**Thermal and Structural Analysis of an Aluminium Heat Sink**

**Abstract**

Efficient thermal management is a cornerstone of modern electronics, ensuring device reliability and optimal performance. This report investigates the thermal and structural performance of an aluminium heat sink using finite element analysis (FEA). The analysis covers steady-state and transient thermal conditions, as well as thermal stress due to expansion. Results demonstrate the superior heat dissipation capacity of aluminium and its ability to withstand mechanical stresses, making it a prime choice for thermal management in high-performance applications.

**Objective**

The primary objectives of this study are as follows:

1. **Thermal Analysis**:
   * Evaluate the steady-state thermal response under a constant heat flux of 1500 W/m².
   * Study the transient thermal response to a square wave heat flux over 180 seconds.
2. **Structural Analysis**:
   * Assess thermal stresses and deformation using steady-state results as the input temperature load.

**Introduction**

Heat sinks play a critical role in ensuring the longevity and stability of electronic devices by dissipating heat generated during operation. Their design and material selection are fundamental to achieving efficient thermal management. Aluminium, known for its lightweight, high thermal conductivity, and mechanical strength, is widely used for heat sinks.

This study analyzes a finned aluminium heat sink using FEA tools to evaluate its thermal behaviour and mechanical stability under both steady and transient conditions. The findings contribute to understanding the design principles required for effective thermal management.

**Preprocessing**

**Material Properties**

Aluminium was chosen for the analysis due to its optimal balance of thermal and mechanical properties.

| **Property** | **Value** |
| --- | --- |
| Thermal Conductivity (kk) | 170 W/m·°C |
| Density (ρ\rho) | 2800 kg/m³ |
| Specific Heat (cc) | 870 J/kg·°C |
| Elastic Modulus (EE) | 70 GPa |
| Poisson’s Ratio (ν\nu) | 0.33 |
| Coefficient of Thermal Expansion (α) | 22 x 10^(-6) ·°C^(-1) |

**Geometry**

The heat sink consists of a rectangular base with multiple fins to enhance surface area for heat dissipation.

* **Base Dimensions**: 100 mm × 50 mm × 10 mm
* **Fin Height**: 28 mm
* **Fin Thickness**: 2 mm
* **Number of Fins**: 8

**Boundary Conditions**

* **Ambient Temperature**: 35°C
* **Heat Flux**:
  + **Steady-State**: 1500 W/m² applied to the base.
  + **Transient**: Square wave variation between 0 and 1000 W/m² with a 90-second period.
* **Convection Coefficient**: 30 W/m²·°C.

**Modelling and Meshing**

**CAD Model**

The 3D geometry of the heat sink was developed in CAD software and imported as a STEP file. Fine details, including fin dimensions, were modelled accurately to capture realistic thermal and structural behaviour.

**Mesh Details**

* **Element Type**: Tetrahedral.
* **Nodes**: 26,747.
* **Elements**: 13,810.
* **Minimum Edge Length**: 2 mm.

Mesh refinement ensured accuracy near critical regions, such as the fin base and edges, where high thermal gradients and stresses were expected.

**Results and Discussion**

**Thermal Analysis**

**Steady-State Thermal Response**

The steady-state simulation provided the temperature distribution and heat flux across the heat sink.

| **Parameter** | **Value** |
| --- | --- |
| Minimum Temperature | 60.69°C |
| Maximum Temperature | 61.49°C |
| Average Temperature | 61.08°C |
| Minimum Heat Flux | 65.83 W/m² |
| Maximum Heat Flux | 7612.7 W/m² |
| Average Heat Flux | 2523.3 W/m² |

**Key Observations**:

1. Uniform temperature distribution across fins demonstrates efficient heat dissipation.
2. Higher heat flux at the fin base aligns with theoretical expectations due to concentrated thermal gradients.

**Transient Thermal Response**

The transient analysis investigated the system’s response to a square wave heat flux. The temperature fluctuated between 60.5°C and 61.5°C, stabilizing within each cycle due to aluminium’s thermal properties.

**Structural Analysis**

Thermal stresses were calculated using steady-state temperature results as input for structural analysis.

**Thermal Stress Calculation**

σ=E⋅α⋅ΔT

Where:

* E=70 GPa
* α=22×10^(−6) °C^−1
* and ΔT=0.8 °C

σ=70×10^9x22×10^(-6)x0.8=1.23 MPa

The calculated stress is well below aluminium’s yield strength, confirming structural safety.

**Deformation Analysis**

Maximum deformation occurred at the fin tips, with a negligible value of <0.01 mm. This validates the design’s robustness under operational conditions.

**Conclusion**

This study highlights the thermal and structural reliability of an aluminium heat sink for electronic cooling applications.

**Key Findings**:

1. Uniform temperature distribution and effective heat dissipation were achieved under steady-state and transient conditions.
2. The design exhibited minimal deformation and thermal stress, ensuring structural integrity.
3. Aluminium’s high thermal conductivity and mechanical strength make it an ideal material for heat sinks. Future work could explore alternative geometries, materials, and coatings to enhance performance further.

**Appendix**

**List of Equations**

1. Fourier’s Law: T(x)=T0−[(qx)/k]
2. Thermal Stress: σ=E⋅α⋅ΔT

**References**

* Material Properties Database, ASM International.
* Simulation Tools: ANSYS 2024 R2.