

## Design and transient thermal analysis of laminated plate using different materials

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**Abstract:** This study investigates the transient thermal behavior of a multi-layered laminate plate composed of various materials including PCB laminate, PTFE/Glass fiber, Aluminum Alloy, Glass ceramic, MCR, and Glass, silica fused (SiO<sub>2</sub>). The laminate is subjected to transient temperature conditions, specifically 45°C and 50°C, to evaluate its thermal response. A finite element analysis is conducted to predict the temperature distribution and thermal stresses within the laminate over time. The analysis considers the unique thermal properties of each material, including thermal conductivity, specific heat capacity, and coefficient of thermal expansion. The results will provide valuable insights into the thermal performance and material suitability for different applications, aiding in the selection of optimal materials for specific operating environments and thermal requirements.

### 1. INTRODUCTION

Laminated composite materials are extensively used in aerospace, defense, marine, automobile, and many other industries. They are generally lighter and stiffer than other structural materials. A laminated composite material consists of several layers of a composite mixture consisting of matrix and fibers. Each layer may have similar or dissimilar material properties with different fiber orientations under varying stacking sequence. Because, composite materials are produced in many combinations and forms, the design engineer must consider many design alternatives. It is essential to know the dynamic and buckling characteristics of such structures subjected to dynamic loads in complex environmental conditions. For example, when the frequency of the loads matches with one of the resonance frequencies of the structure, large translation/torsion deflections and internal stresses occur, which may lead to failure of structure components. The structural components made of composite materials such as aircraft wings, helicopter blades, vehicle axles and turbine blades can be approximated as laminated composite beams.

#### **laminated plate**

A laminated plate is a structural element composed of multiple layers (or laminae) of material bonded together. These layers are typically made of composite materials, such as fiber-reinforced polymers (FRP), metals, or other combinations of materials, and are stacked in a specific sequence to achieve desired mechanical properties.



**Figure:1** laminate plate

### Applications of laminate plates

- Electronics: Used in printed circuit boards (PCBs) for their electrical conductivity and insulation properties.
- Aerospace: Applied in aircraft and spacecraft for lightweight and high-strength materials.
- Automotive: Used in car parts for reducing weight while maintaining strength and durability.

### Objectives:

- To design and development of different laminated plate applications
- To design the laminated plate model was done by using NX 12.0 Software
- To analyse the transient thermal analysis validated the laminated plate heat flux, and temperatures using Ansys 2025 R2

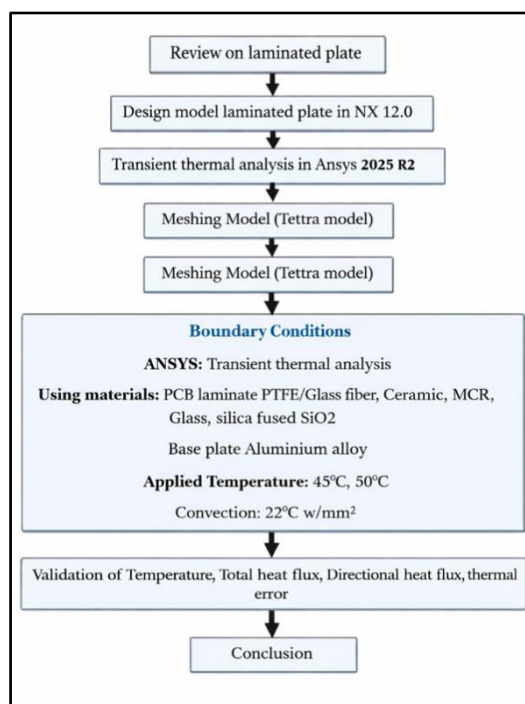
## 2. LITERATURE REVIEW

This literature review outlines the key research areas, methodologies, and findings related to laminated plates, focusing on their design, analysis, and applications. **Ahmed H Ali1 and Widad I Majeed [1]** The current theory accounts for an approximately parabolic distribution of the transverse shear strains on the plate boundary surface through the thickness and tangential stress-free boundary conditions. **D.P. Makhecha, M. Ganapathi [2]** This paper deals with the application of a new higher-order theory that accounts for the realistic variation of in-plane and transverse displacements through the thickness for the dynamic response analysis of thick multi-layered composite plates. **Sahoo R, Chanda A [3]** In the present study, the transient analysis of smart laminated composite plates is presented analytically using inverse hyperbolic zigzag theory. This theory is displacement based with five unknown primary mid-plane variables in conjunction with the zigzag parameters resembling the membrane and the bending components. **Chandrashekhara, K [4]** The present model takes into account the mass and the stiffness of the piezoelectric patches. The formulation is based on the first-order shear deformation theory, which is applicable for both thin and moderately thick plates. An additional feature of the present model is that it does not introduce the voltage as an additional degree of freedom. **Chien H. Thai [5]** This paper presents a novel finite element formulation for static, free vibration and buckling analyses of laminated composite plates. The idea relies on a combination of node-based smoothing discrete shear gap method with the higher-order shear deformation plate theory (HSDT) to give a so-called NS-DSG3 element. **Qu et al. [6]** introduced a variational formulation for predicting the free, steady-state and transient vibrations

of composite laminated shells of revolution subjected to various combinations of classical and non-classical boundary conditions. **Xiang et al. [7]** studied a simple yet accurate solution procedure based on the Haar wavelet discretization method (HWDM) is applied to the free vibration analysis of composite laminated cylindrical shells subjected to various boundary conditions. The Reissner–Naghdi’s shell theory is adopted to formulate the theoretical model. **Sahoo and Singh [8]** proposed a new trigonometric zigzag theory for the static analysis of laminated composite and sandwich plates. This theory considers shear strain shape function assuming the non-linear distribution of in-plane displacement across the thickness. **Rarani et al. [9]** used analytical and finite element methods for prediction of buckling behavior, including critical buckling load and modes of failure of thin laminated composites with different stacking sequences. **Alnefaie [10]** developed a 3D-FE model of delaminated fiber reinforced composite plates to analyse their dynamics. Natural frequencies and modal displacements are calculated for various case studies for different dimensions and delamination characteristics.

### 3. METHODOLOGY

In this chapter to discuss the transient thermal analysis on a laminate plate under specified temperature conditions of 45°C and 50°C, using different materials. The analysis helps in understanding the temperature distribution and thermal behavior over time following Steps:

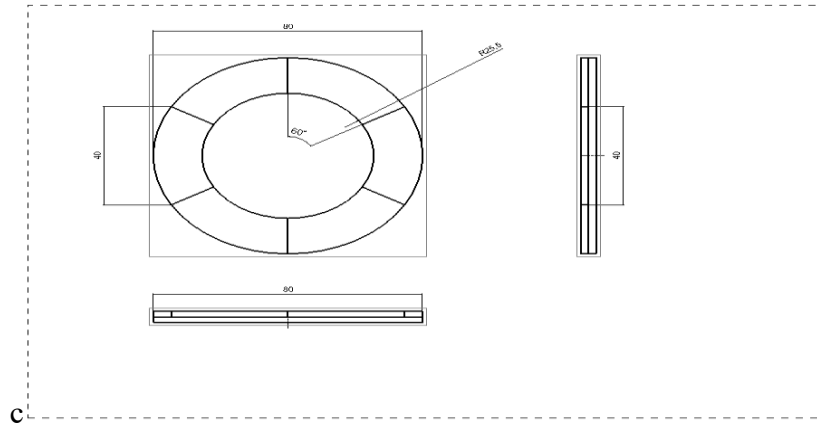


**Figure:2** Design flow chart

#### Working principles of a PCB laminate plate

- **Electrical Conductivity:** PCB laminate plates use copper layers embedded in a non-conductive substrate to create electrical pathways. These copper traces allow the transmission of electrical signals across the board.
- **Multi-Layer Design:** PCBs are often multi-layered, with layers of copper separated by insulating materials. Vias (small conductive holes) connect different layers, enabling complex circuit designs for multi-functional devices.

