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Design and Failure Analysis of Piston

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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 structural analysis of five different aluminum alloy pistons, by using finite element method (FEM). The specifications used for designing the piston belong to four stroke single cylinder engine of Bajaj Pulsar 220cc. Modeling of various aluminium alloy piston are done using SOLID EDGE. 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 different aluminium alloy pistons using FEA. The best aluminum alloy material is selected based on static structural, thermal and fatigue analysis. The analysis results are used to optimize piston geometry of best aluminum alloy.*
***Keywords:** Piston, Pulsar 220, Static Structural, Thermal, Fatigue Life.*

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 design formulae and empirical relations.
2) 3-D piston models are created in SOLID EDGE V20
3) Meshing and analysis of piston is done in ANSYS 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 of damage 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. *Design of Piston*

Engine: Bajaj Pulsar 220 cc petrol engine.

Table-1: Engine Specifications

PARAMETERS	VALUES
Engine type	Four stroke, petrol engine
Induction	Air cooled type
No. of cylinders	Single cylinder
Bore (D)	67 mm
Stroke (L)	62.4 mm
Length of connecting rod	124.8 mm
Displacement volume	220 cm3
Compression ratio	9.5+/-0.5:1
Maximum power	15.51 kW at 8500 rpm
Maximum torque (T)	19.12 N-m at 7000 rpm (N)
No. of revolutions/cycle	2

Mechanical efficiency of the engine (η) = 80 %.
η = Brake power (B.P.)/Indicating power (I.P.) B.P. = 2πNT/60 = 2π*7000*19.12/ (60*1000) = 14.015 kW
Therefore, I.P. = B.P./η = 14.015/0.8 = 17.518 kW
Also, I.P. = P*A*L*N/2 = P*π/4*D2*L*N/2 17.518*1000 = P*π/4*(0.067)2*(0.0624) *(7000)/ (2*60)
So, P = 13.65*105 N/m2 or P = 1.365 MPa
Maximum Pressure (pmax) = 10*P = 10*1.365 = 13.65 MPa

B. *Analytical Design Calculations*

For Alimunium alloy
Thickness of the Piston Head
According to Gershoff's formula the thickness of the piston head is given by:

$t_h = D\sqrt{(3pmax/16\sigma t)}$

where σt = σut/2.5 = 480/2.5 = 192 MPa and D = cylinder bore diameter
Therefore th = 67*√ ((3*13.65)/(16*192)) = 7.735 mm Empirical formula: th = 0.032 D + 1.5 = 3.644 mm
The maximum thickness from the above formula (th) is 7.735 mm.

Piston Rings
The radial width of the ring is given by: b = D√(3*pw/σp) = 67*√ (3*0.025/100) = 1.834 mm
Axial thickness of the piston ring is given by: h = (0.7 b to b) = 0.7*1.834 = 1.284 mm

Width of Top Land and Ring Lands
Width of top land: h1 = (th to 1.2 th) = 7.735 mm
Width of ring land: h2 = (0.75 h to h) = 0.75*1.284 = 0.963 m

Piston Barrel
Thickness of piston barrel at the top end:
t1 = 0.03 D + b + 4.9
Therefore t1 = 0.03*67 + 1.834 + 4.9 = 8.744 mm
Thickness of piston barrel at the open end:
t2 = (0.25 t1 to 0.35 t1)
Therefore t2 = 0.25*8.744 = 2.186 mm

Length of the skirt
Ls = (0.6 D to 0.8 D) = 0.6*67 = 40.2 mm

Length of piston pin in the connecting rod bushing
L1 = 45% of the piston diameter = 0.45*67 = 30.15 mm

Piston pin diameter
do = (0.28 D to 0.38 D) = 0.3*67 = 20.1 mm
The center of piston pin should be 0.02 D to 0.04 D above center of the skirt = 0.03*67 = 2.01 mm above skirt center.
Similarly, analytical design for Al-GHS 1300 and Ti-6Al-4V alloy is also carried out and the dimensions of the three pistons are presented in the table below:

