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THERMAL AND STRUCTURAL ANALYSIS OF DIESEL ENGINE PISTON FOR DIFFERENT COATING MATERIALS: AN APPROACH USING FEM

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Abstract: This paper describes the stress distribution of the single cylinder diesel engine piston by using FEA. ProE wildfire 4.0 Computer Aided Design (CAD) software was used to design the existing piston. The main objectives is to investigate and analyze the temperature distribution and heat flux of piston at the real engine condition during combustion process. The paper describes the use of finite element analysis technique to predict the higher stress and critical region on the component. The original diesel engine piston is coated by using different materials for specific thickness. The optimization is carried out to reduce the stress concentration on the upper end of the piston, i.e. (piston head/crown and piston skirt and sleeve). The coating analysis is tested using ANSYS workbench 11.0 thermal analysis.

Keywords: Piston Crown/Head, Piston Ring And Sleeves, Stress Concentration, Piston, Boundary Conditions, Thermal Analysis, ANSYS

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1 INTRODUCTION

A piston is a component of reciprocating IC-engines. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod.As an important part in an engine, piston endures the cyclic gas pressure and the inertial forces at work, and this working condition may cause the fatigue damage of piston, such as piston side wear, piston head/crown cracks and so on. The investigations indicate that the greatest stress appears on the upper end of the piston and stress concentration is one of the mainly reason for fatigue failure.

On the other hand piston overheating-seizure can only occur when something burns or scrapes away the oil film that exists between the piston and the cylinder wall. Understanding this, it's not hard to see why oils with exceptionally high film strengths are very desirable. Good quality oils can provide a film that stands up to the most intense heat and the pressure loads of a modern high output engine. Thermal analysis is a branch of materials science where the properties of materials are studied as they change with temperature. FEM method are commonly used for thermal Analysis. Due to the complicated working environment for the piston; on one hand, the FEA for the piston became more difficult, on the other hand, though there have many methods which are put forward to apply optimal design, the optimal parameters is not easy to determine. In this study, the piston is used in low idle and rated speed gas engine. In order to enhance the engine dynamic and economic, it is necessary for the piston to implement optimization. The mathematical model of optimization is established firstly, and the FEA is carried out by using the ANSYS software. Based on the analysis of optimal result, the stress concentrates on the upper end of piston has become evaluate, which provides a better reference for redesign of piston.

2. THE FEA OF THE PISTON

2.1 Theoretical Foundation

In engine, transfer of heat takes place due to difference in temperature and from higher temperature to lower temperature. Thus, there is heat transfer to the gases during intakes stroke and the first part of the compression stroke, but the during combustion and expansion processes the heat transfer take place from the gases to the walls.

- Cylinder liners.

- Piston and piston rings.
- Cylinder head
- Exhaust valves.

So the piston crown/head , piston ring and the piston skirt should have enough stiffness which can endure the pressure and the friction between contacting surfaces. In addition, as an important part in engine, the working condition of piston is directly related to the reliability and durability of engine. So it is important for the piston skirt and the piston ring to carry out structural and optimal analysis which can provide reference for design of piston.

So the mean effective pressure on the piston crown ,piston top ring and the piston skirt should be restricted at low idle (850rpm) and at rated speed (2700rpm). The formula can be expressed as,

$$IHP = \frac{\text{Pm}\times \text{L}\times\text{A}\times\text{N}/2}{60\text{X}10^3} \qquad (1)$$

Where,

Pm Mean Effective Pressure (bar) ;

L- stroke length(mm) ; A –Area(mm^2) ;

N-speed (rpm) ;IHP- indicated horse power (watt)

3 THE FINITE ELEMENT ANALYSIS

In this work, due to the symmetry of structure, model of piston has been made in the Pro/E software, and then the FEM is established using ANSYS software. The 3-D 20-node solid element SOLID95 is applied to mesh the whole structure, and 27374 nodes and 14129 elements are obtained. In addition, in order to obtain the better result, the contact pair which is important to carry out the research should be established between the piston crown, piston ring and piston skirt. The contact is highly non-linear and need more computing power. In order to compute effectively, it is important to know the physical property and establish the reasonable model. In this study, the surface-surface contact is applied to the model. The FEA of piston is carried out by using the ANSYS software.

