

A GYÁRTÁSI PARAMÉTEREKNEK A WARPING JELENSÉGRE GYAKOROLT HATÁSÁNAK VIZSGÁLATA NUMERIKUS MÓDSZEREKKEL FFF NYOMTATÁSI ELJÁRÁS ESETÉN

INVESTIGATION THE INFLUENCE OF THE PRINTING PARAMETERS ON WARPING IN FFF 3D PRINTED ABS USING NUMERICAL SOLUTION

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ABSTRACT

Rapid prototyping (RP) technology uses the consecutive deposition of material layers to construct prototypes. When temperature gradients are present during the deposition process, thermal stresses will be generated. This work investigates the warpage deformation during fused filament fabrication (FFF) processes. Each of the factors, including printing speed, layer thickness, and printing temperature, had a quantitative impact on the warpage deformation of the prototype. The correlation between the printing parameters and the warpage deformation was identified based on the analysis's findings.

1. INTRODUCTION

Engineers can use the capabilities of Additive Manufacturing (AM) to create a one-of-a-kind design. On the one side, the machining shape and movement circumstances do not impose any limitations. On the other side, each AM technology has its own set of constraints that must be considered [1], [2]. 3D printing components are currently widely employed in a range of industries, including food [3], aerospace [4], and automobile manufacturing [5]. The different techniques associated with the AM are used in the standard: Additive Manufacturing - General Principles – Terminology, ISO/ASTM 52900:2021. One of the best-known is Fused Filament Fabrication (FFF), also known as Fused Deposition Modeling (FDM). FFF is the most commonly utilized technique because it is significantly easier and less costly to employ than other methods, and it may use a wide range of raw materials such as polylactic acid (PLA), acrylonitrile–butadiene–styrene (ABS), polyamide (PA) 6 and 12, and polyetherimide (PEI) [6]. The raw material, in filament state, is forced through the print head's heated extruder while it moves relative to the build plate, and the molten material is deposited on the plate. This deposition process occurs solely in 2D; after completing a layer, the print head begins to produce a

new layer on top of the previous one. This process has the significant advantage of being able to make hollowed components, which can result in significant weight reduction and cost - savings. However, it must be kept in mind that the printing process might significantly impact the part's qualities. Numerous studies have investigated the qualities of the fabricated parts. Ficzer P, Borbás L [7] studied the effect of the printing direction on the damping properties of PLA material. Shanmugam et al. [8] analyzed the affecting parameters for FDM technology, with a specific focus on fatigue behavior. J. R. C. Dizon, A. H. Espera, Q. Chen, and R. C. Advincula [9] examined the impact of raster angle, layer thickness, and infill pattern on the tensile strength. R. A. Mensah et al. [10] compared the mechanical strength of different parts with different infill densities. Other studies investigated the environmental and economic of AM [11], [12]. P. Ficzer, L. Borbas, and G. Szebenyi [13] investigated the relationship between stress capacity and printing orientation. M. S. Alsoufi and A. El-Sayed [14] investigated the effect of printing speed and printing temperature on the warping deformation.

2. NUMERICAL SIMULATION

2.1. Material and model description

For numerical simulation, bridge geometry with dimensions of 46 mm x 60 mm x 33 mm and 3.75 mm thickness, as shown in **Figure 1**, was implemented because the warping can easily influence the pillars. The used material is ABS with an ultimate strength of 30.46 MPa [15], Poisson's ratio of 0.36, and thermal conductivity of 0.18 mW/(mm.°C). Poisson's ratio and thermal conductivity data were obtained from Digimat-MX, one of Digimat's platforms used for the material database.

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2.2. Printing parameters

This work studied the correlation between printing parameters and the warpage. Three

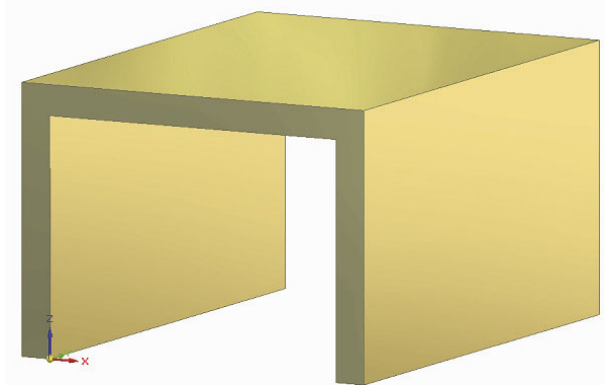


Figure 1. Bridge geometry dimensions

printing factors with four levels of each factor, as illustrated in **Table 1**. The default printing parameters were 60 mm/s for the printing speed, 0.19 mm for the layer thickness, and 250 °C for the printing temperature. The rest of the printing parameters were 70 °C for plate temperature, 100% for infill density, and Zig Zag infill pattern.