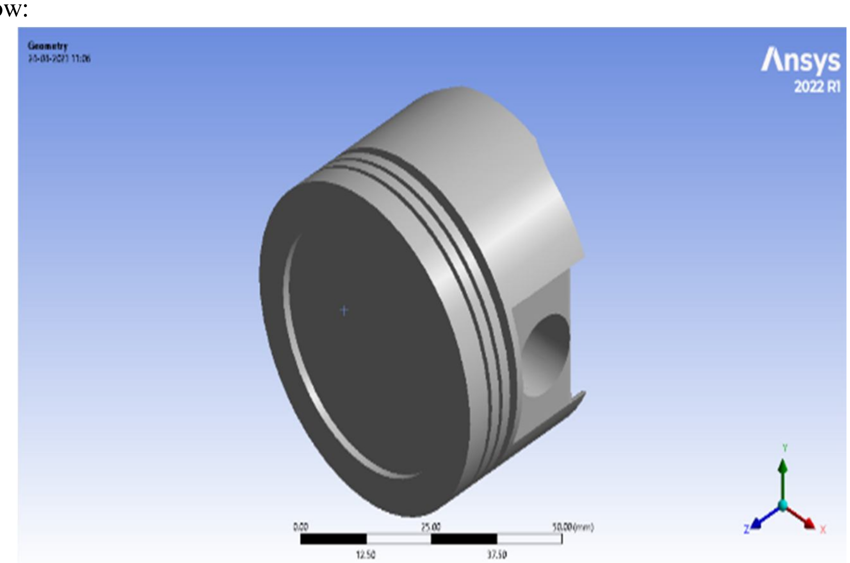

Fig-1: 3-D CAD Model of Piston

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C. Analysis of Piston, Aluminum Alloy

