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Impact of Ceramic Coating on Fatigue Life of Connecting Rod

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Abstract

The study is focused on minimisation of the heat dissipation to the connecting rod from combustion chamber via gudgeoned pin of the piston assembly. High temperature variation has an adverse impact on the fatigue life of the connecting rod. YSZ (Yttria Stabilised Zirconia) is a material having low thermal conductivity and high strength which fulfils the criteria of an effective coating material for the connecting rod. The solid model of coated and uncoated connecting rod geometry was generated on Solidworks for analysis. The geometry file was later imported in ANSYS Workbench for a couple field Steady State Thermal and Static Structural analysis. The simulation results were compared to study the behaviour and impact of coating on the fatigue life of connecting rod.

Keywords: Buckling, simulation, fatigue, deformation

INTRODUCTION

Connecting rod is an integral part of a transmission system of a vehicle which is responsible for transmitting the power from combustion chamber to the crack shaft. Small end of the connecting rod capsules the gudgeoned pin of the piston while the big end is attached to the crack shaft journal. Certain amount of heat generated in the expansion stroke of the engine is transferred from the engine to the connecting rod via piston and gudgeoned pin. Due to increase in temperature and direct heat interaction with the connecting rod and other components of IC engine, the material of these components are subjected to phase change. This dissipated heat interaction with the connecting rod has an adverse impact on the strength and fatigue life of the product which can lead to crack formation and breaking of the connecting rod thereby increasing the possibilities of breakdown in a vehicle. The thermal deformation caused due to this phenomenon can be controlled and heat dissipation can be reduced by application of YSZ plasma coating on the connecting rod.

LITERATURE REVIEW

S. Srikanth Reddy, Dr Sudheer Prem Kumar aimed to analyse and investigate the thermal stress distribution of piston at the real engine condition during combustion process. The CAD model is developed in Catia and later imported in Ansys for simulations. TBC coating material Zirconate is applied on the aluminium piston to determine its effect on the thermal stresses and deformations. Static structural analysis is carried out on piston pre and post application of Zirconate coating and results are compared. Post application of Zirconate coating the maximum stress reduced from 85MPa to 55MPa and deformation reduced from 0.0517mm to 0.0258mm. [1] Kadima Bhargava V Siva Kumar tried to determine the behaviour of the connecting rod made of forged steel and sintered steel under same boundary conditions. Dimensions were obtained from vehicle specifications and a solid model was generated on Pro E software. The geometry file was imported in ANSYS Workbench for Static structural and Steady State Thermal Analysis. In structural analysis the big end was given a fixed support and normal radial pressure of 8 MPa is applied on the external surface of the small end. For steady state thermal analysis the temperature of 35 Degree Celsius was applied at the big end and 350 degree Celsius at small end. It is observed that Von Mises Stress, Directional Heat Flux, Total Heat Flux and thermal error is higher in the forged steel connecting rod. The sintered steel connecting rod has comparatively less deformation and strain energy and is therefore preferred over forged steel connecting rod. [2] Santosh Reddy, Shivaji Shivraj, Maruthi. B. H. performed all types of analysis to critically determine an area for material removal and mass reduction from the connecting rod of 150CC motorcycle. The dimensions were obtained by use of design data book and validated by reverse engineering. Solid model geometry was generated on Catia VR20. For mass optimisation the I-section of the connecting rod was made hollow so as to compare the simulation results of base design with the optimised design. The .IGES file was later imported in ANSYS workbench for multiple analyses. The material assigned to the connecting rod was C70 Steel. Linear and Bilinear static analysis was performed on the connecting rod considering the bearing pressure of 16MPa acting on the small end and the big end fixed. Modal analysis was carried for 6 model with frequency varying from 726.56 to 5217Hz. Fatigue analysis was carried out for 106 cycles. [3]

METHODOLOGY

3D Modelling of Connecting Rod Geometry

Dimensions of the connecting rod of the specific vehicle were obtained by means of reverse engineering. A 3D model of the uncoated and 0.2mm YSZ coated connecting rod was generated using Solidworks for analysis. Rendered image of the solid model can be seen in Figure 1.

Figure 1

Meshing for Steady State Thermal and Static Structural Couple Field Analysis

A .STEP geometry file was saved in solid works and imported in ANSYS Workbench steady state thermal standalone system. Medium Sized global adaptive tetrahedron mesh was applied on the entire geometry. A refined mesh of size 1.5mm was applied on the critical surfaces to obtain accurate results. Figure 2 is the graphic representation of the meshed model for analysis.

