International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-08, Special Issue, MAY 2022

Modelling and Material Optimization of Piston Head to Sustain the Higher Load Conditions Without Failure

Mr. M Devi vara Prasad*, Mr. M Divakar*, Mr. K Ajay Kumar*, Mr. T Surya Kumar*, Mr. M Arbaaz*, Mr. B Bharath Kumar, Ms. M Amrutha****

***UG students, Department of Mechanical Engineering, Pragati Engineering College (A)**

****Faculty, Department of Mechanical Engineering College, Pragati Engineering College (A)**

Abstract: Engine pistons are one of the most complex components among all automotive and other industry field components. The engine can be called the heart of a vehicle and the piston may be considered the most important part of an engine. There are lots of research works proposing, for engine pistons, new geometries, materials and manufacturing techniques, and this evolution has undergone with a continuous improvement over the last decades and required thorough examination of the smallest details. Notwithstanding all these studies, there are a huge number of damaged pistons. Damage mechanisms have different origins and are mainly wear, temperature, and fatigue related. But more than wear and fatigue, damage of the piston is mainly due to stress development, namely- Thermal stress, Mechanical stress. This paper describes the stress distribution on piston of internal combustion engine by using FEA. The FEA is performed by CAD and CAE software. The main objectives are to investigate and analyse the thermal stress and mechanical stress distribution of piston at the real engine condition during combustion process. The paper describes the FEA technique to predict the higher stress and critical region on the component. With using solid works software, the structural model of a piston will be developed. Using ANSYS 2021R1 software, simulation and stress analysis is performed.

Key words: Optimization, CAD, CAE, FEA Ansys, Simulation

I. INTRODUCTION

Increasing the performance of an internal combustion engine requires the transformation of total fuel energy to useful energy at the highest as possible. Increase of inner cylinder heat plays important role in the increase of engine performance and decrease of exhaust emissions. It is understood as a result of literature studies that coating combustion chamber elements with thermal barriers contributes a lot to the increase of inner cylinder heat. This study includes an evaluation of experimental studies and its results carried out upon the methods applied on coating with thermal barrier in diesel engines, the effects of coating on the performance of engine and exhaust emissions. Ceramic coatings applied to diesel engine combustion chambers are aimed to reduce heat which passes from in-cylinder to engine cooling system. Engine cooling systems are planned to be removed from internal combustion engines by the development of advanced technology ceramics. One can expect that engine power can be increased and engine weight and cost can be decreased by removing cooling system elements (coolant pump, ventilator, water jackets and radiators etc. It is important to calculate the piston temperature distribution in order to control the thermal stresses and deformations within acceptable levels. The temperature distribution enables the designer to optimize the thermal aspects of the piston design at lower cost, before the first prototype is constructed. As much as 60% of the total engine mechanical power lost is generated by piston ring assembly Most of the internal combustion (IC) engine pistons are made of aluminium alloy which has a thermal expansion coefficient 80% higher than the cylinder bore material made of cast iron. This leads to some differences between running and the design clearances. Therefore, analysis of the piston thermal behaviour is extremely crucial in designing more efficient engines. The thermal analysis of piston is important from different point of views. First, the highest temperature of any point on piston should not exceed 66% of the melting point temperature of the alloy. This limiting temperature for the current engine piston alloy is about 370 °C. This temperature level can be increased in ceramic coating diesel engines. Ceramics have a higher thermal durability than metals; therefore, it is usually not necessary to cool them as fast as metals. Low thermal conductivity ceramics can be used to control temperature distribution and heat flow in a structure. Thermal barrier coatings (TBC) provide the potential for higher thermal efficiencies of the engine, improved combustion and reduced emissions. In addition, ceramics show better wear characteristics than conventional materials. Lower heat rejection from the combustion chamber through thermally insulated

DOI : 10.35291/2454-9150.2022.0265

components causes an increase in available energy that would increase the in-cylinder work and the amount of energy carried by the exhaust gases, which could be also utilized

1.1.1 Parts of Internal Combustion Engine

The basic components for a combustion cycle in a four-stroke engine are as follows

