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The 3D printing modelling of biodegradable material

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Abstract. One of the most challenging task regarding the design and the engineering of a new 3D printing part is to navigate through the vast number of technologies and materials that are offering variations in properties (like biodegradability, dimensional accuracy, surface finish and post processing requirements) available in order to determinate the solution that is best suited for the desired application. In this paper have been analysed, on an example, the 3D printing mechanism of a part, pipe type made from PET-G. The phenomena of contraction and the thermal stresses that appear during the process were revealed. The considerations formulated on this example lead to the conclusion that the pieces produced by 3D printing after FDM are heterogeneous both in terms of physical and mechanical properties and the stress state due to the deposition of the layers.

1. Introduction

Competitive engineering is a new way of approach all issues related to the emergence of a new product on the market. It is considered that simultaneous solving of engineering problems, in the design, manufacturing and manufacturing phases of a product can lead to substantial time and cost savings in order to solve the conflicts that occurred during the development of a product.

Rapid prototyping (RP) technologies have a great diversity, both in terms of their operating methods and performance, which may be obtained (precision, quality, productivity). The physical realization of the product, in short time, at a low cost, with minimal equipment's and in few phases is the technique accepted by most enterprises.

In terms of applicability of 3D printing processes, in figure 1, is presented the spread area of these technologies in economic and social environment.

The figure 2 shows an overview of the steps performed by the 3D Printing used until now as follows:

a) Design: making model 3D-CAD, which contains a full drawing of part using a different software such as blender, sketchup, solidworks etc. and a method suitable for such technologies;

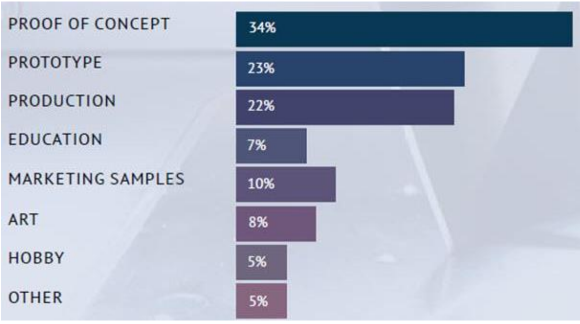
b) Export to STL: transfer of the CAD model to the processor section, which in many cases is achieved even by the CAD program used in modelling;

c) Netfab: the model is then prepared for sectioning and construction;

d) The physical execution of the model (construction) depends on several factors such as:

- type (powder, liquid, solid) and the material nature;
- the support way of the model during execution;

- bonding a layer by the previous layer;
e) Cleaning and finishing model: airbrush, hand paint, sanding, acetone etc.



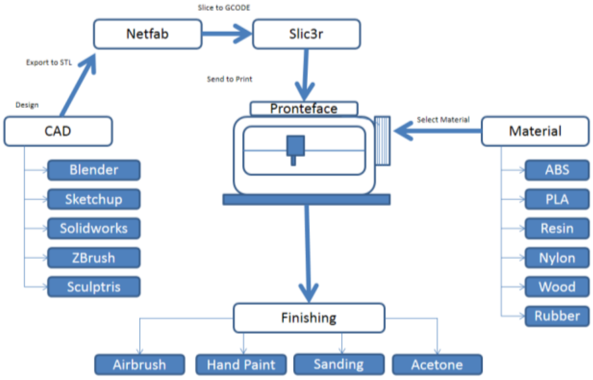


Figure 1. 3D printing applications, [1]. **Figure 2.** Overview of 3D printing, [2].

In this paper, 3D print modelling is performed for the FDM printing process presented in figure 3.

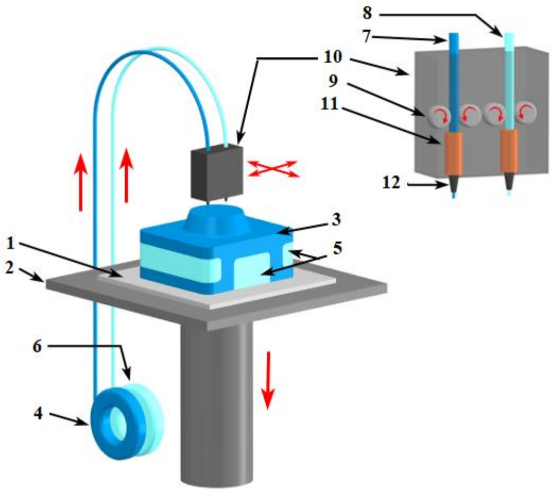


Figure 3. FDM 3D Printing, [3].

