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Analysis and Performance of Coating Material Based Piston of I.C. Engine using CATIA and ANSYS Software

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ABSTRACT

The piston, as an important component of the engine, is subjected to cyclic gas pressure and root stress during use, which can cause fatigue damage to the piston, such as piston side wear, piston head/crown cracks. According to the highest stress occurs at the top end of the piston and stress concentration is a major cause of fatigue failure. The main objective of this research is to look at the analysis of pistons with design changes to reduce volume and improve efficiency. After loading the piston model into the engineering simulation and 3D design software ANSYS, boundary conditions are applied to the piston. Then several properties (stress and deformation) are analyzed, and the results are obtained instantly. In this study the piston is optimized for the piston material. A thermal analysis is performed to determine the overall heat flow in the current piston under specified temperature parameters. The operating temperature is applied to the surface of the piston. The results were also used to calculate the total heat flux of a given material.

KEYWORDS- I.C. Engine piston; CATIA software; ANSYS software:

1 INTRODUCTION

Dr. Ahmad A. et al. Present an analytical study on the effect of heat on a diesel engine piston and its compression rings during contact between the piston and the compression rings. The piston and its compression rings are modeled in three dimensions using ANSYS software. The thermal conductivity of the piston material and contact area as well as their effect on the piston and piston compression rings has been investigated. According to the results of this study, materials with high thermal conductivity are preferred over materials with low thermal conductivity. Thermal Analysis and Optimization of I.C. Engine" by A. R. Bhagat, YM Jebhakte, Thermal analysis is a branch of materials science that studies how the properties of materials change when the temperature changes. Oil can be used to improve the performance of I.C. Engine Cristina Azonin et al. In your essay suggest ideas about heat transfer process in piston heads. Methods used range from simple thermal networks to multidimensional differential equation modeling. Component temperature determines the majority of heat transfer to the combustion chamber of an internal combustion engine.

A study titled “Investigation on design optimization of IC engine piston and its effect on overall assembly” was published by M. Praveen Kumar et al. This paper investigates and analyzes the stress optimization of pistons for study I.C. Engines using FEM. The forces generated by combustion are taken into account to avoid piston failure. The structural stress magnitude should be kept to a minimum to achieve acceptable allowable limits. "Design and Analysis of SIC Composite Material Piston" A piston made of composite material (aluminum silicon carbide) has been designed and tested satisfactorily. After aging, a composite piston made of metal matrix maintains excellent strength even in hostile environments. Silicon carbide has been shown to have a lower deformation, stress and temperature distribution than aluminum. Some limitations of aluminum pistons differ from aluminum silicon carbide pistons.

C. V. Rajam et al "Design Analysis and Optimization of Piston Using CATIA and ANSYS" stated that the deflection due to applied pressure is higher after optimization than before optimization, and this value is a design consideration. Used to do. Piston deformation determines the majority of the pressure distribution on the piston. As a result, the piston crown needs to be strong enough to prevent distortion and thus stress on the concentricity. Vinay V. Kuppast et al published a paper titled "Thermal Analysis of Pistons for Effect on Secondary Motion", this study investigated the effect of thermal load caused by in-cylinder fuel combustion on piston deformation and thermal stress.

An internal combustion engine is an engine in which a fuel (usually a fossil fuel) is burned in a combustion chamber with an oxidizer (usually air). In an internal combustion engine, the expansion of high-pressure and high-temperature gases from combustion applies a direct force to certain engine components, such as pistons, turbine blades, or nozzles. This force moves the components a distance, generating useful mechanical energy. The term internal combustion engine generally refers to an engine in which combustion occurs intermittently, such as the more common four-stroke and two-stroke piston engines, with variations such as the winkle rotary engine. Another class of internal combustion engines uses continuous combustion: gas turbines, jet engines, and most rocket engines, all of which are internal combustion engines described earlier. An internal combustion engine (or ICE) differs greatly from external combustion engines such as steam or combustion engines in that power is supplied to a working fluid that does not contain, or mix with, combustion products. Or not contaminated by it. The working fluid can be air, hot water, pressurized water or even liquid sodium, which is heated in a type of boiler.

