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 conventional engine and copper coated conventional 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
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.

\[ T_g(\theta) \]
\[ H_g(\theta) \]

The boundary condition for the present problem have been taken to be as given below:

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

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 \( T_g(\theta) \) and convective heat transfer coefficient \( H_g(\theta) \) 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, \( H_g = 250 \text{ W/m}^2 - K, T_g = 920 \degree C \)
2. Bottom side of the piston, \( H_{01} = 450 \text{ W/m}^2 - K, T_{01} = 100 \degree C \)
3. Air jacket side of liner, \( H_{02} = 125 \text{ W/m}^2 - K, T_{02} = 30 \degree C \)

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

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

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.

**Table 2: Design Specification of Piston**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Dimensions</th>
<th>Size in (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Length of the Piston (L)</td>
<td>72.14</td>
</tr>
<tr>
<td>2.</td>
<td>Cylinder bore/outside diameter of piston (D)</td>
<td>65</td>
</tr>
<tr>
<td>3.</td>
<td>Thickness of piston head (t_H)</td>
<td>6.45</td>
</tr>
<tr>
<td>4.</td>
<td>Radial thickness of the ring (t_r)</td>
<td>2.8</td>
</tr>
<tr>
<td>5.</td>
<td>Axial thickness of the ring (t_a)</td>
<td>3</td>
</tr>
<tr>
<td>6.</td>
<td>Width of the top land (b_1)</td>
<td>9</td>
</tr>
<tr>
<td>7.</td>
<td>Width of other ring lands (b_2)</td>
<td>2</td>
</tr>
</tbody>
</table>

**ANALYSIS OF COPPER COATED PISTON**

![Figure 2: Model of the Piston](image1)

![Figure 3: Areas of 4 Stroke Copper Coated SI Engine](image2)
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.

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.

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.
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

<table>
<thead>
<tr>
<th>Conventional Engine</th>
<th>Copper Coated Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>193</td>
<td>226</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Position at Which Temperature is Noted</th>
<th>Conventional Engine (K)</th>
<th>Copper Coated Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Outer periphery of piston</td>
<td>433</td>
<td>452</td>
</tr>
<tr>
<td>2.</td>
<td>Inner periphery of piston</td>
<td>520</td>
<td>548</td>
</tr>
<tr>
<td>3.</td>
<td>Outer periphery of liner</td>
<td>396</td>
<td>407</td>
</tr>
<tr>
<td>4.</td>
<td>Inner periphery of liner</td>
<td>498</td>
<td>512</td>
</tr>
</tbody>
</table>

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$_2$N$_4$ and Sic); aluminium, oxides of chromium, and iron (Cr$_2$O$_3$, Al$_2$O$_3$ 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
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>
<thead>
<tr>
<th>S. No.</th>
<th>Conventional Piston (MPa)</th>
<th>Copper-coated (MPa)</th>
<th>Zirconium-coated (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>64.839</td>
<td>72.92</td>
<td>104.96</td>
</tr>
</tbody>
</table>

• 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 Vonmises stress initially optimized conventional piston is 64.839 Mpa after coating the Vonmises 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


