Modeling and Thermal Analysis of I.C. Engine Piston using of CATIA and ANSYS software

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Abstract- The engine operating characteristics and load capacity in terms of compression with respect to the crank angle, air-fuel mixing rate and rotational moments were obtained from the simulation study. The temperature field distribution of the high-density diesel engine piston under constant pressure was calculated and the thermal-mechanical coupling stress was calculated, compared to only the mechanical load, and the results showed that the mechanical load is the main stress. Based on the experimental method design, using the design exploration unit, the piston top floor height and piston pin bore space as input parameters, piston mass, maximum temperature and maximum mechanical pressure.

Keywords- Stress analysis; equivalent stress; Piston; CATIA; ANSYS software

1 Introduction

As one of the most important hot parts of an internal combustion engine, the piston moves at high speed under high thermal load and mechanical load for a long time. The stress generated by these loads affects the service life, which is directly related to the reliability and durability of the internal combustion engine [1].

The general design of the piston includes the flow field, temperature field, structure and other disciplines, and each discipline has a strong interrelationship. At present, the calculation and analysis of the piston generally adopt the method of separate analysis of thermal stress or mechanical stress, and master the stress and deformation of each, so as to complete the entire piston optimization and design. This method does not take into account the coupling effect of various factors, so it cannot accurately simulate and calculate the pressure and deformation of the piston in the working state, and can only provide some reference to the design process. In modern design, based on multidisciplinary optimization design theory, using the concept of global integration design, fully consider the interaction between many disciplines such as fluid dynamics, heat transfer, structural mechanics and elastomer mechanics, coordination of the work of various components, enabling multi-multi-optimal design Specialties and multi-targets for the piston.

The piston is the main part of the engine. The engine, as the main engine, is the important part of the car. Currently, a large number of researches are being conducted to improve the engine in terms of manufacturing techniques and other attributes. There is a lot of investigative work proposing, new dimensional models, and manufacturing techniques on engine pistons and this investigative progress has evolved with continuous development over the previous decades. The piston is an important component of internal combustion engines, both because of the role it plays, but also because of the complex loads that act on it. The resistance of the piston to mechanical loads limits the power of the internal combustion engine. Hence, during the design phase of the piston, there is a need to determine the stresses and deformations caused by mechanical loads, an aspect that has been revealed in many scientific papers that have addressed these issues [2]. Although many experimental investigations have been carried out on modifications of piston geometry, there are only a few numerical studies that focus on three-dimensional structural analysis of a variant of the aluminum alloy piston vessel model [3].

In this analysis, stress and deformation containment efforts were made in FEM analysis by ANSYS software and piston geometry structural analysis was used to change compression ratios by changing the geometry of the piston model. The modified piston geometry of the shallow re-entry piston (SRP) and deep cylinder piston (DCP) was compared with the baseline geometry of the hemispherical existing piston (HEP). Experimental results from the input stress loads were considered to implement the stress and deformation rates. This paper reveals three-dimensional finite element modeling of different aluminum alloy pistons with different compression ratios. The optimum piston geometry model with optimum properties for pressure analysis was found by ANSYS software. The experimental results of combustion cylinder compression were related to stress analysis and the effects of different piston structure were carried out using diesel and biodiesel blends. Maximum safety factor, minimum equivalent stress and low deformation rates have been implemented for the optimum piston model.

2 Materials and methods

A low-performance internal combustion engine was used in real time to analyze the cylinder pressure of each piston using a blend of soybean, rice bran and Pongamia biodiesel. The combustion results of maximum cylinder pressure were taken as operating pressure on different geometries of HEP, SRP and DCP in the 6.5 range respectively. In the combustion chamber due to the explosion of gas, a pressure range was applied to the piston head. Compressive force was taken as a mechanical load applied to the piston head and the same process was taken as a limiting condition in the structural analysis. As the piston moves from TDC to BDC, the fixed support is fixed on the pin-hole surface.

