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Comparative Study and Static Analysis of Piston Using Solid Edge and Ansys

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Abstract: A piston is a component of reciprocating engines. The purpose of piston is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and a connecting rod. It is one of the most complex components of an automobile. In This project we are describes the Thermal analysis by using finite element method (FEM). The specifications used for designing the piston belong to four stroke single cylinder engine of piston. Modeling of piston are done using SOLID EDGE v20. static structural, Thermal and fatigue analysis is performed by using ANSYS WORKBENCH 2022 R1. The parameters used for the simulation are operating gas pressure, material properties of piston. The results predict the maximum stress and strain on pistons using FEA. The best material is selectedbased on static structural, thermal and fatigue analysis. The analysis results are used to optimize piston geometry of best two Materials.
Keywords: Piston, Solid Edge v20, static structural, Thermal and fatigue analysis.

I. INTRODUCTION

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. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder. In some engines, the piston also acts as a valve by covering and uncovering ports in the cylinder.

II. LITERATURE REVIEW

The design of the piston is a complex process that involves several factors, such as the engine's operating conditions, performance requirements, material properties, and manufacturing processes. The piston's design must consider the piston's shape, size, weight, and material composition. Several studies have been conducted on the design of piston. "Design and Analysis of an Automotive Piston using Finite Element Method" by Amit Singh Yash Dhamecha and Vaibhav Saptarshi. This paper presents a finite element analysis (FEA) of an automotive piston to evaluate its strength, stiffness, and deformation under various operating conditions. "A Review of Piston Failure Analysis in Internal Combustion Engines" by Amit Singh Chahar and Ashutosh Kumar. This review paper provides an overview of the causes and mechanisms of piston failures in internal combustion engines. It covers various types of failures, including thermal fatigue, mechanical fatigue, and lubrication-related failures.

Table – 1: Property of Aluminium Alloy

Density	2.77e-06 kg/mm^3
Young s Modulus	71000 MPa
Thermal Conductivity	0.14862 W/mm, ^{0}C
Specific Heat	8.75e+05 mJ/kg, ^{0}C
Tensile Yield Strength	280 MPa
Tensile Ultimate Strength	310 MPa

Table – 2: Property of Ti-6A1-4V

Modulus of Elasticity	113.8 GPa
Compressive Yield Strength	970 MPa
Tensile Strength	1450 MPa
Ultimate Strength	1860 MPa

III. METHODOLOGY

1) Analytical design of pistons based on designformulae and empirical relations.
2) 3-D piston models are created in SOLIDEDGE V20
3) Meshing and analysis of piston is done inANSYS Workbench 2022R1
4) Various stresses are determined by individually performing structural analysis,thermal analysis and thermos-mechanical analysis.
5) Various zones or regions where chances ofdamage in piston are possible are analyzed.
6) Comparison is made between the three materials in terms of stresses, deformation,strain, volume, weight, force and factor of safety.

a) Analysis of Step Head Piston for Aluminum Alloy

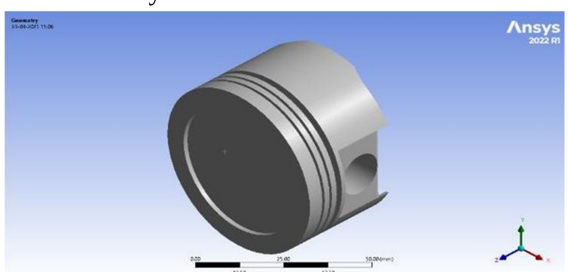

Fig-1: 3-D CAD Model of Step Head Piston

b) Material Assignment

For analysis of piston, the 3-D CAD model prepared in Solid edge v20. is converted in to IGES format so that itcan be imported in ANSYS 2022R1. After importing themodel in ANSYS, material properties are assigned in Engineering data.

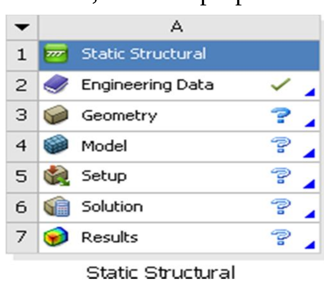

Fig-2: Static Structural Standalone System

3) Meshing of Step Head piston

After assigning material properties, model is opened inmechanical. The whole body of the piston model is selected and meshing is performed. Tetrahedral elements are used and the element size is 1 mm.

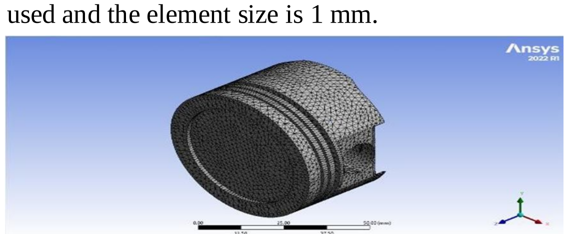

Fig-3: Meshing of Step Head Piston

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4) Static Structural Analysis

In static structural analysis, boundary conditions likepressure and supports are applied. (Refer Table 4)

- Pressure at the head of piston: 20 MPa
- Fixed supports are applied at edges of piston pinhole.

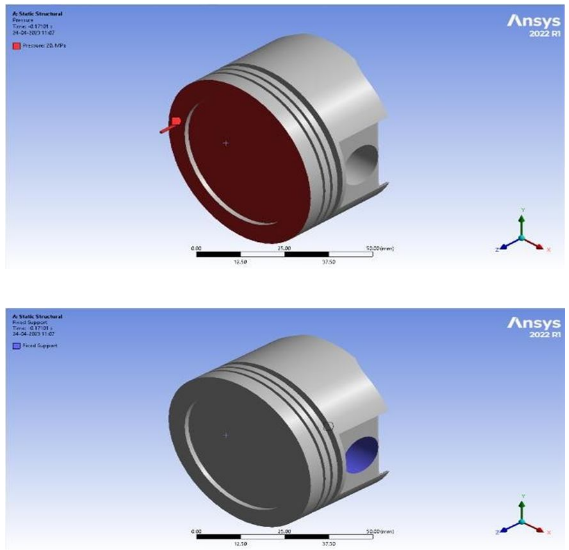

Fig-4: Applying Boundary Conditions

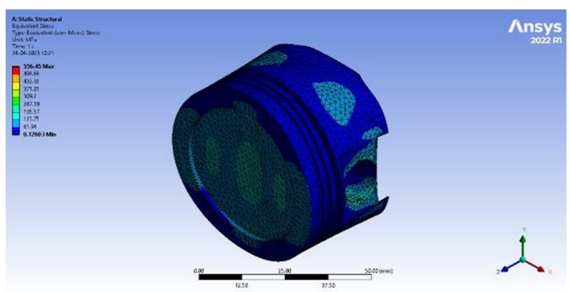

Fig-5: Equivalent Stresses

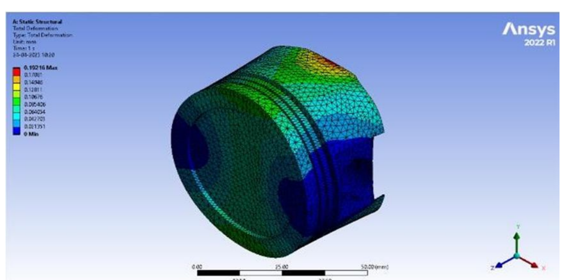

Fig-6: Total Deformation

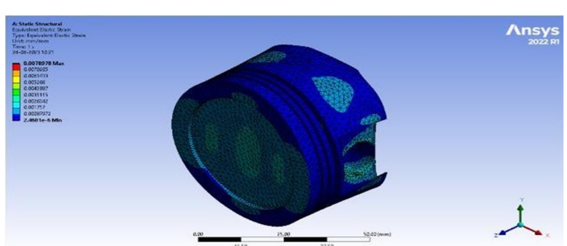

Fig-7: Equivalent Elastic Strain

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5) Steady State Thermal Analysis

In steady state thermal analysis, boundary conditionslike temperature and convection are applied.