1) Material Assignment

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

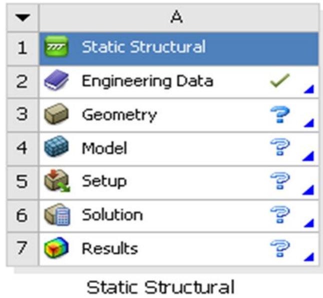

Fig-2: Static Structural Standalone System

2) Meshing of piston Model

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

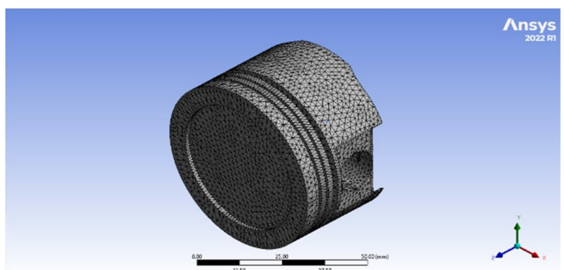

Fig-3: Meshing of Piston 3-d Model

3) Static Structural Analysis

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

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

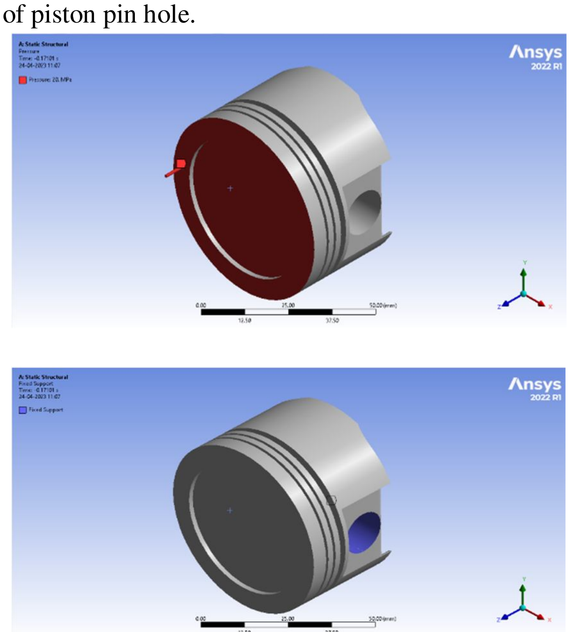

Fig-4: Applying Boundary Conditions

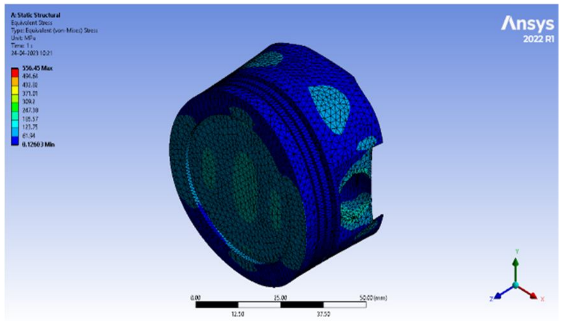

Fig-5: Equivalent Stresses

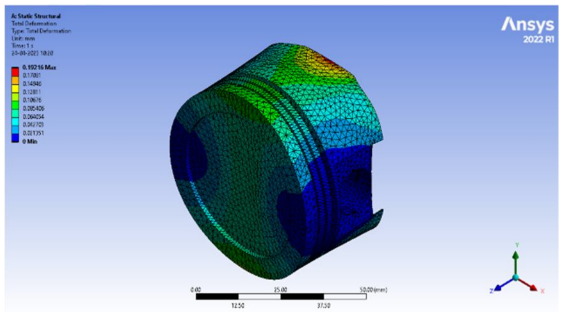

Fig-6: Total Deformation

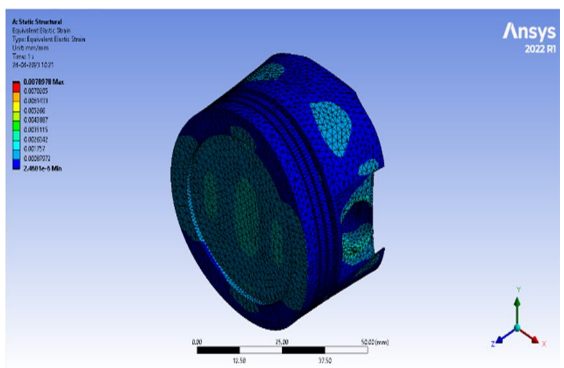

Fig-7: Equivalent Elastic Strain

4) Steady State Thermal Analysis

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

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

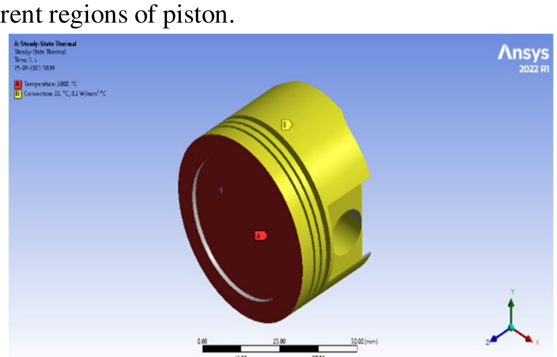

Fig-8: Applying Temperature and Convection Boundary

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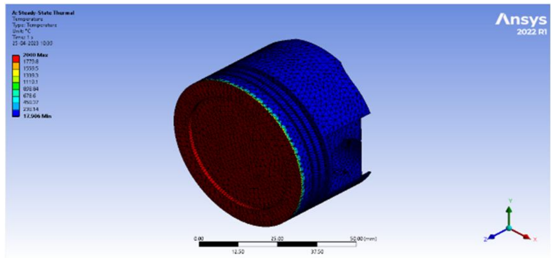

