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Thickness precision of additive manufacturing parts

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Abstract:*Every production technology struggles with production accuracy, which is an essential part of the quality of the final product. The accuracy of the manufactured part depends on the selection of a suitable production technology. Additive production is slowly becoming one of the standard production technologies and is beginning to be commonly used, especially in the case of the production of special components and parts. The published article deals with an experiment that examines the accuracy of manufactured parts produced by FDM / FFF technology. The design of the tested parts, the method of production and measurement, as well as the evaluation process and the results of the experiment are presented.Measured is vertical thickness of parts, which is influenced by number of printed layers and the internal logic of slicing softvare.*

Keywords:*Additive manufacturing, Precision, Accuracy, 3D printing*

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I. INTRODUCTION

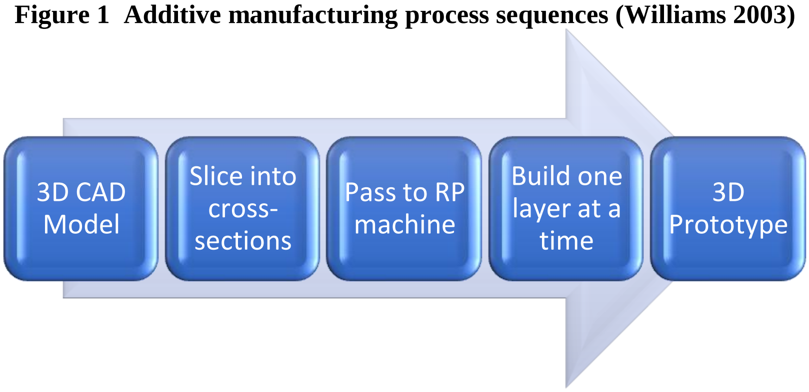
Additive manufacturing brings new look to the mechanical engineering production process.In the beginning, these systems were used mainly in the production of prototypes, where they facilitated the production of complex parts, or parts that would otherwise be unmanufacturable (Akande 2015).Gradually, as the systems improved, they were also used more for piece or small series production. There is a lot of Additive manufacturing technologies, used different materials and processes for production of parts. The process for preparation and production by additive manufacturing could be described as shown on Figure 1. 3D digital model have to be made and then used for pre-processing (Kačmarčík 2018, Witvrouw 2018)), . All the necessary parameters have to be set, as for example temprature of nozle heating, printing bed temperature, material type, printing speed and much more others (Tuan 2018).

Main difference between conventional subtractive and additive manufacturing is displayed on Figure 2. Subtractive technology removing material from semi-product, in contrast to Additive manufacturing where the material is placed layer by layer till whole part is made (Véronneau 2017).

Use of Additive manufacturing and rapid prototyping:

- for verification of parts size and functional principle;
- for verification of shape and design sophistication;
- for market analysis necessity;
- for design of products, tools and fixtures, necessary for serial production of parts.

Figure 1 Additive manufacturing process sequences (Williams 2003)



Advantages of Additive manufacturing techologies:

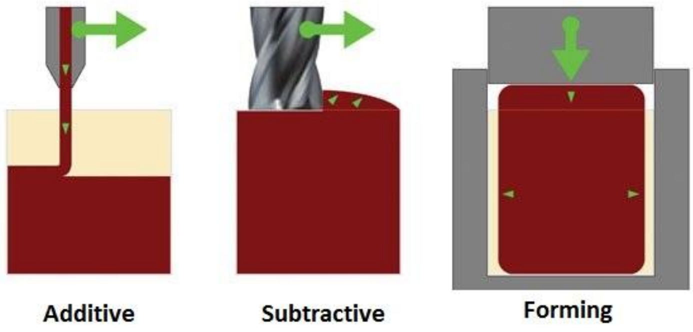
- fast production of prototype or model;
- possibility of model creation form production of real moulds for sand casting or plaster casting;
- possible production of any thinkable geometry;
- only one device – no needed other cost for tool exchange or for machine setup to next operation;
- can be produced more different parts just in one print;
- there is not necessary special trained operator for device control – process is semi-automatic;

Used Materials:

- PC ABS plastics;
- elastomers;
- wax and resin;
- nylon and other polymers;
- metal powders;
- much more.

