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# ANALYSIS AND OPTIMIZATION OF PISTON OF IC ENGINE

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***Abstract:*** The main goal of this research is to look into the analysis of a piston with a design change in order to reduce volume and improve efficiency. This necessitated conducting a thorough thermal analysis. The investigation is focused on dynamic, model, and transient thermal analysis. The focus of this research is on performing analysis and material optimization in the piston. The piston is designed in two stages in this work: design and analysis. First, use the modelling Pro/E software to create the piston model according to the design specifications. After loading the piston model into the engineering simulation and 3D design software ANSYS, the boundary conditions are applied to the piston. Then several characteristics (stress and deformation) are analyzed, and the findings are quickly obtained. The piston is optimized for the piston material in this study. The thermal analysis is carried out to determine the overall heat flow in the existing piston under the specified temperature parameters. The temperature acting on the piston's surface is applied. The findings were also utilized to calculate the total heat flux of a given material.

***Index Terms* - Piston, FEA, ANSYS, Optimization, Aluminum alloy, Pro/E.**

## I. INTRODUCTION

A piston is a component of reciprocating IC engines. A cylinder confines the moving part, which is sealed shut by piston rings. In an engine, a piston rod and/or connecting rod transfer force from the expanding gas in the cylinder to the crankshaft. The piston, as a critical component of an engine, is exposed to cyclic gas pressure and inertial stresses when in use, which can cause fatigue damage to the piston, such as piston side wear, piston head/crown cracks, and so on. The most stress is found at the piston's upper end, according to the research, and stress concentration is one of the key reasons of fatigue failure.

## II. LITERATURE REVIEW

Dr. Ahmed A. et al. present an analytical study on the heat effects on the diesel engine piston and its compression rings during contact between the piston and the compression rings. The piston and its compression rings are modelled in three dimensions using the ANSYS V8 software. [1] The thermal conductivity of piston material and contact area, as well as their impact on the piston and piston compression rings, have been investigated. Materials with high thermal conductivity are chosen over materials with low thermal conductivity, according to the findings of this study. “Thermal analysis and Optimization of I.C. Engine” Author by A. R. Bhagat, Y. M. Jibhakate, Vol2, pp2919- 2921,2012, Thermal analysis is a discipline of materials science that studies how materials' properties vary when temperature changes. The oil could be used to improve the performance of I.C. engines. [2] Krisztina Uzunean et al. propose thoughts about heat transfer processes in piston heads in their article. Simple thermal networks to multidimensional differential equation modelling are among the methodologies used. The temperature of the components determines the majority of heat transmission in the combustion chamber of an internal combustion engine. [3] A study titled “Design Optimization of Piston of an IC Engine and Investigations on its Influence on Overall Assembly” was published by M. Praveen Kumar et al. This thesis study investigates and analyses the stress optimization of pistons for I.C. engines using FEM. The forces created by combustion are taken into account to avoid piston failure. The intensity of structural stresses should be kept to a minimum to achieve acceptable permitted limits. [4] “Design and Analysis of SiC Composite Material Pistons” A piston made of composite material (aluminium silicon carbide) has been designed and tested satisfactorily. After ageing, a composite piston made of metal matrix retains outstanding strength even in hostile environments. Silicon carbide has been demonstrated to have less deformation, stress, and temperature distribution than aluminium. Some of the restrictions of the aluminium piston are overcome by the aluminium silicon carbide piston. [5] C. V. Rajam et al in the paper “Design Analysis and Optimization of Piston using CATIA and ANSYS” state that the deflection due to applied pressure is greater after optimization than before optimization, and this value is used for design considerations. [6] The deformation of the piston determines the majority of the stress distribution on the piston. As a result, the piston crown needs to be strong enough to prevent distortion and thus stress concentration. Vinay V. Kuppast et al published a paper named “Thermal Analysis of Piston for the Influence on Secondary motion” this study has determined the impact of the thermal load created by the burning of fuel inside the cylinder on piston deformation and thermal stresses. The findings could be applied to the development of new IC engines. [7] The research was published in Nano Engineering.