- Temperature at head of piston: 2000°C
- Film coefficients are applied to different regionsof piston.

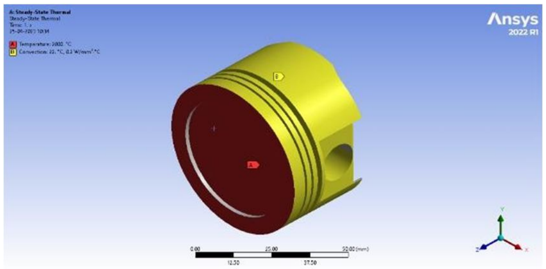

Fig-8: Applying Temperature and ConvectionBoundary

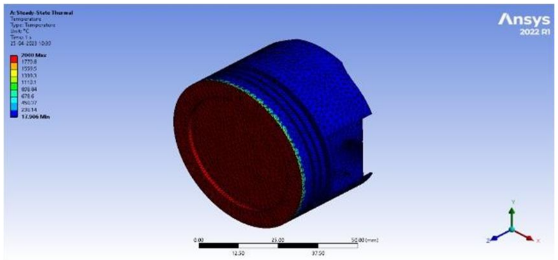

Fig-9: Temperature

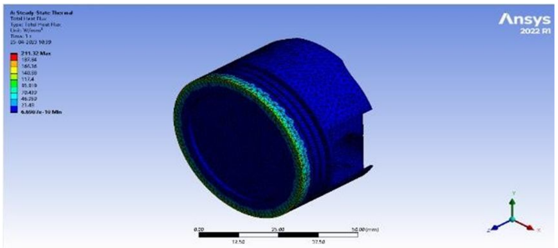

Fig-10: Total Heat Flux

6) Fatigue Analysis

Fatigue analysis is a process used to assess the structuraldurability and lifespan of components subjected to cyclic loading.

