J. KESSLER, K. DRAGANOVÁ, K. SEMRÁD, M. FIĽKO

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MODIFICATION OF THE 3D PRINTER FOR THE PROCESSING OF THE HIGH-PERFORMANCE THERMOPLASTIC POLYMERS IN THE PRODUCTION PROCESS OF TRANSPORT SYSTEM COMPONENTS

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Nowadays, the ability to process the high-performance thermoplastic polymers has been still the domain of the industrial 3D printers. This article describes the possibilities of the commercial 3D printer modification to achieve the required boundary conditions for the processing of the high-performance thermoplastics with adequate mechanical properties. These materials have a very high melting point, and it is inevitable to ensure this increased temperature in the entire print volume. Therefore, it was necessary to perform the numerical simulations focused mainly on the thermal load of the 3D printer construction. Consequently, the simulation results were experimentally verified, and the optimal material in terms of its density and mechanical properties was selected.

Key words: thermoplastic polymers, thermal analysis, numerical simulation, 3D printer, high-performance

INTRODUCTION

The rapid development of the thermoplastic materials [1] for the additive fused deposition modelling (FDM) production [2] have led to a significant improvement in the physical properties of the components produced by this technology [3, 4]. However, the processing of these materials has specific requirements such as a much higher temperature of the hot end and of the heated component and therefore the printer cannot work in an open environment and must be placed in a heated chamber. It results to the high demands on the mechanical strength and thermal resistance of the of the 3D printer components [5, 6] met nowadays only by industrial printers, the application of which is limited due to their dimensions.

3D PRINTER CONSTRUCTION

In our case, the chosen 3D printer has a design based on the renowned Original Prusa Mk1 3D printer.

It is manufactured from the commonly available components and parts that can be also produced using the 3D printer, which is a great advantage because of the final weight reduction and the possibility to produce spare parts necessary for the maintenance and repairs. The printed components made of commonly available thermoplastic materials such as the PET-G are mechanically and especially thermally resistant enough considering the processing of the commonly available materials when the temperature of the heated bed usually does not exceed 100°C. The glass transition temperature of the PET-G material is usually around 70°C, which is insufficient for the printing of the high-performance thermoplastic materials such as PEEK, PEI or PEKK. For this reason, it is necessary to choose a material with the higher glass transition temperature. The thermal load of the structure is not constant in the entire printing volume. The highest load is in the area of the printing pad where the temperature during the printing can reach up to 145°C. The smallest temperature change is in the area of the upper attachment of the Z axis, where the temperature is equal to the ambient temperature maintained inside of the protective box (80°C for PEEK material). Therefore, it is necessary to quantify the amount of the heat radiated by the heated bed into the environment and to choose materials convenient for the 3D printer (Figure 1) construction. The heated bed is attached to the Y-axis structure using four distance spacers, the role of which is not only to create a solid connection with the Y-axis structure, but also to prevent the transfer of heat from the bed to the printer structure (Figure 2). For the numerical analysis, the goal of which was not only to determine the appropriate material, but also the necessary height of the bed from the structure of the axis in order to achieve the smallest possible transfer of heat to the structure, the boundary conditions based on the PEEK material were applied.

Another very important component is the hot end, which is during the printing process heated up to the 435°C, which is together with the components of the attachment of the hot end to the construction of the X-axis carriage cooled by an axial fan with a high air flow.

J. Kessler, K. Draganová, K. Semrád, M. Fiľko, Faculty of Aeronautics, Technical University of Kosice, Kosice, Slovakia
Corresponding author: katarina.draganova@tuke.sk

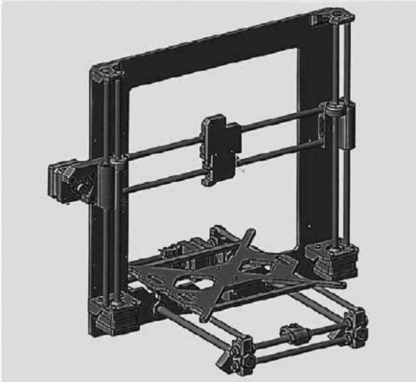

Figure 1 3D printer construction assembly

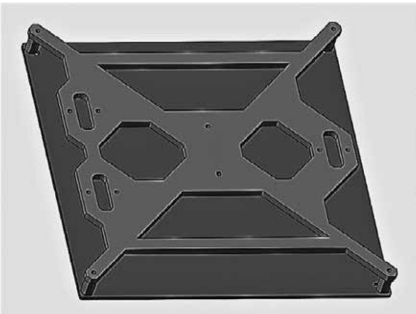

Figure 2 Y axis assembly for the thermal analysis

The temperature values on the X-axis structure during the operation do not exceed 90°C.

MATERIALS

The PEEK, PEI and PEKK are the only materials that can be used in the area with the highest thermal load. The PEKK material has the best mechanical properties. Compared to the aluminium, it has almost 50 % lower density and many times lower thermal conductivity, which is a great advantage in terms of the insulation of the heated bed from the printer structure. The PEEK and PEI materials have similar properties, but the PEEK material has lower thermal resistance and the PEI material lower mechanical strength. For other parts of the structure where the heat load is lower, it is possible to use less durable materials such as polycarbonates or PC-ABS. However, the polycarbonate material has lower thermal conductivity, and the PC-ABS material has a lower density. The utilization of these materials for other parts will significantly reduce the 3D printer production cost, as the prices of the high-performance thermoplastics such as the PEKK, PEEK, PEI are many times higher than the prices of the commonly available materials.

