Topology Optimization for Higher Thermal Efficiency and Resisting Higher Mechanical Load of the Piston

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Abstract - *This paper describes the comparative study of pistons made of three different materials by using Finite Element Method (FEM) and attempts to increase the properties of piston used in Supercars. The parameters used for the analysis are pressure, temperature and many other material properties of piston. The specifications used for the study of these pistons belong to four stroke six cylinder engine of Toyota GR Supra 2998cc. This project represents the procedure for analytical design of Al2618, Al4032 and Ti-3Al-8V-6Cr-4Mo-4Zr alloy piston. The dimensions are obtained and a 3-D CAD model on Solid Works (2022) is prepared. Static structural and thermal stress analyses are performed by using ANSYS 2023R1. The results predict the maximum stress, strain, total deformation and heat flux on the pistons using FEA. The best material is then selected on basis of these results and a comparison is made with the titanium alloy to find out whether the titanium alloy is better than aluminium alloy.*

Key Words: Alloys, Pistons, Al2618, Al4032, Ti-3Al-8V-6Cr-4Mo-4Zr, Stress, Deformation, Analysis

1. INTRODUCTION

1.1 Engine Piston

Engine pistons are the most complex and important part of an engine. The function of the piston is making the crankshaft rotation by using pressure generated in combustion chamber. Piston works in higher temperature, higher pressure, more speed and less lubrication conditions. Piston works with cyclic gas pressure and the inertial forces and this condition may cause the fatigue damage of piston such as side wear, head cracks etc.

Piston in an IC engine must had the following characteristics:

- Strength to resisting gas pressure
- Must have minimum weight
- Must be able to reciprocate with less noise
- Must have required bearing area to prevent wear
- Must disperse the heat generated during combustion
- Must have good resistance to distortion under heavy forces and high temperature.

1.2 Design and Analysis

The main objective of piston design is to predict the pressure and temperature distribution on the body of piston. Most of the car pistons are made up of aluminium alloy which has better thermal expansion coefficient. Also, to improve mechanical efficiency and reduce inertia force in high-speed machines, the weight of the piston also plays a major role.

Finite Element Analysis

Finite element analysis is a computerized method for predicting how a piston reacts to real-world forces, vibration and heat. It is used to reduce the number of physical prototypes, experiments and optimize components in their design to develop better products.

Finite element analysis shows whether a product will break, wear out or work as it was designed. FEA works by breaking down a real object into a large number of finite elements (Meshing). FEA helps predict the behaviour of products affected by many physical effects including stress, strain, deformation, temperature, heat transfer etc.

There are lots of research works proposing for engine pistons, new geometries, materials and this evolution has undergone with a continuous improvement over the years and required thorough examination of the smallest details.

2. PROBLEM DEFINITION

Aluminium alloys are used in the pistons of supercars. The operating pressure and temperatures are very high in such cars and this material struggles to sustain and work in such conditions. That so we introducing titanium alloy piston. The objective of the present work is to design and analyse piston made of Al2618, Al4032 and Ti-3Al-8V-6Cr-4Mo-4Zr alloys, compare the analysis results, find the best material amongst them and choosing that the titanium alloy is a suitable option.

3. METHODOLOGY

- Analytical design of pistons based on standard design.
- 3-D piston models are created in Solid Works.
- Meshing and analysis of piston is done in ANSYS Workbench 2023R1.
- Various stresses are determined by performing structural analysis and thermal analysis.
- Various regions where chances of damage in piston are possible are analyzed.
- Comparison is made between the three materials in terms of stresses, strain, deformation and heat flux.

3.1 Design of Piston

Engine: BMW B58 petrol engine.

Table-1: Engine Specifications

PARAMETERS	VALUES
Engine type	Four stroke, petrol engine
Induction	Water cooled type
No. of cylinders	Six cylinder
Bore (D)	82 mm
Stroke (L)	94.6 mm
Displacement volume	500 cm^3
Compression ratio	11:1
Maximum power	285 kW
Maximum torque (T)	500 N-m at 7000 rpm (N)
No. of rev/cycle	2

3.2 Analysis of Piston

3.2.1 Material Assignment

For analysis of piston, the 3-D CAD model prepared in Solid Works is converted into IGES format so that it can be imported in ANSYS 2023R1. After importing the model in ANSYS, material properties are assigned in engineering data.

