# Finite Element Analysis of Fused Deposition Modeling Process for ABS and PC Materials


## Abstract

This study presents a finite element analysis (FEA) of the fused deposition modeling (FDM) process using ANSYS software. The thermal behavior during the printing process was investigated for two common thermoplastic materials: acrylonitrile butadiene styrene (ABS) and polycarbonate (PC). A simplified model consisting of a 50 mm cubic bed and two layers (each 10 mm thickness) of printed material was developed to analyze both steady-state and transient thermal conditions. Element activation function was employed to simulate the sequential deposition process. Process parameters included bed temperatures of 100°C and 110°C, and nozzle temperatures of 235°C and 280°C for ABS and PC, respectively. Thermal boundary conditions incorporated convection and radiation effects. Results revealed distinct thermal profiles and heat affected zones for each material, with PC exhibiting higher overall temperatures and different cooling rates compared to ABS. The study provides insights into the thermal dynamics of the FDM process, which is critical for understanding and controlling the quality of printed parts.


## 1. Introduction

Additive manufacturing (AM), particularly fused deposition modeling (FDM), has revolutionized the manufacturing landscape by enabling the production of complex geometries with minimal material waste (Ngo et al., 2018). Also known as fused filament fabrication (FFF) or material extrusion AM, the FDM process involves the layer-by-layer deposition of thermoplastic materials extruded through a heated nozzle. The thermal history during printing significantly influences the mechanical properties, dimensional accuracy, and overall quality of the final printed part (Turner et al., 2014).

The thermal behavior during the FDM process is complex, involving heat transfer through conduction between adjacent deposited material, convection to the surrounding environment, and radiation effects. These thermal phenomena are further complicated by the sequential nature of material deposition and the different thermal properties of the printed materials (Bellehumeur et al., 2004). Understanding and predicting the thermal behavior during printing is essential for optimizing process parameters and improving part quality.

Finite element analysis (FEA) offers a powerful tool for studying the thermal aspects of the FDM process without the need for extensive experimental work. Previous studies have demonstrated the effectiveness of FEA in predicting temperature distributions, thermal gradients, and cooling rates during the FDM process (Costa et al., 2017; Zhang et al., 2019). However, most studies focus on a single material, and comparative analyses between materials with different thermal properties are limited.

This study aims to address this gap by developing a simplified FEA model to compare the thermal behavior of two common thermoplastic materials in FDM: ABS and PC. The specific objectives are:

1. To develop an FEA model using ANSYS that can simulate the FDM process with element activation to represent sequential material deposition
2. To investigate and compare the thermal behavior of ABS and PC during the printing process under both steady-state and transient conditions
3. To analyze the results in terms of temperature profiles, heat affected zones, and temperature evolution over time

The findings of this study will contribute to a better understanding of how material properties influence thermal behavior during FDM, which is crucial for process optimization and quality control.

## 2. Methodology

### 2.1 Geometric Model

A simplified geometric model was created to represent the FDM printing process. The model consisted of:

- A cubic bed with dimensions of 50 mm × 50 mm × 50 mm.
- Two layers of printed material, each layer containing 10 elements of Cuboid shape.
- Each cuboid with dimensions of 10 mm × 10 mm × 25 mm.

The geometry was initially designed in SolidWorks and then imported into ANSYS for simulation. Figure 1 shows the model geometry with the printing layers displayed on top of the bed.