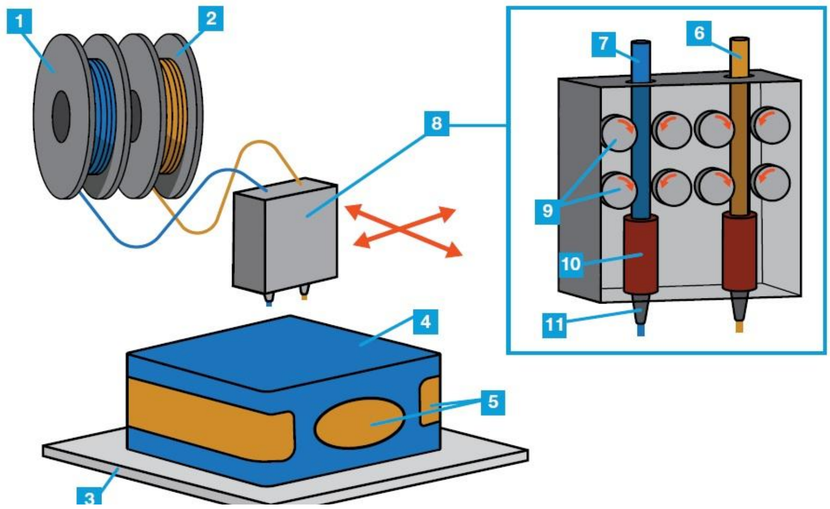
There are various techniques for part production by Additive manufacturing. Each of this techniques have their advantages and disadvantages. In following section will be discussed only by FDM Technology (Fused Deposition Modeling) (Alsoufi 2017, Camposeco 2020)). This technique using two materials – modeling and support. The material application system and FDM technique is presented on Figure 3. FDM technique works on similar principle as hot melt gun. The material is unwind from spool to fuse head, where is melted and applying on the device table surface (Chua 2003).

Figure 2 Differences between conventional machining and rapid prototyping (Lennings 2013)



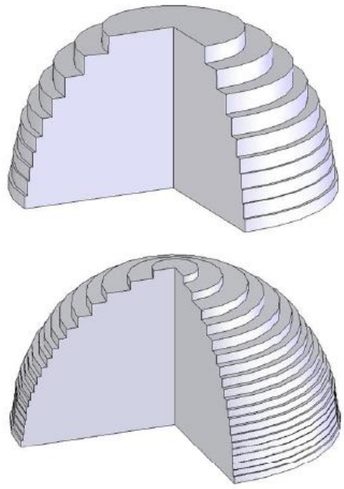
Support material is used in places, where the model material should by placed to the air, what is unthinkable, therefore is necessary to build supporting structure from support material. After model creation, the supporting structure is braked off or melted in special bath (Lieneke 2015).

Figure 3 Fused deposition modeling process (FDM) (Stratasys 2018)



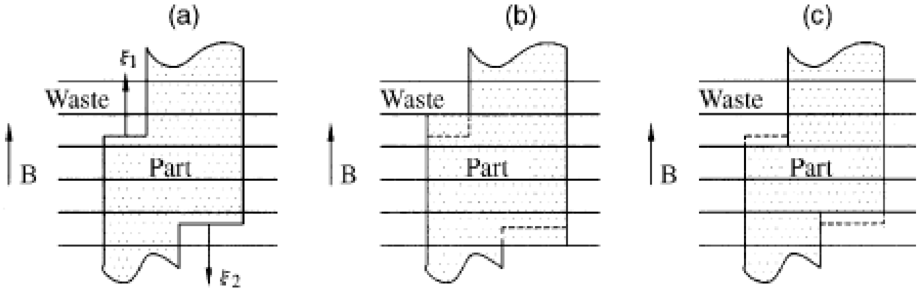
On the Figure 4 we can see the way of material deposition, layer by layer. From the thickness of deposited layer subsequently depends also shaped and dimensional precision of final model. This is valid mostly for models with surface, which is sloping toward horizontal surface with some angle. If the angle is smaller then we can see bigger offset in individual deposited layer (Petropolis 2015, Msallem 2020).

Figure 4 Layer Thickness influence to model precision (Yang 2012)



From dimension of part thickness and extruded wire thickness (layer thickness) depends accuracy of printed model, let us say accuracy of thickness printed model (Kushagra 2018). Different situations which are possible in the practice, can be seen on following Figure 5.

