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Structural & Thermal Analysis of Diesel Engine Piston by Changing the Number of Ribs and Materials

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Abstract

A piston is a component of reciprocating engines, reciprocating pumps, gas compressors, hydraulic cylinders and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. The power produced by the engine & its efficiency depends on piston. In this paper both Structural & Thermal Analysis is carried out on Diesel engine piston considering three materials such as Aluminum Alloy (Al6061) & Forged Steel also by varying number of ribs. For this Analysis, Modeling of a piston is done using Catia V5 Software & then it is imported into Ansys Workbench. Stress, Strain & Deformation Values are decreased with the increase of Ribs in the Piston Design. The amount of heat flux is more for a piston provided with six ribs. Considering both Structural & Thermal Analysis it is observed that Aluminum Alloy with EIGHT Ribs has shown good results

Keywords: *cylinder piston, heat flux, structural analysis, thermal analysis, deformations, stress-strains*

1. Introduction

The piston, a fundamental component in internal combustion engines, plays a pivotal role in transforming energy and powering various mechanical systems [1]. Essentially a cylindrical piece of metal, typically made of aluminum alloy, the piston moves up and down within a cylinder as part of the engine's combustion process. The primary function of a piston is to convert the pressure generated by the combustion of fuel and air into mechanical motion [2]. This occurs within the engine's cylinder, where the piston moves in response to the expanding gases produced during combustion. As the fuel-air mixture ignites, it creates high-pressure conditions that force the piston to move Downward, transferring this mechanical energy to the engine's crankshaft [3]. Pistons come in various designs and sizes, tailored to the specific requirements of different engines. They are often equipped with piston rings to create a tight seal between the piston and the cylinder wall, preventing gas leakage and ensuring efficient energy transfer [4]. Additionally, pistons are crucial components in maintaining the engine's overall performance, contributing to factors such as fuel efficiency, power output, and durability [5]. Beyond internal combustion engines, pistons find application in a range of mechanical systems, including hydraulic and pneumatic devices. Their versatility makes the essential power in diverse array of machinery, from automotive engines to industrial equipment [6].

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2. Literature Review

Krishnan S, Vallavi MS, Kumar M, Hari Praveen A highlights the potential of using Al 6061-SiC composite to improve piston durability and engine performance

Sinha, Sarkar, Mandal optimizing the engine's piston for better performance and efficiency. Piston dimensions are optimized in SolidWorks to minimize weight while keeping stress within limits. Different Thermal Barrier Coatings (TBC) are applied and analyzed in ANSYS for their thermo- mechanical performance

G Gopal, L. Kumar, K Reddy, and Rao the paper focuses on analyzing the assembly of a four-wheeler petrol engine's piston, connecting rod, and crankshaft. It highlights the need for both rigid-body and flexible-body analysis due to the need for both rigidity and mechanism function.

Koteswara Rao, Mansoor Ahamed, Raju this research demonstrates the potential of using fly ash in aluminum-SiC MMCs to produce lighter and stronger pistons for car engines. This could lead to improved fuel efficiency and reduced emissions for vehicles.

Sonar, Chattopadhyay This research contributes to the ongoing pursuit of better pistons, ultimately paving the way for more efficient, reliable, and durable engines. Such advancements hold immense potential across various sectors, from automotive and transportation to power generation and industrial applications.

Muhammed Hilman Karem, Al Emran Ismail the assessment of different piston head geometry made of an aluminium and magnesium alloy. And by the static analysis they compared the stresses which are produced in a flat head piston and round head piston.

3. Methodology

In this paper the modelling of a cylinder piston is done by using CATIAV5, and the structural and thermal analysis was done by using ANSYS workbench 19.2 (student version). Figure 1, 2 & 3 shows the modelling of piston with 4, 6, 8 ribs are done in Catiav5 CAD software which is imported in Ansys 19.2 student version to perform structural and thermal analysis in the Ansys workbench 19.2. From the Table 1, 2 and 3 specifies the engine, materials and piston dimensions.

Table 1 Engine Specifications

Type	4-stroke, air cooled, single cylinder
Fuel	Diesel
Number of cylinders	Single cylinder
Bore	100 mm
Stroke	125 mm
Fuel consumption	0.15 Kg/BP/Hr.
Gas Pressure	5 MPa
IMP	0.75 MPa
Efficiency	80 %
Speed	2000 rpm

Table 2 Materials Properties

S. No	Material Type	Young's Modulus (GPa)	Poisson's Ratio	Density (Kg/m^3)	Thermal conductivity (W/m°C)
1	Forged Steel	221	0.3	7750	51
2	Aluminum Alloy (Al6061)	68.9	0.33	2710	174

Table 3 Piston Dimensions

S.No	Description	Nomenclature	Value in mm
1	Thickness of piston head	tH	16
2	Diameter of Piston	D	100
3	Radial width of piston ring	T1	3
4	Axial thickness of piston ring	T2	3
5	Width of top land	B1	18
6	Width of ring land	B2	2.5
7	Thickness of piston barrel at the top end	T3	11.3
8	Length of skirt	Ls	90
9	Length of piston pin in the connecting rod bushing	L1	45
10	Piston pin diameter	D0	35

