International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 5, Issue 5
May 2018

Thermal and Structural Analysis of Four Stroke SI Engine Combustion Chamber

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Abstract

The heat from combustion is not fully converter to work as heat leak from inlet and outlet valve seat. Thermal coat studies have been suggesting that heat loss can be reduced by metal coating on engine combustion chamber. The objective of this work is to study the effect of copper coating on performance of lubricating oil as it has evaporative temperature limit around 280^{0}Cand its effect on life of piston. Experimentally it is difficult to check the temperature flow between piston and liner wall where the lubricating oil presents, therefore a numerical method of finite element method is adopted. Modeling is created using solid works; boundary conditions are calculated analytically using empirical formulas. It is observed that copper coating enhances the heat transfer by pre flame propagation and piston experienced wear and cracks in long run.

Keywords: copper coat, piston, liner, SI engine, thermal analysis

1. Introduction

Higher efficiencies, lower specific fuel consumptions and reduce emissions in modern internal combustion (IC) engines has become the center of attention to engine researchers and manufacturers. The global concern over the depletion of fossil fuels and the more stringent emissions regulations has placed the obligation on the engine industry to produce practical, economical and environmentally conscious solutions to power our automobiles. Heat utilization is one of the primary loss mechanisms in an internal combustion engine and it plays a crucial role in all aspects of engine operation. As a result, the want to better understand the effects of heat transfer on engine dynamics has led to a great deal of work in the field.

Silvio Memme[1] investigated and compared a baseline copper coating and a metal TBC. It was found reducing surface roughness of both coatings increased in-cylinder temperature and pressure as a result of reduced heat transfer through the piston crown. These increases resulted in small improvements in both power and fuel consumption, while also having measurable effect on emissions. Engine modification with copper coating on piston crown and inner side of cylinder head improves engine performance as copper is better conductor of heat and good combustion is achieved with copper coating. [2-3]. Muralikrishna etal.[4-6] studies the performance of SI engine by changing fuel composition, change of combustion chamber design and with provision of catalytic converter. Methanol blended gasoline (gasoline blended with methanol, 20%, by vol) improved engine performance and decreased pollution levels when compared with pure gasoline on CE. Ravindra Gehlot et.al.[7] analyzed ceramic coated diesel engine piston and found a significant increase in the pistons top surface temperature occurs with coating having holes. Although, the substrate temperature is decreasing with increase the radius of the holes. S.Srikanth Reddy et.al.[8] performed thermal analysis using ANSYS and optimized the piston using finite element analysis. The influence of ceramic coating thickness on temperature variations are studied by finite element method using ANSYS. S. Krishnamani et.al.[9], The temperature distribution analyses were conducted for the ceramic coating thickness of 0.3 mm over the piston crown surface. The results of the piston coated with two different coatings were analyzed. Dr.K.Kishor determined the temperature distribution across the piston, liner and cylinder head of conventional Engine (CE) and Copper Coated Engine (CCE) to study the performance of lubricating oil with the help of finite element method (FEM) using ANSYS software package. Hongyuan zhang[11] introduced the principle of thermal analysis for the combustion engine piston, gets the heat exchange coefficient of the piston top and the heat exchange coefficient distribution of the piston and the cooling water through calculation, calculates the temperature field of the piston with the finite element method and modifies the calculation model by repeatedly comparing the result with the measured temperature. It is found out that the temperatures of the piston top and the first circular groove are relatively high after calculating the temperature field and based on the results the optimization scheme of adding the cooling oil chamber is applied to the piston structure. Results show that, after optimization, the maximum temperature of the piston top is decreased to 264^{0}C, and the temperature at the first ring is decreased to 204^{0}C, thus improving the working condition of the piston ring. Soniya kaushik[12]

2. Materials and method

2.1 materials

Table.1 Engine specifications

Bore	70 mm
Stroke	66.7 mm
Rated output	2.2 kW
Speed	3000 rpm
Sparkignition timing	25 ^{o} BTDC
Compression ratio	3:1 to 9:1
Specific fuel consumption	475 gm/ kW h
Lubricating oil	SAE-40
Make	Greaves Limited

2.2 Methods

Experiment was conducted on the engine of four- stroke, single-cylinder, variable compression ratio (3:1–9:1) and variable spark timing (25^0 to 28^0 BTDC), water-cooled, SI engine with a maximum power of 2.2 kW coupled with eddy current dynamometer.

