Analysis and Simulation of 4-Stroke Engine Piston using Titanium Alloy and Cast Aluminium Alloy

Abhishek[1], Aswin P A[2], Krishnakanth V[3], Niyas Hussain[4], Prof. Ajith U K Nair[5]

[1-4]UG Student, Department of Mechanical Engineering
[5]Assistant Professor, Dept. of Mechanical Engineering, Rajadhani Institute of Science and Technology, Kerala, India.

Abstract - *The modern style is to develop IC Engine of increased power capacity. One of the design criteria is the attempt to reduce the structures weight and thus to reduce fuel consumption. This has been made feasible by improved engine design. In the internal combustion engine, many reciprocating parts are responsible for giving the motion to the engine. The piston is "Heart" of the engine and its working condition is the nastiest one of the key parts of engine in the working environment. Therefore, it is very important for design and structural analysis of the piston. There are a lot of study proposing, for engine pistons, new geometries, materials and manufacturing techniques, and this advancement has undergone with a continuous development over the last decades and required thorough assessment of the smallest details. The purpose of this project is to reduce the weight of the piston to increase the fuel efficiency by replacing the conventional Aluminum alloy, cast, 336.0 material with Titanium alloy. The piston is modeled for a 4-stroke petrol engine with two different design specifications for titanium alloy and cast aluminum alloy in SOLID EDGE ST10. Then giving it the constrains which acts on the working condition of the piston, Static Structural and Steady State Thermal analysis are performed to study the performance of piston and the results are compared to find out the best suitable material.*

Key Words: Piston, Equivalent stress, Deformation, Heat flux, Total deformation.

1. INTRODUCTION

The piston reciprocates inside the cylinder to complete the cyclic events and pass on gas force to the crankshaft through the connecting rod. Piston is the most significant part in an internal combustion engine. The working condition of piston in an internal combustion is so bad. During the combustion stroke the fuel, get ignited with the aid of spark plug. Due to this burning of gases in the cylinder the thermal deformation and mechanical deformation causes piston cracks, tortuosities etc. It is very essential to test out or analyse the stress distribution, temperature distribution, heat transfer, thermal load, mechanical load in order to minimize the stress, minimize the thermal stress and different loads on running condition of the piston. In this study, firstly we draw the piston models for Aluminium alloy, cast, 336.0 and Titanium alloy in SOLID EDGE ST10 software and finally the pistons are analysed in ANSYS 2020 software.

The two steps implicated in this study are:

1. To design an IC engine pistons by using SOLID EDGE ST10 software.

2. To perform the structural and thermal analysis of pistons by using ANSYS 2020 software.

2. PROJECT OVERVIEW

2.1 Piston Design Features

1. Have enough mechanical strength and stiffness.

2. Can efficiently block the heat reached the piston head.

3. Elevated temperature corrosion resistance.

4. Dimensions as packed in as possible, in order to decrease the weight of the piston.

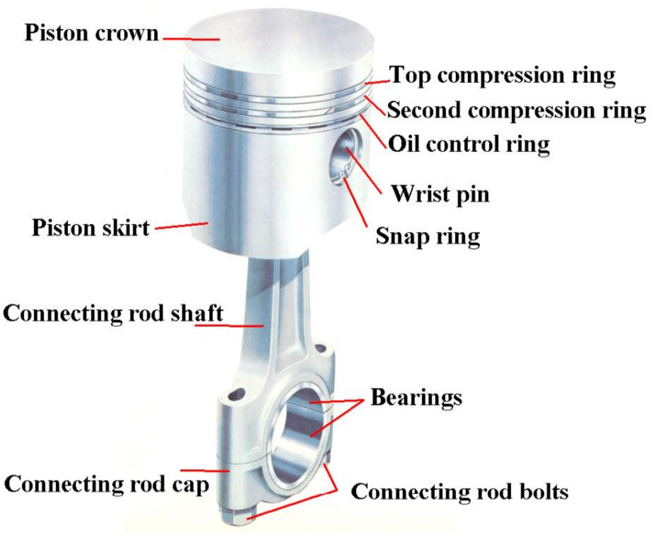

Fig 1: Piston

2.2 Properties of Materials

2.2.1 Aluminium Alloy Cast 336

Aluminium alloys are known for strong corrosion resistance. Aluminium alloys are sensitive to high temperatures ranging between 200 and 250°C (392 and 482°F), and have a propensity to lose some of its strength. However, the strength of Aluminium/Aluminium alloys can be enhanced at subzero temperatures, making them ideal low-temperature alloys. The datasheet below will provide more details about Aluminium alloy, cast, 336.0.