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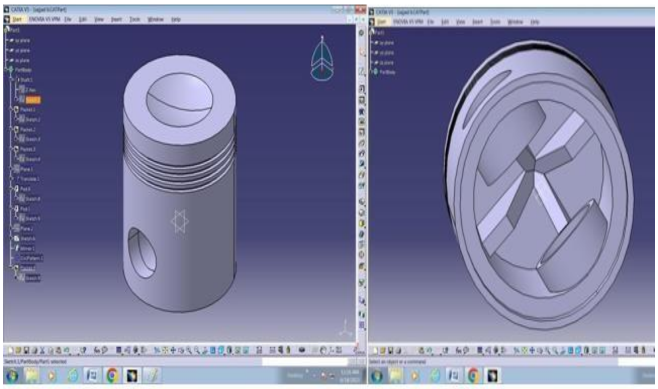

Figure 1 3D Modelling of piston

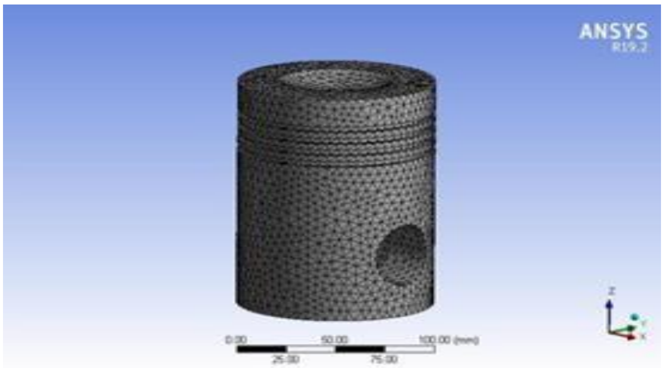

Figure 2 Meshed Modeling Ansys Workbench

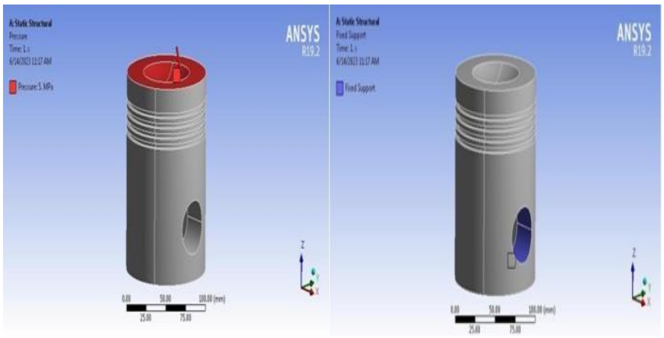

Figure 3 Boundary conditions on piston

4. Results and Discussion

4.1 Structural Analysis

4.1.1 Material Type: Forged steel

Piston with Four Ribs

Figure 4, 5 & 6 shows the Deformation, Strain & Stress for the Diesel Engine Piston which is made of Forged Steel & Provided with FOUR number of Ribs. The result shows Maximum Deformation of 0.0142 mm, Strain of 0.0004 mm & Stress Value of 90.99 MPa.

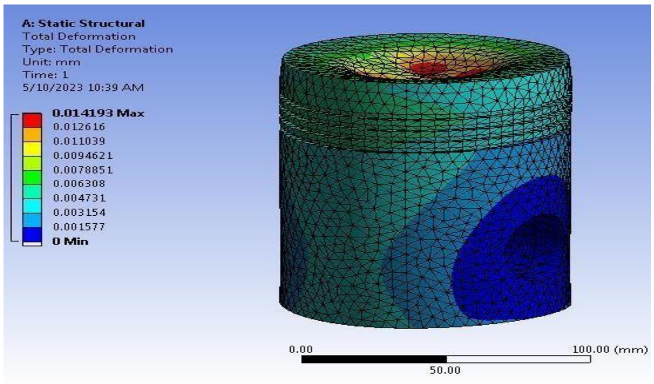

Figure 4 Total Deformation

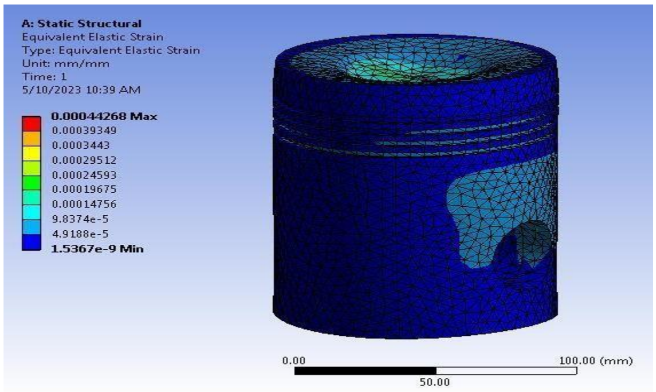

Figure 5 Vonmises Strain

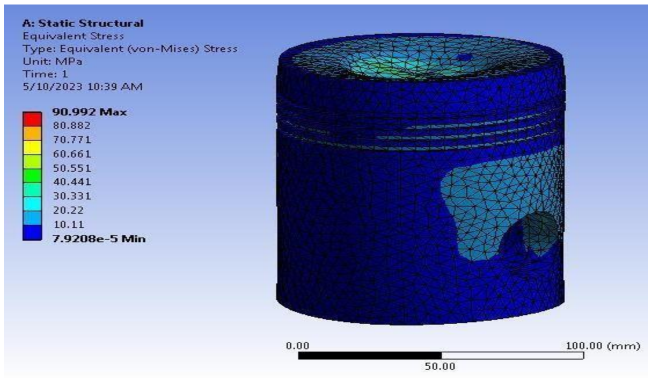

Figure 6 Vonmises stress

Piston with Six Ribs

Figure 7, 8 & 9 shows the Deformation, Strain & Stress for the Diesel Engine Piston which is made of Forged Steel & Provided with SIX number of Ribs. The result shows Maximum Deformation of 0.0117mm, Strain of 0.00039mm & Stress Value of 79.68 MPa