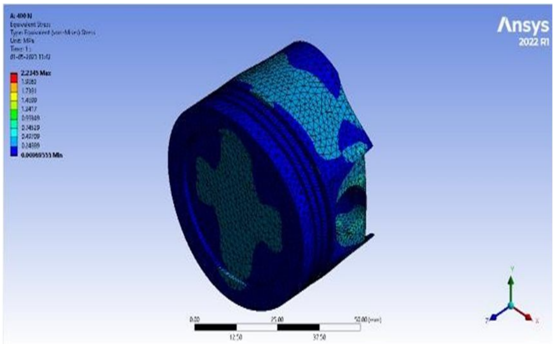

Fig-11: Equivalent Stresses

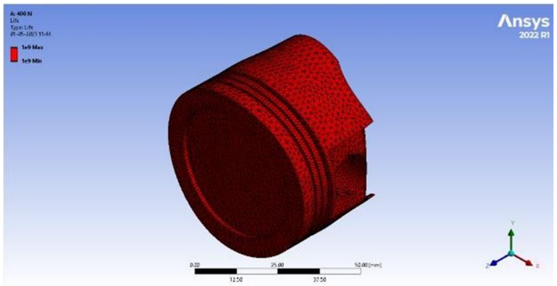

Fig-12: Life

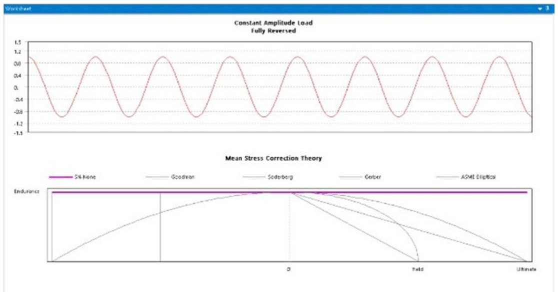

Fig-13: Stress Life

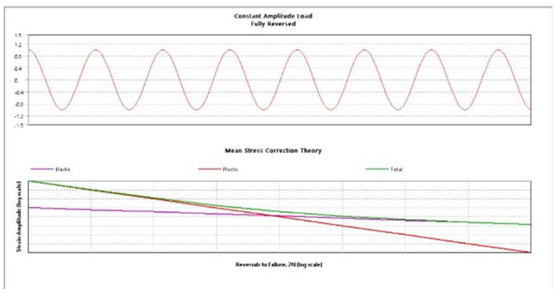

Fig-14: Strain Life

7) Analysis of Flat Head Piston for Ti-6A1-4V

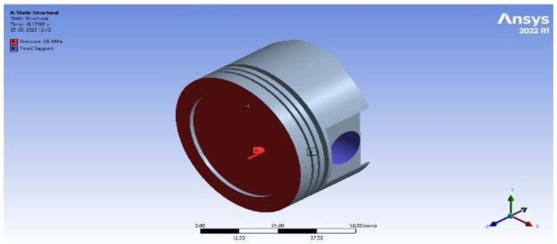

Fig-15: Applying Boundary Conditions

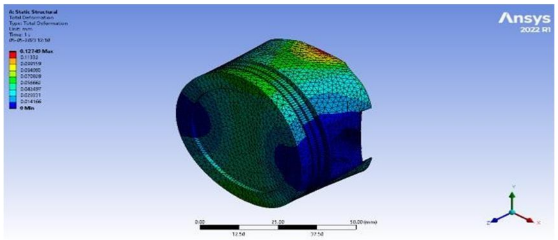

Fig-16: Total Deformation

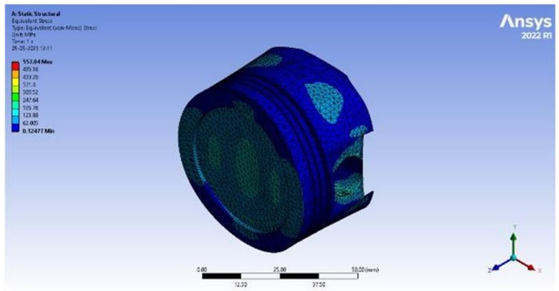

Fig-17: Equivalent Stresses

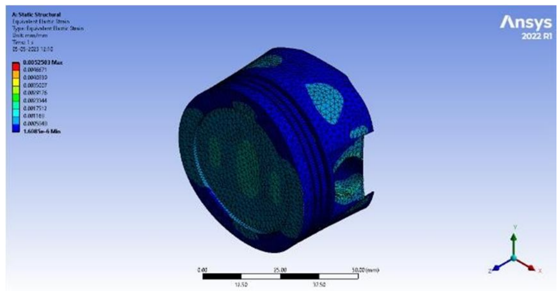

Fig-18: Equivalent Elastic Strain

8) Steady State Thermal Analysis

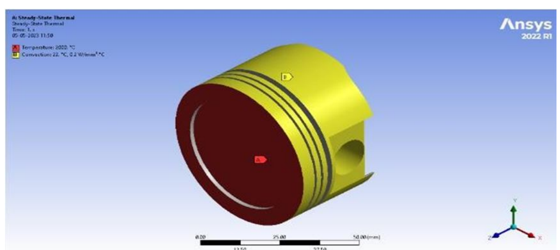

Fig-19: Applying Temperature and Convection Boundary

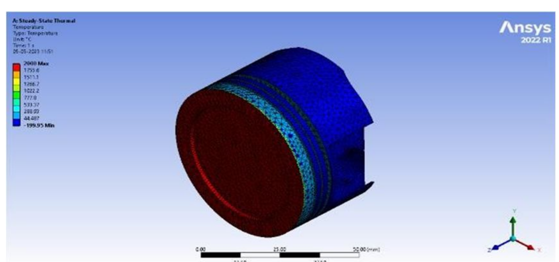

Fig-20: Temperature

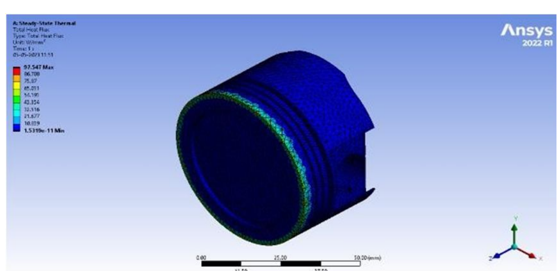

Fig-21: Total Heat Flux

9) Fatigue Analysis

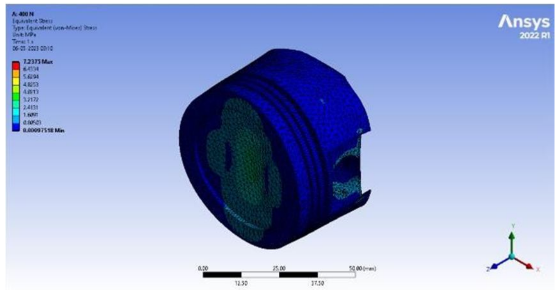

Fig-22: Equivalent Stresses

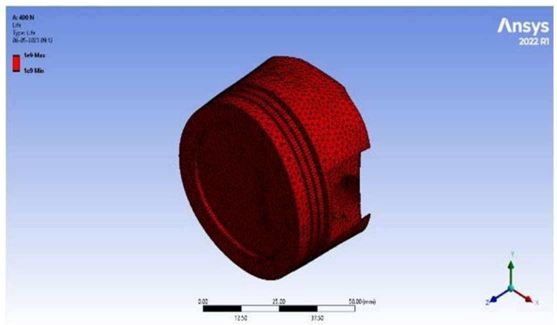

Fig-23: Life

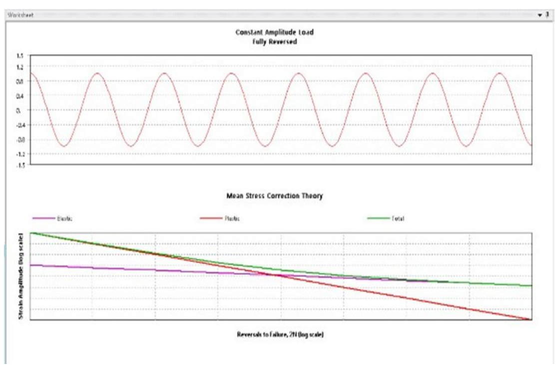

Fig-24: Strain Life

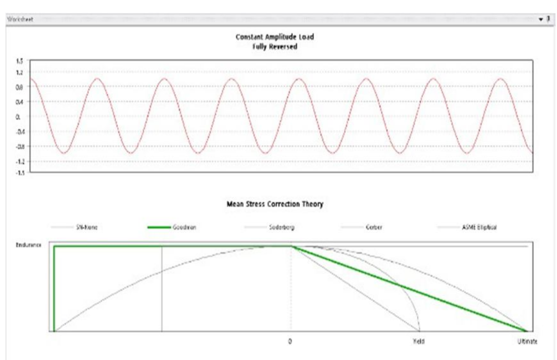

Fig-25: Stress Life

