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Effect of Dimensional Accuracy of Parts Manufactured Using Fused Deposition Modelling Process

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ABSTRACT
This paper presents the results of effect of Fused modelling process which is highly efficient rapid prototyping approach that's makes it possible to rapidly generate even a much-complicated part. It includes research of additive technology using thermoplastics as a build material, namely Fused Deposition Modelling (FDM). Aim of the study was to identify the relation between basic parameter of the FDM process model orientation during manufacturing and a dimensional accuracy and repeatability of obtained products. A set of samples was prepared they were manufactured with variable process parameters and they were measured using 3D scanner. This paper also presents effect of deviation control parameter step-size of Creo modelling software on surface roughness, dimensional Accuracy, circularity and compression strength of ASTM standard test specimens modelled by FDM process from 3D printer from ABS material. Effect of deviation control parameter step size on surface roughness, circularity at horizontal, vertical and 45 degree print orientation. Effect of slicing parameter on surface roughness and circularity is also measure. As step size increases surface roughness increases and circularity decreases. Horizontal print orientation gives better surface finish whereas vertical print orientation gives better circularity.

Keywords: circularity manufacturing accuracy, fused deposition modelling, rapid prototyping ABS, step-size

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INTRODUCTION

Fused deposition modeling is a process of rapid prototyping of additive manufacturing technologies commonly used for various process parameters like orientation, object fill, print orientation, extruder temperature, travel speed, extrusion temperature, layer thickness, platform temperature, no of shells, etc. Rapid Prototyping (RP) and Additive Manufacturing (AM), also known as Layered Manufacturing, It is a group of technologies that allow to produce a physical prototype based only on the 3D CAD model, without need to prepare tooling of any kind. RP technologies have found their place among other, traditional manufacturing technologies – they are invaluable when there is a need of quick manufacturing of a physical prototype of a designed part. Materials use for this process are ultem, abs, pla etc. The effect of above process parameters is analyzed on the different materials, surface roughness, mechanical properties, dimensional, and geometrical characteristics are evaluate in this study. Manufacturing accuracy of any part is a degree of its compatibility with an ideal part [1–11]. Two types of accuracy in manufacturing can be distinguished. Dimensional accuracy is a degree of compatibility of linear or angular dimensions with dimensions of a perfectly produced part, dimension deviations being a direct measure of this accuracy. Shape accuracy is a degree of compatibility of specific shapes with the perfect part or with other shapes – direct measures of this type of accuracy are deviations from the ideal cylinder, sphere, straight line, plane etc. Just like all other technical and economic indexes of products manufactured in an additive manner, accuracy is strongly affected by parameters of manufacturing process – products of the same nominal geometry will have entirely different properties if they are manufactured using different sets of values of these parameters.

The most important parameter is the model orientation – set of angles between basic planes of the object and the manufacturing direction. Effect of slicing parameter on surface roughness and circularity is also measure. As stepsize increases the surface roughness increases and circularity decreases. Horizontal print orientation gives better surface finish whereas vertical print orientation gives better circularity. The acquired results are shown together with the results of earlier work by the authors, regarding the relations between orientation and mechanical properties of additively manufactured products [6]. The authors have also worked on a similar problem in the past (influence of process parameters on accuracy of FDM parts), but the layer filling strategy was the parameter investigated instead of the orientation. It is impossible to obtain a product with an optimal combination of these two properties without identifying the relations between them and process properties – and this is what this paper is about.

BASIC INFORMATION

Additive Manufacturing Using Thermoplastics –Fused Deposition Modelling

This paper is devoted to study of the effects generated by the Fused Deposition Modelling production parameters on the tensile strength and on the stiffness of the generated components, tackling the question from both the experimental and the numerical points of view. For this purpose, an analytical model was developed, which is able to predict the strength and the stiffness properties, based on the number of contours deposited around the component edge and on the setting of the other main parameters of the deposition process. The ABS material is frequently used, other thermoplastics can be used too, depending on the machine and head type. Obtained models are considerably strong and can be subjected to further treatment by machining, gluing or painting, to obtain desired surface quality. The produced part is ready for use immediately after support material removal.