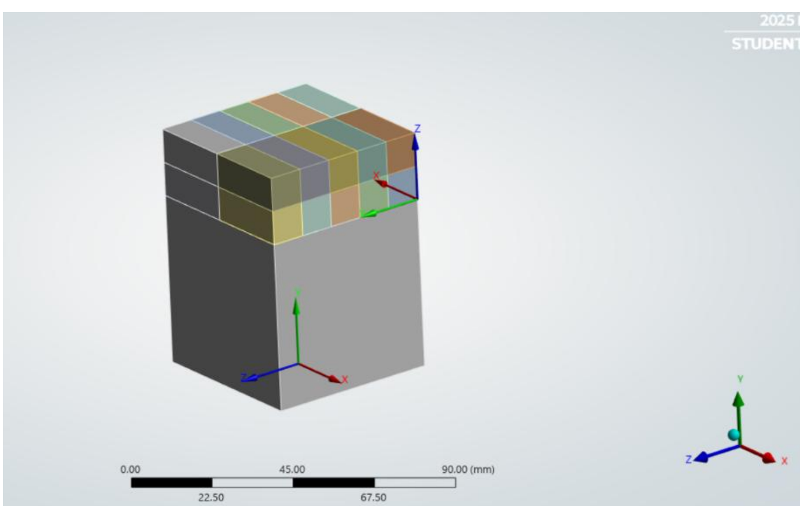


**Fig 1:** Model geometry

### 2.2 Material Properties

Two thermoplastic materials were investigated: ABS and PC. The material properties were obtained from the ANSYS material library and scientific literature. The key thermal properties used in the simulation are presented in Table 1.

**Table 1:** Thermal properties of materials used in the simulation

| Property | ABS | PC |
|---|---|---|
| Density (kg/m³) | 1050 | 1200 |
| Thermal Conductivity (W/m·K) | 0.17 | 0.20 |
| Specific Heat (J/kg·K) | 1470 | 1200 |
| Glass Transition Temperature (°C) | 105 | 147 |

### 2.3 Simulation Setup

The FEA model was developed using ANSYS Mechanical with thermal analysis capabilities. The simulation was conducted in two parts:

1. **Steady-state thermal analysis:** This analysis focused on the final temperature distribution after the printing process reached equilibrium.
2. **Transient thermal analysis:** This analysis investigated the temperature evolution over time during the printing process.

#### 2.3.1 Mesh Generation

A tetrahedral mesh was generated with refinement in the regions of interest, particularly at the interfaces between deposited material and the bed. The mesh consisted of approximately 125,000 elements, with higher density in the printed layers to capture thermal gradients accurately.

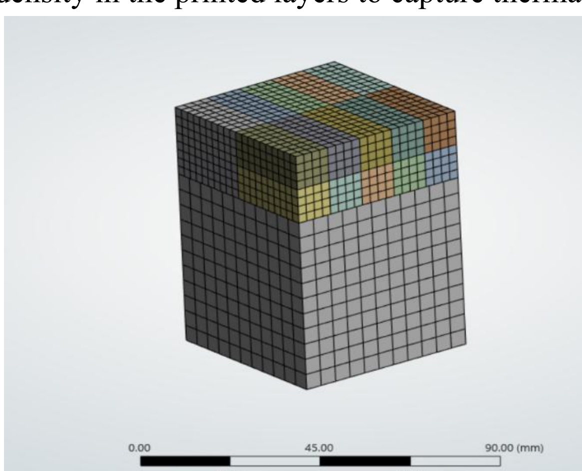


**Fig 2:** Model with mesh generated

### 2.3.2 Boundary Conditions

The following boundary conditions were applied to the model:

- **Initial temperature:** Ambient temperature of 22°C was set for the entire domain at the beginning of the simulation.
- **Nozzle temperature:**
  - ABS: 235°C
  - PC: 280°C
- **Bed temperature:**
  - ABS: 100°C
  - PC: 110°C
- **Convection:** A convection coefficient of 10 W/m²·K (0.00001 W/mm²·K) was applied to all external surfaces exposed to air.
- **Radiation:** Surface-to-ambient radiation was considered with an emissivity of 0.05 for both materials.

### 2.3.3 Element Birth and Death Technique

The element birth and death feature in ANSYS was utilized to simulate the sequential deposition of material during the FDM process. Initially, all elements representing the printed material were "killed" (deactivated), and then "born" (activated) according to the printing sequence. The elements were activated in a layer-by-layer sequence, from bottom to top, and within each layer from one end to the other, mimicking the actual printing path.

