JOINT INSTITUTE FOR NUCLEAR RESEARCH

Dzhelepov Laboratory of Nuclear Problems

Final report on,

INTEREST PROGRAMME

On Topic:

“Study of Adhesives for Use in the Construction of Particle Detectors”.

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Supervisor:

Dr. Maribel Herrera Barrera.

Student:

Nisar Ahamed G

Amity University, Noida, India.

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Abstract:

This project tends to analyze the mechanical behavior of adhesives commonly used in fixing components within the housing of a particle collision detector, especially focusing on the Internal Tracking System for MPD. Using Ansys Workbench, finite element analysis (FEA) is conducted for simulating the response of adhesives under normal and high-energy environments varied working conditions.

This report outlines the research conducted on adhesive damages and service life, the methodology employed for 3D modeling and FEA.

Chapter-1

Introduction

Particle collision detectors, such as the Internal Tracking System for the Multi-Purpose Detector (MPD), are like really complex instruments vital for advancing our understanding of fundamental particles and their interactions [1]. These detectors comprise intricate components meticulously assembled to ensure precise performance and reliability. Among the crucial aspects of assembly is the fixation of components within the detector housing, often achieved through the use of like adhesives.

The mechanical behavior of these adhesives under varying conditions is paramount to the operational integrity and longevity of the particle collision detector. Understanding how adhesives respond to normal operating conditions, as well as extreme high-energy events resulting from particle collisions, is essential for optimizing the design and ensuring the long-term stability of the detector.

The objective of this project is to like, determine the capabilities of Ansys, a super widely used finite element analysis (FEA) software, in simulating the behavior of adhesives employed in fixing components within the housing of particle collision detectors. By conducting comprehensive research into the state of the art regarding adhesive damages and service life under normal and high-energy conditions, followed by the development of a 3D model for finite element analysis, this study aims to provide like really valuable insights into the mechanical performance of adhesives within particle collision detector systems.

Chapter-2

Objectives:

- **Identify the Suitable Work Module in Ansys:** The main objective of this project is to identifying the appropriate Ansys work module for simulate adhesive behavior. This involves evaluating various modules within the Ansys software suite to select the one that best suits the requirements for finite element analysis (FEA) of adhesive materials.

- **Investigate Damages and Service Life of Adhesives:** Conducting a comprehensive investigation into the damages and service life of adhesives under normal and high-energy conditions is a key objective. This entails reviewing existing literature, experimental data, and case studies to understand the factors that influence adhesive performance and durability.

- **Develop a 3D Model for Finite Element Analysis:** Creating a detailed 3D model is very essential for accurately simulate the mechanical behavior of adhesives under different working conditions. This objective involves designing and modeling a representative 100x30x10mm bar with a 30x30x2mm adhesive layer using CAD software. Material properties are assigned to both the bar and adhesive to accurately represent their mechanical behavior.

- **Perform Finite Element Analysis:** Utilizing the selected Ansys work module, this objective focuses on performing finite element analysis of the adhesive-bar system under various working conditions. Two primary analyses are conducted.

  - **Steady-State Thermal Analysis:** This analysis evaluates the temperature distribution within the adhesive-bar system under steady-state thermal conditions. It helps understand the thermal behavior of the adhesive and its potential impact on mechanical properties.
  - **Static Structural Analysis:** This analysis assesses the mechanical response of the adhesive-bar system to applied loads, boundary conditions, and constraints. It provides insights into stress distribution, deformation, and potential failure modes of the adhesive under different loading scenarios.

Chapter-3

Literature Review:

- **Adhesives used in particle collision detectors**: Common types of adhesives utilized in particle collision detectors include epoxy resins, cyanoacrylates, and polyurethanes [2]. These adhesives must meet stringent requirements for bonding strength, thermal stability, and radiation resistance to withstand the demanding environment of particle collision experiments.

- **Mechanical behavior and properties of adhesives:** Studies on the mechanical properties of adhesives under normal conditions reveal crucial parameters such as tensile strength, shear strength, and fatigue resistance, essential for ensuring reliable bonding of detector components.

