Temperature Distribution across the Piston, Liner and Cylinder Head of Conventional and Catalytic Coated 2-Stroke SI Engine Using Finite Element Analysis by ANSYS

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ABSTRACT

The temperature distribution across the piston, liner and cylinder head of conventional Engine (CE) and Copper Coated Engine (CCE) was determined to study the performance of lubricating oil with the help of finite element method (FEM) using ANSYS software package. For any engine, the use of lubricating oil is a must and it should not be deteriorated, which causes mechanical damage to the engine and decrease in the efficiency. Hence, if the engine is to be tried with any alternative fuel and the engine is to be modified in design, the performance of lubricating oil is to be checked. As it is very difficult to do this experiment practically, FEM helps in this situation. Also, this method (finite element analysis) is used to calculate the wall temperature which is used in combustion calculations. The temperature at the component surfaces was predicted to be increased with CCE over CE. The temperature of lubricating oil was found to be increasing with CCE over CE but it was within the safe temperature limit to avoid deterioration.

Keywords: Finite element analysis, ANSYS, Temperature distribution, copper coating, lubricating oil

1. INTRODUCTION

The paper is divided into i) Introduction, ii) Materials and Methods, iii) Results and Discussions, iv) Conclusions, Research Findings, Future scope of work followed by References.

Knowledge on temperature distribution in the piston, liner and cylinder head of copper coated engines is highly essential for a designer for arriving at a reasonable configuration of the piston, liner and cylinder head without sacrificing the strength. Many researchers [1, 2] adopted different theoretical techniques for predicting the temperatures not only in the conventional piston but also in CCE piston employing copper coating. However, these researchers concentrated their efforts for predicting the heat flow either for the piston or the liner but not the assembly of the piston, liner and cylinder head. That too in all these situations, the major bottleneck was on the choice of boundary conditions close to the practical situations, as no reliable data was available for complex situation of piston and liner of the engine. With advanced computer codes like ANSYS and NISA, attempts on the temperature predictions using finite element analysis increased in the recent past. The purpose of predicting temperature distribution in the piston, liner and cylinder head by FEM technique is to evaluate the performance of lubricating oil in between piston and the liner. These studies are conducted on CE and also on CCE in order to emphasize the advantage of CCE over CE in producing efficient combustion.

2. METHODOLOGY

This section deals with fabrication of CCE (top surface of piston crown and the inner surface of cylinder head being coated with a high thermal conductive catalytic material like copper by flame spray technique).

Plate 1 shows the photographic view of copper coated piston, liner and copper coated cylinder head of CCE.

Plate 1 Photographic view of copper coated piston, liner and copper coated cylinder head

Figure 1 shows the configuration of the assembly of the piston, liner and cylinder head showing different materials in various zones for CE and CCE respectively.

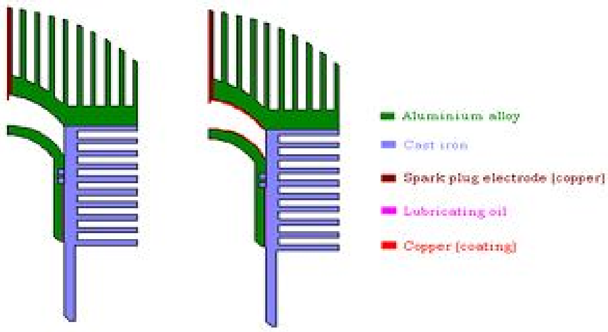

Figure 1 Configuration of the assembly of piston, liner and cylinder head for CE and CCE

This section deals with the geometric modeling and finite element modeling. In geometric modeling, the outer boundary of one half of the piston, liner and cylinder head are created and necessary patching is generated. Solid quadrant 4-node 55 (axi-symmetric) 2-dimensional (acts as plane 55) elements are chosen [3], as their performance is the best and are very cost effective for analysis.

Figure 2 shows the geometric model created for the thermal analysis for CCE (the assembly of copper coated piston, liner and copper coated cylinder head).

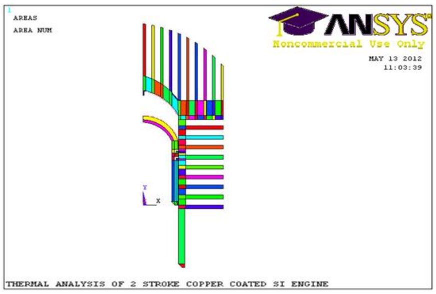

Figure 2 Geometric model created for the thermal analysis for CCE

In the finite element modeling, each patch is further divided into smaller elements in critical areas like crown and cylinder head, where temperature gradients are high while coarser grid is adopted in the regions of the piston and the liner where variation of temperature is not much. Mesh is refined based on convergence requirements and the final mesh is shown in **Figure 3** for CCE.

Figure 3 Mesh employed in the thermal analysis for CCE

The methodology was obtained from [4], [5, [6] for determining temperature distribution for piston, liner and cylinder head respectively for SI engine. However, the actual boundary conditions for the present problem were obtained with the values of experimentation [1] and were given below:

1. Top surface of piston, $h_c =$ 235 W/ m^2 K, T = 920 ^{0}C
2. Bottom side of the piston, $h_c =$ 450 W/ m^2 K, T = 100 ^{0}C
3. Air jacket side of liner, $h_c =$ 200 W/ m^2 K, T = 60 ^{0}C
4. Fins, $h_c =$ 120 W/ m^2 K, T = 30 ^{0}C

In the ANSYS program, the characteristic matrices are evaluated from which the nodal temperatures are estimated. The data has been converted in the post processing into the plotter mode and the plots of isotherms diagrams are obtained for each configuration of the piston, liner and cylinder head.