- **Thermal Management:** PCB laminates are designed to dissipate heat, preventing overheating of components. Materials like fiberglass and epoxy resin are chosen for their thermal properties to ensure proper heat distribution.
- **Mechanical Integrity:** The laminate provides structural strength and rigidity to the PCB, making it resistant to physical stress, such as bending or impact, ensuring long-lasting durability and performance.



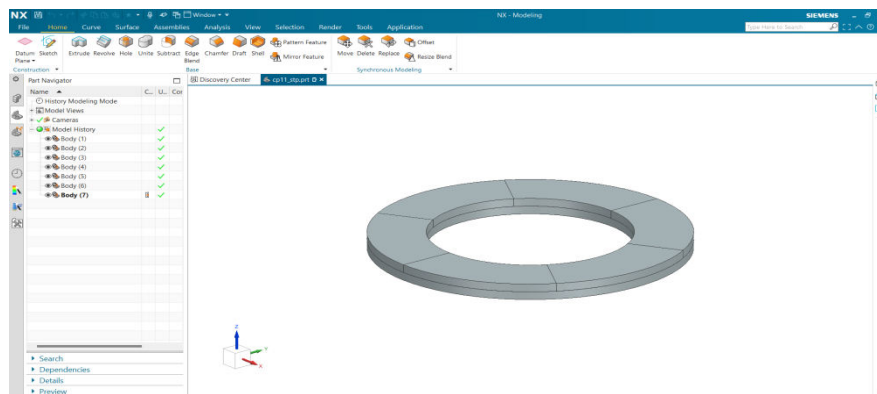
**Figure:3** Geometry model

#### Overall Dimensions and Features:

**Length:** The overall length of the beam is 80 mm.

**Width:** The width of the beam is 40 mm.

**Thickness:** The thickness of the beam is 10 mm.



**Figure:4** Design model in NX 12.0

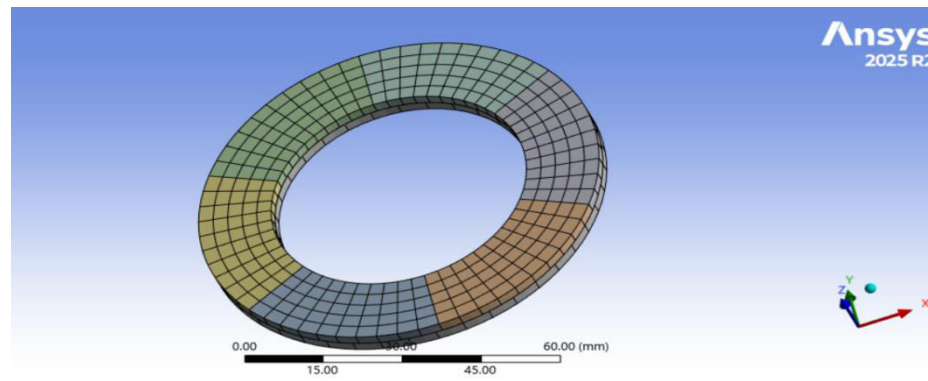


Figure:5 Meshed model

This image represents the meshed model of a laminated plate, prepared using ANSYS (2025 R2). The mesh is essential for finite element analysis (FEA) to divide the geometry into smaller elements where equations for heat transfer, stresses, or other phenomena are solved

#### 4. RESULTS AND DISCUSSIONS

In a transient thermal analysis, the objective is to determine the temperature distribution and heat dissipation behavior of the laminate plate over time. Using materials (PCB laminate, PTFE/Glass fiber, Glass ceramic, MCR, Glass, silica fused, SiO<sub>2</sub> base plate Aluminium alloy) with varying thermal properties, we examine their response at initial temperatures of 45°C and 50°C.

##### PCB laminate, PTFE/Glass fiber using at 45<sup>0</sup>C

Using PTFE/Glass Fiber PCB Laminate in applications involving temperatures up to 45°C requires careful consideration due to the thermal, mechanical, and electrical properties of the material. Below is an analysis and conclusion based on the material's characteristics and suitability for high-temperature applications.

