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Research Paper

MODELING AND THERMAL ANALYSIS OF SI ENGINE PISTON USING FEM

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The isotherms of cooper coated 4 stroke variable compression ratio petrol engines with pure gasoline operation and compared with conventional engine. The variation of Isotherms and heat flux with respect to radius, height of piston, liner, cylinder head and thermal analysis is also attempted in this paper. Copper coated engine showed higher temperature at salient points when compared with conventional engine at salient points like, on the top of the piston and liner. Temperatures were determined below SIT of the fuel. Deterioration of lube oil was not observed as temperatures were lower than the required combustion chamber wall temperature and this was found out so as to substitute in the equations of combustion model. First thermal analysis was done and analysed the temperature distribution over the convectional engine and copper coated convectional engine. In the second stage structural analysis was carried out using the thermal loads obtained in the first stage. Three different types of materials were taken for analysis.

Keywords: CATIA, ANSYS, Thermal analysis, Structural analysis, Copper coating, Piston head

INTRODUCTION

Energy conservation and efficiency have always been the quest of engineers concerned with IC engines. The diesel engine generally offers better fuel economy than its counterpart petrol engine. Theoretically if the heat rejected could be reduced then the thermal efficiency would be improved. The knowledge on temperature distribution in the piston and liner of a petrol engine is of immense use to the designer for calculating the fatigue strength, thermal stresses and achieving higher output. This data on temperature distribution is of much importance especially in SI engines. Air, being a bad conductor of heat energy, provides an effective thermal barrier inside the piston and liner, which brings drastic changes in the temperature distribution in air gap piston and liner. Due to practical difficulties involved in measuring temperature in different

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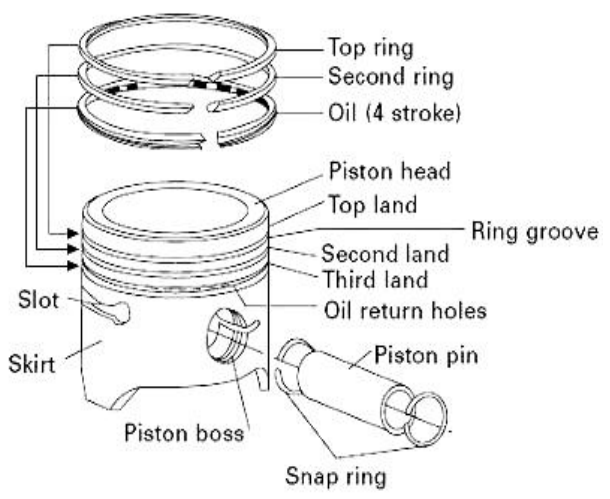
locations of piston and liner researchers are forced to adopt analytical and numerical methods for evaluating heat transfer rates through the piston and liner under varying conditions of engine.

PISTON

A piston is a component of reciprocating engines, reciprocating pump and gas compressors a moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to piston for the purpose of compressing or ejecting the fluid in the cylinder.

Figure 1: Piston Assembly



THE BOUNDARY CONDITIONS

One of the most important aspects to be considered during the analysis in order to achieve maximum accuracy is the selection of the boundary conditions. The top surface of the piston is subjected to hot gases which takes different values of temperature of gases T_g ( ) and convective heat transfer coefficient H_g ( ) for the different crank angles. The boundary condition for the present problem have been under taken to be as given below

1. Top surface of the piston, $H_g = 250$ W/m^2 – K, $T_g = 920$ °C
2. Bottom side of the piston, $H_{01} = 450$ W/m^2 – K, $T_{01} = 100$ °C
3. Air jacket side of liner, $H_{02} = 125$ W/m^2 – K, $T_{02} = 30$ °C

Table 1: Experimental Investigation on Performance of Copper Coating Spark Ignition Engine

Metal and Alloy	Temp °C	Density gm/cc	Thermal Condu-ctivity w/m-k	Specific Heat J/kg-k	E (Gpa)
Aluminum	200	2.75	155	915	71
Cast iron	500	7.2	40-55	480	80-120
Zirconium	1000	5.2-6.1	2.2-3.8	400-700	140-210
Copper	970	8.9	390	390	110

