Thermo Mechanical Analysis and Weight Reduction of Piston using CATIA and ANSYS

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Abstract: ***The purpose of this study is to analyze the thermo mechanical behavior of a titanium piston and to investigate the potential for weight reduction. This is achieved through the use of computer-aided design software (CATIA) and finite element analysis software (ANSYS). The study involves the design and modeling of the piston using CATIA, followed by the analysis of the thermo mechanical behavior of the piston using ANSYS. The results of the analysis are then used to optimize the design of the piston with the aim of reducing its weight while maintaining its structural integrity.***

Keywords: Thermo Mechanical, Weight Reduction, Piston, CATIA, ANSYS

1. Introduction

Titanium pistons and aluminum pistons have different characteristics and are suitable for different applications.

Titanium pistons are lighter and stronger than aluminum pistons. They have a high strength-to-weight ratio, which makes them ideal for high-performance racing engines where weight reduction is crucial. However, titanium is more expensive than aluminum, which can make it less practical for budget-conscious engine builders.

Titanium pistons are increasingly being used in high-performance engines due to their high strength-to-weight ratio and excellent thermal properties. However, there is still scope for further weight reduction in these pistons without compromising their structural integrity. In this study, we aim to use CATIA and ANSYS to analyze the thermo mechanical behavior of a titanium piston and investigate the potential for weight reduction.

2. Methodology

The first step in the study is to design and model the titanium piston using CATIA. The piston is designed to meet the specifications of a typical high-performance engine, with a diameter of 100 mm and a stroke of 80 mm. The model is then imported into ANSYS for thermo mechanical analysis.

The thermo mechanical analysis involves subjecting the piston to a range of temperatures and pressures, which simulate the conditions experienced by the piston in a high-performance engine. The results of the analysis are then used to optimize the design of the piston with the aim of reducing its weight while maintaining its structural integrity.

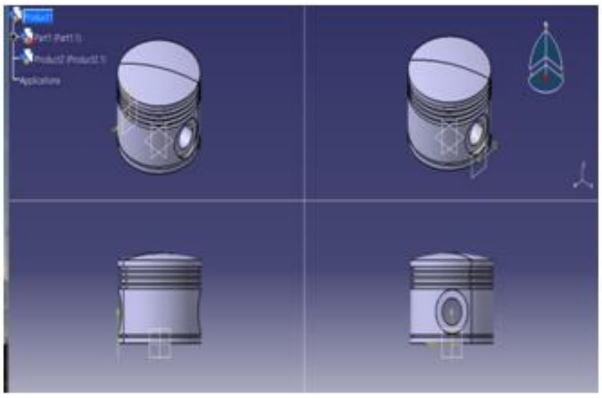


Figure 1: Model of piston

Meshing

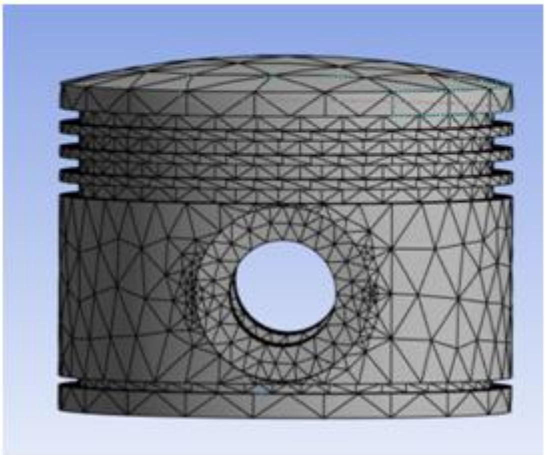
Meshing is an important step in the finite element analysis (FEA) process, which is used to simulate the behavior of complex structures and systems. In ANSYS, meshing refers to the process of dividing a complex 3D geometry into a mesh of smaller, simpler elements that can be analyzed using numerical methods.

Thermal load and heat transfer coefficient of piston

The purpose of meshing in ANSYS is to convert a complex geometry into a series of simpler elements, which can then be analyzed using finite element methods. By dividing the geometry into smaller elements, ANSYS is able to analyze the behavior of the structure at a more detailed level, which allows for more accurate predictions of how the structure will perform under different loads and conditions.