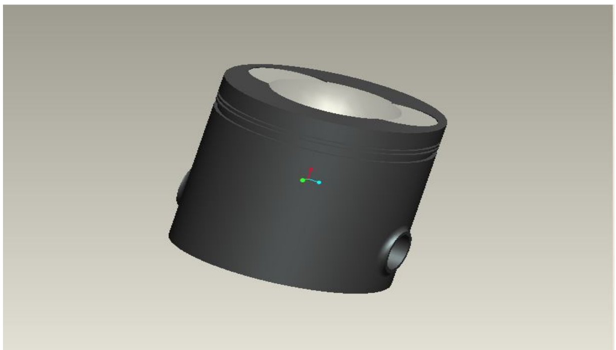

Figure CAD model of existing piston

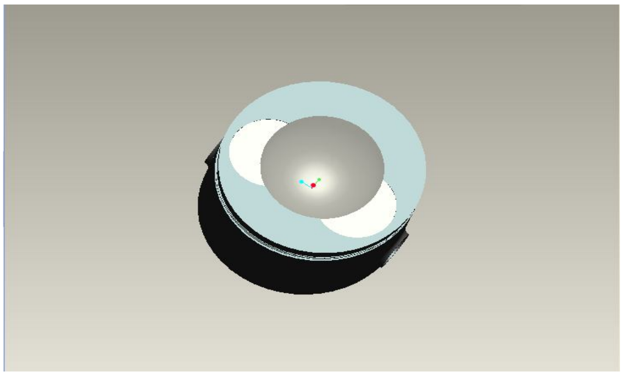

Figure CAD model of existing piston

3.1 Meshing

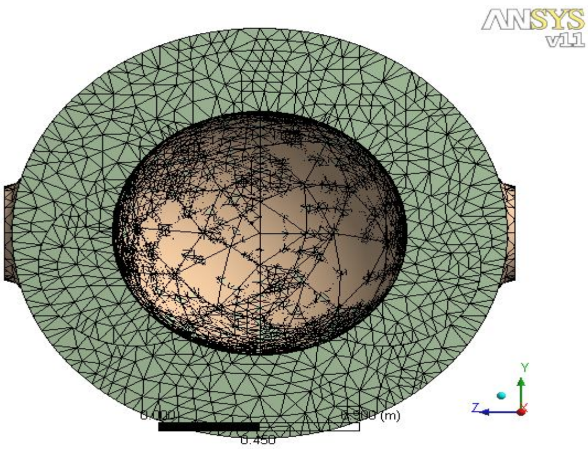

Figure Meshed Body

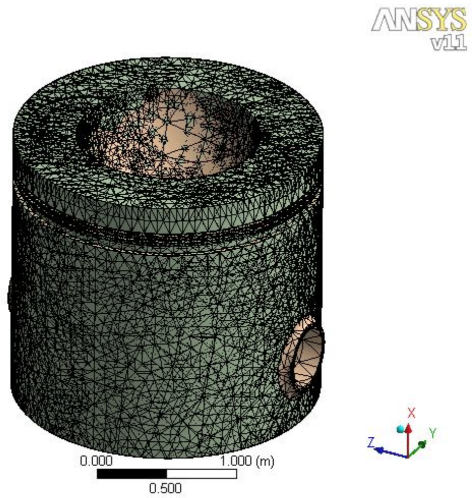

Figure Meshed Body

3.2 Input Boundary Conditions Of Temeprature And Pressure

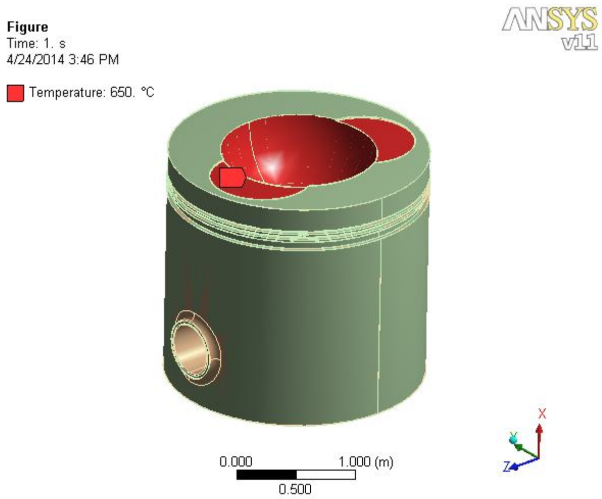

Figure : Applied Temperture on top surface