FINITE ELEMENT ANALYSIS

In order to have fuller understanding of phenomenon of heat flow through the piston and liner, the temperature distribution within the piston and liner will come handy for the designers. The transient nature of heat flow involving more than single variable, complicated method of measuring temperature across the length of the liner and ambiguous boundary conditions pose serious problems for the analysis of heat flow through the piston and liner of a petrol engine. Added to this, the composite structure of the insulated piston and the liner explained in chapter-2 consisting of a separate material for the piston crown and the liner insert, and different material for the rest of the piston and liner bodies will bring in variation of material

properties within the piston and the liner. In such complex situations with complex shape of the objects, the finite element analysis is best suited and hence the temperature distribution in insulated piston and stress are studied by employing finite element technique using ANSYS program.

MODEL OF THE PISTON CATIA

Piston Design

The design of the piston is according to the procedure and specification which are given in machine design, data hand books. The dimensions are calculated in terms of SI Units. The pressure is applied on piston head, temperatures of various areas of the heat flow, stresses, length, diameter of piston and thicknesses, hole, etc., parameters are taken into consideration.

Design Considerations for a Piston

In designing a piston for an engine, the points mentioned in Table 2 is taken into consideration:

- It should have enormous strength to withstand the high pressure.
- It should have minimum weight to withstand the inertia forces.
- It should form effective oil sealing in the Cylinder.
- It should provide sufficient bearing area to Prevent undue wear.
- It should have high speed reciprocation without noise.
- It should be of sufficient rigid construction to withstand thermal and mechanical distortions.
- It should have sufficient support for the piston pin.

Table 2: Design Specification of Piston

S. No.	Dimensions	Size in (mm)
1.	Length of the Piston (L)	72.14
2.	Cylinder bore/outside diameter of the piston (D)	65
3.	Thickness of piston head (t_H)	6.45
4.	Radial thickness of the ring (t_1)	2.8
5.	Axial thickness of the ring (t_2)	3
6.	Width of the top land (b_1)	9
7.	Width of other ring lands (b_2)	2

Figure 2: Model of the Piston

ANALYSIS OF COPPER COATED PISTON

Figure 3: Areas of 4 Stroke Copper Coated SI Engine

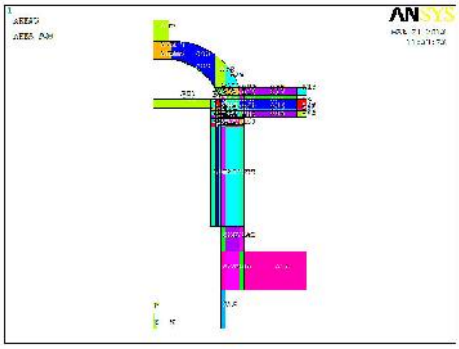
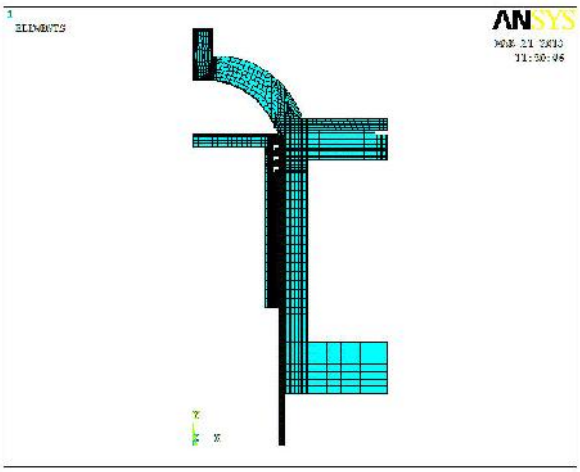


Figure 4: Mesh of a 4 Stroke Copper Coated SI Engine



RESULTS OBTAINED ON ANSYS

The solution phase deals with the solution of the problem according to the problem definitions. All tedious work of formulating and assembling of matrices are done by the computer and finally nodal temperature values and stress.