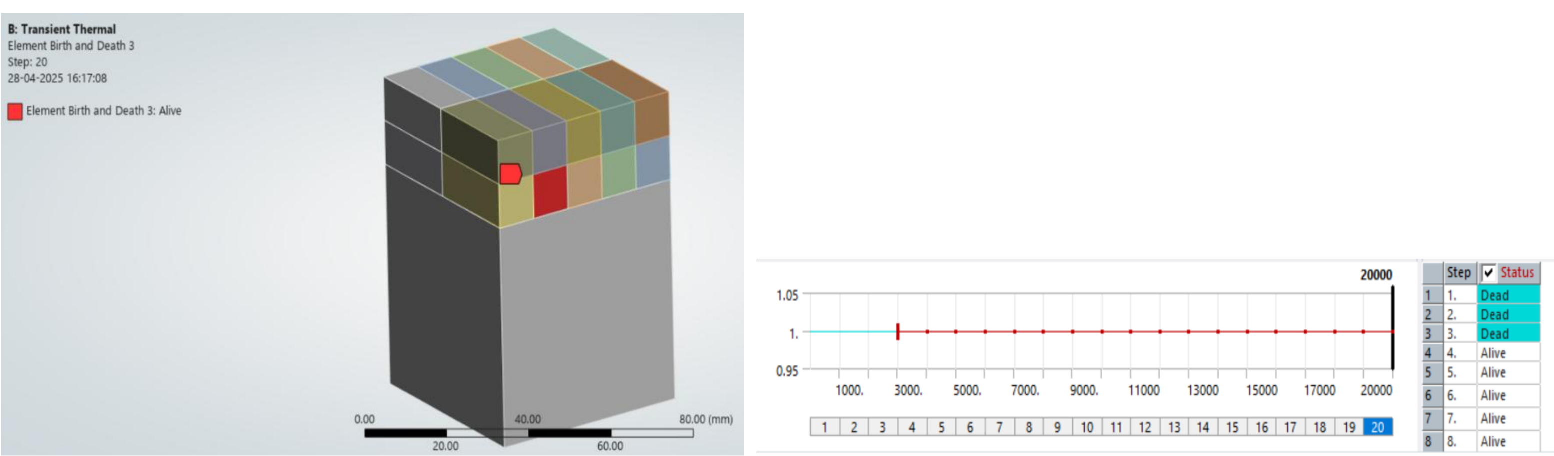


**Fig 3:** Element Birth and Death feature in ANSYS

### 2.3.4 Connection Setup

No physical connections were established between the printing elements themselves and the bed during the geometry design in SolidWorks by unticking the merge option. However, connections were defined manually between adjacent printed elements and between the printed material and the bed in ANSYS by using manual contact region option.

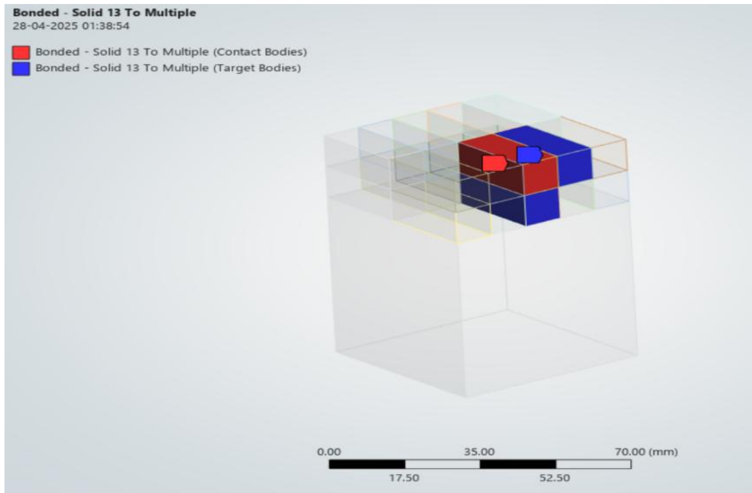


**Fig 4:** Connection of current element with previously printed element

### 2.4 Analysis Methods

The simulation results were analyzed using the following methods:

1. **Temperature distribution:** Contour plots were generated to visualize the temperature distribution throughout the model at different time points.
2. **Heat affected zone (HAZ):** Cross-sectional views were extracted to identify regions where the temperature exceeded the glass transition temperature of each material, defining the heat affected zone.
3. **Temperature evolution:** The minimum, maximum, and average temperatures were plotted against time for the transient analysis to study the thermal history during the printing process.
4. **Heat flux analysis:** Heat flux vectors were analyzed to understand the direction and magnitude of heat flow during the printing process.

