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USING NUMERICAL SIMULATION TO INVESTIGATE THE EFFECT OF LAYER THICKNESS ON RESIDUAL STRESS AND WARPING OF SPECIMENS MADE OF ABS

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Abstract: Fused Filament Fabrication (FFF) is an additive manufacturing technology that is used to create a wide range of parts and applications. Along with its benefits, there are some challenges regarding the printed parts' mechanical properties, which are associated with printing parameters like layer thickness, infill density, print speed, and nozzle temperature. Experimentally investigation of these pamperers is costly and time-consuming. Some simulations are available to use the numerical solution in the investigation. This work used Digimat-AM simulation to investigate the effect of layer thickness on the residual stress and warping deformation of printed ABS parts.

Keywords: *Additive Manufacturing, ABS, Residual stress, Warping deformation, Digimat-AM*

1. INTRODUCTION

3D printing, often known as additive manufacturing (AM), produces viable, robust, and permanent parts. One of AM's benefits is that it does not require any specialized or expensive tooling, allowing it to work with various materials [1], [2]. By 2025, the AM market will provide an annual economic impact of $200 billion to 600 billion dollars [3], [4]. 3D printing impacts how items are created and made, and its application will expand in the coming years [5], [6]. Material extrusion (ME) [4] is preferable for polymer AM because of its low cost and simplicity of constructing complicated shapes. Since it is a trademark of Stratasys Inc., ME is also known as fused deposition modelling (FDM) or fused filament fabrication (FFF). ME offers a wide range of polymers, both reinforced and unreinforced. Various companies produce and sell 3D printers based on that technology, with varying characteristics such as filament types, accuracy, and printing workspace. In FFF, the material is extruded through a nozzle. That extruded material is a heated filament; then, the material comes out from the nozzle in a molten state to form the layer. It solidifies and binds with outer layers when extruded on the previous layer on the building platform [7]. FFF uses process parameters to print a product, much like any other manufacturing technique. The outcome is affected by changes in certain operating characteristics. Using diverse AM technologies, researchers investigated the influence of 3D printing parameters on various reactions like printing orientation, printing pattern, nozzle temperature, printing speed [8]–[13]. Samples are formed of polylactic acid (PLA), acrylonitrile–butadiene–styrene (ABS), polyamide (PA) 6 and 12, a combination of PC and ABS, polycarbonate (PC), polyether-ether-ketone (PEEK), or polyetherimide (PEI).

The relationship between printing parameters and mechanical characteristics is determined by many types of testing like compression, torsion, tensile. The FFF technique also produces manufacturing time and the accuracy dimension of the printed part as output variables. Researchers have chosen a simulation to make a numerical solution to investigate different ME factors in plastic materials, with various goals and objectives. One proposal is to study the manufacturing process solely from the standpoint of material deposition, neglecting the mechanical characteristics of the printed parts. A further approach is to analyze the mechanical properties of 3D printed samples using simulations that do not duplicate the material extrusion process but change the printing parameters such as layer thickness, infill density, print speed, and nozzle temperature.

Residual stress is a result of plastic materials' ME. It changes the mechanical characteristics of specimens and should be considered for further research into AM components Studies related to residual stresses fully understand simulations that anticipate them. After that, the part's mechanical properties are calculated, considering the residual stresses that have built up during the printing process. Softwares such as Abaqus, Digimat, and ANSYS are used to generate computational models. ABS, PLA, nylon, and polyphenylene sulfide (PPS) are common materials. Printing parameters are changed to predict the magnitude and position of residual stresses. Various types of heat transfer occur during printing when materials are extruded and deposited. The most important is the heat exchange with the environment via convection and conduction between neighbouring layers and machine support [14]. Thermal history is associated with the formation of residual thermal stresses, which affect component dimensional precision and mechanical behaviour [15], [16]. Changes in the temperature profile of AM parts during the production process could cause problems. The molten material is deposited on a building platform at a high temperature, generating a fast cooling rate that impacts the part's mechanical characteristics [17]. The present paper investigates the effect of layer thickness on the residual stress and warping deformation using Digimat-AM software.

2. SIMULATION PROCEDURES

The simulation process starts with a 3D modelling design created with Solid Edge software. Solid Edge is commonly utilized in various industries, including architecture, manufacturing, electronics, and aerospace. Solid Edge 3D software includes several outstanding features, such as the wide range of platforms available in the mechanical engineering sector, which allows for the creation of unique design aspects. A three-dimensional cuboid prototype was created (in STL format) with 100 mm long, 100 mm depth, and 5 mm thickness, as shown in *Figure 1*.

