Transient state thermal analysis of a 4 stroke CI engine Piston

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Abstract - *This study employs ANSYS software to conduct a comparative investigation of the thermal behavior of an internal combustion (IC) engine piston made of four different materials, Aluminium Alloy, AlSi10Mg, Titanium Alloy (Ti-6Al-4V) and Gray Cast Iron. The goal is to examine the thermal behavior of the piston built of each material under various operating circumstances. The temperature distribution and heat flux within the piston for each material are the main topics of the simulations, which also consider a variety of boundary conditions. Results are given, compared, and their implications for choosing materials for IC engine piston applications are examined. This study illustrates the capability of ANSYS in simulating and comparing the thermal behavior of intricate mechanical systems and offers insightful information about the comparative thermal behavior of an IC engine piston constructed of four different materials.*

Key Words: **IC Engine, Heat flux, Temperature Distribution**

1.INTRODUCTION

The design and material choices used for internal combustion (IC) engine parts like pistons have a significant impact on the engine's overall effectiveness and performance. Thermal behavior of IC engine pistons is one of the crucial elements that might have a considerable impact on their performance. The engine's overall performance and dependability may be impacted by the high temperatures and pressures the piston is subjected to during operation. These conditions can also lead to material degradation and thermal strains. The thermal behavior of an IC engine piston made of four different materials—Aluminum alloy, AlSi10Mg, Titanium Alloy (Ti-6Al-4V) and Gray Cast Iron—is compared in this research using the ANSYS program. The goal is to examine the thermal response of the piston made of each material and offer details on how an IC engine piston made of various materials compares thermally. The study focuses on the temperature and thermal stresses within the piston for each material, while the simulations consider various thermal loads and boundary conditions.

The findings of this study offer useful knowledge for engineers engaged in IC engine design and optimization. This study can assist engineers in making the best material choice for the piston to achieve the desired performance and dependability of the engine by evaluating the thermal behavior of the piston constructed of various materials. The thermal behavior of the pistons in IC engines may be studied using the ANSYS simulations in an economical and effective manner, which is crucial as engine efficiency and environmental restrictions become more stringent.

1.1 Piston Terminology

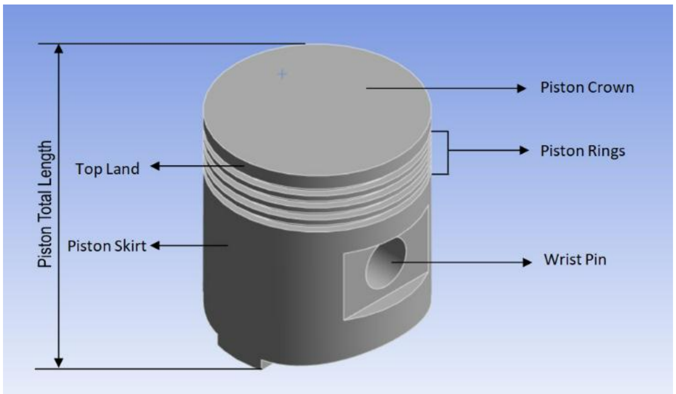


Fig 1.1: Piston Terminology

- The **crown**, which is the top of the piston, is made to resist the high pressure and high temperature of the combustion chamber.
- The lower part of the piston, called the **skirt**, acts as a guide to make sure the piston goes straight and stays in the right alignment with the cylinder bore.
- The **wrist pin**, which is another name for the piston pin, joins the piston to the connecting rod and enables reciprocating movement of the piston.
- **Piston rings**, which are used to seal the combustion chamber and transport heat to the

cylinder walls, are mounted to the piston's outer circle.

- The **total length of the piston** is length from piston crown to bottom of piston. Sum of the length of the upper platform, the length of the annular section and the length of the skirt.
- The portions on the piston between the piston rings known as "**ring lands**" give the rings structural support and keep them from spinning within the piston groove.
- The piston rings are held in position by the machining channels in the **ring grooves** of the piston.