## III. NEED OF THERMAL ANALYSIS OF PISTON

Though there is lot of development can be seen in engine and piston too, large number of piston damages is matter of concerned. Piston damages may have different origins like mechanical stresses, thermal stresses. Different causes of piston damages are as follows:

**1) Seizure Due to Insufficient Clearances:** The clearance between the piston and the cylinder wall is set to provide for less friction during relative motion between the former and the latter. During engine operation, the piston reaches a much higher temperature than the cylinder, resulting in distinct thermal expansion behaviour of the piston and cylinder.

**2) Seizure Due to Lack of Lubrication:** If there is enough room between the cylinder wall and the piston, this form of seizure happens. Due to high temperatures or gasoline inundation, the oil film breaks down during the process. Components such as the piston, cylinder, and piston ring rub against each other without any lubrication, causing seizure and severely worn surfaces in a short period of time.

**3) Seizures Due to Overheating:** When a seizure occurs as a result of overheating, the lubricating coating breaks down due to the high temperature. At first, this results in a mixture of friction and separate friction marks. As the damage worsens, the material warms up even more, and the cylinder liner and piston become completely lubricated.

With all the above mentioned causes of piston damage, damage due to abnormal combustion is also prominent one in case of a gasoline engine. Thus for the design point of view it is necessary to analyze the piston of internal combustion engine thermally and select the proper material for it among the available alternatives. [8] [9] [10] With an objective to analyze the piston of internal combustion diesel engine and to select better material for the piston between cast iron and aluminium alloy numbers of analysis are carried in a Finite Element Analysis code named ANSYS Workbench.

## IV. METHODOLOGY

ANSYS is a finite element analysis (FEA) software suite that may be used for a variety of applications. While solving any problem in ANSYS one has to go through different steps like solving any analytical problem, these steps are:

1. Build geometry
2. Define material properties
3. Generate mesh
4. Apply loads
5. Obtain solution
6. Present result

ANSYS is capable for structural analysis, thermal analysis, fluid flow analysis and vibration analysis. Complete analysis of any component is carried out in three parts listed as follows:

1. Pre-processing
2. Solver
3. Post processing

To carry out thermal analysis of piston of CI engine, the engine of Tata Indica V2 DLS BSII Engine is selected which has specification as follows:

**Table 1.** Engine Specifications

| Engine Type | In-Line |
|---|---|
| Engine Description | 1.4L 53.5bhp 4 cyl |
| ECU Engine Displacement (cc) | 1396(cc) |
| No. of Cylinders | 4 |
| Maximum Power | 53.5@5,500 (PS@rpm) |
| Maximum Torque | 8.5@2,500 (kgm@rpm) |
| Bore x Stroke | 75 x 79.5 mm |
| Compression Ratio | 22:01 |

## V. MODELING AND ANALYSIS

The finite element method (FEM), also known as finite element analysis (FEA), is a computational methodology that is used in engineering to generate approximate solutions to boundary value issues. Simply put, a boundary value issue is a mathematics problem in which one or more dependent variables must satisfy a differential equation everywhere inside a known domain of independent variables while also satisfying specific boundary conditions.

STEPWISE APPROACH FOR THERMAL ANALYSIS

The complete thermal analysis is divided in to 4 steps which are as follows.

1) Create CAD geometry in Pro/E
2) Preprocessing.
3) Solver
4) Post processing.

The 3D geometry of piston, gudgeon pin and connecting rod was created in the Pro Engineer and assembled it as a single unit as per the engine specifications.