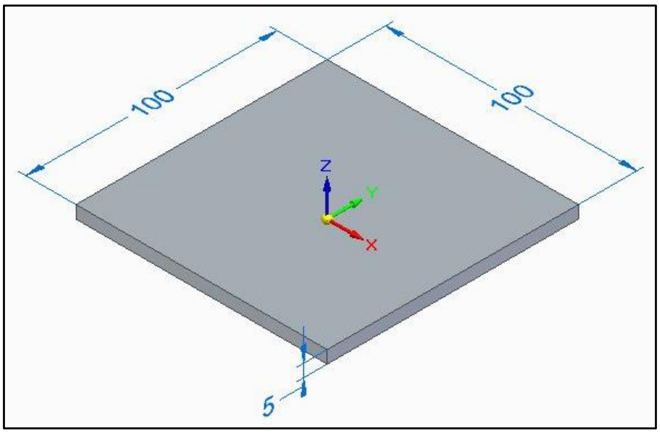

Figure 1. *The 3D shape of the specimen*

The STL (Standard Triangle Language) file type is transformed into printing commands of thin layers using slicer software like Ultimaker Cura or Slic3r, creating a G-Code (G-Programming Language) file containing all orders and instructions such as layer thickness, printing path, and printing orientation. The printing path of the designed specimen is +45°/–45°, as shown in *Figure 2*.

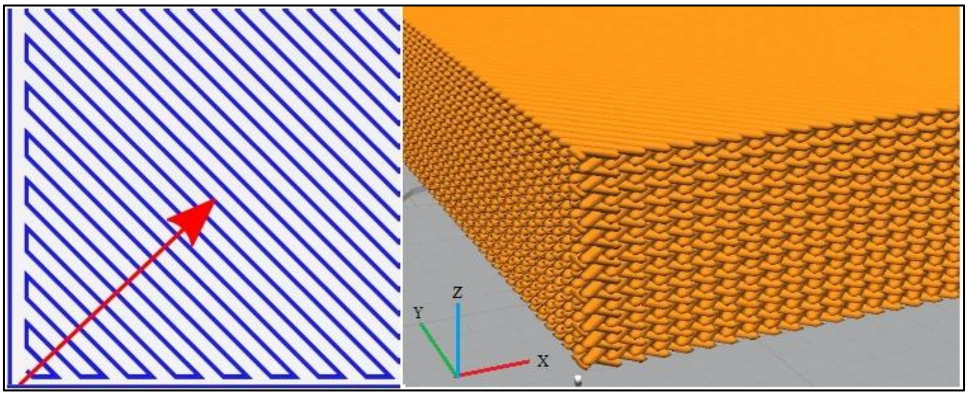

Figure 2. *Printing pattern +45°/–45°*

The STL file and G-Code file are used in Digimat-AM software. Digimat-AM simulates different types of polymers and composites, and it provides a prediction of warpage and residual stresses of a printed part. Digimat-AM software has a workflow that is illustrated in *Figure 3* [18].

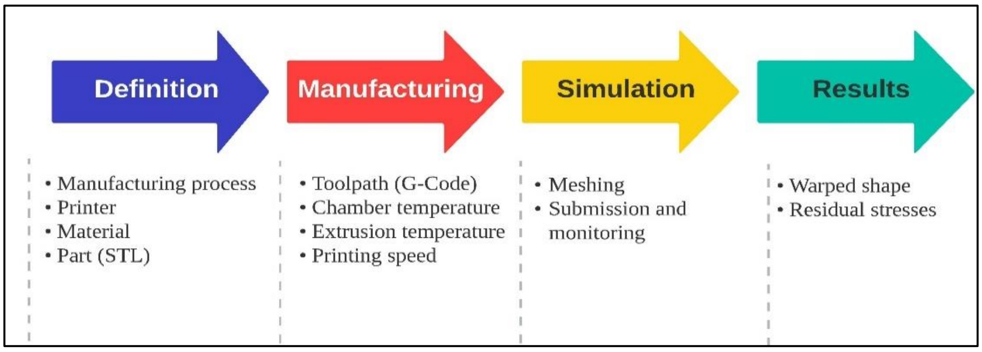

Figure 3. *Digimat-AM workflow* [18]

In the definition step, the FFF manufacturing process is selected with a generic FFF printer with a chamber size of 200 × 200 × 200 mm and a fixed platform. The ABS material is chosen from the Digimat database. Then the geometry is imported using the STL file. The process parameters are defined in the manufacturing stage. For this investigation, the parameters are illustrated in *Table 1*. The toolpath of printing is determined using a G-Code file.