3 Methodologies

The principle of reverse engineering is applied to piston design in this research work. Piston design data was collected from various sources. It is 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. The piston dimensions are measured using tools such as calipers, helical gauge, gauge etc. The 3D model of the piston is created with dimensions measured with CATIA. The boundary conditions for the maximum gas pressure are fixed at the top surface of the piston 6MPa and the temperature at 480°C. Three types of materials are chosen from the software library for piston design. FEA is performed using ANSYS to determine mechanical deformation and stress. The steady-state thermal analysis is estimated with the surface temperature distribution range and the total heat flux.

4 FEA for piston

Heat transfer in the engine occurs due to the temperature difference and from high to low temperature. Thus, there is a transfer of heat to the gases during the intake stroke and the first part of the compression stroke, but during the combustion and expansion processes, heat transfer from the gases to the walls occurs. Therefore, the piston crown/head, piston ring and piston skirt must be rigid enough to withstand pressure and friction between the mating surfaces. Moreover, 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 that the piston skirt and piston ring perform a structural and optimization analysis that can provide a reference for the piston design.

5 Coefficient of convection and heat transfer of the piston

The top of the piston is the part of the piston that comes into contact with the gas, so the top temperature is very high, up to 800°C. The overhead heat transfer coefficient is selected from the test data from relevant research. The coefficient of heat transfer from the top of the ground is estimated to be 540 W/(m2°C). The heat transfer between the piston and the oil film occurs between the piston and the cylinder by convection.

6 boundary conditions and calculated loads

6.1 Stress boundary condition

The boundary conditions for the piston under the action of mechanical load alone are strong boundary conditions and displacement boundary conditions. This paper deals only with the effects of mechanical and thermal loads on the piston at rest. Therefore, the force-limit condition ignores the reciprocating inertia force and the lateral pressure of the piston, considering only the maximum gas pressure, the value of which is Pmax ¼ 20 MPa; The gap between the part and the cylinder is choked, 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 other ground and circular groove is ignored. The indirect method is used to calculate the thermal machine coupling stress of the piston, that is, to calculate the steady-state temperature of the piston first, and the obtained piston temperature field result is loaded as a limit condition from the calculation of the thermal machine coupling stress, and then the solution is coupled to the mechanical pressure of the piston.

6.2 Displacement boundary condition

When analyzing the pressure caused by the sudden burst pressure of the piston, the piston and the piston pin in the contact area at the top of the pin seat produce the same displacement along the radial direction of the piston pin. The axial displacement of the piston pin and the displacement in the circumferential direction are independent of each other. Moreover, the piston supports the bottom of the piston pin with the width of the small end of the connecting rod, and does not generate displacement in the radial contact direction in the areas in contact with each other, and the displacement in the axial direction and circumferential direction is not restricted. Therefore, all nodes on the upper side of the piston pin bore hole are shifted radially; Offset all nodes in the lower half of the piston pin bore hole along the axial direction of the piston pin.

6.3 Temperature boundary condition

This paper deals with the dynamic equilibrium of heat exchange between the piston with the cooling oil cavity and the outside world, and on this basis the steady-state temperature field distribution of the piston is calculated. The difficulty in determining these heat transfer boundary conditions is that it is difficult to find a general formula for an accurate calculation of the heat transfer coefficient between the piston and the surrounding medium, so the boundary conditions must be determined according to the refrigerant oil temperature, flow rate, lubricating oil temperature and gas temperature calculated by a scale strength, etc.

The heat transfer boundary conditions determined by these empirical and quasi-empirical formulas may be very different from the actual conditions. Therefore, it is necessary to constantly correct the thermal boundary conditions by comparing the results of the simulation calculation with the temperature results of the corresponding points on the piston obtained by experiment. So that the final calculation result is in good agreement with the measured results, thus improving the accuracy and accuracy of the calculation, so as to obtain the third type of thermal boundary condition with a more accurate thermal analysis of the piston.