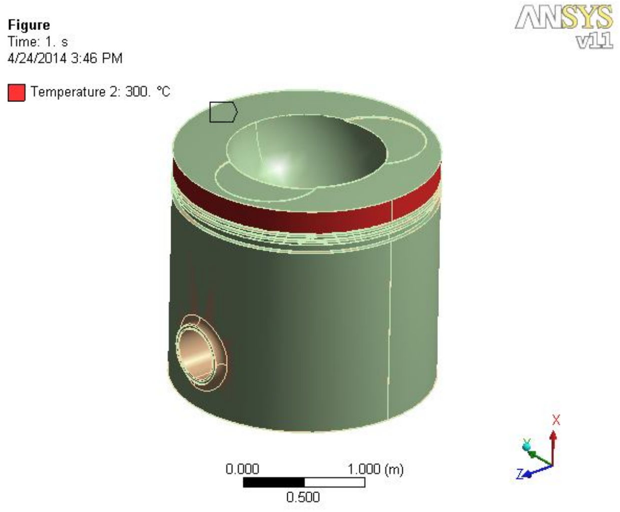

Figure : Applied Temperture on side surface

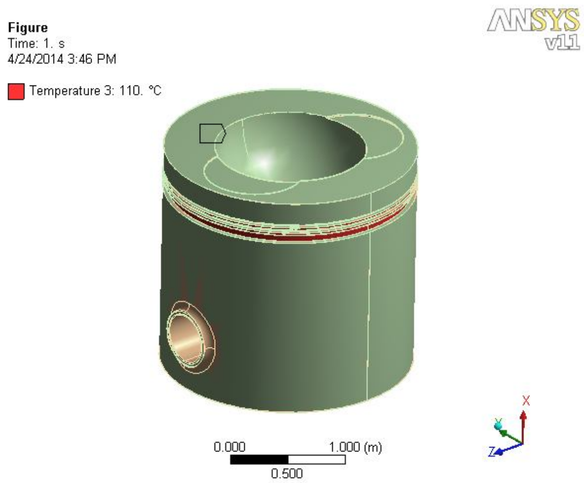

Figure : Applied Temperture on ring side

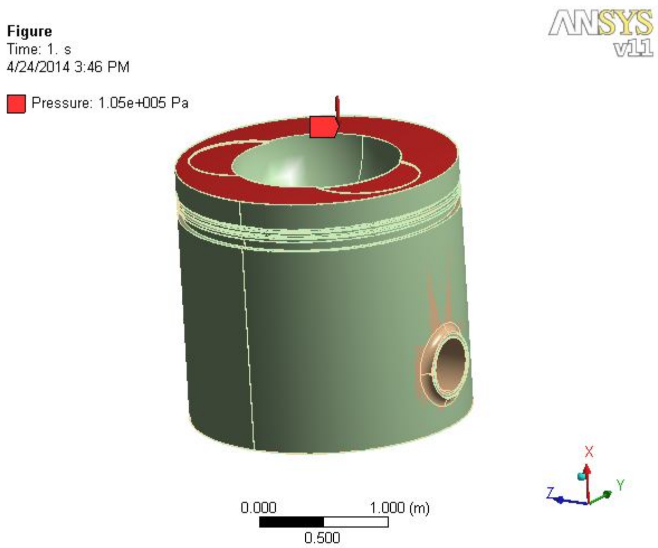

Figure : Applied pressure on top side

The results are tested for the convective temperature condition as described above. The pressure is applied on the top surface when the thermal conditions are exists.