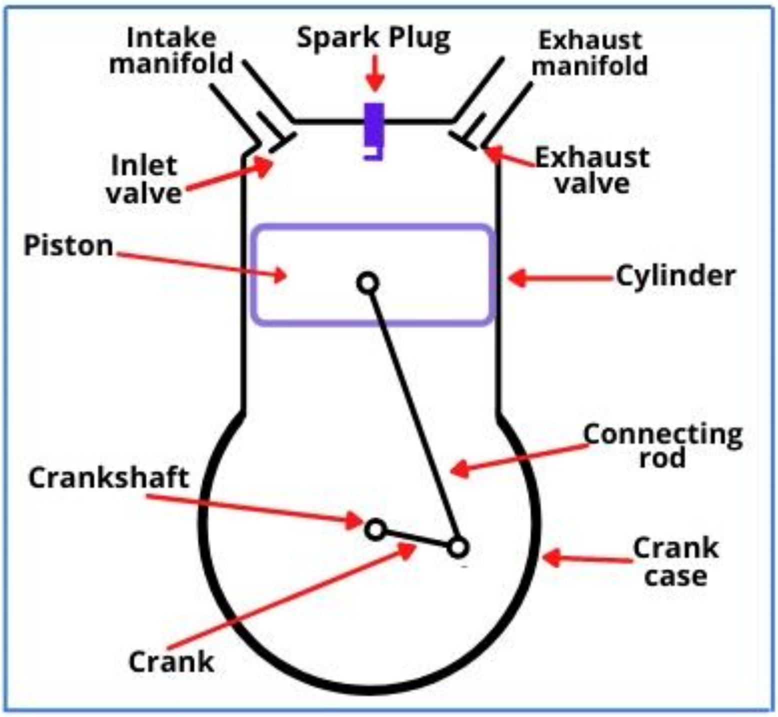

Figure 1 Internal combustion engine

2 LITERATURE REVIEW

Buyukkaya et al. (2018) investigated conventional (uncoated) diesel pistons made of aluminum alloy, silicon and steel. Thermal analysis was performed on MgO-ZrO2 coated pistons using the commercial code ANSYS. Finally, the results of four different presses are compared with each other. The effect of coatings on the thermal behavior of the piston has been studied. It has been shown that the maximum surface temperature of a piston coated with a low thermal conductivity material is improved by about 48% for AlSi alloys and 35% for steel. **Cody et al. (2018)** show that for every 10% reduction in vehicle weight, a 6 to 8% improvement in fuel consumption is expected. Better engine design requires better engine components. Engine piston is one of the most analyzed components in automobile or other industrial sectors. Damage to the crown, ring pommel, pin hole and skirt is assessed. Thermal stress and mechanical fatigue damage are presented and analyzed in this work. Linear static stress analysis, using "universe functions", is used to determine the stress distribution during combustion. Stresses also appear in the piston head and pin bores, as do grooves and skirts due to ground clearance.

Rajam et al. (2019) in the paper “Design Analysis and Baler Optimization Using CATIA and ANSYS” show that the deflection due to applied stress is higher after optimization than before optimization, and this value is considered for design consideration. is used. The deformation of the piston determines most of the pressure distribution in the piston. As a result, the piston head must be strong enough to avoid distortion and thus stress. **Saad et al. (2019)** conducted a numerical analysis to analyze the stresses induced by thermal cycling using different aluminum piston compositions. The finite element method was used to evaluate the coupling field (thermal stress) in the piston. ANSYS5.4 finite element code is used to implement the modeling process to determine the coupling stresses. Two models were built in 3 dimensions. The first is used to evaluate the temperature distribution in the piston volume, and the second is used to evaluate the temperature gradient and thermal stress distribution due to different materials. The result shows that the maximum temperature range is 4.3 °C and increases with decreasing thermal conductivity of the material. Thermal stress is concentrated at the edges of the piston and depends on the material type.

Vinay F. Kopast et al. (2020) a paper entitled "Analysis of Thermal Effect of Piston on Secondary Motion", this study determined the effect of in-cylinder fuel combustion-induced convection on piston deformation and thermal stress. **Zeng et al. (2020)** piston temperature ranges for diesel combustion and DME are calculated separately using ANSYS 10.0. The result shows that the thermal load change by replacing diesel with DME is still within the thermal resistance of the material. The temperature of a DME fueled diesel engine decreases from top to bottom along the piston axis. The piston temperature of a DME-fed engine increases overall compared to a diesel burner. However, the distribution of the temperature field does not change significantly, and it decreases and then increases from the center to the edge of the combustion chamber, and decreases again towards the edge of the piston top. **Gudimetal et al. (2020)** reported a CAD model of a damaged internal combustion engine (IC) piston and then used the advanced finite element analysis package ANSYS to perform linear static analysis and component thermal analysis. In addition, a parametric evaluation of material properties with respect to operating conditions is performed to create a relevant database to arrive at optimal design solutions for pistons under different operating conditions. **Christina Azonian et al. (2020)** proposed ideas about heat transfer processes in piston heads in their article. Simple heat networks are among the methods used for multidimensional differential equation modeling. The temperature of the components determines most of the heat transfer in the combustion chamber of an internal combustion engine. **Wang et al. (2020)** reported a solid model consisting of a piston and a piston pin of a new piston designed by Pro/E software, and also a finite element analysis model using ANSYS software. The thermomechanical conduction and tensile stress distributions were calculated first. Taking into account the non-linear properties of the piston material and piston pin, the Newton-Raphson equilibrium method is used. The calculation results show that the maximum pressure concentration is located at the upper end of the inner hole of the piston pin leader and is mainly due to the peak pressure of the fuel gas.