7 Results and discussions

The ANSYS Software was used to examine the structural properties and temperature distribution of the piston geometry by the condition of the compressive strength limits. The stress analysis of the piston geometry was performed under structural boundary conditions that were applied to the finite element model of the pistons. A maximum pressure of 8.2473 MPa and a minimum pressure of 0.001175 MPa is observed with a total deformation of 0.0015612 mm which is relatively good even after a longer duty cycle.

7.1 Analysis without coating material

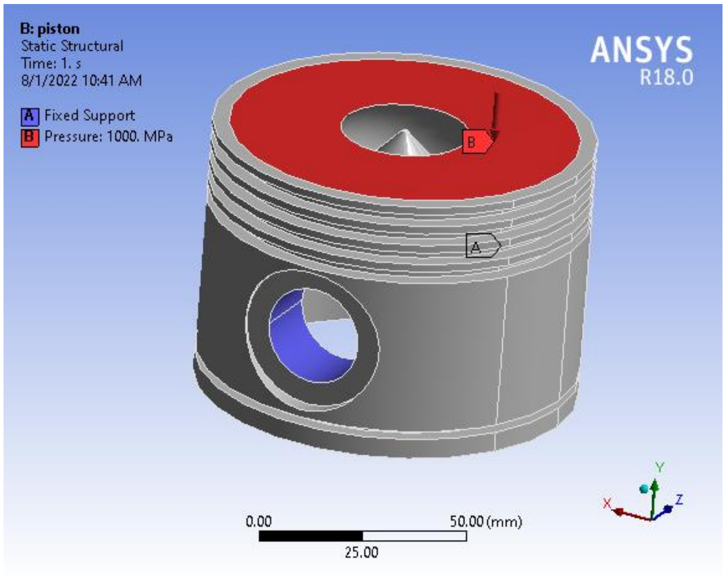

Figure 1 Static Structural of Piston

Total Deformation

Total deformation is a deformation option that enables it to see all deformation results related to its model, in three coordinates (X, Y, and Z). Direction: In directional deformation, it can specify coordinates (X, Y, or Z) to see the result of deformation of its physical model in that direction.

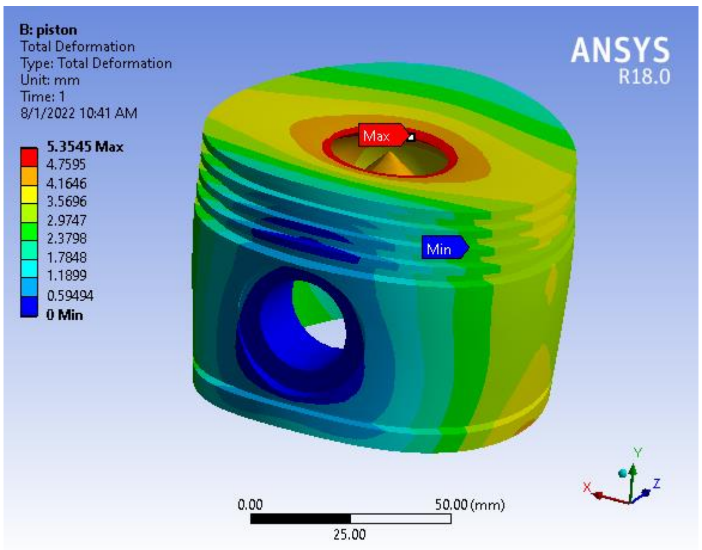

Figure 2 Total Deformation

Equivalent Stress

"Equivalent stress" is the stress type chosen for the yield criterion, and the equivalent stress results are the result that follows the stress-strain curve. To evaluate the stress outcomes, we need 9 contour plots to visualize the stress tensor. • Equivalent pressure allows one to view the stress of the structure through a single plot. The von Mises equation is a measure of the "shear" stress in a material and does not account for the component of hydrostatic stress.

