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DIMENSIONAL ACCURACY OF PROTOTYPES MADE WITH FDM TECHNOLOGY

DIMENZIJSKA NATANČNOST PROTOTIPOV PROIZVEDENIH S FDM TEHNOLOGIJO

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Abstract

Under the term “additive manufacturing”, commonly known as 3D printing, we distinguish various methods of manufacturing technologies. Common to all these processes is manufacturing a model layer by layer from a digital form. The aim of this paper is to experimentally determine which material provides dimensionally more accurate prototypes on a Fused Deposition Modelling (FDM) additive machine. Acrylonitrile Butadiene Styrene (ABS) and PolyLactic Acid (PLA) materials were used. The dimensional accuracy was checked by comparing the Computer-Aided Design (CAD) model with each of ten models obtained by the method of 3D scanning. The results show that prototypes manufactured from PLA are dimensionally more accurate those made from ABS.

Povzetek

Pod izrazom proizvodnja z dodajanjem materiala oziroma pogosteje uporabljenim izrazom 3D tiskanje ločimo različne metode proizvodnih tehnologij. Skupno vsem procesom je proizvodnja modela po plast za plastjo iz digitalne oblike. Namen tega prispevka je eksperimentalno določiti, kateri material zagotavlja dimenzijsko natančnejše prototipe izdelane s FDM tiskalnikom. Uporabljena sta bila 2 materiala akrilonitrilbutadienstiren (ABS) in polimlečna kislina (PLA).

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Dimenzijska natančnost je bila preverjena tako, da je bilo vseh deset natisnjenih modelov pretvorjenih v računalniške s pomočjo skeniranja in nato primerjani z modeliranim računalniškim modelom. Rezultati kažejo, da so prototipi izdelani iz PLA materiala dimenzijsko natančnejši od prototipov izdelanih iz ABS materiala.

1 INTRODUCTION

Fused Deposition Modelling (FDM) is an additive manufacturing process by which a model, prototype or finished product is manufactured. The process was invented by Crump in the late 1980s, and the procedure has been commercially available since 1990. It is also known as FFF (fused filament fabrication) process or PJP (plastic jet printing). Upon the expiration of the patent for this technology, the possibility of creating affordable 3D printers for homes and offices has emerged. Equipment that cost $20,000 in 2010 now costs less than $1,000, *[1].* Although the technology has become widely accepted it has some limitations, such as layer thickness, and producing very thin walls that are prone to warping, etc., *[2]*.

For this work, the FlashForge Creator X device with two nozzles (two extruder heads) was used. The device has relatively small dimensions and can be used as office equipment (Figure 1).

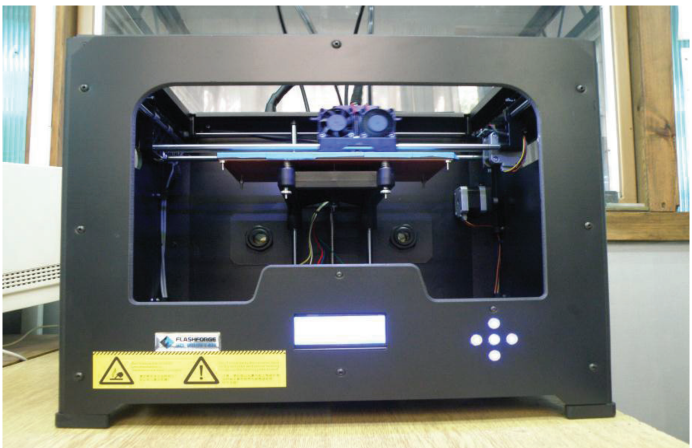

Figure 1: *FDM machine Flashforge Creator X.*

As with all other FDM devices, the material is supplied to the head with a plastic (teflon) tube guide. The material is in the form of a wire with a diameter of 1.75 mm wound on a drum located on the rear panel. The principle of operation is as with other FDM devices. The workpiece is created layer by layer in the direction of the z-axis. The extruder head with the nozzles is shifted in the x- and y-axes using an electric motor, belt, and metal rails. After applying the first layer, the work bed is lowered to a height of one layer in the z-axis, and the next layer is printed. The procedure is repeated until the last layer is finished.

Currently a wide variety of materials is available, but the most commonly used are Acrylonitrile Butadiene Styrene (ABS) and PolyLactic Acid (PLA), *[3]*.

Some studies report the dimensional properties of different materials used in FDM technology, but they mostly depend on orientation, layer thickness, machine, curing, etc., *[4-6]*.

2 DESIGN

The first step in our experiment was modelling the body of the electronic casing (3D model) in SolidWorks 2014 (Figure 2). A wall thickness of only 2 mm is a major problem when manufacturing on a desktop FDM device. Prototypes with thin and high walls (requiring a long time to manufacture) made on this device are not as dimensionally stable as prototypes made on industrial devices. In practice, the device had problems with both materials. ABS had a greater tendency to warping visually or splitting away from the work bench. With using PLA material, there were difficulties in clogging of the extruder.

