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Thermal Analysis of Ceramic Coated Steel Alloy Piston Used in Diesel Engine Using FEM

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Abstract

The goal of this project is to determine both temperature and thermal stress distributions in ceramic coating on an steel alloy piston crown to improve the Thermal efficiency of a diesel engine. Effects of the coating thickness on temperature and thermal stress distributions are investigated, including comparisons with results from an uncoated piston by means of both static and thermal analysis. For changing the design here we added 0.4mm thickness material on the top surface which is called ceramic coating and we used two materials for this one is zirconium and another one is silicon dioxide, for the analysis of both steel and al-alloy pistons with these coatings. Thermal and static analysis are performed for various coating thicknesses from 0.2 to 1.6mm excluding the bond coat layer. Now in this project we add ceramic coated thickness of 0.4mm. Temperature at the coated surface is significantly higher than that of the uncoated piston. It is observed that the coating surface temperature increases with coating thickness by decreasing rate. By adding 0.4mm thickness of coating, we have to improve the thermal efficiency of the coated piston compared to uncoated piston.

Keywords: *Temperature, Coating thickness, Thermal barrier, stress, Piston crown temperature etc*.

1. Introduction

The demand for energy is increasing day by day. The world is depending mostly on fossil fuels to face this energy needs. The increase in standard of living demands better mode of transport, hence a large number of automobile companies has been introduced. Automobiles provide better transport but the combustion of fuel in automobile engine creates harmful effluents, which has an adverse effect on water and air. Combustion generated pollution is by far the largest man made contribution to atmospheric pollution. The principal pollutants emitted by the automobile engines are CO, NO_X, HC and particulates. The modern day automobiles is a result of several technological improvements that have happened over the years and would continue to do so to meet the performance demands of Exhaust-Gas Emissions, Fuel Consumption, Power Output, Convenience and Safety. In order to reduce emissions and increasing engine performance, modern car engines carefully designed to control the amount of fuel they burn. An effective way for reducing automotive emission and increase engine's performance is accomplished by coating automobile piston head with low thermal conductivity material such as ceramic. This process is known as Thermal Barrier Coating (TBC).

1.1 Ceramic:

A ceramic is an in organic, non metallic solid material, nonmetal or metalloid atoms primarily held in ionic and covalent bonds. The crystalline ceramic materials ranges from highly oriented to semi-crystalline, and often completely amorphous (e.g., glasses). Varying crystalline and electron consumption in the ionic and covalent bonds cause most ceramic materials to be good thermal and electrical insulators and extensively researched in ceramic engineering. With such a large range of possible options for the composition/structure of a ceramic (e.g. nearly all of the elements, nearly all types of bonding, and all levels of crystalline), the breadth of the subject is vast, and identifiable attributes (e.g. hardness, toughness, electrical conductivity, etc.) are hard to specify for the group as a whole. General properties such as high melting temperature, high hardness, poor conductivity, high modulus of elasticity, chemical resistance and low ductility are the norm, with known exceptions to each of these rules (e.g. piezoelectric ceramics, transition temperature, super conductive ceramics, etc.). Many composites, such as fiber glass and carbon fiber, while containing ceramic materials, are not considered to be part of the ceramic family.

2. Literature Survey

Ravinder Reddy Pinninti [1] et al has investigated to determine both temperature and thermal stress distributions in a plasma sprayed magnesia-stabilized Zirconia coating on Silicon Carbide (SiC) piston crown to improve the performance of a diesel engine. The coating is done on the piston crown to the extent 1.6 mm coating thickness with magnesia zirconia excluding the bond coat layer. Effects of the coating thickness on temperature and thermal stress distributions are investigated, including comparisons with results from an uncoated piston by means of the finite element analysis.

Ekrem Buyukkaya [7], Muhammet Cerit [6] et al (2007) has investigated a conventional (uncoated) diesel

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piston, made of aluminum silicon alloy and steel. He has performed thermal analyses on pistons, coated with MgO–ZrO_2 material by means of using a commercial code, namely ANSYS. Finally, the results of four different pistons are compared with each other. The effects of coatings on the thermal behaviors of the pistons are investigated.

M. L. S. Dev Kumar [15] et al has investigated a conventional (uncoated) diesel piston, made of aluminum silicon alloy and steel. He has performed thermal analyses on pistons, coated with MgO–ZrO_2 material by means of using a commercial code, namely ANSYS. Finally, the results of four different pistons are compared with each other. The effects of coatings on the thermal behaviors of the pistons are investigated.