Fig-9: Temperature

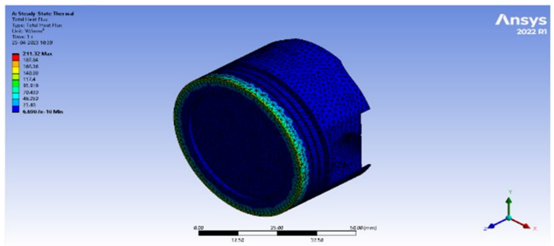

Fig-10: Total Heat Flux

5) Fatigue Analysis

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

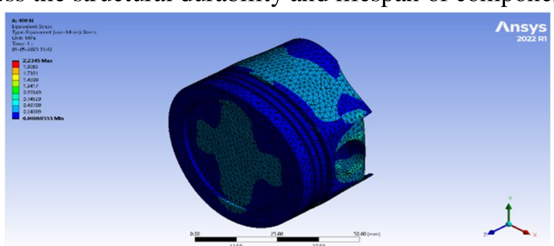

Fig-11: Equivalent Stresses

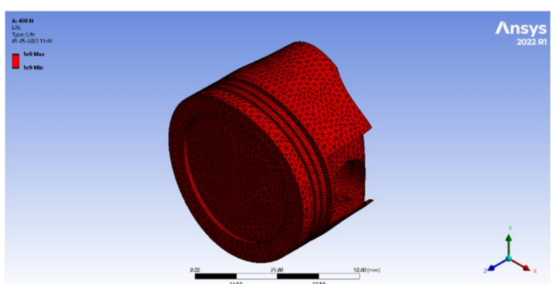

Fig-12: Life

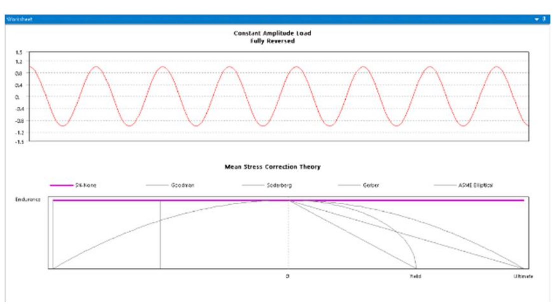

Fig-13: Stress Life

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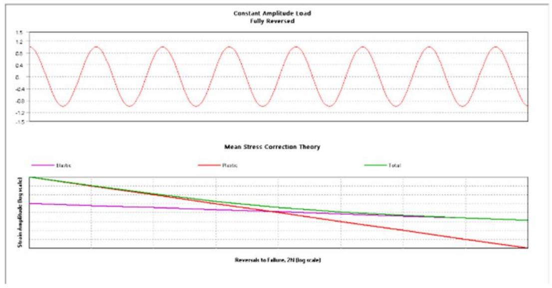