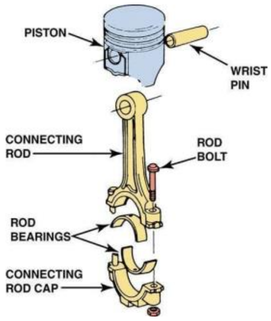
1. Cylinder
2. Piston valves
3. Connecting Rod
4. Crank
5. Crank Shaft
6. Flywheel

1.2 Diesel Engine

A diesel engine (also known as a compression-ignition engine) is an internal combustion engine that uses the heat of compression to initiate ignition to burn the fuel, which is injected into the combustion chamber during the final stage of compression. This is in contrast to spark-ignition engines such as a petrol engine (gasoline engine) or gas engine (using a gaseous fuel as opposed to gasoline), which uses a spark plug to ignite an air-fuel mixture. The diesel engine is modeled on the Diesel cycle. The engine and thermodynamic cycle were both developed by Rudolf Diesel in 1897.

1.2.1 Diesel Cycle Operation

The diesel cycle is the cycle used in the diesel (compression-ignition) engine. In this cycle the heat is transferred to the working fluid at constant pressure. The injection and burning of the fuel in the actual engine. The cycle in an internal combustion engine consist of induction, compression, power and exhaust strokes.



CHARACTERISTICS OF PISTON

1. It should be silent in operation both during warm-up and the normal running.

2. The design should be such that the seizure does not occur.

3. It should offer sufficient resistance to corrosion due to some properties of combustion Ex: Sulphur dioxide.

4. It should have the shortest possible length so as the decrease overall engine size.

5. It should be lighter in weight so that inertia forces created by its reciprocating motion are minimum.

6. Its material should have a high thermal conductivity for efficient heat transfer so that higher compression ratios may be used without the occurrence of detonation.

7. It must have a long life.

PISTON RINGS

Piston rings are fitted into the grooves of the piston to maintain good seal between the piston and the cylinder wall.

Functions of piston rings

1. To prevent the leakage of the compressed and expanding gases above the piston into the crankcase.

2. To control and provide the lubricating oil between piston skirt and cylinder walls.

3. To prevent the entry of lubricating oil from crankcase to the combustion chamber above the piston head.

4. To prevent the deposit of carbon and other materials (matter) on the piston head caused by burning of lubricant.

5. To provide easy transmission of heat from piston to cylinder walls.

Types of piston rings

There are two types of piston rings.

a. Compression rings or Gas rings.

b. Oil control rings or Oil regulating rings.

This topic shows review on design analysis of piston on the basis of improving strength according to the material properties. Vichada et. al. (2014), studied that Design analysis and optimization of piston and deformation of its thermal stresses using CAE tools, he had selected I.C. engine piston from TATA motors of diesel engine vehicle. He had performed thermal analysis on conventional diesel piston and secondly on optimized piston made of aluminum alloy and titanium alloy material. Conventional diesel piston made of structural steel. The main objective of this analysis is to reduce the stress concentration on the upper end of the piston so as to increase life of piston. After the analysis he conclude that titanium has better thermal property, it also helps us to improve piston qualities but it is expensive for large scale applications, due to which it can be used in some special cases. Ch. Venkata Rajma et. al. (2013), focused on Design analysis and optimization of piston using CATIA and ANSYS. He had optimized with all parameters are within consideration. Target of optimization was to reach a mass reduction of piston. In this analysis a ceramic coating on crown is made. In an optimization of piston, the length is constant because heat flow is not affected the length, diameter is also made constant due to same reason. The volume varied after applying temperature and pressure loads over piston as volume is not only depending on length and diameter but also on thickness which is more affected. The material is removed to reduce the weight of the piston with reduced material. The results obtained by this analysis shows that, by reducing the volume of the piston, thickness of barrel and width of other ring lands, Von miss stress is increased by and Deflection is increased after optimization. But all the parameters are with in design consideration. V. V. Makiwara et. al. (2015), describes the stress distribution of two different Al alloys by using CAE tools. The piston used for this analysis belongs to four stroke single cylinder engine of Bajaj Pulsar 220 cc motorcycle. He had concluded that deformation is low in AL-GHY 1250 piston as compare to conventional piston. Mass reduction is possible with this alloy. Factor of safety increased up to 27% at same working condition. He used Al-GHY 1250 and conventional material Al-2618 and results were compared, he found that Al-GHY 1250 is better than conventional alloy piston. Manjunath T. R. et. al. (2013), under look specification for both high pressure and low-pressure stages and analysis is carried out during suction and compression stroke and identify area those are likely to fail due to maximum stress concentration. The material used foe the cylinder is cast-iron and for piston aluminum alloy for both low and high pressure. He concluded that the stress developed during suction and compression stroke is less than the allowable stress. So, the design is safe. Swati S. chougule et. al. (2013), focused on the main objective of this paper is to investigate and analyze the stress distribution of piston at actual engine condition during combustion process the parameters used for simulation is operating gas pressure and material properties of piston. She concluded that there is a scope for reduction in a scope for reduction in thickness of piston and therefore 0ptimization of piston is done with mass reduction by 24.319% than non-optimized piston. The static and dynamic analysis is carried out which are well below the permissible stress value. The study of Lokesh Singh et. al. (2015) is related to the material for the piston is aluminum silicon composites. The high temperature at piston head, due to direct contact with gas, thermal boundary conditions is applied and for maximum pressure mechanical boundary conditions are applied. After all this analysis all values obtained by the analysis is less than permissible value so the design is safe under applied loading condition. The study of R. C. Singh et. al. (2014), discussed about failure of piston in I.C. engines, after all the review, it was found that the function coefficient increases with increasing surface roughness of liner surface and thermal performance of the piston increases. The stress values obtained from FEA during analysis is compared with material properties of the piston like aluminum alloy zirconium material. If those value obtained are less than allowable stress value of material then the design is safe.