**Table 2.** Piston and Piston Ring Specifications

| | | | |
|---|---|---|---|
| Piston diameter =74.94mm | | | |
| Piston Length =73mm | | | |
| Piston Ring | | | |
| | Ring Thickness in mm | Axial clearance in piston groove in mm | Butt Clearance in mm |
| 1st Compression Ring | 1.99 | 0.065 | 0.2 |
| 2nd Compression Ring | 1.99 | 0.040 | 0.3 |
| 3rd Oil Control Ring | 2.99 | 0.030 | 0.2 |

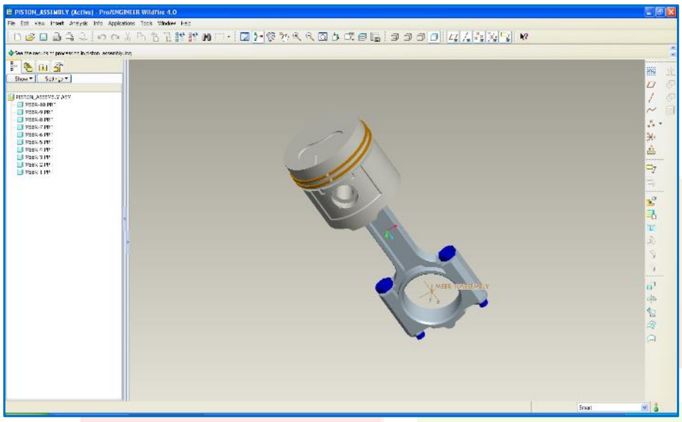

**Figure 1:** Piston Assembly in Pro/E

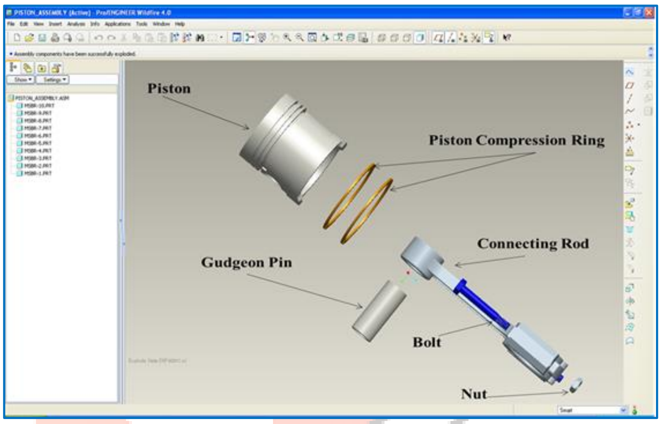


**Figure 2:** Exploded view of Piston assembly in ProE.

Preprocessing includes defining the model, defining the material properties of the geometry, defining the element types to be used, Define the element connectivity (mesh the model) and defining the physical constraints (boundary conditions). [11] [12] While doing the transient thermal analysis, environmental condition steady state thermal is considered with ambient temperature 28$^{O}$C. Import the Piston Geometry: From the ANSYS Design modular we have imported the piston assembly and generated the model into the ANSYS workbench FE code.

Material Properties for Piston: For the high performance piston in automobile piston of Al-Si alloy is used and for comparative study we have used cast iron. Hence for the analysis purpose we have selected NASA 398 Aluminum alloy and cast iron. NASA 398 hypereutectic alloy (16% w. Si): Similar to SAE A390.0, Mahle 126, Zolloy Z16 and AE 425. For high strength and wear resistance applications at increased temperatures, a heat treatable Al-Si alloy consists of small polygonal primary silicon particles evenly distributed in an aluminium matrix. It has the following properties:

- Density: 2.76 g/cm3 (0.099 lb/in3) at 25°C for NASA 398,
- Liquidus temperature: 619°C (1156°F) for NASA 398.
- Solidus temperature: 486°C (907°F) for NASA 398,
- Solidification temperature range: 619°C-486°C for NASA 398

**Table 3.** Properties of Aluminum Alloy for Thermal Analysis.

| | |
|---|---|
| Young's Modulus | 5.54e+010 Pa |
| Density | 2760. kg/m³ |
| Thermal Expansion | 19.93 1/°C |
| Thermal Conductivity | 131.4 W/m·°C |
| Specific Heat | 990. J/kg·°C |