## 3. Results and Discussion

### 3.1 Steady-State Thermal Analysis

The steady-state analysis provided insights into the final temperature distribution after the system reached thermal equilibrium. Figure 5 and Figure 6 shows the temperature contours for both ABS and PC materials respectively.

### 3.1.1 Temperature Distribution

For ABS, the maximum temperature in the steady-state condition was approximately 235°C, occurring at the most recently deposited layer. The minimum temperature was 100°C at the bed.

For PC, the maximum temperature was higher, reaching approximately 280°C at the topmost layer. The minimum temperature was 110°C at the bed, higher than that observed in ABS.

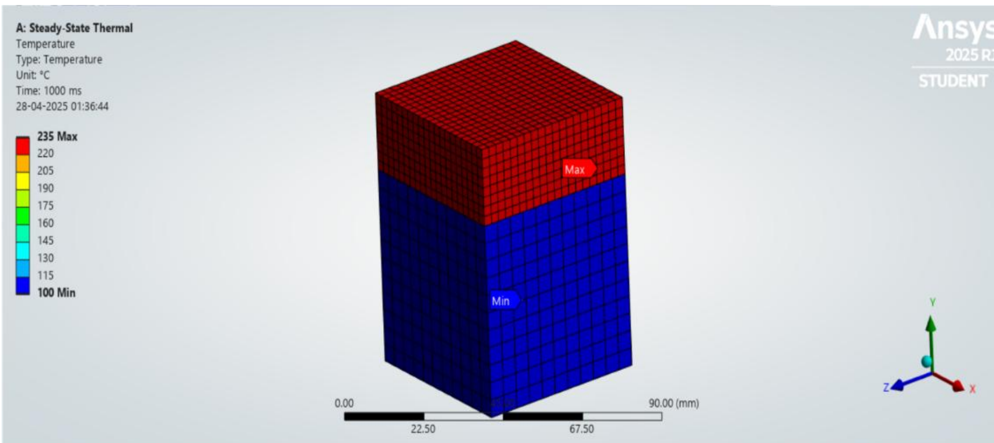


**Fig 5**: Steady State temperature contour for ABS

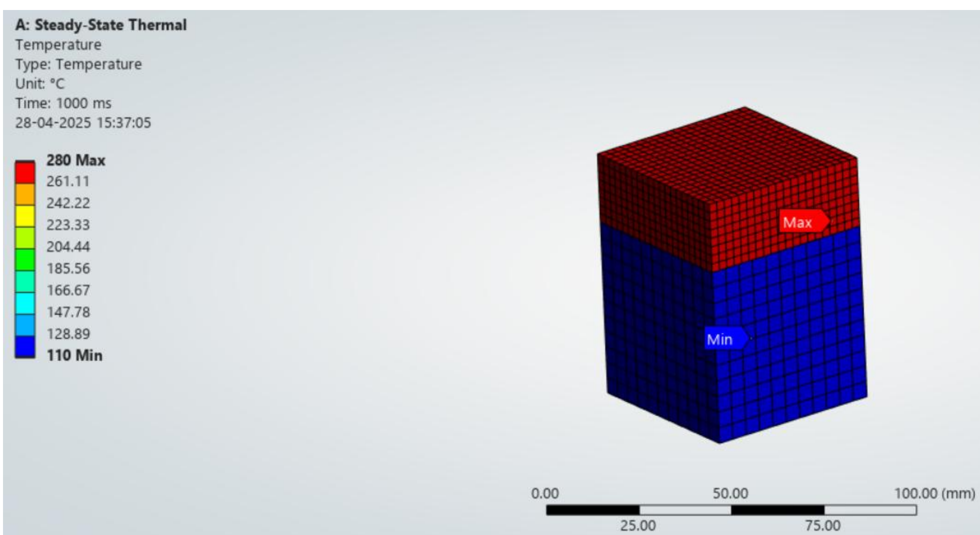


**Fig 6:** Steady State temperature contour for PC

## 3.2 Transient Thermal Analysis

The transient analysis provided a more detailed understanding of the thermal evolution during the printing process.