FEA Steps

Pre-preferences-Pre-processor-Solution-Postprocessor

Experimental setup

1.Engine, 2.Eddy current dynamometer, 3. Loading arrangement, 4. Orifice meter, 5. U-tube water monometer, 6. Air box, 7. Fuel tank, 8. Three-way valve, 9. Burette,10. Exhaust gas temperature indicator, 11 CO analyzer, 12. Air compressor, 13. Outlet jacket water temperature indicator, 14. Outlet jacket water flow meter,15. Directional valve, 16. Rotometer, 17. Air chamber and 18. Catalyst chamber 19. Filter, 20. Rotometer, 21. Heater, 22. Round bottom flasks containing DNPH solution

International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 5, Issue 5
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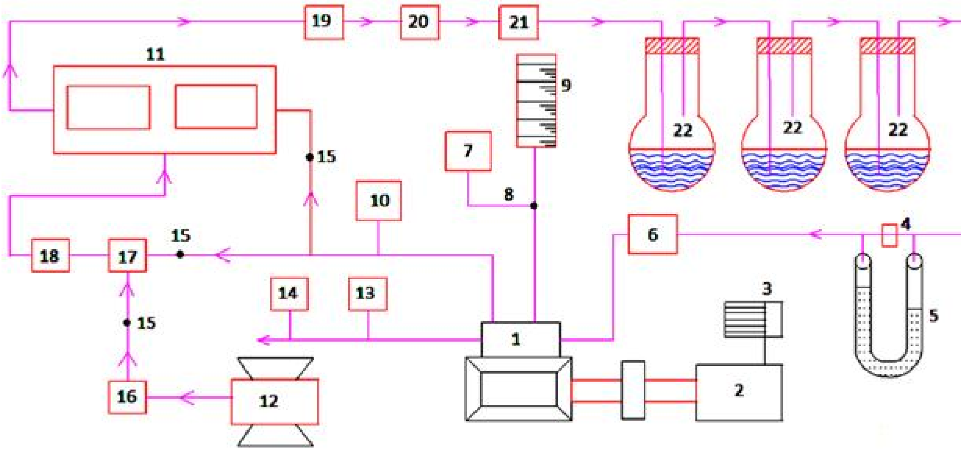


Fig.1 Schematic Diagram of experimental set–up

2.1.1 Modeling and meshing

A 3D geometric model of piston was created using modeling software Solid works. The dimensions were taken from experimental engine setup: piston bore diameter is 70 mm, stroke is 66.7 mm with cast aluminum alloy as material and copper coat thickness is 3 mm. The part drawing converted into STEP. File and exported to ANSYS Workbench where meshing and simulation was performed. The model and mesh was shown in figure.2and 3.

