Design and Static Thermal Analysis of a Piston for a 110 CC Bike Engine

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ABSTRACT

The piston plays a vital role in determining the efficiency and durability of an internal combustion engine. This study examines the thermal performance of a Honda CD 110cc bike piston using ANSYS software, comparing two materials: Aluminum alloy and graphite. Aluminum alloy is widely used for its excellent thermal conductivity, lightweight properties, and manufacturability. In contrast, graphite is known for its exceptional heat resistance and minimal thermal expansion. These distinct material properties make them suitable candidates for evaluating thermal behavior in demanding engine conditions. The analysis focuses on assessing thermal stresses, heat flux, and temperature distribution under typical operating conditions. Real-world scenarios are simulated by applying boundary conditions, including combustion chamber pressure and convective cooling, with heat flux determined based on standard combustion temperatures. The results highlight temperature gradients, hotspots, and potential thermal stresses that could impact the piston's performance and longevity. Comparative findings reveal the advantages and limitations of both materials. Aluminum alloy offers effective heat dissipation and structural integrity but may be prone to higher thermal expansion. Graphite, on the other hand, demonstrates superior thermal stability and resistance to high temperatures but may face challenges in load-bearing applications. The study's outcomes provide critical insights for optimizing piston materials and cooling designs in small engine applications. These findings contribute to enhancing engine efficiency, minimizing wear, and extending operational life, making them valuable for advancing lightweight and high-performance engine technologies.

Keywords: Bike piston, steady-state thermal analysis, Temperature, stress, crown temperature

1. INTRODUCTION

The piston is a crucial component of an internal combustion engine, converting combustion energy into mechanical motion. In small engine applications, such as the Honda CD 110cc motorcycle, the piston operates under extreme mechanical loads and high-temperature conditions. During combustion, it experiences significant pressures and temperatures, leading to substantial heat flux and thermal gradients. Effective thermal management, heat dissipation, and material resistance to thermal stresses are essential for ensuring optimal engine performance, durability, and reliability. Thermal analysis plays a key role in understanding surface temperature distribution and identifying potential areas of thermal failure or excessive wear. Advanced simulation tools like ANSYS have become essential for accurately assessing thermal behavior under real-world operating conditions. This study utilizes ANSYS to model

https://doi.org/10.5281/zenodo.14607414

the thermal response of a Honda CD 110cc bike piston made from two materials: aluminum alloy and graphite.

Material selection plays a critical role in effective thermal management. Aluminum alloys are commonly used for engine pistons due to their lightweight nature and excellent thermal conductivity, which enables efficient heat dissipation. Alternatively, graphite offers significant advantages in terms of high-temperature stability, minimal thermal expansion, and exceptional resistance to heat, making it a viable material for enhancing a piston's ability to withstand extreme temperatures.The choice of material not only affects the piston's ability to manage thermal stresses but also influences overall engine performance and durability. This study aims to evaluate and compare the thermal behavior of aluminum alloy and graphite by conducting a detailed thermal analysis of the Honda CD 110cc bike piston using ANSYS software.