### 3.2.1 Temperature Evolution

Figure 7 and Figure 9 shows the temperature contour for transient analysis. The maximum and minimum temperature for ABS was 270.75℃ and 14.838℃, whereas for PC it was 325.12℃ and 14.857℃.

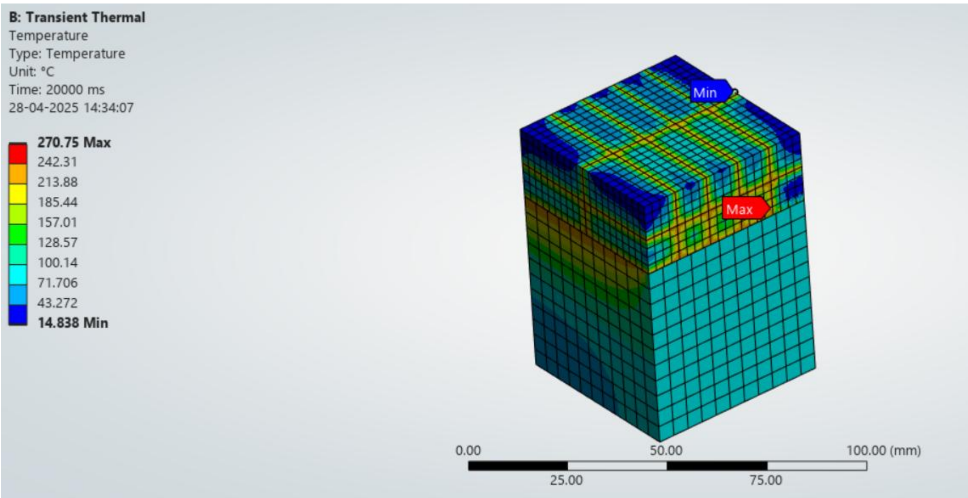


**Fig 7:** Transient temperature contour for ABS

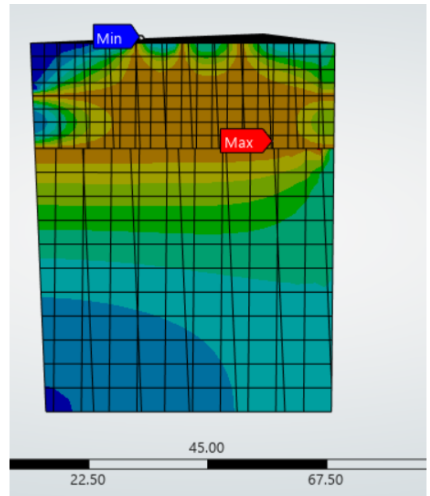


**Fig 8:** Cross-sectional view

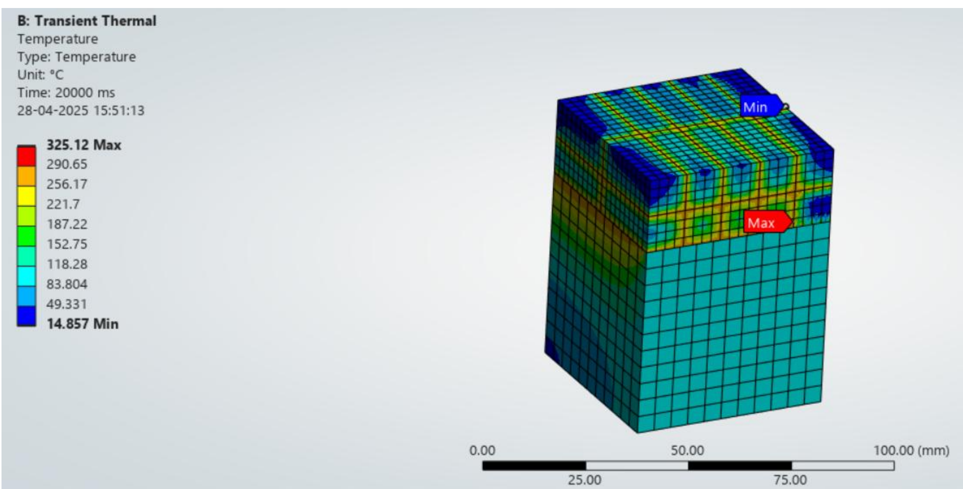


**Fig 9:** Transient temperature contour for PC

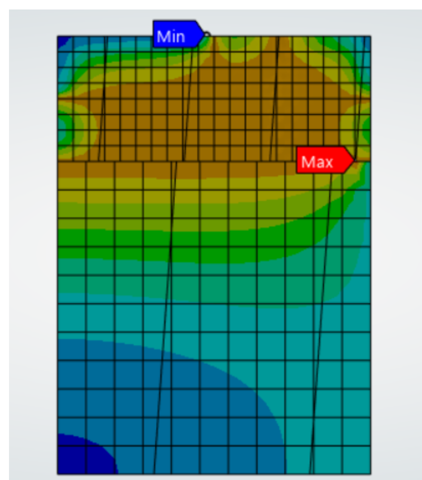


**Fig 10:** Cross-sectional view

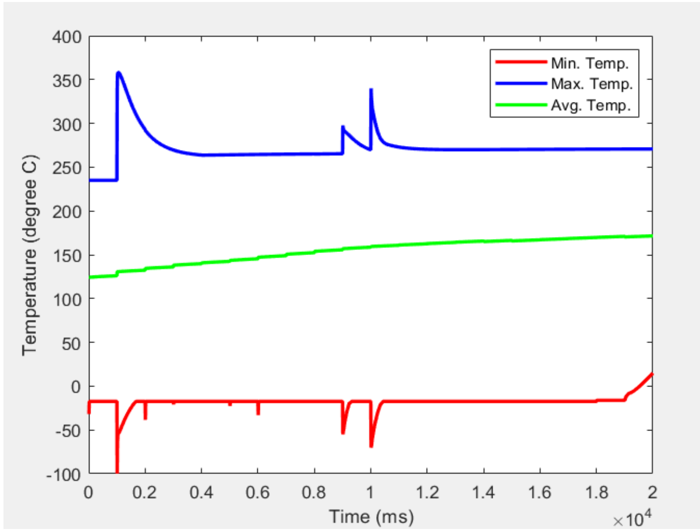