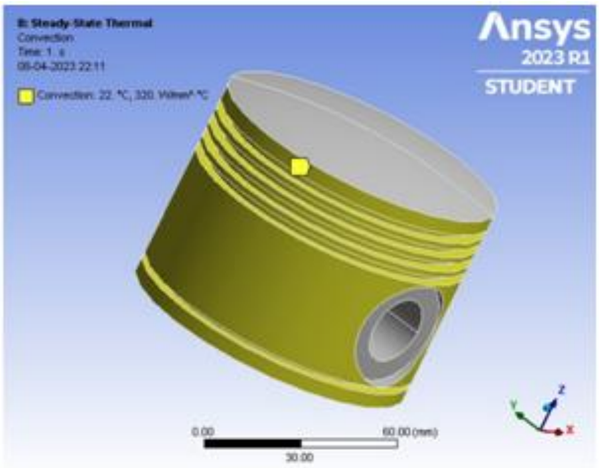
Meshing also allows ANSYS to analyze the behavior of a structure under different types of loads and conditions, including stress, strain, temperature, and fluid flow. By varying the type and magnitude of these loads and conditions, ANSYS can provide valuable insight into how a structure will perform in real-world scenarios.

Overall, the use of meshing in ANSYS is critical to the FEA process, as it allows for the accurate and detailed analysis of complex structures and systems, which can help engineers and designers to optimize their designs and ensure that they meet performance and safety requirements.



Thermal load and heat transfer coefficient of piston

The piston top land is the part of piston which comes in contact with the gas, so the temperature of the top land is very high, up to 700°C. The heat transfer coefficient of top land is chosen from test data of related research. the heat transfer coefficient of top land is estimated to be equal to 320 W/(m2oC) .The analysis is a steady – state thermal one. The heat transfer between the piston and the oil film between the piston and the cylinder takes place by convection. The Heat transfer coefficients used for different parts of piston is given in Fig



Temperature and convection can have significant effects on the behavior and performance of a piston in an internal combustion engine. Here's how they can act on a piston:

1) Temperature: Temperature refers to the amount of heat energy in a system, and in the case of a piston, it is primarily affected by the combustion of fuel in the engine. When fuel is burned in the combustion chamber, it generates high temperatures and pressures, which cause the piston to move and provide power to the engine. However, high temperatures can also cause the piston to expand, which can lead to friction and wear against the cylinder walls. Additionally, high temperatures can cause the piston to weaken and potentially fail, which can lead to catastrophic engine damage.
2) Convection: Convection refers to the transfer of heat energy through a fluid, such as air or a coolant. In the case of a piston, convection can occur through the flow of air or coolant over the surface of the piston. This can help to dissipate heat and reduce the temperature of the piston, which can help to prevent expansion and reduce wear on the cylinder walls. However, convection can also lead to uneven cooling and thermal stresses in the piston, which can cause deformation or failure.

In order to mitigate the effects of temperature and convection on a piston, engineers often design the piston to have features that promote cooling, such as cooling channels or heat sinks. They also use materials that are capable of withstanding high temperatures, such as titanium or other high-performance alloys. Additionally, they may use computational tools such as ANSYS to simulate the behavior of the piston under different operating conditions and optimize the design to minimize the effects of temperature and convection.

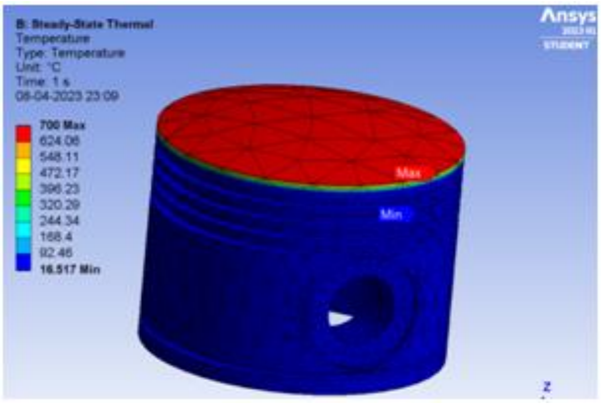


Figure showing applied temperature on piston

Time [s]	Minimum [°C]	Maximum [°C]	Average [°C]
1.	16.517	700.	38.605

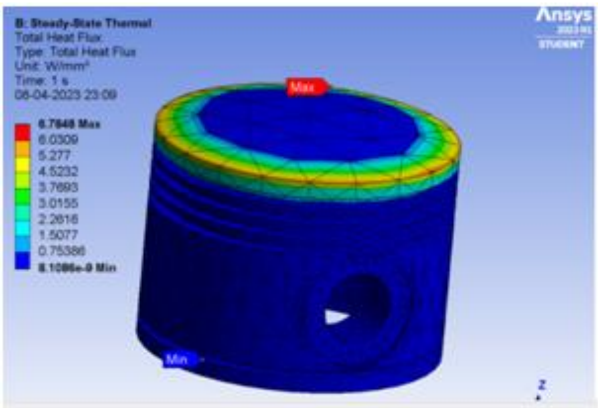


Figure showing total heat flux

Time [s]	Minimum [W/mm²]	Maximum [W/mm²]	Average [W/mm²]
1.	8.1086e-009	6.7848	0.11825