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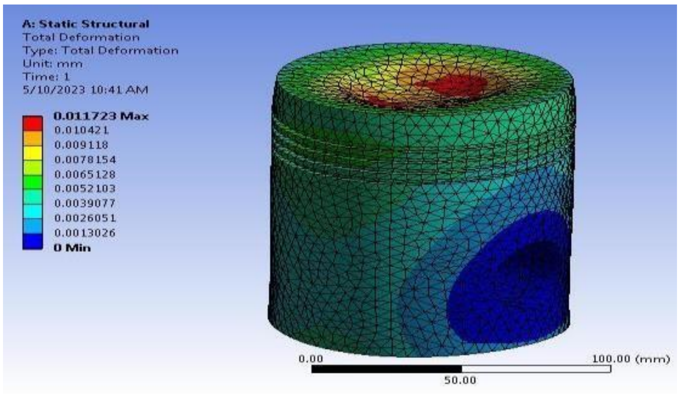

Figure 7 Total Deformation

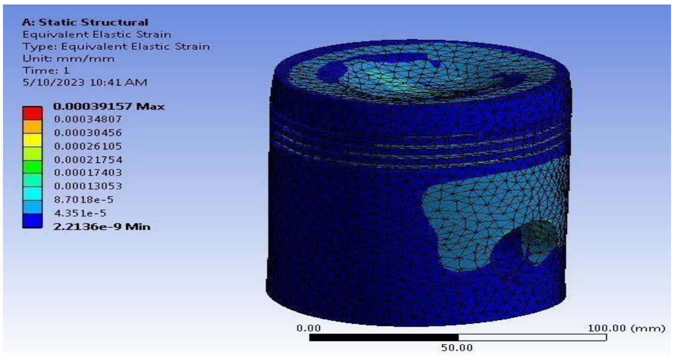

Figure 8 Vonmises Strain

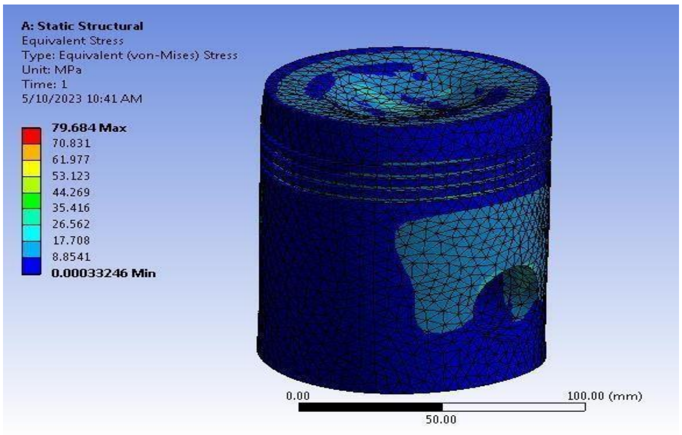

Figure 9 Vonmises Stress

Piston with Eight Ribs

Figure 10, 11 & 12 shows the Deformation, Strain &Stress for the Diesel Engine Piston which is made of Forged Steel & Provided with EIGHT number of Ribs. The result shows Maximum Deformation of 0.0099 mm, Strain of 0.00034 mm & Stress Value of 68.97 MPa.