  Research into adhesive behavior under high-energy conditions investigates the effects of particle collisions and radiation exposure on adhesive performance [3]. Understanding degradation mechanisms and durability is vital for maintaining detector integrity over prolonged operation periods.

- **Finite element analysis (FEA) of adhesive behavior:** FEA techniques have been employed to simulate adhesive behavior in particle collision detectors, enabling detailed analysis of stress distribution, deformation, and failure modes. ANSYS modules such as Structural Mechanics, Adhesive Bonding, and Composites offer specialized tools for modeling adhesive behavior. Studies utilize these modules to apply realistic boundary conditions and validate simulation results against experimental data.

- **Simulation of adhesive behavior in particle collision detectors:** Literature specific to the simulation of adhesive behavior within particle collision detectors like the Internal Tracking System for MPD is limited but crucial [2]. Such studies focus on accurately representing the complex geometries and material properties of detector components, considering mechanical loads, thermal effects, and radiation exposure.

- **Gaps in the literature and future research directions:** Despite advancements, gaps exist in understanding the long-term behavior and reliability of adhesives in particle collision detectors, particularly under extreme operating conditions.

  Future research directions may include developing advanced modeling techniques to account for nonlinear behavior, incorporating multiscale approaches for accurate prediction of adhesive performance, and exploring novel adhesive formulations tailored for particle physics applications.

Chapter-4

3D Modeling and Analysis

4.1 3D Modeling:

- **3D Modeling Process:**
  The 3D modeling of the bar and adhesive layer was conducted using Solid Edge, a parametric solid modeling software known for its robust capabilities in creating detailed 3D models. The dimensions of the components were specified as 100*30*10 mm for the bar and 30*30*2 mm for the adhesive layer, ensuring accurate representation of the physical dimensions.

- **Bar Modeling:**
  The bar component was modeled as a solid rectangular prism with dimensions of 100*30*10 mm. This geometry was chosen to simulate a typical component within the particle collision detector housing.

- **Adhesive Layer Modeling:**
  The adhesive layer was modeled as a separate component with dimensions of 30*30*2 mm, designed to fit between two surfaces of the bar.
  Similar to the bar modeling process, Solid Edge's parametric modeling tools were employed to create a detailed representation of the adhesive layer.

- **Assembly:** Once the individual components (bar and adhesive layer) were modeled, they were assembled together to create a complete representation of the adhesive-bonded structure.

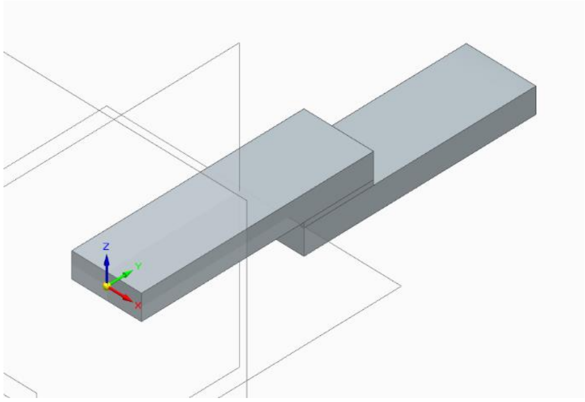

Fig 4.1: Case-1 Assembled view.

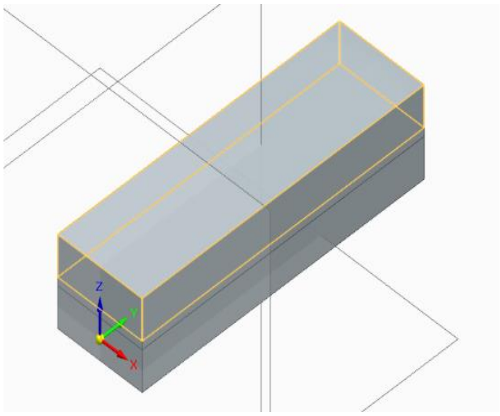

Fig 4.2: Case-2 Assembled view.