Fig-14: Strain Life

6) Analysis of Piston, Ti-6A1-4V

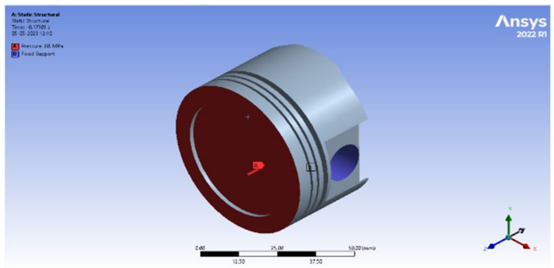

Fig-15: Applying Boundary Conditions

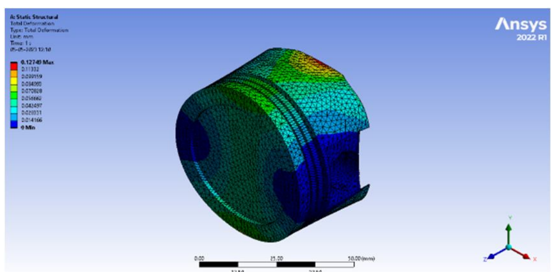

Fig-16: Total Deformation

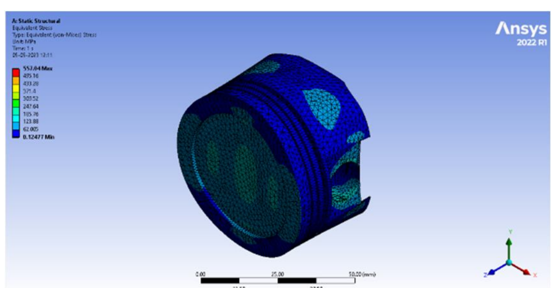

Fig-17: Equivalent Stresses

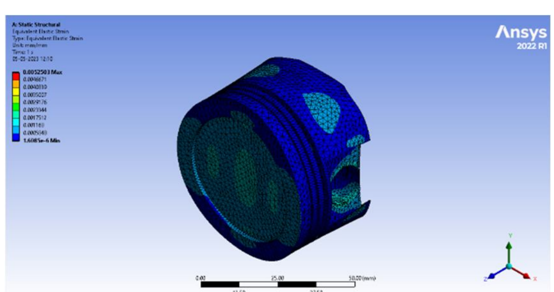

Fig-18: Equivalent Elastic Strain

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7) Steady State Thermal Analysis

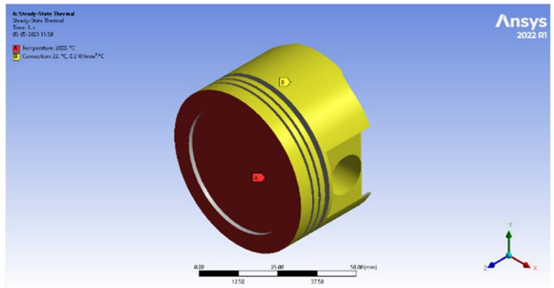

Fig-19: Applying Temperature and Convection Boundary

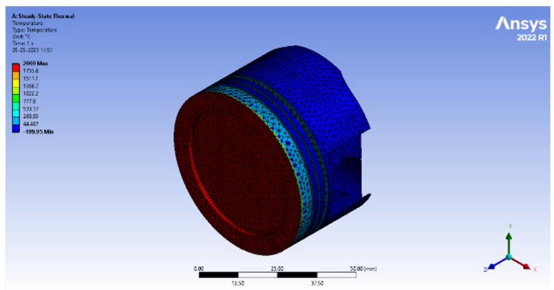

Fig-20: Temperature

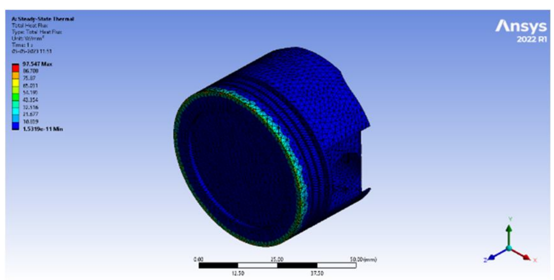

Fig-21: Total Heat Flux

8) Fatigue Analysis

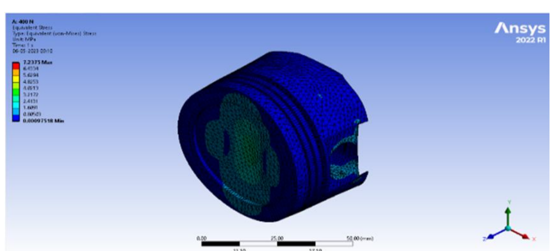

Fig-22: Equivalent Stresses

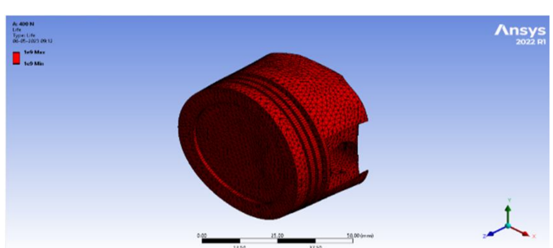

Fig-23: Life

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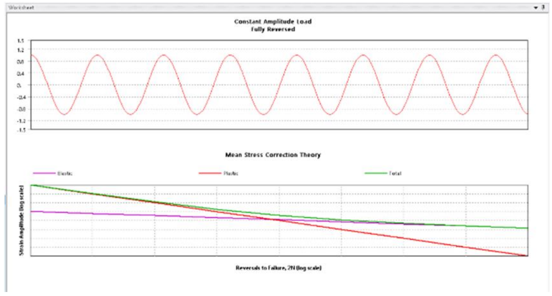