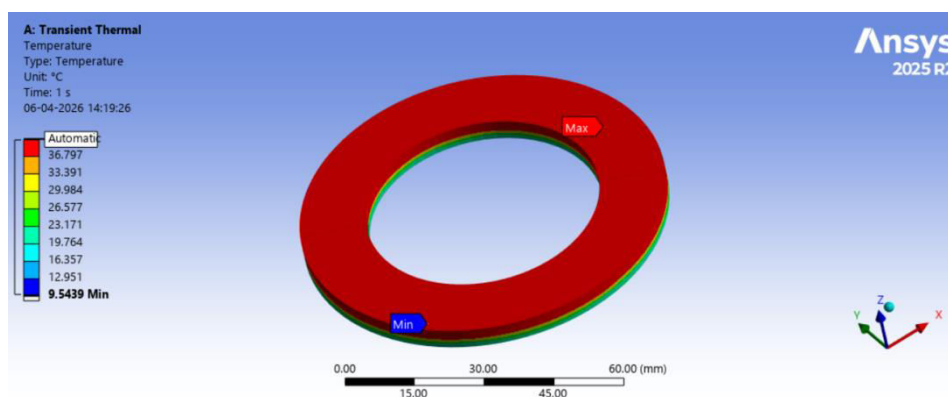


Figure:6 Temperature

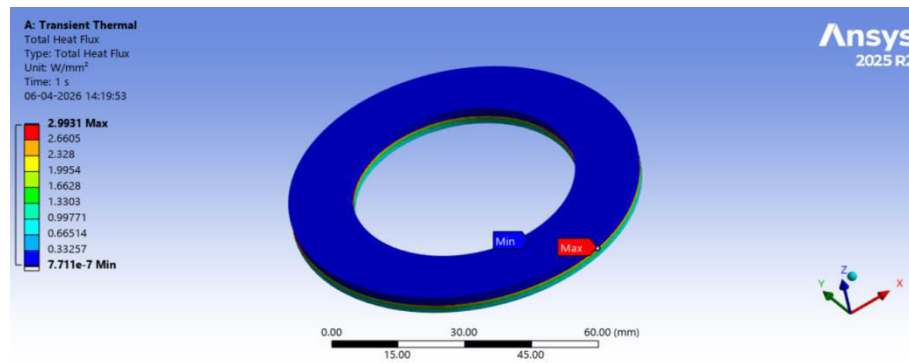


Figure:7 Total heat flux

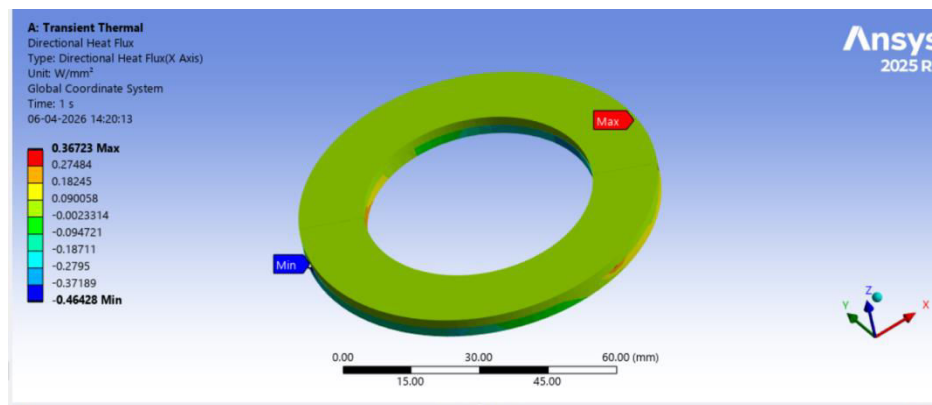


Figure:8 Directional heat flux

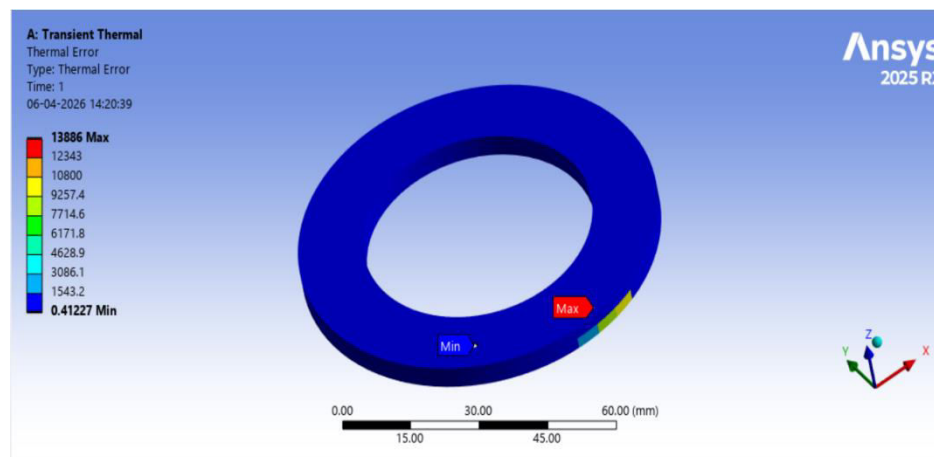


Figure:9 Thermal error

### PCB laminate, PTFE/Glass fiber using at 50°C

Using PTFE/Glass Fiber PCB Laminate in applications involving temperatures up to 50°C requires careful consideration due to the thermal, mechanical, and electrical properties of the material. Below is an analysis and conclusion based on the material's characteristics and suitability for high-temperature applications.