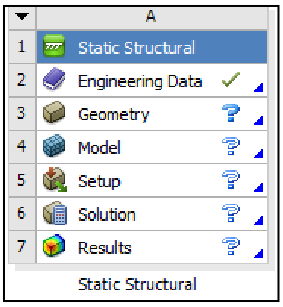

Fig-1: Static Structural Standalone System

Material properties of the three materials are mentioned inthe table below:

Table-2: Material Properties

PARAMETERS	VALUES		
	Al 2618	Al 4032	Ti-3Al-8V-6Cr-4Mo-4Zr
Elastic modulus (GPa)	75	80	96
Ultimate tensile strength(MPa)	441	370	1070
Poisson's ratio	0.33	0.33	0.33
Thermal conductivity (W/(m-K))	146	155	21
Density (kg/m^3)	2767.9	2690	4620

3.2.2 Meshing of Piston Model

After imported material properties, model is opened in mechanical. The whole body of the piston model is selected and meshing is performed. Tetrahedral elements type is used and the meshing element size is 2 mm.

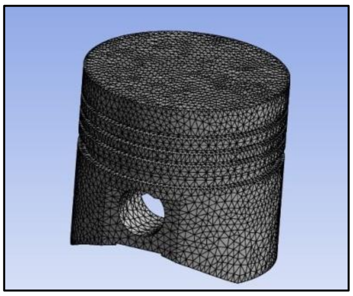

Fig-2: Meshing of Piston 3-D Model

3.2.3 Static Structural Analysis

In static structural analysis, boundary conditions are applied.

- Pressure at the head of piston: 13.65 MPa
- Fixed supports are applied at edges of gudgeon pin hole.