Figure 5. Decision in number of module layers, a) real model, b) positive tolerance, c) negative tolerance (Chiu 2004)



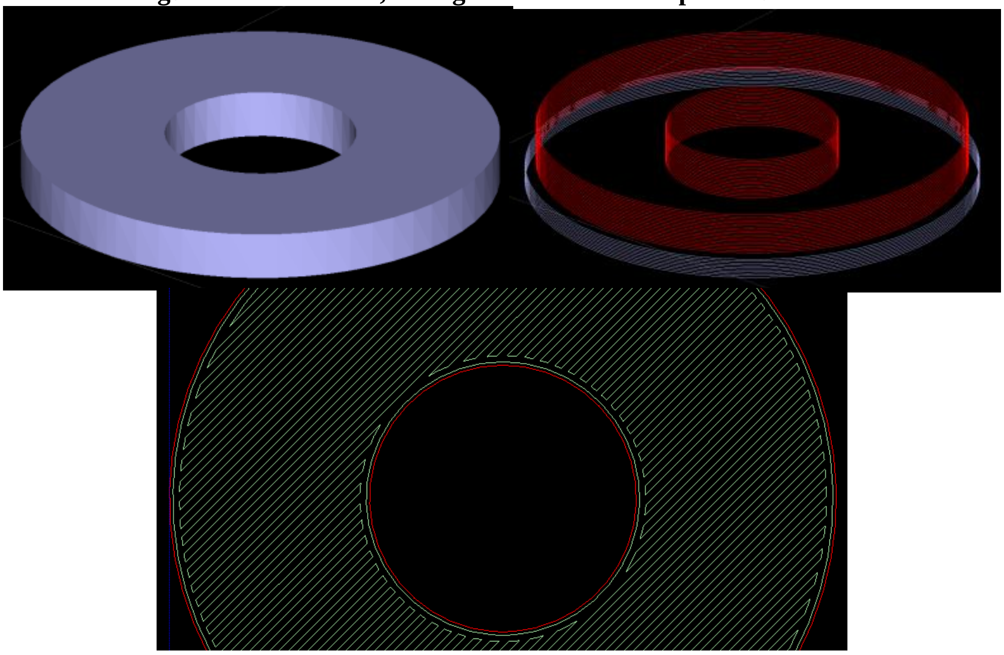
II. EXPERIMENTAL PROCEDURE

To compare the accuracy 3D models production we choose device Dimension SST, which is available of our department. It is device with FDM technique, which use PC ABS plastic to print the parts. Allows to print the parts in two possible extruded layer thickness, 0,254 mm and 0,3302 mm. There are available on this device different possibilities of printer setup, for example horizontal or vertical accuracy, Solid or Sparse model version and also possibilities of support structure building as Sparse, Basic, Surround and Break-away.

In following we can see, that was printed more model shapes (Figure 7 and Figure 8), what was not essential for this case, but models was printed with respect for further planed experiments, focused on comparison of inner and outer dimensions, shapes and geometry, produced in various style and with various setting of Dimension SST device.

We are interesting mostly on device print accuracy in axis Z direction, so height h of printed model, which is depended from extruded layer thickness and from that, how are this layers applied at each other. We can suppose, that height of printed model is possible to easy calculate from data as is thickness of extruded layer and from number of deposited (extruded) layers. Inaccuracy should be right thickness of extruded layer in case when system have to decide in the ultimate state if add or reduce one layer, as it is shown on Figure 5.

Figure 6 Solid Model, slicing of model and Toolpath illustration



On Figure 6 we can see Solid model, how is designed in CAD system environment, on next view we can see layering of model to layers, which will be printed on 3D printer device. On the last view is the toolpath of printing tool (nozzle), which extruding plastic material. The layering of model, toolpath and also placement of support material (support structure) is generated automatically by software for device control, only based on defined input data.

The height of models was chosen for values 5,0mm; 5,1mm; 5,2mm; 4,953mm, for Print No.1, so in case when thickness of extruded layer is set to 0,254mm. The value of height of printed model 4,953mm was chosen because right for this value we reach theoretical number of printed layers 19,5 (4,953/0,254=19,5) and we want to know, if this limit value will affect the accuracy of printed model (its height).

For case of Print No.2 was chosen similar values, 5,0mm; 5,1mm; 5,2mm and 5,1181mm. And again the dimension 5,1181mm was chosen so that we can reach limit value of layers number 15,5.