Duration etc. (2021) performed a steady-state thermal analysis using Abaqus© finite element (FE) software to evaluate temperature gradients in patterns and two different partially stabilized ceramic-coated pistons. As a result of the FE simulation, a sharp increase in the temperature of the coated area of the piston is observed. It is concluded that Y-PSZ coil coating can play a better role in reducing HC emissions in cold start and steady state without auto-ignition than Mg-PSZ, because the temperature in the region is a fast native. Increase. According to their results, pistons with Zamak have a higher heat flux value than conventional materials. Pistons with SiC-reinforced ZrB2 composite materials have lower deflections than aluminum alloys and gray cast iron for temperature and pressure. It is also noted that the stresses for all materials are within the allowable range for the respective materials. Silicon carbide has been found to have less deformation, less stress, and better temperature distribution than aluminum, and the engine operates at higher loads and speeds due to higher pressures and higher temperature combustion of the fuel inside the engine cylinder. . High thermal and structural stresses result in the piston inside the engine cylinder, and if these stresses exceed design values, piston failure occurs. **Jinju etc. (2021)** attempted to reduce thermal and structural stress magnitudes by using silicon nitride ceramic material as a material for the piston crown (top of the piston). Between the natural ceramic crown and the aluminum alloy flange, a strip of reinforced ceramic fibers is inserted to prevent the failure of the ceramic crown due to its brittle nature when subjected to shock loads from an explosion of combustion gases. In this work eutectic aluminum alloy (Si 11-13%) was taken as piston material. Initially, a thermal and compositional analysis was performed on an alloy piston without a silicon nitride crown and then with a silicon nitride crown using ANSYS software.

3 NEED OF THERMAL ANALYSIS OF PISTON

Although considerable progress can be seen in the engine and pistons as well, the high number of piston losses is alarming. The origin of piston damages can be different like mechanical stress, thermal stress. The various causes of piston losses are as follows: 1) Seizure due to insufficient clearance: The clearance between the piston and the cylinder wall is set to provide less friction during relative movement between the former and the latter. During engine operation, the piston reaches a much higher temperature than the cylinder, resulting in distinct thermal expansion behavior of the piston and cylinder. 2) Stroke due to lack of lubrication: If there is enough space between the cylinder wall and the piston, this form of stroke occurs. Due to high temperatures or gasoline immersion, the oil film breaks down during this process. Components such as pistons, cylinders, and piston rings rub against each other without lubrication, causing shocks and badly worn surfaces in a short period of time. 3) Seizures due to overheating: When seizures occur as a result of overheating, the lubricating coating breaks down due to the high temperature. First, it results in a mixture of friction and distinct friction marks. As damage increases, the material becomes even hotter, and the cylinder liner and piston become completely lubricated. Along with all the above mentioned causes of piston damage, damage due to abnormal combustion is also prominent in case of petrol engine. Thus the design approach requires thermal analysis of the internal combustion engine piston and selection of suitable materials from among the available alternatives.

4 PISTON FEATURES

Piston features include piston head, piston pin bore, piston pin, skirt, annular grooves, ring bases and piston rings. The piston head is the top surface of the piston (closest to the cylinder head) that is subjected to high forces and heat during normal engine operation. A piston pin hole is a hole on the side of the piston perpendicular to the piston stroke that receives the piston pin. The piston pin is a hollow shaft that connects the short end of the connecting rod to the piston. The piston flange is the part of the piston closest to the crankshaft that helps align the piston as it passes through the cylinder bore. Some skirts have cutout profiles to reduce piston mass and provide clearance for a rotating crankshaft counterweight. The circular groove is a recessed area around the circumference of the piston that is used to retain the piston ring. The ring heads are two parallel surfaces of the ring groove that act as the sealing surface of the piston ring. A piston ring is a split, expandable ring used to provide a seal between the piston and the cylinder wall.

