The Impact of Temperature Changing on Dimensional Accuracy of FFF process

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Abstract: Fused filament fabrication (FFF) is a process that produces 3D printed models by addition of solid material. All printed prototypes should have best accuracy to satisfy all requirements. In the current research was investigated if the parameter of fused filament temperature has an influence on accuracy of 3D printing. A low cost 3D printer called Ultimaker was used to print the items. Polylactic acid (PLA) was used as main polymeric material for printing. All dimensions (six points) of the models were measured with a micrometer (range 0-25mm).

Key-Words: Fused Filament Fabrication, 3D Printing, Dimensional Accuracy

1 Introduction

Fused filament fabrication (FFF), can be found also as fused deposition modeling (FDM) that creates computer aided design (CAD) models to be 3D printed from Polylactic Acid (PLA) [1] or Acrylonitrile Butadiene Styrene (ABS).

This technique is very easy and cheaper than other methods of rapid prototyping thus can be implemented in many applications: Architecture, Product Design, Biomedicine, Aerospace, Education [2] etc. FFF 3D printers are very popular during last years on the market.

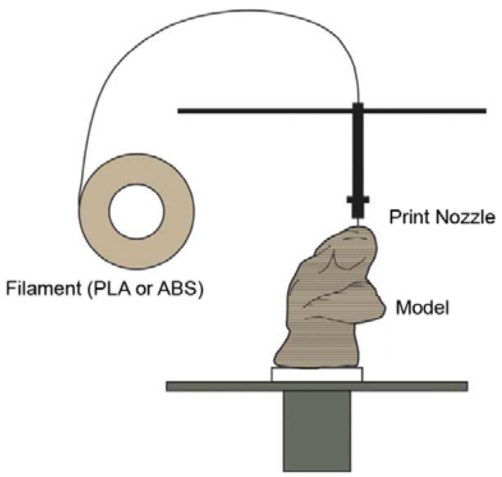

Fig. 1. Fused Filament Fabrication process

These machines extrude plastic into thin layers which are cooled very fast (with cold fan) thus the next layer can be added into the previous layer (Fig. 1). The 3D model is made by positioning of the nozzle in relation to the Plexiglas print bed, while depositing fused PLA onto the built part [3]. All parts are printed on this print bed. This Plexiglas bed may be stationary or may move along one the X, Y, Z axes. In this research a 3D printer with a stationary print bed was used. There are many printers with different technical specifications such as: quality of print (Layer resolution), build volume, print speed.

The main difference of SLA (Stereolithography) 3D printers is that SLA printers are used for high detailed printed objects. Anyone is able to decide which parameters can change to take the best print in FFF process [4]. In this research Cura software was chosen for performing of described above. Cura (created by the makers of the Ultimaker printer) is a free software that prepares the model that is designed in the CAD program (Autocad in this case). This software converts STL (or OBJ) files (slice the model) into G-Code.

The printer must handle the file that is designed in order for the model to be translated into a suitable format. Dividing the model into thin layers is called slicing.

Cura is suitable software for Ultimaker printer for performing slicing. By this software lots of settings can be changed such as layer height or layer thickness. All CAM (Computer Aided Manufacturing) software need an STL file in order to turn a 3D model into a machine (3D printer) friendly format. This format is called G-Code and Cura converts STL files to G-Code.

2 3D printer

All 3D printers are composed of electromechanic components (hardware) and software applications that are developed by engineering companies [5]. Home edition 3D printers have more easy functions than rapid prototyping machines. These are suitable for small offices (you can put it on your desk) and using less of energy. Manufactured of printing small plastic objects, home edition 3D printing technology is a low cost procedure and there is continuous development so the price of these machines will be reduced compared to expensive rapid prototyping machines.

For measures in this research popular 3D printer called Ultimaker was used (Fig. 2). The Ultimaker Original (by Ultimaker Ltd) is an open source 3D printer and it is based on the Rep Rap (Replicating Rapid-prototyper) technique. This model has been awarded as fastest and most accurate 3D printer in 2012. It can print complex drawings that have been designed in CAD software. Ultimaker supplies PLA (Polylactic Acid) and ABS (Acrylonitrile Butadiene Styrene) as materials for printing.

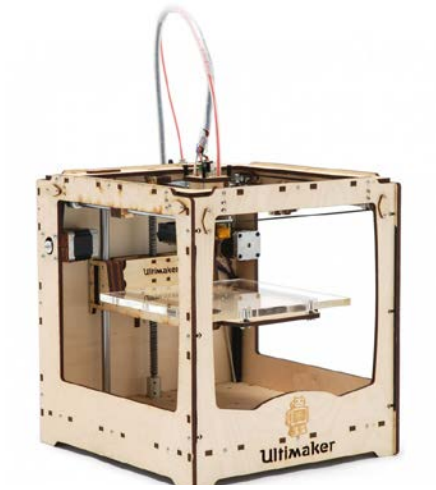

Fig. 2. Ultimaker 3d Printer

3 Technical details

Some technical specification of the printer are given: Layer resolution up to 20 μm, Build volume 21 cm × 21 cm × 20.5 cm, Print speed 30-300 mm/s, Travel speed 30-350 mm/s, Recommended filament diameter 2.85 mm, Nozzle diameter 0.4 mm, Printing technology Fused filament fabrication (FFF), Stand-alone SD-card printing, Frame dimension X Y Z: 35.7 cm × 34.2 cm × 38.8 cm, Operation nozzle temperature: 180-260 °C, Software: Cura - Official Ultimaker.

PLA is a biodegradable polyester and non-toxic material suitable for many applications [6]. There are many appliances such as medical usage, injection molding, packaging and 3D printing within past years. Its smell is very pleasant during printing. By this material you can get very good quality of prints in any color.