Design of piston:

The piston and piston rings are designed according to procedures and specifications given in machine design and design data book. Dimensions are calculated and these are used for modeling the piston and piston ring in CATIA V5R20 as shown in Fig 1and Fig 2
Major headings are to be column centered in a bold font without underline. They need be numbered. "2. Headings and Footnotes" at the top of this paragraph is a major heading.

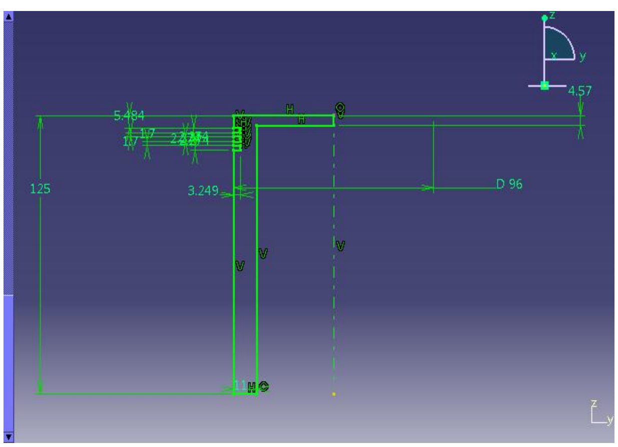

Fig.2.1 Piston Drawing and Dimension

These were then imported to ANSYS 14.5 for structural and thermal analysis. Structural analysis of piston is performed on ANSYS 14.5 mechanical APDL and thermal analysis is performed on ANSYS 14.5 workbench. Structural and thermal analysis of piston ring is performed on the ANSYS 14.5 workbench.

Boundary Conditions for Structural Analysis of Piston:

Combustion of gases in the combustion chamber exerts pressure on the head of the piston during power stroke. The pressure force will be taken as boundary condition in structural analysis using ANSYS mechanical APDL. Fixed support has given at surface of pin hole. Because the piston will move from TDC to BDC with the help of fixed support at pin hole. So whatever the load is applying on piston due to gas explosion that force causes to failure of piston pin.

Boundary Condition for Thermal Analysis of Piston:

The thermal boundary conditions consist of applying a convection heat transfer coefficient and the bulk temperature, and they are applied to the piston crown land sides, piston skirt.

3. Methods for Design & Analysis to Develop the Work

3.1 CREO:

Computer aided design (cad) is defined as any activity that involves the effective use of the computer to create, modify, analyze, or document an engineering design. CAD is most commonly associated with the use of an interactive computer graphics system, referred to as cad system. The term CAD/CAM system is also used if it supports manufacturing as well as design applications.

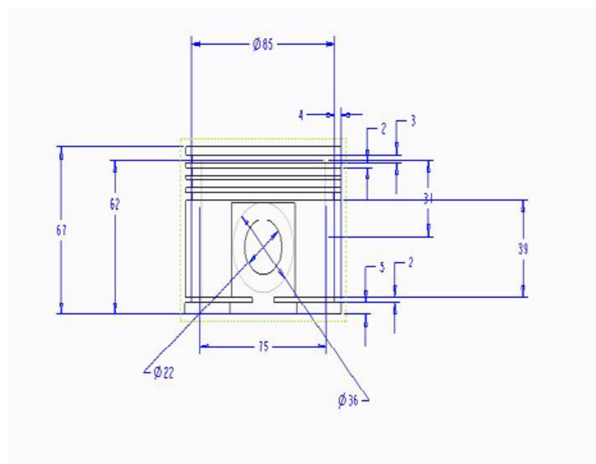

Fig: 3.1 Design Parameters of Piston

3.2 ANSYS:

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them. all creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

4. Analysis

The goal of this project is to determine both temperature and thermal stress distributions of ceramic coated steel alloy piston crown to improve the Thermal efficiency of a diesel engine. Effects of the coating thickness on temperature and thermal stress distributions are investigated, including comparisons with results from an uncoated piston by means of both Static and Thermal analysis Using CREO and ANSYS.

4.1 Static Analysis:

For uncoated steel alloy:

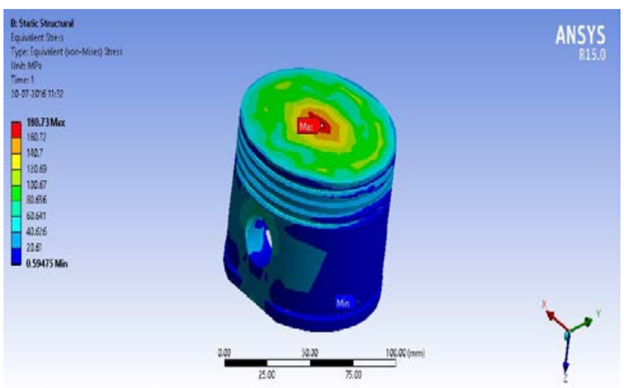

Fig 4.1: static analysis for steel material stress

Above Fig. shows when we applied 6mpa pressure on the top surface of the exciting material un coated steel alloy Piston crown, it produces 180.73 M Pa of stress.