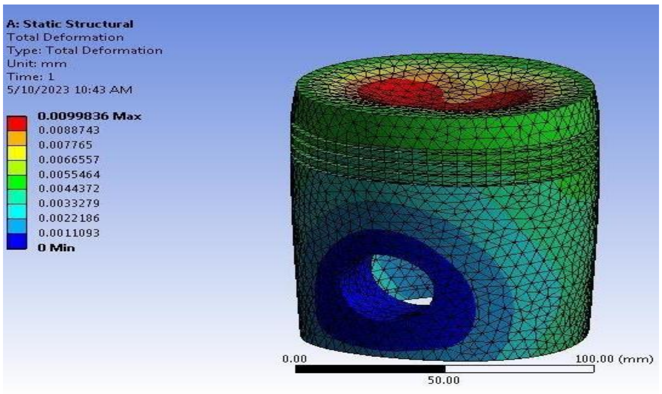

Figure 10 Total Deformation

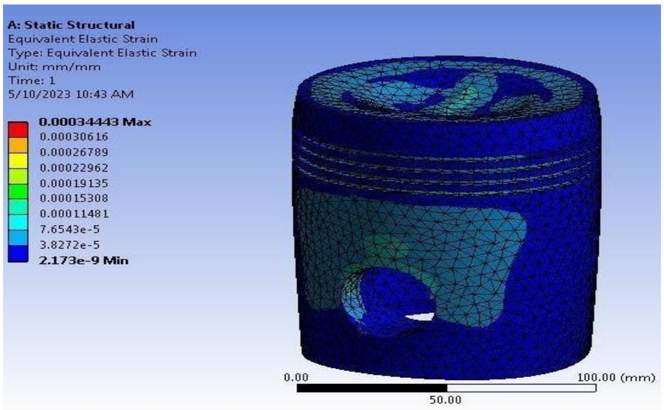

Figure 11 Vonmises Strain

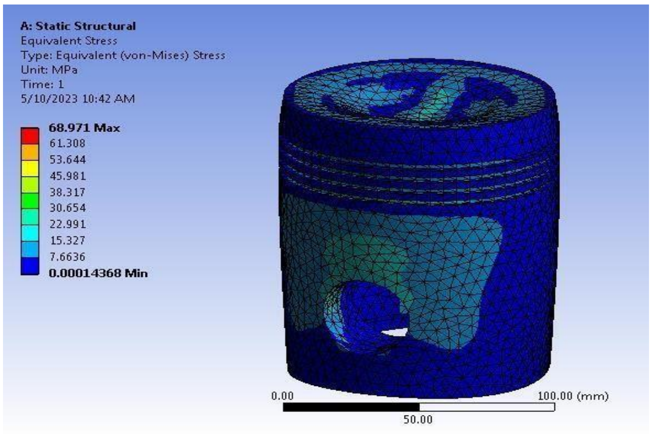

Figure 12 Vonmises Stress

4.1.2 Material Type: Aluminum Alloy (Al6061)

Piston with Four Ribs

Figure 13, 14 & 15 shows the Deformation, Strain & Stress for the Diesel Engine Piston which is made of Aluminum Alloy & Provided with FOUR

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number of Ribs. The result shows Maximum Deformation of 0.0455 mm, Strain of 0.0014 mm & Stress Value of 89.76 MPa.

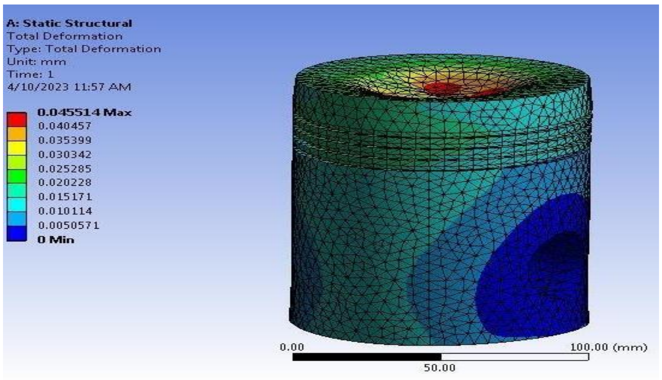

Figure 13 Total Deformation

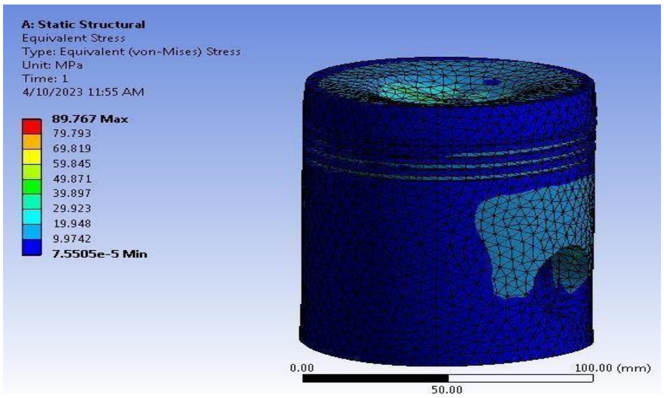

Figure 14 Vonmises stress

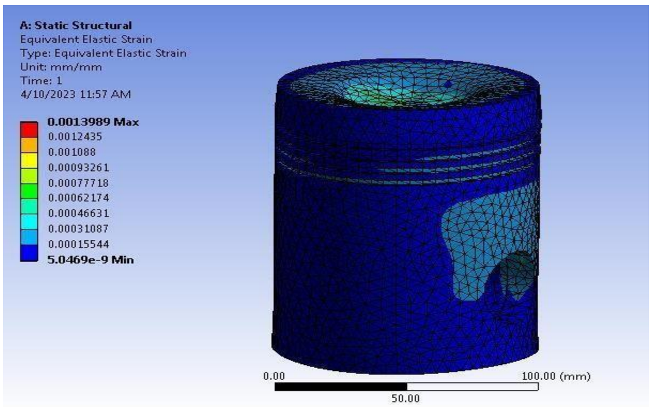

Figure 15 Vonmises strain

Piston with Six Ribs

Figure 16, 17 & 18 shows the Deformation, Strain & Stress for the Diesel Engine Piston which is made of Aluminum Alloy & Provided with SIX number of Ribs. The result shows Maximum Deformation of 0.0376 mm, Strain of 0.0012 mm & Stress Value of 79.01 MPa