1.2 Piston Design

Internal combustion engine piston design is a complicated procedure that considers a variety of aspects in order to obtain the best performance and efficiency. For the purpose of this analysis, we have taken dimensions of a 4-stroke diesel engine piston into account. We have used ANSYS software for the purpose of design.

S.NO.	Piston part	Dimension (mm)
1.	Length of the Piston	152
2.	Cylindrical bore/outside dia. Of the piston	140
3.	Thickness of the piston/head	9.036
4.	Radial thickness of the piston rings	5.24
5.	Axial thickness of ring	5
6.	Width of the top land	10
7.	Width of the other ring land	4

Table 1: Piston Dimensions

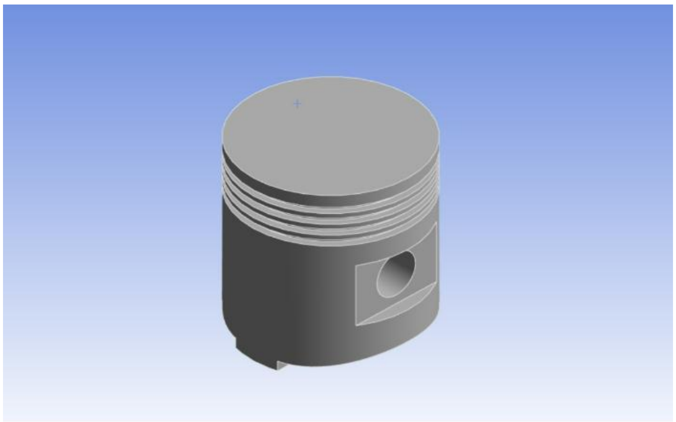


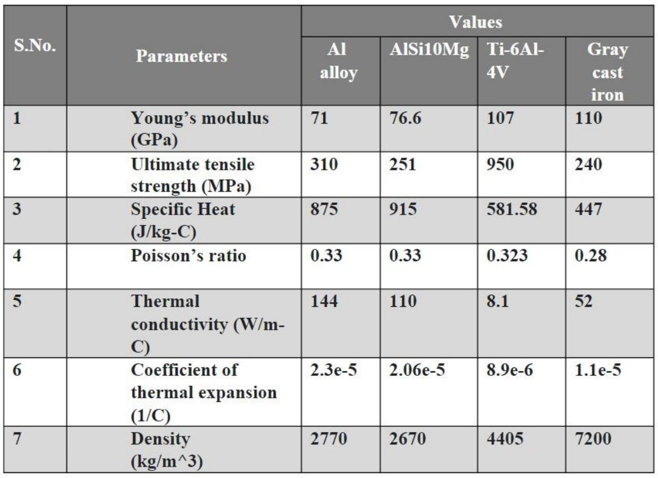
Fig 1.2: Model in ANSYS

2. Transient State Thermal Analysis

Thermal analysis of pistons is done to assess how well they can tolerate the high temperatures and thermal stresses that occur during engine running. We can find possible weak spots in the piston design and strengthen it for better heat dissipation and decreased thermal stresses by assessing temperature distribution and heat flux.

2.1. Selection of Material

Consideration of several parameters, including as thermal conductivity, specific heat capacity, thermal expansion coefficient, and strength, is necessary when choosing a material for a piston's thermal analysis. The best materials to employ in pistons are those that have the correct mix of these characteristics, resulting in an engine that runs reliably and effectively. Materials used for this project are Aluminium alloy, AlSi10Mg, Titanium alloy (Ti-6Al-4V) and Gray cast iron.