4 RESULTS

	Piston with	Existing Material AlSi no Coat	Coat of NiCrAl *Nickel Chromium Aluminum Composite*	Coat of 3YSZ	Coat of Mullite	Coat of La2Zr2O6 *Lanthanum chromites*
	Weight Of Piston **(Kg)**	2.931	5.0659	4.9245	4.665	4.897
	Weight of coat for 0.15mm thickness	0	2.1349	1.9935	1.734	1.966
Thermal Analysis	Maximum Temperature Attend	651.46 °C	651.19 °C	650.2 °C	650.0 °C	650.37 °C
	Total Heat Flux	8.4e+5 W/m²	6.11e+5 W/m²	2.48e+5 W/m²	2.86e+5 W/m²	2.20e+5 W/m²

	Thermal Error	1.6952e+005 J	45051 J	22322 J	28854 J	22101 J
Pressure Analysis	Total Deformation	7.0444e-4 m	5.4021e-5 m	5.0212e-5 m	5.6788e05 m	5.1017e-5 m
	Equivalent Stress	2.2827e+7 Pa	7.9121e+6 Pa	1.1267e+7 Pa	4.0451e+6Pa	1.0824e+7 Pa
	Shear Stress	7.9094e+6 Pa	2.4048e+6 Pa	3.5692e+6 Pa	1.0263e+6 Pa	3.4139e+6 Pa
	Max Principal Stress	1.5217e+7 Pa	4.7623e06 Pa	6.7375e+6 Pa	2.1777e+6 Pa	6.3244e+006 Pa
	Total Energy Lost	477.21 J	3.9254 J	3.6972 J	4.0845 J	3.7458 J

5 MULLITE CERAMIC PROPERTIES

Mullite or porcelainite is a rare silicate mineral of post-clay genesis. It can form two stoichiometric forms 3Al2O32SiO2 or 2Al2O3 SiO2. Unusually, mullite has no charge balancing cations present. As a result, there are three different Al sites: two distorted tetrahedral Al sites and one Al other site which adopts a higher co-ordinate octahedral state.

Mullite was first described in 1924 for an occurrence on the Isle of Mull, Scotland.[3] It occurs as argillaceous inclusions in volcanic rocks in the Isle of Mull, inclusions in sillimanite within a tonalite at Val Sissone, Italy and with emery like rocks in Sithean Sluaigh, Scotland.

Mullite is a good, low cost refractory ceramic with a nominal composition of 3Al2O3•2SiO2. The raw materials for mullite are easily obtainable and are reasonably priced. It has excellent high temperature properties with improved thermal shock and thermal stress resistance owing to the low thermal expansion, good strength and interlocking grain structure.

- .Key Mullite Properties

o Good thermal shock and stress resistance

o Low thermal conductivity

o Good strength

- o Wear resistant
- o Usable to high temperatures
- • Typical Mullite Uses
- o Protection tubes
- o Furnace liners
- o Electrical insulators

6 CONCLUSION

Piston skirt may appear deformation at work, which usually causes crack on the upper end of piston head. Due to the deformation, the greatest stress concentration is caused on the upper end of piston, the situation becomes more serious when the stiffness of the piston is not enough, and the crack generally appeared at the point A which may gradually extend and even cause splitting along the piston vertical. The stress distribution on the piston mainly depends on the deformation of piston. Therefore, in order to reduce the stress concentration, the piston crown should have enough stiffness to reduce the deformation. The coating of different material for the thickness of 0.15mm can be done and tested it is observed that Mullite is best suited material for the coating of the piston in the given operating condition.

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