Table 1. factors and levels of simulation

Factor	levels			
	1	2	3	4
Printing speed (mm/s)	20	40	60	100
Layer thickness (mm)	0.19	0.29	0.39	0.49

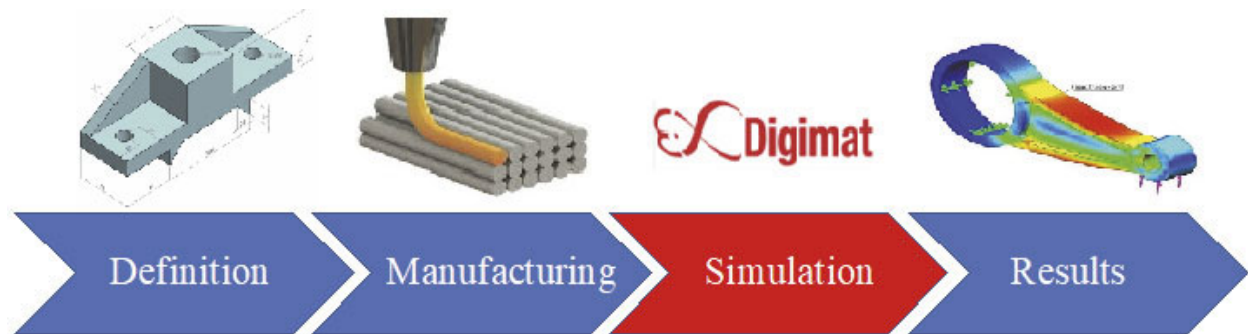


Figure 2. Digimat-AM workflow

3. RESULTS AND DISCUSSION

A total of twelve runs were executed, and the results were obtained. For the printing speed factor, the results showed that by increasing the printing speed, the warping slightly decreases, and **Figure 3** illustrates the trend. At 20 mm/s speed, the warping was 3.9 mm, whereas, at a speed of 100 mm/s, the warping was 3.2 mm. The reason

Printing (Extrusion) temperature (°C)	230	240	250	260
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2.3. Finite Element Analysis (FEA) of FFF

The Computer-Aided Engineering (CAE) presented in this investigation was executed in Digimat-AM. It is a platform that offers an FEA analysis of AM processes. Digimat-AM is software used to collect data of samples built by one of the manufacturing processes and their mechanical characteristics. Digimat-AM simulates AM of composites and polymers, and predicts warpage and residual stresses of a printed part. This program provides a workflow that includes the stages depicted in

Figure 2. In the definition stage, the FFF process is selected along with the build plate dimension of a generic printer. The selected printer is a moving build plate with 200 x 200 x 180 mm dimensions. Digimat-AM uses a thermos-mechanical or inherent strain approach, selecting the former one for analysis. Then, the geometry is defined using a stereolithography (STL) file. The final step is to select the material, which is ABS, unfilled, and amorphous. In the manufacturing stage, the toolpath is provided in a G-Code file which is exported from a slicing program such as Slic3r, Cura, or PrusaSlicer. The printing speed and the extrusion temperature are set based on the levels in **Table 1**. The rest of the manufacturing parameters were 30 °C for chamber temperature, 23 °C for room temperature, 23 °C for final temperature, and the convection coefficient is equal to 0.015 mW/mm² °C. The printing steps are ordered as printing, then cooling, and lastly, support removal. In the simulation stage, the mesh is created by defining the voxel size. Finally, the results given by the simulation consist of residual stress and warpage.

behind this trend is that by increasing the printing speed, the temperature difference between the new and previous layers will be less. For the layer thickness effect, the results, as demonstrated in **Figure 4**, showed that the layer thickness significantly influences the warping deformation. By increasing the layer thickness, the warping deformation decreases. At 0.19 mm layer thickness, the warping was 3.59 mm, while at 0.49 mm

layer thickness, the warping deformation was 1.78 mm. This decrease in the warping happened because by increasing the layer thickness, the number of layers will decrease, and then the thermal loss will decrease.