S.No.	Parameters	Values			
		Al alloy	AlSi10Mg	Ti-6Al-4V	Gray cast iron
1	Young's modulus (GPa)	71	76.6	107	110
2	Ultimate tensile strength (MPa)	310	251	950	240
3	Specific Heat (J/kg-C)	875	915	581.58	447
4	Poisson's ratio	0.33	0.33	0.323	0.28
5	Thermal conductivity (W/m-C)	144	110	8.1	52
6	Coefficient of thermal expansion (1/C)	2.3e-5	2.06e-5	8.9e-6	1.1e-5
7	Density (kg/m^3)	2770	2670	4405	7200

Table 2: Materials Properties

2.2. Generating Mesh

To generate mesh, the default mode was used with tetrahedral elements, the solid model being meshed into 23290 elements and 41502 nodes.

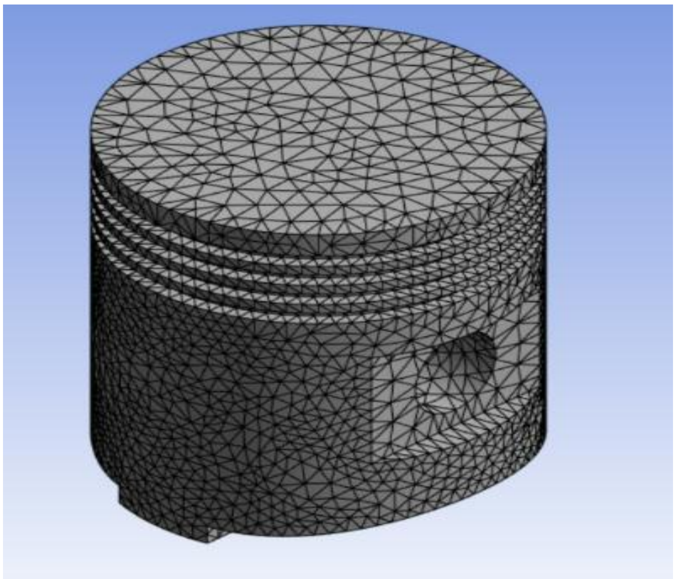


Fig 2: Mesh Model in Ansys

3. RESULTS

We have performed transient state thermal analysis on the piston and compared results of four materials with the boundary condition of temperature being set as 400°C at the top of piston.