Figure 5: Temperature Distributions on Piston, Liner, and Cylinder Head of a Conventional Engine

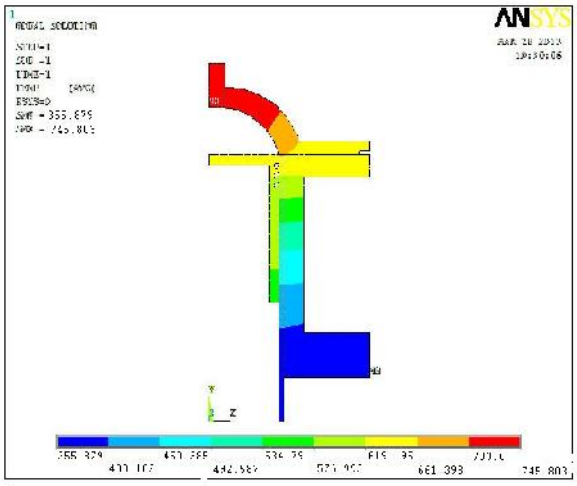
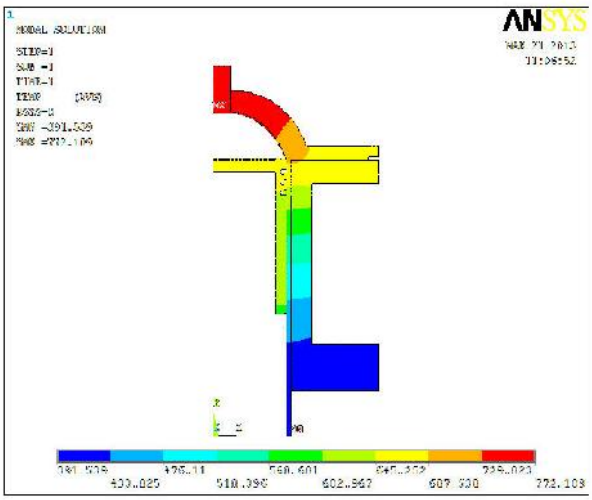


Figure 6: Temperature Distributions on Piston, Liner, and Cylinder Head of a Copper Coated Engine



PREDICTION OF TEMPERATURES ALONG HEIGHT OF THE PISTON FOR CONVENTIONAL AND CCE

From the isothermal plot the temperature at specific and salient locations on the axis on the piston skirt have been identified for SI engine. The temperature predicted by FEA analysis in the copper coated piston of SI engine was higher.

Figure 7: Variation of Non-Dimensional Temperature with Non-Dimensional Height Along the Axis of the Piston for CE and CCE

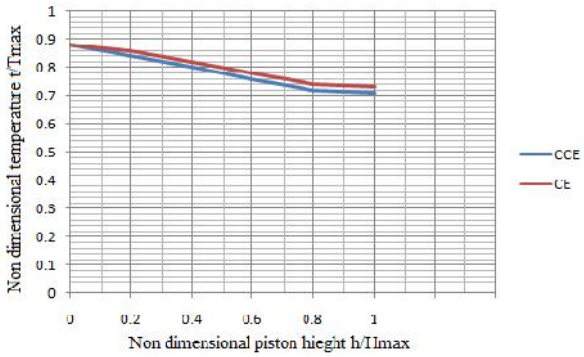
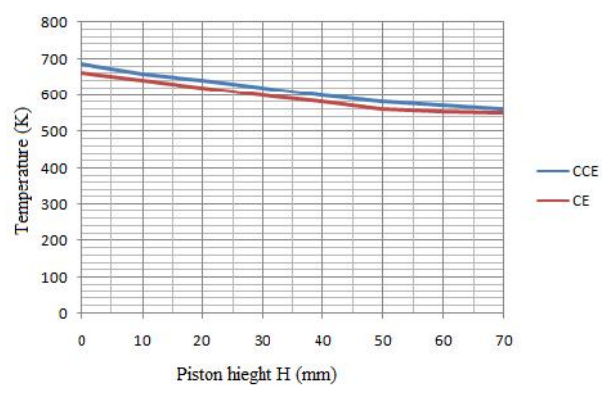


Figure 8: Variation of Temperature with Height Along the Axis of the Piston for CE and CCE



From the Figure 8 as the piston height increases, temperature decreases as heat absorbed by surrounding materials.