4.2 Finite Element Analysis:

Utilizing the selected ANSYS work module, Finite Element Analysis (FEA) was conducted to simulate the behavior of adhesive bonding between the bar and glue components within the particle collision detector assembly. The analysis focused on evaluating stress distribution, deformation of the adhesive under two loading conditions: point load and uniform load.

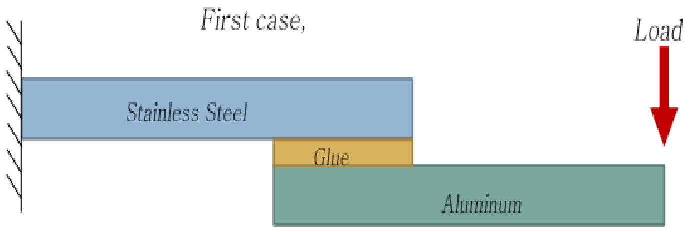

Fig 4.3: Point Load.

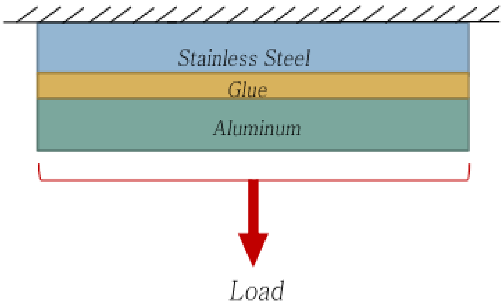

Fig 4.4: Uniform Load.

4.3 Methodology:

Importing 3D Model:

The 3D model of the assembly, consisting of the bar and adhesive layer, was imported into ANSYS. This model accurately represented the geometry and dimensions of the components as created in Solid Edge.

Material Assignment:

Material properties were assigned to both the bar and adhesive layer within ANSYS. These properties were based on experimental data or literature values and included parameters such as Young's modulus, Poisson's ratio, and density [4].

Density	1.65 kg/cm^3
Young’s modulus	3770 MPa
Poisson’s ratio	0.34

Table 1: Defined Properties of Adhesive layer.

Work Module in ANSYS for Adhesive Simulation:

In the analysis of adhesive behavior, selecting the appropriate ANSYS work module is critical to ensure accurate representation of adhesive materials and realistic simulation results. For the investigation of adhesive behavior in particle collision detector components, particularly under high radiation conditions, two ANSYS modules were selected: **Steady State Thermal Analysis and Static Structural Analysis.**

❖ Steady State Thermal Analysis:

This module is well-suited for assessing the thermal behavior of adhesives under steady-state conditions. It allows for the simulation of heat transfer phenomena within structures, providing insights into temperature distribution and thermal stresses.

In particle collision detectors, where components are exposed to high radiation levels, understanding the thermal response of adhesives is crucial for assessing their durability and reliability.

○ Boundary Conditions:

- Heat flux of 0.0004 W/mm^2.
- Convection film coefficient of 0.04 W/mm^2℃.
- Ambient temperature to 26℃ to represent the initial temperature of the surrounding environment.

❖ Static Structural Analysis:

The Static Structural Analysis module is used to analyze the mechanical behavior of structures under static loads. It enables the simulation of stress distribution, deformation, and potential failure modes of adhesive-bonded components. By applying appropriate boundary conditions and loads, this module facilitates the assessment of adhesive performance under different working conditions.

○ Boundary Conditions:

- **For Case 1:**
  - Fix one edge of the bar to simulate a clamped boundary condition.
  - Apply a point load of 500N at the opposite edge.

- **For Case 2:**
  - Fix one face of the bar to simulate a fixed boundary condition.
  - Apply a uniform load of 500N distributed over the opposite face of the bar where the adhesive is present.