Table -1: Material properties of Aluminium Alloy Cast 336

Material Properties of Aluminium Alloy Cast 336	
Density	$2.713e^{-6}$ kg/mm^{3}
Coefficient of Thermal Expansion	$2.3e^{-5}C^{-1}$
Specific Heat	9.628 e^{5} mJ kg^{-1} C^{-1}
Thermal Conductivity	0.1171 W mm^{-1} C^{-1}
Young's Modulus	73040 MPa
Poisson's Ratio	0.3299

2.2.2 Titanium Alloy

Titanium is a low-density element (around 60% of the density of iron) that can be able to strengthened by alloying and deformation processing. Titanium is nonmagnetic and has good heat-transfer properties. Its coefficient of thermal expansion is rather lower than that of steels and less than half that of aluminium. One of titanium's valuable properties is a high melting point of 3135°F (1725°C). Titanium alloys are light in weight, have very good corrosion resistance and the ability to withstand extreme temperatures. It is highly resistant to chemical attack and has the utmost strength to weight ratio of any metal. These unique properties make Titanium suitable for a wide collections of applications. It's stiffness to weight ratio, as steel is similar to steel meaning it be able to used as a substitute where weight is an important consideration. It is highly recyclable which reduces costs involved in its production. Its inertness means that it can survive weathering and inevitably has a lower lifetime cost that other metals applied in architecture and construction. The datasheet below will provide more details about Titanium alloy.

Table -2: Material properties of Titanium Alloy

Material Properties of Titanium Alloy	
Density	$4.62e^{-6}$ kg/mm^{3}
Coefficient of Thermal Expansion	$9.4e^{-6}$ C^{-1}
Specific Heat	$5.22e^{5}$mJ kg^{-1} C^{-1}
Thermal Conductivity	$2.19e^{-002}$ W mm^{-1} C^{-1}
Young's Modulus	96000 MPa
Poisson's Ratio	0.36

2.3 Piston Modeling

Firstly, 2D drawings were created using sketcher toolbar; tools in profile tool bar like line, circle, rectangle, points, reference lines etc. and sketch references like grid, vertex, and dimensions are used. The created drawings were then fully constrained using the tool in constraint tool bar like constraint and auto constraint. Then 2D drawings were converted into 3D using sketch based features tools like revolve command. 3D objects are modified as required with the help of engineering feature tool bar, tools like edge fillet, chamfer are used. For Aluminium alloy cast 336 standard piston dimensions are used and the 2D sketch is created using Solid Edge ST10. As Titanium alloy has good strength to weight ratio the thickness of the standard piston is reduced from 8mm to 6mm and the 2D sketch is created .Then both the 2D sketches are revolved and 3D model is finally created for both the material.

