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STRUCTURAL ANALYSIS OF ALUMINA COATED DIESEL ENGINE PISTON USING FINITE ELEMENT METHOD

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Abstract: *This paper describes the stress and temporal and stress distribution of the piston by using FEA. The finite element analysis is performed by using computer aided design (CAD) software. The main objectives are to investigate and analyze the thermal and stress distribution of piston at the real engine condition during combustion process. The paper describes the materialistic optimization with using finite element analysis technique to predict the higher stress and critical region on the component. 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). With using computer aided design (CAD), Autodesk Inventor software the structural model of a piston will be developed. Furthermore, the finite element analysis performed with using software Ds Solid-works.*

I. INTRODUCTION

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 behavior 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 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. A lot of experimental study has been done to utilize these ceramic properties to improve thermal efficiency by reducing heat losses, and to improve mechanical efficiency by eliminating cooling systems. When cylinder-cooling losses are reduced, more of the heat is delivered to the exhaust system. This effective recovery of energy by exhaust improves the thermal efficiency of low heat rejection engine (LHR). However, installing heat recovery systems needs considerable effort; a lot of changes are necessary in the engine configuration. Even without heat recovery systems, some of the heat is converted to piston work and increases thermal efficiency. Therefore, LHR engines without exhaust heat recovery systems are worth to study.

Material	AlSi	Steel	NiCrAl	MgZrO3	Oil ring	Compression ring
Thermal conductivity [W/m °C]	155	79	161	08	25-42	46-59
Thermal expansion 10−6 [1/°C]	21	122	12	8	10-13	10
Density [kg/m3]	2700	7870	7870	5600	7200	7300
Specific heat [J/kg °C]	960	500	764	50		
Poisson's ratio	0.3	0.3	0.27	0.2	0.29	0.3
Young's modulus [GPa]	90	200	90	46	160-135	110-140

Table 1: Material properties of piston, ring and ceramic

In the literature, although there are a lot of experimental studies on thermal barrier coatings in the internal combustion engines, there are a few numerical studies focused on 3-D structural and thermal analyses on a diesel piston model. This paper presents 3-D finite element modeling of AlSi alloy and steel conventional diesel engine piston and ceramic coating diesel engine piston.

II. **DIFFERENT TYPES OF PISTONS:** Various types of pistons are employed on different engines. This is because each type fulfils some specific requirements on a particular engine. Some pistons have complex head formation, some have specially formed skirts, and other has geometrical peculiarities. Based on various considerisation, the piston may be categorized as follows:

1) On the basis of head formation:

a) Deflector head piston

b) Combustion chamber type piston

c) Domed and depression headed piston

2) On the basis of skirt profile:

a) Slipper piston

b) Cut way piston
3) On the basis of skirt piston:
a) Solid skirt piston
b) Split skirt piston
4) On the basis of other specialties:
a) Cam ground piston
b) Taper piston
c) Oval piston

FUNCTIONS OF THE PISTONS

1. To receive the impulse from the expanding gas & transmit the energy to the crank shaft through the connecting rod.
2. It transmits the force of combustion gases to the crank shaft.
3. It controls the opening & closing of the parts in a 2-stroke engine.
4. It acts as a seal to escape of high pressure gases in to the crank case.

CHARACTERSTICS OF PISTON

1. Hammering effect of a combustion gas pressure.
2. High temperature of the gases.
3. Light in weight.
4. Silent in a operation.
5. Mechanically strong

III. THERMAL BARRIER COATING AND ITS FUNDAMENTALS

Thermal barrier coatings (TBC) are multi-system materials with the prime function of thermally insulating components. The thermal conductivity of the TBC dictates the temperature difference across the coating and the heat loss or gain. Greater fuel efficiency can be achieved when engines work at high temperatures, which expose components to extreme service conditions. TBCs are designed to improve the thermal efficiency of an engine without increasing the surface temperature of the substrate alloy, enabling the engine to operate at gas temperatures above the melting point of the alloy. The major driving force for the development of TBCs has been the benefits to be gained from the extended life of metallic components in the hottest section of a turbine engine by decreasing their surface temperature.

ADVANTAGES	DISADVANTAGES
Resistant to high temperatures High chemical stability High hardness values Low densities Can be found as raw material form in environment Resistant to wear Low heat conduction coefficient High compression strength Glazed ceramic does not stain	Dimensional tolerances difficult to control during processing. Weak in tension. Poor shock resistance, i.e., Can crack when hit with heavy items.