Piston rings are usually made of cast iron.

5 MODELING

5.1 THE FEA OF THE PISTON

Heat transfer in engine is due to temperature difference and high temperature to low temperature. Thus, heat transfer occurs to the gases during the intake stroke and the first part of the compression stroke, but during the combustion and expansion processes, heat transfer occurs from the gases to the walls. Therefore, the piston crown/head, piston ring and piston skirt must be sufficiently hardened to withstand the pressure and friction between the mating surfaces. Furthermore, as an important part of the engine, the working condition of the piston is directly related to the reliability and durability of the engine. Therefore, it is important for the piston skirt and piston ring to have a structural and ideal analysis that can provide a reference for piston design.

5.2 MATERIALS AND METHODS

A real-time low-efficiency internal combustion engine was used to analyze the cylinder pressure of each piston using a blend of soybean, rice bran and bongami biodiesel. The maximum cylinder pressure combustion results were taken as operating pressures at different geometries of HEP, SRP and DCP in the range of 6.5 respectively. In the combustion chamber, a pressure band was applied to the piston head due to the gas explosion. The compressive force was taken as the mechanical load applied to the piston head and the same process was taken as the limit state in the structural analysis. When the piston moves from TDC to BDC, a fixed support is applied to the surface of the pinhole.

5.3 THERMAL LOAD AND HEAT TRANSFER COEFFICIENT OF THE PISTON

The top of the piston is the part of the piston that is in contact with the gas, so the temperature at the top is very high, up to 800 degrees Celsius. The heat transfer coefficient of the upper floor is selected from the test data of relevant research. The heat transfer coefficient from the surface of the earth is estimated at 540 W/(m 2 °C). Heat transfer between the piston and the cylinder and between the piston and the oil film is by convection.

5.4 Design procedure

1. Definitions of the problem and its scope.
2. Domain's discretion continues
3. Identification of state variables.
4. Formulation of the problem.
5. Establishment of coordinate system.
6. Construction of approximate functions for the elements.
7. Obtaining element matrix and equation.
8. Coordinate change.
9. Assembly of element equations.
10. Introducing the last set of simultaneous equations.
11. Interpretation of results

6 GEOMETRY

CATIA V5 software is used to create the piston. CATIA software is capable of producing different types of engineering, assembly, sheet metal work, etc. using different types of modules. An assembly of part design was used to develop the 3D model of the piston.

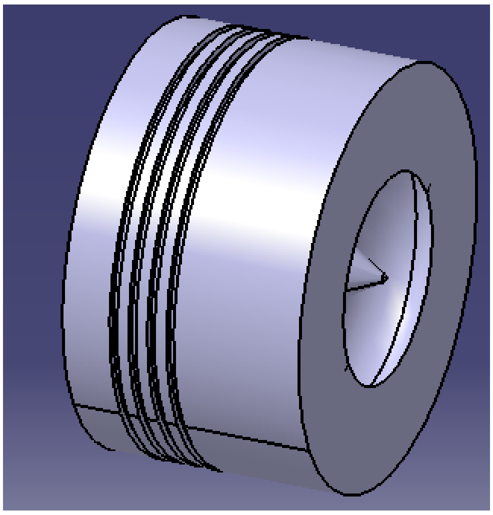

Figure 2 Geometry of Piston

Table 1 Parameters and magnitudes

Sl. No.	Parameter	Magnitudes
1	Number of nodes	715843
2	Number of elements	514962
3	Elastic modulus	7200 MPa
4	Poisson ratio	0.3
5	Linear expansion coefficient	2.3×10^{-5} K^{-1}
6	Thermal conductivity	163W/(m·K)
7	tensile strength	250 MPa.
8	Density	2730 kg/m^3

In this research work, the principle of reverse engineering has been applied to the design of the piston. Piston design data was collected from various sources. It has been found that material selection plays an important role in determining both static structural analysis and steady state thermal analysis. An air-cooled, single-cylinder four-stroke engine was considered for our study. Piston dimensions are measured using tools like calipers, spiral gauge, gauge etc. A 3D model of the piston is created using CATIA with measured dimensions.

The boundary conditions for the maximum gas pressure at the top surface of the piston are set at 6 MPa and a temperature of 480 °C. Three types of materials are selected from the software library for piston design. FEA is performed using ANSYS to determine the mechanical deformation and stress. Steady-state thermal analysis evaluates the extent of surface temperature distribution and the total heat flux.