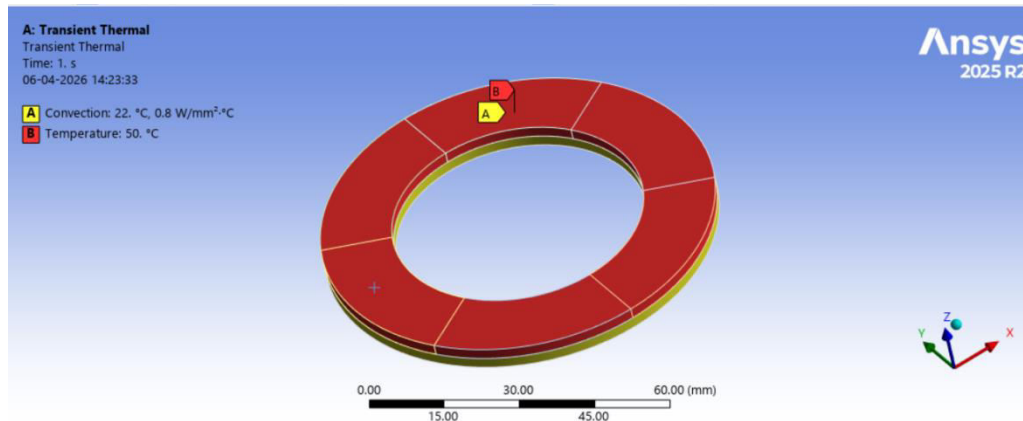


Figure:10 Applied temperature laminated plate at 50<sup>0</sup>C

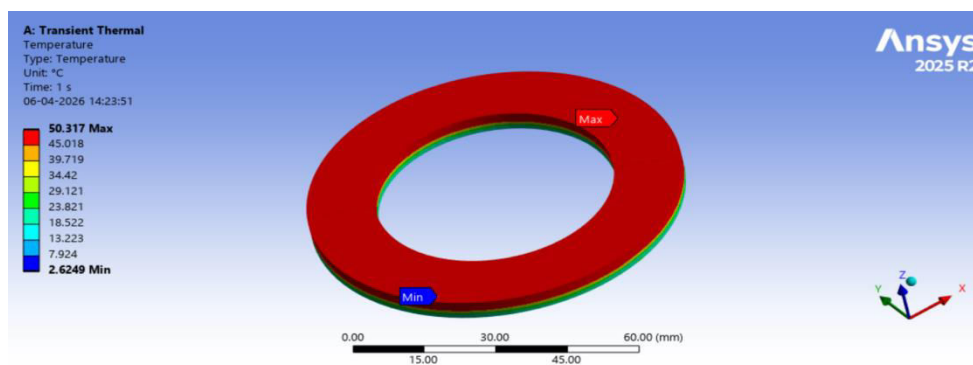


Figure:11 Temperature

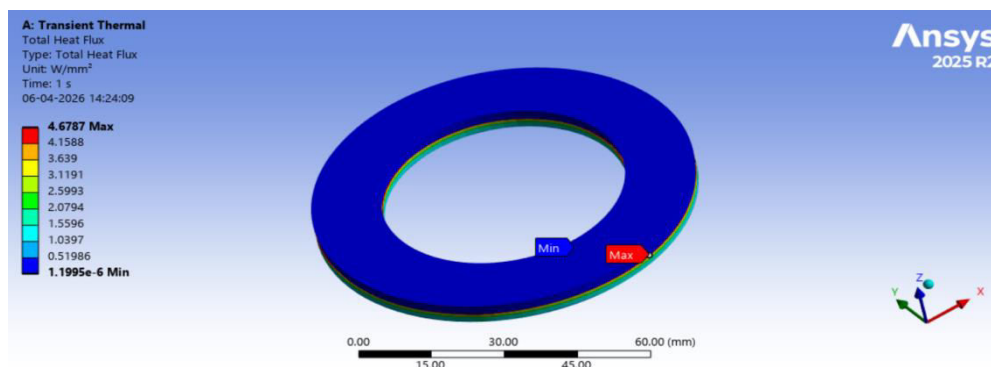


Figure:12 Total heat flux

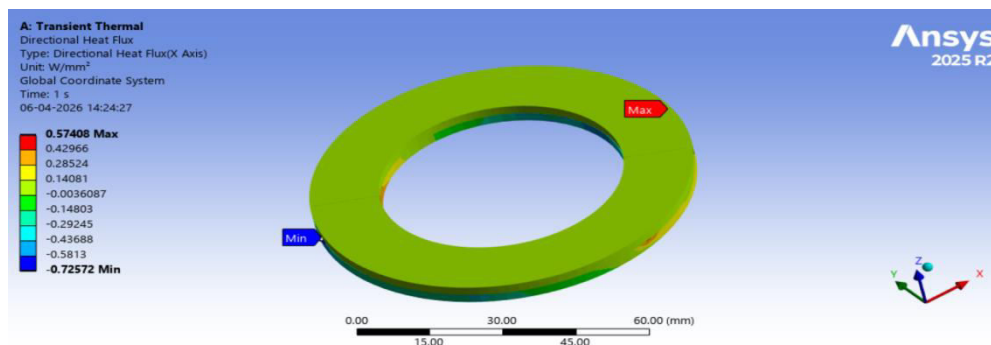


Figure: Directional heat flux

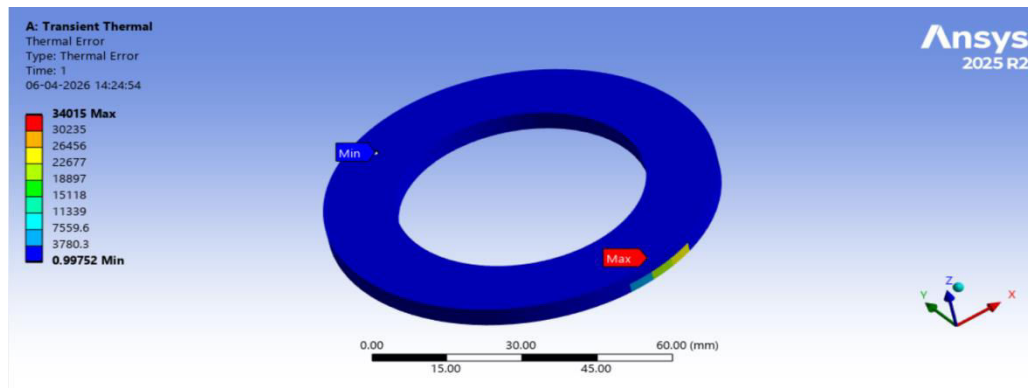


Figure:13 Thermal error

**Glass Ceramic, MCR using at 45°C**

The provided image shows a laminate plate material assignment with the material defined as Glass Ceramic, MCR in an ANSYS 2025 R2 simulation. Here is a detailed analysis of the material and its implications for simulation.

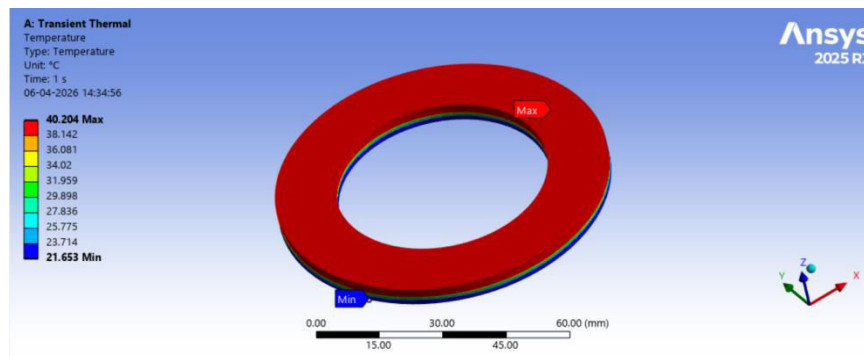


Figure:14 Temperature

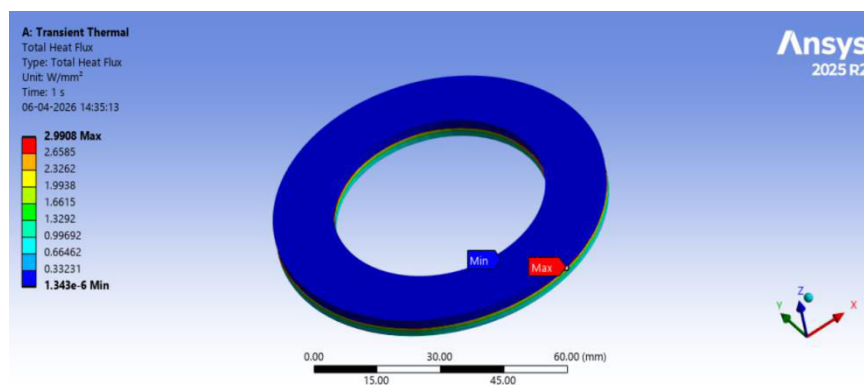
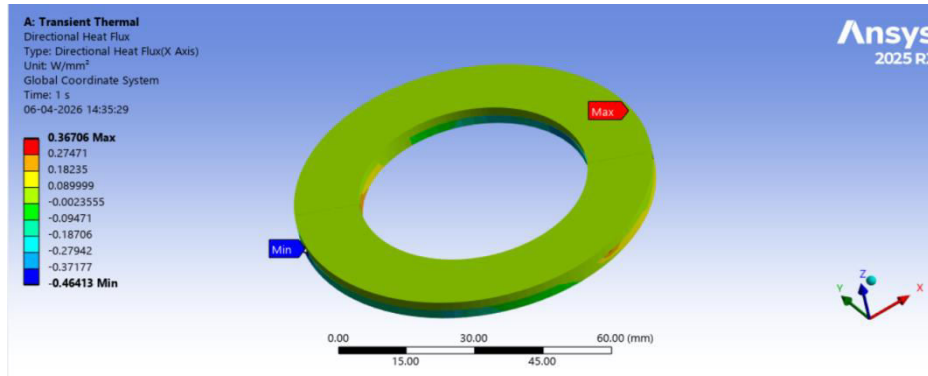
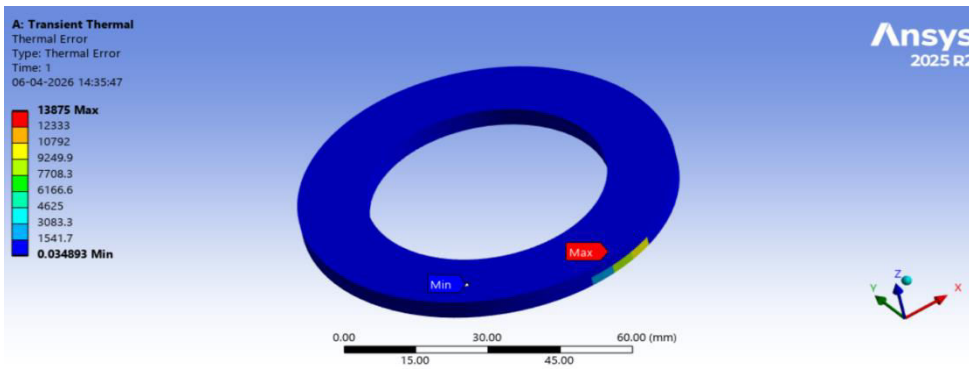