Piston materials:

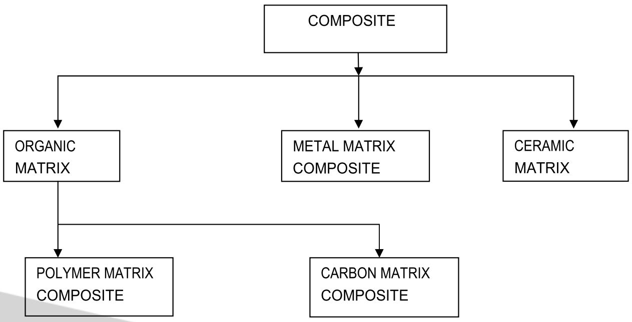
1 Aluminum alloy (Al GHS 1300)

2 Sic reinforced Zrb2 composite material

3 NASA 398 T5 (Aluminium Alloy)

CLASSIFICATION OF COMPOSITE MATERIAL

The composite materials are classified as



Comparison of composite with aluminium

1. Composites offer significant weight saving over existing metals. Composites can provide structures that are 25-45% lighter than the conventional aluminium structures designed to meet the same functional requirements. This is due to the lower density of the composites.

2. Unidirectional fibre composites have specific tensile strength (ratio of material strength to density) about 4 to 6 times greater than that of steel and aluminium.

3. Unidirectional composites have specific -modulus (ratio of the material stiffness to density) about 3 to 5 times greater than that of steel and aluminium.

4. Fatigue endurance limit of composites may approach 60% of their ultimate tensile strength. For steel and aluminium, this value is considerably lower.

5. Fibber composites are more versatile than metals and can be tailored to meet performance needs and complex design requirements such as aero-elastic loading on the wings and the vertical & the horizontal stabilisers of aircraft.

Advantages

Summary of the advantages exhibited by composite materials are as follows:

- High resistance to fatigue and corrosion degradation.
- High 'strength or stiffness to weight' ratio. As enumerated above, weight savings are significant ranging from 25-45% of the weight of conventional metallic designs.
- Due to greater reliability, there are fewer inspections and structural repairs.

DOI : 10.35291/2454-9150.2022.0265

- Improved dent resistance is normally achieved. Composite panels do not sustain damage as easily as thin gage sheet metals.

- It is easier to achieve smooth aerodynamic profiles for drag reduction. Complex double- curvature parts with a smooth surface finish can be made in one manufacturing operation.

- Composites offer improved torsional stiffness. This implies high whirling speeds, reduced number of intermediate bearings and supporting structural elements. The overall part count and manufacturing & assembly costs are thus reduced.