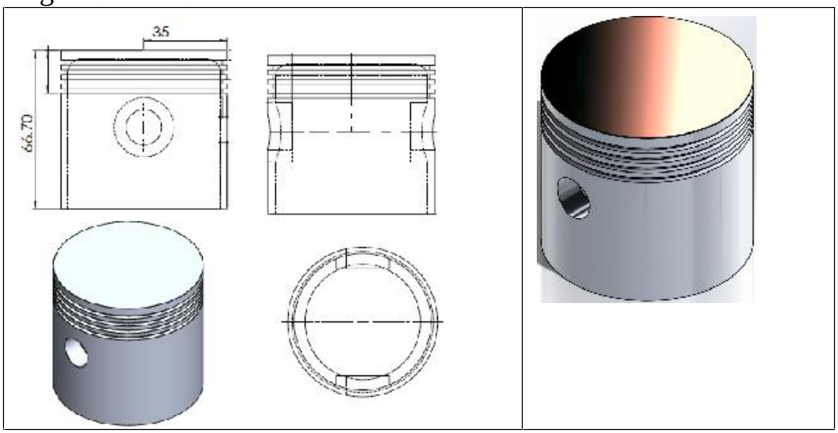


Fig.2 Solid modeling of a piston with copper coating

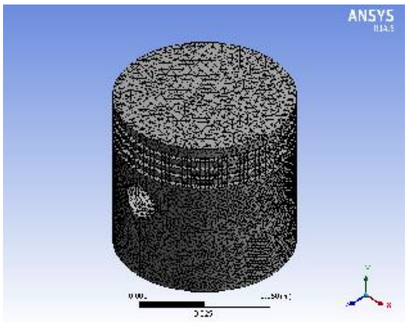


Fig.3 Meshing of a piston

2.1.2 Boundary conditions and analysis

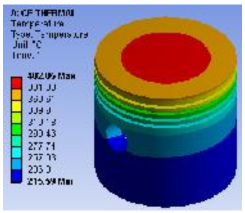
The boundary conditions have been calculated from experimental analysis. A heat flux of 2e5 w/m^2 has been applied on top of the piston i.e piston crown and an environmental initial condition of convection coefficient 10w/m^2 K applied to the skirt of the piston, and for structural analysis a fixed support at gad joint pin and pressure of 4.1 Mpa has been applied.

A steady state analysis was performed under above said operating conditions.

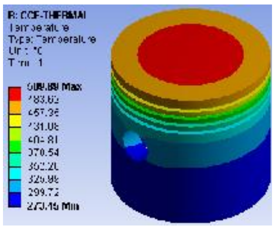
3. Results and discussion

3.1 Thermal analysis results

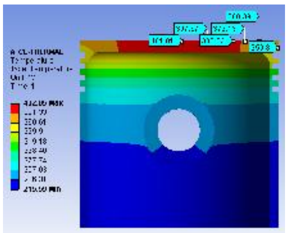
The results of analysis is shown in Fig.4



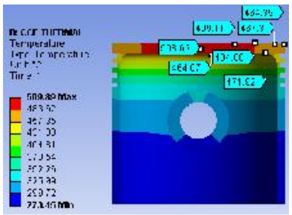
Nodal temperature in conventional engine



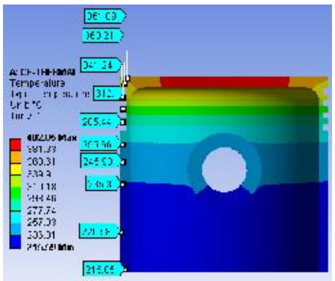
Nodal temperature in coated engine



Radial temperature in conventional engine



Radial temperature in coated engine



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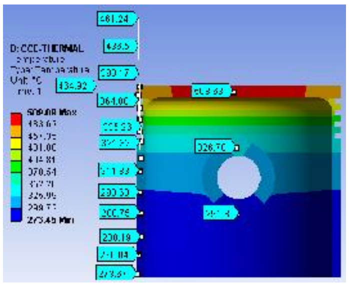
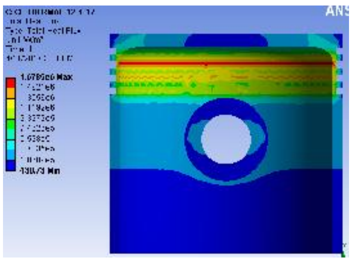
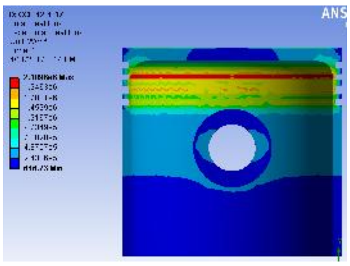


Radial temperature in coated engine



Heat flux in conventional engine



Heat flux in coated engine

Fig.4 Comparison of temperature flow in conventional and copper coated engine piston

ISSN 2394 – 3386
Volume 5, Issue 5
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Fig.4 shows the temperature distribution in piston with copper coat on top of the piston. It is observed that a lower heat rejection from the combustion chamber through thermally insulated components causes an increase in available energy which in turn would increase the in-cylinder work and the amount of energy carried by the exhaust gases, which could also be utilized in later stages. It is relatively a thermal barrier copper coating material which has approximately 26.8% more thermal stability than conventional piston. It can resist phase transition up to 1300^0K with thermal conductivity of 0.7 W/mK which is an added advantage in terms of reliability of engine operation in the event of sudden surge in temperature during combustion.