Table 1

Process parameters for simulation

Process parameter	**Value**	**Unit**
Chamber temperature	30	°C
Extrusion temperature	250	°C
Room temperature	23	°C
Printing speed	60	mm/s
Final temperature	23	°C

Finally, in the simulation step, the geometry has meshed then, the job is submitted to get the results. In this study, four simulations were done with different layer thicknesses. The chosen layer thickness was 0.19 mm, 0.29 mm, 0.39 mm, and 0.49 mm.

3. Results and Discussion

Table 2 shows the results of the simulation with different layer thicknesses. *Figure 4* demonstrates the results of residual stresses and warping deformations of a printed part with a layer thickness of 0.29 mm in the Digimat-AM simulation.

Table 2

Results of residual stress and warping deformation with different layer thicknesses

Layer thickness[mm]	**Residual stress [MPa]**	**Warping deformation [mm]**
0.19	5.025	1.522
0.29	2.683	1.525
0.39	1.102	1.473
0.49	0.207	1.445

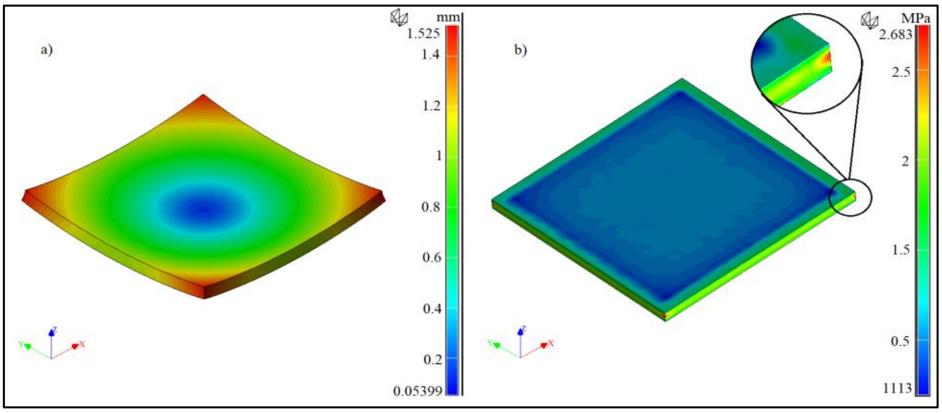

Figure 4. *Results provided by Digimat-AM for 0.29 mm layer thickness: a) the warping deformation, b) the residual stress (von Mises)*

As shown in *Figure 5*, there is a negative correlation between the layer thickness and the residual stress. The mean residual stress was 2.25 ±1.05 MPa. While there is no correlation between the layer thickness and the warping deformation, as shown in *Figure 6*. The mean of warping deformation was 1.49 ±0.019 mm.

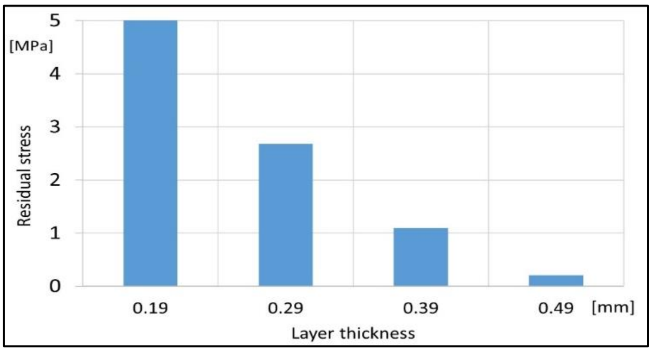

Figure 5. *The relation between layer thickness and residual stress*

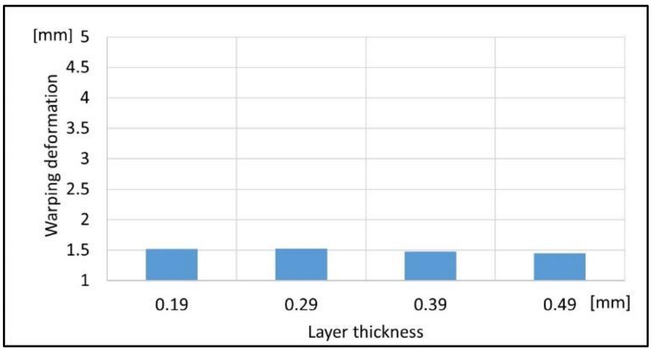

Figure 6. *The relation between layer thickness and warping deformation*

4. Conclusions

The present work used numerical simulation to investigate the impact of layer thickness on residual stress and warping deformation of 3D printed parts made of ABS material. The results showed a significant negative correlation between the layer thickness and the residual stress. Meanwhile, the warping deformation did not change by changing the layer thickness. The total warping deformation is relatively high with respect to the entire thickness of the part. This warping is extremely higher than the layer thickness, which may lead to failure in the physical printing due to collusion between the part and the printing nozzle.

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