- **Load Application:**

  Two loading scenarios were considered:

  - **Point Load:** A point load was applied at the end of the bar, where the other end was fixed. This represents a common scenario where a component is subjected to localized loading.
  - **Uniform Load:** A uniform load of 500N was applied to one end of the bar, while the other end was fixed. This simulates a scenario where the entire length of the bar is subjected to a distributed load.

- **Simulation Setup:** Steady-state thermal analysis was conducted to evaluate the temperature distribution within the adhesive and bar components under different loading conditions. This analysis provided insights into thermal effects on adhesive behavior. Following the thermal analysis, static structural analysis was performed to analyze the mechanical behavior of the adhesive-bar assembly under point and uniform loading conditions. The analysis focused on stress distribution, deformation, and potential failure modes of the adhesive.

- **Post-processing:** post-processing is a critical phase of finite element analysis (FEA) that involves interpreting simulation results to gain insights into the behavior of adhesives in particle collision detector components. Post-processing focuses on analyzing stress distribution, deformation patterns, and potential failure modes of the adhesive.

Chapter-5

Results

❖ Steady state thermal analysis:

■ Heat Flux Analysis:

✓ **Case 1:**

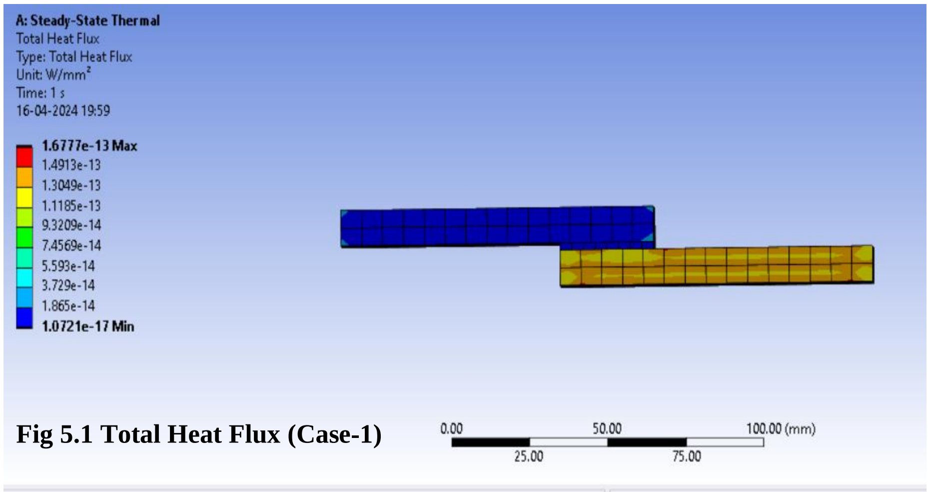

Fig 5.1 Total Heat Flux (Case-1)

- ➢ The minimum heat flux is observed at the end of the bar that is fixed. This region experiences minimal heat transfer due to the constraint applied, resulting in a low heat flux value of approximately **1.0721×10−17 W/mm2**.
- ➢ The stainless-steel material of the fixed bar is known for its relatively low thermal conductivity, contributing to the limited heat transfer in this region.
- ➢ The aluminum material exhibits a relatively higher thermal conductivity compared to stainless steel, leading to enhanced heat transfer through the adhesive interface.
- ➢ The maximum heat flux value is approximately **1.6777×10−13W/mm2,** indicating significant thermal energy transfer across the adhesive layer.
- ➢ The average heat flux observed in the assembly is approximately **4.7069×10^−14 W/mm^2.**
- ➢ Utilizing the Probe tool, the heat flux at the adhesive layer was determined to be **3.4927×10^-15 W/mm^2.**

✓ **Case 2:**

- ➢ The minimum heat flux was observed within the adhesive layer, located between the two bars. The value obtained was approximately **6.0434e-017 W/mm^2.**