The analysis involves modeling the piston under typical operating conditions, simulating combustion-induced heat flux, and evaluating the resulting temperature distribution and thermal stresses. The study's objective is to understand the thermal behavior of piston materials to identify the most suitable option for improving engine efficiency, reducing wear, and enhancing longevity.Satya Prakash Gupta et al. examined changes in piston materials and their effects under static and thermal stress conditions. Their study highlighted that static structural analysis evaluates stresses under specific loading conditions, while thermal analysis assesses material behavior with varying temperatures, both using the finite element method. Similarly, A. Jithendra Kumar and J. Srikanth conducted static and thermal analysis of IC engine pistons using FEM to investigate mechanical properties and stress distribution for five different materials. In another study, Professor Anurag Kulshrestha and Manoj Darwai reviewed the application of composite materials for steady-state thermal analysis of pistons, emphasizing advancements in the design and performance of pistons for petrol-powered bike engines. Building on these insights, this work uses finite element analysis to model the thermal and mechanical performance of a Honda CD 110 piston, focusing on material optimization to enhance engine durability and efficiency. With the advancement of computer-aided engineering tools, engineers can efficiently design and analyze products by modeling residual stresses, structural responses, thermal effects, and fatigue in automotive components. Prof. Brijendra Kumar Yadav, Rajat Singh, and colleagues explored thermal design analysis of pistons using the Response Surface Method (RSM), emphasizing that pistons are exposed to high gas pressure and temperatures during combustion. These conditions, combined with the support of the piston pin and the small end of the connecting rod, create significant mechanical and thermal loads.Wan Mohd Wardi Wan Abdul Rahman, Muhammad Amirul Firdaus Abu Bakar, and their team highlighted that pistons, as the engine's primary heat-absorbing components, operate under high load and temperature conditions for extended periods. The piston's large heating surface and limited heat dissipation capabilities make managing thermal loads a critical challenge. In their study on piston static structural and steady-state thermal analysis, Raghuveer Singh, Bharat Bhushan, and collaborators demonstrated the effectiveness of Finite Element Analysis (FEA) in ANSYS. They showed that early-stage FEA results could significantly enhance component design by providing insights into structural and thermal performance under operational conditions. These studies underline the importance of simulation tools in optimizing piston design to address the challenges posed by high thermal and mechanical stresses.The primary objective of this work is to reduce the stresses and deformation of the piston without compromising its performance. Internal combustion engines are widely used in modern applications, as noted by Lokesh Tadisetti et al., but the high temperatures generated during operation can result in significant thermal stresses. According to Bikkavolu Joga Rao et al., simulation parameters such as operating gas pressure and piston material properties are critical in predicting equivalent stress, total deformation, and heat flux using Finite Element Analysis (FEA). J. Srikanth and A. Jithendra Kumar, in their study on static thermal analysis and modeling of IC engine pistons, utilized the finite element method (FEM) and mechanical property evaluations to analyze stress distribution and thermal stresses across five different piston materials. Similarly, Anup Kumar Shetty and Abijeet focused on stress analysis to identify the most suitable aluminum alloy material, optimizing the piston geometry based on their findings. B. Anjaneyulu and Y. Zamsheed Ahammed highlighted that the piston is one of the most stressed components of an internal combustion engine, operating under extreme thermal and mechanical conditions compared to other engine parts. These studies collectively underscore the importance of material selection and advanced analysis techniques in enhancing piston performance, reliability, and durability.

2. BOUNDARY AND LOADING CONDITIONS FOR STEADY STATE THERMAL ANALYSIS

In the steady-state thermal analysis of the piston, the following boundary and loading conditions are applied to simulate realistic operating conditions based on the material properties and engine function

2.1 Convection Heat Transfer:

The surface of the piston is exposed to convective heat transfer from the combustion gases and the surrounding environment. A convective heat transfer coefficient (film coefficient) is applied to the external surface of the piston, which typically varies depending on the material and operating conditions. For example, the aluminum alloy piston crown is given a film coefficient of 1.24 W/m²°C, and the bulk temperature is set to 220°C.

2.2 Heat Flux from Combustion:

Heat flux due to combustion is applied to the piston head, with the assumption that the piston absorbs a certain amount of heat from the combustion gases. This heat flux is typically applied to the areas of the piston that are directly in contact with the combustion chamber, creating a temperature gradient through the piston structure.

2.3 Ambient Temperature:

The piston is assumed to be exposed to ambient temperature conditions at various areas, such as the piston skirt and pin bore, which might have different thermal loads due to coolant and air circulation. The ambient temperature is typically set around room temperature (25°C or higher), depending on the engine's cooling system.

2.4 Displacement Boundary Condition:

The piston is modeled with fixed support at the gudgeon pin (piston pin) interface, where frictionless boundary conditions are applied. This allows for the piston to move freely in the Z direction but restricts movement in the X and Y directions.

2.5 Thermal Expansion:

The material’s thermal expansion is considered for the piston, which causes it to expand and change shape with increasing temperature, particularly in areas like the piston pin bore.

2.6 Internal Pressure (Gas Pressure):

The piston is subjected to high internal pressures due to combustion. The pressure is applied to the combustion side of the piston crown, simulating the forces exerted by the gas mixture during combustion.

