Fused Deposition Modeling Design Rules for Plastics

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Recently, there is market need to develop technologies focused on manufacturing custom and unique parts. Additive Manufacturing technologies create geometrical parts layer by layer and satisfy this necessity. In this article we try to establish a set of rules to be followed in FDM - Fused Deposition Modeling 3D printing process using ABS (Acrilonitril-Butadien-Styren) type plastic materials. The objects have been printed on a 3D "Ultimaker –2" printer. ABS (Acrilonitril-Butadien-Styren) filament was used to print the objects. The article also refers to printing constraints generated by the machine work load limitations and the extruded material.

Keywords: Acrilonitril-Butadien-Styren, Fused Deposition Modeling, 3D printing

The technological process of a part created using additive manufacturing combines only the actual manufacturing process for the parts and assembly of the final product, successfully eliminating auxiliary operations like part transport between different operations, execution of the SDVs, etc.

The technological process of addition is directly linked to the free form modification, dimensions and physical properties of the resulting part. When the shape and dimensions of finished parts are obtained by adding material, a process is performed by processing of materials by addition.

Additive manufacturing technological process is briefly described in figure 1.

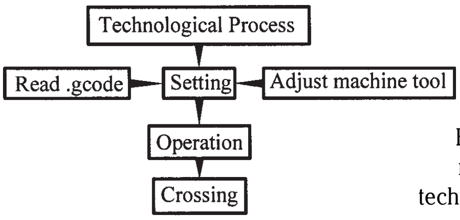

Fig. 1. Additive manufacturing technological process.

Regardless of the complexity of an assembly, the individual parts can be broken into basic geometric shapes.

These simple shapes completely define the corresponding part (fig. 2).

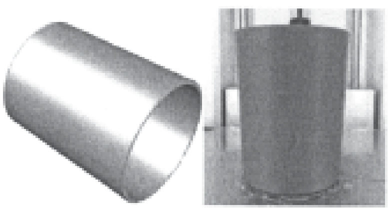

Fig. 2. 3D modelling used for printing

The additive manufacturing technology are influenced by the following facts:

- production characteristics, which is usually, unique;
- parts construction;
- material used.

Finished parts are manufactured without machining allowances. In this way you get minimum material consumption but you have a longer execution time and a more expensive and complex process.

Specific consumption is defined as the amount of material needed to make a part.

In case of an ideal additive manufacturing process, specific consumption is the same as net consumption, and technological losses are virtually null.

In this case, the coefficient of material use, which is defined by the ratio of the part's net weight to material net weight, tends to be unitary.

Therefore, when talking about using this technology, parameters related to material consumption are generally disregarded. But, in terms of geometrical – constructive characteristics of a part, a series of design constraints may lead to increase in specific consumption.

Experimental part

Materials and methods

The experimental part of this article followed the Additive Manufacturing Process described in figure 1, for independent parts with basic geometric shapes. The shapes were chosen so that a series of geometrical and constructive parameters are to be determined and later implemented in a set of design rules.

Printing filaments used to be limited to ABS, but today there is a wide range of different materials on the market [1]. ABS (Acrilonitril Butadien Styren) filament was used to build the objects in experimental part of this article.

Before printing, it is vital that the material is dry. The general printing conditions require heating the plastic material in the extruder to a temperature range of 215-260° C and the printing baseplate to a range of 90 -115° C [2].

Extrusion temperature in the experimental parts was 260° C, no rafts were used, while the extrusion speed was kept at 50 mm/s.

The technical characteristics of the printing filaments used in the experimental research are: filament diameter 2.85 mm and filament diameter after extrusion 0.3 mm.

Because this type of printing process requires a heated base, printing baseplate temperature was set to 115°C.

Other parameters can be found in table 1.

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Parameters	Value
Layer height	0.1 [mm]
Shell thickness	0.8 [mm]
Fill bottom/top thickness	0.6 [mm]
Fill Density	100%

Tabel 1
PARAMETERS OF EXTRUSION-BASED SYSTEMS

Attachment of the part to the printing baseplate was done using a substance that contains: acetone, butyl acetate, alcohol, paraffinum licquidum and Acrilonitril Butadien Styren.

The extrusion method functions under the following principle: the extrusion material (filament input) is brought into a semi-solid state and forced through a nozzle to form a filament with a narrower diameter than the diameter of the input filament that will rapidly solidify after the extrusion [3] (fig. 3).

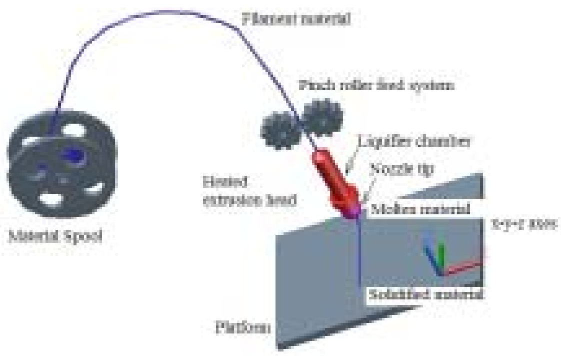


Fig. 3. Schematic of Extrusion-Based Systems [3]

If the speed of the nozzle on the baseplate as well as the pressure on the melted material are both constant, than the extruded material will have a uniform cross section diameter.

Current standards for this technology only define the terminology for additive manufacturing processes [4, 5].

The .stl or .obj file types were converted to .gcode using Cura software provided by Ultimaker [6-8].

The geometric shapes were created using a 3D software supplied by Autodesk [9-11].