From the Figure 7 as non-dimensional height increases, non-dimensional temperature decreases, because of which efficient combustion was provided with copper coating leading to generate maximum temperatures.

Table 3: Temperature of the Air Gap of the Conventional and Copper Coated Engines

Convectional Engine	Copper Coated Engine
193	226

Table 4: Comparison of Temperatures Between the Conventional and Copper Coated Engines at Various Positions

S. No.	Position at Which Temperature is Noted	Conventional Engine (K)	Copper Coated Engine
1.	Outer periphery of piston	433	452
2.	Inner periphery of piston	520	548
3.	Outer periphery of liner	396	407
4.	Inner periphery of liner	498	512

Table 4 (Cont.)

S. No.	Position at Which Temperature is Noted	Conventional Engine (K)	Copper Coated Engine
5.	Outer periphery of cylinder head	645	667
6.	Inner periphery of cylinder head	745	772

THERMAL STRESS (VONMISSES) DISTRIBUTION IN THE PISTON

Coated Piston Materials

The piston is coated with copper and zirconium; the details of material are as follows:

Conventional metals and lubricants fail to perform at elevated temperatures, the advanced ceramic materials such as nitrides and carbides of silicon (Si_2N_4 and Sic); aluminium, oxides of chromium, and iron (Cr_2O_3, Al_2O_3 and FeO_2); and partially stabilized oxide of zirconium (ZrO_2 or PSZ) provide an alternative low tensile strength, Low ductility. The zirconium and Copper Coating

Figure 9: Vonmisses Stress Before Optimization on the Piston Crown

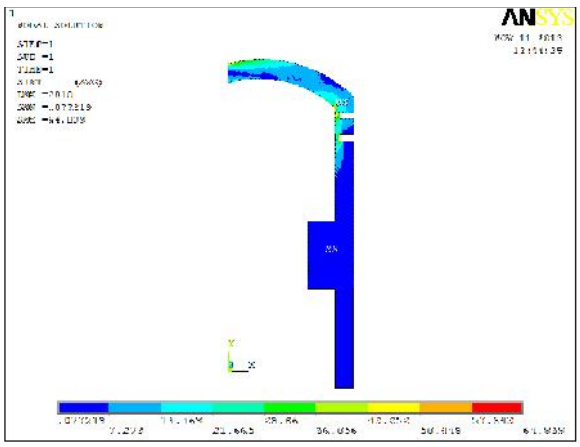


Figure 10: Vonmisses Stress Copper Coated on the Piston Crown

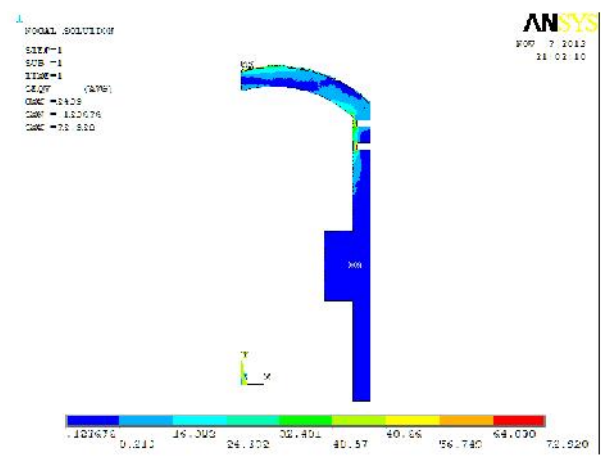
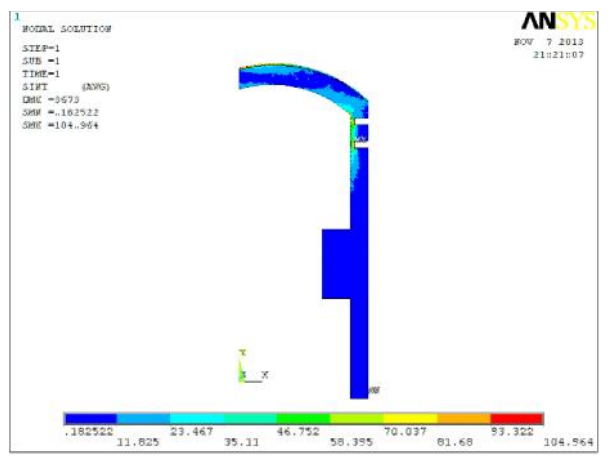