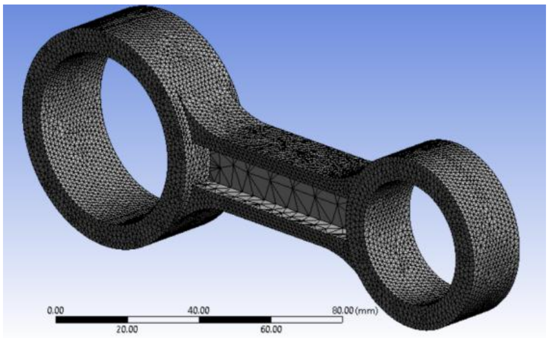

Figure 2

Loading Calculations for Boundary Conditions

Density = 737.22 × 10-9kg/mm3

Molecular weight = 114.228 g/mole

Ideal gas constant of air = 8.3143 J/mol k

Rsp Gas constant = $\frac{R}{M}$

$= \frac{8.3143}{114.22 \times 10^{-3}}$

= 72.79 J/kg k

Pressure of petrol acting on the piston due to combustion is calculated by Ideal Gas Equation

PV = mRT

$P \quad = \frac{mRT}{V}$

$P = \frac{737.22 \times 10^{-9} \times 150 \times 10^{3} \times 72.79 \times 288}{150 \times 10^{3}}$

P = 0.01545 J/mm3

P = 15.45 N/mm2

Force acting on connecting rod is due to gas pressure which is called as gas force

Gas force = Area × Pressure

Gas force = $\frac{\pi}{4} \times D^2 \times P$

$= \frac{\pi}{4} \times 57^2 \times 15.45$

= 39429.78 N

System is always designed for max force hence buckling force acting on connecting rod is given by,

Buckling force Wb = Gas force × FOS

Assuming FOS= 2

Wb = 39429.78 × 2

= 78859.56 N

Recorded Max Temperature: 133 °C

Convection: 19.1 W/mm²·°C

Steady State Thermal and Static Structural Couple Field Analysis

For the analysis, the coated and uncoated geometries were subjected to same boundary conditions as per the calculations. Material for the connecting rod is taken as Structural Steel while the Coating material is taken as YSZ Plasma. For the steady state thermal analysis, the small end of the connecting rod was subjected to a temperature of 133 °C and a convection of 19.1 W/mm²·°C was applied to the other outer surfaces except the big end as it is attached to the crank journal. Results of steady state thermal analysis were imported in Static Structural Analysis to accurately determine the thermal stresses and fatigue life of the component. Small end of the connecting rod is subjected to bearing buckling force while a fixed support is applied to the big end of the connecting rod. Fatigue life of the uncoated and coated connecting rod can be observed from the simulation results in Figure 3 and Figure 4 respectively.

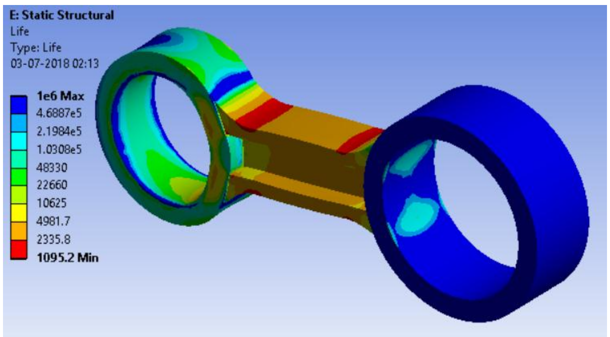

Figure 3. Uncoated Fatigue Life

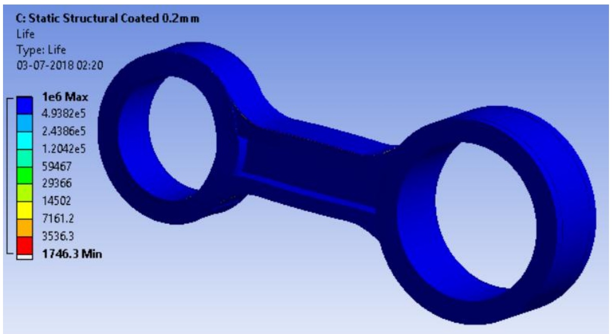

Figure 4. Fatigue Life YSZ Plasma Coated Component.

RESULTS AND CONCLUSION

Table 1 gives a description of Equivalent Thermal Von Mises Stress, Total Deformation and Fatigue Life pf the coated and uncoated models analysed in the paper.

Table 1. Simulation Result Chart

	Uncoated	0.2mm YSZ Coated
Thermal Stress (MPa)	555.92	464.61
Thermal Deformation (mm)	0.15063	0.14529
Fatigue Life (Cycles)	1095.2	1746.3

The simulation results prove that application of ceramic coating on the connecting rod has resulted in significant reduction of thermal stress by 22.18%. Application of ceramic coating has significantly reduced the dissipation of heat to the connecting rod and therefore enhanced the fatigue life of the connecting rod. This further improves the performance of the IC engine and reduces the probability of breakdown of the vehicle. YSZ coating of increased thickness i.e. 0.4mm or 0.6mm can further enhance multiple life parameters of the vehicle. Effect of YSZ coating can be analysed on other components of IC engine assembly. Application and development of distinguished and enhanced thermal barrier coating material on the components of IC engine can further optimise the life and performance of the vehicle.

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