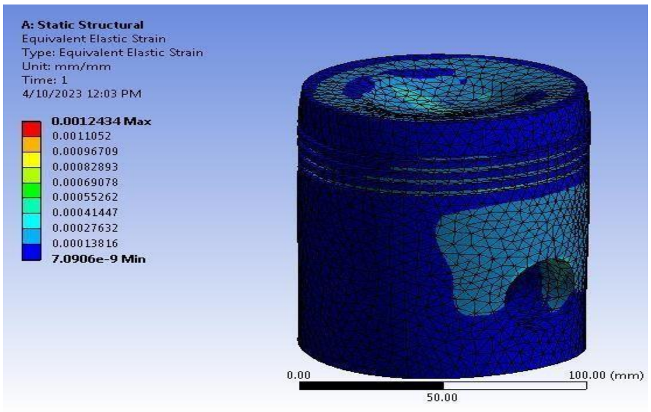

Figure 16 Vonmises Strain

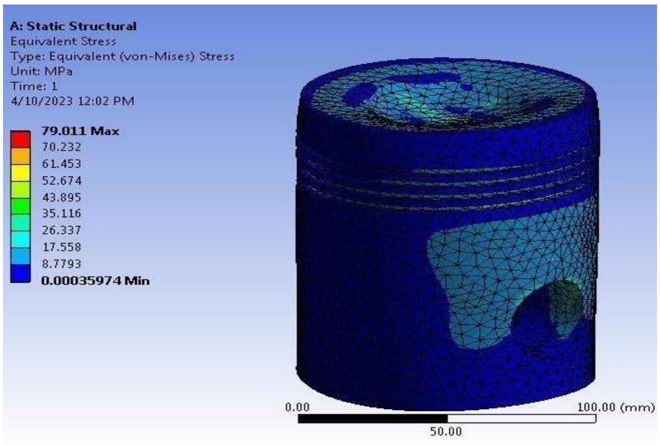

Figure 17 Vonmises Stress

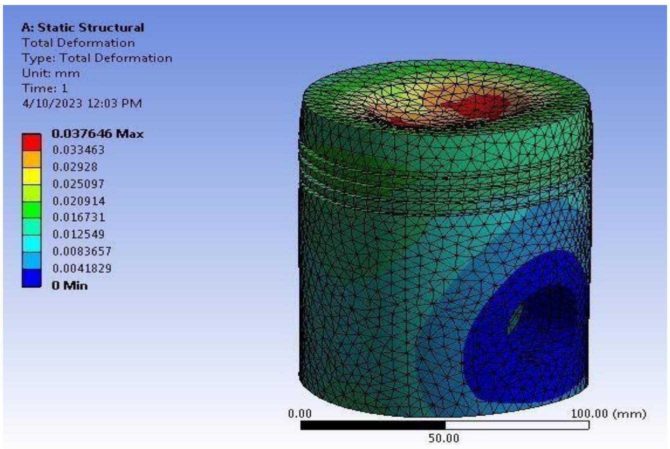

Figure 18 Total Deformation

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Piston with Eight Ribs

Figure 19, 20 & 21 shows the Deformation, Strain & Stress for the Diesel Engine Piston which is made of Aluminum Alloy & Provided with EIGHT number of Ribs. The result shows Maximum Deformation of 0.0320mm, Strain of 0.0010mm & Stress Value of 67.72 MPa. Table 4 shows structural analysis results.