DISADVANTAGE OF COMPOSITES

Some of the associated disadvantages of advanced composites are as follows:

- High cost of raw materials and fabrication.
- Composites are more brittle than wrought metals and thus are more easily damaged.
- Transverse properties may be weak.
- Matrix is weak, therefore, low toughness.
- Reuse and disposal may be difficult.
- Difficult to attach.
- Repair introduces new problems, for the following reasons:

II. DESIGNING OF PISTON IN SOLID WORKS

Computer aided three dimensional interactive applications as high-end CAD/CAE/CAM tool used worldwide. solid works is developed by Dassault Systems. France is a completely re- engineered next generation family of CAD/CAM/CAE software solutions for product lifecycle management. Through its exceptionally easy to use state of the art user interface solid works delivers innovative technologies for maximum productivity and creativity from concept to the final product. Solid works reduces the learning curve as it allows the flexibility of using feature based and parametric designs. Solid works provides three basic platforms – P1, P2 and P3. P1 is for small and medium sized process-oriented companies which wish to grow towards the large scale digitized product definition. P2 is for the advanced design engineering companies that require product, process and resources modeling. P3 is for the high-end design application and is basically for automotive and aerospace industry where high equality surfacing or Class-A surfacing is used for designing. The subject of interpretability offered by solid works includes receiving legacy data from the other CAD systems and even between its own product data management modules. The real benefit is that the links remain associative. As a result, any changes made to this external data are notified and the model can be updated quickly. Solid works serves the basic tasks by providing different workbenches. A workbench is defined as a specific environment consisting of a set of tools which allows the user to perform specific design tasks in a particular area.

Fig 4.4: front view of piston

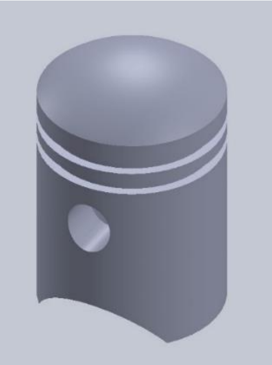


Fig 4.5: Isometric view of piston

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimisation of variational calculation to obtain approximate solution to vibration systems. Shortly thereafter, a paper published in 1956 by M.J Turner, R.W Claough, H.C Martin and L.J Top, Established a broader definition of a

STEP 2: MESH

GENERATE MESH

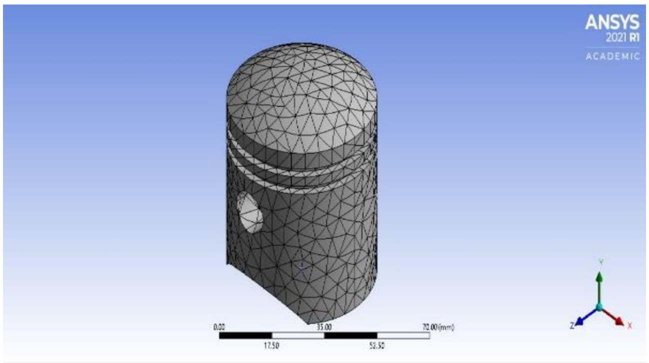


Fig 5.2: Mesh view of model

STEP 3: STATIC STRUCTURAL _FIXED SUPPORTS

Apply- fixed supports- on side holes.