Strains occur due to differences in temperature between the work bed and the workpiece, and that also includes the temperature difference between the separate layers of the workpiece along the z-axis, *[2]*. The tendency of the material to warp may also depend on its chemical composition.

Separation of the two layers while printing is called "stratification", which is a relatively frequent phenomenon when printing with ABS material. Stratification is eliminated by installing the device in a place with no draft, which rapidly cools the workpiece. Newer generations of FDM devices have acrylic panels for outer protection.

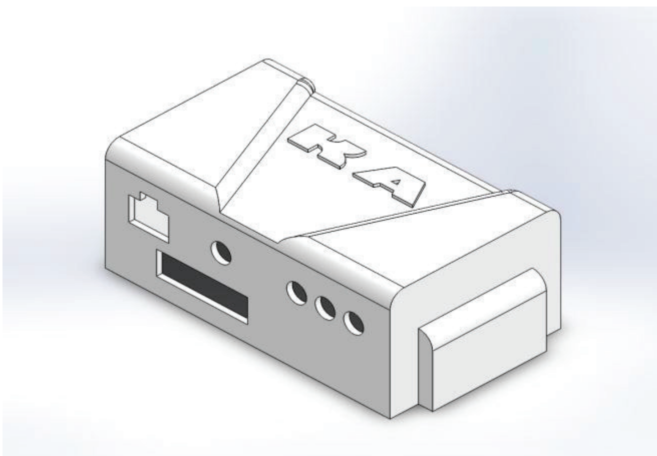

Figure 2: *3D model of electronic casing.*

3 MANUFACTURING ON FDM MACHINE

After designing the virtual product or 3D model, the next step is converting it to STL (Standard Tessellation Language) file format and manufacturing it with the FDM device. Ten prototypes were printed: five in ABS (white casing), and five in PLA material (blue casing). The casing has dimensions of 100×60×41 mm (L×W×H) with a wall thickness of 2 mm.

When printing ABS material, the following parameters were used (Table 1). Infill of only 10% was used in order to save on material and reduce printing time. This type of device is not suitable for working with the infill from 70–100%, because the results are poor in appearance and quality. A layer height of 0.20 mm is the standard option for this device. The working temperature of the heated workbed is usually set between 100 and 110 °C (Table 1).

Table 1: *Settings used while printing in ABS and PLA material.*

SETTINGS	ABS	PLA
Infill (%)	10	10
Layer thickness, mm	0.2	0.2
Extruder temperature, (°C)	225	210
Work bed temperature, (°C)	102	60
Extrusion speed while printing, (mm/s)	60	60
Extrusion speed while changing position, (mm/s)	90	90

While printing PLA material, some settings needed to be changed. Layer height and extrusion speed remained identical. The temperature of the heated work bed was changed and set to 60 °C. The temperature of the extruder was set to 210 °C (Table 1). All ten prototypes were made over a time interval of ten days in closed office space so that external influences were minimal (Figure 3).

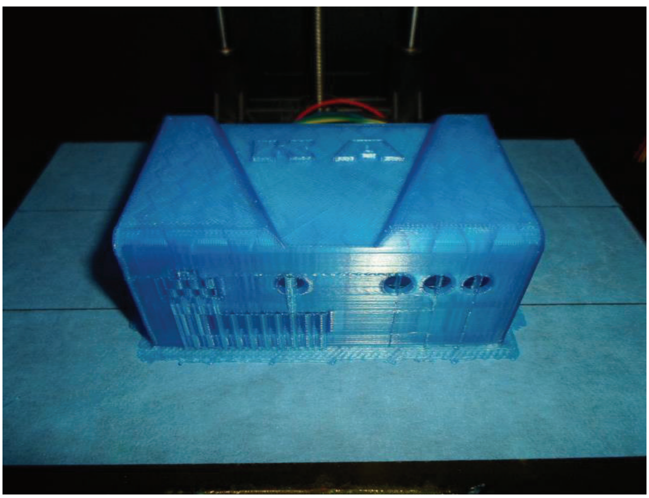

Figure 3: *Finished prototype in PLA material.*

4 3D SCANNING

The process of digitalization was done on a Steinbichler Optotechnik series Comet5 1.4M industrial 3D scanner. The process of digitizing (3D scanning) with this equipment is very quick, easy, and accurate. The characteristics of the device are listed in Table 2.