Fig-24: Strain Life

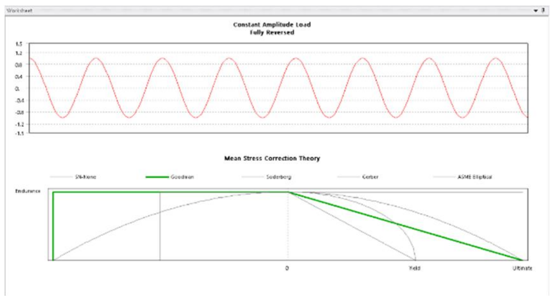


Fig-25: Stress Life

IV. RESULTS

A. Static Structural Analysis

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

B. Steady Thermal Analysis

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

C. Fatigue Analysis

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

As it can be seen from the tables above:

- The maximum stress occurs in Ti-6Al-4V (7.2375 MPa) while minimum is in Aluminum alloy (2.2345 MPa).
- The Factor of Safety (F.O.S.), which is ratio of ultimate tensile strength and maximum stress generated (σuts/σmax), is maximum for Aluminum alloy (15) and minimum for Ti-6Al-4V (15).

V. CONCLUSIONS

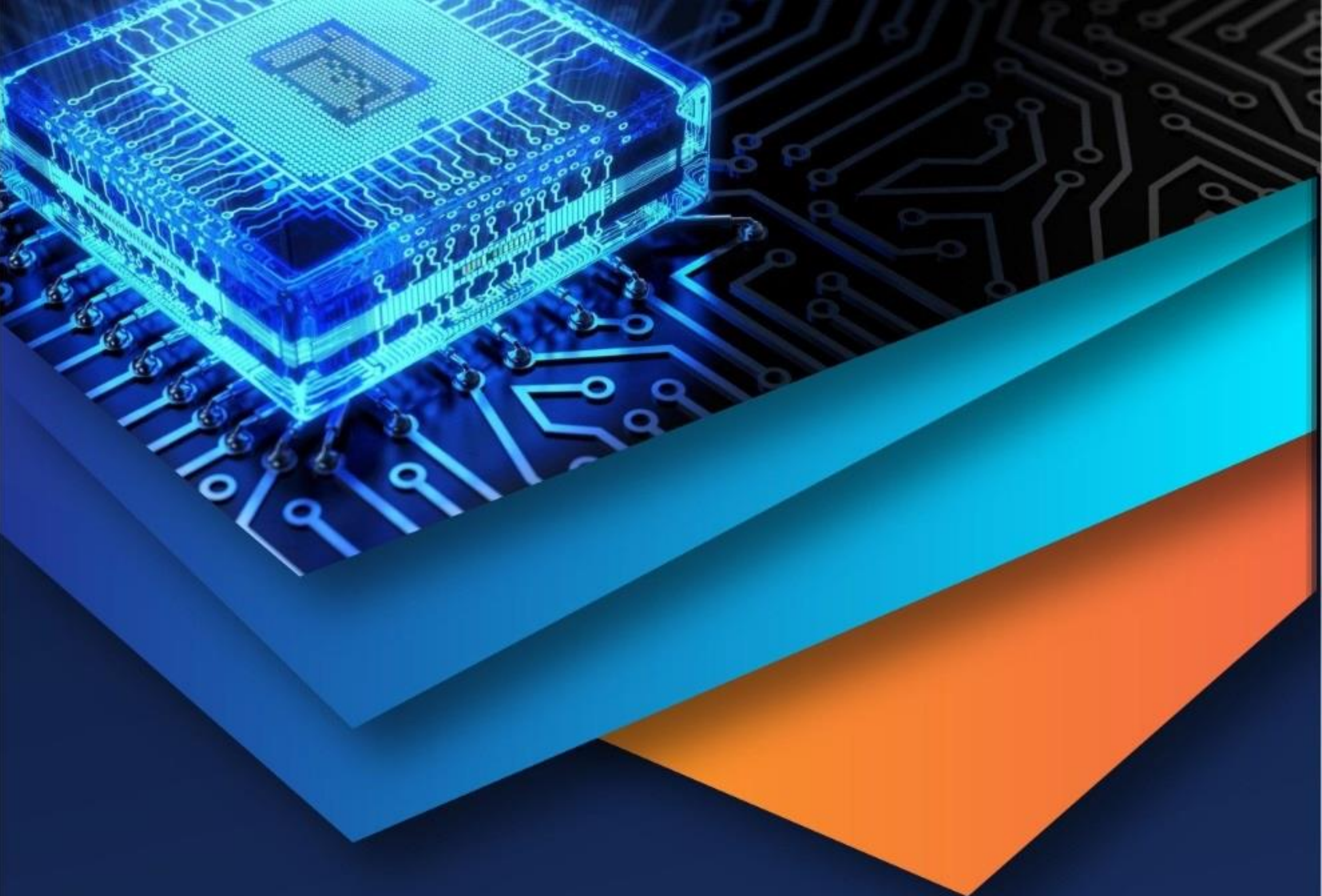
The titanium alloy Ti-6Al-4V is widely used in pistons of supercars and this led us to the assumption that if it is used in such high-performance cars, then it's possible that it can also be used in motorbikes. The material properties of titanium alloy were also suggesting the same but our analysis clearly demonstrates that it isn't a feasible option. From our analysis results, it is concluded that Ti-6Al-4V is the best material for piston of Bajaj Pulsar 220cc. This is due to the following reasons.