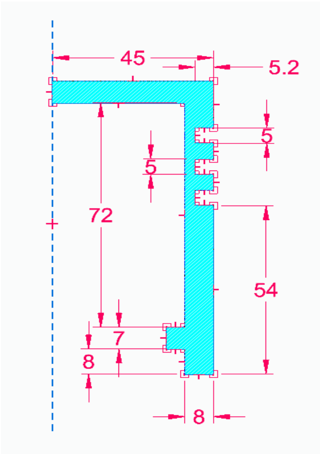

Fig 2: AL336

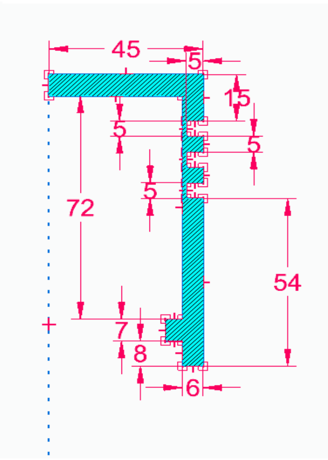

Fig 3: Ti

Fig 4: 3D model of Aluminium alloy cast 336

Fig 5: 3D model of Titanium alloy

3. FINITE ELEMENT ANALYSIS

Finite element analysis is one of the most accepted mechanical engineering applications offered by existing cad/cam systems. FEA tool is the mathematical glorification of real system. With the help of computer based technique it splits geometry into elements and contacts a series of equations to each and solves the equations at the same time to evaluate the behaviour of the entire system. It is used in situations where geometry, loading, and material properties are complex and exact analytical solution is difficult to achieve. Most often used for structural, thermal, fluid analysis,but widely valid for other type of analysis and simulation.
Initially, Automatic meshing method is used to mesh the model in ANSYS 2020 R1. The mesh grid is shown as figures below:

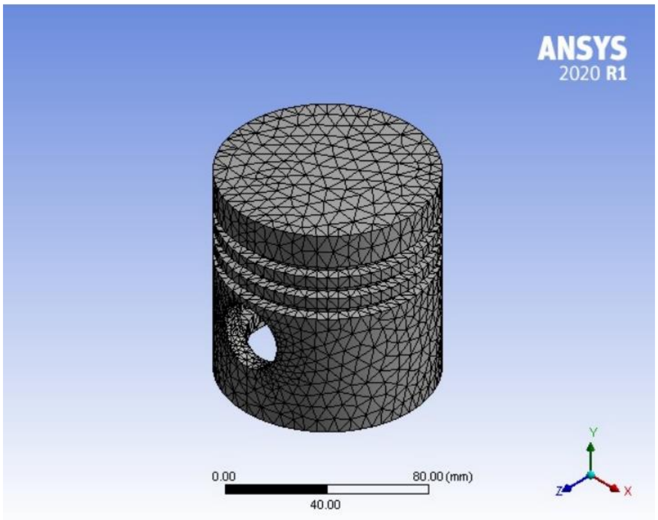

Fig 6: FEA mesh model of Aluminium Alloy Cast 336

The Aluminium Alloy Cast 336 model has a total of 27970 nodes and 17556 elements.

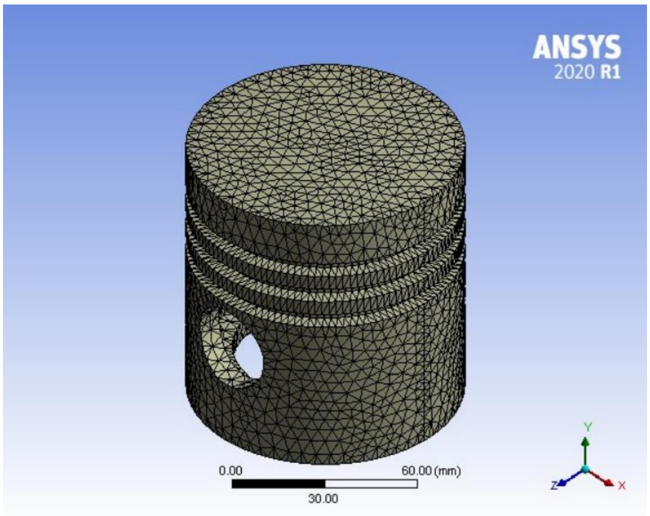

Fig 7: FEA mesh model of Titanium Alloy

The Titanium Alloy model has a total of 35150 nodes and 20490 elements.

3.1 Static structural analysis

A static structural analysis determines the displacements, stresses, strains, and forces in the structures and components caused by loads that do not persuade significant inertia and damping effects. Steady loading and response conditions are supposed that, the loads and the structure's response are assumed to vary slowly with respect to time. A static structural load can be performed using the ANSYS. In other words, these features are used more static loading situation which does not change over the time and location. A static analysis calculates the effects of study loading conditions taking place in a structure, while ignoring inertia and damping effects, such as those caused with time varying loads. A static analysis can conversely take account of steady inertia loads and time varying loads that can be approximated as static equivalent loads. Static analysis is used to find out the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia with damping effects. Steady loading and reaction conditions are assumed, i.e. the loads and the structures responses are assumed to differ slowly with respect to time