Effect of the FDM Process Parameters on Features of Obtained Products

Finished product manufactured using Fused Deposition Modelling technology can be characterized by technical indexes – strength of certain kind (tensile, flexural strength or impact resistance), dimensional and shape accuracy, as well as economic indexes, such as manufacturing time and amount of support and build material used. Many factors have direct influence on these indexes [2]. A phenomenon specific for the described technology is relatively high significance of additive process parameters. Additive technologies make no use of any tooling, it is their most important advantage. The role of the tooling in the aspect of influencing technical and economic indexes is taken by the process parameters (more specifically, the sets of parameters), which may be directly or indirectly controlled by the process engineer (Figure 1).

Orientation of the model in the working chamber during layered manufacturing process can be intuitively described as an angular difference between plane determining direction of the object division into layers and selected, basic plane of the manufactured object (Figure 2).

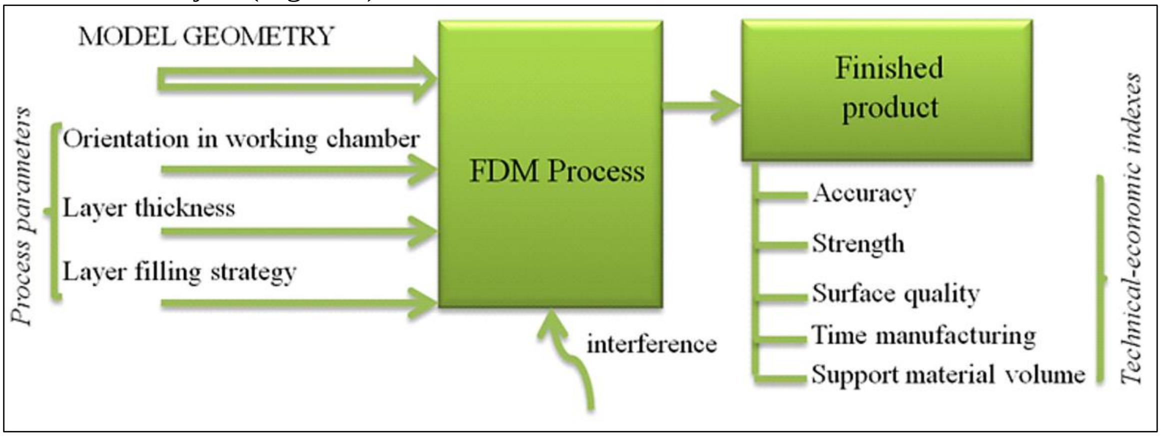

Fig. 1. *Parameters of the FDM process and technical and economic indexes of the finished product.*

