Original Article

COMPARISON OF GEOMETRIC PRECISION OF PLASTIC COMPONENTS MADE BY SUBTRACTIVE AND ADDITIVE METHODS

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ABSTRACT

The paper presents information on manufacturing processes of plastic components. Basic subtractive and additive methods are described. There were also manufactured elements of fan housing by using this two types of methods. Then, the elements were measured using a touch probe. The obtained results were analyzed, on which a comparison of components' geometric accuracy was performed.

Keywords: rapid prototyping, fused deposition modelling, machining, touch probe measurement, points cloud.

INTRODUCTION

The manufacture of plastic components is currently dominated by injection moulding. The method is suitable for mass production because the time of a single piece is very short. However, the preparation process, the production of the punch, die and tooling is very time-consuming and costly. In many cases, we need to make individual elements, in this case, it is reasonable to apply the additive and subtractive methods. The article focuses on two methods of preparation of plastic components. Two identical parts were made, the first one by fused deposition modelling (FDM) method and the second by milling. Both elements were compared from the point of complexity and the results obtained.

SUBTRACTIVE AND ADDITIVE MANUFACTURING

Subtractive manufacturing is a process in which a piece of material is cut into a final shape and size by a material-removal process.

Subtractive manufacturing can be divided into:
- machining,
- chip machining,
- abrasive machining,
- erosion machining.

Depending on the desired shape and roughness of the surface there are used different types and methods of machining. They differ between themselves in used tools and the nature of the movements which perform the tool and the workpiece [1, 2].

The principal machining processes are turning, milling, boring, drilling, sawing, shaping, planing, and grinding. Except those mentioned machining methods, others such as reaming, countersinking, broaching, honing and lapping are known. Depending on the accuracy, shape and size of the work surface, there are the following types of machining: coarse, fine and very fine, called finishing.

The term additive manufacturing refers to the production technologies that create objects through a sequential layering process. Elements that are manufactured additively can be used anywhere during the product life cycle, from pre-production (rapid prototyping – RP) to full-scale production (rapid manufacturing – RM), in addition to tooling applications.

The most popular methods of RP are: fused deposition modelling (FDM), Stereolithography

(SLA), 3D printing (3DP), Electron Beam Free-form Fabrication (EBF), Direct metal laser sintering (DMLS), electron beam melting (EBM), selective heat sintering (SHS), selective laser sintering (SLS), Laminated object manufacturing (LOM), Digital Light Processing (DLP) etc.

Rapid Prototyping is an additive technology which is capable of providing a physical model of the designed object from a 3D model in CAD system. Regardless of which method will be used to make an actual element, CAD model is converted to STL format, which is an informal language of this technology. Then, a transverse division of model into layers is conducted, the thickness of which, in the case of FDM technology, depends on the size of the nozzle used for part construction (0.127–0.33). Real-time execution of Rapid Prototyping methods is disproportionately shorter than standard machining. This methods create both illustrative models and functional elements, used directly in the construction of machines or equipment and those that are used for example in a foundry [6].

Models are made of thermoplastic materials. Most materials used in model manufaturing are PC (Polycarbonate), ABS (acrylonitrile – butadiene – styrene), and their modification example ABSI (methyl methacrylate ABS) and mixtures.

FDM METHOD

One of the method of rapid prototyping is FDM (Fused Deposition Modeling). FDM is a technique involving the extruded deposition of plasticized model and supporting material with two-nozzle head. The material is deposited on a working platform, which decreases gradually with a coating of plasticized material (in a form of filaments) forming the model in accordance with the arrangement of successive layers of a virtual STL model. Nozzle during imposing plasticized material moves over the platform in the XY plane, and the platform moves along the Z axis [6]. The scheme of the method is shown in Figure 1.

As a part of this work a fan housing element was made in FDM technology. Figure 2a illustrates a CAD model of the considered element prepared in SolidWorks program, and in Figure 2b the same model with superimposed grid saved in STL format is presented.

