# USABILITY OF THERMOPLASTICS FOR 3D PRINTING OF PROTOTYPE PRODUCTS

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**Abstract**

New materials are available for the well-known thermal process of 3D printing which involves consecutive deposition of layers of heated thermoplastics. This means that machine components can be made not only from the most common plastics, such as ABS, but also from PLA, HIPS, PET, PVA, PETG, PC, and others. By means of 3D printing, intricately shaped parts can be produced in a flexible manner and prototypes can be easily fabricated from various thermoplastics. This paper demonstrates the use of a thermoplastic aliphatic polyester (PLA) for 3D printing of a part intended for operation under mild thermal loading. One of the advantages of PLA is its good degradability. This is because its production is based on the use of corn starch or dextrose. Despite this, PLA structures can be created which exhibit higher hardness and strength than ordinary ABS.

**Keywords:** 3D printing, PLA, thermoplastic materials, renewable resource, polylactid acid

## 1. INTRODUCTION

Advances in 3D printing have made it possible to create not only conventional machine components from PLA and ABS, but also from other materials such as HIPS, PET, PVA, PETG, NYLON, PC, etc.

3D printing enables the easy manufacture of test prototypes from various plastics which can undergo material and strength analyses (using FEM). The components must meet demands in terms of construction, material and electrical insulation. Printing allows the deposition of individual layers to be modified to meet the design requirements. A control program enables the creation of a ‘composite’ with layers of the same material and PLA or ABS which is a mixture of wood or carbon particles.

Thermoplastic aliphatic polyester (PLA) is suitable for components used in less demanding thermal environments, and is made from renewable materials such as corn starch. It is characterised by very good colour fastness, does not shrink during cooling, thus not creating stresses in the product; although it is less heat resistant than e.g. ABS, as it starts to soften at around 60 °C, the processing temperature (for printing) is between 190-210 °C. The layers connect better during the creation of prototypes, and there is less tendency for layers to peel apart, making the structure stronger and harder than for example ABS.

### 1.1. Basic principles of fused deposition modelling

Fused Deposition Modelling (FDM) is the most frequently used technique for printing prototypes and function samples of a product, design elements, etc. It works on the basis of extruding melted plastic - thermoplastic - in the form of a fibre (typical diameter 1-3 mm). The print head melts the material at a temperature between 190-250°C and a thin stream (approx. 0.2 mm) is extruded. There is an arrangement of print heads which move across the working desk (X and Y axis), and the working desk moves along axis Z. The printing space is therefore determined by axes X, Y and Z (**Figure 1**). The principle of 3D printing is based on the deposition of layers of a material to create a final product.

The source file of data for the 3D printer is a 3D computer model of the product in *.STL format. This data model is uploaded to the control software where the technical set up for the particular 3D printer is done, and the data model is prepared for production. For low-cost 3D printers the settings are automatic, whereas for printers for professional use the settings are done by an operator who adjusts them as necessary. 3D printing is based on the principle of extrusion and deposition of layers of material (**Figure 1**), which can be changed according to the technical requirements of the future product.

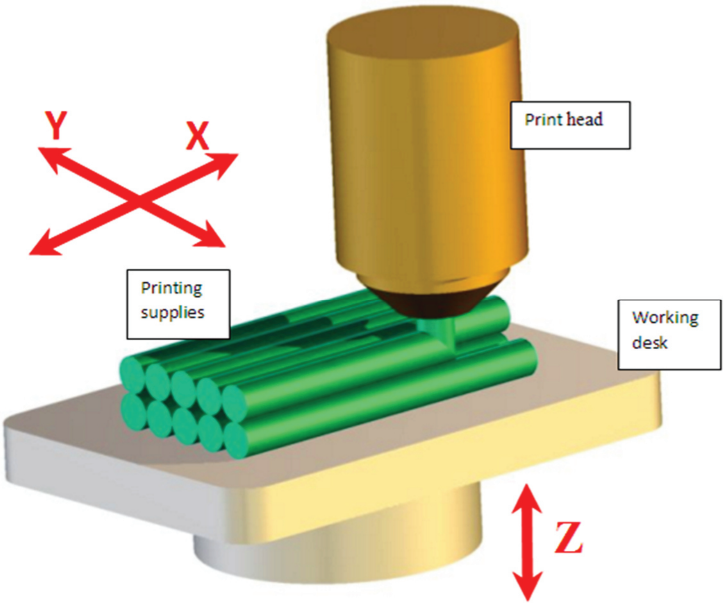


**Figure 1** Working space of 3D printer

### 1.2. Design, creation, settings

The total time necessary from designing to the final 3D model (**Figure 2**) for a prototype is very short, including the transfer of the 3D model data file to the printer's software. Other steps are the correct selection of important parameters (melting temperature, speed and direction of layering, correct choice of rotating the future product, etc.). The following figure summarizes the procedure:

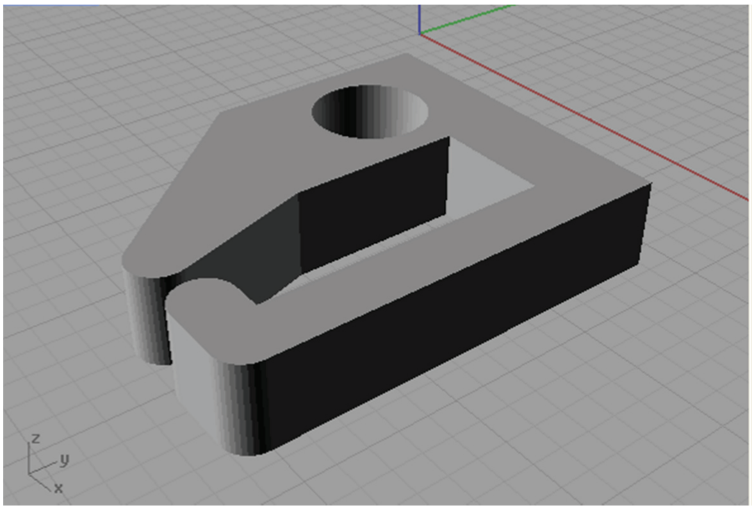

**Figure 2** Creation of 3D model in CAD, saving it in *. STL file and transfer to 3D printer's SW

Then follows the accurate definition of the parameters:

- type of print material
- setting temperature and speed of print
- setting print structure (layers, tracks, positions, etc.)

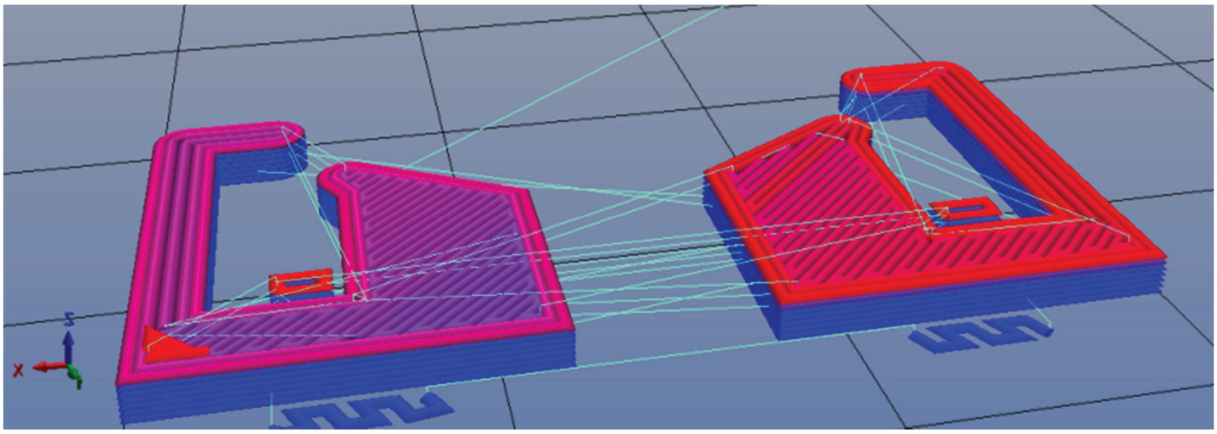


**Figure 3** Following the simulation of tracks, layering and cooling of layers in the control SW

The correct selection of parameters (**Figure 3**) not only influences the overall quality of the final product, but can also create its mechanical properties (strength, durability, stiffness, etc.) which are important for a prototype and a functional product [3, 4].

## 2. PLA - MATERIALS CHARAKTERISTICS

Polylactid acid is a biodegradable thermoplastic aliphatic polyester derived from renewable resources such as corn starch, tapioca roots or sugarcane. In 2010, PLA had the second highest volume of consumption of all bioplastics in the world [1].

In comparison with ABS, it is easier and faster to process under the same initial conditions, but the products made from it are significantly less resistant to higher temperatures, and it begins to soften at about only 60 ° C, while ABS has a 'glass transition temperature' boundary up to 100 ° C. The temperature at which the material can be processed is from 190 ° C to 210 ° C and it is heated directly in the print head.