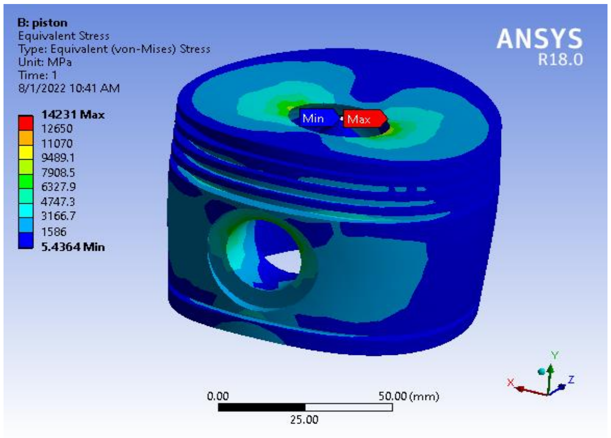

Figure 3 Equivalent Stress

Maximum Shear Elastic Strain

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.

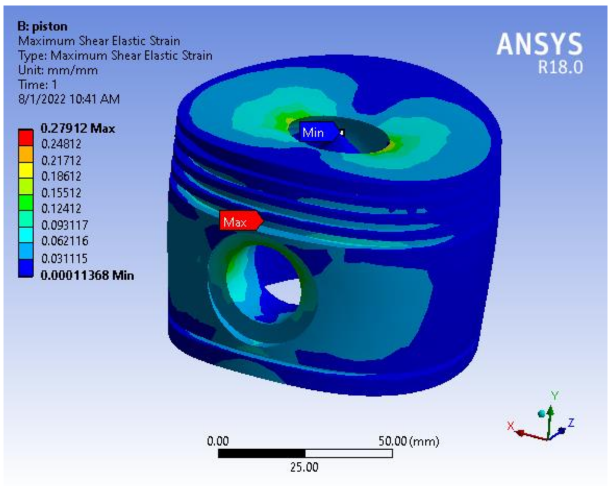

Figure 4 Maximum Shear Elastic Strain

Temperature Distribution

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

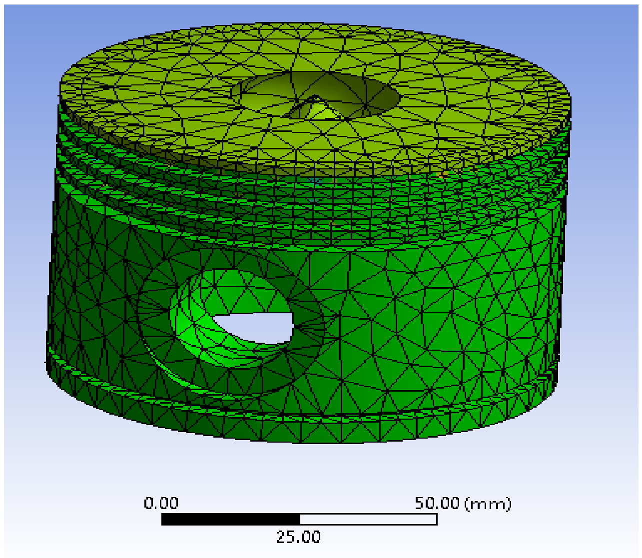

Figure 4 Temperature Distribution

Temperature Probe

A probe thermometer is a thermometer with a pointed metal stem that can be inserted into food. Using a probe thermometer helps ensure that proper internal food temperatures are reached and maintained.