The printing process takes place on the foam base (1) situated on the equipment build platform (2). The printed part (3) using the build material spool (4) it is orientated on part supports (5) realized from the support material spool (6). The material wires (4, 6) are passing on support material filament (7) and build material (8), which in turn is oriented with the help of drive wheels (9), which can be found in the extrusion head [10] and are brought in melting state using liquifiers (11). Prior to laying on the surface, the wires pass through the extrusion nozzles (12).

The FDM process can also be used successfully for printing biodegradable materials such as liquid wood. There are three types of liquid wood, Arbofill, Arboblend and Arboform. In the technical literature some experimental results concerning the mechanical, thermal and structural properties can be found [6-12] but there are no results regarding the 3D printing of liquid wood.

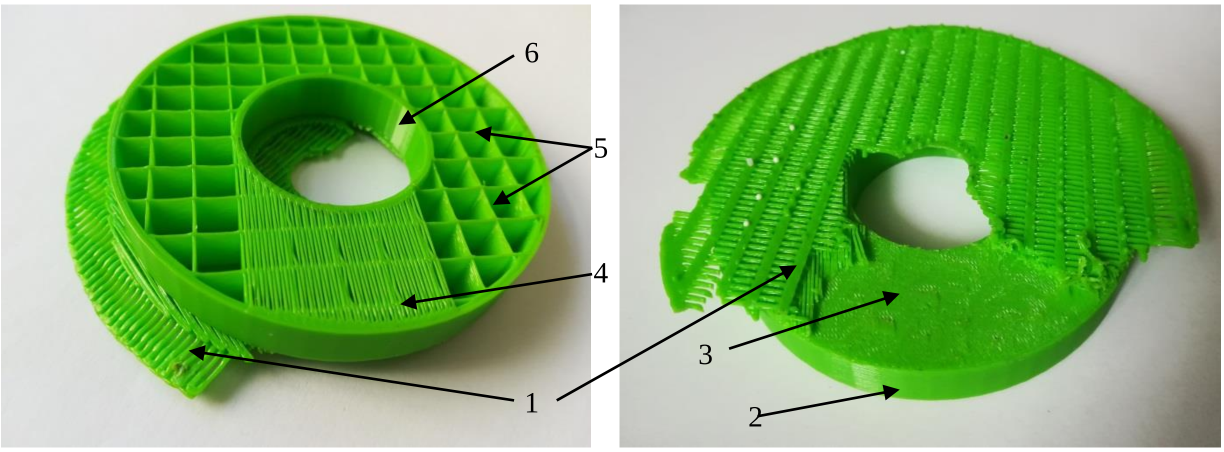
2. Kinematic analysis of the process of making a part through 3D printing via FDM

A specialized program in parallel planes named layers decomposes the STL format of the part. The distance between these plans is given by the thickness of the thermoplastic material submitted. In each of these planes, the program defines, after a certain algorithm according to certain user-set parameters, the trajectory of the extruder head.

The part is realized on a support created early in the process from the same thermoplastic material (in case of equipment with a single extrusion head) or other thermoplastic (in the case of two-head extruder). In the second situation, the material is chosen such that at the end of the work-piece the support can be easily removed from it. The support secures the piece adhesion on the equipment table during the 3D manufacturing process.

An important parameter of the 3D print process is the piece filling degree. This one it can reach 99% values (compact parts case) and can drop to close to 10%.