It is observed that the temperature variation in CE was 402^0C to 215^0C against 509.89^0C to 273.45^0C which indicates the heat enhancement in copper coated engine due to low heat rejection to neighboring components like piston liner and head. Temperature along the radius of the piston was determined 401.91^0C to 359.8^0C and 508^0C to 464^0C in CE and CCE respectively indicates that the nodal temperature was uniform in CCE when compared to CE.

The vertical temperature was observed from top of the piston to bottom of the piston which is to be 361.89^0C to 215.81^0C for CE and 461.24^0C to 273.61^0C for CCE. A temperature of 280^0C and 298^0C for CE and CCE was noted at the place of lubricating oil which is under safe limit of SAE40 lubricant oil melting temperature according to data available.Distribution of heat flux also uniform in CCE than CE resulted in better heat transfer per unit area for CCE.

3.1 Thermo-Structural analysis results

It is observed that the thermal stress is maximum at the centre for coated model and at edges for the uncoated model. This rise in thermal stress at the coatings is due to the high thermal conductivity of copper. The stresses are generated at the interfaces due to the presence of different materials with each material possessing different properties. Therefore copper coating has a significant effect on the overall stresses and temperature.

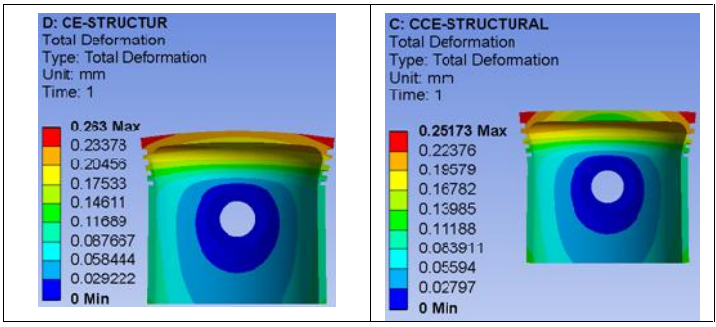

Fig. 5 Deformation in conventional and coated piston engine

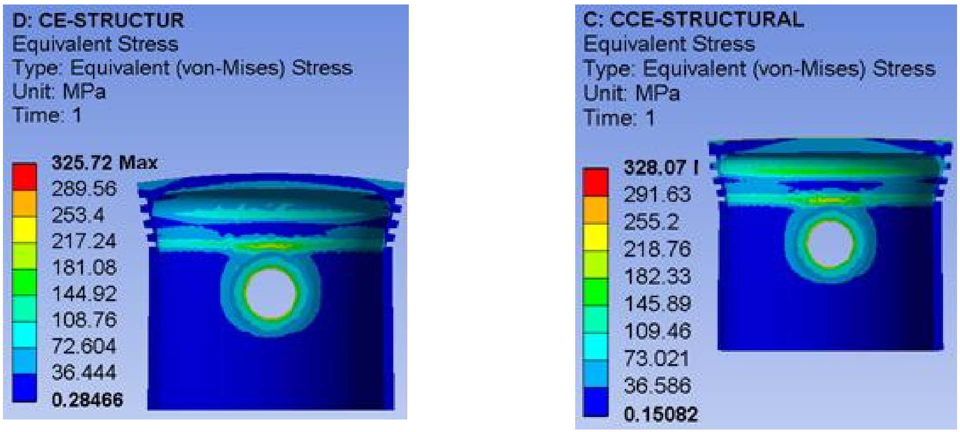

Fig. 6 Stress in conventional and coated piston engine

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The counters of nodal temperature, deformation and von-misses stress in piston liner assembly with copper coating on top of the piston and inside of the liner are shown in Fig. 7, 8 and 9.