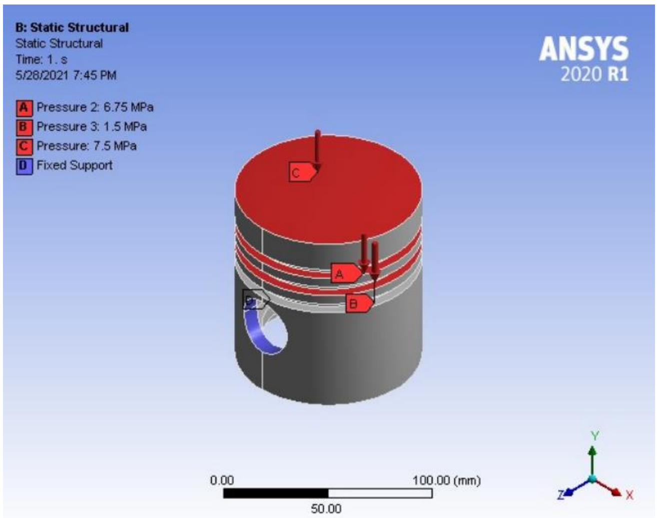

Fig 8 : Static Boundary Conditions

3.2 Steady state thermal analysis

Steady state thermal analysis can be used to decide the temperature distributions in an object with thermal loads that do not change with time. The heat transfer in steady state thermal analysis contains conduction, convection and radiation. Most thermal analyses are steady state thermal analysis. Steady-state thermal analysis is calculating the thermal equilibrium of a system in which the temperature remains constant over time. In other words, steady-state thermal analysis involves assessing the equilibrium state of a system subject to constant heat loads and conservational conditions. When the internal combustion engine works, the value of the coefficient of radiation heat transfer is much lesser than the value of the convection of heat transfer, so ignored the thermal radiation. When estimate the temperature field of piston, determined the boundary conditions of the piston rationally, this can be based on the value of the temperature of the piston's surface point and use it to classify and revise. The third kind boundary condition is used to analyse the temperature distribution. Whatever the theoretical analysis and experimental studies, it is not probable to develop the actual and experimental operation of piston by the first and second kind of boundary conditions.

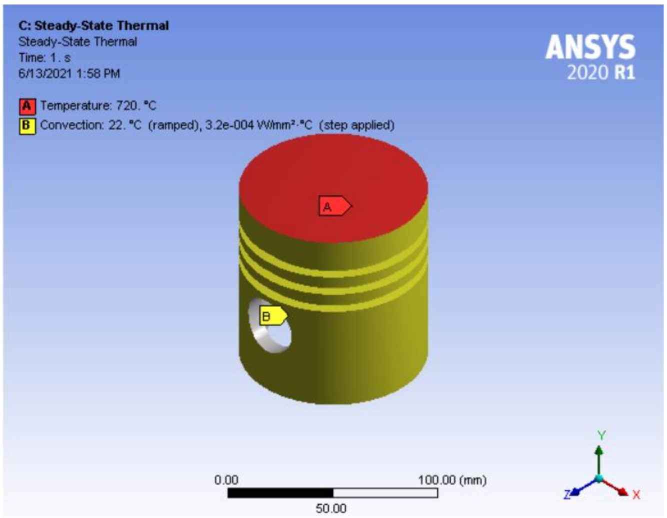

Fig 9: Thermal Boundary Conditions

4. RESULTS AND DISCUSSION

The constructed piston in SOLID EDGE ST10 is analysed using ANSYS 2020 R1 and the results are shown below. Combustion of gas in the combustion chamber exerts the pressure on head of the piston during power stroke. Fixed support has specified at surface of pinhole. Because the piston will move from top dead centre to bottom dead centre with the help of fixed support at pinhole.

Table 3: Comparison of parameter values

Comparison of maximum and minimum values for different parameters		
PROPERTIES	TITANIUM ALLOY	ALUMINIUM ALLOY CAST 336
Max Temp (C)	720	720
Min Temp (C)	25.997	127.05
Max Heat flux (W/mm^2)	0.88458	2.9043
Min Heat flux (W/mm^2)	7.0712e-6	0.00016832
Max Equivalent stress (MPa)	179.28	222.43
Min Equivalent stress (MPa)	0.44874	0.55485
Max Total Deformation (mm)	0.20036	0.26696

Min Total Deformation (mm)	0	0
Max Shear Stress (MPa)	101.97	99.933
Min Shear Stress (MPa)	-101.67	-105.03