Figure:16 Total heat flux



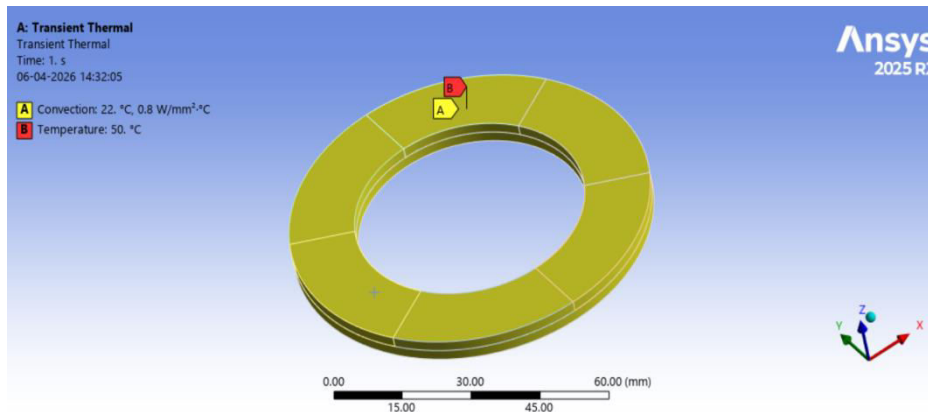
**Figure:17 Directional Heat flux**



**Figure:18 Thermal Error**

**Glass Ceramic, MCR using at 50<sup>0</sup>C**

The provided image shows a laminate plate material assignment with the material defined as Glass Ceramic, MCR in an ANSYS 2024 R1 simulation. Here is a detailed analysis of the material and its implications for simulation.