Aluminium Alloy

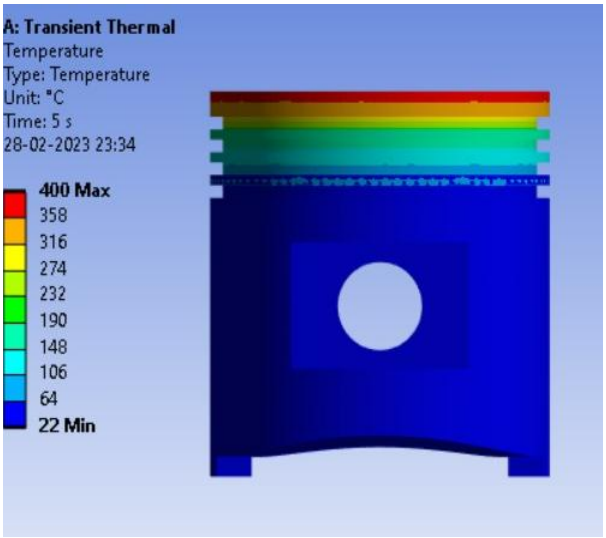


Fig 3.1: Temperature Distribution of Al Alloy

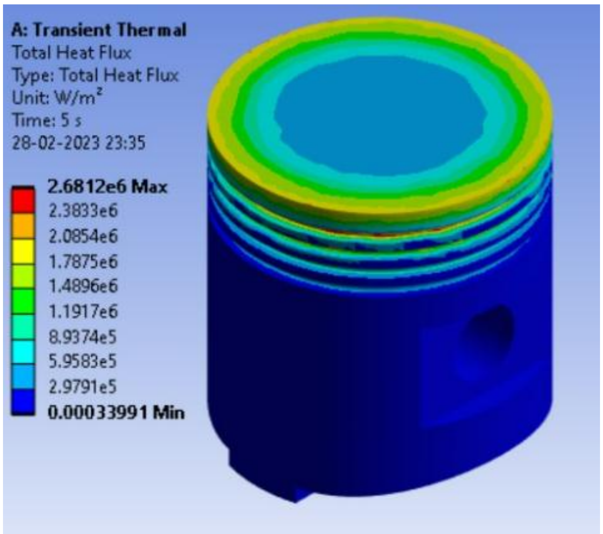
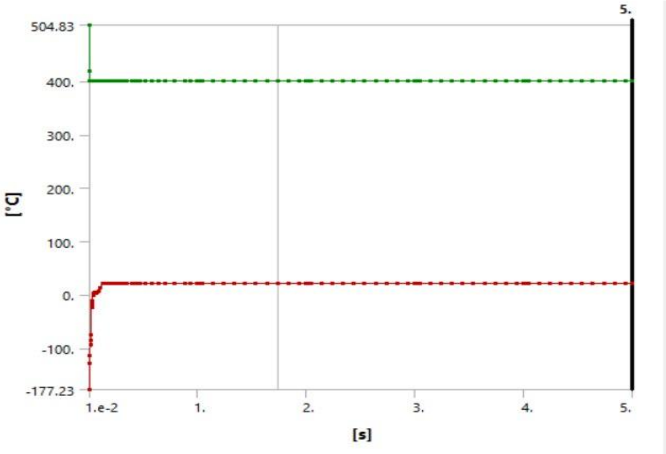
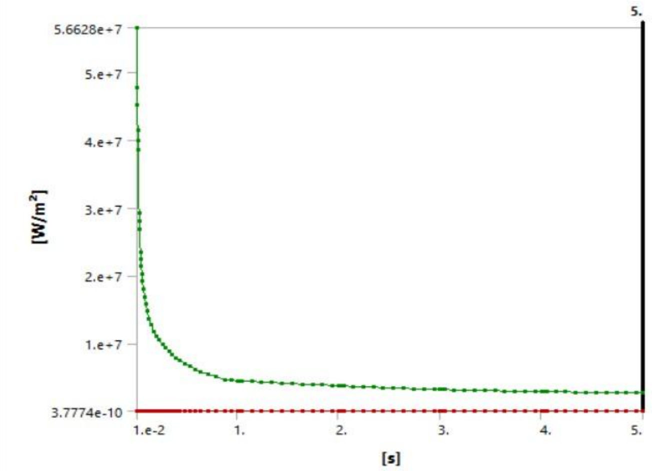