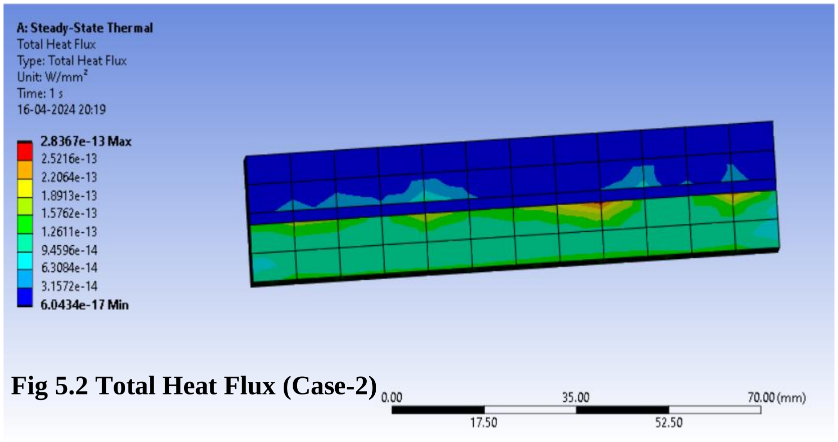

Fig 5.2 Total Heat Flux (Case-2)

- This indicates that the adhesive layer experiences minimal heat transfer compared to the surrounding materials, suggesting efficient thermal insulation properties of the adhesive in maintaining stable temperatures within the assembly.
- The maximum heat flux was detected at the aluminum bar, with a value of approximately **2.8367e^-13 W/mm^2.**
- This indicates that the aluminum bar is experiencing the highest rate of heat transfer within the assembly.
- The average heat flux across the assembly, including both bars and the adhesive layer, was calculated to be approximately 5.0252e^-014 W/mm^2.
- Utilizing the Probe tool, the heat flux at the adhesive layer was determined to be **9.0554×10^-15 W/mm^2.**

❖ Static Structural Analysis:

■ Equivalent Elastic Stress:

✓ **Case-1:**

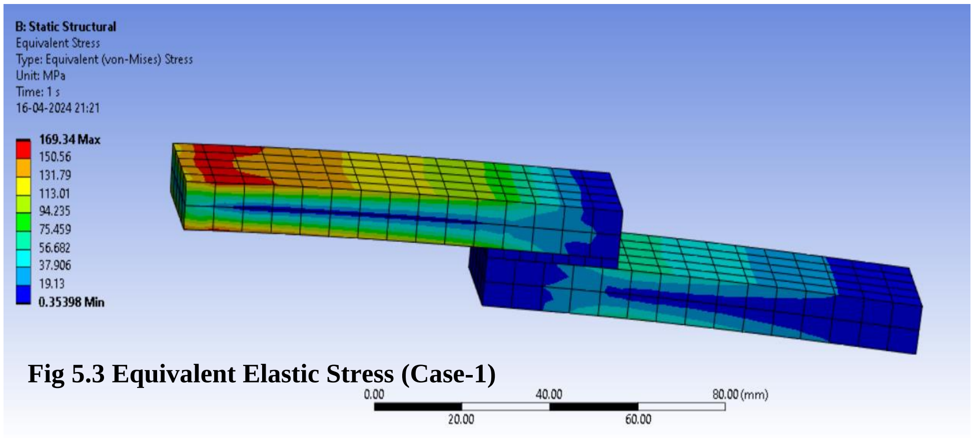

Fig 5.3 Equivalent Elastic Stress (Case-1)

- Equivalent elastic stress reflects the stress distribution within the components of the assembly, providing insights into the structural integrity and load-bearing capacity.
- The minimum equivalent elastic stress was observed in the aluminum bar, indicating the lowest stress level experienced by the material **(0.35398 MPa).**
- The maximum equivalent elastic stress was found in the stainless-steel bar, which experienced the highest stress due to its stiffness and load-bearing role **(169.34 MPa).**
- The average equivalent elastic stress across the assembly was calculated to be **37.414 MPa**, representing the average stress experienced by the components.
- Utilizing the Probe tool, the equivalent elastic stress at the adhesive layer was determined to be **27.548 MPa**.

