Self Project

Thermal–Structural Coupled Analysis of Composite and Metallic Plates Using ANSYS

Submitted by:

Jayshree Chauhan
24M0045

Aerospace Engineering Department

Indian Institute of Technology, Bombay

Contents

List of Figures

1 Introduction

Structural components in aerospace and automotive applications are often exposed to combined thermal and mechanical loading during service. Materials used in such environments must maintain dimensional stability, strength, and durability under elevated temperatures and mechanical stresses. Metallic alloys like structural steel have long been employed due to their high strength and reliability; however, their relatively higher thermal expansion and weight can pose limitations. In contrast, fiber-reinforced polymer (FRP) composites, particularly carbon fiber reinforced polymer (CFRP), offer advantages such as high specific strength, low thermal expansion, and excellent fatigue resistance, making them promising candidates for thermomechanical applications.

The present project focuses on an integrated thermal–mechanical finite element modeling (FEM) study of structural steel and CFRP plates using ANSYS. A coupled thermal–structural analysis was carried out to evaluate the material response under simultaneous thermal and mechanical loads. Key aspects such as stress distribution, thermal expansion, deformation, and potential failure zones were investigated. The comparative study highlights CFRP's superior dimensional stability and load-carrying capacity over structural steel, demonstrating its effectiveness in reducing deformation and enhancing structural performance in thermally stressed environments.

2 Model Geometry, Material Properties, and Setup

2.1 Geometry Definition

The simulation was carried out using a plate modeled,designed to study the behavior under thermal and mechanical loading. The geometry was constructed in ANSYS Workbench using precise dimensions.

The Composite Plate was designed using ANSYS ACP(Pre) module to define layups and desired fiber orientation.

The main features of the geometry include:

- A rectangular plate with defined length, width, and thickness to represent a structural component under tensile loading.

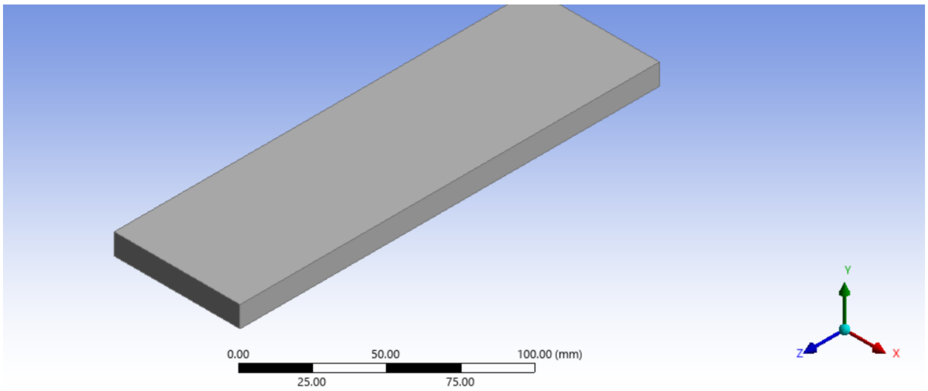

Figure 1: Steel Plate Model for Analysis

The dimensions of the plate are as follows:

- **Length:** 200 mm
- **Width:** 60 mm
- **Thickness:** 10 mm

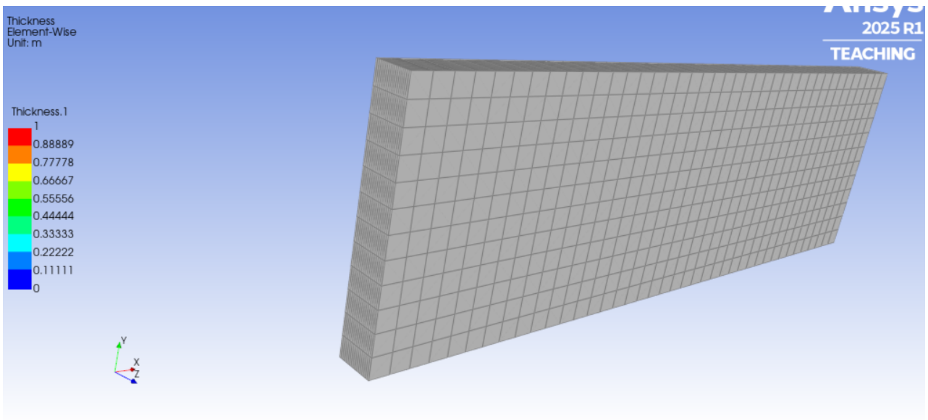

Figure 2: CFRP Plate Model for Analysis

2.2 Material Properties

The component was assumed to be made from structural steel, which is commonly used in engineering due to its high strength and fracture resistance. Linear elastic material properties were defined in ANSYS Engineering Data, including:

- Elastic modulus (E)
- Poisson's ratio (ν)

Properties of Outline Row 3: Steel

	A	B	C
1	Property	Value	Unit
2	Material Field Variables	Table	
3	Isotropic Elasticity		
4	Derive from	Young's Modulus an...	
5	Young's Modulus	2E+11	Pa
6	Poisson's Ratio	0.3	
7	Bulk Modulus	1.6667E+11	Pa
8	Shear Modulus	7.6923E+10	Pa

Figure 3: Steel Properties

Also the CFRP which is orthopic material, the properties are used which is available in ANSYS material library.

Properties of Outline Row 3: Epoxy Carbon UD (230 GPa) Prepreg

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	1490	kg m^-3		
3	Orthotropic Secant Coefficient of Thermal Expansion				
4	Coefficient of Thermal Expansion				
5	Coefficient of Thermal Expansion X direction	-4.7E-07	C^-1		
6	Coefficient of Thermal Expansion Y direction	3E-05	C^-1		
7	Coefficient of Thermal Expansion Z direction	3E-05	C^-1		
8	Orthotropic Elasticity				
9	Young's Modulus X direction	1.21E+11	Pa		
10	Young's Modulus Y direction	8.6E+09	Pa		
11	Young's Modulus Z direction	8.6E+09	Pa		
12	Poisson's Ratio XY	0.27			
13	Poisson's Ratio YZ	0.4			
14	Poisson's Ratio XZ	0.27			
15	Shear Modulus XY	4.7E+09	Pa		
16	Shear Modulus YZ	3.1E+09	Pa		
17	Shear Modulus XZ	4.7E+09	Pa		

Figure 4: CFRP Properties

2.3 Simulation Setup

The geometry was imported into ANSYS Mechanical, and steady state thermal and static structural modeling is done to study the response of both plates.The following steps were taken in the setup:

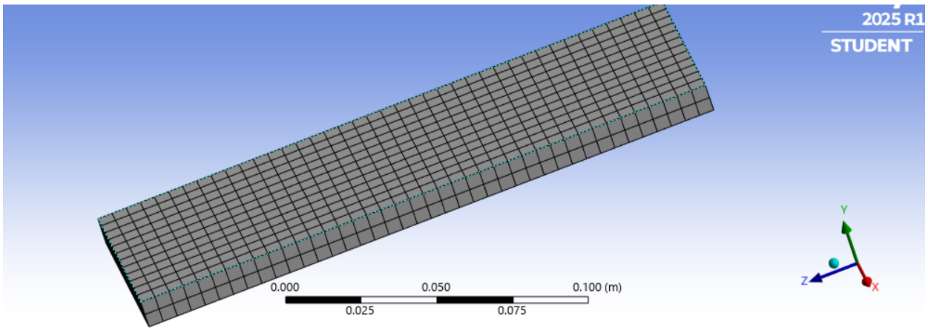

Figure 5: Meshing

Boundary Conditions:

