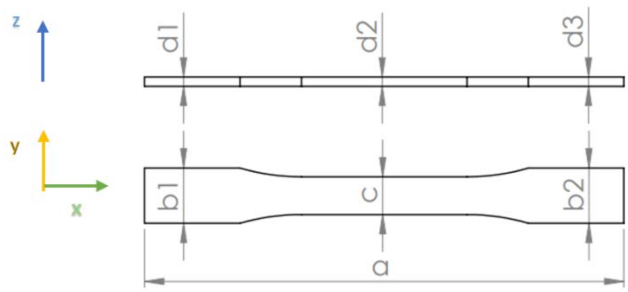

Figure 1 - technical drawing

Table 3 - reference values

A [mm]	b_1 [mm]	b_2 [mm]	C [mm]	d_1 [mm]	d_2 [mm]	d_3 [mm]	M [g]
165	19	19	13	3.2	3.2	3.2	11

Regarding surface roughness, 3 parameters were measured: Ra, – the arithmetic average of the absolute values of the profile height deviations from the main line, Rz, – the average of the five highest peaks and five deepest valleys, and Rmax, – the largest single roughness depth within the evaluation length.

The testing was carried out on an SD26 drive unit using the probe BFW A 10 – 45 2/90. The traverse length of 1.76 mm and the traverse speed of 0.5 mm/s were chosen. In order to get most accurate results on each specimen, 2 tests were performed: one where the specimen is placed parallel with the moving of the measuring probe and the other where the specimen is placed by an angle of 45 degrees. The reason behind choosing exactly 45 degrees is that the inner lines were printed in the same direction to achieve the best mechanical properties [2]. These tests are shown in Figure 2, and Figure 3, respectively.

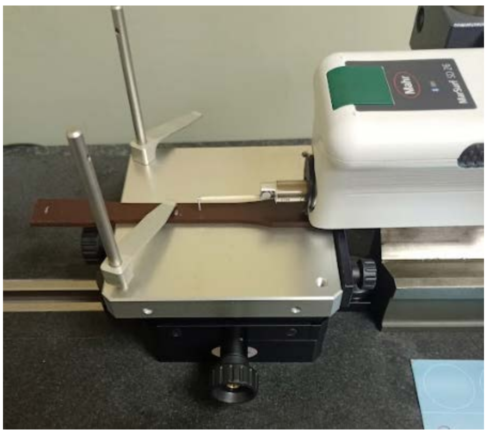

Figure 2 – longitudinal surface roughness measuring

Figure 3 – surface roughness measuring at 45° angle

Mass measurements were performed on an electronic scale with an accuracy of 0.01 grams.

3. Results

3.1. Dimensional accuracy

The main goal of dimensional accuracy is to find a percentage deviation in every direction of the coordinate system. Also, important parameters to know are tolerances and accuracy of obtained results (meaning that the obtained values of the measured parameters for selected material for all specimens made in one series show the same tendency). Knowing that information it is possible to scale the future parts in order to get higher accuracy. Measured values, percentage deviation and tolerances are shown in Tables 3, 4 and 5 respectively. The average percentage deviation is shown in Table 6.

Table 4 – measured values

PLA								
SN	a	b1	b2	c	d1	d2	d3	dsr
1	166.65	19.11	19.18	13.17	3.51	3.6	3.59	3.57
2	166.65	19.19	19.12	13.15	3.37	3.44	3.46	3.42
3	166.7	19.22	19.1	13.11	3.39	3.46	3.42	3.42
PLA + Carbon								
1	167.2	19.36	19.32	13.39	3.48	3.56	3.53	3.52
2	167.2	19.42	19.41	13.36	3.52	3.55	3.54	3.54
3	167.25	19.45	19.35	13.34	3.69	3.85	3.88	3.81
ABS								
1	166.1	19.21	19.15	13.2	3.47	3.4	3.46	3.44
2	166.2	19.24	19.2	13.14	3.44	3.42	3.51	3.46
3	166.35	19.16	19.26	13.17	3.43	3.43	3.45	3.44