7 RESULTS AND DISCUSSION

The Finite Element Method (FEM) provides a platform for obtaining approximate solutions to real problems. The finite element method is a numerical method for determining approximate solutions to engineering and scientific problems. In FEM, a complex region defined by continuity is divided into simple geometric shapes called elements. Governing properties and relationships are assumed on these elements and expressed mathematically in terms of unknown values at specific points in the elements called nodes.

7.1 MESH

Mesh a very important role in finite element analysis. A grid divides an element into a finite number of elements. Generally, according to the requirements, the researcher takes fine, medium and coarse mesh. The simulation time is directly proportional to the length of the loop shown in the helical spring of the loop.

7.2 TEMPERATURE BOUNDARY CONDITION AND CALCULATED LOADS

This study deals with the dynamic balance of heat exchange between the piston with the cooling oil cavity and the outside world and based on this, the steady state temperature field distribution of the piston is calculated. The difficulty in determining the heat transfer boundary conditions is that it is difficult to find a general formula for the accurate calculation of the heat transfer coefficient between the piston and the surrounding medium, so determining the boundary conditions Refrigerant oil temperature should be adjusted, flow rate, lubricating oil temperature and gas temperature calculated by scale force, etc.

The heat transfer boundary conditions determined by these empirical and semi-empirical formulas may be very different from the actual conditions. Therefore, it is necessary to continuously correct the thermal boundary conditions by comparing the simulation calculation results with the temperature results of corresponding points on the piston obtained by experiment.

7.3 STRESS BOUNDARY CONDITION AND CALCULATED LOADS

The boundary conditions for a piston under the action of mechanical loads only are the solid boundary conditions and the displacement boundary conditions. This work deals only with the effects of mechanical and thermal loads on the piston at rest. Therefore, the limiting force condition considers only the maximum gas pressure, neglecting the mutual inertia force of the piston and the lateral pressure, which has a value of Pmax ¼ 20 MPa;

The gap between the part and the cylinder is throttled, the gas pressure around the first ground and circular groove is 0.75Pmax, the gas pressure around the second ground and circular groove is 0.25Pmax, and the gas pressure around the second ground and circular groove is 0.25Pmax. is the pressure of the gas. The drain is ignored. The indirect method is used to calculate the coupling pressure of a piston heat engine, that is, to first calculate the steady state temperature of the piston, and the result of the obtained piston temperature field is used to calculate the piston calculation range. is conditionally loaded. Temperature machine coupled voltage temperature, and then the solution is combined with piston mechanical pressure.

7.4 DISPLACEMENT BOUNDARY CONDITION

When analyzing the pressure caused by the sudden burst pressure of the piston, the piston and piston pin in the contact area at the top of the pin set produce the same displacement along the radial direction of the piston pin. The axial displacement and circumferential displacement of the piston pin are independent of each other.

In addition, the width of the small end of the piston connecting rod supports the lower part of the piston pin, and it does not produce displacement in the direction of radial contact in the contact areas with each other, and the displacement in the axial direction And the axial direction is not limited. Therefore, all nodes at the top of the piston pinhole are radially displaced. Shift all nodes in the lower half of the piston pin hole along the axial direction of the piston pin.

Total Deformation

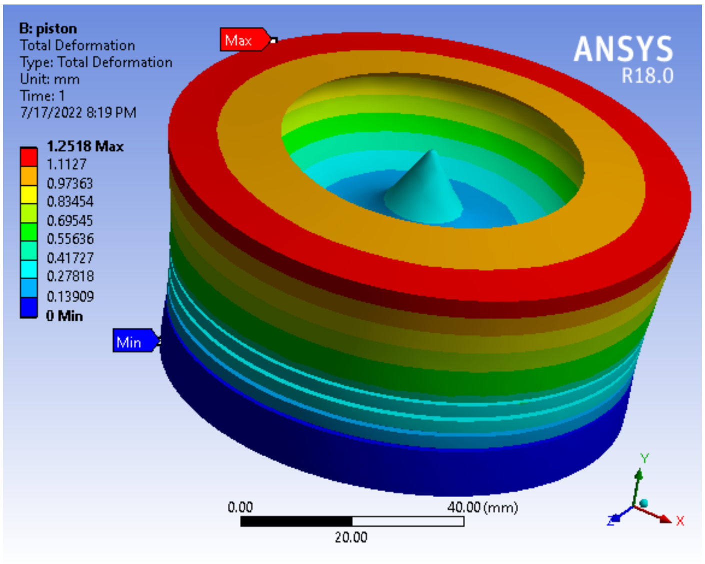

Figure 3 Total Deformation

Figure 3 shows that the total deformation is the deformation options that see all deformation outcomes related to the model, in three coordinates (X, Y, and Z). Direction: In directional deformation, coordinates (X, Y, or Z) can be specified to see the result of deformation of the physical itr model in that direction.