Then the STL file was exported to the device in which it was manufactured. Figure 3 shows the final element.
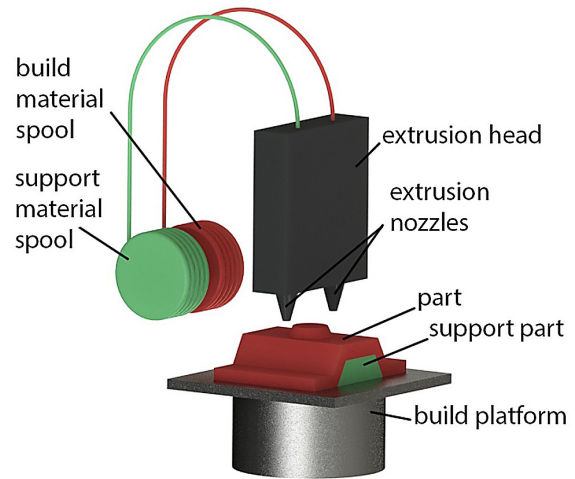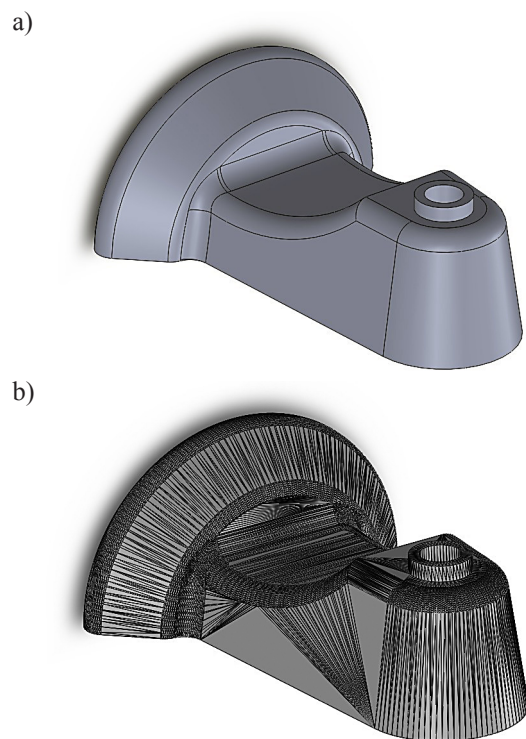

Fig. 1. The scheme of FDM method

a)

b)

Fig. 2. A fan housing element, a) CAD model, b) STL model

Fig. 3. Element made in FDM method

MILLING

Virtual model has been saved in data exchange format (.STL). An integrated CAD/CAM software (Inventor/HyperMILL) was used for preparing the machining simulation. The advantage of the integration of CAD-CAM systems is the ability to make changes of the detail design features with automatic updates designed machining paths (no need to re-define them).

Subsequent machining operations, the parameters and the used tools are shown in Table 1. Operations from 1 to 2 are roughing operations, while others are finishing.

Table 1. Machining operations, parameters and tools

No	Operation (HyperMill)	Tools	The machining parameters
1.	Rough	End mill Ø16	S = 3000 [rpm] f = 5000 [mm/min] a$_p$ = 2 [mm] machining allowance 0.15 [mm]
2.	Rough	End mill Ø8	
3.	Flat		S = 3000 [rpm] f = 5000 [mm/min] a$_e$ = 0.1 [mm] (distance between paths)
4.	Naba sides		
5.	Steep	Shell end mill Ø16	
6.	Foot	Ball end mill Ø8	
7.	Ridge		
8.	Rounded	Ball end mill Ø4	
9.	Steep	Ball end mill Ø4	