✓ Case 2:

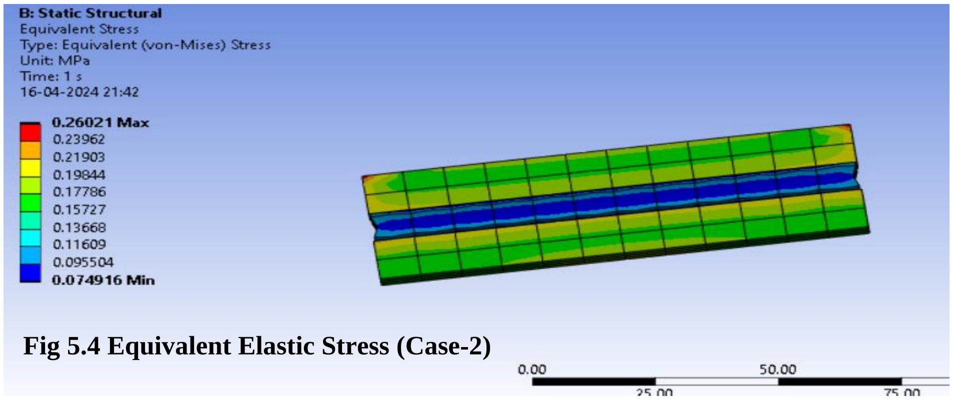

Fig 5.4 Equivalent Elastic Stress (Case-2)

- Equivalent elastic stress represents the stress experienced by the material, considering both normal and shear stress components.
- The minimum and maximum equivalent elastic stress values were observed in the stainless-steel bar, with respective values of **7.4916e-002 MPa** and **0.26021 MPa**. This indicates that the stress distribution within the stainless-steel bar varies from low to moderate levels.
- The average equivalent elastic stress across the stainless-steel bar was calculated to be **0.14744 MPa**, reflecting the overall stress distribution within the material.
- By utilizing the Probe tool, the equivalent elastic stress at the adhesive interface was determined to be **0.11366 MPa.**

■ Equivalent Elastic Strain:

✓ Case-1:

- Equivalent elastic strain quantifies the deformation of materials under stress, providing insights into their elastic behavior.

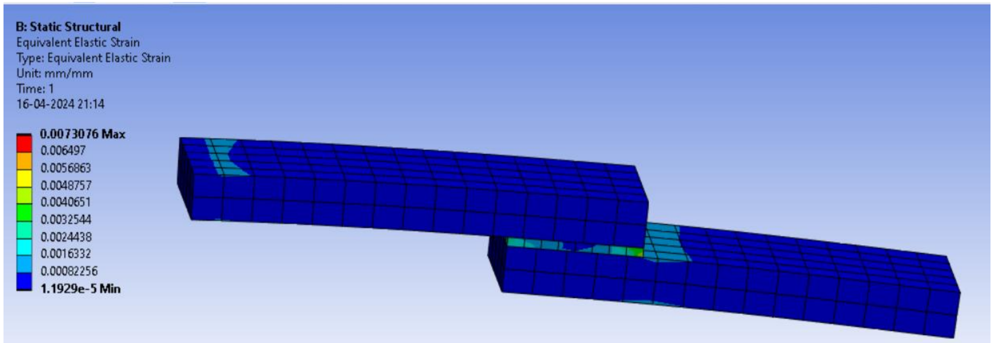

Fig 5.5 Equivalent Elastic Strain (Case-1)

- ➢ The maximum equivalent elastic strain is observed at the adhesive layer, reaching a value of **7.3076×10^-3**. This indicates significant deformation and strain within the adhesive due to the applied load.
- ➢ The minimum equivalent elastic strain is observed in the aluminum bar, with a value of **1.1929×10^-5**, indicating minimal deformation in the aluminum material.
- ➢ The average equivalent elastic strain across the assembly is calculated to be **6.5362×10-^4**, representing the average deformation experienced by the materials under stress.
- ➢ By utilizing the Probe tool to analyze the equivalent elastic strain at the adhesive layer, a value of **7.3076×10^−3** was obtained.