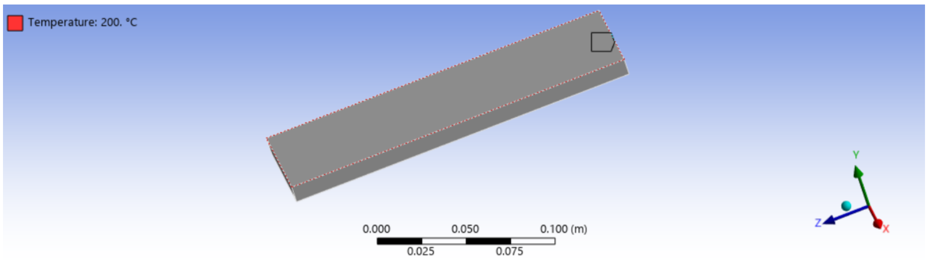

Figure 6: Temperature

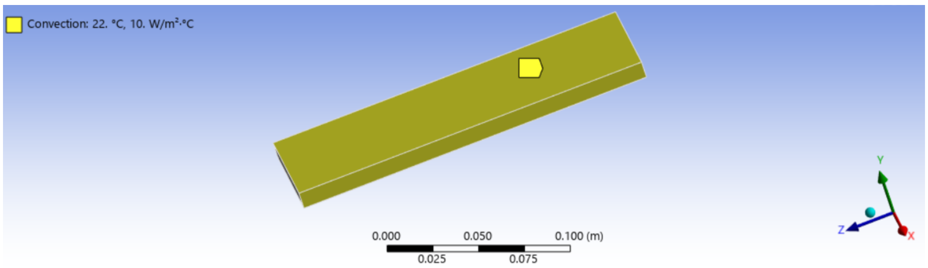

Figure 7: Convection

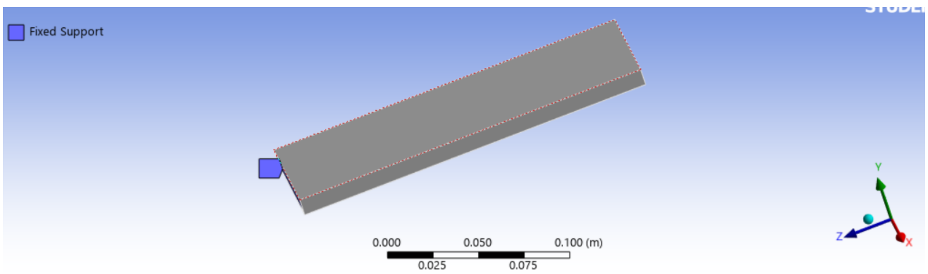

Figure 8: Fixed Support

3 Results and Discussion

This section presents the outcomes of the coupled thermal–mechanical finite element analysis performed on structural steel and CFRP plates. The results include equivalent stress distribution and total deformation contours for both materials under identical loading conditions. By comparing these responses, the influence of material properties on stress concentration, thermal expansion, and dimensional stability is evaluated. The discussion highlights the contrasting behavior of steel and CFRP, providing insights into their suitability for thermomechanical applications.

3.1 Equivalent Stress Distribution

The equivalent stress contour for the CFRP plate (Figure 9) shows a maximum value of 3.13×10^7 Pa, whereas the structural steel plate (Figure 10) exhibits a much higher peak stress of 7.62×10^8 Pa under the same combined thermal–mechanical loading. This significant difference demonstrates the stress-dissipating capability of CFRP due to its anisotropic nature and superior stiffness-to-weight ratio. The stress concentration in steel is localized near the constrained edge, indicating susceptibility to localized yielding, while CFRP shows a more distributed stress pattern with reduced intensity.