Table 2: *Characteristics of 3D scanner.*

Measuring volume (x,y,z)	46×34×50 mm^3
Camera resolution	1.4 Mpx
Measuring distance (z)	850 mm
Measuring distance of neighbour points (x,y)	0.033 mm
Capturing time	2 sec. (high-speed module)
Light source	200 W
Supported data formats	CATIA V4/V5, IGES, STEP, Pro/E, TXT, STL

Prototypes made from PLA had highly reflective surfaces, which are difficult to digitize so they were sprayed with a very thin layer of non-reflective white coating. White products from ABS had matte surfaces and did not have this problem.

The aim of digitization is to obtain an STL file or a 3D model of the manufactured prototype on the computer. A product that is digitized is positioned on a rotating table. The computer program operating the scanner was adjusted to the desired number of images to digitize over a full rotation (360°) of the stand. If the number of desired images is set to 10, for example, the table is rotated by 36° for each picture. After a full circle, the computer screen displays a 3D model of a digitized product. It is necessary to review the model to detect potential flaws or errors. Sometimes it is necessary to fill holes on the surface of the model, because it was not well digitized, or to repeat scans at certain custom angles. These are common phenomena during this procedure. Constant temperature and light are conditions in which digitization should be conducted. The 3D scanner comprises a temperature sensor so that the deviation in temperature does not affect the results. If the temperature sensor reads a temperature above or below the set limits, the device disables recording. The amount of light should be constant (best with no light), because it directly affects the digitizing, or appearance of the 3D model. To prevent light affecting accuracy, measurements were taken in a dark room isolated from outer environmental light.

5 RESULTS

Comparison of dimensions between CAD and digitized 3D model is possible by using a computer program to check deviations. INSPECTplus software allows users to align scan data with other scan data or CAD 3D models. Once aligned, the user can generate surface comparison reports, comparisons of cross sections and border lines with needle diagrams, feature comparisons and traditional measurements. Select the CAD model (ideal computer model), in this case called “box ver 8”. Next, select the model prepared by the process of digitalization. Products in this paper are marked as ABS and PLA 1-5 to prevent confusion during the processing of results. Furthermore, to compare the dimensions, it is necessary to align the models in the same coordinate system. To align the models, the best fit option is selected (Figure 4).

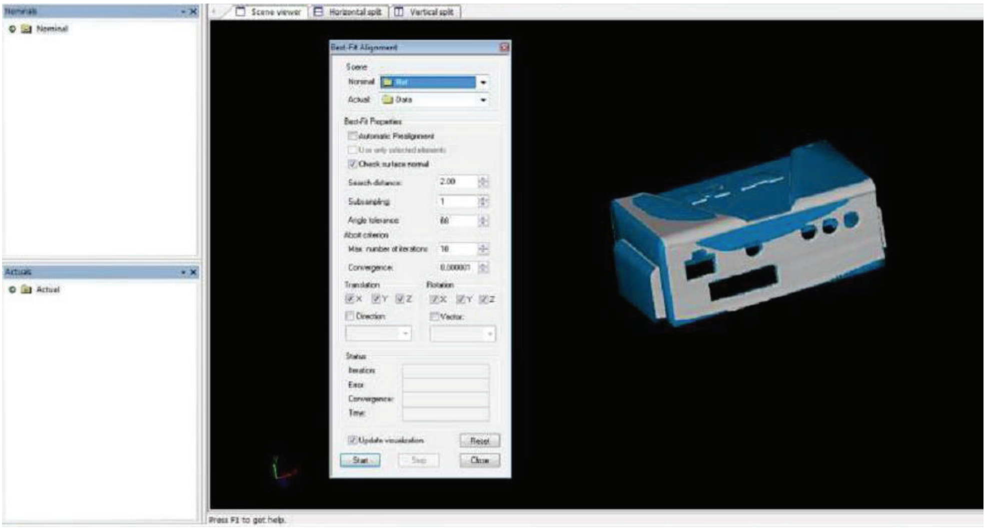

Figure 4: *Alignment of CAD (blue) and digitized model (grey).*

The next step is to check the values of deviation. The easiest way to achieve this is by the inclusion of the so-called “Color table” representation that uses different colours to mark deviations in the model being checked. Red defines deviations in the positive direction (surfaces placed or leaning outside the CAD model) and blue in the negative direction (surfaces placed to the interior of the CAD model). Maximum deviation limits on the “Color table” (dark red and dark blue) can be set by the user, and are often selected by trial and error until a satisfactory representation is generated.

Finally, it is possible to analyse deviations for any selected point on the model using the “Flyer” tool. For the purpose of this paper, the point of maximum deviation in the positive and negative direction was read for every digitized model (Figure 5).