Figure 7 The models printed on 3D printer Dimension SST, Model 1 and Model 2

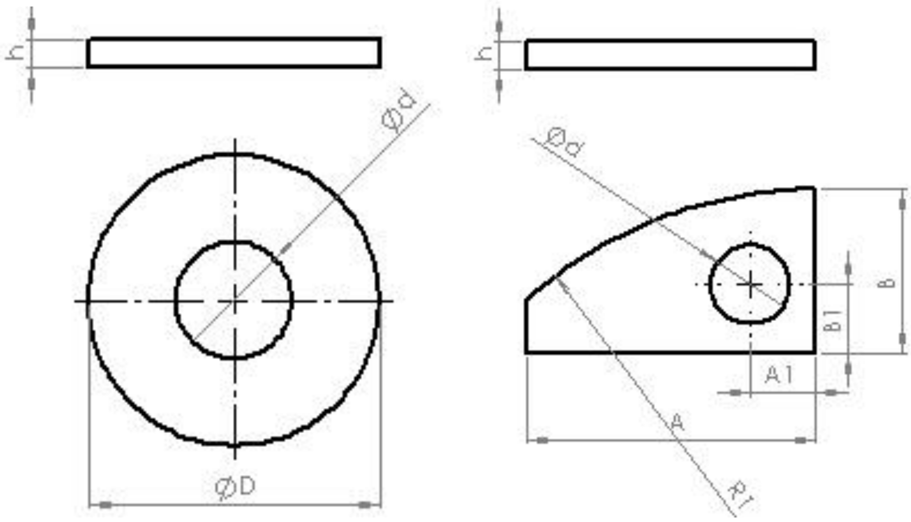


Table 1 Thickness of Model 1 (circle) for Print No. 1 and Print No.2

Print No. 1	1	2	3	4	5	6	7	Average	Dev.	Var.
h (mm)	5,24	5,19	5,18	5,19	5,2	5,22	5,19	5,2014	0,02115	0,000384

Print No. 2	1	2	3	4	5	6	7	Average	Dev.	Var.
h (mm)	5,24	5,29	5,38	5,32	5,31	5,36	5,32	5,3171	0,04572	0,001792

Table 2 Thickness of Model 2 (arch) for Print No. 1 and Print No.2

Print No. 1	1	2	3	4	5	6	7	Average	Dev.	Var.
h (mm)	5,14	5,22	5,22	5,27	5,31	5,29	5,22	5,2385	0,05698	0,002784

Print No. 2	1	2	3	4	5	6	7	Average	Dev.	Var.
h (mm)	5,21	5,23	5,35	5,3	5,27	5,26	5,36	5,2828	0,05707	0,002792

The printed models have been then put to measuring process, to measure all dimensions, how they are shown on Figure 7 and Figure 8. For our need of fast experiment evaluation, we choose only height h of printed model, where should be the most visible influence of accuracy extruded layers of plastic material on the model. Measured values of height (from model shape view as a total it is thickness h) are marked in Table 1, Table 2, Table 3, and Table 4, where are also calculated average values, standard deviation and variance of measured values.