Fireproof PLA is able to withstand temperatures of about 110 ° C. Unlike ABS, PLA is not so prone to deformations and defects due to the cooling of the printed material, therefore it does not require strict use of a heating pad. A subjective advantage of PLS over ABS among some home users is the fact that when melting, PLA produces a scent reminiscent of frying vegetable oil, while ABS smells like burnt plastic. From the material point of view, products from PLA are less flexible and have a higher gloss than ABS products.

PLA can be recycled by chemical means. Unlike mechanical recycling, in which waste can contain various impurities, chemical recycling takes place until the decomposition of the monomers of lactic acid by thermal depolymerisation or hydrolysis. After purification, the isolated monomers may be reused for the manufacture of virgin PLA without loss of the original characteristics. This is a distinct advantage, and PLA is therefore fully recyclable [2].

Compared to ABS, it shows a much smaller degree of deformation, which enables more accurate models to be printed. This makes it possible to achieve high surface quality and accuracy of the individual printed layers (**Figure 5**). Surface quality and precise layering of material is seen in the macro photograph of the surfaces of representative samples.

Basic mechanical properties for PLA are given in the material certificate, tensile strength at room temperature, according to ISO 527-2 is measured in the range between 15 to 72 MPa. Another important indicator is ductility, which is between 1- 8.5% according to ISO 527-2. For a comprehensive overview of the mechanical properties of PLA, it is necessary to know the impact strength test by impact bending according to Charpy, which is performed on notched specimens, at room temperature according to ISO 179 and its value is measured in the range from 0.67 to 2.6 ft -lb / in2. It was found that the value varies depending on the printing conditions, which are obtained depending on the type of 3D printer used. Results of recent studies show that the act of 3D printing PLA affects its properties.

This is the reason why the first experimental work was aimed at the evaluation of the effect of 3D printing method on mechanical properties of PLA. Mechanical properties of 3D printed PLA samples were preliminarily tested on a MTII/Fullam Tester stage (**Figure 4**). The final shapes of tensile samples were produced directly by 3D printing, which eliminated the risk of changes of surface structure and properties by final machining necessary for conventional sample preparation. Flat samples (**Figure 5**) with the same dimensions were prepared by three different printing methods (**Figure 6**) to test the potential of formation of composite materials with various mechanical properties.

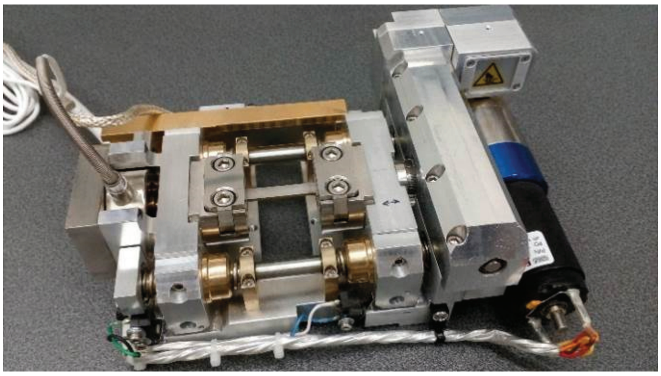

**Figure 4** Deformation stage MTII / Fullam SEM Tester

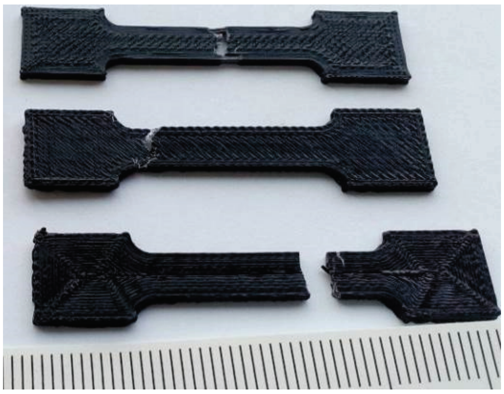

**Figure 5** Samples (A, B, C -top to bottom) after tensile test

In the first sample (A), two sets of material layers were printed at an angle of +45°/-45° with respect to the longitudinal axis of the sample. The layers crossed each other at the longitudinal axis and their respective angle was therefore 90°. An additional 3 layers of material were printed alongside the whole sample as a seal. The second sample (B) had the same layout of intersecting layers inside, however there was only one layer printed around the whole sample. In the last sample (C), all the layers were printed along the longitudinal axis of the sample.