**Figure:19 Applied Boundary Conditions**

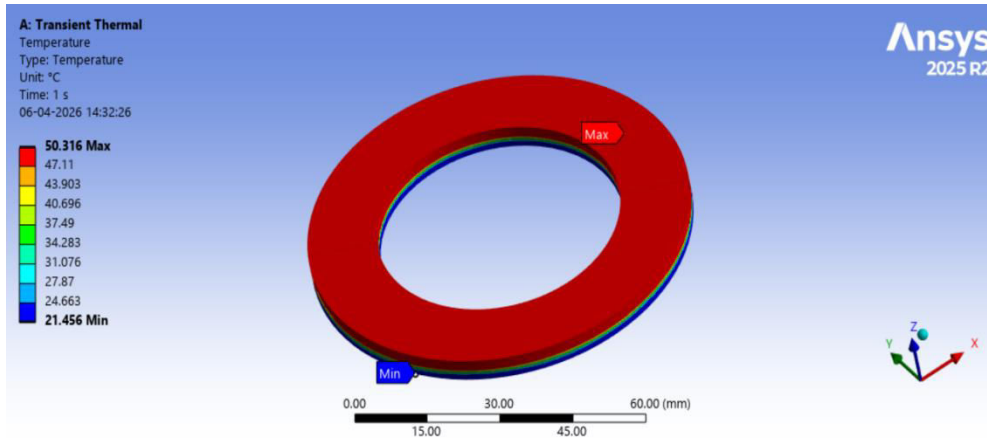


Figure:20 Temperature

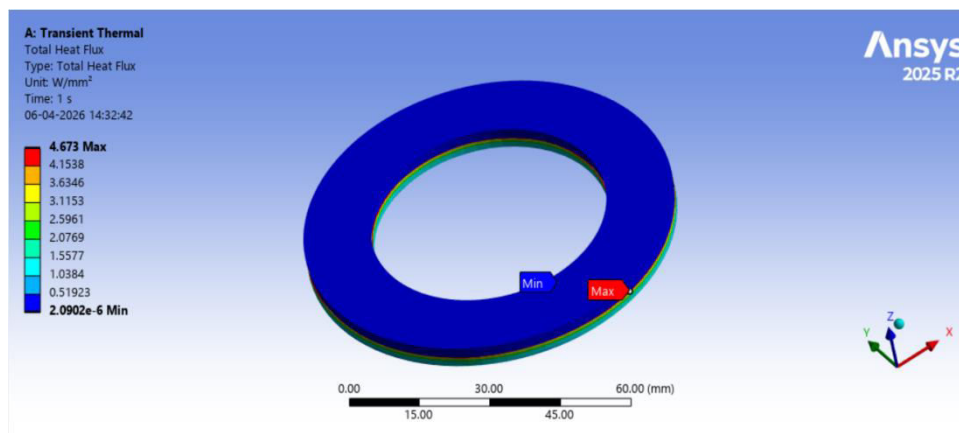


Figure:21 Total heat flux

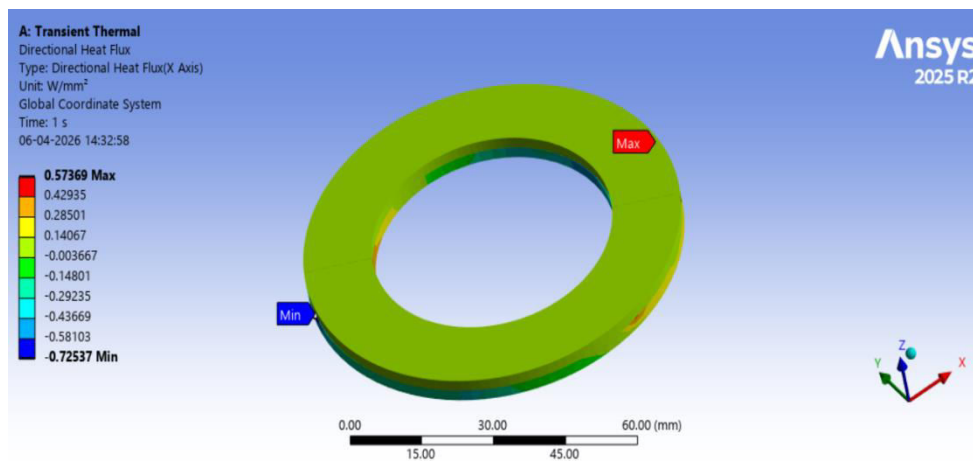


Figure:22 Directional heat flux

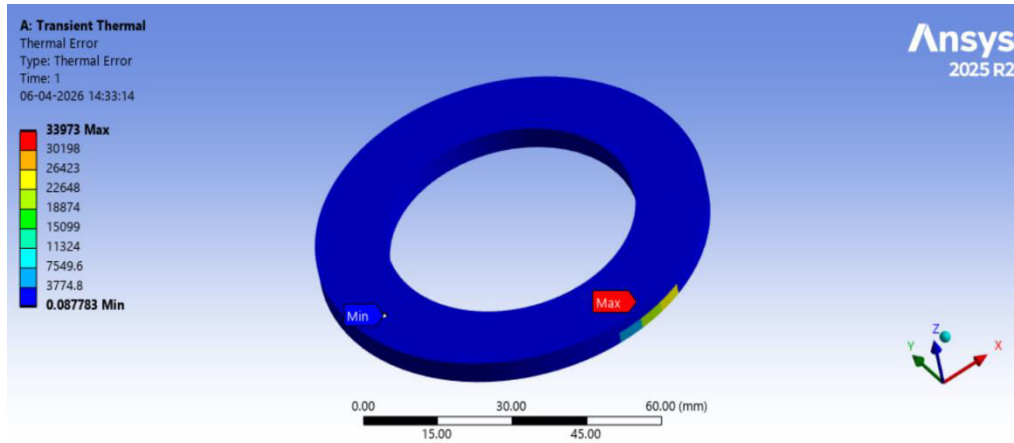


Figure:23 Thermal error

**Laminate plate using Glass, silica fused, SiO<sub>2</sub> material at 45<sup>0</sup>C**

This property describes how well a material conducts heat. Fused Silica (SiO<sub>2</sub>) generally has a lower thermal conductivity than most glasses. This means heat will transfer more slowly through the fused silica layers compared to the glass layers

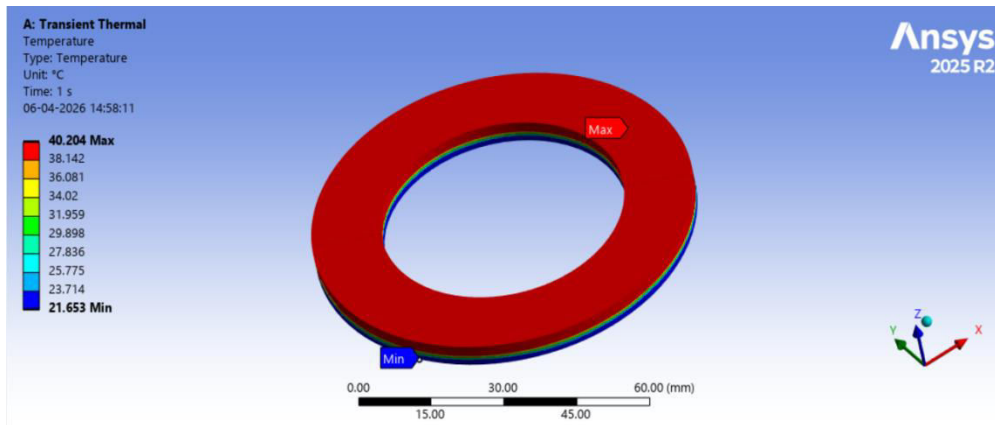


Figure:24 Temperature

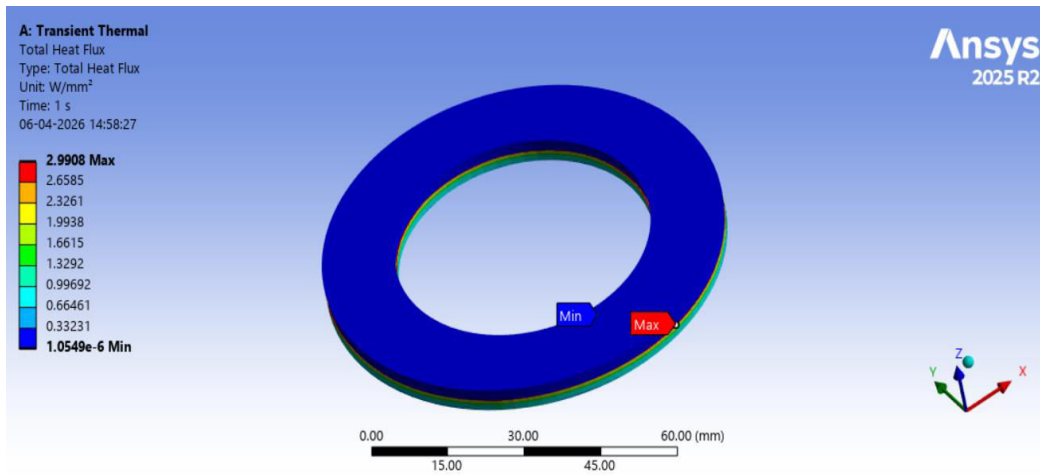


Figure:25 Total heat flux

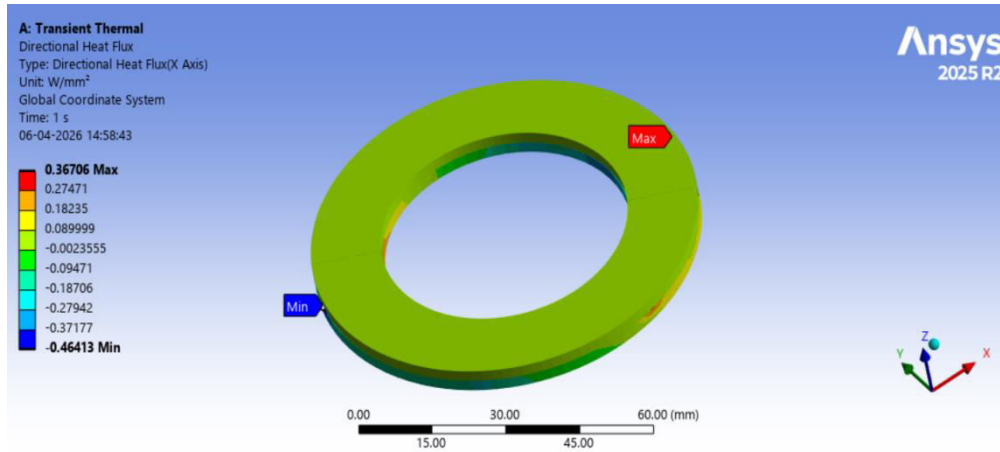


Figure:26 Directional heat flux

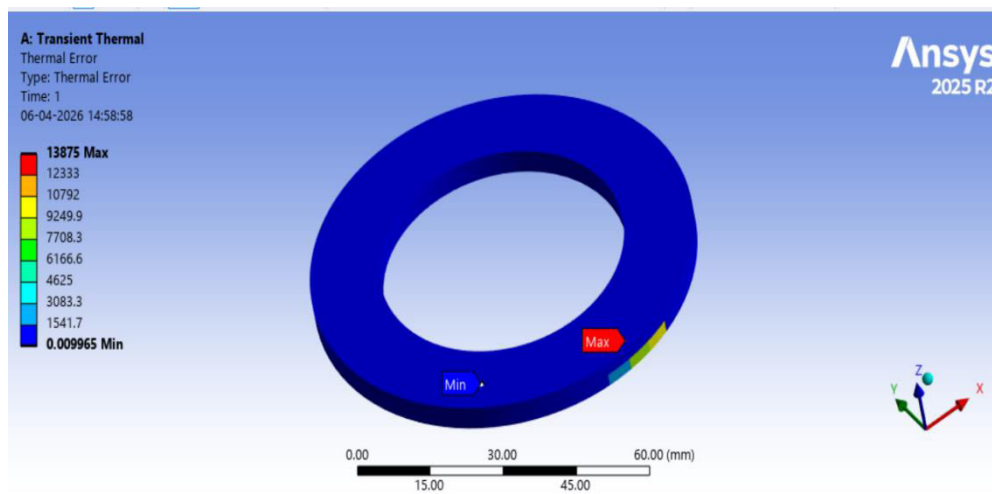


Figure:27 Thermal Error

**Laminate plate using Glass, silica fused, SiO<sub>2</sub> material at 50°C**

This study investigates the transient thermal behavior of a multi-layered laminate plate composed of alternating layers of Glass and Fused Silica (SiO<sub>2</sub>). The laminate is subjected to a temperature of 50°C, simulating a high-temperature environment. A finite element analysis is conducted to predict the temperature distribution within the laminate over time, considering the thermal properties of each material and their interface interactions.