4.1 Equivalent stress diagram

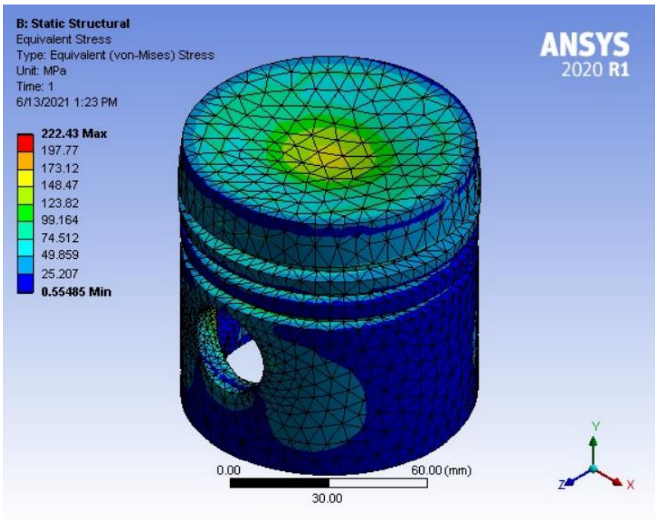

Fig 10: Equivalent Stress diagram of Aluminium Alloy Cast 336

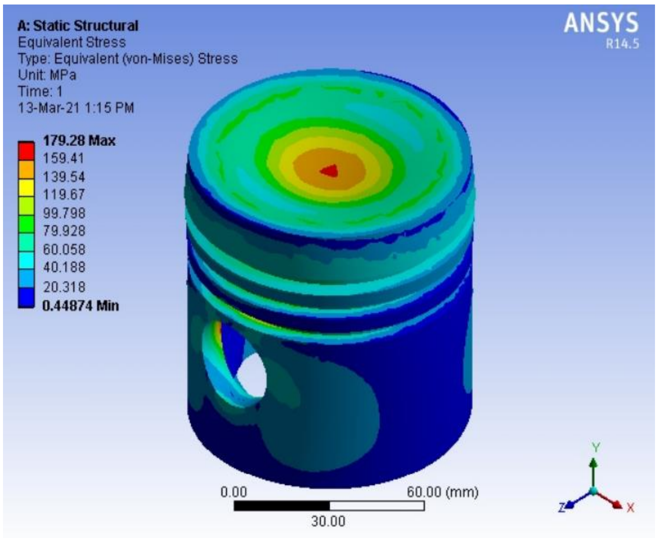

Fig 11: Equivalent Stress diagram of Titanium Alloy

The piston made of Titanium alloy is found to have less equivalent stress of 179.28 MPa in comparison with 222.48 MPa of Aluminium Alloy Cast 336.