Fig 3.2: Heat flux distribution of Al Alloy



Graph 3.1: Time vs Temperature for Al Alloy



Graph 3.2: Time vs Heat flux for Al Alloy

AlSi10Mg

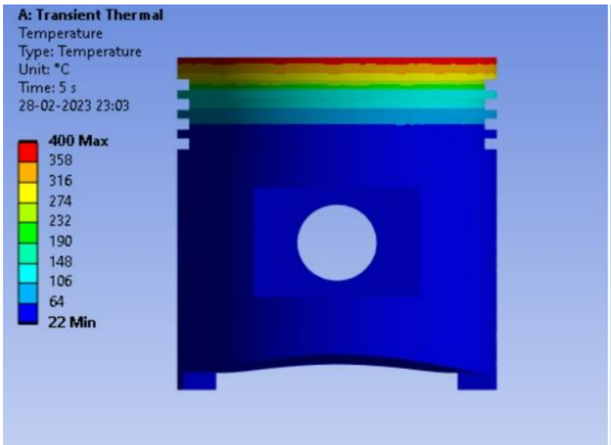


Fig 3.3: Temperature Distribution of AlSi10Mg

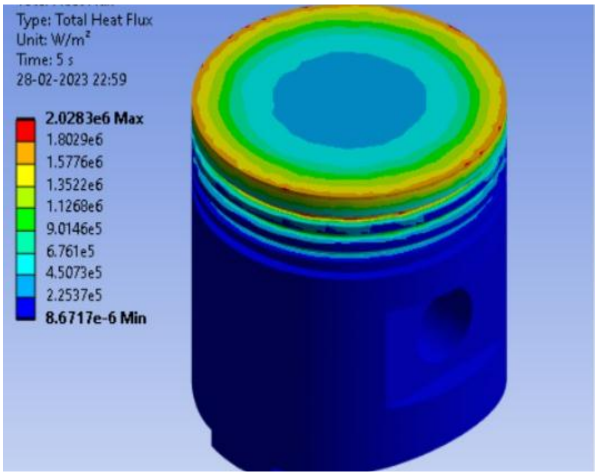
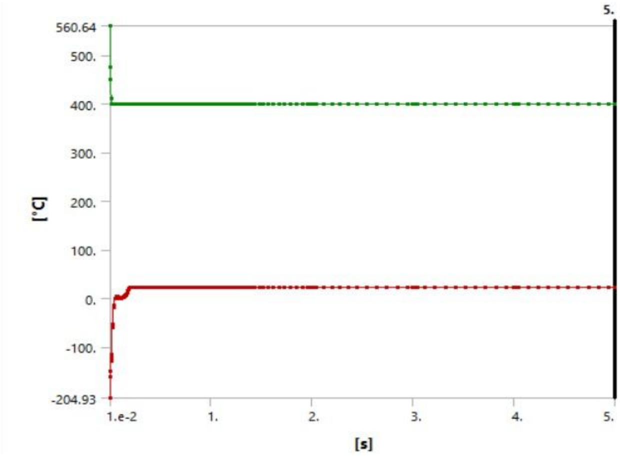
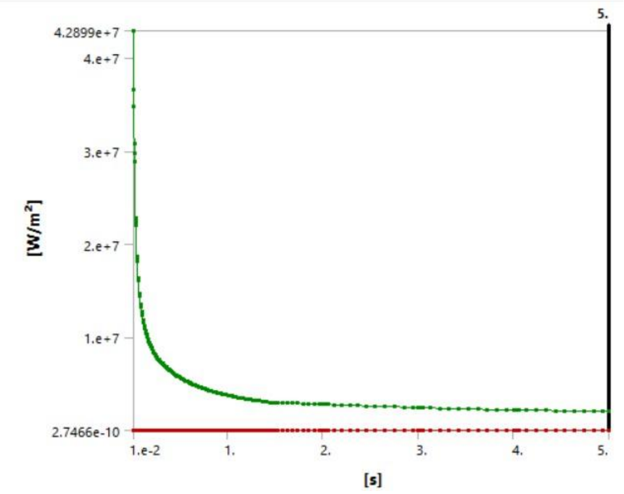


