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Thermo-Structural Performance analysis IC Engine Piston under Thermal Barrier Coatings Using Finite Element Analysis

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Abstract

Initially piston is modeled as per the dimensions and later built into a three dimensional model. This model is imported to Hypermesh for quality meshing. Due to complicity shape, tetra mesh is used for the problem. Load collectors are created to apply the boundary conditions. Thermo-mechanical analysis is carried out using Ansys. The results shows safety of the piston for the given loads. But higher stresses due to these load, may create possible creep and fatigue failures to the piston. Since main stress development is due to temperature, thermal barrier coatings are used to reduce the temperature and in turn stress in the piston structure. Analysis is carried out to find the effect of thickness of top coat on stress and temperature drop on the structure. The results shows, thickness of top coat has higher effect on stress and temperatures.

Keywords—TBC, Piston, FEA, Stress, Thermal Load

1. INTRODUCTION

IC engines are the heat engines where power is obtained by combustion process inside the constrained space. Combustion takes place between fuel and the air (oxygen) which generates the heat in the process. This heat increases the pressure of the burnt gas which expands and drives the mechanism. The expansion takes places through piston and connecting rod to the crank shaft of the engine. The first successful commercial engine was built by Etienne Lenoir in 1859 and first modern IC engine was developed by Nikolaus Otto in 1876. Various scientists and engineers contributed to the development of IC engines.

2. LITERATURE

Design of machine components is complicatory process due to complexity of loads, materials and environmental conditions along with aesthetic effects. This will become still more complex in the engines due to thermal loading along with its complications of creep and thermal shock problems. So higher factor of safety in the engineering components is the best way to solve the failure problems. Piston is an important element of engine which is subjected to burnt gas temperature along with burnt gas pressure loads. Due to linear motion and time based load applications, proper design and factory of safety is an essential consideration in the working piston. Chen[1] explained the need of thermal barrier coatings in prevention of high temperatures to the machinery in the high temperature environment like gas turbines and rocket engines. The ceramic materials which used as thermal barrier coatings with their lower thermal conductivity, has the advantages of high temperature capacity, thermal fatigue resistance with minimum thermal expansion coefficient. Hassan Mohammad[2] has applied thermal barrier coatings to improve the life span of pistons. In his observations, the working range of the combustion chamber can be increased from 550 degrees to 1760 degrees with proper size and shape of the thermal barrier coatings. As per the Aluminum Automotive Manual[3], pistons are mainly subjected to thermal and structural loads. As per the manual, the pressure ranges varies to higher value of 200 bar. Even high acceleration loads also creates large stresses in the structure. These are again increased by thermal stresses. Especially these thermal stresses are generated due to higher thermal gradient on the top of the piston. Ravi Kumar[4] explained about the need of thermal barrier coatings to improve the combustion chamber efficiency. By coating, the heat dissipation to the surroundings is less and so the efficiency of combustion chamber is increased. The percentage of unburnt fuel is reduced. Vishnu Sankar[5] has discussed about improving the engine performance. He detailed the methodologies to improve the engine performance through thermal barrier coating to obtain higher efficiency, lower fuel consumption, reduced emissions. He suggested that a partial thermal barrier coating is better to provide on the crown surface for better fuel burning. K. Thiruselvam[6] has analysed the effects of thermal barrier coatings on the performance of IC engines. He observed that, the coatings will help in improving the thermal and structural performance of the engines. Better thermal insulation helps in reducing the stress and failure chances of the engine system. As per Prof Parvez[7], the maximum efficiency obtained to the IC engines varies from 38 to 42%. Remaining energy will be waster through either to the exhaust or to the un-burnt fuel or to the structure. To improve this, insulation should be provided at the combustion chamber Better combustion also influences the energy used in the burning process. Balbheem Kamanna[8] has done finite element analysis on a 150cc Engine piston to study the thermal behavior and resulting stress behavior. As per his observation, thermal insulation helps in increasing the performance of the engine.

3. GEOMETRY

The geometry of the piston is as follows with the dimensions.

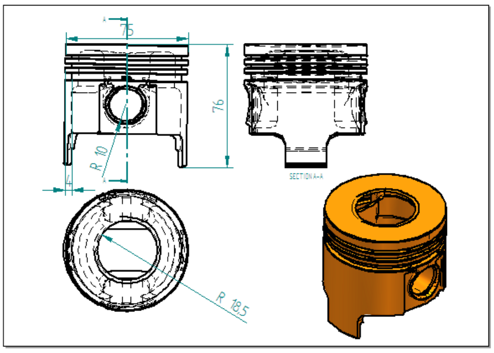

Fig1: Geometry of the Piston

4. FE Model

Mesh is the most important part of finite element analysis. Here the geometric model or continuum model will be converted to mathematical model. Without this conversion, the problem can't be solved by finite element analysis. Mesh converts infinite degrees of freedom to finite degrees of freedom.

Fig2: Finite Element Mesh

5. ANALYSIS RESULTS

The thermal analysis results are as follows without any thermal insulation.