✓ <u>Case-2:</u>

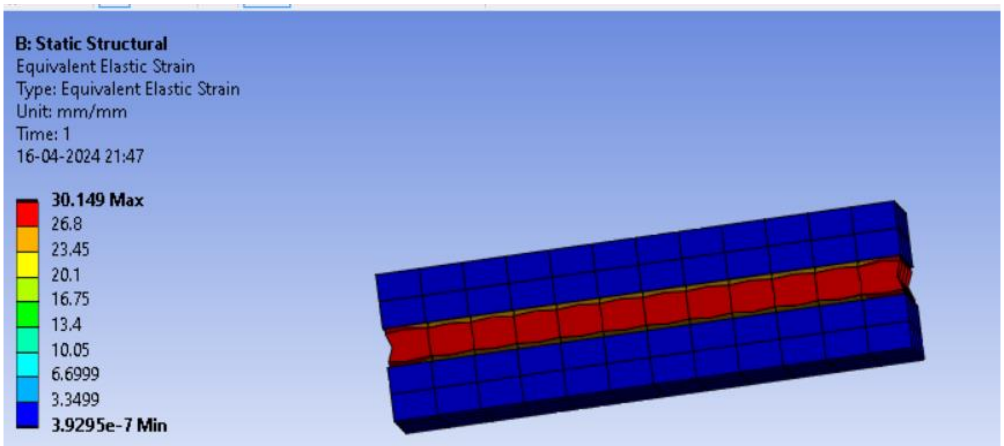

Fig 5.6 Equivalent Elastic Strain (Case-2)

- ➢ The equivalent elastic strain, which represents the amount of deformation relative to the material's elastic properties, was found to be highest in the adhesive layer.
- ➢ The maximum equivalent elastic strain observed in the adhesive was **30.149**, indicating significant strain accumulation within the adhesive material.

- Stainless-steel bar exhibited minimal equivalent elastic strain, with a minimum value of **3.9295×10-7**. This suggests that the stainless-steel bar experiences negligible deformation compared to the adhesive layer.
- The average equivalent elastic strain across the adhesive layer was calculated to be **5.9659**, reflecting the overall strain distribution within the adhesive material.
- By utilizing the Probe tool to analyze the equivalent elastic strain at the adhesive layer, a value of **30.149** was obtained.

■ Total Deformation:

✓ Case-1:

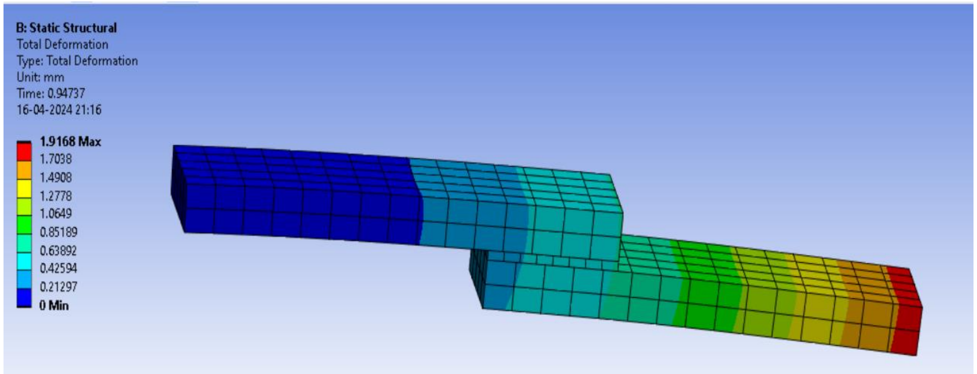

Fig 5.7 Total Deformation (Case-1)

- The total deformation represents the overall displacement of the components in response to the applied load.
- The minimum total deformation is observed in the stainless-steel bar, which is fixed at one end, indicating minimal movement due to its high stiffness.
- The maximum total deformation occurs in the aluminum bar, where the point load of 500N is applied. This deformation value is measured at **1.9168mm**, indicating significant displacement under the applied load.
- The average total deformation across both bars is calculated to be **0.62404mm**, providing an indication of the overall deformation experienced by the assembly.
- By utilizing the Probe tool at the adhesive interface, the total deformation at the adhesive layer was measured to be **0.69375mm.**

✓ Case-2:

- The total deformation was found to be minimal in the stainless-steel bar that is fixed, with a deformation value of **0mm.** This is expected as the fixed bar remains immobile under the applied load.