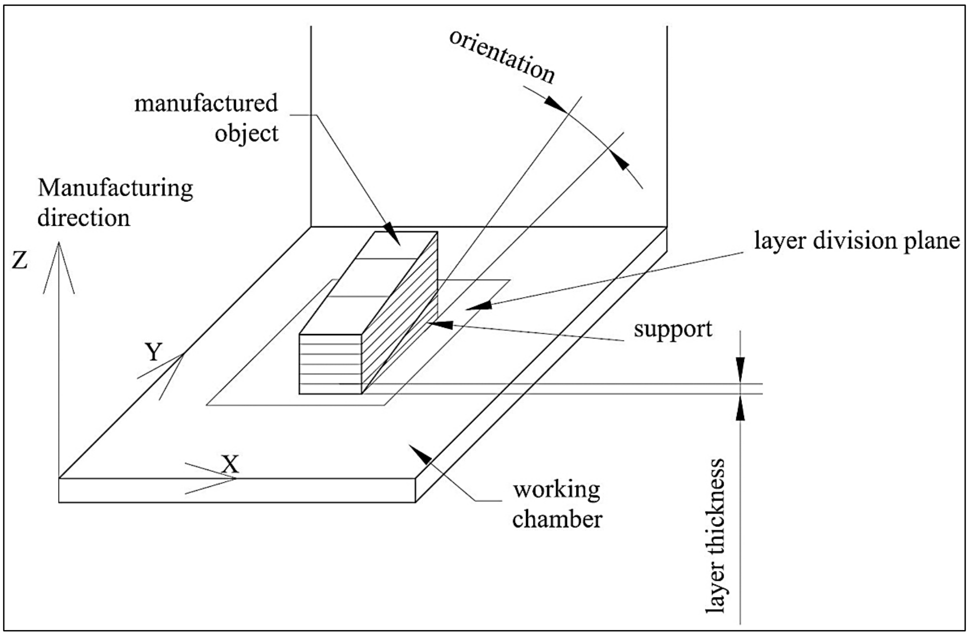

Fig. 2. *Orientation of the model in the working.*

The orientation directly affects the internal structure of the model [6], deciding, among other obtained with FDM method has not been fully investigated yet.

This paper is aimed at preliminary identification of the relation between model orientation and two basic characteristics related to accuracy of the obtained products:

(1) dimensional accuracy, understood as degree of compatibility of basic dimensions of the obtained product with dimensions of the ideal product (nominal dimensions)
(2) repeatability – degree of dimensional compatibility of two products of the same nominal geometry, manufactured in the same conditions, with identical values of the process parameters

Preparation of Samples for Measurements

For the accuracy study of FDM made parts, tensile test samples were selected as a nominal geometry (they contain both straight and curved profiles, so it is also possible to evaluate shape accuracy, Figure 3).

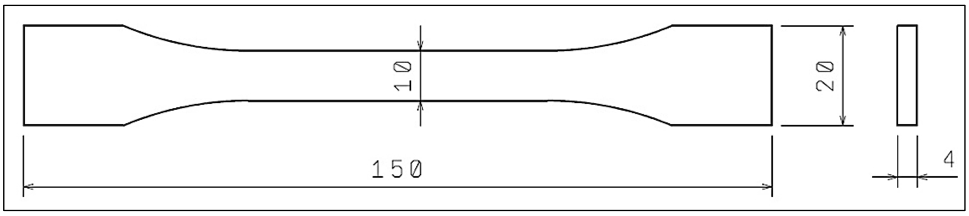

Fig. 3. *Sample used in accuracy studies.*

Sample Measurement – 3D Optical Scanning

Three-dimensional scanners use light (mostly white, blue is also used) of a known structural pattern – usually it is a fringe sequence of known, variable width and density. Light is projected on an object and fringe pattern image is registered by cameras. Deformation of the pattern is then analyzed by the software to map each point from the camera matrix with an appropriate point coordinates in space. A single measurement (up to 20 seconds), also named scan, gives as many measured points as the camera matrix has – in case of the scanner used in the research it is a value of 0.8 MPix, so it is 800,000 points, practically representing the whole measured surface.

Processing of the Measurement Results

After the measurements are finished, a preliminary data processing must be carried out. It consists of the following stages:

- Joining the data from all scans together – performed automatically, with some corrections able to be performed manually;
- Removal of useless points (representing fixtures or other objects present in the measurement volume), manually or automatically;
- Assignment of a coordinate system to the object (basing) by the “plane, line, point” method – definition of Z plane, X axis and point 0 by indication of points forming these geometries (3 points for plane, 2 for line, 1 for coordinate system beginning);
- Generation of triangular mesh on the basis of the processed point cloud and export of the generated mesh to an STL format.