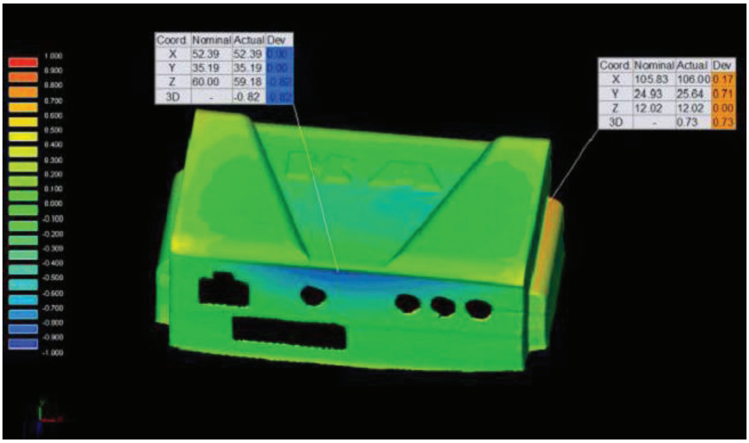

Figure 5: *Deviation of dimensions on prototype ''ABS 2''.*

Prior to the analysis of results, the readings had to be systematized. Accordingly, every surface on the model was marked with a cipher so they could be correlated with certain areas (surfaces/faces) on the model when determining the deviations (Figure 6).

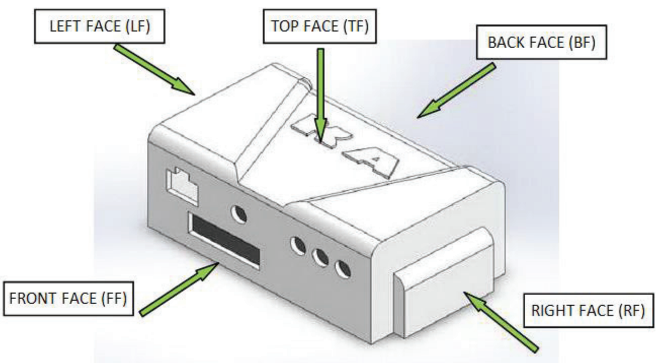

Figure 6: *Faces of the model with markings.*

Analysing the results in Table 3, clearly there are minor deviations in the production of the PLA material prototypes. Product ABS 3 has the largest recorded deviation of 1.01 mm. The reason for such a deviation in geometry is probably an error in material while manufacturing. More specifically, it is possible that some impurities appeared in the material and affected the final result.

Observing the locations of the maximum deviations in the negative direction (indentation of material) for both PLA and ABS, we can see constant repetition of the front (50%) and back faces (50%). Since these sides are the longest, they tend to have the largest indentations because there was no reinforcement on those sides. When the top layers are printed, the material cools, contracts and pulls the sides closer. To eliminate these deformations, some reinforcements should be added in the form of ribs to provide more strength to the faces

(FF/BF). In 70% of the cases, maximum deviations in the positive direction are located either on the left (LF) or right faces (RF) due to the warping of the material. While printing, the edges (LF/RF) first start to pull away from the work bed so that probably caused the deviations. In 30% of the cases, the maximum deviation occurred on the top face, probably due to impurities in the material.

When compared, prototypes made from PLA showed fewer deformations and were more stable and warp-resilient. Table 3 summarizes all the data collected.

Table 3: *Measured results.*

PROTOTYPE	MAX. POSITIVE DEVIATION (mm)	FACE	MAX. NEGATIVE DEVIATION (mm)	FACE
ABS 1	0.70	RF	- 0.75	FF
ABS 2	0.73	RF	- 0.82	FF
ABS 3	1.01	TF	- 0.67	BF
ABS 4	0.79	TF	- 0.73	FF
ABS 5	0.70	RF	- 0.70	FF
ABS_{AVG}	0.79 ± 0.13		- 0.73 ± 0.06	
PLA 1	0.26	RF	- 0.59	BF
PLA 2	0.24	TF	- 0.52	BF
PLA 3	0.26	RF	- 0.54	BF
PLA 4	0.24	LF	- 0.53	BF
PLA 5	0.39	LF	- 0.52	FF
PLA_{AVG}	0.28 ± 0.06		- 0.54 ± 0.03	

Total average deviation of ABS is 0.79 ± 0.13 and -0.734 ± 0.06. The deviation of PLA prototypes is 0.28 ± 0.06 and -0.54 ± 0.03. This means that prototypes from PLA were more accurate and dimensionally stable than those made from ABS.

6 CONCLUSION

The aim of this study was to experimentally investigate which material produces more dimensionally accurate prototypes. ABS and PLA materials, which are commonly used with FDM technology, were tested. The dimensional accuracy check was performed by comparing the CAD model with each of the ten digitized prototypes. Comparing the results of maximum deviations leads to the conclusion that the manufacturing of products with thin walls while using PLA material leads to smaller deviations in geometry.

In this case analysis, but accompanied by general experience, has shown that regardless of the geometry of the prototype, they are more accurate when manufactured from PLA material.

In office environments, it is safe to leave the device in operation, while working on another project. ABS generally requires more attention while printing to detect errors in a timely manner.

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