**Meshing the Geometry in ANSYS Workbench**

After importing the geometry, the mesh needed to be prepared, which is a crucial but time-consuming operation. It's because the quality of the mesh affects the accuracy of the finite element analysis. The application of components and nodes to existing geometry is known as mesh generation. To generate the mesh on geometry in which the tetrahedrons patch conforming mesh is generated, we choose the Automatic method control. To masher, the patch conforming tetrahedron mesh has the following features:

**Table 4.** Properties of Cast Iron for Thermal Analysis.

| | |
|---|---|
| Young's Modulus | 1.1e+011 Pa |
| Density | 7200. kg/m³ |
| Thermal Expansion | 1.1e-005 1/°C |
| Thermal Conductivity | 52. W/m·°C |
| Specific Heat | 447. J/kg·°C |

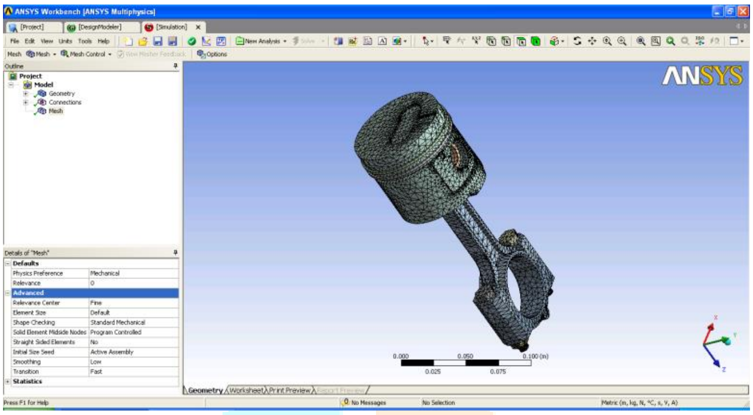

**Figure 3:** Meshed Geometry

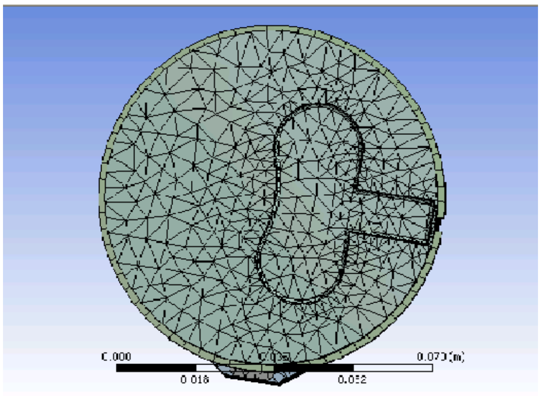

**Figure 4:** Piston Crown Mesh

The mesh is generated with 90069 nodes and 44443 elements. The meshing is generated till the overlapping of elements, negative element not generated. Fig 4.3 shows the tetrahedron mesh on the piston geometry.

**Thermal Boundary Conditions**

The thermal boundary conditions consist of applying a convection heat transfer coefficient and the bulk temperature, and they are applied to the piston crown, piston ring land sides , piston ring groove lands. At the piston crown a constant temperature of about 400 $^0$C is applied .The conditions are listed as follows:

**a) Boundary Conditions on Piston Crown Surface**

Depending on equation (2)and at the mean gas pressure equal to (7.1 bar ) ,the bulk temperature is equal to ( 925 K ) , and piston velocity equal to ( 5.5 m/sec), so the heat transfer coefficient is equal to :

hg=376.95 W/m$^2$K …(4.1)

**b) Boundary Conditions on the Piston Ring Land Sides and Piston Skirt**

A convection heat transfer coefficient (h) equal to (1111.725 W/m$^2$ K) which is computed from equation 4.1 is applied to the areas which are signaled by white spots as shown in Figure 4.5.

**c) Boundary Conditions on Piston Ring Groove Lands**

Depending on equation 4.1 the heat transfer coefficient (hr) is equal to (444.69 W/m$^2$ K) being applied between the side land of the grooves and the inner face of the rings.

