Thermo-Structural Analysis of Piston Head Using ANSYS Mechanical

Abstract

This research report presents a comprehensive finite element study on engine components: the piston head. The piston head, made of gray cast iron, is subjected to extreme thermal loading, while another Piston head, made of aluminium alloy, experiences high-pressure mechanical loads. Simulations were carried out using ANSYS Mechanical 2024 R1 to evaluate thermal distribution, deformation, and stress response under realistic conditions. Results reveal critical insights into material behaviour, thermal gradients, and mechanical vulnerabilities that are essential for design optimization and performance enhancement.

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1. Introduction

Internal combustion engine components operate under harsh conditions involving high temperatures and pressures. This study combines thermal and mechanical analyses of two vital parts:

- Piston Head: Focuses on heat transfer and thermal gradients.
- Piston Head: Focuses on stress and deformation under pressure.

By analysing both, the report provides an integrated perspective on thermo-mechanical behaviour, essential for robust and reliable engine design.

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2. Objectives

- To simulate thermal distribution in a Gray cast iron piston head.
- To evaluate stress and deformation in an aluminium engine head.
- To identify hot spots, stress concentration zones, and failure risks.
- To recommend material and design improvements for enhanced durability.

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3. Methodology

3.1. Geometry and Mesh

Component	Source	Mesh Type	Elements	Nodes
Piston Head	IGES CAD model	Tetrahedral	15,619	28,589
Engine Head	AGDB CAD model	Solid Elements	53,242	81,106

Adaptive meshing and boundary layer refinement techniques were used for both models

3.2. Materials

Property	**Gray Cast Iron**	**Aluminium Alloy**
Density (tonne/mm³)	7.2e-9	2.77e-9
Thermal Conductivity (W/mm·K)	0.052	0.114–0.175 (temp. dep.)
CTE (K^{-1})	1.1e-5	2.3e-5
Young's Modulus (MPa)	110,000	-
Poisson's Ratio	0.28	-
UTS (MPa)	240 (tensile), 820 (comp)	310
Yield Strength (MPa)	-	280

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4. Thermal Analysis of Piston Head

4.1. Boundary Conditions

- Initial Temperature: 25°C
- Combustion Heat Load: Ramped up to 1000°C
- Convection: 2.98e-4 W/mm²·°C on 61 faces

4.2. Results

Parameter	Value
Max Temperature	1000 °C
Min Temperature	19.43 °C
Average Temperature	130.02 °C

- Significant thermal gradients from combustion face to piston interior.
- Hot spots localized on upper crown; core remains cooler.

4.3. Discussion

- Low thermal conductivity leads to heat accumulation.
- High CTE poses risk of thermal expansion and fatigue.
- Enhanced cooling (e.g., oil spray or forced convection) needed in future designs.

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5. Static Structural Analysis of Engine Head

5.1. Loading and Boundary Conditions

- Pressure Load: 20 MPa applied on 2 faces
- Support: Fixed boundary to prevent rigid motion
- Temperature: Uniform ambient (22°C)

5.2. Results

Parameter	Value
Max Deformation	235.6 mm
Average Deformation	106.41 mm
Max von Mises Stress	412.83 MPa
Average von Mises Stress	30.87 MPa

- Stress exceeds yield strength (280 MPa) indicating plastic deformation risk.
- Deformation is localized; high-stress zones correspond to geometric discontinuities.

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6. Design and Research Implications

6.1. Piston Head – Thermal Analysis

- Recommendation: Improve cooling and consider high-conductivity alloys or ceramic coatings.
- Next Steps: Couple with structural analysis to compute thermal stress.

6.2. Piston Head – Structural Analysis

- Recommendation: Modify geometry at stress concentration zones; use stronger alloy or reinforcement ribs.
- Next Steps: Fatigue analysis under cyclic pressure and temperature.

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7. Future Work

- Thermo-Mechanical Coupling: Simultaneous heat and stress analysis.
- Multiphysics Integration: Add fluid flow for realistic coolant modeling.
- Experimental Validation: Thermocouple and strain gauge tests.
- Design Optimization: Apply parametric and AI-driven design tools.

8. Conclusion

This integrated thermo-structural study highlights critical vulnerabilities in engine component design. The piston head requires better thermal management, while the engine head exhibits mechanical overstress under high load. These findings form a foundation for advanced analysis and optimization, ensuring safer and more efficient engine systems.