10) Analysis of Flat Head Piston for Aluminum Alloy

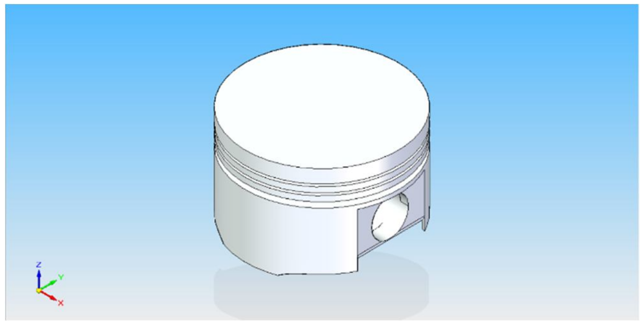

Fig-26: 3-D CAD Model of Flat Head Piston

11) Meshing of Flat Head piston Model

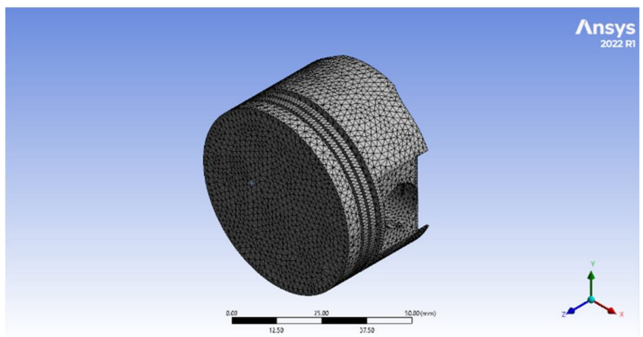

Fig-27: Meshing of Flat Head Piston

12) Static Structural Analysis

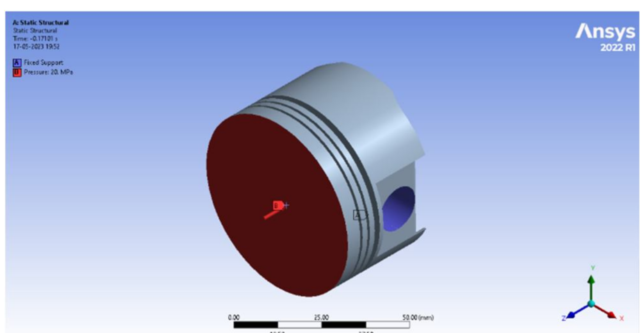

Fig-28: Applying Boundary Conditions

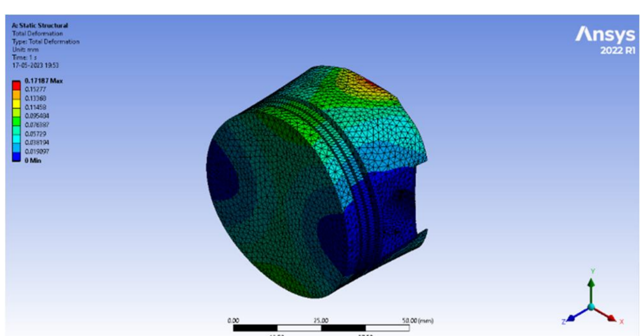

Fig-29: Total Deformation

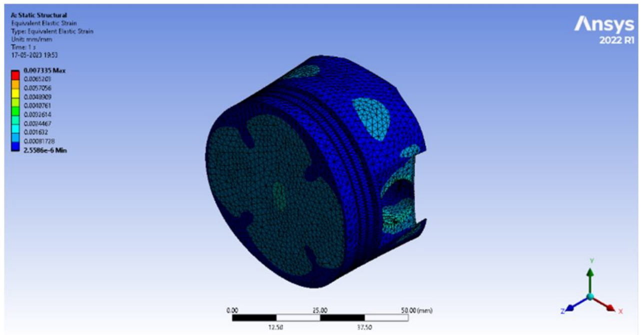

Fig-30: Equivalent Elastic Strain

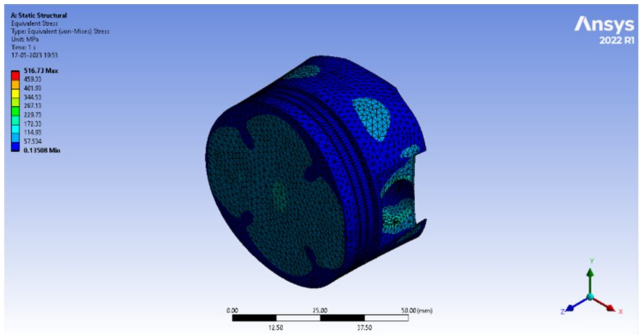

Fig-31: Equivalent Stresses

13) Steady State Thermal Analysis

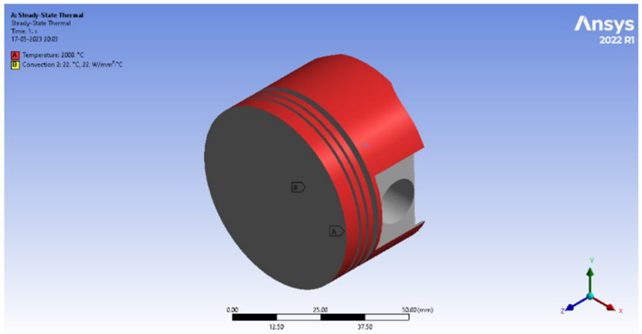

Fig-32: Applying Temperature and Convection Boundary

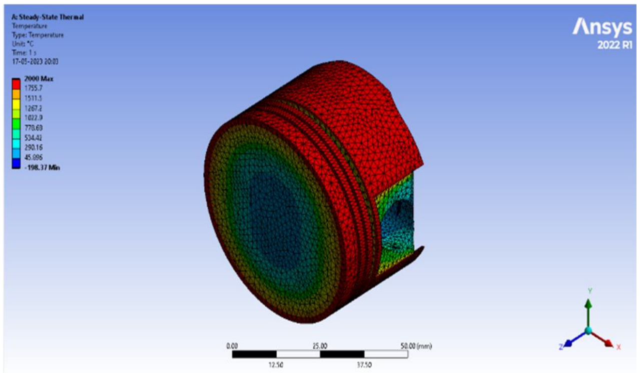

Fig-33: Temperature

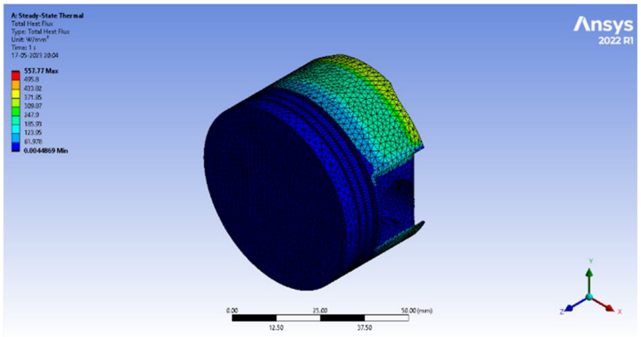

Fig-34: Total Heat Flux

14) Fatigue Analysis

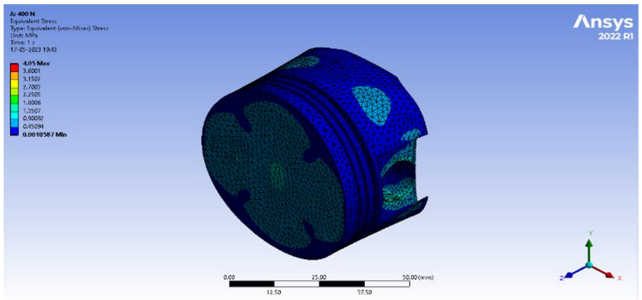

Fig-35: Equivalent Stresses

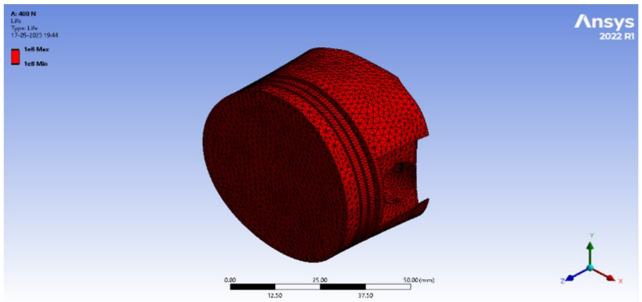

Fig-36: Life

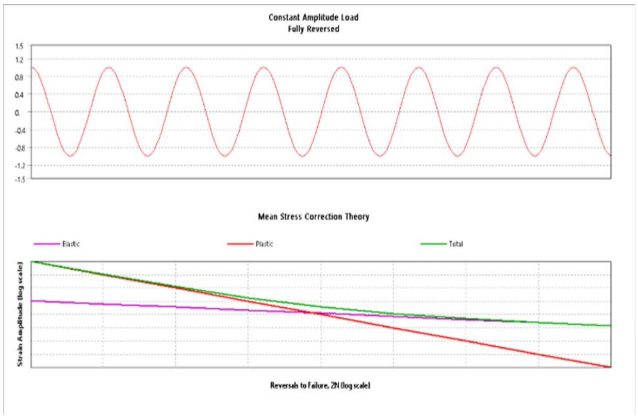

Fig-37: Strain Life

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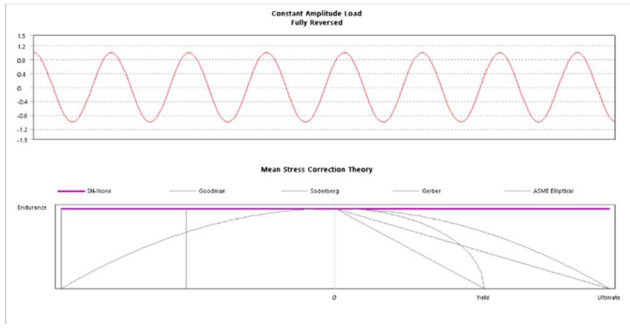