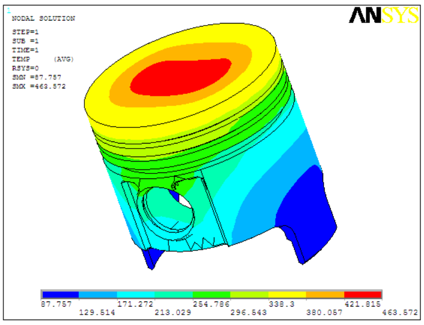

Fig3: Temperature Plot

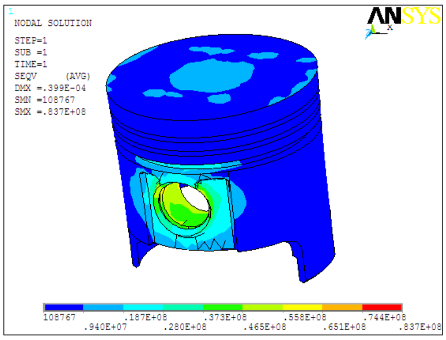

Fig4: Vonmises Stress Plot

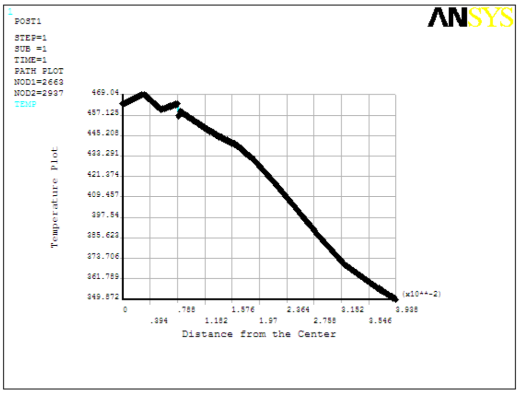

Fig5: Temperature Variaton

5 Analysis Results with Thermal Barrier Coatings

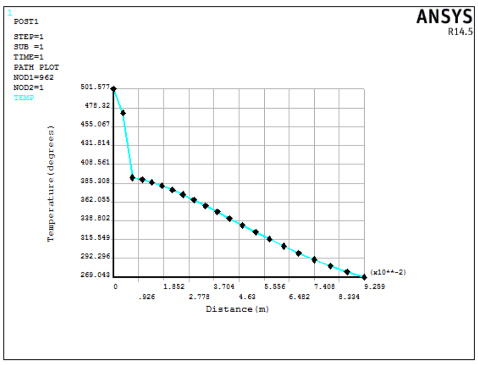

Fig6: Temperature Variaton with Thermal Barrier Coating

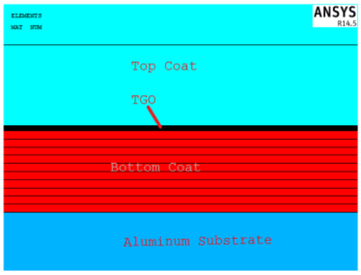

Fig7: Modeling of Thermal Barrier Coatings

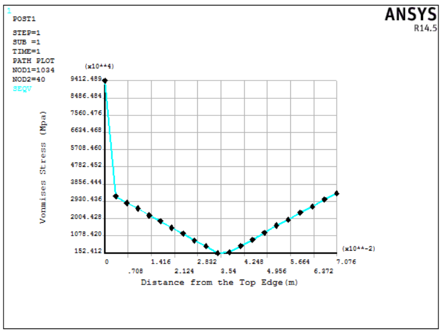

Fig8: Stress Variation with Thermal Barrier coatings

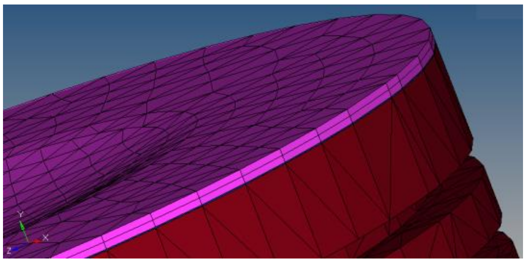

Fig9: Top Coat Modelling on Piston

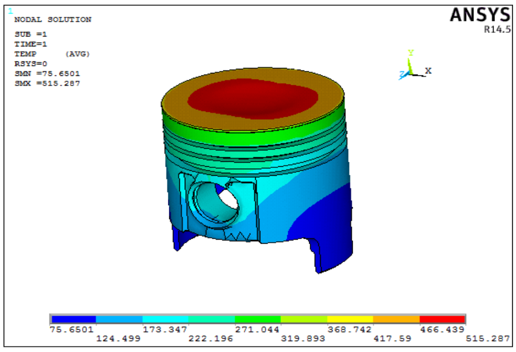

Fig10: Temperature Distribution with Thermal barrier Coatings

6. CONCLUSIONS

Finite element analysis is carried out to find the effect of thermal barrier coatings on the thermal performance of piston for temperature and stress conditions. The results shows greater improvement of piston load carrying capacity due to reduction of temperature in the piston material. The top coat has greater influence compared to TGO and bottom coat of the structure. Finite element analysis can be effectively utilized to find the optimum thickness over the top coat for the best possible life for the piston material.

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