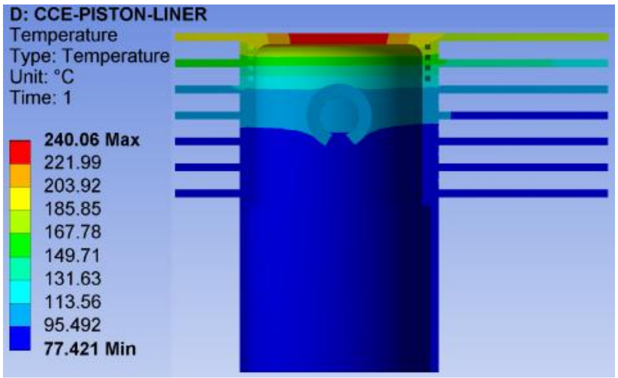

Fig.7 Nodal temperature in copper coated piston and liner assembly

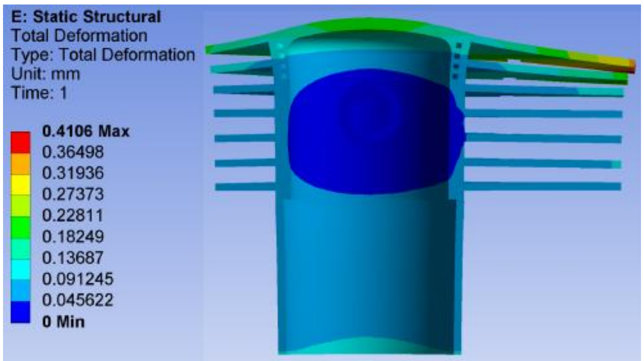

Fig.8 Deformation in copper coated piston and liner assembly

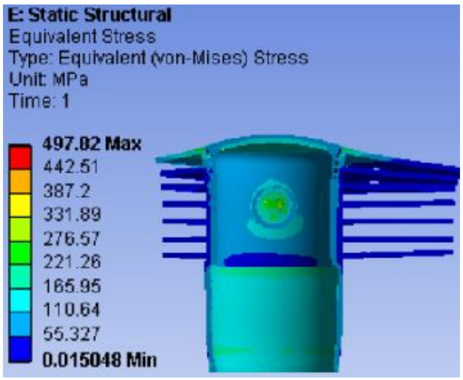

Fig. 9 Von-mises stress in copper coated piston-liner assembly

It is observed that the copper coating on both piston and liner has a significant effect on structural stability of engine. The stress is about 498 Mpa which shows structural instability by considering this experiment was carried out only for copper coating on piston crown.

4. Conclusions

The following conclusions are made from the numerical analysis.

1. Copper coated piston showed 23.34% increased heat flux over conventional.
2. A uniform temperature distribution was observed in CCE than CE.

3. Heat rejection to liner was lessening in CCE when compared to CE by 21.13%.
4. More heat of 5.019% is converter into work using copper coating on piston crown which leads to over all increased performance of engine.
5. From the analysis it was observed oil used for lubrication was not evaporated due to copper coated, resulted temperature (273^0C to 311^0C) was within the limit which indicates the safe guard to liner.
6. The stress in piston was 325 MPa for CE and 328 Mpa for CCE. From this it was clear that coated combustion chamber can be wear out after long operation.
7. Coating on both inside of liner and top crown of the piston resulted in more stress compared to coating on only piston crown, indicated that cracks in combustion chamber components.

Acknowledgements:

My heartfelt thanks to Dr.M.V.S.Muralikrishna, Prof., MED, CBIT , he is my continuous source of information and inspiration to make this work success. It is my pleasure to give thanks to Dr.P.Usha Sri, Prof., MED,OU as she motivated me towards the numerical methods.My thanks to Dr.P.Ravinder Reddy, Prof., Head , MED for his support to do my simulation work in CAD/CAM lab.

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