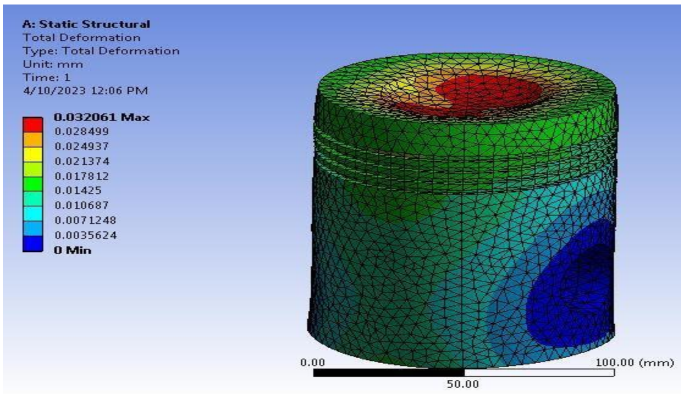

Figure 19 Total Deformation

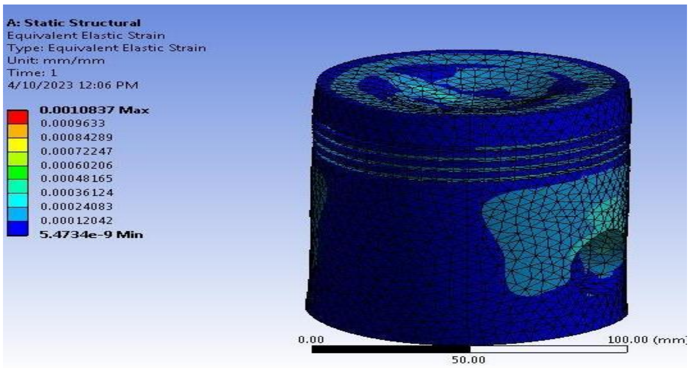

Figure 20 Vonmises Strain

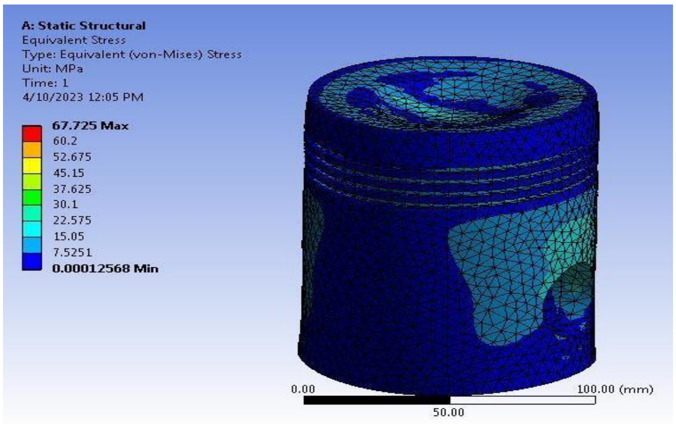

Figure 21 Vonmises stress

Table 4 Structural Analysis Results

S.NO	Material type	Result	FOUR ribs	SIX ribs	EIGHT ribs
1	Forged Steel	Stress(MPa)	90.99	79.68	68.97
		Deformation (mm)	0.0142	0.0117	0.0099
		Strain (Mpa)	0.0004	0.00039	0.00034
2	Aluminium Alloy (Al 6061)	Stress (Mpa)	89.76	79.01	67.72
		Deformation (mm)	0.0455	0.0376	0.0320
		Strain (Mpa)	0.0014	0.0012	0.0012

4.2 Thermal analysis

4.2.1 Material Type: Forged Steel

Piston with Four Ribs

From the Figure 22 & 23, we can observe that the heat flux and temperature distribution of a diesel engine piston with four ribs. In this, the maximum value of heat flux is 1.885x106 W/m2 and minimum value of heat flux is 0.13259 W/m2 and temperature distribution maximum value is 950.09°C and minimum value is 87.57°C

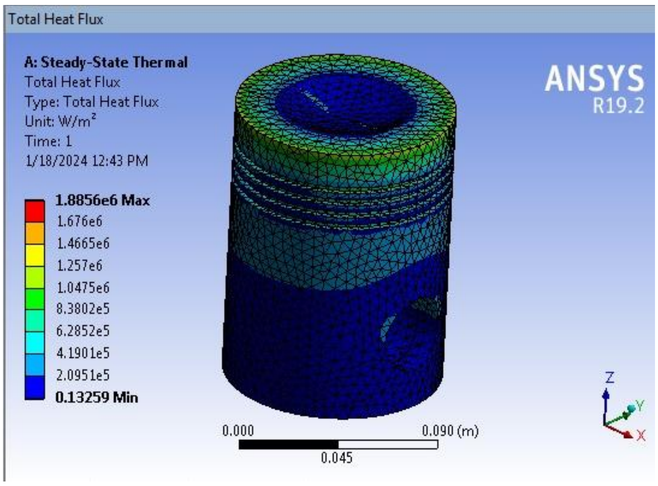

Figure 22 Heat flux

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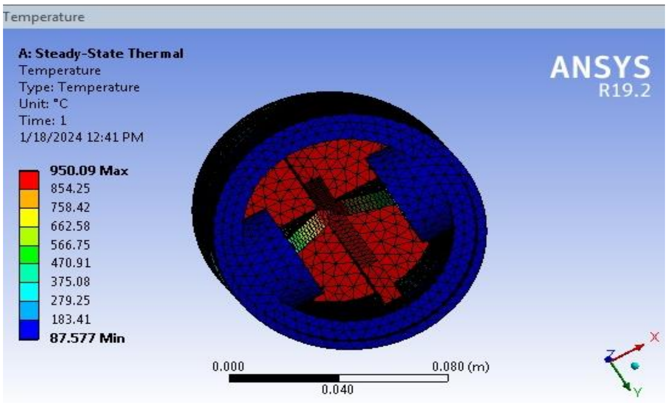

Figure 23 **Temperature distribution**

Piston with Six Ribs

From the Figure 24 & 25, we can observe that the heat flux and temperature distribution of a diesel engine piston with six ribs. In this heat flux the maximum value of is 2.0038x106 W/m2 and minimum value of heat flux is 0.3633 W/m2 and temperature distribution maximum value is 950°C and minimum value is 87.835°C