Maximum Shear Elastic Strain

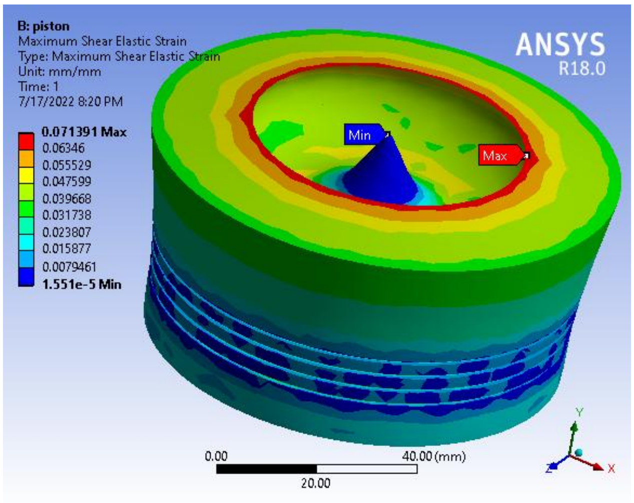

Figure 4 Maximum Shear Elastic Strain

Figure 4 shows the maximum elastic shear stress, failure of a material or component will occur when the total shear stress energy per unit volume exceeds the specified value of the shear stress energy per unit volume.

Maximum Shear Stress

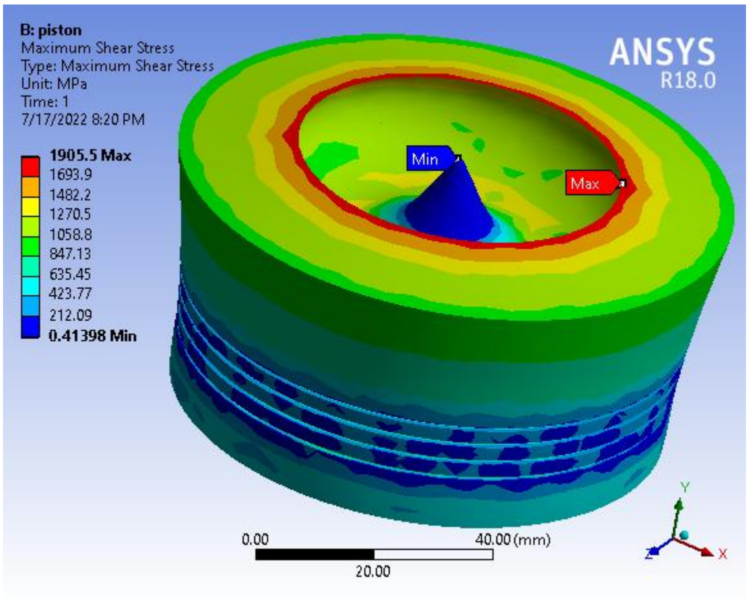

Figure 5 Maximum Shear Stress

Figure 5 shows the maximum shear stress, the maximum shear stress was taken at the maximum shear force concentrated in a small area. It is critical for the structural engineer to locate and evaluate the maximum shear stress in a member in order to design the member in such a way as to withstand it.