2.7 Heat Flux Distribution:

A uniform heat flux is applied across the combustion side of the piston, simulating the thermal loading that results from the combustion process. The heat flux is calculated based on engine operating conditions and material properties.

2.8 Material Properties:

The specific heat, thermal conductivity, and coefficient of thermal expansion for both aluminum alloy and graphite are assigned to their respective regions in the model, allowing the software to calculate temperature gradients and thermal stresses effectively.

2.9 Steady-State Assumptions:

The analysis assumes a steady-state condition, meaning the temperature and heat distribution have stabilized, and there are no transient effects. The heat flux and convection effects are balanced, ensuring a uniform temperature distribution once the system reaches thermal equilibrium.

By applying these boundary and loading conditions, the steady-state thermal analysis provides a detailed understanding of the temperature distribution, thermal stresses, and potential failure points in the piston under typical engine operating conditions.

3. PISTON DESIGNS

The design of the piston follows established standards and guidelines from the design data book and machine design principles. The calculated dimensions, shown in Figures 1 and 2, are used to create the piston model in CATIA V5R20. Some pistons feature an elliptical shape, which is essentially one half of an oval mirrored to form the other half. This design allows the piston to adapt to the changing dimensions of the cylinder bore over time. The elliptical shape is particularly beneficial when the piston is cold, as it accommodates the slight differences in bore dimensions. As the engine reaches its operating temperature, the piston pin bore expands more significantly than the thinner areas of the piston. This thermal expansion causes the piston to transform into a nearly round shape, which improves its fit with the cylinder bore, enhancing sealing and combustion efficiency.

Table 1 Design Parameters

Parameters	Values
Engine type	4 stroke, petrol engine
Displacement	110cc
Bore	47mm
Stroke	31.56mm
Compression Ratio	9.5:1
Material	Aluminum Alloy Graphite
Compression ratio	8.4
Cooling System	Air-cooled

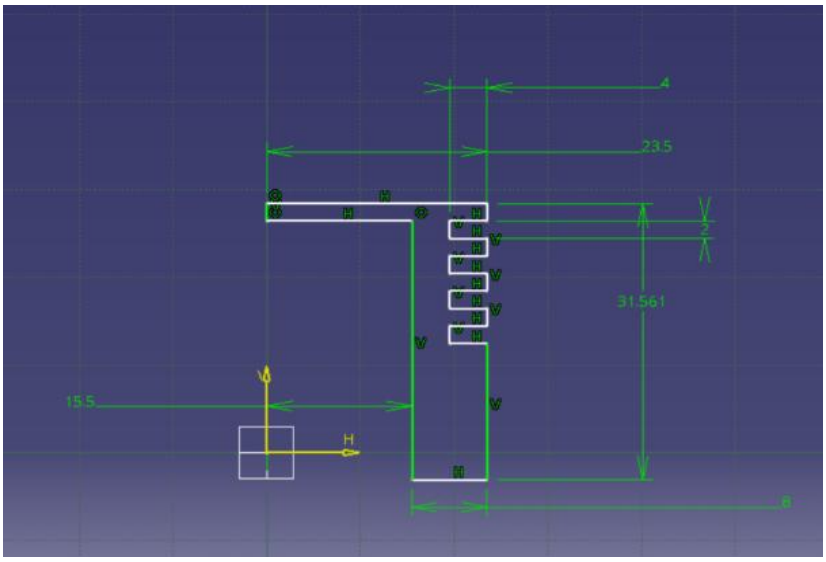

Figure 1. Piston drawing and Dimensions

The piston model was imported into ANSYS 14.5 for thermal and structural analysis. Thermal analysis was performed using ANSYS 14.5 Workbench at the pin hole, while structural analysis was carried out through ANSYS 14.5 Mechanical APDL. The piston experiences significant load due to the gas explosion during combustion, which can lead to failure of the piston pin. As a key component in the engine, the piston plays a crucial role in converting the energy from fuel into heat and pressure during combustion.