Fig-38: Stress Life

15) Analysis of Flat Head Piston for Ti-6A1-4V
16) Static Structural Analysis

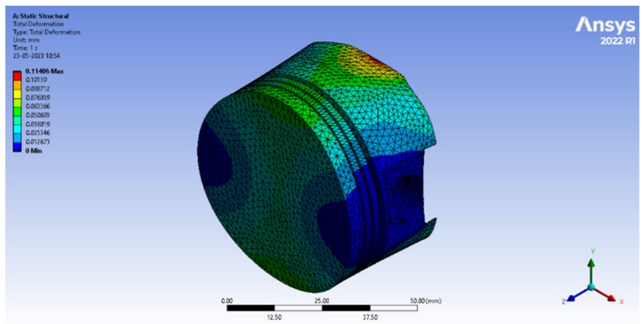

Fig-39: Total Deformation

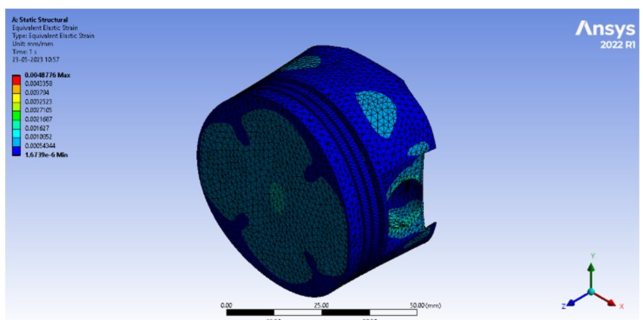

Fig-40: Equivalent Elastic Strain

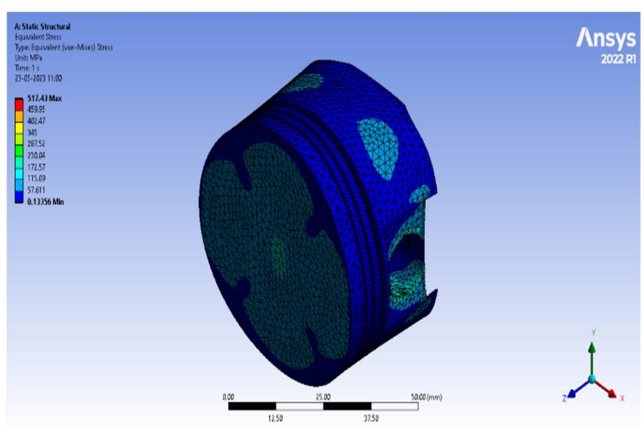

Fig-41: Equivalent Stresses

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17) Steady State Thermal Analysis