The most suitable material for other components must therefore be chosen from the first half of Table 1. Although the polycarbonate has the highest heat resistance, it also has high density resulting into the higher weight, which is for this application a significant disadvantage. For the initial testing, the PC-ABS material was chosen, which is a combination of the polycarbonate and ABS materials to improve the mechanical properties.

Table 1. **Comparison of the mechanical properties**

Material	Density / g·cm^{-3}	Tensile Strength / MPa	Deflection Temp. / °C
PET-G	1,24	45	70
ASA	1,07	45	95
PC	1,20	62	135
PC-ABS	1,14	59	126
PEEK	1,30	100	145
PEKK	1.29	105	182
PEI	1,34	54	158

NUMERICAL ANALYSIS

The numerical analysis of the components of the Y-axis structure focused on the temperature load caused by the 3D printer operation was performed using the CAE Creo-Simulate software involving the Thermal module for the precise analysis of the steady or transient effects of the temperature fields on the particular components. In our case, it is possible to simplify the assembly of the structure to only a few necessary components, such as the heated bed, on which the temperature load is applied, distance spacers and the heated bed platform. The components attached to the bottom of this platform can be omitted to reduce the time required to perform the thermal FEM analysis significantly, as the final temperature of the platform will be the decisive parameter for the selection of the material for these parts.

The initial analysis of the distance spacer made of PEKK material was performed using the Live Simulation function, which can be used for the continuous control during the design of the individual models or assemblies. From Figure 3 it can be seen that the chosen length of 15 mm is sufficient for the effective isolation of the heated pad from the 3D printer structure. The shape of the distance spacer was deliberately chosen as a hexagon to optimize the mechanical properties and with respect to the 3D printing process. By the analyses results shown in Figure 3 it was confirmed that the PEKK material has many times lower thermal conductivity coefficient than commonly used materials such as steel and aluminium. However, these materials achieve much higher strength, which allows to apply higher printing process speed in comparison to the PEKK material. In our case, the speed of the printing process is not a very important parameter. Our goal was to design the 3D printer with the lowest possible weight using the largest number of the components produced by the 3D printer itself.

Figure 4 shows the simulation results of the heated bed assembly attached to the supporting platform using the designed distance spacers made from the PEKK material. Thanks to the PEKK material, the platform is isolated from the heated bed, and it is heated only by the radiating heat from the bed. The amount of the heat radiation from the bottom part of the heated pad can be reduced using a silicone insulating layer. The thermal analysis result is an increase in the temperature on the platform of only about 5°C compared to the ambient temperature.

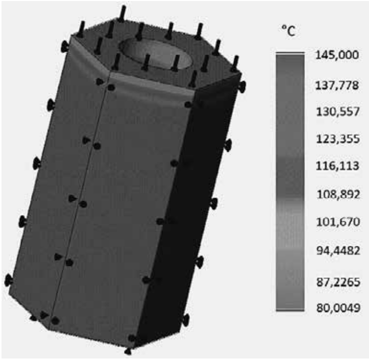

Figure 3 Thermal analysis results of the distance spacer – PEKK material

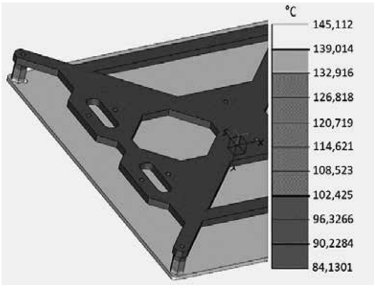

Figure 4 Thermal analysis results of the heated pad – PEKK material

In case of low-carbon steel utilization, the heat is transferred to the structure by the flow significantly and it would be necessary to use the high-performance thermoplastics such as the PEKK, PEI, etc. in the entire structure of the Y axis. Thanks to the distance spacers made of the PEKK material, it is possible to use conventional materials such as the polycarbonate or the PC-ABS for other parts of the structure, which greatly exceed the conditions necessary for the 3D printer operation, and their price is many times lower.

EXPERIMENTAL MEASUREMENT

The experimental measurement was performed using the Flir i3 thermal camera with the emissivity coefficient set to 0,8, as this value appropriately represents the analysed components.

From Figure 5 it can be seen that the heating body with the insulation is attached to the bottom of the heating pad and the heat distribution is concentrated to the pad center. The temperature in the printing surface corners is on average 3 to 8 °C lower than the required (simulated) temperature. This means that the real thermal load applied on the distance spacers will be lower in comparison to the numerical analysis results. The experimental measurements confirmed not only the numerical analysis results but also the correct setting of the heated bed temperature regulation.

CONCLUSIONS

The numerical analysis and the subsequent experimental measurement verified the potential of the conventional 3D printer modification into a 3D printer capable of the processing even of the most demanding

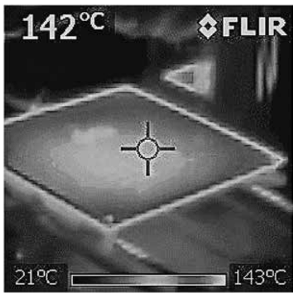

Figure 5 3D printer thermal image

thermoplastics requiring high temperatures during their processing. This problem can be effectively solved using the high-performance thermoplastics such as the PEKK, PEEK or PEI for the construction of the 3D printer. By the modified 3D printer design, it is possible to achieve the quality of the 3D printing process and to process materials at the comparable level to the industrial 3D printers for the rapid production of components even in the conditions where it is not possible to operate large industrial 3D printers. Moreover, this solution will ensure partial self-sufficiency in terms of the 3D printer maintenance and repairs.

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