DOI : 10.35291/2454-9150.2022.0265

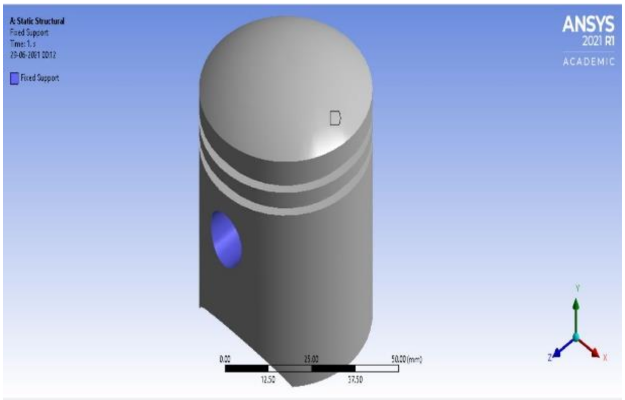


Fig 5.3: Applying fixed support

STEP 4: STATIC STRUCTURAL _FORCE

Apply –fixed supports- force – on piston top surface

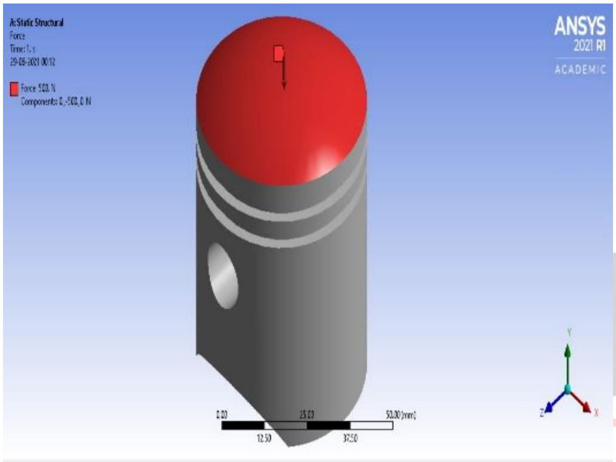


Fig 5.4: Applying loading condition top of the piston

III. ANALYSIS RESULTS:

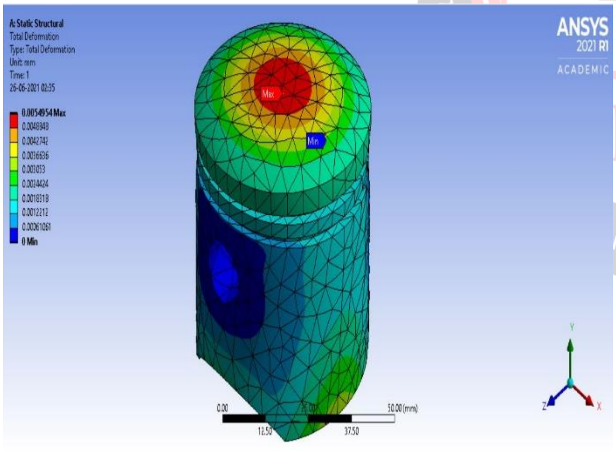


Fig 6.1: Deformation of piston with Al GHS 1300 material

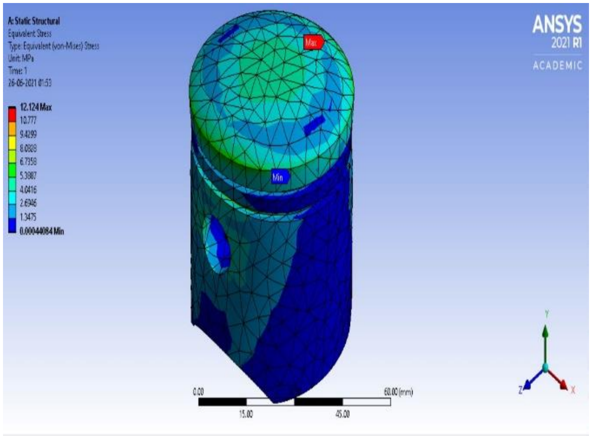


Fig 6.2: Stress distribution of piston with Al GHS 1300 material

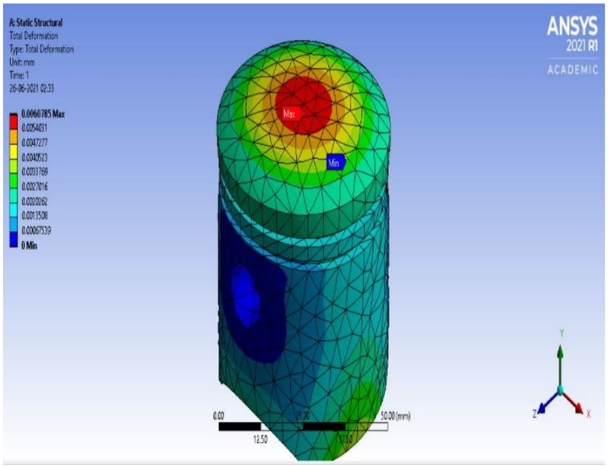


Fig 6.3: Deformation of piston with NASA 398 T5 material

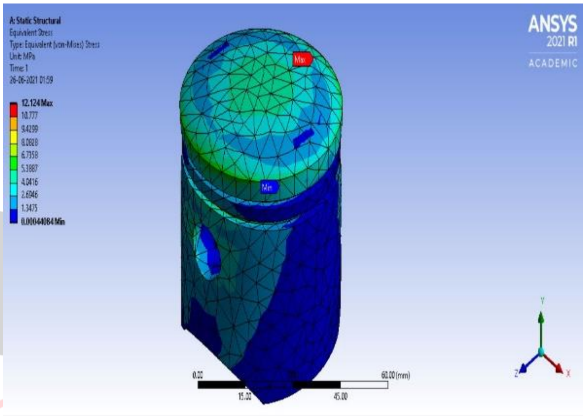


Fig 6.4: Stress distribution of piston with NASA 398 T5 material

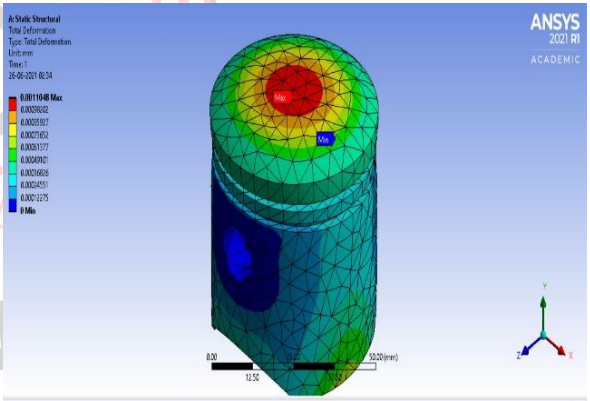


Fig 6.5: Deformation of piston with Sic Zrb2 material

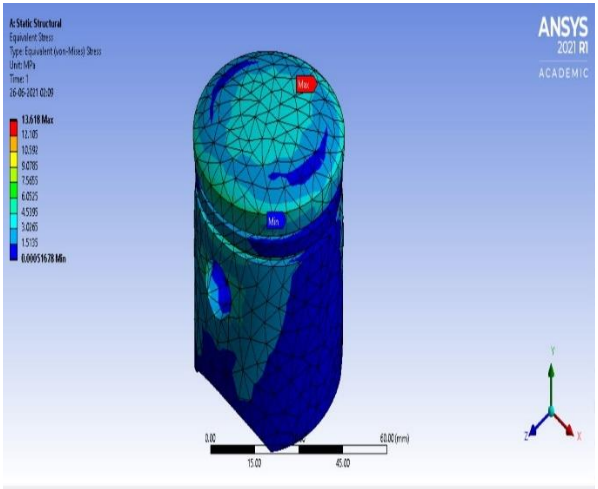


Fig 6.6: Stress distribution of piston with Sic Zrb2 material

DOI : 10.35291/2454-9150.2022.0265

6.2 Steady State Thermal Analysis of Piston

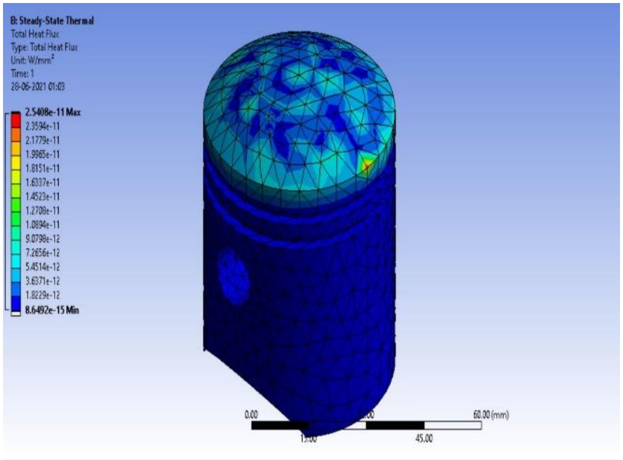


Fig 6.7: total heat flux with Al GHS 1300 material

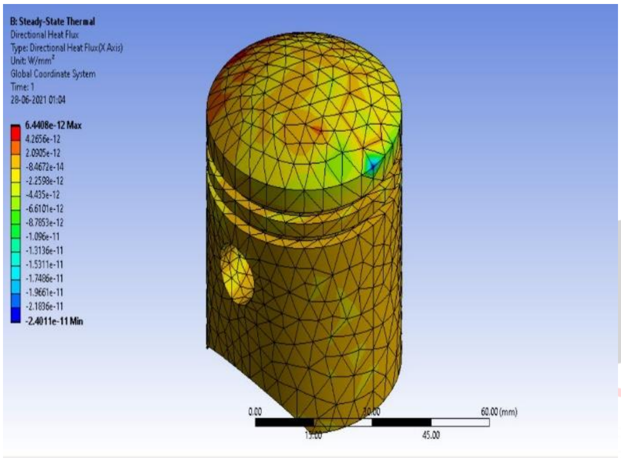