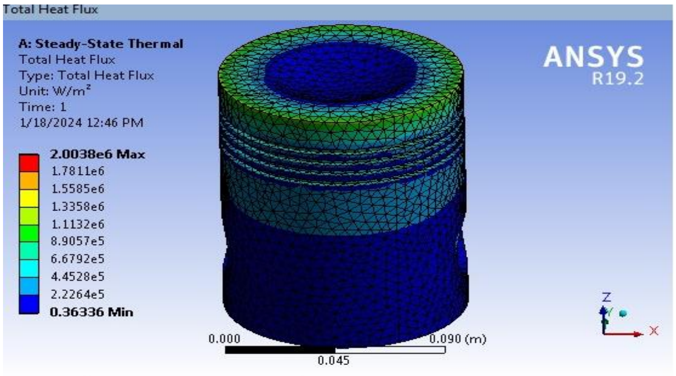

Figure 24 **Heat flux**

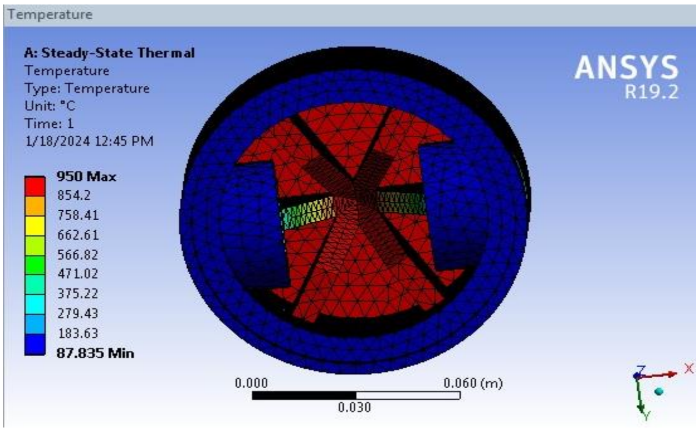

Figure 25 **Temperature distribution**

Piston with Eight Ribs

From the Figure 26 & 27, we can observe that the heat flux and temperature distribution of a diesel engine piston with eight ribs. In this heat flux the maximum value of is 1.90x106 W/m2 and minimum value of heat flux is 0.602 W/m2 and temperature distribution maximum value is 950°C and minimum value is 88.271°C

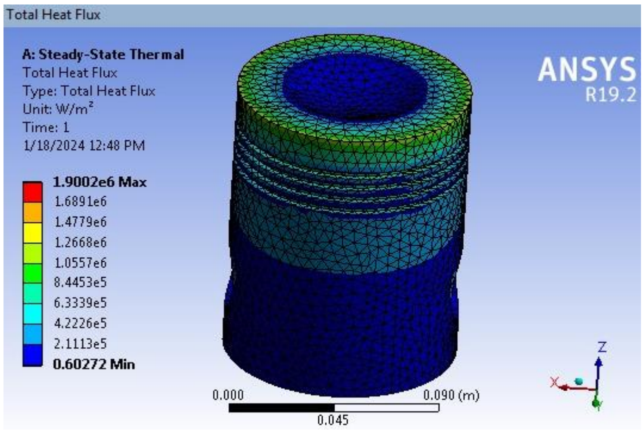

Figure 26 **Heat flux**

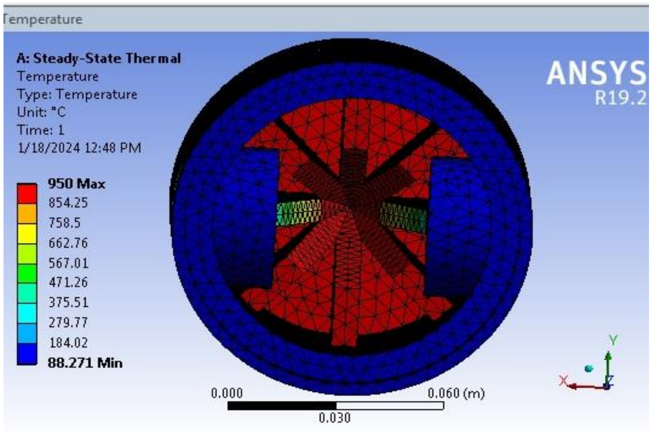

Figure 27 **Temperature distribution**

4.2.2 Material Type: ALUMINUM ALLOY (Al6061)

Piston with Four Ribs

From the Figure 28 & 29, we can observe that the heat flux and temperature distribution of a diesel engine piston with four ribs. In this, the maximum value of heat flux is 3.521x106 W/m2 and minimum value of heat flux is 0.111 W/m2 and temperature distribution maximum value is 950.06°C and minimum value is 315.56°C

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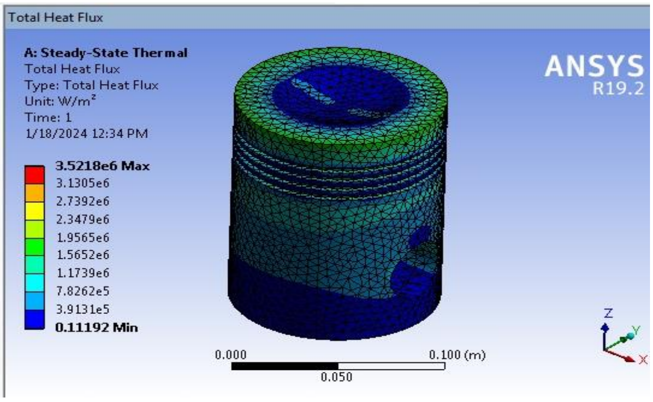

Figure 28 Heat flux

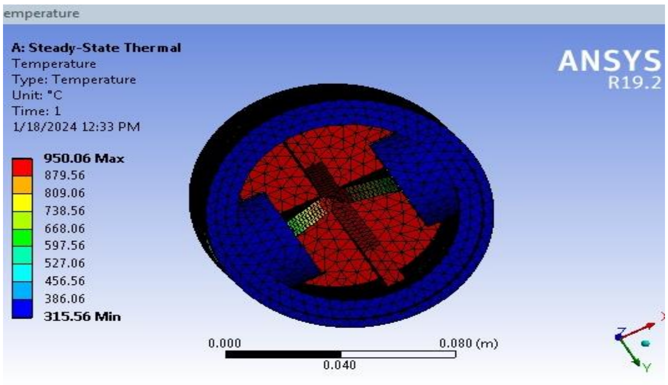

Figure 29 Temperature distribution

Piston with Six Ribs

From the Figure 30 & 31, we can observe that the heat flux and temperature distribution of a diesel engine piston with six ribs. In this, the maximum value of heat flux is 4.256x106 W/m2 and minimum value of heat flux is 1.0415 W/m2 and temperature distribution maximum value is 950°C and minimum value is 316.1°C. Table 5 shows the thermal analysis.