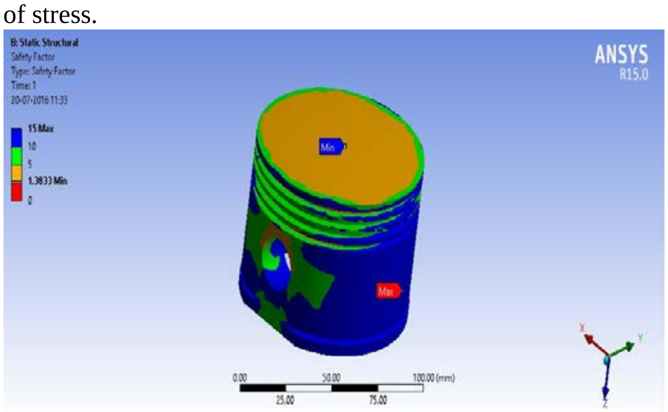

Fig 4.2: static analysis for steel material Factor of Safety

Above Fig. shows when we applied 6mpa pressure on the top surface of the exciting material un coated steel alloy Piston crown, it produces 1.3833 of factor of safety.

For ceramic (SiO_2) coated steel alloy:

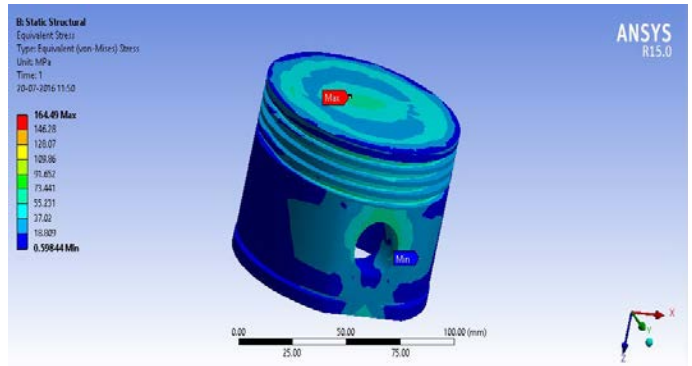

Fig 4.3: static analysis for steel- sio_2 material stress

Above Fig. shows when we applied 6mpa pressure on the top surface of the ceramic coated of Silicon dioxide on steel alloy Piston crown, it produces 164.49M Pa of stress.

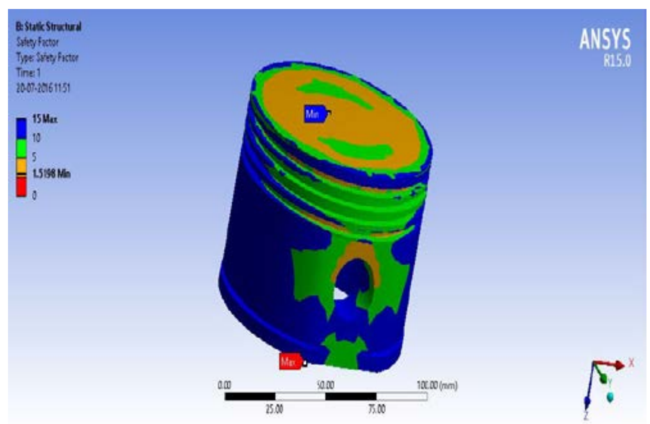

Fig 4.4: static analysis for steel- sio_2 material Factor of Safety

Above Fig. shows when we applied 6mpa pressure on the top surface of the ceramic coated of Silicon dioxide on steel alloy Piston crown, it produces 1.5198 of factor of safety.

By adding SiO_2 coated for steel alloy piston, stress has been decreased from 180Mpa to 164.49M Pa and safety factor increased from 1.3 to 1.51.

4.2 Thermal Analysis:

For uncoated steel alloy:

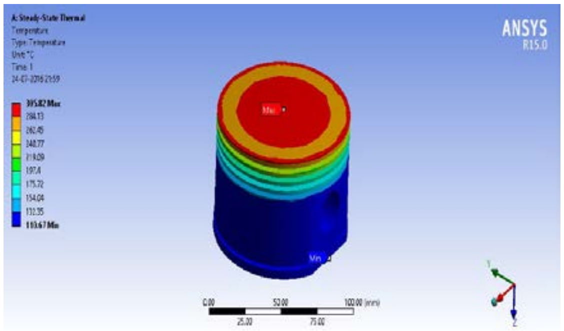

Fig 4.5 : Thermal analysis for steel material temperature distribution

Above Fig. shows when we applied 700^0C ambient temperature and 7e-4 film coefficient on the top surface of the exciting material steel alloy Piston crown, it produces 305.82^0C of temperature distribution.