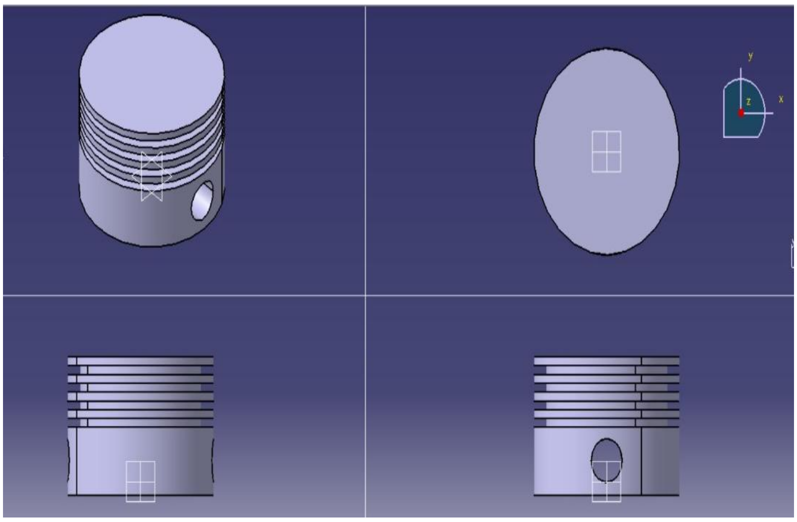

Figure 2. Design of piston using Catia

This energy rapidly builds up as heat and pressure within the combustion chamber, and the piston's task is to convert this energy into mechanical work. Typically, the piston is designed as a hollow cylinder, closed at one end, and features a segmented piston head, skirt, pin boss, and ring belt. The piston head transmits the gas forces (from the fuel-air mixture) through the pin boss, piston pin, and connecting rod to the crankshaft, enabling the engine to function efficiently.

Table 2: Thermal and Geometrical Properties of Piston Materials

S.NO	PROPERTY	AL-ALLOY	GRAPHITE
1	Poisson ratio	0.33	0.15
2	Young's modulus	70 GPa	20GPa
3	Thermal conductivity	120-160 W/m.k	120W/m.k
4	Coefficient of thermal expansion	21-23	5-10x10^-6
5	Density	2700kg/m^3	2200kg/m^3

4. PROCEDURE EXPLAINED

After assigning materials to the model in ANSYS Workbench, the component's geometry, as shown in Figure 3, is meshed using a tetrahedron mesh with an element size of 1 mm, resulting in 47,376 elements and 82,687 nodes. Following the meshing process, ANSYS Workbench applies the appropriate boundary conditions based on the piston's operational principles. The

https://doi.org/10.5281/zenodo.14607414

piston head is supported frictionless on both sides of the gudgeon pin, and the boundary condition for displacement is applied only in the Z direction, with zero displacement maintained along the X and Y axes.