Figure 11: Vonmisses Stress Zirconium Coated on the Piston Crown



is applied on head of the optimized piston with 65 mm diameter, 0.003 mm and 0.003 thicknesses. The above coating process and Analysis is performed in ANSYS workbench. The properties of materials are as follows.

Table 5: The Vonmisses Stress on the Piston Crown Comparison, Copper Coated and Zirconium Coated

S. No.	Convectional Piston (MPa)	Copper-coated (MPa)	Zirconium-coated (MPa)
1.	64.839	72.92	104.96

- After doing the three different coupled (thermal and structural) analysis with three different materials, we found that the maximum stresses for those three materials.
- The Vonmisses stress initially optimized conventional piston is 64.839 Mpa after coating the Vonmisses Stress is obtained as 72.928 Mpa and 104.96. It is permissible up to 110 Mpa. So the piston with these considerations can withstand easily and is under linear control. Finally we concluded that the zirconium was the best material.

CONCLUSION

Finite element analysis for predicting the isotherms in the piston and liner for conventional engine and copper coated engine.

- ANSYS program in which finite element mesh generated employing quad node elements predicted isotherms well for copper coated piston, liner, copper coated cylinder head, conventional piston, liner, and conventional cylinder head for the copper coated and conventional engines.
- The peak surface temperature of copper coated engine was predicted be increased to 772 K from 745 K of the conventional engine amounting to an increase of 3.5%.
- The peak surface temperature of top edge of the copper coated piston of CCE was predicted to be increased to 645 K from 619 K of the piston of conventional engine, amounting to an increase of 4%.
- The peak surface temperature of surface of the liner of CCE was found to be increased to 687 K from 661 K of the liner

of the conventional engine, amounting to an increase of 3.8%.

- From the above discussions it is clear that the percentage increase in the temperature is high in the copper coated engine compared to conventional engine.

REFERENCES

1. Dyachenko N K, Kostin A K, Pugachev B P, Pusionv R V and Melnikov C V (1974), "Theory of Internal Combustion Engines", pp. 449-450, Mashinostroenie (Leningrad Division), Leningrad.
2. "Emission Control of Small Spark Ignited Off Road Engines and Equipment", January 2009.
3. Karthikeyan S, Arunachalam M, Srinivasan Rao P and Gopala Krishanan K V (1985), "Performance of an Alcohol, Diesel Oil Dual-Fuel Engine with Insulated Engine Parts", Proceedings of 9th National Conference of I.C. Engines and Combustion, pp. 19-22, Indian Institute of Petroleum, Dehradun.
4. Mallikarjuna J M (2006), "Optimization of Inlet Valve Closure Timing and Clearance Volume of a SI Engine for Better Performance at Part Loads—A Numerical and Experimental Research", *Indian Journal of Engineering & Material Sciences*, Vol. 13, August, pp. 307-321.
5. Ponnusamy P, Subramanian R and Nedunchezhian N (2011), "Experimental Investigation on Performance, Emission and Combustion Analysis of a Four Stroke SI Engine with Various Catalytic Coatings", *European Journal of Scientific Research*, Vol. 63, No. 2, pp. 182-191, ISSN 1450-216X.
6. Thet T Mon, Rizalman Mamat and Nazri Kamsah I A E N G (2011), "Thermal Analysis of SI Engine Using Simplified Finite Element Model", Proceedings of the World Congress on Engineering, Vol. 3, July 6-8, London, UK.
7. Wallace F J, Kao T K, Tarabad M, Alexander W D and Cole A (1984), "Thermally Insulated Diesel Engines", Proceedings I. Mech. E., Vol. 198A, No. 5.