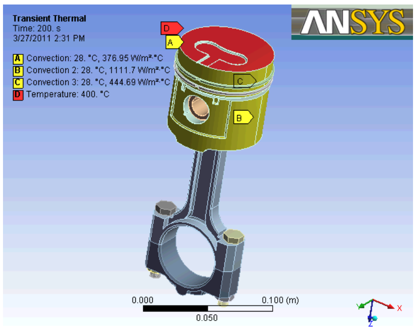


**Figure 5:** Boundary Conditions on Piston.

**SOLVERS**: During the solution phase, finite element software assembles the governing algebraic equations in matrix form and computes the unknown values of the primary field variable(s).

**POST PROCESSING:** In this work the temperature distribution profile on the piston geometry is obtained which would be helpful to decide the critical region on the piston. The temperature results generated by finite element analysis are viewed in ANSYS post processor.

## VI. RESULTS AND DISCUSSION

The temperature is defined as the measure of the molecular activity of a substance where the greater the movement of the molecules the higher the temperature. Since piston and piston compression rings are subjected to non-constant thermal loads from region to region, the temperatures of the piston and the piston compression rings is constant but is distributed along piston body from maximum values to minimum ones .The maximum values of the temperatures are studied according to their thermal effects on the temperature distribution.

### TEMPERATURE DISTRIBUTION ON PISTON OF ALUMINUM ALLOY

In this project, two materials are used as piston material for thermal analysis of piston of an internal combustion engine piston. First one is aluminum alloy which is well known piston material and the second one is cast iron. The temperature distribution in the piston and the piston compression rings in a piston made of aluminum alloy are shown in figure 5.1. The maximum temperature in the piston is equal to 400$^0$C and the minimum temperature is equal to 72.823$^0$C.The maximum temperature in the first compression ring equal to 322.8$^0$C and the maximum temperature in the second compression ring is 300$^0$C.Figure 5.2 shows the heat flux distribution on the piston made aluminum alloy, it is very clear from the figure that heat flux is more concentrated at the peripheral surface of the piston crown and with magnitude of 2.5 ×$10^6$ $\frac{W}{m^2}$. It decreases towards the lower part of the piston assembly to the value of 0.0052 $\frac{W}{m^2}$.

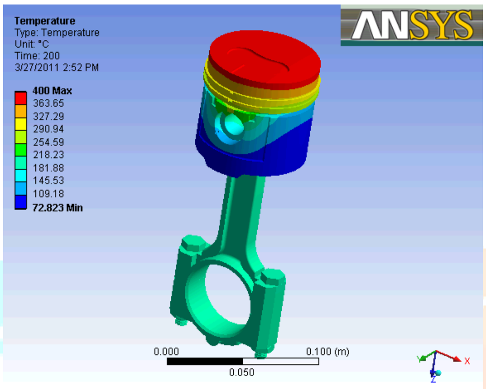


**Figure 6:** Temperature Distribution on Piston Made of Aluminum Alloy

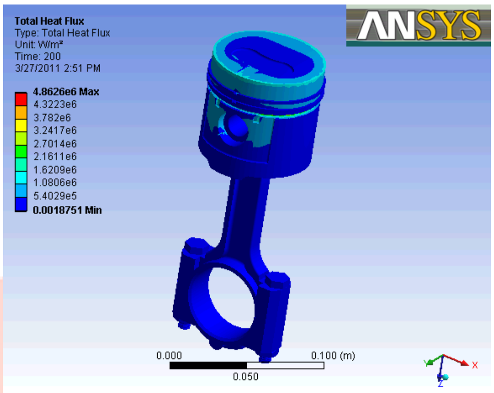


**Figure 7:** Heat Flux Distribution in Piston Made of Aluminum Alloy

### TEMPERATURE DISTRIBUTION ON THE PISTON MADE OF CAST IRON.

In the piston made of cast iron material, the temperature distribution of piston and it's compression ring is shown in the figure 5.2 .From it is very clear that the maximum temperature in the piston is equal to 400$^0$C and minimum temperature is equal to 38.2920C .The maximum temperature in the first compression ring is equal to 273.67$^0$C while in the second ring maximum temperature is equal to 246.98$^0$C.