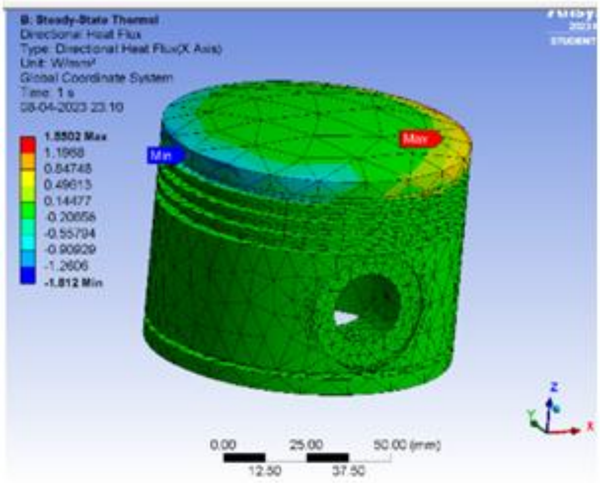


Fig showing directional heat flux

Steady-State Thermal (B5) > Solution (B6) > Directional Heat Flux

Time [s]	Minimum [W/mm²]	Maximum [W/mm²]	Average [W/mm²]
1.	-1.612	1.5502	-3.1276e-004

Titanium Alloy > Constants

Density	4.62e-006 kg mm^-3
Coefficient of Thermal Expansion	9.4e-006 C^-1
Specific Heat	5.22e+005 mJ kg^-1 C^-1
Thermal Conductivity	2.19e-002 W mm^-1 C^-1
Resistivity	1.7e-003 ohm mm

Static structural analysis

The structural analysis of a piston is important for several reasons:

1) Performance optimization: Structural analysis can help optimize the design of a piston to improve its performance. By analyzing the stresses and strains on the piston under different operating conditions, engineers can determine the optimal shape, size, and material for the piston to ensure that it can withstand the loads and stresses it will experience during engine operation.
2) Durability: Structural analysis can also help to ensure the durability of the piston. By analyzing the stresses and strains on the piston, engineers can identify potential failure modes and design the piston to resist them. This can help to prevent premature failure of the piston and ensure the longevity of the engine.
3) Safety: A failed piston can cause catastrophic engine damage, and in some cases, even pose a safety hazard. Structural analysis can help to identify potential failure modes and design the piston to prevent them, which can help to improve the safety of the engine and prevent accidents.
4) Cost savings: Structural analysis can also lead to cost savings by identifying potential design issues before the piston is manufactured. By simulating the behavior of the piston under different operating conditions, engineers can identify potential failure modes and make design changes to prevent them. This can help to avoid costly manufacturing errors and reduce the need for expensive repairs or replacements.

Overall, the structural analysis of a piston is a crucial step in the design process that can help to optimize the performance, durability, and safety of an engine while also reducing costs.

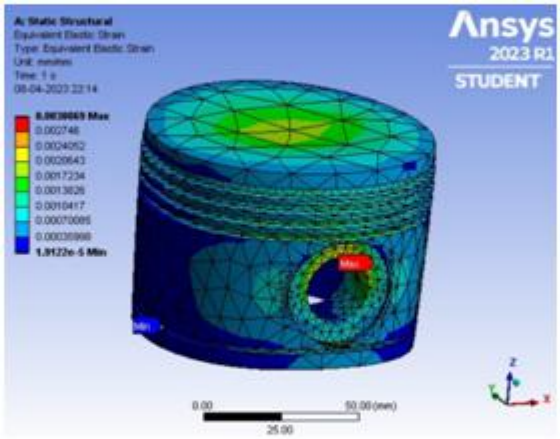


Figure Showing equivalent elastic strain

Static Structural (A5) > Solution (A6) > Equivalent Elastic Strain

Time [s]	Minimum [mm/mm]	Maximum [mm/mm]	Average [mm/mm]
1.	1.9122e-005	3.0869e-003	8.4093e-004