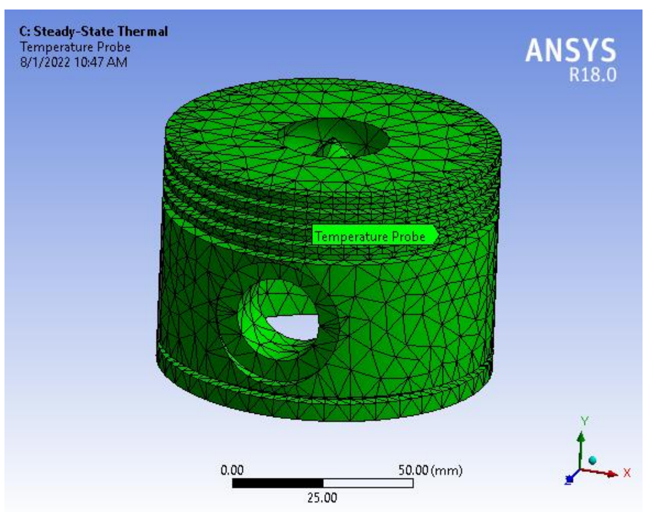

Figure 5 Temperature Probe

7.2 Analysis with coating material of Titanium alloy

Total Deformation

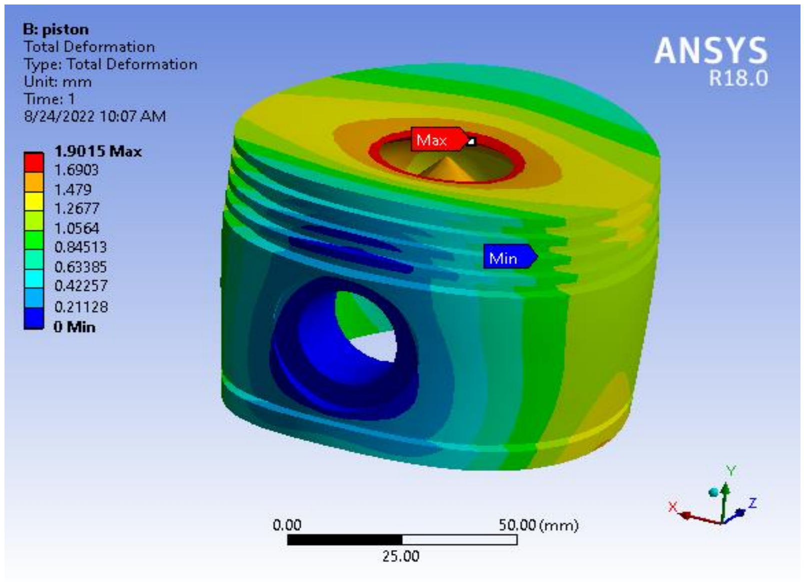

Figure 5 Total Deformation

Equivalent Stress

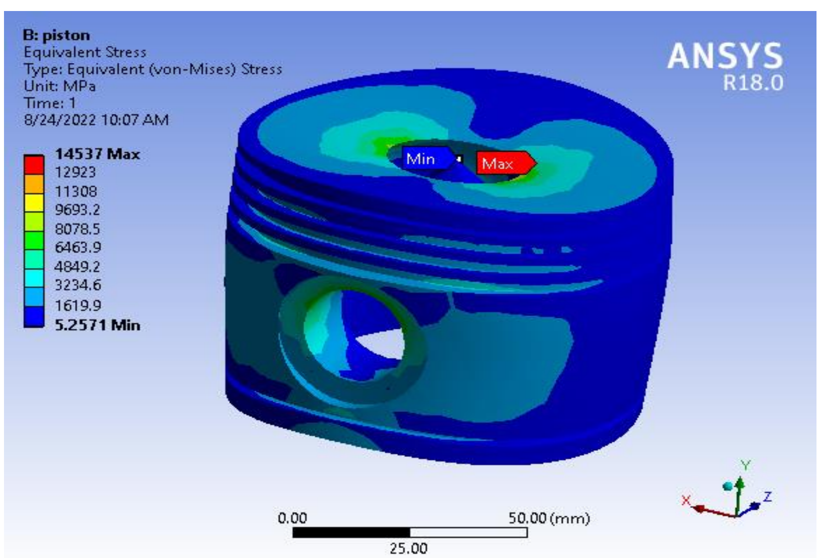

Figure 6 Equivalent Stress

Maximum Shear Elastic Strain

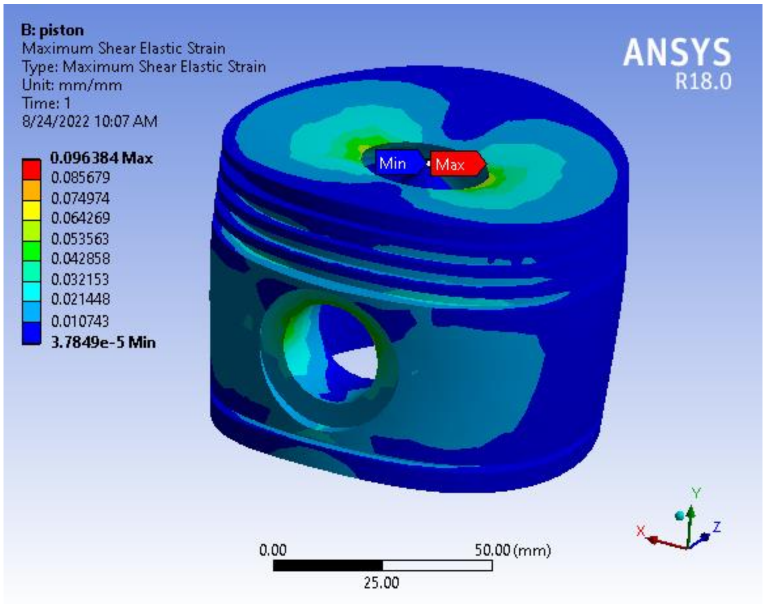

Figure 7 Maximum Shear Elastic Strain

Temperature Distribution

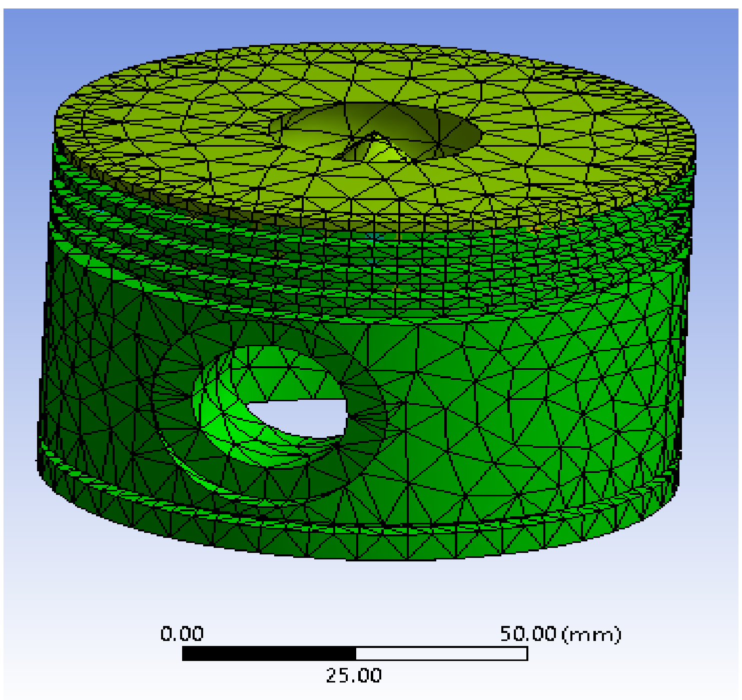

Figure 8 Temperature Distribution

8 Conclusions

Analysis without coating material, the temperature field distribution of the piston is shown in Figure 4. It can be seen from Figure 4 that the temperature distribution of the entire piston is very uneven, and the highest temperature is shown in the middle of the top of the piston. The combustion chamber, the highest temperature value is 438 ° C, it goes down from top to bottom along the axis of the piston, the lowest temperature is shown at the bottom of the piston flange, and the minimum temperature is 136 ° C. The maximum temperature of the groove of the first ring of the piston is 215 ° C. Analyzes are used with a titanium alloy coating material on the piston to improve the temperature field and reduce the temperature, as shown in Figure 8. The highest temperature value is 388 ° C, it decreases from top to bottom along the axis of the piston, the lowest temperature is shown at the bottom from the piston skirt, and the minimum temperature is 117 ° C. The maximum temperature of the groove of the first ring of the piston is 181 ° C.

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