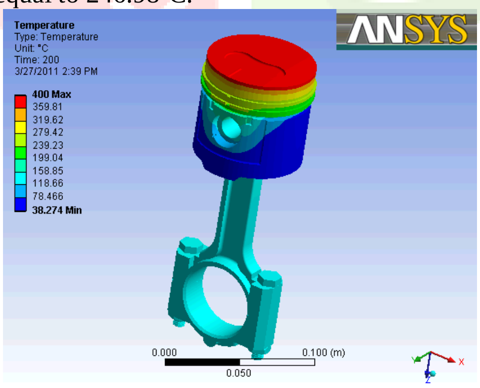


**Figure 8:** Temperature Distribution in the Piston Made of Cast Iron.

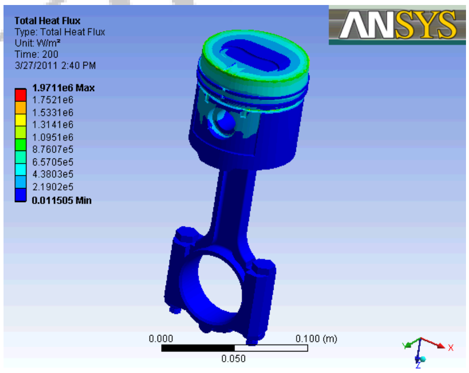


**Figure 9:** Heat Flux Distribution in the Piston Made of Cast Iron.

Figure 9 heat flux distribution in the piston made up of cast iron shows that the heat flux is more concentrated at the peripheral surface of the piston with the magnitude of 8.7× 105 $\frac{W}{m^2}$. It goes on decreasing towards the lower portion of the piston skirt and assembly with a least value of 3.2 × 105$\frac{W}{m^2}$.

**A COMPARISON ALUMINUM ALLOY PISTON AND CAST IRON**

A comparison between a piston made of aluminum alloy and one that made of cast iron clears that the maximum temperature region in the piston of cast iron is less than that of the aluminum alloy.