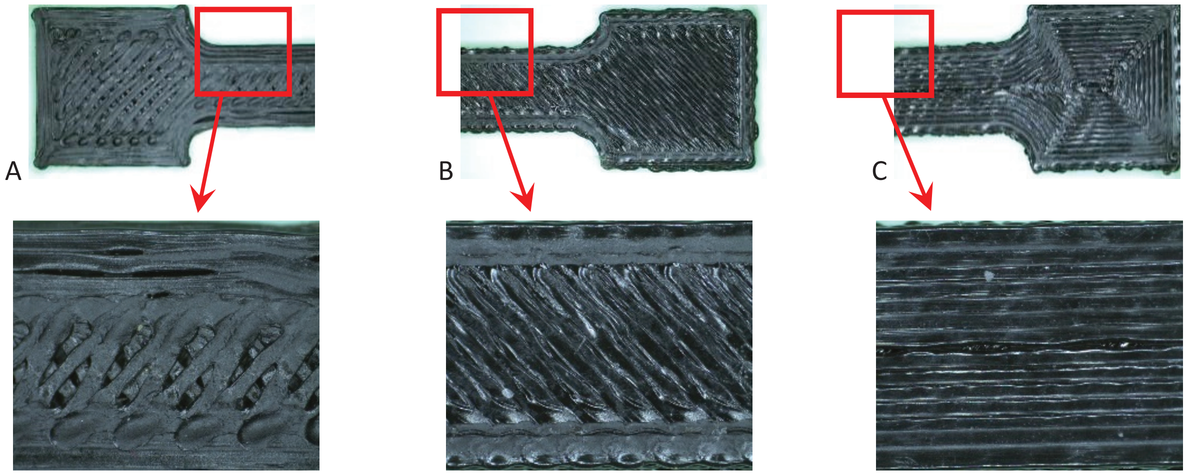


**Figure 6** Macro-images of samples (top) and details of various layers layout (bottom) for samples A, B, C

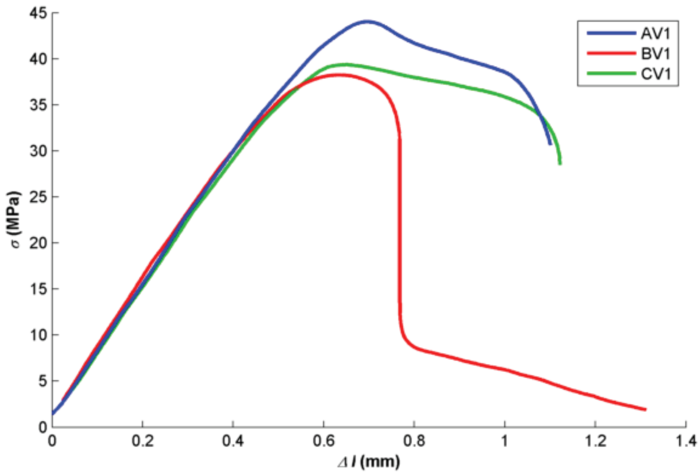


**Figure 7** Tensile test graphs. Tensile strengths of samples A, B, C were 44MPa, 38MPa and 39MPa respectively.

Based on the mechanical properties (**Figure 7**) of the samples A, B and C, it can be stated that the most suitable printing method was method A with crossing layers inside and three layers around the sample. The highest tensile strength of 44MPa was in this case accompanied by good ductility A10mm= 6.8%. It was also observed that even though the central part of the sample with crossing layers was already fractured, the two halves of the sample were still held together after the test by three un-fractured layers surrounding the whole sample (**Figure 5**). Similar behaviour was also noted for sample B, where only one surrounding layer was still able to hold the fractured parts together after the test. This could play an important role in safety considerations for further practical applications of 3D printed PLA products.

Sample B did not fail in the middle, and therefore measured properties may not be really representative, and further microstructure and fractographic analysis will be carried out to explain this behaviour. Sample C printed with only longitudinal layers had a tensile strength of 39MPa and the highest ductility was above 7 %. Even though this sample had the lowest tensile strength, it was still well within the range given by ISO 527-2.

## 3. CONCLUSION

The usability of FDM 3D printing technology is limited only by the structural stress on the product. If the important parameters are respected and properly set, the structural elements are able to withstand the required load and it can be utilized in the production of prototype components and equipment, piece production or small-lot production, where there are demands on the speed of prototyping and on costs.

Thanks to the excellent mechanical, material and processing properties of PLA materials, they can be applied to 3D printing of smaller components which must have good surface quality, fine structure, material properties and important design features which can be influenced by the 'composition' of layers such as for composite materials (carbon or glass) [4, 5]. This material is ideal for producing very small prototype products. Mechanical properties of a prototype can be shaped by selecting the proper melting temperature, the direction of printing of the individual fibres, their arrangement or by adding a mixture of wood or carbon particles.

An indisputable advantage is that this material is biodegradable and is obtained from natural sources, such as corn starch. Another advantage for the use of this plastic material is that it is fully recyclable chemically, whereby after recycling it can be reused to produce new PLA blanks.

## ACKNOWLEDGEMENTS

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