3. RESULTS AND DISCUSSION

This section deals with i). temperature distribution predicted by finite element analysis in the piston, liner and cylinder head of CE and CCE, and , ii) temperature distribution predicted by finite element analysis in the lubricating oil between the outer periphery of piston and inner wall of the liner of CE and CCE.

3.4 Temperature distribution

Figure 4 shows the distribution of isotherms from finite element analysis in CE, while **Figure 5** represents the distribution of isotherms in CCE from finite element analysis.

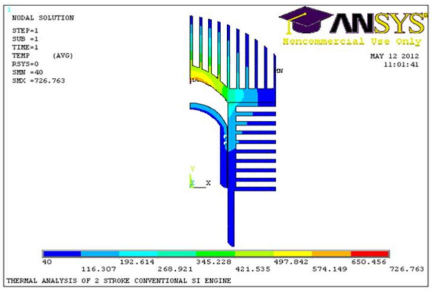

Figure 4 Isotherms of thermal analysis for CE

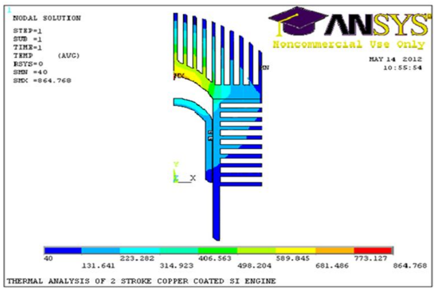

Figure 5 Isotherms of thermal analysis for CCE

The predicted values of temperatures at various locations of the components were obtained from ANSYS software for both CE and CCE at various points (locations) of piston, lubricating oil, liner and cylinder head are presented in the **Table 1**.

Table 1: Temperatures predicted by FEM at various locations of CE and CCE

Component →	**Piston**			**Liner**		**Cylinder head**		
Location → / **Engine version ↓**	**Top surface (Crown)**	**Bottom surface**	**Outer periphery**	**Inner wall**	**Outer radius**	**Bottom (inner surface)**	**Top surface**	**Outer radius**
CE	183	105	164	228	123	634	429	311
CCE	236	206	217	244	141	703	506	395

From the **Table 1** it was observed that, the surface temperature of each component of CCE is greater than that of CE. This was due to copper coating done on the piston crown and on the inner surface of cylinder head. Because copper has high thermal conductivity, it increases the temperature, as it absorbs heat from the vicinity of the component. Since the thermal conductivity of copper is very high, the thermal resistance offered by copper is less and hence the temperature drop is also less along the axis of each component. The temperature decreases at the outer periphery of each component, as it is subjected to the combined cooling effect of the lubricating oil and fins.

3.5 Validation of computer predictions of FEA results

For any engine, the use of lubricating oil is a must and it should not be deteriorated, which causes mechanical damage to the engine and decrease in the efficiency. Hence, if the engine is to be tried with any alternative fuel and the engine is to be modified in design, the performance of lubricating oil is to be checked. As it is very difficult to do this experiment practically, FEM helps in this situation. FEM analysis is important in evaluating the lubricating oil deterioration, as the liner is subjected to high temperatures and the piston crown and inside of the cylinder head are coated with copper.

Figure 6 shows the isotherms in the lubricating oil between the liner and piston of CE, while **Figure 7** shows those of CCE from the Finite Element Analysis.

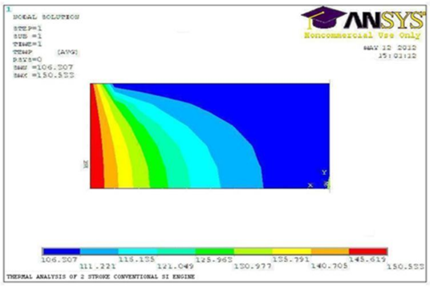

Figure 6 Isotherms from FEA in the lubricating oil between piston and liner inner surface for CE

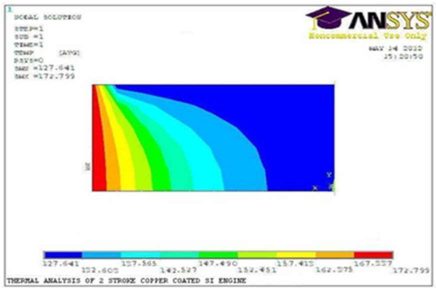

Figure 7 Isotherms from FEA in the lubricating oil between piston and liner inner surface for CCE

From the **Figure 6** it was observed that, the lubricating oil temperature varied between 106^0C to 150^0C for CE, while it varied between 127^0C to 172^0C for CCE as seen in **Figure7**. This shows that, the lubricating oil temperatures are within the limits, as the safe temperature limit to avoid deterioration of lubricating oil [2], [7] was 180^0C. Hence, it was mentioned that, catalytic coated engine will not result in the deterioration of lubricating oil.

4. CONCLUSIONS

1. The temperature at the top surface of the piston crown was increased from 183^0C with the base engine to 236^0C with the catalytic coated engine.
2. At the outer periphery of the piston, the temperature was increased from 164^0C with the base engine to 217^0C with the catalytically activated engine.
3. The temperature at the inner wall of the liner in contact with lubricating oil was increased from 228^0C with the base engine to 244^0C with the copper coated engine.
4. The lubricating oil temperature varied between 106^0C to 150^0C for the base engine, while it varied between 127^0C to 172^0C for the catalytic coated engine and was within the limits. Hence copper coating will not deteriorate the lubricating oil.
5. At the bottom of the cylinder head the temperature was increased from 634^0C in the base engine to 703^0C in the catalytic coated engine.

4.1 Research findings and future scope of work

Finite element analysis can be extended to study the heat flow rate across the piston, liner and cylinder head of CE and CCE, thermal stresses and fatigue strength at different operating conditions.

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