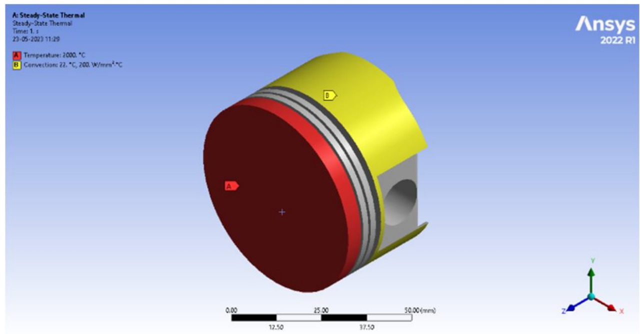

Fig-42: Applying Temperature and Convection Boundary

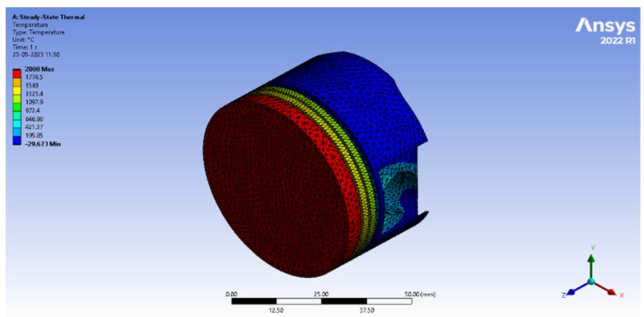

Fig-43: Temperature

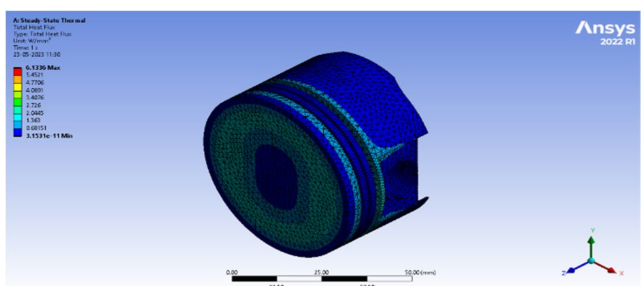

Fig-44: Total Heat Flux

18) Fatigue Analysis

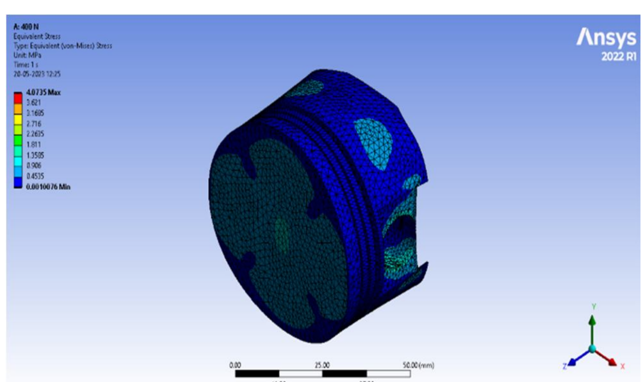

Fig-45: Equivalent Stresses

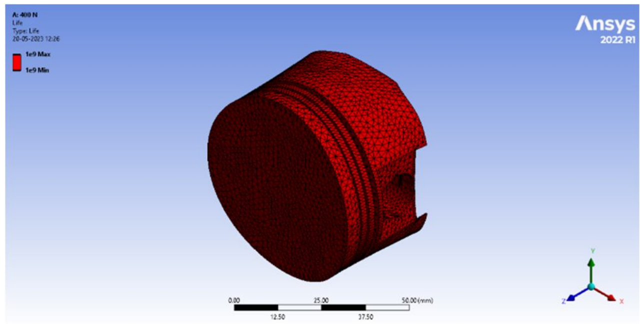

Fig-46: Life

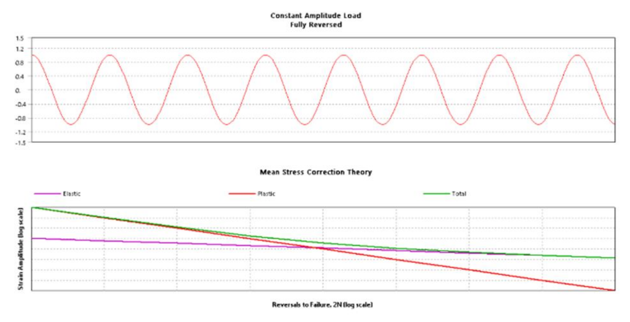

Fig-47: Strain Life

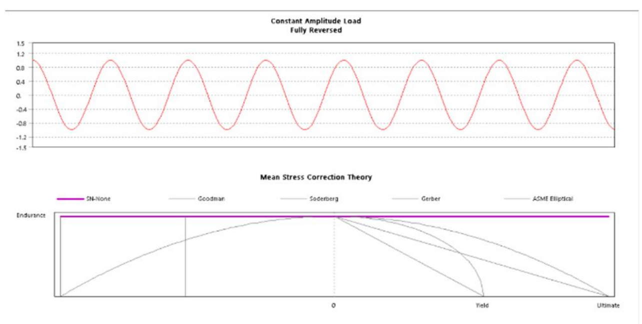

Fig-48: Stress Life

19) Analysis of Dom Head Piston for Aluminum Alloy

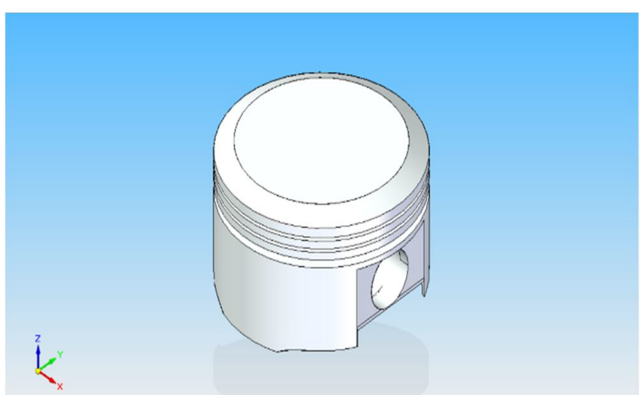

Fig-49: 3-D CAD Model of Dom Piston

20) Meshing of Dom Head piston Model

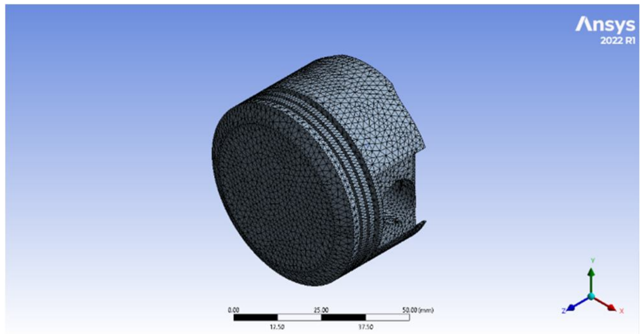

Fig-50: Meshing of Dom Head Piston

21) Static Structural Analysis

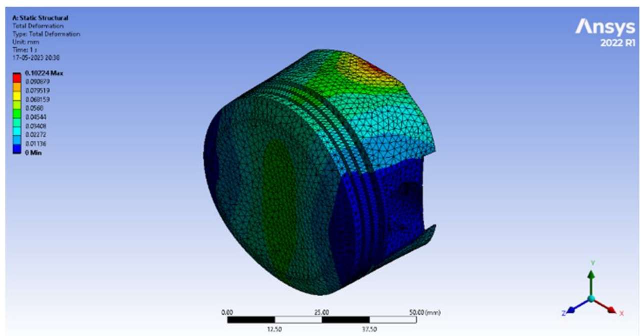

Fig-51: Total Deformation

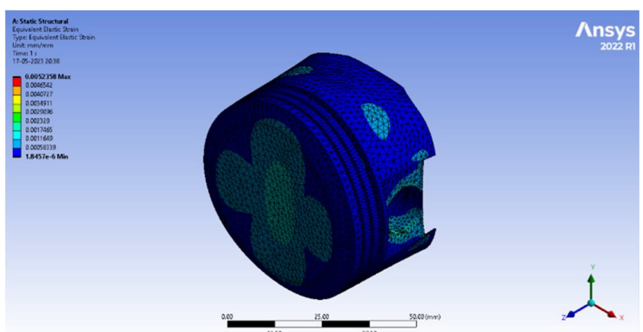

Fig-52: Equivalent Elastic Strain

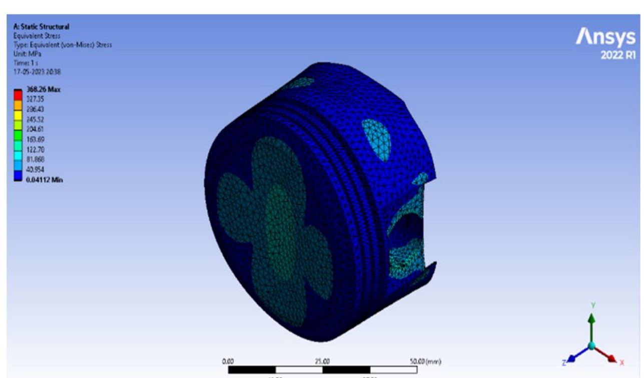

Fig-53: Equivalent Stresses

22) Steady State Thermal Analysis

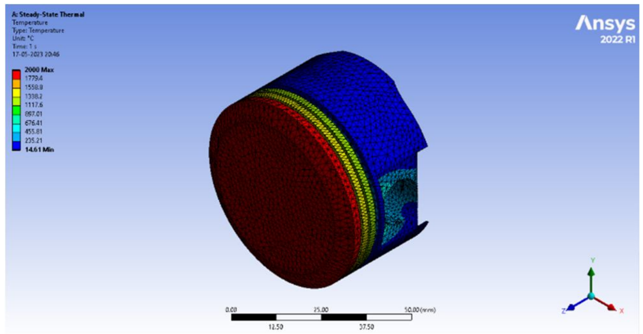

Fig-54: Temperature

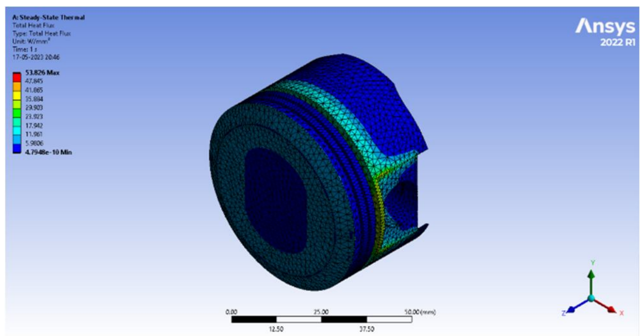

Fig-55: Total Heat Flux

23) Fatigue Analysis

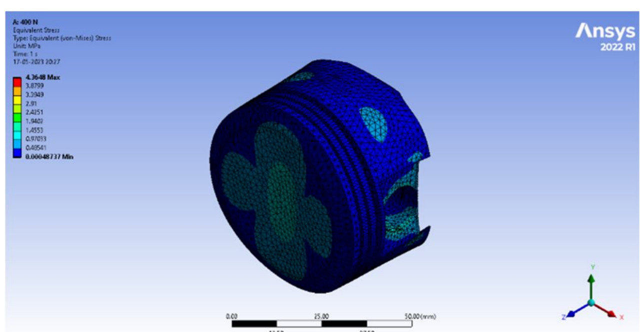