Fig 6.8: directional heat flux with Al GHS 1300 material

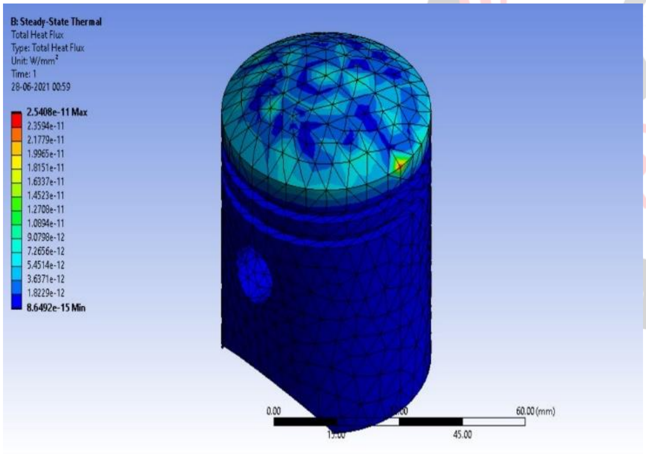


Fig 6.9: total heat flux of piston with NASA 398 T5 material

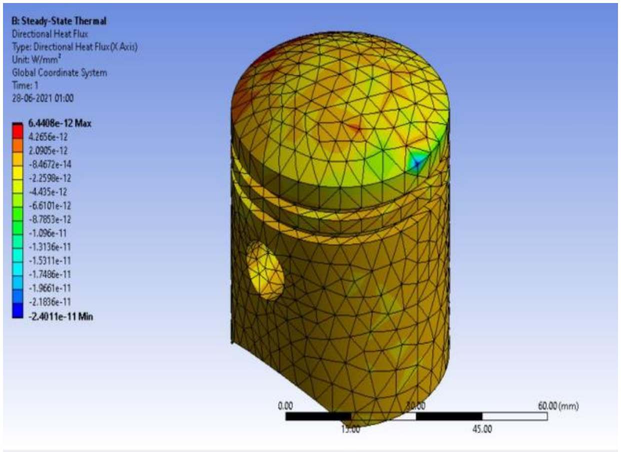


Fig 6.10: total heat flux of piston with NASA 398 T5 material

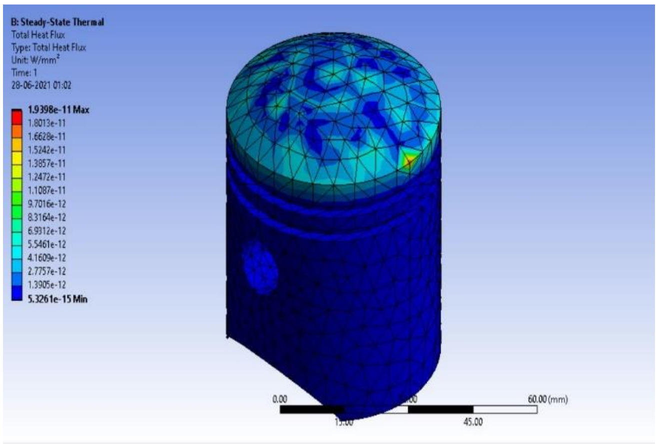


Fig 6.11: total heat flux of piston with Sic Zrb2 material

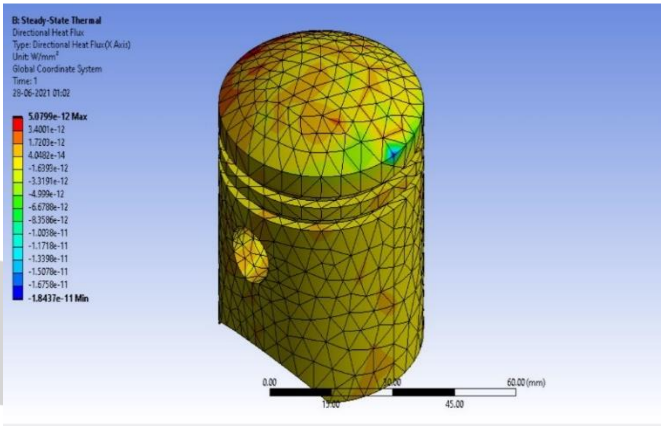


Fig 6.11: Directional heat flux of piston with Sic Zrb2 material

IV. CONCLUSION

The Static structural and Thermal Analysis is carried out in the ANSYS 2021 R1 software and the results are obtained for Al GHS 1300, NASA 398 T5 and Sic Zrb2. By comparing the results, it is found that the Sic Zrb2 has lesser Deformation in the applied boundary conditions and the Al GHS 1300, NASA 398 T5 lesser Equivalent stress compared with the Sic Zrb2 since the difference is very close Sic Zrb2 composite more suitable. While in the thermal analysis the Sic Zrb2 has a better Heat flux distribution than the Al GHS 1300, NASA 398 T5. Thus, with the obtained results from the analysis the Sic Zrb2 is found to be suitable to be used as piston material.

The analysis work can be carried out for different materials and for different designs of piston.