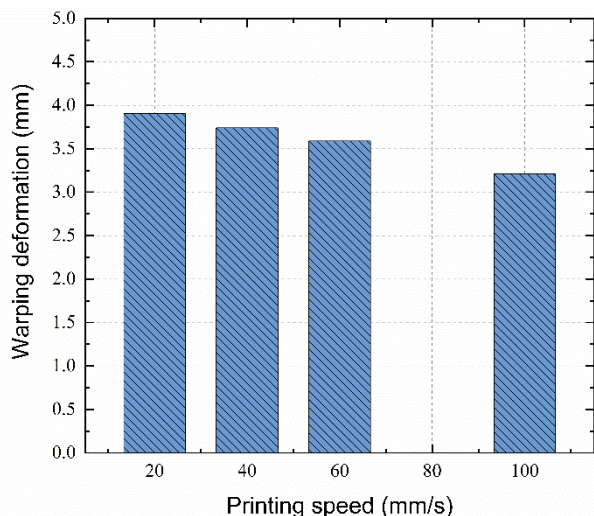


Figure 3. The influence of printing speed on the warping deformation

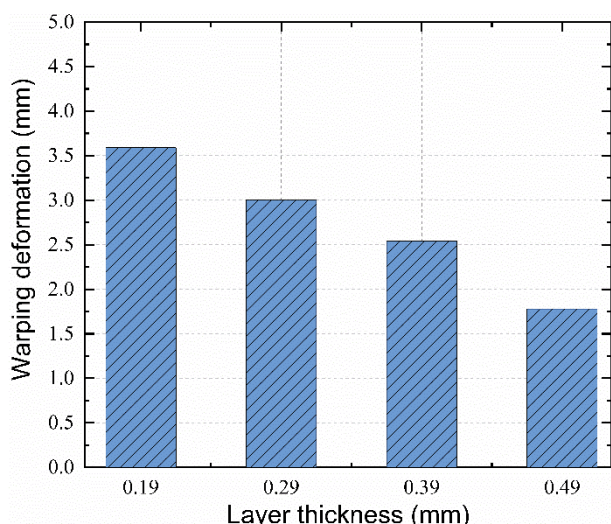


Figure 4. The effect of layer thickness on the warping deformation

The printing temperature had the opposite influence on the warping deformation. As depicted in **Figure 5**, the printing temperature was proportional to the warping deformation. The warping deformation lightly increases by increasing the printing temperature. The warping deformation was 3.3 mm at 230 °C, then increased to 3.73 mm at 260 °C. **Figure 6** demonstrates the warping deformation results provided by Digimat-AM with the default printing parameters.

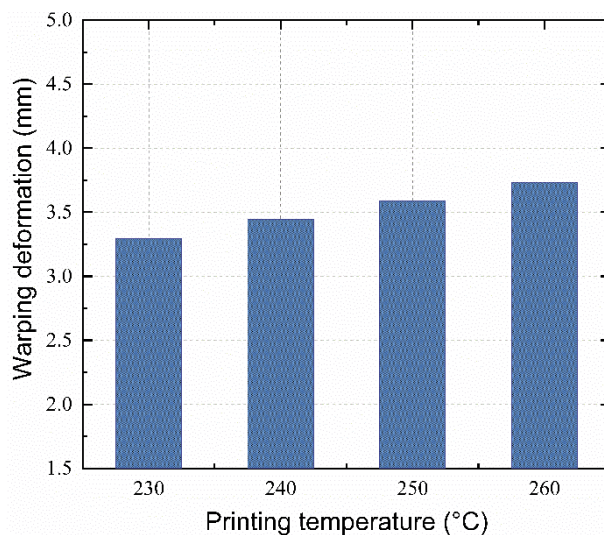


Figure 5. The correlation between the printing temperature and the warping deformation

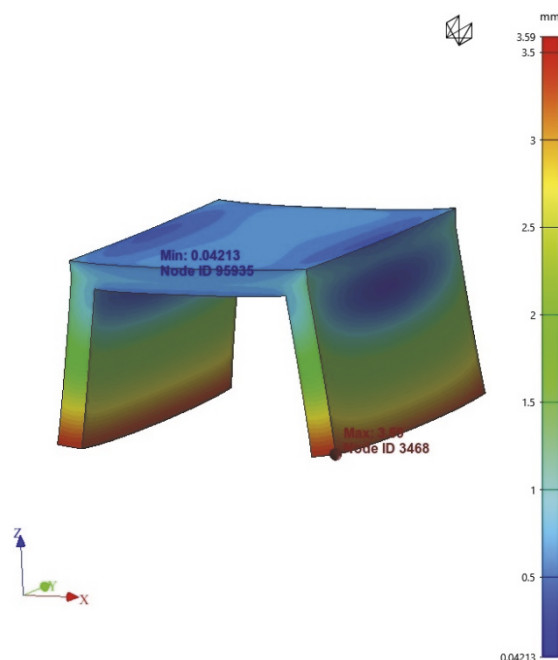


Figure 6. Results provided by Digimat-AM with the default printing parameters

4. CONCLUSION

For assessing the quality of a Fused Filament Fabrication (FFF) prototype, warp deformation is a key success factor. The FFF prototype's warping is influenced by some factors. Material characteristics, printing parameter settings, the CAD model's geometrical structure, and deposition path design are some of these factors to take into account. The printing speed, layer thickness, and printing temperature were the three printing parameters that underwent a numerical analysis. Each printing parameter had four levels. Based on the findings, it can be concluded that the warping deformation is positively

connected with the printing temperature but negatively correlated with both printing speed and layer thickness. A scientific approach for minimizing and controlling the deformation can be provided by the numerical solution.

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