Simulation of Temperature Field in FDM Process

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Abstract. In order to improve the precision and mechanical properties of FDM molding parts, the temperature field of the rectangular thin block was simulated and studied by using the finite element method. The analysis results were consistent with the actual process. On this basis, the temperature field distribution of the molded parts under different printing speeds was compared, providing guidance for the reasonable selection of printing speeds.

1. Introduction

As a representative process technology of 3D printing, FDM technology has many advantages, such as low cost of small batch manufacturing, fast speed, strong complex manufacturing capacity, high material utilization rate and good adaptability, and has been widely applied in many fields. However, sometimes the precision and mechanical properties of FDM molding parts cannot fully meet the requirements of functional parts. In order to improve the precision and mechanical properties of the molded parts, many researchers have conducted numerical simulation on the FDM molding process in recent years to optimize the molding process. Samar Jyoti Kalita, Susmita Bose et al. from Washington State University carried out simulation on different materials used by FDM, providing a theoretical basis for rational selection of printing materials [1].

2. Introduction to FDM technology

FDM technology is a representative 3D printing technology, and its extruded materials are generally filament-like thermoplastic materials, mainly including PLA, ABS, PC, nylon, etc. [2]. The filamentous thermoplastic material enters into the nozzle at high temperature through the wire feeding mechanism of FDM, changes from solid to molten state, and extrudes from the nozzle under the extrusion of stepping motor and rapidly solidifies on the worktable. After each layer is printed, the printing table drops or the nozzle rises to print the next layer, and the solidified part of the previous layer serves as the foundation of the next layer.

Since FDM technology perfectly meets the demand of rapid development of modern advanced manufacturing industry and sharply shortened product research and development cycle, with the rapid development of new high-strength molding materials, the development of FDM technology is very rapid. It can be said that FDM is one of the most widely used 3D printing technologies [3].
3. Establishment of finite element model for FDM process

3.1. Characteristics of FDM

(1) In the molding process, the nozzle, as the heat source concentration point, keeps moving in the process of layer-to-layer accumulation. The molding process needs to consider the influence of space and time. Therefore, the 3d finite element solid element shall be selected for the simulation process.

(2) The molding process is a transient thermal analysis process, and the main heat transfer modes are thermal convection and heat conduction; The state of thermoplastic material changes all the time in the molding process, so the influence of latent heat of phase change should be considered.

(3) The phase change process of materials will inevitably cause changes in internal stress, so there will be residual stress and deformation at the end of molding [4-5].

3.2. Definition of material parameters

PLA was selected for the simulation process in this paper. As the temperature changes, the material parameters also change to a certain extent. The mechanical performance parameters at different temperatures are shown in Table 1.

| The temperature °C | The density Kg/m³ | Coefficient of thermal conductivity W/m °C | Specific heat capacity J/kg °C | Poisson's ratio | Coefficient of heat 10⁻⁵/ °C | Young's modulus GPa | The yield strength MPa |
|--------------------|------------------|----------------------------------------|-----------------------------|----------------|-----------------------------|--------------------|---------------------|
| 20                 | 1400             | 0.25                                   | 2400                        | 0.35           | 8.5                         | 3.5                | 65                  |
| 100                | 1400             | 0.25                                   | 2400                        | 0.35           | 8.5                         | 1.2                | 18                  |
| 150                | 1400             | 0.25                                   | 2400                        | 0.35           | 8.5                         | 0.45               | 3.2                 |
| 200                | 1400             | 0.25                                   | 2400                        | 0.35           | 8.5                         | 0.06               | 0.65                |

3.3. Model establishment and grid generation

According to the characteristics of FDM process, the SOLID70 unit provided by ANSYS is used to conduct grid division of the analysis object, which is divided into 2mm×2mm×2mm units.

3.4. Define boundary conditions and loads

In the simulation process of FDM, room temperature and latent heat of phase change are mainly treated. The nozzle temperature in this paper T₁ is 210 °C, assumes that molding chamber temperature will remain constant after preheating, the room temperature T₀ set to 25°C.

According to the principle of FDM, the influence of heat exchange should be considered in the simulation process. In order to simplify the calculation, considering that the influence of other factors such as heat radiation is relatively small in the actual molding process, this paper takes heat convection as the main heat conduction mode in the calculation, and the heat transfer coefficient of heat convection (h) is 72W/m² °C.

For the treatment of latent heat of phase change, ANSYS usually considers the influence of latent heat of phase change by defining the enthalpy change of material in the process of thermodynamic analysis. In general, the heat change of latent heat of phase transition is often transformed and replaced by the mutation of specific heat capacity in the whole fusing process, which is called specific heat capacity mutation method [6].

4. Temperature field simulation of FDM

4.1. Simulation process of temperature field

After establishing the finite element model, defining the material parameters and determining the boundary conditions, the birth and death element method is adopted in the simulation of the molding
process. First, "kill" all the units of the model; then, the "activation" of the unit is carried out in sequence according to the molding path. After the unit is "activated", temperature and convection load are applied to solve temperature field. After the solution is completed, the unit is "killed" again. With the continuous "killing" and "activating" of the unit, the calculation of temperature field keeps advancing.

4.2. Analysis of temperature field simulation results

4.2.1. Temperature distribution of molded parts at different times. The FDM process of is a process of layer upon layer molding as the nozzle moves, and the temperature distribution diagram at different times is shown in Figure 1.

Figure 1 shows: in the 50s temperature field distribution diagram, the minimum temperature is 25°C, molding at room temperature for setting, the model temperature in the bottom area is higher, for having completed the activation and the temperature of other units away from heat source is very low, namely the units are in a state of "killed"; Over time, in the 100 s temperature field distribution diagram, the highest temperature is 210°C, close to the temperature of the nozzle, the highest temperature is in higher position compared with 50s moment, is located in the middle part of the model. In the 100s temperature field distribution diagram, the Z coordinate of the highest temperature zone increases, and it can be noted that the bottom unit has been cooled to room temperature because it is far away from the heat source. In the 200s temperature field distribution diagram, the model is printed at this time, and the highest temperature is located in the top area of the model just completed.
4.2.2. Temperature gradient distribution at the end of molding. The temperature gradient distribution has an important influence on the thermal deformation of the molded parts, and the more significant the temperature gradient value is, the easier the stress concentration will be generated. Therefore, the analysis of the temperature gradient distribution in FDM process is of great significance for predicting the molding quality of FDM. The temperature gradient distribution of the model at the end of the extraction molding is shown in Figure 2.

![Temperature gradient distribution at the end of molding](image)

Figure 2. Temperature gradient distribution at the end of molding

a), b) and c) respectively represent the temperature gradient distribution of the model in the X direction, Y direction and Z direction, and d) represents the final vector sum of the temperature gradient of the finished product. It can be seen from the figure that the temperature gradient in the X direction and Y direction is relatively small, but the distribution is not regular. The gradient distribution in the Z direction is relatively uniform and closest to the final vector sum figure. FDM is a process of layer upon layer, and the thickness of each layer is very small. Therefore, the XOY plane is the main processing plane and the plane most prone to deformation. The information obtained through gradient distribution is basically consistent with the actual process.

5. Conclusion
In this paper, the finite element method was used to simulate the temperature field in the FDM process, and the temperature distribution of the shaped parts at different times and the temperature gradient distribution at the end of the molding were obtained. The analysis results are consistent with the actual process, indicating that the finite element model and simulation process established in this paper are
reasonable. On this basis, the temperature field distribution of molded parts at different printing speeds is analyzed, which provides guidance for rational selection of printing speed.

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