The thermoplastic material deposition takes place in such a way that, regardless of piece filling degree, the surfaces that border it to be "full". For exemplification, we consider the extreme case of a 10 mm cylindrical pipe, the outer diameter 70 mm and the inner 30 mm, for which a 13% fill rate was chosen (figure 4). We used a 1.75 mm diameter PET-G material and a 0.5 mm extrusion nozzle diameter. The 3D print process was interrupted during the last layers (the upper layers of the piece).



a. top view b. bottom view

Figure 4. Cylindrical parts manufactured by 3D Printing (FDM): 1 – support; 2 – outer cylindrical surface; 3 – lower front part (in contact with the support); 4 – upper front part (at the manufacturing beginning); 5 – piece fill elements (for a 13% fill rate); 6 – inner cylindrical surface.

From figure 4, it is noted that all four surfaces that edge the piece are made with the minimum distance of the thermoplastic jet through the extrusion head nozzle (1.5 mm). Cylindrical surfaces are made by depositing two concentric layers of material. The front surfaces are also made of two layers deposited according to the orthogonal directions of the extrusion head.

These surfaces border a volume "filled" with a thermoplastic material for 13% degree filling, established at the 3D printing process beginning setting.

The printing process takes place as follows: on the support layer is deposited a circular layer corresponding to the outer diameter of the work piece. The scrolling direction of the circle is decremented and reversed so that the second concentric outer layer is realized. In the same plan follows the deposition of the rectilinear trajectories but of thermoplastic material opposite directions. The filling of this space is done successively on 4 zones (figure 5). Completing the first layer forming process is finished by depositing two concentric layers (corresponding to the inner cylindrical face) in the sense of diameter decreasing. It follows the platform increment with 0.15 mm feed and repeating the deposition process in the order shown at the first layer. The difference consists in the fact that the rectilinear trajectories of the extrusion head will be executed perpendicular to the ones traversed in the first layer generation. The third layer will be formed after incrementing the platform by 0.15 mm.

Starting with this layer and up to the last two layers, the incremental distance between the rectilinear trajectories and opposite directions will increase according to the filling degree. In the situation of the presented piece, the distance is 6.2 mm. By overlaying these trajectories result some areas of square section. The last two layers of the piece are similar to the first two layers. Figure 4.a shows the beginning penultimate layer creation.

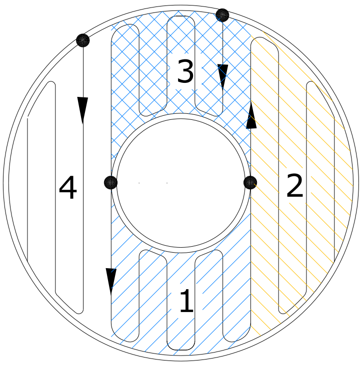


Figure 5. Extrusion head trajectory for creating a layer.

Depending on the piece shape, the program will generate other auxiliary supports during manufacture. Generally, they are required to make piece parts located at a certain height in the direction of equipment platform movement (Z) and who's projection in the original support plane not enter in the original area of the piece. An example is the sloping parts with an angle greater than 60° to the platform's travel direction. Figure 6 shows an example in which an auxiliary support for 3D printing of a fastening tab has been created.

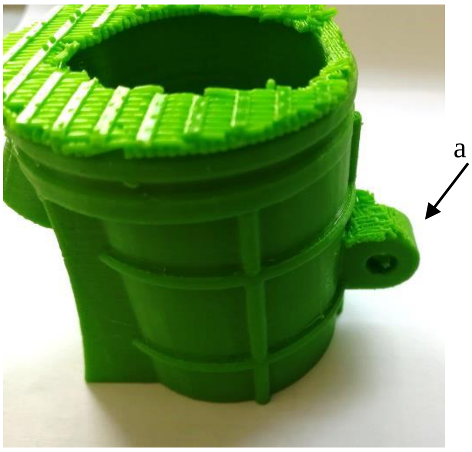


Figure 6. Auxiliary holder (a) for 3D printing of a fastening tab.

3. Thermal contraction influence on functional characteristics of 3D printed parts

3D printing by FDM requires the deposition of a thermoplastic heated at temperatures generally above 200° C over solidified layers of the same material at temperatures generally below 40° C. Cooling of these materials is followed by a strong contraction. Specialty literature mentions that thermoplastic materials have linear contraction coefficients (dilatations) higher than metallic materials [13, 14].