Equivalent Stress

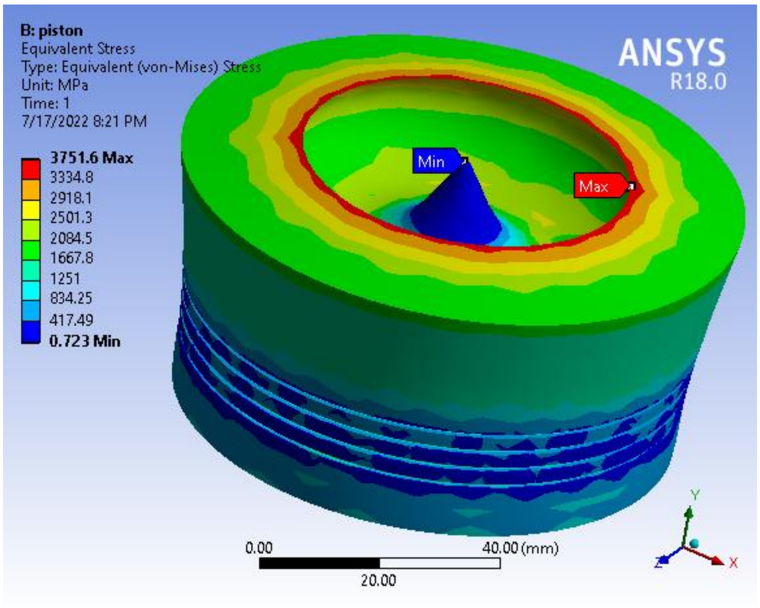

Figure 6 Equivalent Stress

Equivalent stress is shown in Fig. 6. Equivalent damage stress is defined similarly to the von Mises plastic equivalent stress for plasticity as the one-dimensional stress σ* which, for the same value of damage, yields the same value of elastic stress energy density as in the three-dimensional case.

Equivalent Elastic Strain

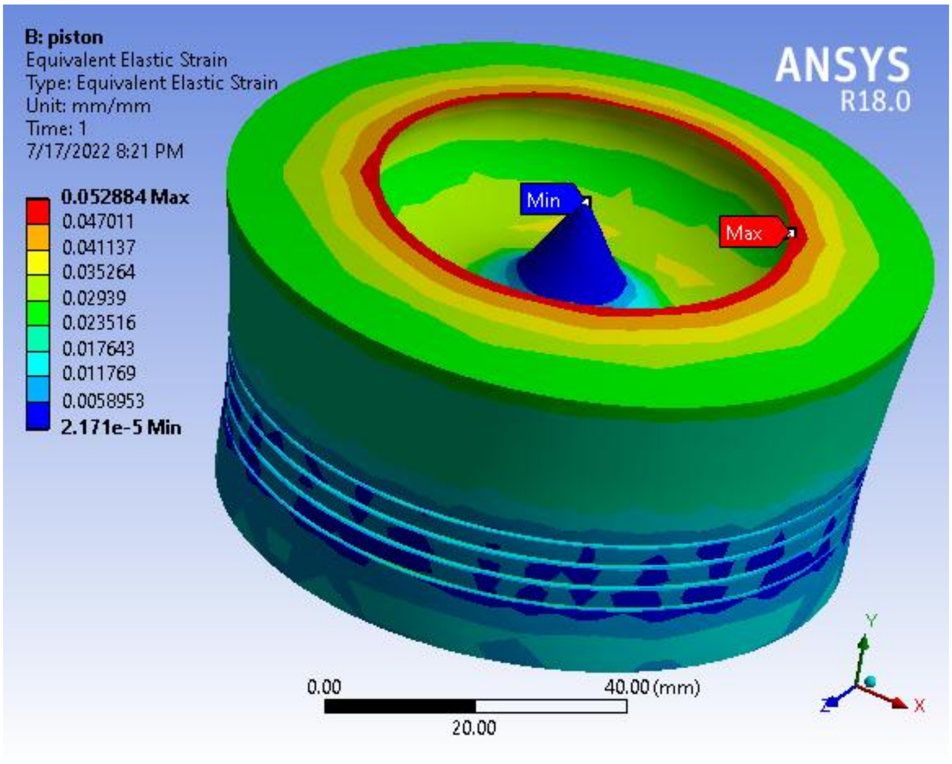

Figure 7 Equivalent Elastic Strains

Figure 7 shows the equivalent elastic strain. Equivalent elastic strain is defined as the maximum stress values to which an object will rebound and return to the original shape when the load is removed. The elastic limit is defined as the point on the stress-strain curve where an organism changes its elastic behavior to plastic behavior.

Temperature

Figure 8 shows the temperature in the thermal steady state. Heat energy transferred from one substance to another per unit time and area indicated by the temperature change measured in watts per square meter of units. In simple terms, it is the heat transferred per unit area.