PLA or Polylactic acid derived from renewable resources like corn starch, tapioca roots or sugarcane. It is very ecological thermoplastic polyester because it naturally degrades in outdoor environment conditions. Different parameters in RepRap additive manufacturing system for PLA models could be selected [7].

For this research a 3D model was designed (Fig.3) by Autocad software and it was extracted in STL format. It have been converted by Cura software to G-Code and the layer was built with Ultimaker 3D printer. Suitable settings have been put into software changing only two parameters (filament temperature and shell thickness) each time. The printing settings were: layer thickness (height - mm) - 0.2 , shell thickness (mm): 3-2-1, fill density (%) - 20, print speed (mm/sec) - 100, printing temperature (°C): 210-220-230.

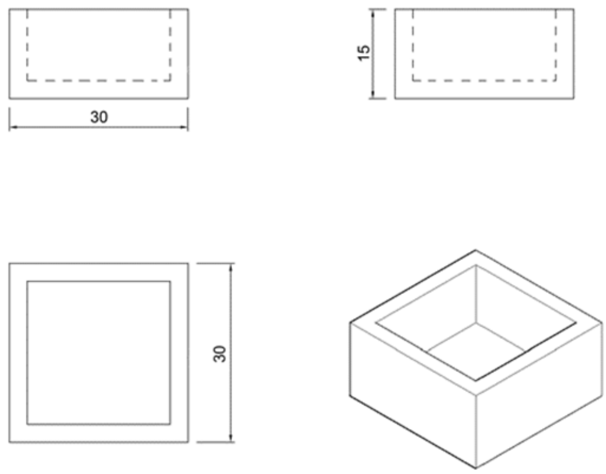

Fig. 3. 3D model

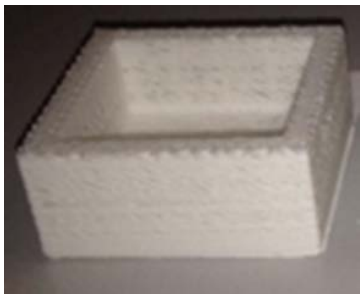

Fig. 4. 1st part (3mm, 210 °C)

Fig. 5. 2nd part (3mm, 220 °C)

Fig. 6. 3rd part (3mm, 230 °C)

Fig. 7. 4th part (2mm, 210 °C)

Fig. 8. 5th part (2mm, 220 °C)

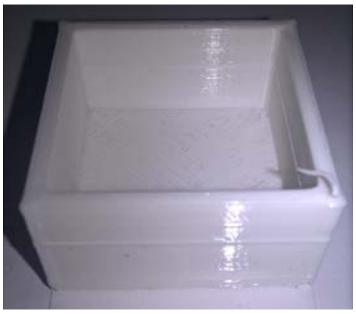

Fig. 9. 6th part (2mm, 230 °C)

Fig. 10. 7th part (1mm, 210 °C)

Fig. 11. 8th part (1mm, 220 °C)

Fig. 12. 9th part (1mm, 230 °C)

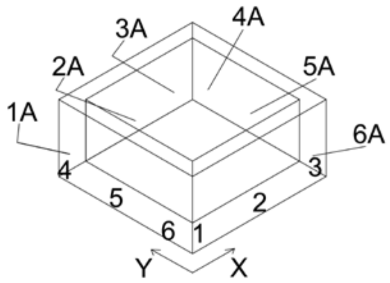

Fig. 13. Measurements points

Nine items were printed (Fig. 4-12, shell thickness 1, 2, and 3mm) by three different temperature printing parameters (210-220-230 °C) and all models were measured on six points (Fig. 13) with a micrometer (measuring range 0-25 mm). The obtained results are in the following tables:

Point	**Model 1 (210 °C) Mm**	**Model 2 (220 °C) mm**	**Model 3 (230 °C) mm**
Y6-6A	30.04	30.01	30.03
Y5-5A	30.04	30.00	30.03
Y4-4A	30.07	30.00	30.07
Mean Y	**29.91**	**29.84**	**30.04**
X1-1A	29.85	29.93	30.04
X2-2A	29.96	29.85	30.03
X3-3A	29.94	29.75	30.04
Mean X	**30.05**	**30.00**	**30.04**

Table 1. Dimensional accuracy measurements (3mm shell)

Point	**Model 4 (210 °C) Mm**	**Model 5 (220 °C) mm**	**Model 6 (230 °C) Mm**
Y6-6A	30.01	30.09	30.03
Y5-5A	30.02	30.08	30.00
Y4-4A	30.02	30.12	30.05
Mean Y	**29.94**	**29.95**	**29.97**
X1-1A	29.99	29.90	29.97
X2-2A	29.94	29.93	29.97
X3-3A	29.89	30.03	29.97
Mean X	**30.02**	**30.10**	**30.03**

Table 2. Dimensional accuracy measurements (2mm shell)

Point	**Model 7 (210 °C) Mm**	**Model 8 (220 °C) mm**	**Model 9 (230 °C) Mm**
Y6-6A	29.96	29.98	30.01
Y5-5A	29.92	29.96	30.01
Y4-4A	29.95	30.04	30.04
Mean Y	29.89	29.93	29.97
X1-1A	29.91	29.94	29.99
X2-2A	29.95	29.90	29.91
X3-3A	29.81	29.94	30.00
Mean X	29.94	29.99	30.02

Table 5. Dimensional accuracy measurements (1mm shell)

4 Conclusion

The examination of influence of temperature factor to the dimensional accuracy was made. Changing the value of temperature from 210 to 230 degrees (°C) the main XY dimensions of the model do not change (Table 1-3) and the values are so close to optimized result of 30 mm (XY). In next research the surface roughness of 3D printed models can be measured.

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