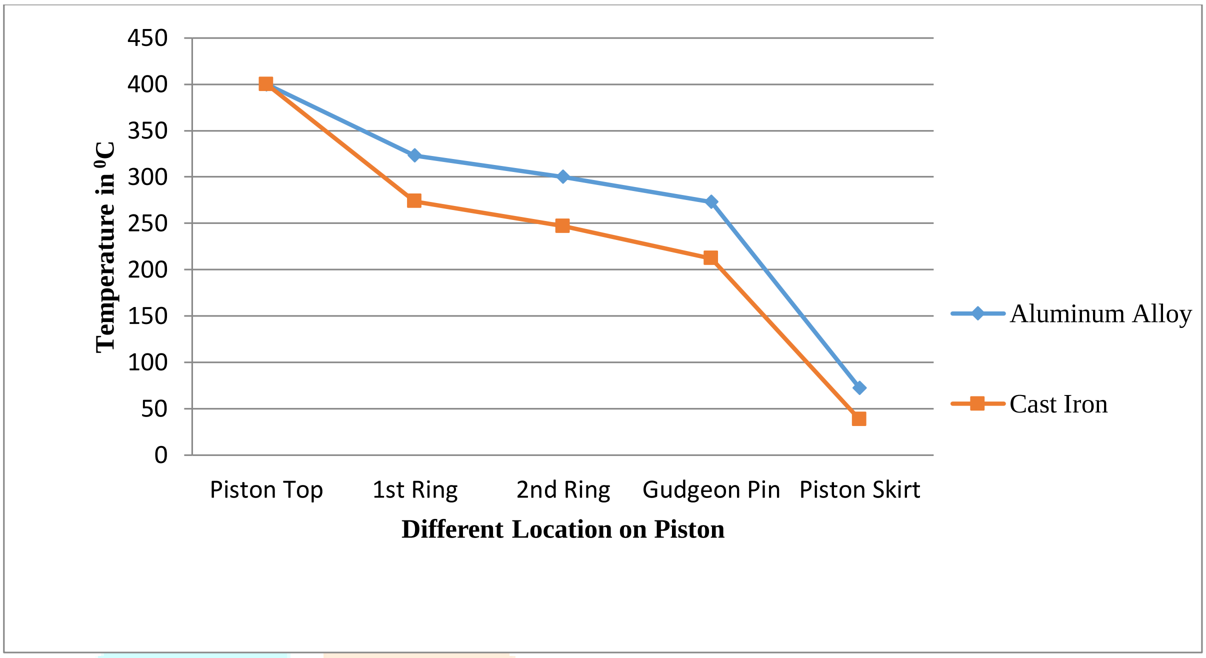


**Figure 10:** Temperatures at Different Location on Piston of Cast Iron and Aluminum Alloy

Figure 11 shows the comparison in the heat flux distribution in the piston made of cast iron and aluminum alloy. It is very clear from the graph that the value of heat flux in both cases is minimum at the top of the piston. This low value of heat flux at the top is low due to the larger area at the top than at any part of the piston. Moreover ,the values of heat flux at other points on the piston like piston ring and skirt are more for aluminum alloy piston than that of cast iron piston because aluminum is having greater conductivity than cast iron.

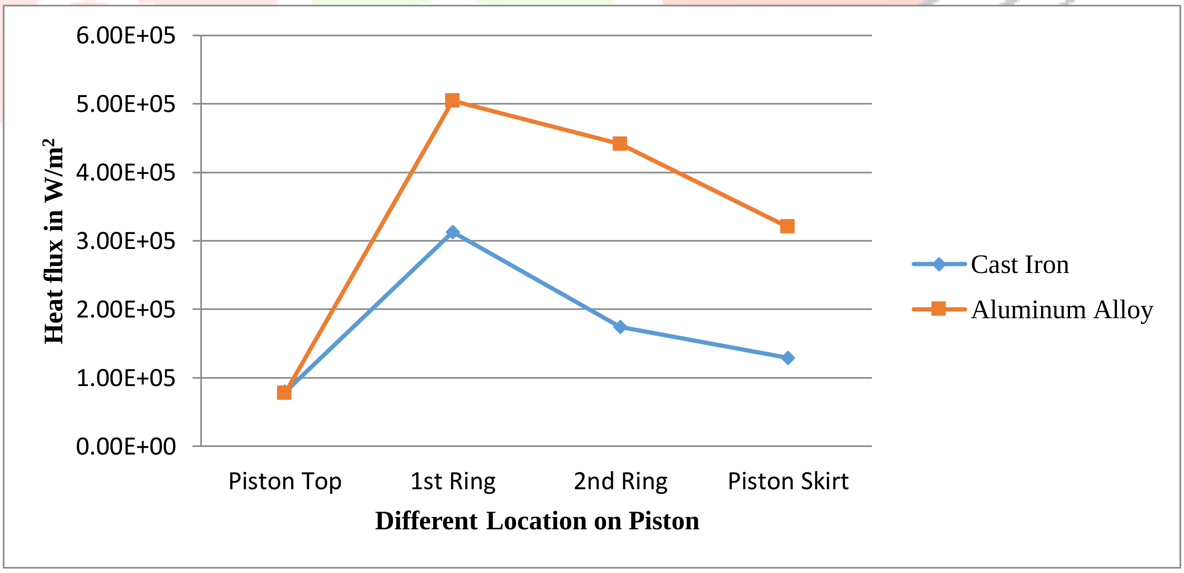


**Figure 11:** Heat Flux at Different Location on Piston of Cast Iron and Aluminum Alloy.

## VII. CONCLUSION

The results of the thermal study of an internal combustion engine piston yielded several important insights. The temperature is highest at the top of the piston and drops to the lowest at the piston skirt. The temperature profile of a cast iron piston and an aluminium alloy piston differs, with the cast iron piston seeing a greater temperature decrease than the aluminium alloy piston. The value of the heat flux is greatest at the peripheral surface of the piston crown for both aluminium and cast iron pistons.

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