For ceramic (SiO_2) coated steel alloy:

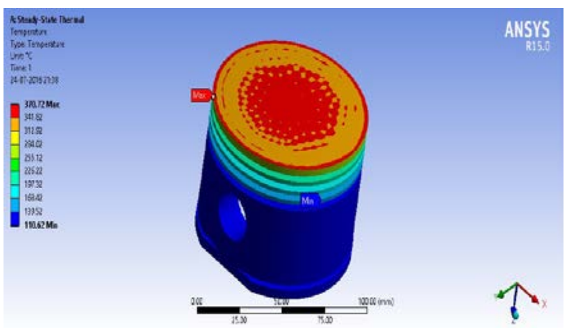

Fig 4.6: Thermal analysis for steel-SiO_2 material temperature distribution

Above Fig. shows when we applied 700^0C ambient temperature and 7e-4 film coefficient on the top surface of the ceramic coated of SiO_2 on steel alloy Piston crown, it produces 370.72^0C of temperature distribution.

5. Results and Discussion

Table: 5.1: Static Analysis Between uncoated steel and ceramic coated Steel-sio2

Material	**Safety factor**	**Stress(Mpa)**
Steel	1.3833	180.73
Steel-sio2	1.5198	164.49

From above table the results steel-sio2 combination produced very less stress 164.49Mpa among uncoated steel alloy piston and it has safety factor 1.5198 it means high strength, so we can say by comparison of coated and un coated steel, ceramic coated steel- sio2 produces very less stress and having good strength.

Table: 5.2: Thermal Analysis Between uncoated steel and ceramic coated Steel-sio2

Material	**Total Heat flux (w/mm^2)**	**Temperature (^{O}c)**
Steel	0.59121	305.82
Steel-sio2	0.52725	370.72

From Above table , the results Steel-sio2 combination produced very high temperature distribution 370.72^0C among uncoated steel alloy piston and it has 0.52725w/mm^2 of heat flux. So we can say by comparison of coated and un coated steel, ceramic coated steel- sio2 produces very high temperature by thermal analysis.

Conclusion

- In this project we have done one piston model by using CAD tool (creo-2) and then imported into CAE tool (ANSYS). To improve results here we selected another material Al-Alloy and existing material is steel only. And applied real time boundary conditions on it but in this case we get good results for existing material only. So we decide to change the design.
- For changing the design here we added 0.4mm thickness material on the top surface which is called Ceramic coating and we used two materials for this one is zirconium and silicon dioxide, we analysis for both steel and al-alloy pistons with these coatings.
- In static conditions when we applied 6Mpa pressure on existing piston (steel) produced 180.73MPa by changing design and adding zirconium coating we reduced it to 158.72Mpa nearly 22MPa stress have been reduced but in real time conditions these results are not enough so we have analyze these models with thermal loads also.
- In thermal analysis the existing model with existing material gained temperature 305.82^0c only by changing design steel-zirconium gained 355.43^oc and steel–sio_2 gained 370.72^0c. Ceramic coating increased exhaust gases temperatures at every operational condition. Exhaust gases temperatures were increased 50 to 70^0 C according to standard engine configuration. This increase corresponds to 15 to 25 percent of standard engine exhaust gases temperatures.

When a turbine is combined to the system, exhaust energy can be converted to useful mechanical energy.

- From the above we can say in thermal conditions steel-sio_2 combination produces better results compare with other. And it also has good static results.
- Finally we conclude steel with sio_2 ceramic coated piston will satisfy both static and thermal conditions. And it increases the piston efficiency compared with the uncoated steel alloy piston.

Scope of Future Work

- In this work simulation is carried out for two types of ceramic coating materials and two types of piston materials. This work can be extended to study for various coating materials and for different compositions. The simulation results can also be validated with experimental results by conducting experiments with coated pistons.
- The efficiency of diesel engine can be increased by using of TBC method but it is difficult to perform it experimentally. When ceramic coating is used in IC engine, the different types of practical problems are occur such as thermal mismatch due to improper adhesion and difference in thermal expansion coefficient between bond coat and piston materials and it has to withstand with wear and tear. In future try to develop new material or select proper material to avoid the above problem and reduce NOx emission also.

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