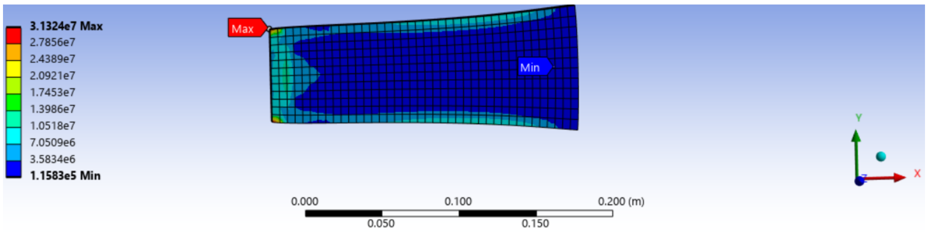

Figure 9: Equivalent Stress Distribution in CFRP Plate

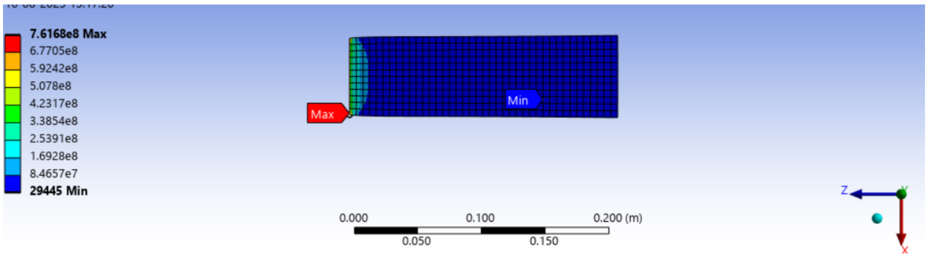

Figure 10: Equivalent Stress Distribution in Steel Plate

3.2 Total Deformation

The total deformation plots highlight the dimensional stability of CFRP compared to steel. The CFRP plate (Figure 11) shows a maximum deformation of 0.000156 m (0.156 mm), whereas the structural steel plate (Figure 12) deforms nearly 0.000299 m (0.299 mm) under identical loading conditions. This reduction of nearly 48% in deformation confirms the higher resistance of CFRP to thermally induced expansion and bending. The results validate the advantage of composites in maintaining geometric integrity under thermomechanical environments, which is critical for aerospace and automotive applications.

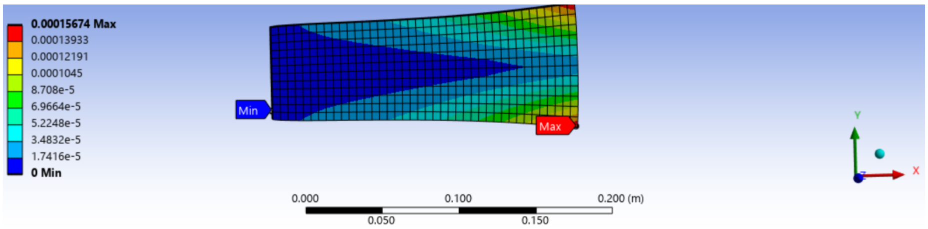

Figure 11: Total Deformation in CFRP Plate

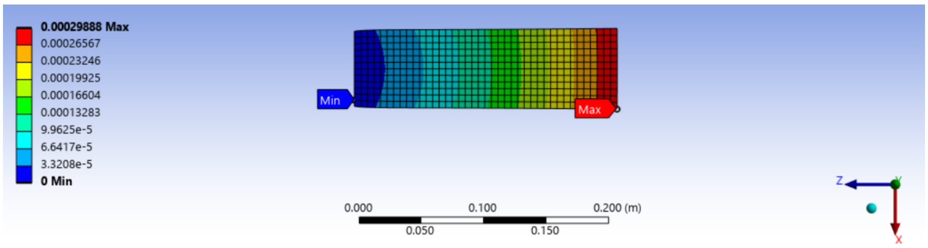

Figure 12: Total Deformation in Steel Plate

3.3 Comparative Analysis

From the coupled thermal–structural analysis, it is evident that CFRP exhibits superior thermomechanical performance over structural steel. While steel carries higher stress, it also undergoes larger deformation, which may compromise dimensional tolerances in high-precision applications. In contrast, CFRP not only restricts stress levels but also minimizes deformation, offering better stability and higher load-carrying efficiency. This aligns with the material's inherent low coefficient of thermal expansion and high stiffness-to-weight ratio.

3.4 Key Observations

- CFRP plate shows $25\times$ lower maximum stress compared to structural steel.
- CFRP experiences 48% lower deformation under identical thermal and mechanical loading.
- Stress distribution in CFRP is more uniform, whereas steel shows localized concentration at the fixed boundary.

These results strongly suggest CFRP's suitability for lightweight, thermally stable structural applications compared to traditional metallic plates.