IV. COATING MATERIALS

The zirconia-based ceramic coatings are used as thermal barrier coatings owing to their low conductivity and their relatively high coefficients of thermal expansion, which reduce the detrimental interfacial stresses. Material properties of the MgZrO3, NiCrAl and piston material made of AlSi alloy are listed in Table 1. Piston is coated with a 350 µm thickness of MgZrO3 over a 150 µm thickness of NiCrAl bond coat (Fig. 1).

V. THERMAL ANALYSIS BY FINITE ELEMENT METHOD

In the numerical performed a truck engine piston, made of AlSi alloy and steel, is taken as the basis in the simulation. 3-D finite element thermal analyses are carried out on both conventional and ceramic-coated engine piston. The finite element mesh of the piston model used ANSYS code is shown in Fig. 2. In the thermal analyses, eight nodes thermal elements are used. In the model, surface to surface contact elements are defined between piston ring and ring grove. Piston thermal boundary conditions consist of the ring land and skirt thermal boundary condition, underside thermal

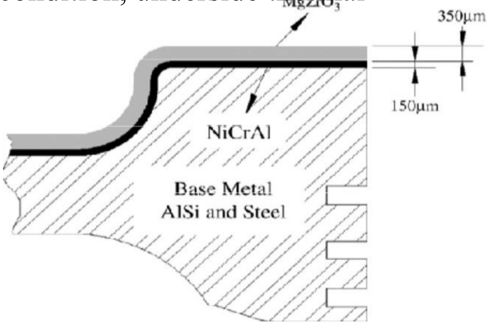


Fig. 1. Thermal barrier coating thickness. boundary condition, piston pin thermal boundary condition, combustion side thermal boundary condition.

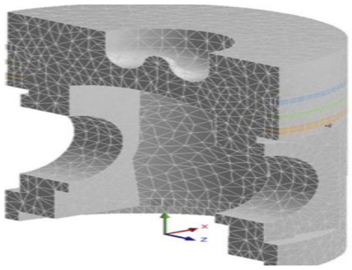


Fig. 2. The finite element mesh.

VI. PROCEDURE OF EXPERIMENT

The analysis procedure is carried out on the assembly are as follows:

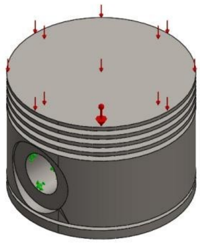
Open the tool.

Then go for the assembly.

Then import the components required for the assembly to complete. After completing the mates, move to the analysis. To perform the analysis on the assembly part you must go for office products, in that select "simulation". Then you can find a dialogue box at the top, from that select the study advisor. Now just click the following options in the said order: I am concerned about excessive loads and deformation. Next Now apply the material for the components that are to be analyzed. Next apply the fixtures and also the loads to be tested.

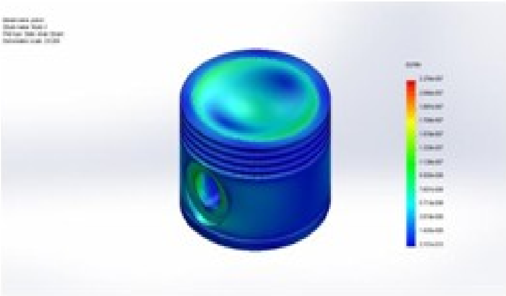
After it go for creating the mesh. At last click the run option to get the results. The results can be obtained in the form of analyzed report by clicking the report option found at the centre of the tool box.

VII. REPORTS



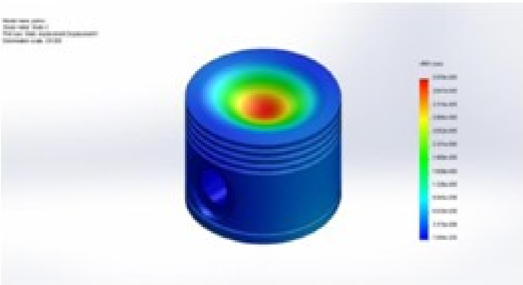
Properties and study results while using Material-1