Figure 8 The models printed on 3D printer Dimension SST, Model 3 and Model 4

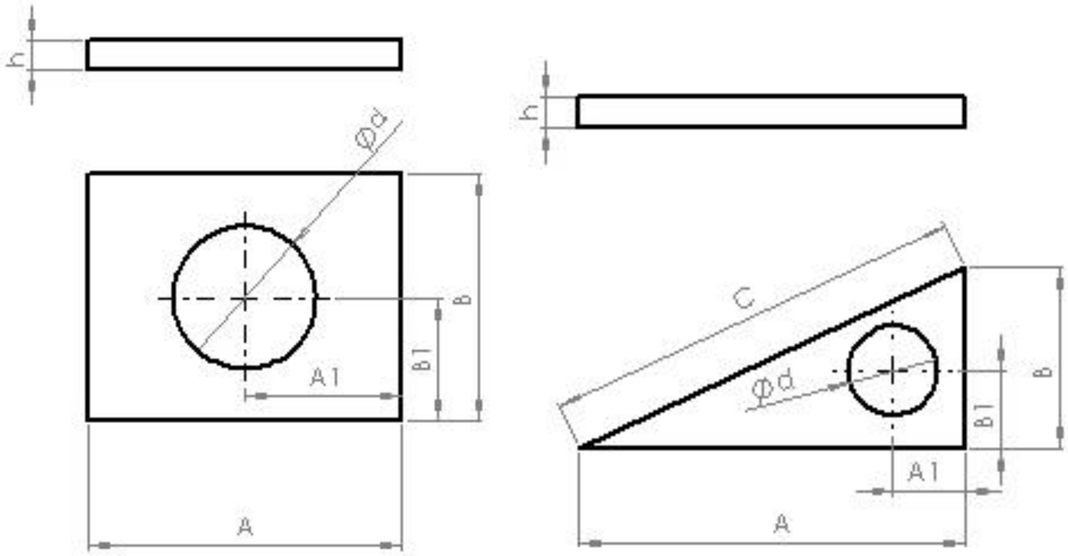


Table 3 Thickness of Model 3 (rectangle) for Print No. 1 and Print No.2

Print No. 1	1	2	3	4	5	6	7	Average	Dev.	Var.
h (mm)	5,01	4,94	5,12	5,07	5,1	5,5	5,06	5,114286	0,180357	0,027882

Print No. 2	1	2	3	4	5	6	7	Average	Dev.	Var.
h (mm)	5,28	5,33	5,3	5,37	5,25	5,23	5,26	5,2885	0,04879	0,002041

Table 4 Thickness of Model 4 (triangle) for Print No. 1 and Print No.2

Print No. 1	1	2	3	4	5	6	7	Average	Dev.	Var.
h (mm)	5,09	5,27	5,29	5,33	5,21	5,28	5,39	5,2657	0,09519	0,007767

Print No. 2	1	2	3	4	5	6	7	Average	Dev.	Var.

h (mm)	5,34	5,2	5,16	5,25	5,27	5,29	5,34	5,2642	0,06754	0,003910

III. RESULTS AND DISCUSSIONS

Measured data have been statisticaly evaluated. As we said before, in this experiment are evaluated just data about thickness of printed parts, which are connected with number of layers, defined by the sicing software. In Following tables (Table 5 and Table 6) are the final comparison of measured values.

Table 5 Basic parameters of produced parts for Print No. 1

Print No. 1	Model 1 (Circle)	Model 2 (arch)	Model 3 (rectangle)	Model 4 (triangle)
CAD model Thickness (mm)	5,0	5,2	4,953	5,1
Set layer Thickness (mm)	0,254	0,254	0,254	0,254
Theoretical Number of Layers	19,685	20,4724	19,5	20,0787
Min theoretical thickness (mm)	4,826	5,08	4,826	5,08
Max theoretical thickness (mm)	5,08	5,334	5,08	5,334
MeasuredThickness (mm)	5,201	5,2385	5,1142	5,2657
Difference (measured-model) (mm)	0,201	0,0385	0,1612	0,1657

Table 6 Basic parameters of produced parts for Print No. 2

Print No. 2	Model 1 (circle)	Model 2 (arch)	Model 3 (rectangle)	Model 4 (triangle)
CAD model Thickness (mm)	5	5,2	5,1181	5,1
Set layer Thickness (mm)	0,3302	0,3302	0,3302	0,3302
Theoretical Number of Layers	15,1423	15,748	15,5	15,4451
Min theoretical thickness (mm)	4,953	4,953	4,953	4,953
Max theoretical thickness (mm)	5,2832	5,2832	5,2832	5,2832
MeasuredThickness (mm)	5,3171	5,2828	5,2885	5,2642
Difference (measured-model) (mm)	0,3171	0,0828	0,1704	0,1642

We can see in the bottom row (Difference) the theoretical difference between average measured value of model thickness and thickness which are defined in processing in CAD system. If we see the values reported in this tables, there is no bigger difference between measured value and exact height of model, than thickness of extruded layer. We can also see, that all measured values approach the maximum theoretical value or even exceed this value.

In case of models printed with layering 0,254, we can see that there could be 19 or 20 layers. Mor Model 2 with thickness 5,2mm is the best precision, because calculated and real number of layers are very close.

The same situation is also in case of model 2 with thickness 5,2mm with layering 0,3302mm.

IV. CONCLUSION

The slicing softvare calculate the final number of layers by the setting we provide in software. We can see that if the theoretical thickness exceed the CAD model thickness and is very close to this number, the precision is very high. But there are also others softvares for model slicing, which have different logic for calculation. There is different border, where the software add one more layer, what also influence the precidion of final models. For this reason there is necessary to bring more experiments to state better conclusion. It is necessary to print bigger spectrum of model height dimensions and on this possible measured values find relation between different setting of 3D printer device and printed models accuracy.

Conflict of interest

There is no conflict to disclose.

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