Examples of roughing path (machining operation number 1) are shown in Figure 4a. For this operation, Figure 4b shows the appearance of the blank after the machining. Prepared motion tools path were used to create NC code.
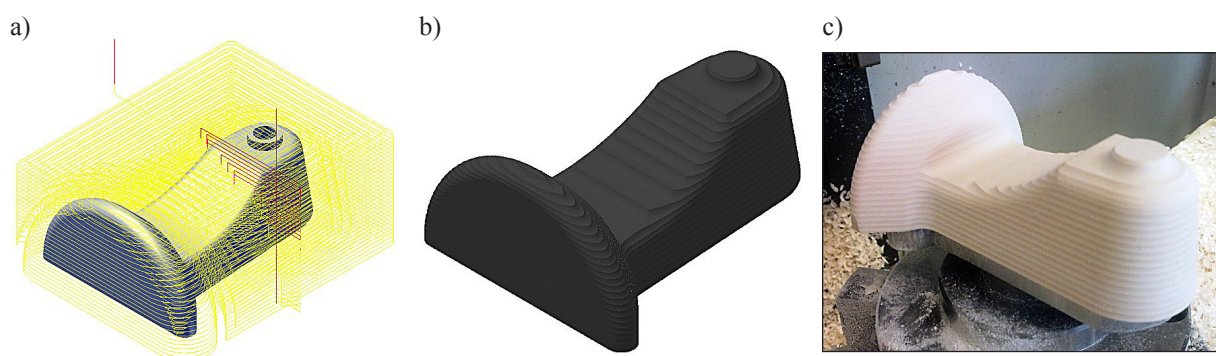
The part was machined on the CNC HAAS VF2 milling machine. Modeling disc was used as a blank. The mechanical and physical properties of the semi-finished product, are given in Table 2.

CAD model after the virtual machining simulation and real part after machining are shown in Figure 5.

ANALYSIS OF THE COMPONENT ACCURACY

Both parts (machined and FDM model) were mounted on the CNC machine (V2 HAAS). Using the touch probe (RENISHAW OMP40-2) points on the objects were measured. While measuring flat surfaces perpendicular or parallel to the direction of measuring NC driver software automatically compensates the contact coordinates of the measuring ball radius [2].

The problem during the measurement of the surface at an angle is that the machine controller, depending on the direction of approach (perpendicular or parallel to the Z-axis) compensates the coordinates of the measuring tip along the feed axis (Fig. 6) [2]. The solution of this problem would be:
- rotation of the model in A, B or C axis (if machine allows to control this axis) by an angle of slope of the wall (which must be known) so that the measuring ball in contact with the object along the normal to the surface being measured [3, 5];
- use the correction methods (method of cross-product, cross-product method using weighting factors, the method uses a distance crite-

Fig. 4. Roughing model a) after path generation, b) after machining simulation, c) after milling

Table 2. Mechanical and physical properties of the modelling disc material

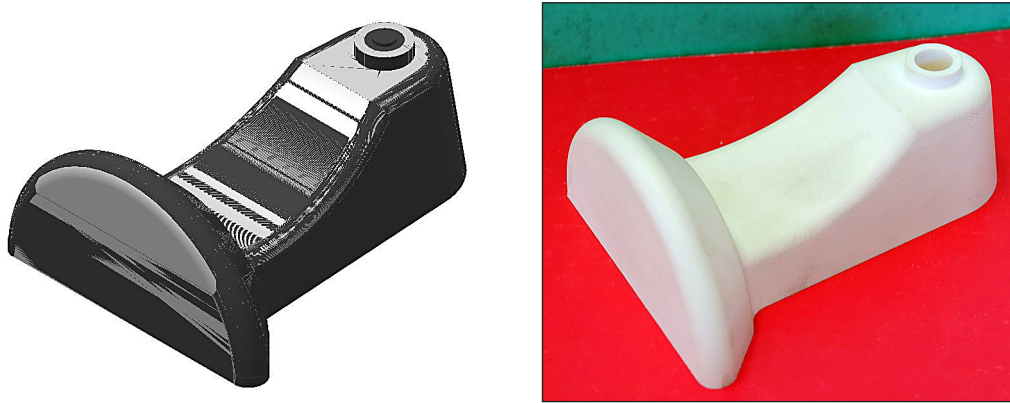| Material name	Color	Shore hardness	Compressive strength [MPa]	Bending strength [MPa]	Density [kg/dm³]	Heat deflection temperature [⁰C]
Ebazell 80	beige	approx. 30	approx. 8.6	approx. 12	0.08	approx. 80

Fig. 5. The model after virtual machining simulation in program HyperMILL and after the milling
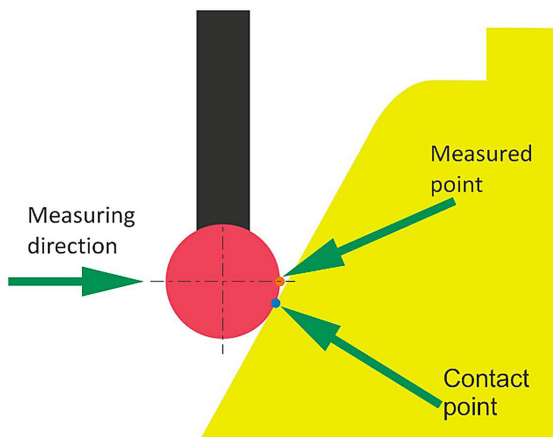

Fig. 6. Measured point on slope walls

rion to select neighboring points) when free surfaces are measured [7].