4.2 Total deformation diagram

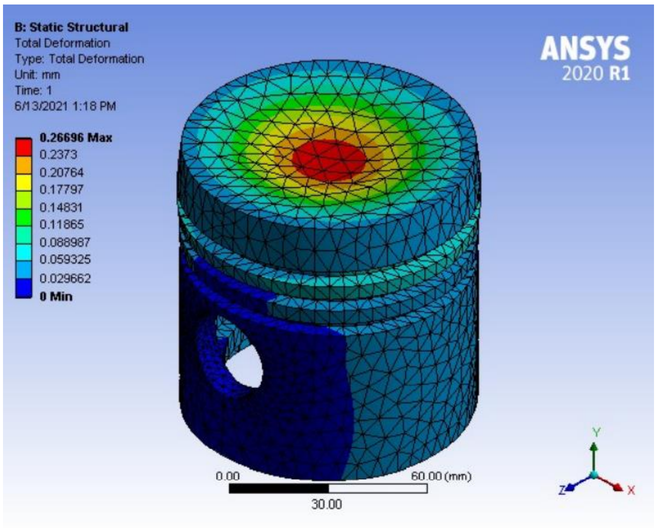

Fig 12: Total Deformation Diagram of Aluminium Alloy Cast 336

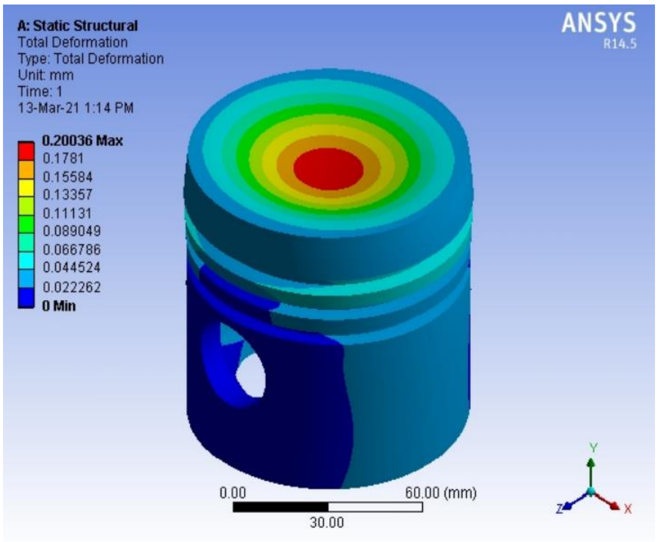

Fig 13: Total Deformation Diagram of Titanium Alloy

We can observe that in case of total deformation, piston made of Titanium Alloy is found to have least total deformation of 0.20036 MPa in comparison with Aluminium Alloy Cast 336. Highest total deformation of 0.26696 MPa is observed in piston made of Aluminium Alloy Cast 336. Hence Titanium alloy shows a better result than Aluminium alloy cast 336 in the case of deformation.

4.4 Temperature diagram

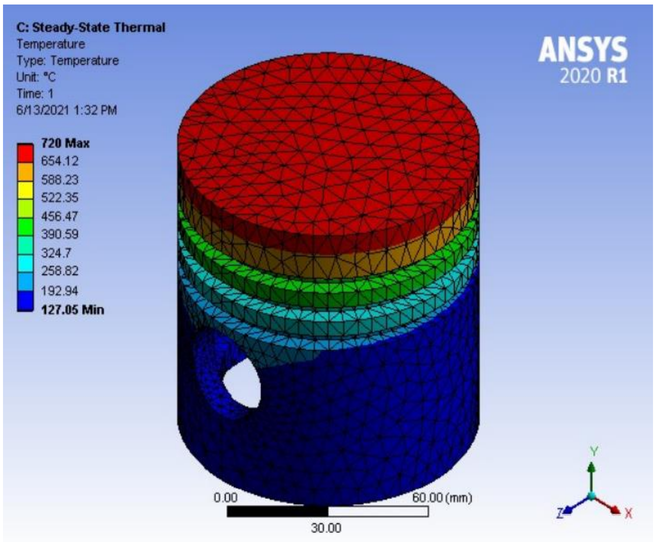

Fig 16: Temperature Diagram of Aluminium Alloy Cast 336

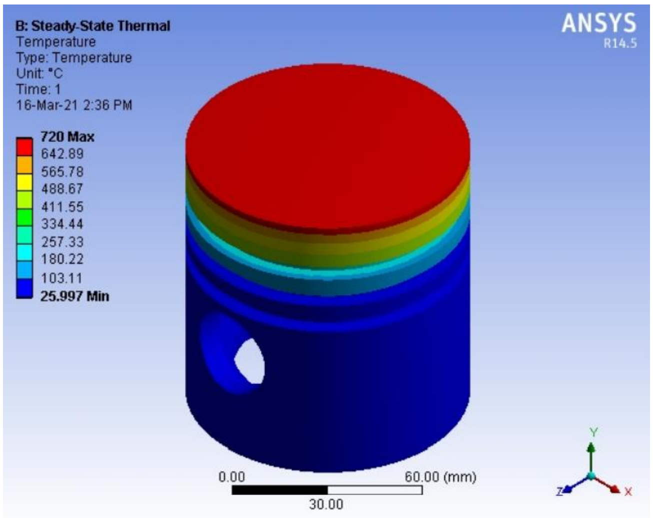

Fig 17: Temperature Diagram of Titanium Alloy

Here Aluminium alloy cast 336 has maximum temperature of 720 C and minimum of 127.05 C whereas Titanium Alloy has a maximum of 720 C and a minimum of 25.997 C. By comparative study of the temperature diagram of both Titanium alloy and aluminium alloy cast 336 it clearly shows that Titanium is less effected by the temperature.