Results and discussions

The designer starts to define a part of perfect form with shape and dimensions that fit the functions – the nominal model [12].

The following rules are required in order to achieve shape and dimensional precision:

- placement of the future part on the baseplate must be done in such a way (if possible) that functional areas to be positioned perpendicular or parallel to the Z axis;
- using an average nozzle speed (the average is given by the maximum and minimum printing speed of the plastic material, in our case, ABS);
- designing a part through this method must eliminate, from the early stages of modeling, any defects due to the “scale effect”; the scale effect does not apply to linear lengths perpendicular or parallel to the Z axis.

To be noted that this defect occurs also in case of any supporting structures, these being manufactured in the same manner.

There are two types of surfaces for revolution bodies: surfaces in the vicinity of the apparent contour generatrix which forms an angle with the horizontal growth values - b° and surfaces in the vicinity of the apparent contour generatrix which forms an angle with the horizontal decreasing values, complementary angle for angle c°; width of this zone is directly proportional to the radius of the revolution body; thus taking into account these aspects it was established that: for an inclination of the axis with a° > 30° the workpiece is in corresponding parameters, for an inclination of the axis with a° > 30°-15° the workpiece can be considered recoverable rebut which needs a finishing operation and for an inclination of the axis with a° <15° the workpiece can be considered rebut (complementary angle layers no longer be built without support structures) (figs. 4 and 5); if the angle is less than 15° is necessary to use support structures.

Preferably the support structures are as few as possible.

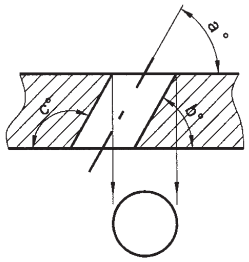
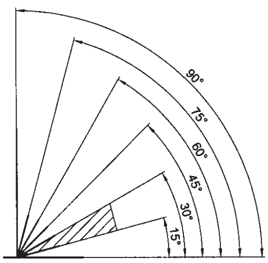


Fig. 4. Determining of the inclination angle of the axis of revolution



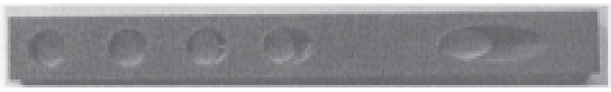


Fig. 5 Type of sample determined according to the inclination of the axis of revolution bodies

Plane surfaces shall worship to the following values 0 < b° = 90° and 0 < c° > 150° (figs. 6 and 7);

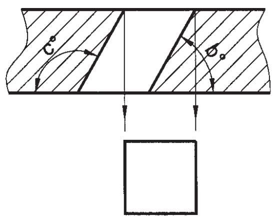


Fig. 6. Determining of the inclination angle of the plane surfaces

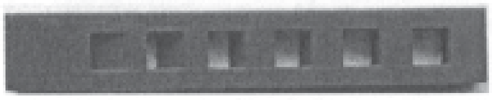


Fig. 7. Type of sample determined according to the inclination of the plane surfaces

The contact area size between the manufactured part and the printing baseplate is determined based on the thickness of the deposited layer and the printing speed, parameters that influence the contraction area at the base of the part. The cooling is also very likely to be nonlinear [8]. If this nonlinear effect is significant, then it is possible the resulting part will distort upon cooling [8]. In these tests, the minimum print area was determined to be A=328 mm^2 regardless of the part’s base perimeter shape. Figure 8 shows a few test samples. For base areas A<328mm^2, there are signs of base contraction. If base area A<16mm^2,

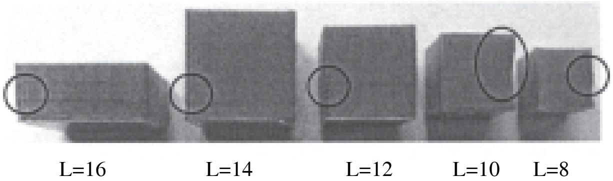


Fig. 8. Areas of concentration of the workpiece

contraction is total (within the mass of the part) (fig. 9). In figure 8 we denote by L [mm] the base side printing.

- The min size of a gap depends on the wall thickness of the part;
- Rounding radiuses of the part are to be positioned for manufacturing as concave surfaces relative to the direction of the construction (fig. 10);
- Due to the manufacturing process of adding layer over layer, the parts are more resistant to compression that tension. For an optimum use of materials, parts have to be designed so that they are subject only to (as far as possible) compression forces;
- Sudden shifts in cross sections are allowed;
- It is allowed to have complex shapes with plane surfaces and variable rounding radius (big rounding radiuses do not increase the cost of the part); there are no restrictions to transitions from plane surfaces to cylindrical ones (it can be tangential but not only);
- Inaccessible recesses and corners are not to be avoided, but they need to be positioned on the printing baseplate in such a way that they can be physically manufactured.

Conclusions

The proposed rules should serve as a basis to revise and update the existing standards given by the manufacturers, according to a unitary and systematic approach, to offer a clear geometric modelling.

This should be used and understood by the people involved in the part design, manufacturing and control using this technology.

The study of the basic geometric shapes to be printed has a major impact in defining and understanding any modelling restrictions.

For example, knowing the values of the "scale effect" prevents aby rebuts if applied in the first modelling stages. Also, knowing different possibilities to manufacture recesses has an impact in designing the cooling channels of the plastic injection molds, which are manufactured using additive technologies [13].

Fig. 9. Total contraction of the workpiece

Fig. 10. The rounding radius construction

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