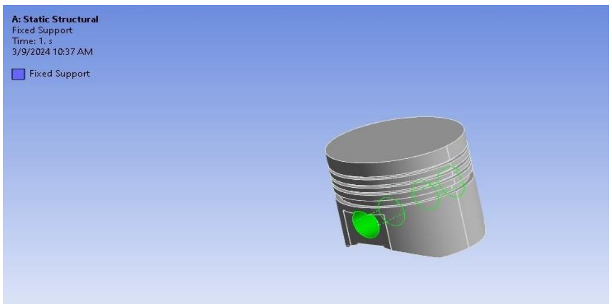

Fig-3: Fixed support

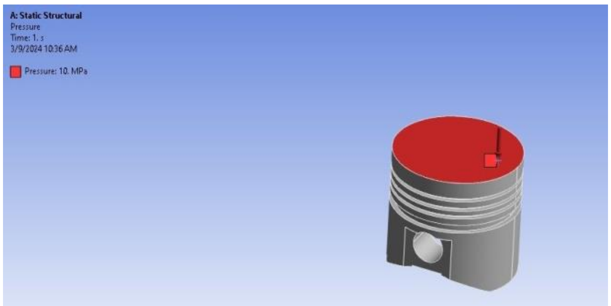

Fig-4: Pressure

a) Al 2618 alloy

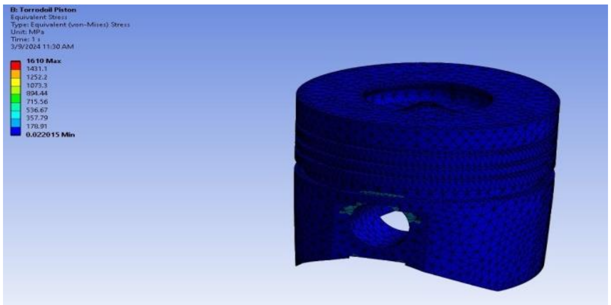

Fig-5: Stress

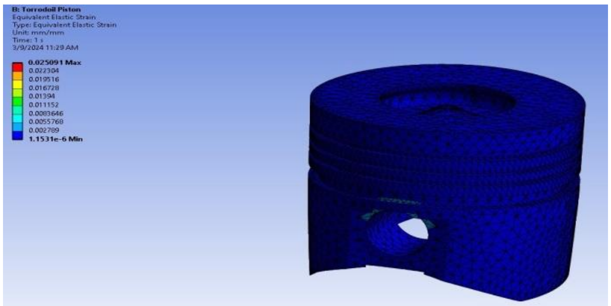

Fig-6: Strain

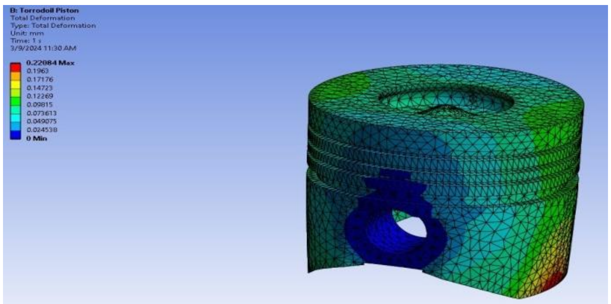

Fig-7: Total Deformation

b) Al 4032 alloy

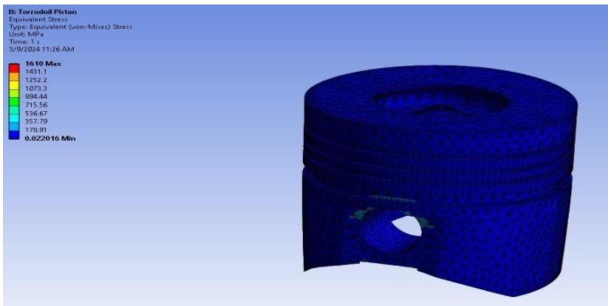

Fig-8: Stress

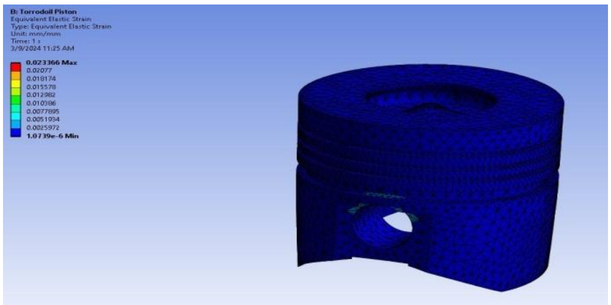

Fig-9: Strain

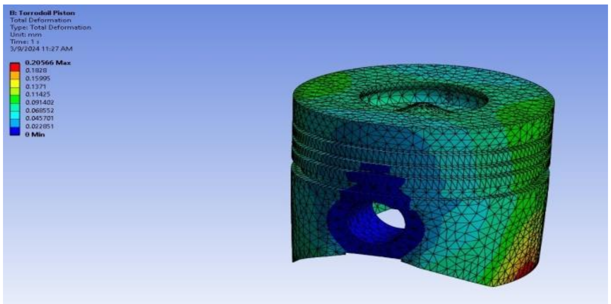