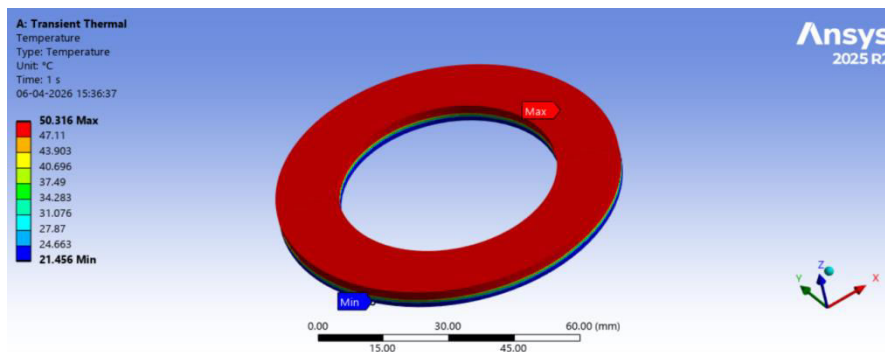


Figure:28 Applied temperature at 50°C

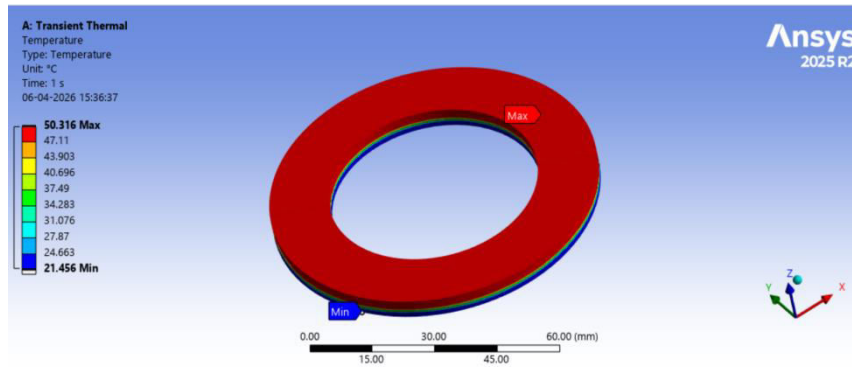


Figure:29 Temperature

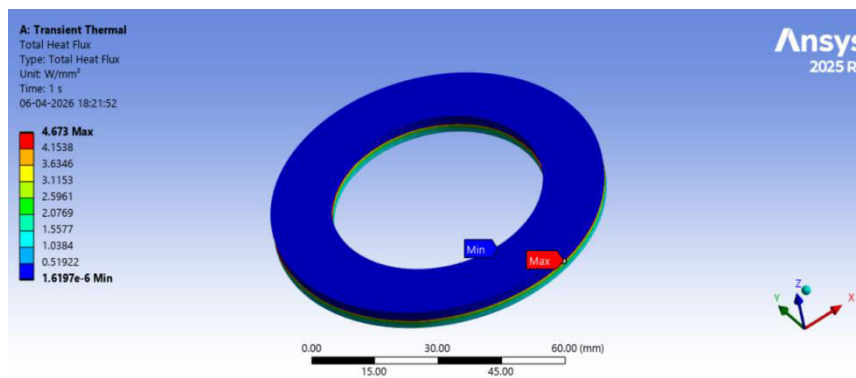


Figure:30 Total heat flux

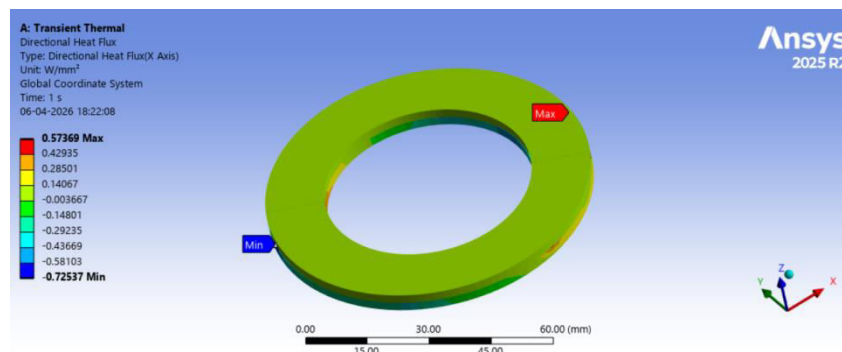


Figure:31 Directional Heat flux

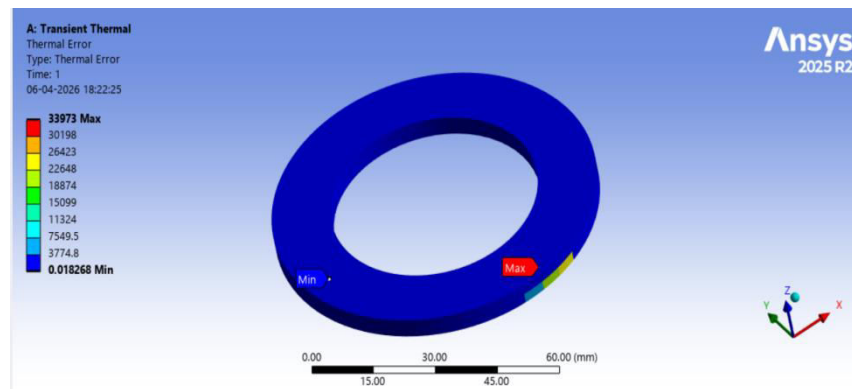
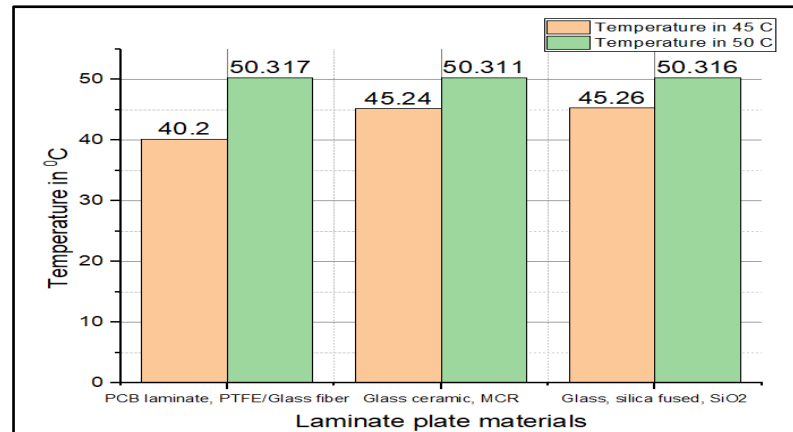