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

This result is because of the design of the piston of Bajaj Pulsar 220cc. 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.

REFERENCES

[1] Vaishali R. Nimbarte and Prof. S.D. Khamankar, "Stress Analysis of Piston using Pressure Load and Thermal Load", IPASJ International Journal of Mechanical Engineering (IIJME), August 2015.
[2] Lokesh Singh, Suneer Singh Rawat, Taufeeque Hasan and Upendra Kumar, "Finite Element Analysis of Piston in ANSYS", International Journal of Modern Trends in Engineering and Research.
[3] Gadde Anil Kumar and Chandolu Nehemya Raj, "Design and Analysis of an I.C. Engine Piston and Piston Rings by using Three Different Materials", International Journal of Advances in Mechanical and Civil Engineering, April 2017.
[4] Hitesh pandey, 2014 "Thermal Stress Analysis of a Speculative IC Engine Piston using CAE Tools" Int. Journal of Engineering Research and Applications Vol. 4, Issue 11(Version - 5), page.60- 64
[5] Dilip Kumar Sonar, 2015"Theoretical Analysis of Stress and Design of Piston Head using CATIA & ANSYS" International Journal of Engineering Science Invention. Volume 4 Issue 6 June 2015 Page .52-6
[6] A. P. Carlucci, A. Ficarella, D. Laforgia, and A. Renna, "Supercharging system behavior for high altitude operation of an aircraft 2-stroke diesel engine," Energy Conversion and Management, vol. 101, pp. 470–480, 2015.
[7] Z. Pan and Q. He, "High cycle fatigue analysis for oil pan of piston aviation kerosene engine," Engineering Failure Analysis, vol. 49, pp. 104–112, 2015.
[8] L. Rebhi, B. Krstic, A. Boutemedjet et al., "Fatigue fracture analysis of an ADF antenna in a military aircraft," Engineering Failure Analysis, vol. 90, pp. 476–488, 2018.
[9] S. K. Bhaumik, M. Sujata, and M. A. Venkataswamy, "Fatigue failure of aircraft components," Engineering Failure Analysis, vol. 15, no. 6, pp. 675–694, 2008.
[10] B. Krstic, L. Rebhi, D. Trifkovic et al., "Investigation into recurring military helicopter landing gear failure," Engineering Failure Analysis, vol. 63, pp. 121–130, 2016.



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