Fig-10: Total Deformation

c) Ti-3Al-8V-6Cr-4Mo-4Zr alloy

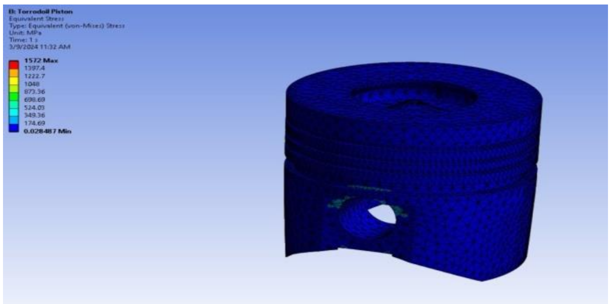

Fig-11: Stress

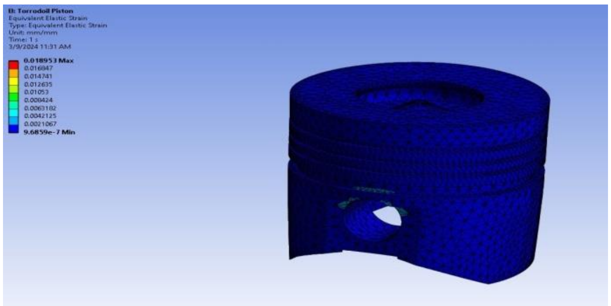

Fig-12: Strain

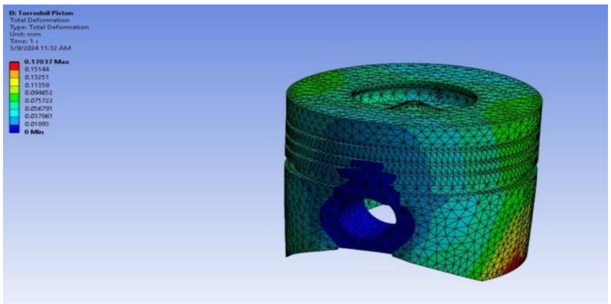

Fig-13: Total Deformation

3.2.4 Steady State Thermal Analysis

In steady state thermal analysis, boundary conditions are applied.

- Temperature at head of piston: 450°C
- Film coefficients of the piston are found be around 450 W/mm2C from similar paper carried out in research paper.