Fig-56: Equivalent Stresses

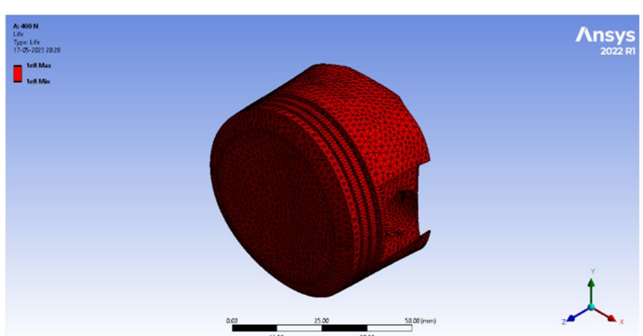

Fig-57: Life

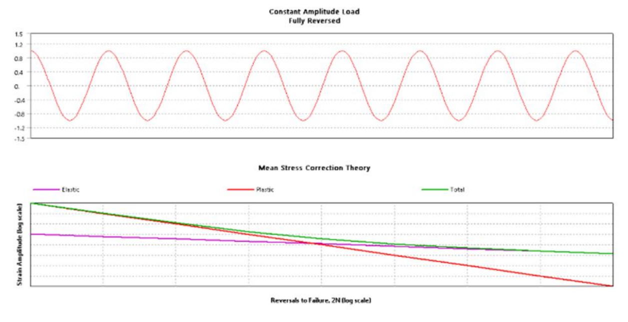

Fig-58: Strain Life

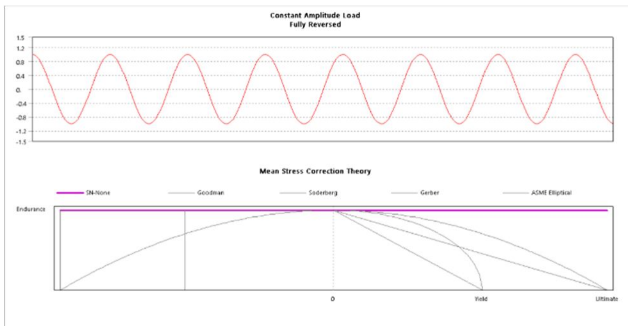

Fig-59: Stress Life

24) Analysis of Dom Piston for Ti-6A1-4V

25) Static Structural Analysis

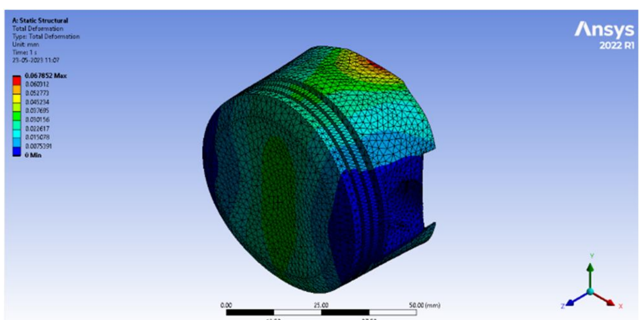

Fig-60: Total Deformation

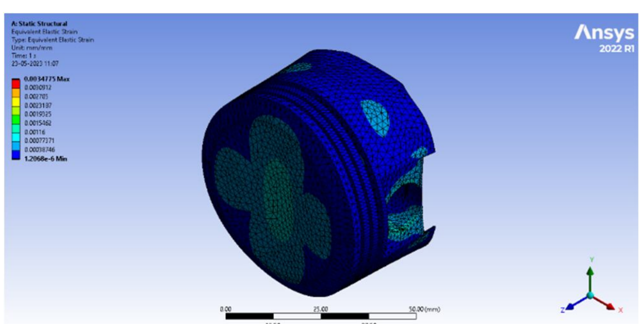

Fig-61: Equivalent Elastic Strain

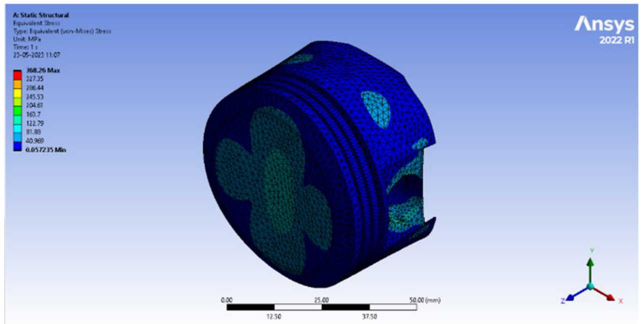

Fig-62: Equivalent Stresses

26) Steady State Thermal Analysis

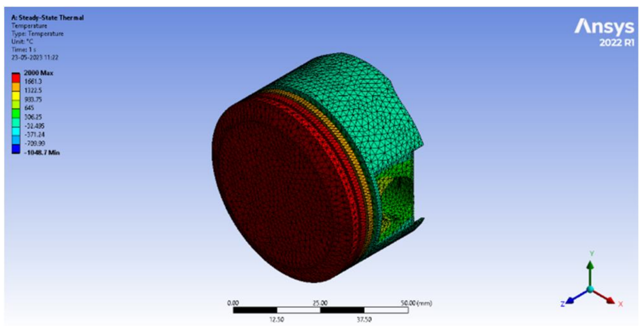

Fig-63: Temperature

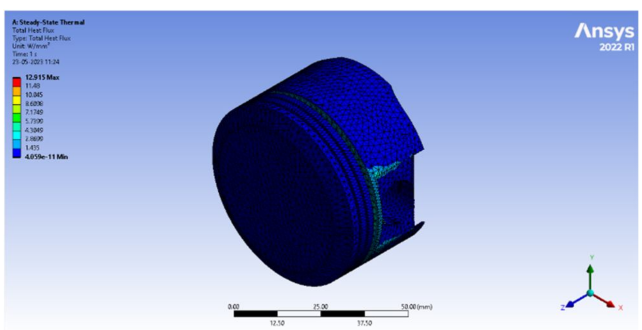

Fig-64: Total Heat Flux

27) Fatigue Analysis

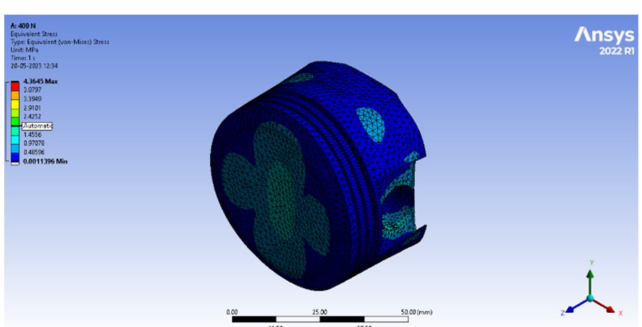

Fig-65: Equivalent Stresses

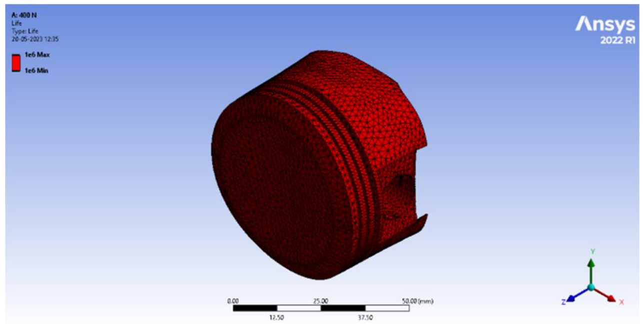

Fig-67: Life

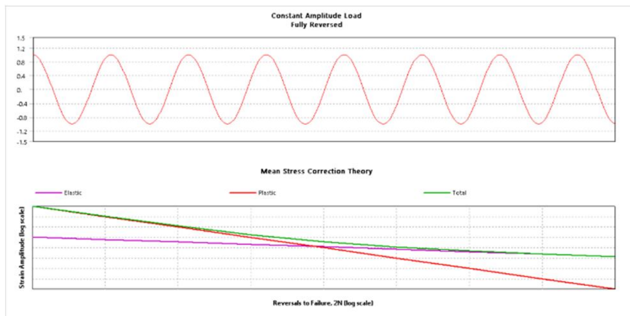

Fig-68: Strain Life

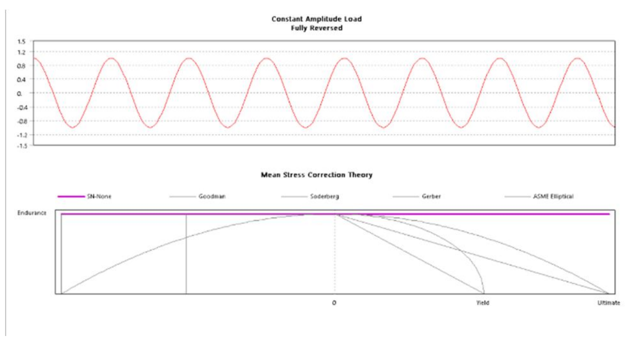

Fig-69: Stress Life

IV. RESULTS

A. Static Structural Analysis of Step Head

Table-4: Static Structural Analysis Results

PARAMETERS	VALUES	
	Aluminum Alloy	**Ti-6A1-4V**
Equivalent Stress (MPa)	556.45	557.04
Total Deformation (mm)	0.19216	0.12749
Equivalent elastic strain (mm/mm)	0.0078978	0.0052503