**Fig 11:** Temperature vs Time plot for ABS

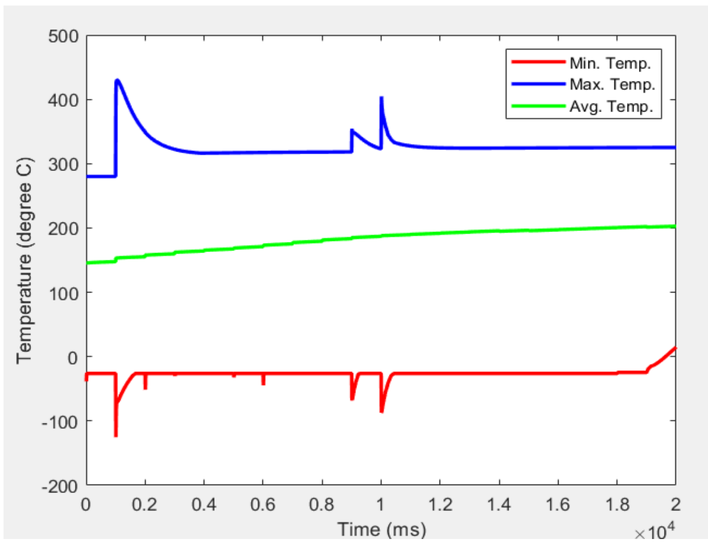

**Fig 12:** Temperature vs Time plot for PC

### 3.2.2 Heat Flux Analysis

The heat flux analysis revealed the direction and magnitude of heat flow during the printing process. For both materials, the highest heat flux was observed at the interfaces between newly deposited material and the underlying layer or bed. The magnitude of heat flux was generally higher for PC, reaching up to 8.2588 W/mm² compared to 6.5584 W/mm² for ABS at similar locations.

