# SYSTEMIC ANALYSIS OF A DIESEL ENGINE PISTON WITH BRITTLE MATERIAL COATED 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.

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 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. Necessary in the engine configuration.

Table 1: Material properties of piston, ring and ceramic

Therefore, LHR engines without exhaust heat recovery systems are worth to study.

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:

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

| 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 |

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:
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

## III.    THERMAL BARRIE 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

extended life of metallic components in the hottest section of a turbine engine by decreasing their surface temperature.

## 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 A N A L Y S I S  B Y  F I N I T E 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
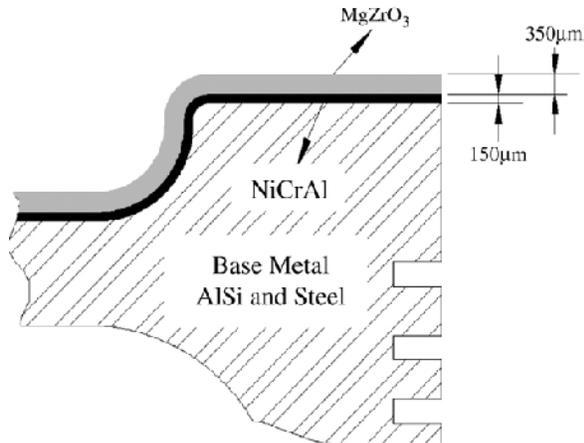


Fig. 1. Thermal barrier coating thickness.

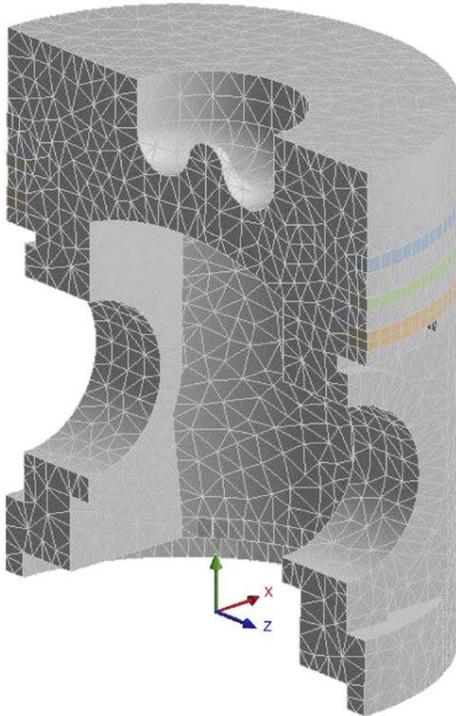Boundary condition, piston pin thermal boundary condition, combustion side thermal boundary condition.

Fig. 2. The finite element mesh.

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

| Name: | AISI 1045 Steel, cold drawn |
|---|---|
| Model type: | Linear Elastic Isotropic |
| Default failure 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 expansion coefficient: | 1.15e-005 /Kelvin |

## 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 analysed.

• 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.
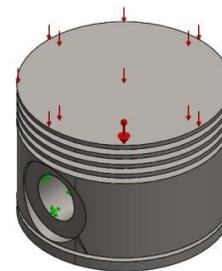
## VII. REPORTS
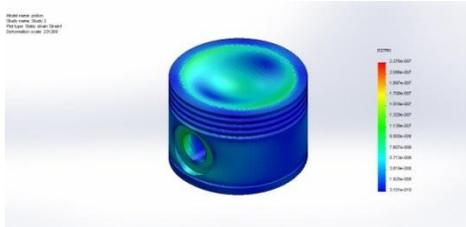


**Properties and study results while using Material-**
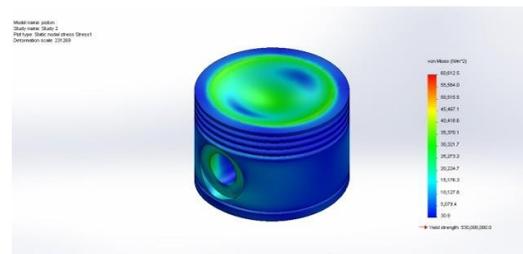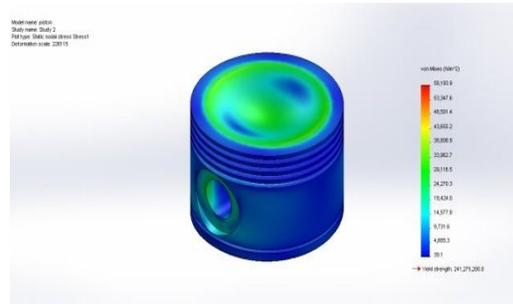


MIN STRESS: 30.8848 N/m^2 MAX STRESS: 60612.5 N/m^2

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

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 STRESS: 39.1149 N/m^2

MAX STRESS: 58193.9 N/m^2

| Selection set | Units | Sum X | Sum Y | Sum Z |
|---|---|---|---|---|
| Entire Model | N | 0.000622037 | 9.4135 | 0.00063 |

**Table 3: Resultant forces while using material 2.**
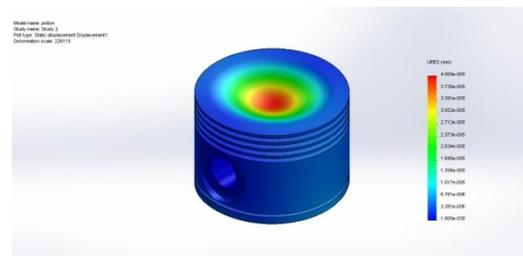


MIN DISPLACEMENT: 0mm
MAX DISPLACEMENT: 4.06873e-005 mm
MIN STRAIN: 3.33135e-010
MAX STRAIN: 2.25617e-007**Table 2: Resultant forces while using material 1.**

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
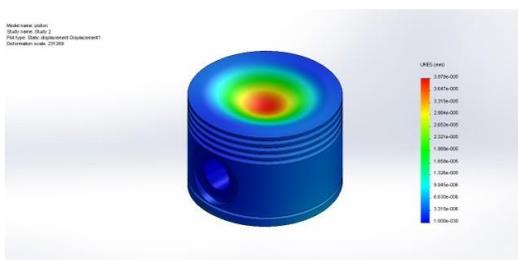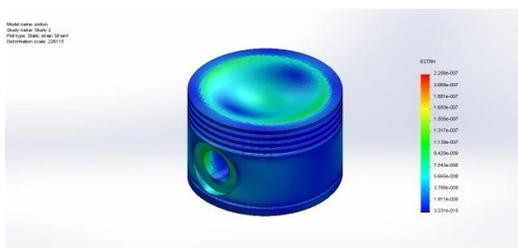
the piston mainly depends on the deformation of piston. Therefore, in order to reduce the stress

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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