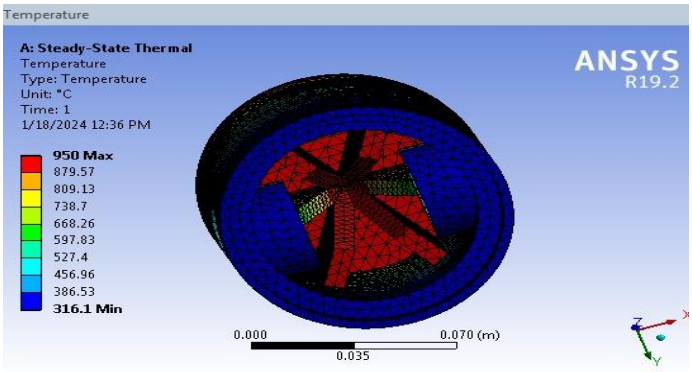

Figure 30 Temperature distribution

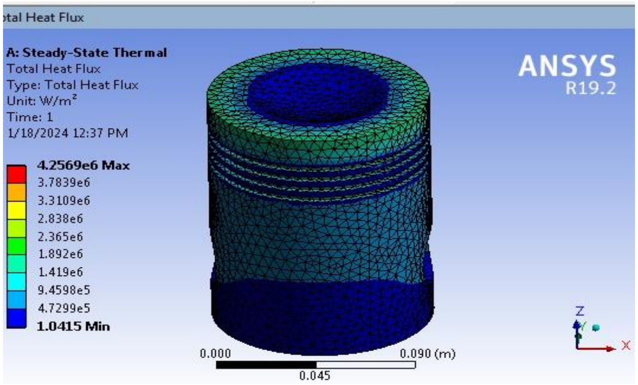

Figure 31 Heat flux

Piston with Eight Ribs

From the Figure 32 & 33, we can observe that the heat flux and temperature distribution of a diesel engine piston with eight ribs. In this, the maximum value of heat flux is 4.055x106 W/m2 and minimum value of heat flux is 1.547 W/m2 and temperature distribution maximum value is 950°C and minimum value is 317°C

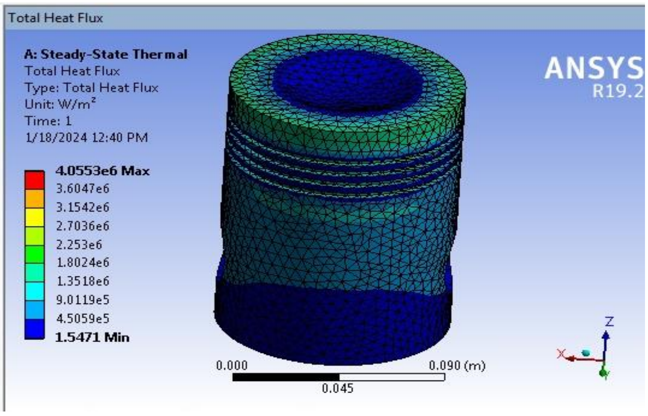

Figure 32 Heat flux

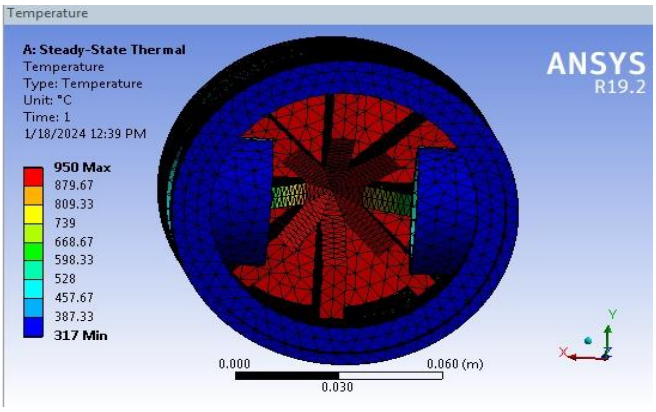

Figure 33 Temperature distribution

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Table 5 Thermal Analysis Results

S.No	Material	Heat Flux(W/m^2)			Temperature distribution (°C)		
		Piston With 4 Ribs	Piston with 6 Ribs	Piston With 8 Ribs	Piston With 4 Ribs	Piston with 6 Ribs	Piston With 8 Ribs
1	Aluminim Alloy (Al 6061)	$3.52X10^6$	$4.25X10^6$	$4X10^6$	315.56	316.1	318
2	Forged Steel	$1.88X10^6$	$2X10^6$	$1.9X10^6$	87.577	87.835	88.271

Conclusion

- Stress, Strain & Deformation Values are decreased with the increase of Ribs in the Piston Design.
- As per the structural Analysis the stress value obtained for Aluminium Alloy piston with EIGHT Ribs is less when compared with all the cases.
- Based on stiffness criteria Forged Steel Piston with EIGHT Ribs has given good results
- Considering both strength and stiffness criteria, it is observed that Forged Steel with EIGHT Ribs has shown good results
- As per Thermal Analysis Diesel Engine Piston of Aluminium Alloy (Al6061) provided with SIX Number of Ribs has shown good results
- Considering both Structural & Thermal Analysis it is observed that Aluminium Alloy with EIGHT Ribs has shown good results

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