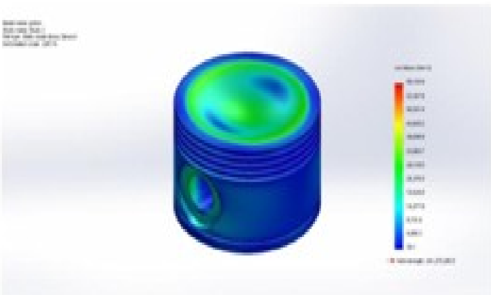
Name:	**AISI 1045 Steel, cold drawn**
Model type:	**Linear Elastic Isotropic**
Default criterion	**Max von Mises Stress**
Yield strength:	**5.3e+008 N/m^2**
Tensile strength:	**6.25e+008 N/m^2**
Elastic modulus:	**2.05e+011 N/m^2**
Poisson's ratio:	**0.29**
Mass density:	**7850 kg/m^3**
Shear modulus:	**8e+010 N/m^2**
Thermal coefficient	**1.15e-005 /Kelvin**



MIN STRESS: 30.8848 N/m^2
MAX STRESS: 60612.5 N/m^2

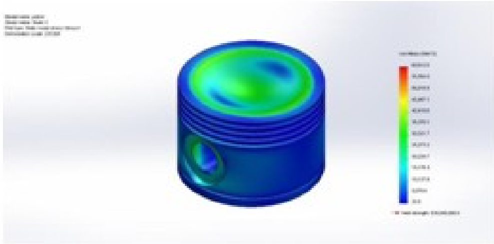
Shear modulus:	**7.8e+010 N/m^2**
Thermal expansion coefficient:	**1.5e-005 /Kelvin**





MIN DISPLACEMENT: 0mm

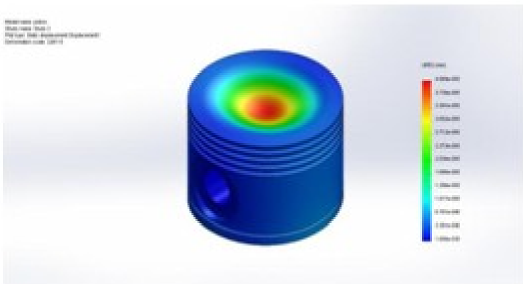
MAX DISPLACEMENT: 3.97804e-005 mm



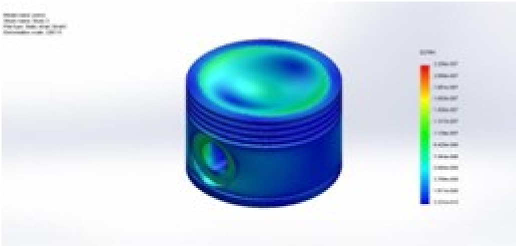
MIN STRAIN: 3.10142e-010
MAX STRAIN: 2.27576e-007

Properties and study results while using Material-2

Name:	**Cast Alloy Steel**
Model type:	**Linear Elastic Isotropic**
Default failure criterion:	**Max von Mises Stress**
Yield strength:	**2.41275e+008 N/m^2**
Tensile strength:	**4.48083e+008 N/m^2**
Elastic modulus:	**1.9e+011 N/m^2**
Poisson's ratio:	**0.26**
Mass density:	**7300 kg/m^3**



MIN DISPLACEMENT: 0mm
MAX DISPLACEMENT: 4.06873e-005 mm



MIN STRAIN: 3.33135e-010
MAX STRAIN: 2.25617e-00

Table 3: Resultant forces while using material 2

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-7.95342e-005	10.1174	0.000591584	10.1174

Table 2: Resultant forces while using material 1.

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.000622037	9.4135	0.000633885	9.4135

VIII. CONCLUSIONS

The piston skirt is the main area of the piston at which the deformation may appear while at work, which usually causes crack on the upper end of piston head. Due to this 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. In this project we have created a model of a flat head piston and also a curved head piston using Inventor software. Then material is assigned to the piston specimens for the analytical purpose. From the analytical reports presented in the chapter 6, it is clear that the piston with curved head is processing the best results. The optimal mathematical model which includes deformation of piston crown and quality of piston and piston skirt. The FEA is carried out for standard piston model used in diesel engine and the analysis results indicate that the Resultant force has changed from 10.1174 to 9.4135 kN. And biggest deformation has been reduced from 3.97804e-005 mm to 1.17057e-005 mm.

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