Also as coefficient of thermal expansion of Titanium alloy is lower than that of Aluminium alloy cast 336 we can expect a better performance and life in Titanium alloy piston. Hence we can conclude that Titanium alloy will be a better material in the case of the temperature.

7.5 Heat flux diagram

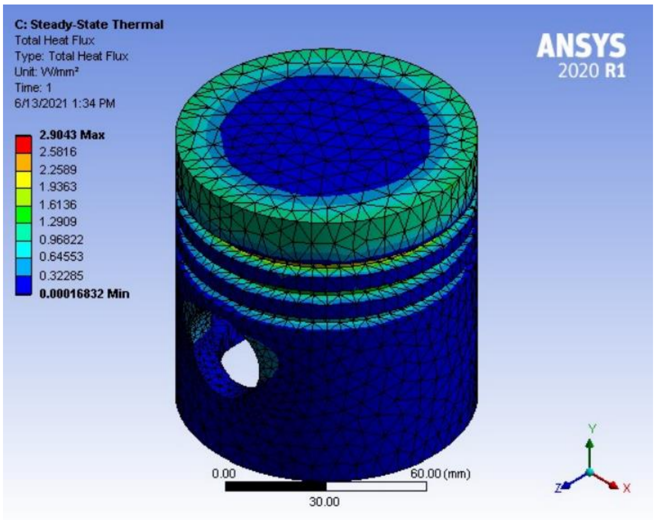

Fig 18: Heat Flux Diagram of Aluminium Alloy Cast 336

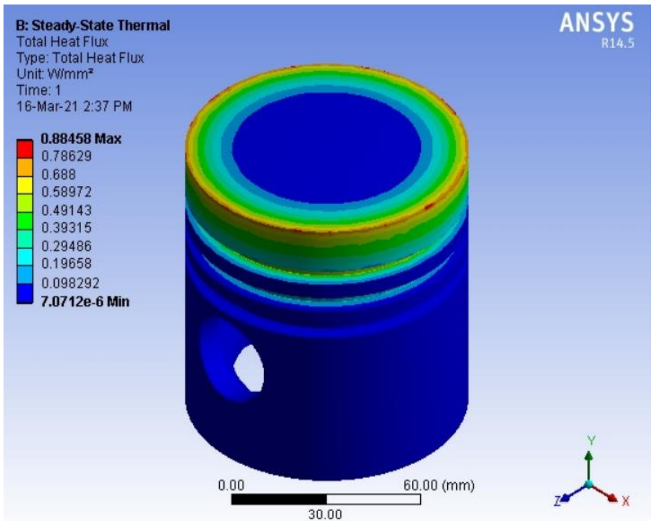

Fig 19: Heat Flux Diagram of Titanium Alloy

Here total heat flux varies in Titanium Alloy from 7.0712e-6 min to 0.88458 max and in Aluminium Alloy 336 from 0.00016832 min to 2.9043 max.

5. CONCLUSIONS

A piston made of Titanium alloy is designed and analysed successfully with Aluminium alloy cast 336. Titanium alloy piston offers high strength retention on ageing even at severe environments. Compared to Aluminium alloy cast 336, the Titanium alloy is found to have lesser deformation, lesser stress and good temperature distribution. Some of the limitations faced by Aluminium alloy cast 336 piston are overcame by the Titanium alloy piston. From this project, we get the clear knowledge about the Titanium alloy and its features.

The Titanium alloy is widely used in pistons of supercars and The Titanium alloy is generally used in pistons of supercars and this led us to the assumption that if it is used in such high performance cars, then it is probable that it can also be used in motorbikes.

In structural analysis and in thermal analysis the pistons were analyses to find out the equivalent (von-misses) stress, total deformation, heat flux, shear stress and temperature distribution.

A conclusion can be drawn that even after reducing the thickness of the piston of Titanium alloy, it has a better thermal property than Aluminum alloy cast 336. Also Titanium alloy piston has a well performance in deformation comparison with Aluminum alloy cast 336. Besides, it can be seen that Titanium alloy can help us to improve piston quality. As a final point, we were able to conclude that the Titanium alloy piston designed after reducing the weight could meet the power produced by Aluminium alloy cast 336 piston with greater thickness.

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