The dimensional accuracy coefficient is basically calculated as an average of deviation from all inspected dimensions, which is why it must be treated only as a general index. The formula for the accuracy coefficient is the following:

$$k_d = \frac{k_{len} + k_{w1} + k_{w2} + k_h}{4} \quad (1)$$

where: *kd* – coefficient of dimensional accuracy of the specific sample type, *klen*, *kw1*, *kw2*, *kth* – coefficients of accuracy of 4 checked dimensions (length, two widths and thickness), with a single coefficient formula as following:

$$k_x = \frac{\sum_{i=1}^{n} \frac{d_i}{x_{nom}}}{n} \cdot 100 \quad (2)$$

where: *x* – dimension (*x* stands for length, widths and thickness, formula (2) was used for all four coefficients), *n* – number of samples taken into account (n=3 in this paper), *dxi* – average from deviation from the dimension *x* in sample number *i* [mm], absolute value, x_{nom} – nominal value of the dimension *x* (see Figure 3 for all nominal dimension values).

The repeatability coefficient is calculated as an average difference in dimensional accuracy coefficients calculated for each sample separately. The formula is as following:

$$k_r = \frac{|k_1 - k_2| + |k_2 - k_3| + |k_1 - k_3|}{3} \quad (3)$$

where: kr – repeatability coefficient of the specific sample type, $k1$, $k2$, $k3$ – accuracy coefficients calculated as in formulas (1) and (2), but separately for each of the three samples.

The higher the repeatability coefficient, the lower the repeatability can be achieved for the sample – perfectly repeatable process would result in coefficient equal to 0. Both coefficients are dimensionless, although they could be treated as a percentage.

RESEARCH RESULTS

Dimensional Accuracy and Repeatability Measurement Results

Using formulas (1–3), the accuracy and repeatability coefficients were determined for each sample. Table 1 contains the most generalized form of actual research results – coefficients kd and kr for each sample type.

Table 1. *Coefficients of accuracy of samples made using fused deposition modelling technology (kd – accuracy, kr – repeatability, lower value = better).*

Coefficient / Sample ID	k_d	k_r
0F	0.976	0.090
0S	1.403	0.409
45F	0.665	0.080
45S	0.852	0.603
90	1.046	0.668

CONCLUSIONS

After analysis of the obtained data, the following conclusions can be drawn.

(1) The effect of the parameters on surface roughness, dimensional characteristics, geometrical characteristics, mechanical properties and some other parameters.
(2) Study includes FDM process parameters like object infill (%), print location, extruder temperature, print orientation, travel speed, extrusion speed, plate form temp, layer thickness, no of shells, Infill density, infill pattern, infill shell spacing, feed rate.
(3) Also, the effects of above process parameters give us effect on the mechanical properties, surface roughness, dimensional and geometrical characteristics.
(4) As step size increases deviation control parameter chord angle, chord height and step size increases meshing size of tessellated triangles.
(5) It is also confirmed that the orientation directly influences both the accuracy and repeatability of FDM parts. Character of the $A = f(O)$ functional relation (A – accuracy, O – orientation) is non-linear and rather hard to describe mathematically with such small number of sample types.
(6) Relation between calculated accuracy and repeatability coefficients can also be described as non-linear, at least for coefficients calculated only on the basis of deviations from specific dimensions.
(7) Accuracy of FDM made parts should be considered as low in comparison with other plastic forming technologies, with deviations of meaningful dimensions above 2% in some cases.
(8) Analysis of deviations of particular dimensions brings an interesting conclusion – deviations are relatively smaller for higher dimensions, i.e. the greater the object size is, the more accurately it will be manufactured. This only applies to relative deviations (i.e. deviation/nominal dimension ratio), as absolute deviation values remain on more or less the same level, regardless of the nominal dimension value.
(9) Strength of FDM made parts is not particularly related to the accuracy, although some minor positive coupling can be observed in some cases.
(10) The most beneficial sample out of the manufactured 5 types, regarding all the

possible criteria (accuracy, repeatability, strength, cost, time, surface quality) with assumption that all criteria are equally significant, is the 0F sample, as a combination of both technical and economic indexes is optimal for this product, although its strength, accuracy and repeatability are not the best.

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