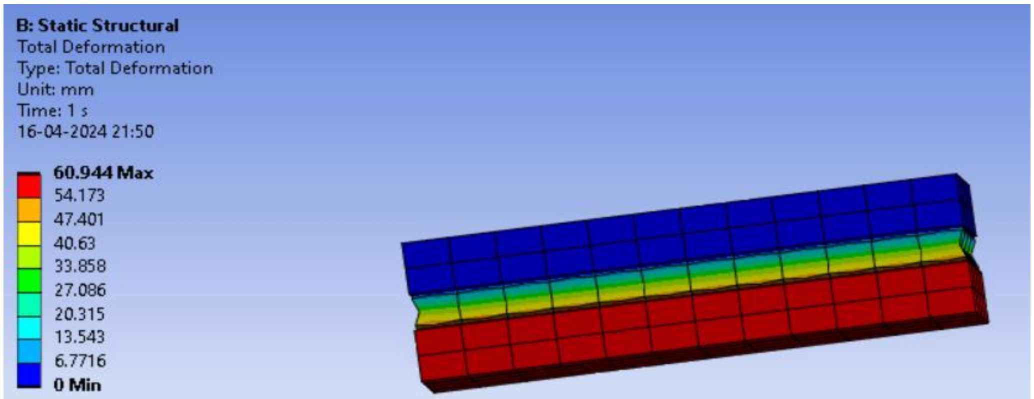

Fig 5.8 Total Deformation (Case-2)

- The maximum total deformation was observed in the adhesive layer, reaching a value of **60.944mm**. This significant deformation indicates that the adhesive undergoes substantial strain and displacement due to the applied load.
- The average total deformation was calculated to be **30.016mm**, reflecting the overall deformation behavior of the adhesive under the given loading conditions.

Chapter-6

CONCLUSION

The comprehensive analysis conducted through steady state thermal analysis and static structural analysis has provided valuable insights into the behavior of the adhesive layer within the assembly of particle collision detector components. This method has proven to be effective in understanding critical aspects such as stress distribution, strain, deformation, and heat transfer within the adhesive layer under various loading conditions.

Information Obtainable from FEA Simulations of Glue:

- **Stress Distribution:** FEA simulations can identify areas of high stress concentration within the adhesive, aiding in the prediction of potential failure points.
- **Strain and Deformation:** The analysis can estimate the extent of deformation the glue undergoes under load, providing insights into its flexibility and its impact on joint integrity.
- **Heat Transfer:** Thermal analysis assesses the efficiency of heat conduction within the glue, vital for applications experiencing temperature variations.

Suitable Model for Glue Analysis: For most cases, static structural analysis proves more appropriate for analyzing glue behavior, focusing on mechanical stresses and deformations under static loads. However, scenarios involving significant temperature fluctuations may necessitate a combination of steady-state thermal analysis and static structural analysis to understand the combined effects of mechanical stress and thermal loads on the adhesive.

Limitations to Consider:

- **Material Models:** The accuracy of FEA simulations heavily relies on chosen material models for the adhesive and surrounding materials. Accurate material properties are crucial for reliable results.
- **Idealized Models:** Simulations are based on idealized models and may not perfectly capture the complex behavior of real-world glues, which exhibit viscoelasticity and time-dependent responses.

FEA serves as a powerful tool for understanding glue behavior and optimizing adhesive joints. However, acknowledging the limitations and ensuring the chosen models and material properties accurately reflect real-world scenarios are essential for reliable analysis and optimization efforts.

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Dr. Maribel Herrera Barrera Mam,

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