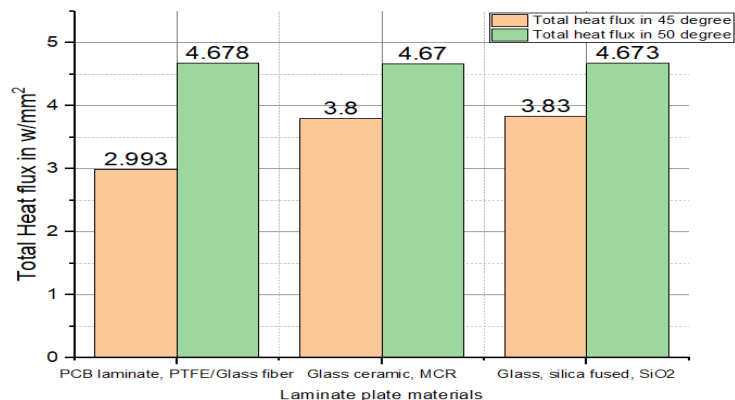
Figure:32 Thermal Error



**Figure:33** Validation of laminated plate Temperature in °C

The graph only presents temperature values for two specific ambient conditions. More data points at different temperatures would be needed to draw more comprehensive conclusions about the thermal behavior of these materials.

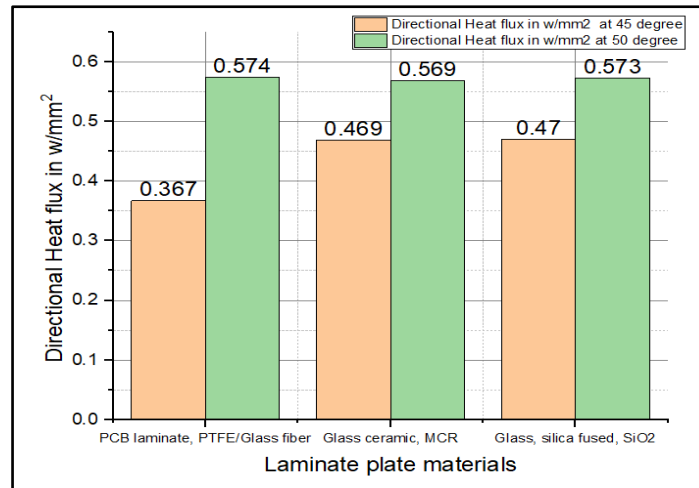
- PCB laminate, PTFE/Glass fiber: 40.2°C (45°C condition) and 50.317°C (50°C condition)
- Glass ceramic, MCR: 45.24°C (45°C condition) and 50.311°C (50°C condition)
- Glass, silica fused, SiO<sub>2</sub>: 45.26°C (45°C condition) and 50.316°C (50°C condition)



**Figure:34** Validation of laminate plate at Directional Total heat flux w/mm<sup>2</sup>

The graph presents the total heat flux in W/mm<sup>2</sup> for three different laminate plate materials to Investigate the thermal properties of the materials, such as thermal conductivity and thermal diffusivity, to gain further insights into their heat flux behavior.

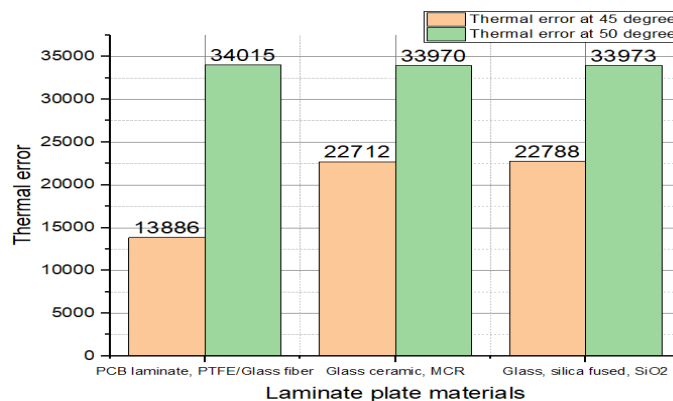
- PCB laminate, PTFE/Glass fiber: 2.993 W/mm<sup>2</sup> (45°C condition) and 4.678 W/mm<sup>2</sup> (50°C condition)
- Glass ceramic, MCR: 3.8 W/mm<sup>2</sup> (45°C condition) and 4.67 W/mm<sup>2</sup> (50°C condition)
- Glass, silica fused, SiO<sub>2</sub>: 3.83 W/mm<sup>2</sup> (45°C condition) and 4.673 W/mm<sup>2</sup> (50°C condition)



**Figure:35 Validation of laminate plate at Directional heat flux w/mm<sup>2</sup>**

The graph presents the directional heat flux in W/mm<sup>2</sup> for three different laminate plate materials to presents heat flux values for two specific temperature conditions. More data points at different temperatures would be needed to draw more comprehensive conclusions about the thermal behavior of these materials.

- PCB laminate, PTFE/Glass fiber: 0.367 W/mm<sup>2</sup> (45°C condition) and 0.574 W/mm<sup>2</sup> (50°C condition)
- Glass ceramic, MCR: 0.469 W/mm<sup>2</sup> (45°C condition) and 0.569 W/mm<sup>2</sup> (50°C condition)
- Glass, silica fused, SiO<sub>2</sub>: 0.47 W/mm<sup>2</sup> (45°C condition) and 0.573 W/mm<sup>2</sup> (50°C condition)



**Figure:36 Validation of laminate plate at thermal error**

The graph only presents thermal error values for two specific temperature conditions. More data points at different temperatures would be needed to draw more comprehensive conclusions about the thermal behavior of these materials.

- Under both the 45°C and 50°C conditions, the PCB laminate, PTFE/Glass fiber exhibits the lowest thermal error.
- Glass ceramic, MCR and Glass, silica fused, SiO<sub>2</sub> show relatively similar thermal error values.
- Temperature Influence: The thermal error increases significantly for all materials when the temperature is raised from 45°C to 50°C.

## Conclusions

The transient thermal analysis of laminated plates using various materials, including PCB laminate, PTFE/Glass fiber, Aluminum Alloy, Glass ceramic, MCR, Glass, Silica fused, and SiO<sub>2</sub>, has provided valuable insights into their thermal behavior under temperature conditions of 45°C and 50°C. The following key conclusions can be drawn

- **Aluminum Alloy:** Offers the best heat dissipation due to high thermal conductivity, making it ideal for heat sinks and thermal shields.
- **SiO<sub>2</sub> and Silica Fused:** Provide excellent thermal resistance and stability under high temperatures, making them suitable for insulation and high-temperature environments.
- **Glass Ceramic:** Maintains stability under transient conditions, ideal for applications exposed to extreme thermal cycles.

**Material Choice:** Selecting the right material is crucial; high thermal conductivity materials like Aluminum Alloy are perfect for heat management, while SiO<sub>2</sub> and Silica Fused are better for insulation and stability in high-temperature applications.

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