The analysis carried out can be successfully integrated in the laboratory and experimental approach can be used to analyse the piston.

REFERENCES

[1] Deovrat Vibhandik, Ameya Pradhan, Sampada Mhaskar, Nikita Sukthankar, Atul Dhale, (2014) , Design Analysis and Optimization of Piston and Determination of its Thermal Stresses Using CAE Tools, 3(5), pp.273-277.

[2] Ch. Venkata Rajam, P. V. K. Murthy, M. V. S. Murali Krishna, G. M. Prasada Rao, (2013), Design analysis

DOI : 10.35291/2454-9150.2022.0265

and optimization of piston using CATIA and ANSYS, International Journal of Innovative Research in Engineering & Science, 1(2), pp. 41-51.

[3] Vaibhav V. Mukkawar, Abhishek D. Bangale, Nititn D. Bhusale, Ganesh M. Surve, (2015), Design analysis and optimization of piston using CAE tools, International Conference, Pune, India

[4] Manjunatha.T. R, Dr. Byre Gowda. H. V, Prabhunandan. G. S, (2013), Design and Static Structural Analysis of Cylinder and Piston of Two Stage Reciprocating Compressors Using ANSYS, International Journal of Innovative Research in Science, Engineering and Technology , 2 (12), pp. 7590-7596.