Table 5 – percentage deviation

PLA							
SN	δa	δb1	δb2	δc	δd1	δd2	δd3
1	1.00%	0.58%	0.95%	1.31%	9.69%	12.50%	12.19%
2	1.00%	1.00%	0.63%	1.15%	5.31%	7.50%	8.12%
3	1.03%	1.16%	0.53%	0.85%	5.94%	8.12%	6.87%
PLA + Carbon							
1	1.33%	1.89%	1.68%	3.00%	8.75%	11.25%	10.31%
2	1.33%	2.21%	2.16%	2.77%	10.00%	10.94%	10.63%
3	1.36%	2.37%	1.84%	2.62%	15.31%	20.31%	21.25%
ABS							
1	0.67%	1.11%	0.79%	1.54%	8.44%	6.25%	8.12%
2	0.73%	1.26%	1.05%	1.08%	7.50%	6.87%	9.69%
3	0.82%	0.84%	1.37%	1.31%	7.19%	7.19%	7.81%

Table 6 - tolerances

Tolerances				
Material		Length (x)	Width (y)	Height (z)
PLA	Min	+1.65	+0.1	+0.37
	Max	+1.67	+0.22	+0.6
PLA + Carbon	Min	+2.2	+0.32	+0.48
	Max	+2.25	+0.45	+0.88
ABS	Min	+1.1	+0.14	+0.4
	Max	+1.35	+0.26	+0.51

Table 7 – average percentage deviation

Material	Length (x)	Width (y)	Height (z)
PLA	1.01%	0.91%	8.47%
ABS	1.34%	2.28%	13.19%
PLA + CARBON	0.74%	1.15%	7.67%

3.2. Surface roughness

For surface roughness, it is important to see which material performs best and what values can be expected. Two methods of measurement performed here show us also how obtained results vary depending on the angle of measurement. The results in Table 7 show us that the best performer is ABS followed by PLA and PLA + Carbon in the end. Table 8 shows average values for surface roughness for each material.

Table 8 - measured surface roughness values

Along the length of the specimen					45degrees (along the 3D printed lines)		
Material	SN	Ra	Rz	Rmax	Ra	Rz	Rmax
PLA	1	3,152	13,931	20,954	0,528	2,345	8,214
	2	2,133	11,278	22,233	0,382	2,145	3,044
	3	2,770	15,062	30,967	0,404	1,899	5,460
ABS	1	1,073	5,069	7,656	0,353	1,768	3,760
	2	0,759	3,516	5,247	0,209	1,214	1,605
	3	0,943	4,246	7,758	0,307	1,975	2,680
Carbon	1	4,020	21,247	26,142	1,563	7,334	11,213
	2	2,231	10,933	18,830	2,642	10,823	12,831
	3	2,956	17,463	24,678	2,217	11,903	13,807

Table 9 - average surface roughness values for each material

Average values						
	Along the length of the specimen			45degrees (along the 3D printed lines)		
Material	Ra	Rz	Rmax	Ra	Rz	Rmax
PLA	2,685	13,424	24,718	0,438	2,130	5,573
ABS	0,925	4,277	6,887	0,290	1,652	2,682
Carbon	3,069	16,548	23,217	2,141	10,020	12,617

3.3. Mass accuracy

The results obtained here show us the accuracy of software mass predictions. The way the software calculates the mass for each part is by measuring the extrusion of material which is used to calculate the volume and then the mass is determined by multiplying the volume with density. For PLA and PLA + Carbon the predictions were 11g and for ABS it was 9g. Percentage deviation for PLA and PLA + Carbon is similar, 2.55% and 2.79% respectively. For ABS the percentage deviation is 1.07%. Measured values and percentage deviation for mass accuracy are shown in table 9.

Table 10 - measured values and percentage deviation for mass accuracy

Mass (g)			
Material	Software prediction	Measured values	Percentage deviation (%)
PLA	11	10,67	2.55
		10,75	
		10,74	
PLA + Carbon	11	10,52	2.79
		10,79	
		10,77	
ABS	9	9,07	1.07
		9,1	
		9,12	

4. Conclusion

Knowing how materials effect the end characteristic of printed parts, what their benefits and drawbacks are, and how to achieve best results in accordance with the requirements that components need to meet is essential to avoid errors. It is also crucial to prevent additional mistakes by taking into account the influence of the external environment, improper material use and material storage, as well as other factors. Results presented here shows us what we can expect when printing future parts. The obtained values of the measured parameters for selected material for all specimens made in one series show the same tendency.For the best dimensional accuracy PLA + Carbon is preferred.Best performed in terms of surface roughness and mass prediction was ABS.

5. References

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