The heat flux vectors indicated that heat predominantly flowed from the newly deposited material downward toward the bed and outward toward the environment. However, PC showed more pronounced lateral heat flow within the printed structure, which can be attributed to its higher thermal conductivity.

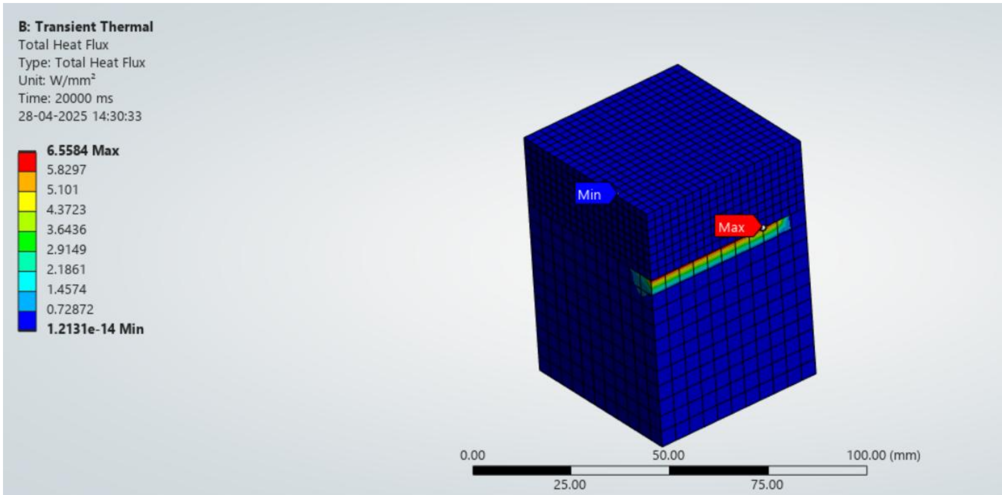


**Fig 13:** Heat flux contour for ABS

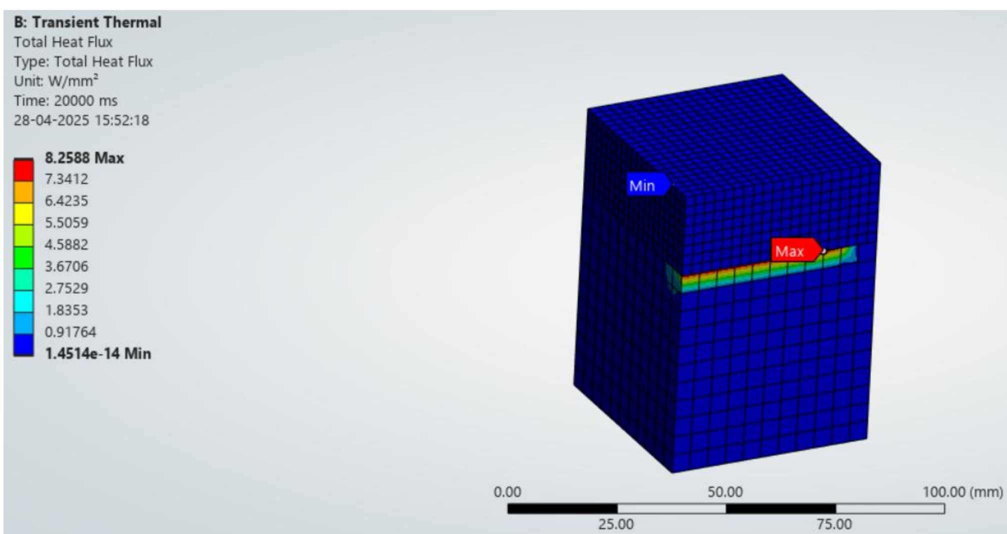


**Fig 14:** Heat flux contour for PC

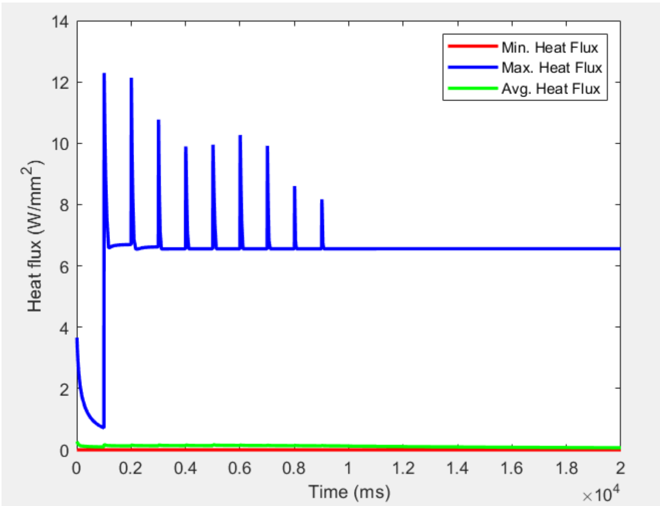


**Fig 15:** Heat flux vs Time plot for ABS

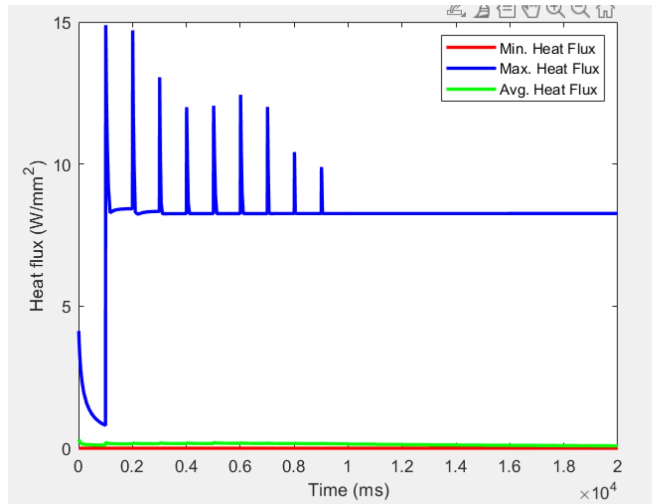


**Fig 16:** Heat flux vs Time plot for PC

## 4. Conclusion

This study presented a comprehensive FEA model of the FDM process for two common thermoplastic materials: ABS and PC. The simulation successfully captured the thermal behavior under both steady-state and transient conditions, providing valuable insights into the temperature distribution, heat affected zones, and thermal evolution during the printing process.

Key findings from the study include:

1. PC exhibited higher overall temperatures and steeper thermal gradients compared to ABS, which is consistent with its higher printing and bed temperatures.
2. Despite PC's higher glass transition temperature, its heat affected zone was smaller than ABS due to more efficient heat dissipation and the higher temperature threshold for defining the HAZ.
3. The cooling behavior differed significantly between the two materials, with ABS showing faster initial cooling but more variation in cooling rates throughout the printing process.
4. Heat flux analysis revealed more pronounced lateral heat flow in PC, attributed to its higher thermal conductivity.

These findings have important implications for FDM process optimization. For ABS, the faster and more variable cooling rates suggest a need for more careful control of printing parameters to minimize warping and residual stresses. For PC, the higher overall temperatures and more efficient heat dissipation indicate better layer adhesion potential but require appropriate cooling strategies to prevent excessive heat buildup.

This study demonstrates the utility of FEA in understanding the thermal aspects of the FDM process and how material properties influence thermal behavior. Future work could extend this approach to more complex geometries, additional materials, and incorporate mechanical analysis to predict residual stresses and part deformation.

## References


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