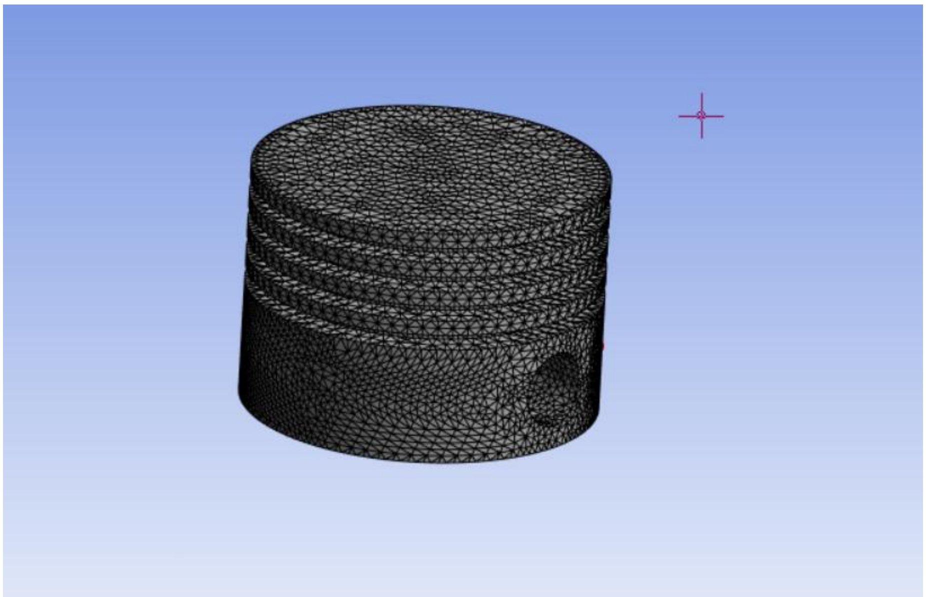

Figure 3. Meshing of the piston with triangular element

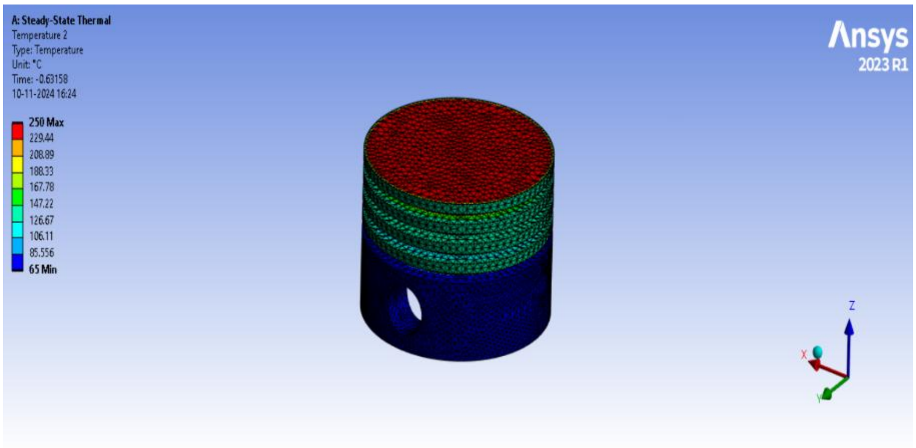

Figure 4. Maximum temperature for Al-alloy

The material of interest, an aluminum alloy piston crown, has a film coefficient of 1.24 W/m²°C and a bulk temperature of 220°C, as depicted in Figure 4. This results in a total temperature of 450°C. Figure 5 demonstrates the steady-state thermal analysis results for two materials, with the corresponding thermal profiles displayed in the figures below.

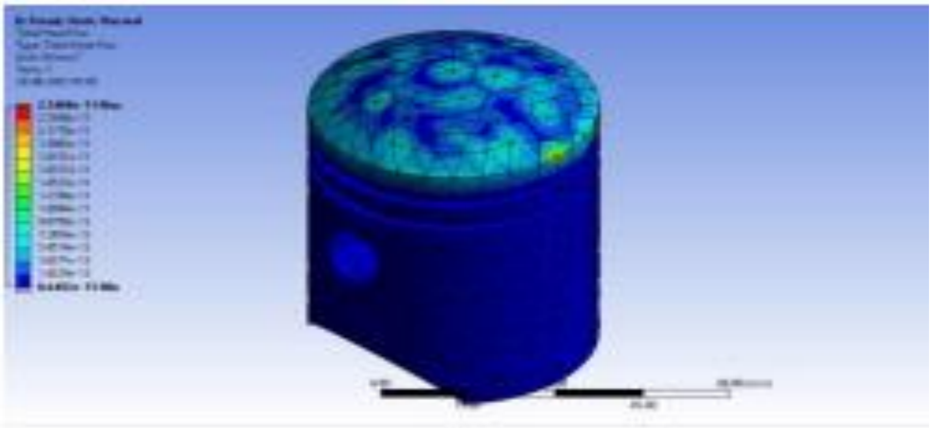

Figure 5. Total heat flux of Al-alloy

5. CONCLUSION

The results above highlight the distinct mechanical and thermal properties of the two materials. Aluminum alloy pistons, with their relatively high thermal conductivity, effectively dissipate heat and reduce thermal stress, despite experiencing moderate thermal expansion. In contrast, graphite pistons exhibit lower thermal expansion, which enhances their stability at high temperatures and helps maintain consistent clearances. Furthermore, graphite's self-lubricating properties reduce friction and improve wear resistance. While aluminum alloy is cost-effective and durable for standard engine use, graphite offers superior wear resistance and thermal stability, making it more suitable for high-performance applications with further design optimizations.

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