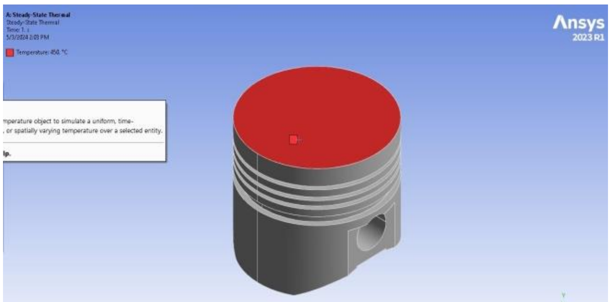

Fig-14: Temperature

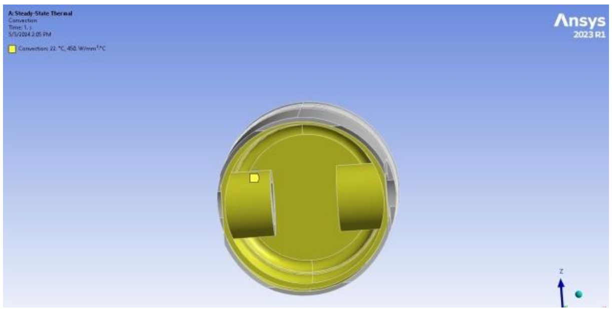

Fig-15: Convection

a) Al 2618 alloy

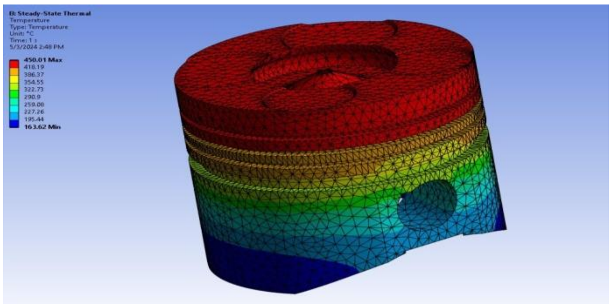

Fig-16: Temperature

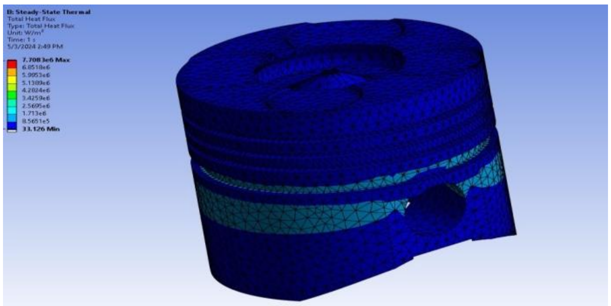

Fig-17: Heat flux

b) Al 4032 alloy

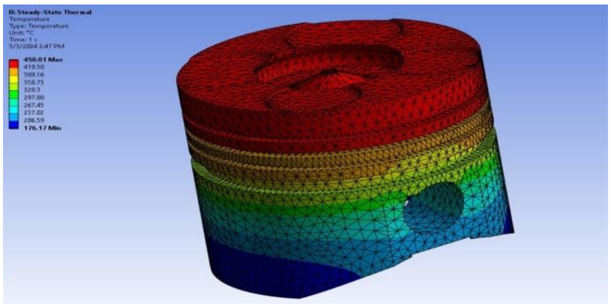

Fig-18: Temperature

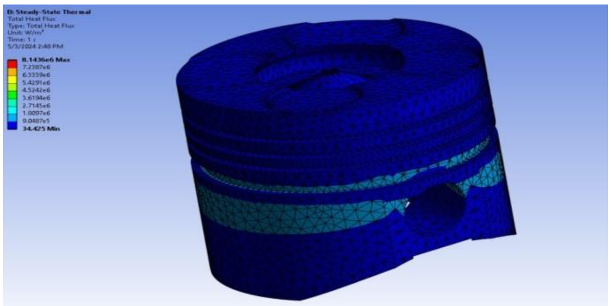

Fig-19: Heat flux

c) Ti-3Al-8V-6Cr-4Mo-4Zr alloy

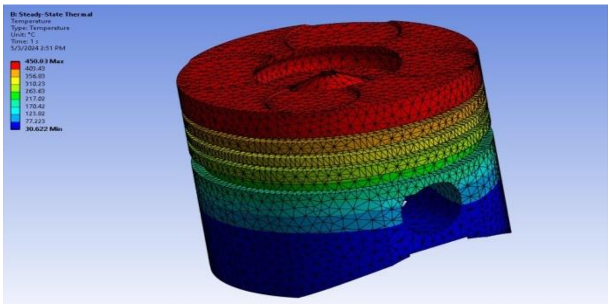

Fig-20: Temperature

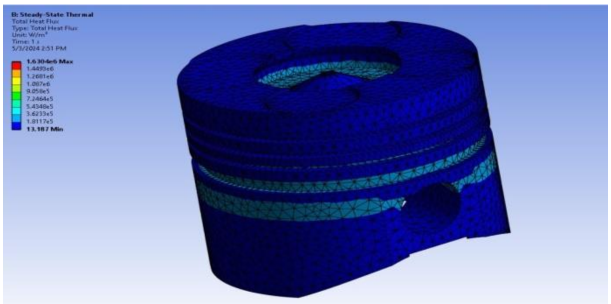

Fig-21: Heat flux

4. RESULTS

4.1 Static Structural Analysis

Table-3: Static Structural Analysis Results

PARAMETERS	VALUES		
	Al 2618	Al 4032	Ti-3Al-8V-6Cr-4Mo-4Zr
Equivalent stress (MPa)	1610	1610	1572
Equivalent elastic strain (mm/mm)	0.025091	0.023366	0.018953
Total deformation (mm)	0.22084	0.20566	0.17037

4.2 Steady State Thermal Analysis

Table-4: Steady State Thermal Analysis Results

PARAMETERS	VALUES		
	Al 2618	Al 4032	Ti-3Al-8V-6Cr-4Mo-4Zr
Temperature (^{0}C)	418.19	419.58	403.43
Heat flux (W/m^2)	7.7083	8.1436	1.6304

5. CONCLUSIONS

In conclusion, the research into the possibility of enhancing car pistons has been an important thing. After much research, it was clear that the typical use of aluminium alloys in supercars had limitations in terms of lifetime, strength, and thermal stability. To overcome these problems, switching to titanium alloy is the most suitable option.

Titanium alloy have good strength, durability, wear resistance and thermal resistance than aluminium alloys. It is slightly higher weight but other properties like ductility, hardness and thermal stability make it to overcome like that drawbacks.

We got the results in terms of stress, strain, deformation and heat flux is favorable to titanium alloy. So, we conclude titanium is the best option for piston making to supercars.

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