The points cloud from the measured model were imported into CATIA. In this environment, they were changed into surfaces representing the model [4]. The side surfaces of the object were shifted by the radius of the ball in the direction of the measuring probe directions to the model.

A comparative analysis of the real geometry of the model and the reference model was made. Referenced model was a CAD model in STL format, used to create a machining program and the implementation of a rapid prototyping method.

The results of the analysis are shown in Figure 7. In Table 3 the maximum absolute values of the differences between the model and the actual model are shown.

On flat surfaces the measuring area was defined (Fig. 7). During measuring on the rounded surfaces the measuring head can be easily damaged because of its bending. Measurement of the hole consisted of determining the diameter at different depths and the position of its axis.

Table 3. Accuracy of the performed models

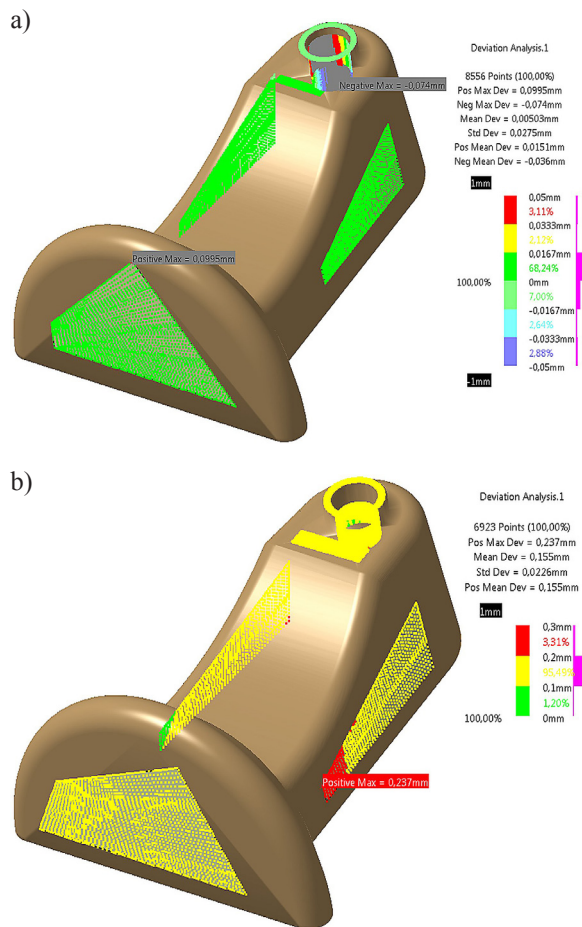| Specification	Ebazell 80 [mm]	FDM [mm]
Surface parallel to the milling machine table	<0.016	>0.13
Surface perpendicular to the milling machine table	<0.016	>0.13
Internal hole	<0.032	>0.13
Slope surface	<0.016	>0.13

a)

b)

Fig. 7. Analysis of the accuracy of geometric object made in a) subtractive method, b) additive method

CONCLUSION

Basing on our studies we can conclude the following:

- model made in machining (milling) have smaller errors than the object made in an additive method,
- model geometry errors made in additive method are largely due to the thickness of the material layer,
- curved surface measurement using the probe is not possible due to the nature of measurement (pressure of measuring ball causes deflection of the probe and its further movement would cause measuring head damage),
- performance of individual item made by machining is much more labour-intensive (CNC machine and machining program are required) than in FDM method (FDM ~126 min, machining ~150 min),
- accuracy measurements directly at the milling machining (in one fixing) allow to avoid an error in determining the base and allow dimensional control during processing,
- both methods are ideal for the production of a single prototype.

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