1) Steady Thermal Analysis of Step Head

Table-5: Steady Thermal Analysis Results

PARAMETERS	VALUES	
	Aluminum Alloy	**Ti-6A1-4V**
Temperature	2000	2000
Heat flux (W/mm^2)	211.32	97.547

2) Fatigue Analysis of Step Head

Table-6: Fatigue Analysis Results

PARAMETERS	VALUES	
	Aluminum Alloy	**Ti-6A1-4V**
Equivalent Stress (MPa)	2.2345	7.2375
Factor of Safety	15	15
Life	1e9	1e9s

B. Static Structural Analysis of Flat Head

Table-4: Static Structural Analysis Results

PARAMETERS	VALUES	
	Aluminum Alloy	**Ti-6A1-4V**
Equivalent Stress (MPa)	516.73	617.25
Total Deformation (mm)	0.18169	0.22602
Equivalent elastic strain (mm/mm)	0.00725	0.00552

1) Steady Thermal Analysis of Flat Head

Table-5: Steady Thermal Analysis Results

PARAMETERS	VALUES	
	Aluminum Alloy	**Ti-6A1-4V**
Temperature	2000	2000
Heat flux (W/mm^2)	667.65	7.133

2) Fatigue Analysis of Flat Head

Table-6: Fatigue Analysis Results

PARAMETERS	VALUES	
	Aluminum Alloy	**Ti-6A1-4V**
Equivalent Stress (MPa)	5.05	5.02545
Factor of Safety	15	15
Life	1e8	1e9s

C. Static Structural Analysis of Dom Head

Table-4: Static Structural Analysis Results

PARAMETERS	VALUES	
	Aluminum Alloy	**Ti-6A1-4V**
Equivalent Stress (MPa)	3483.26	486.32
Total Deformation (mm)	0.20355	0.01365
Equivalent elastic strain (mm/mm)	0.007884	0.0073503

1) Steady Thermal Analysis of Dom Head

Table-5: Steady Thermal Analysis Results

PARAMETERS	VALUES	
	Aluminum Alloy	**Ti-6A1-4V**
Temperature	2000	2000
Heat flux (W/mm^2)	44.353	13.6566

2) Fatigue Analysis of Dom Head

Table-6: Fatigue Analysis Results

PARAMETERS	VALUES	
	Aluminum Alloy	**Ti-6A1-4V**
Equivalent Stress (MPa)	5.3624	5.3469
Factor of Safety	15	15
Life	1e8	1e6

V. CONCLUSIONS

The titanium alloy Ti-6Al-4V is widely used in pistons of supercars and this led us to the assumption that if it is used in such high-performance cars, then it's possible that it can also be used in motorbikes. The material properties of titanium alloy were also suggesting the same but our analysis clearly demonstrates that it isn't a feasible option. From our analysis results, it is concluded that Ti-6Al-4V Dom Head Piston is the best material for piston.

This is due to the following reasons.

1) Its Factor of Safety (F.O.S.) is maximumamongst the one material.
2) Mass of Aluminum alloy is also least.

This result is because of the design of the piston. The piston design of supercars is significantly different from the piston design of motorbikes. To make titanium alloy a feasible option,we need to make a lot of changes in the design of piston which will result in a change in the overall design of the engine which is beyond the scope of this work. Still, there's a lot that can be done. The same can be done for other motorbikes/vehicles too. Other analyses apart from thermal and structural can also be performed for these materials. Also, these materials can be compared on the basis of cost like cost of manufacturing, cost of machining, etc.

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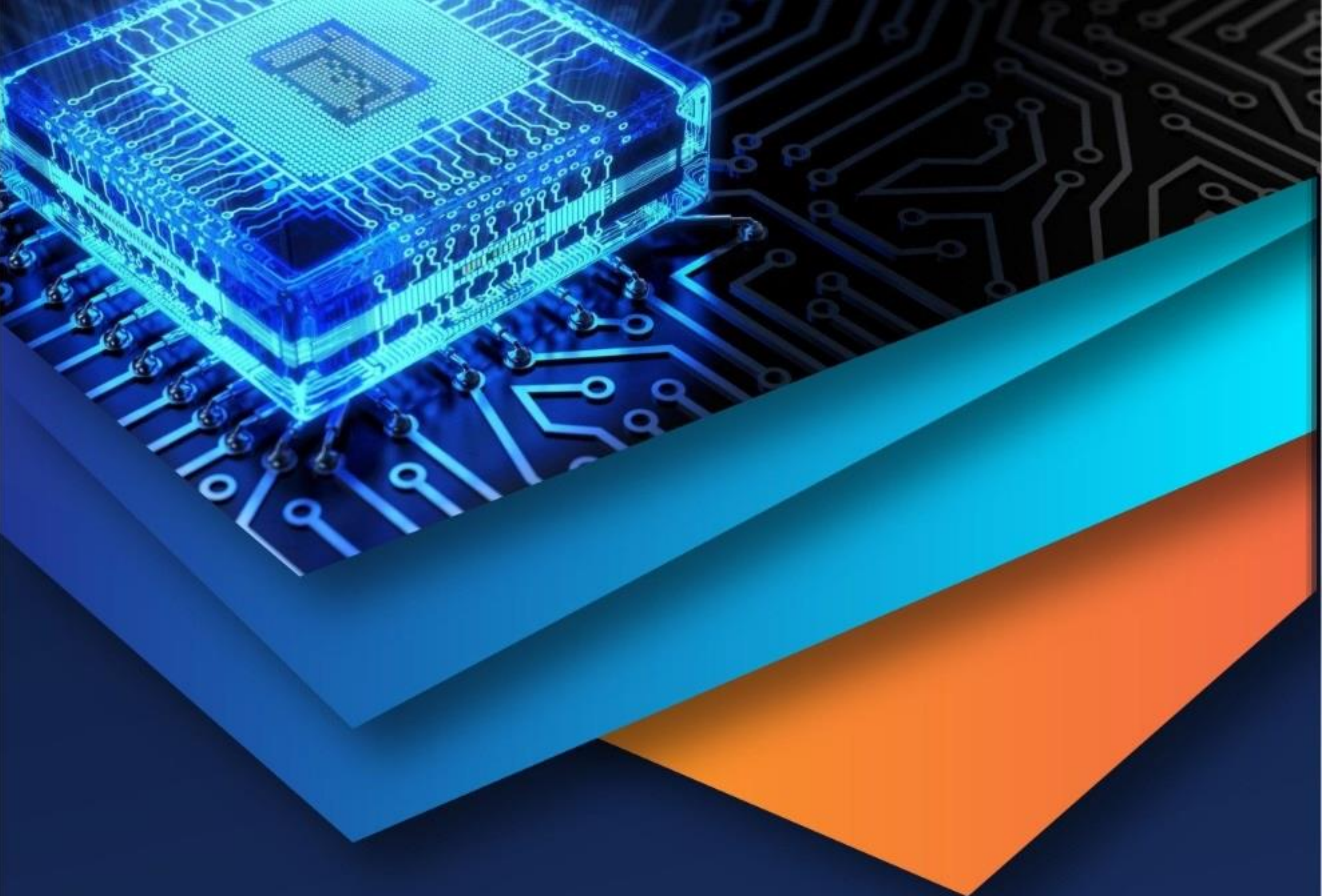

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