Fig 3.4: Heat flux distribution of AlSi10Mg



Graph 3.3: Time vs Temperature for AlSi10Mg



Graph 3.4: Time vs Heat flux for AlSi10Mg

Ti-6Al-4V

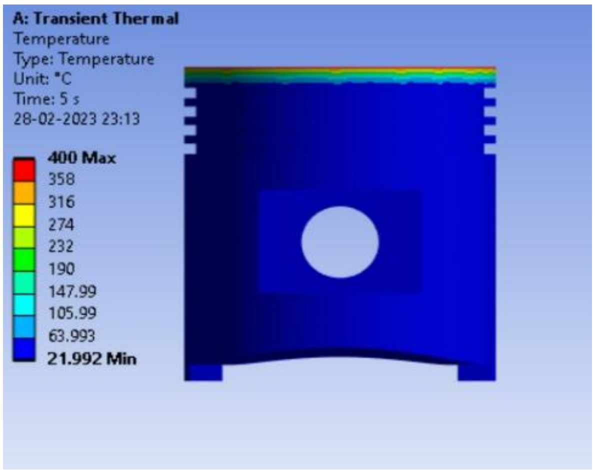


Fig 3.5: Temperature Distribution of Ti-6Al-4V

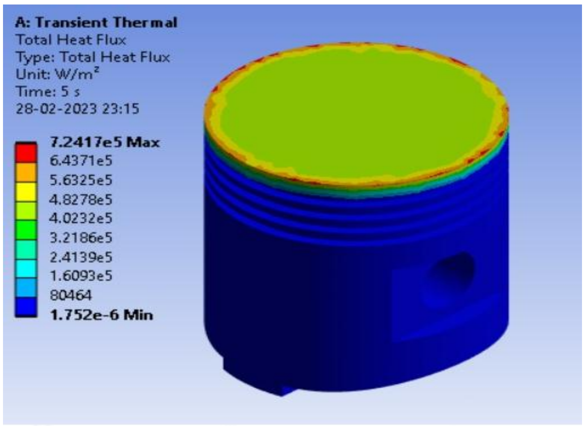
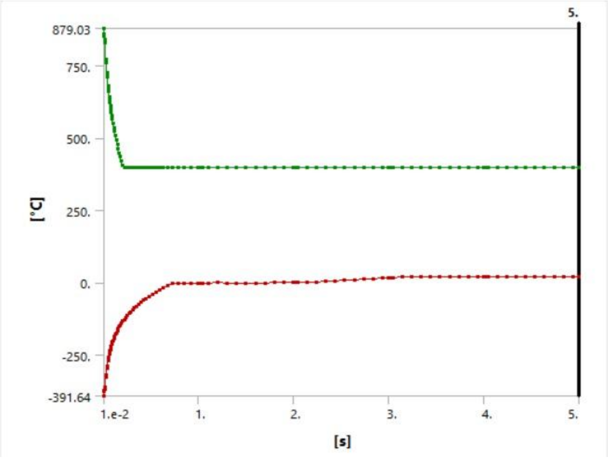
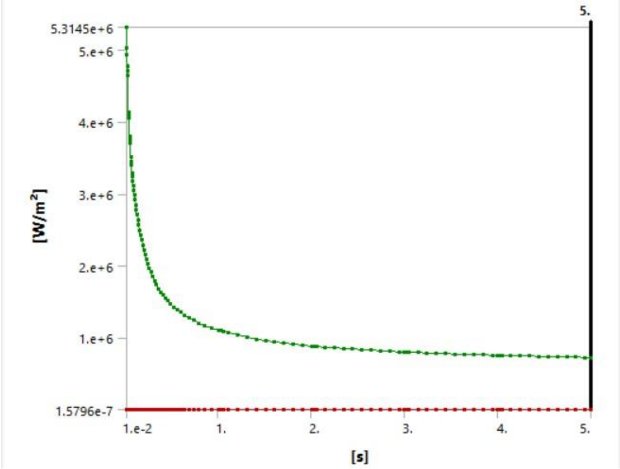