[5] Swati S. Chougule, Vinayak H. Khatawate, (2013), Piston Strength Analysis Using FEM,International Journal of Engineering Research and Applications, 3, pp.124-126.

[6] Lokesh Singh, Suneer Singh Rawat, Taufeeque Hasan, Upendra Kumar, (2015), Finite element analysis of piston in ansys, 02, pp. 239-241.

[7] R. C. Singh, Roop. Lal, Ranganath M. S., Rajiv Chaudhary, (2014), Failure of Piston in IC Engines: A Review, IJMER, 4.

[8] R. C. Singh, Roop. Lal, Ranganath M. S., Rajiv Chaudhary, (2014), Failure of Piston in IC Engines: A Review, IJMER, 4.

[9] Gantla Shashidhar Reddy and N. Amara NageswaraRao, (2013), Modeling and analysis of diesel engine piston, International journal of Mathematics and Engineering, 2, pp. 199 – 202.

[10] Gantla Shashidhar Reddy and N. Amara NageswaraRao, (2013), Modeling and analysis of diesel engine piston, International journal of Mathematics and Engineering, 2, pp. 199 – 202.

[11] S. Srikanth Reddy, Dr. B. Sudheer Prem Kumar, (2013), Thermal Analysis and Optimization of I.C. Engine Piston Using Finite Element Method, International Journal of Innovative Research in Science, Engineering and Technology, 2, pp. 319-323

DOI : 10.35291/2454-9150.2022.0265