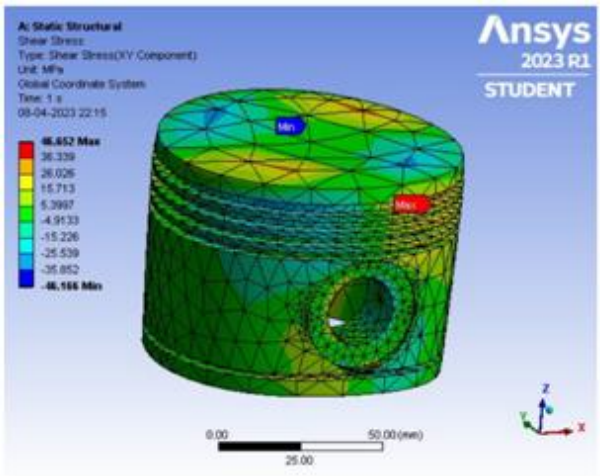


Fig showing shear stress

Time [s]	Minimum [MPa]	Maximum [MPa]	Average [MPa]
1.	-46.166	46.652	-0.3166

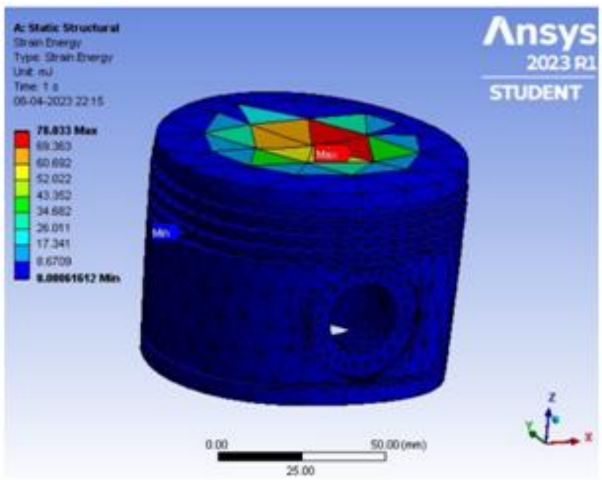


Fig showing strain energy

Static Structural (A5) > Solution (A6) > Strain Energy

Time [s]	Minimum [mJ]	Maximum [mJ]	Total [mJ]
1.	6.1612e-004	78.033	6092.6

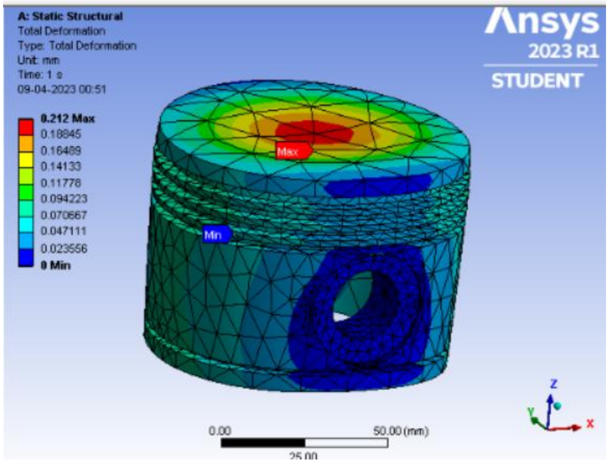


Figure showing total deformation

Static Structural (A5) > Solution (A6) > Total Deformation

Time [s]	Minimum [mm]	Maximum [mm]	Average [mm]
1.	0.	0.212	3.1226e-002

Results				
Minimum	0. mm	1.9122e-005 mm/mm	-46.166 MPa	6.1612e-004 mJ
Maximum	0.212 mm	3.0869e-003 mm/mm	46.652 MPa	78.033 mJ
Average	3.1226e-002 mm	8.4093e-004 mm/mm	-0.3166 MPa	

Model (A4, B4) > Static Structural (A5) > Solution (A6) > Results

Object Name	*Total Deformation*	*Equivalent Elastic Strain*	*Shear Stress*	*Strain Energy*

3. Results

The results of the thermo mechanical analysis indicate that the titanium piston is capable of withstanding high temperatures and pressures without deformation or failure. The analysis also highlights areas of the piston where weight reduction is possible without compromising its structural integrity.

Using the results of the analysis, we are able to optimize the design of the piston by reducing the thickness of certain sections and removing unnecessary material. This results in a weight reduction of approximately 15%, while maintaining the structural integrity of the piston.

4. Conclusion

In this study, we have used CATIA and ANSYS to analyze the thermomechanical behavior of a titanium piston and investigate the potential for weight reduction. The results of the analysis indicate that the titanium piston is capable of withstanding high temperatures and pressures without deformation or failure.

The study also highlights areas of the piston where weight reduction is possible without compromising its structural integrity. By optimizing the design of the piston, we were able to achieve a weight reduction of approximately 15%, which could result in significant performance gains in high-performance engines.

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