Fig 3.6: Heat flux distribution of Ti-6Al-4V



Graph 3.5: Time vs Temperature for Ti-6Al-4V



Graph 3.6: Time vs Heat flux for Ti-6Al-4V

Gray Cast Iron

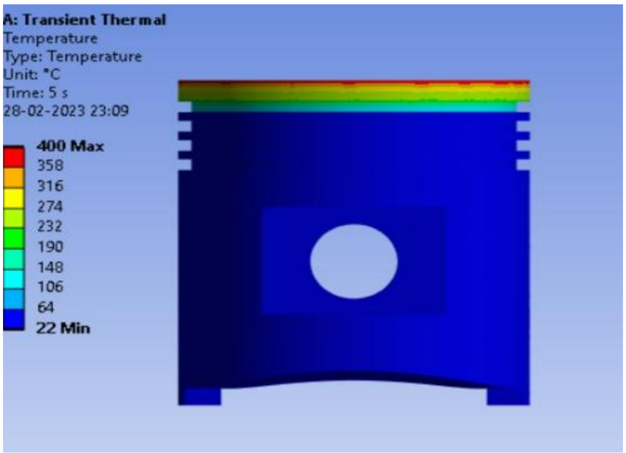


Fig 3.7: Temperature Distribution of Gray Cast Iron

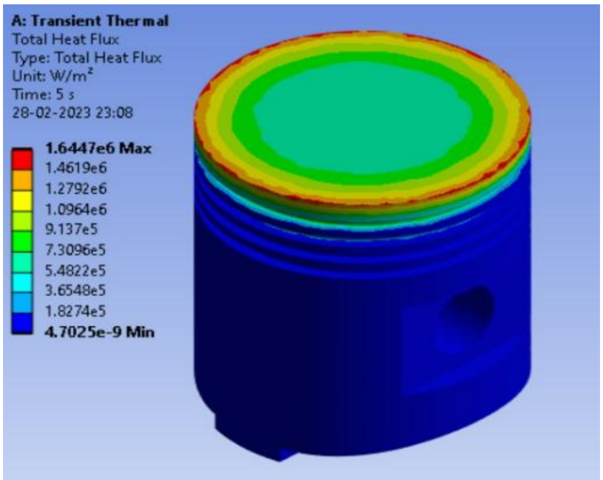
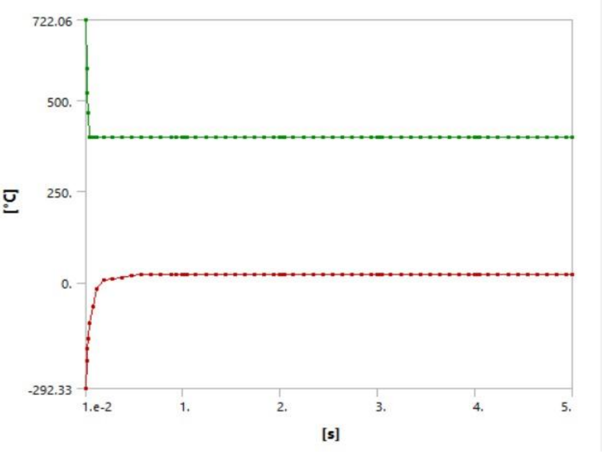
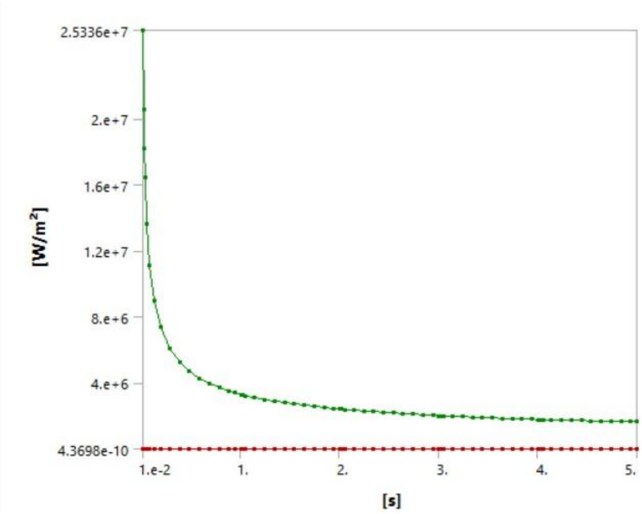


Fig 3.8: Heat flux distribution of Gray Cast Iron

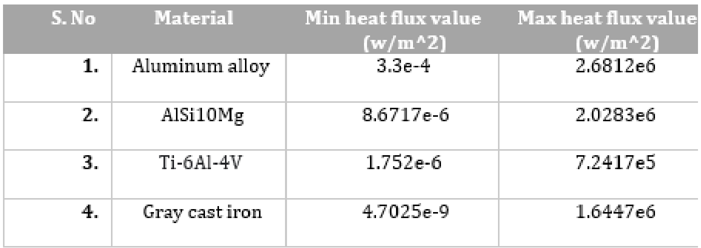


Graph 3.7: Time vs Temperature for Gray Cast Iron



Graph 3.8: Time vs Heat flux for Gray Cast Iron

The results from the transient state thermal analysis of piston are presented in a tabular format below:



S. No	Material	Min heat flux value (w/m^2)	Max heat flux value (w/m^2)
1.	Aluminum alloy	3.3e-4	2.6812e6
2.	AlSi10Mg	8.6717e-6	2.0283e6
3.	Ti-6Al-4V	1.752e-6	7.2417e5
4.	Gray cast iron	4.7025e-9	1.6447e6

Table 3: Results of Analysis

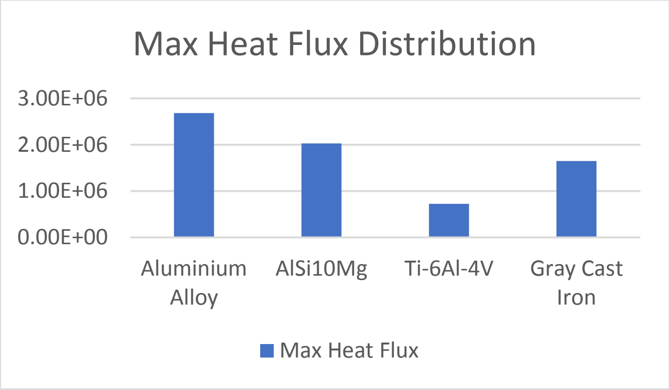


Chart: Max. heat flux distribution for different materials

The results of the thermal study of pistons constructed of various materials offer some intriguing new information about how well these materials transport heat. The substance that transfers heat the fastest is aluminium alloy, which has a maximum heat flux value of 2.6812e6 w/m2. The closest competitor, AlSi10Mg, has a maximum heat flux value of 2.0283e6 w/m2. The maximum heat flux values for Ti-6Al-4V and grey cast iron are lower, at 7.2417e5 w/m2 and 1.6447e6 w/m2, respectively.

CONCLUSION

- The alloy made of aluminium has a maximum heat flux value of 2.6812e6 W/m2, which is the highest. This shows that under specific operating situations, the aluminium alloy piston may face high heat loads, which could cause thermal stress and deformation. Nonetheless, the aluminium piston is also capable of effectively dispersing heat and maintaining lower temperatures under typical working conditions, as indicated by the lowest heat flux value of 3.3e-4 W/m2.

- The Ti-6Al-4V alloy, in contrast, has a maximum heat flux value that is substantially lower (7.2417e5 W/m2), indicating that it would be subject to less thermal stress and deformation than the aluminium alloy. However, the titanium piston may not be as efficient at dispersing heat under low-load circumstances, as indicated by the minimum heat flux value of 1.752e-6 W/m2.

- For both the lowest and maximum heat flux, grey cast iron and the AlSi10Mg alloy have intermediate values. In comparison to titanium alloy, the AlSi10Mg alloy has a higher maximum heat flux value, but a lower minimum heat flux value. The grey cast iron has a lower maximum heat flux value than the other materials, but it also has a lower minimum heat flux value, suggesting that its temperature distribution may be more consistent.

The materials' thermal conductivity and specific heat capacity are to blame for these outcomes. In comparison to Ti-6Al-4V and grey cast iron, aluminium alloy and AlSi10Mg have stronger thermal conductivities allowing them to transmit heat more effectively. It is crucial to remember that these results do not necessarily represent the materials' general performance in a piston application. While choosing a material for piston manufacture, other aspects such as mechanical qualities, price, and availability should also be taken into consideration. Overall, the study's findings can help engineers and designers make knowledgeable selections when choosing materials for piston applications.

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