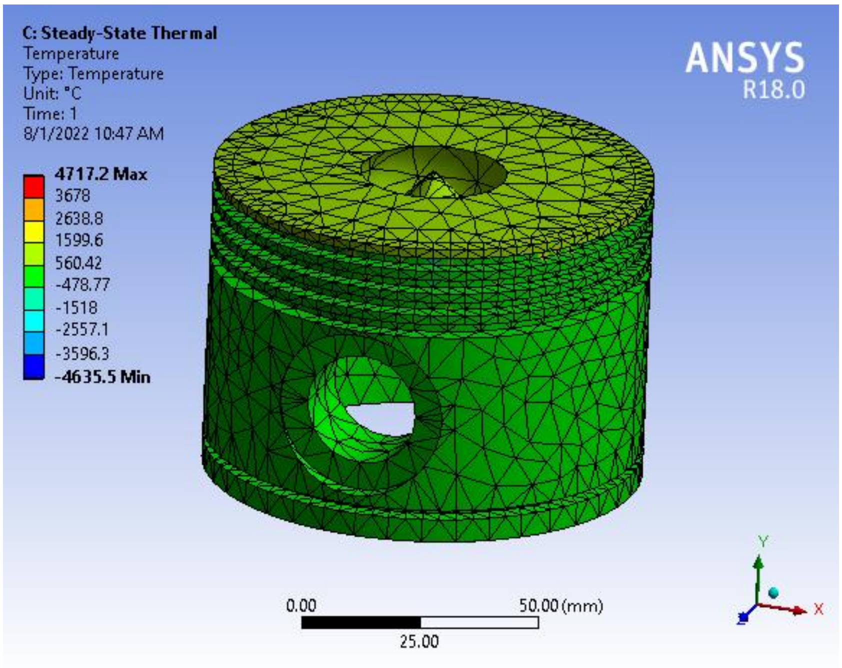

Figure 8 Temperature on steady state thermal condition

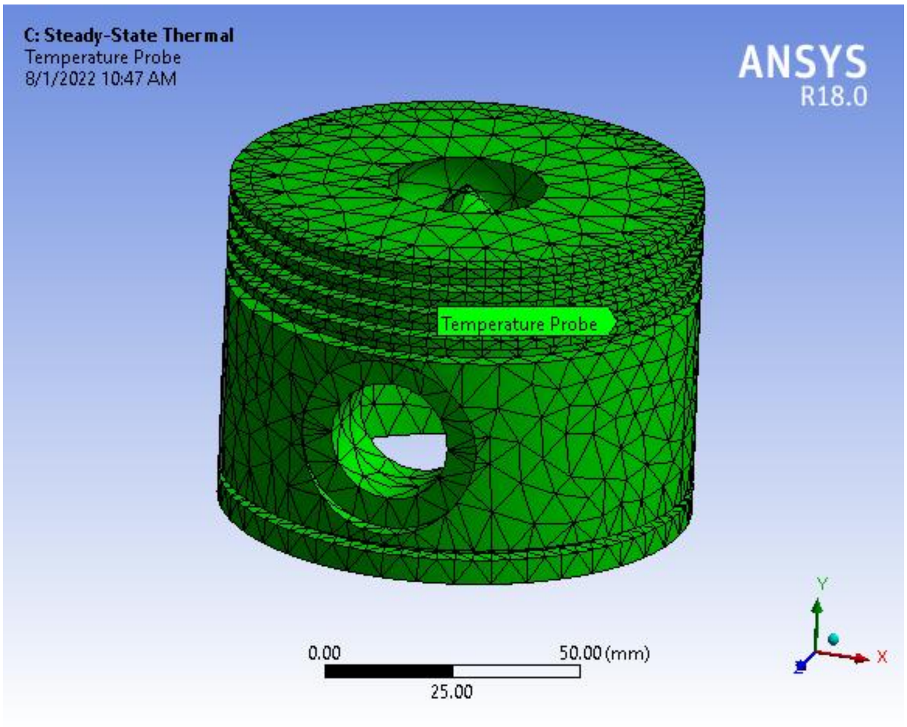

Figure 10 Temperature probe on steady state thermal condition

Figure 10 shows a temperature probe in a constant thermal state. A probe thermometer is a thermometer that has a tapered metal stem that can be inserted into food. Using a probe thermometer helps make sure that proper internal food temperatures are reached and maintained.

8 CONCLUSIONS

It is concluded that the maximum total deformation (1.2518 mm), the maximum elastic shear stress (0.071391Mpa), the maximum shear stress (1905.5 MPa), the maximum equivalent stress (3756.6 MPa), the maximum equivalent elastic strains (0.052884 mm/mm) and the temperature The saturation is 560.42 °C at the steady state thermal state shown in Figures 3 to 8 respectively. The results of the thermal study of the piston of an internal combustion engine yielded several important insights. The temperature is highest at the piston top and lowest at the piston skirt. Temperature is defined as a measure of the molecular activity of a substance where the more the molecules move, the higher the temperature. Since the piston and piston compression rings experience unsteady thermal loads from one area to another, the temperatures of the piston and piston compression rings are constant but distributed along the piston body from maximum values to minimum values. They are studied according to their thermogenic effects on the temperature distribution.

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