This phenomenon causes the apparence of tensions between the layers and residual stresses in the FDM parts. In addition to the physical properties of the thermoplastic material, a major influence on the stress state of the obtained parts is the extrusion head route and the 3D print parameters.

3.1. The deposition mechanism of thermoplastic layers

Figure 7 shows the deposition mechanism of thermoplastic layers. The nozzle with the diameter of the extrusion channel d is close to the distance h_1 of the deposition surface ($h_1 < d$) and moves at speed V.

The molten material is pushed with a Q flow. The width of the deposited layer is approximately equal to the diameter d of the die. In order for the deposition of the layer to occur without the occurrence of a pronounced repulsion of the deposited material, the flow rate of the extruded material Q should be approximately equal to the displacement speed of the extrusion head, V.

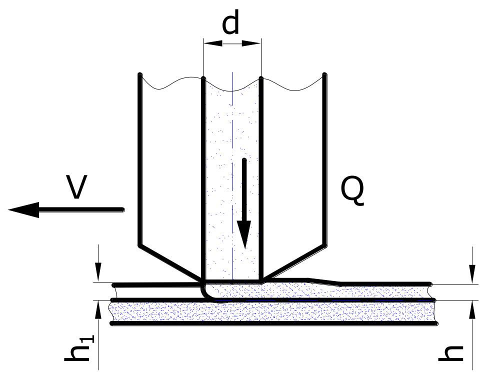


Figure 7. The thermoplastic layer deposition mechanism: 1 - layer deposited previously; 2 - Layer in progress; 3 - nozzle; 4 - heated thermoplastic material.

After the cooling of the deposited layer and after the shrinkage, its width will reach the value l (*l* <*d*) and the height h.

In the case of the piece from figure 4, the width of the filler elements 5 was 0.46 mm. The theoretical calculation with the data in the literature indicates a contraction of 0.023 mm for the nozzle diameter of 0.5 mm, [6].

3.2. Thermal voltages between layers of thermoplastic material deposited

Due to the post-solidification shrinkage and adhesion to the lower layer at a lower temperature, stretching stresses will occur in the layer deposited at the interface with the existing layer, while compressive stresses occur in the existing layer. For these reasons, the layers in the cylindrical surfaces (interior and exterior) - 2 and 6 of figure 4 - will have a stress distribution as presented in figure 8.

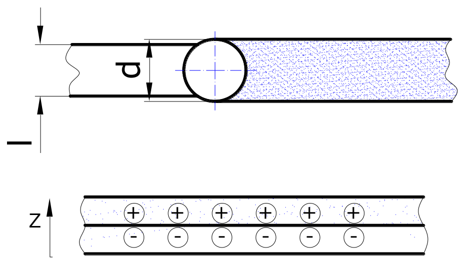


Figure 8. Distribution of stresses between successive layers.

At the interface between the concentric deposited layers, the stresses appear for the same reasons, but they are not equally distributed: they are less when changing the layer and growing up with the removal from this point.

In the filling area (zone 5 of figure 4) the tensions occur in the contact areas between two layers in succession. The tensile stresses occur across the wire because of the shrinkage after cooling (figure 6).

Filling degree is a parameter that influences not only the aspect in the section and the physico-mechanical properties of the part but also the state of tension. A high degree of filling allows a large amount of material to be deposited in the deposition area, a greater contact surface between the previously deposited and the deposited layer, ensures that a higher temperature is maintained in the deposition area and, finally, higher stresses reduced to the interfaces between layers.

4. Conclusions

The 3D printing via FDM is one of the most widespread manufacturing processes. The process uses a variety of thermoplastic materials.

The above considerations lead to the assertion that, by successive deposition of the thermoplastic layers, a body of rigid yarns with a pseudo-rectangular section is obtained. The surfaces that surround the body are made up of superimposed layers in the same direction. The filling areas of the workpiece are made of successive layers of layers according to the orthogonal directions. Programs that set the route to 3D-specific programming algorithms make the extrusion head command. Some equipment allows user intervention in these programs.

Between the layers, there are uneven distributed voltages depending on the extrusion head path. If the path passes to a non-cooled layer, the stresses are lower relative to the cooler state of the layer. For this reason, the piece is heterogeneous as tensions and physic-mechanical properties.

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