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Research Article

Comparative Temperature Predictions of Copper Coated SI Engine Piston and Cylinder Head over uncoated Components

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Abstract

To avoid the deterioration of lubricating oil placed in between piston and liner of SI engine, the temperature distribution and heat flow across the engine components must be determined. As the experimentation is difficult, the temperature and heat flow predictions was done by finite element analysis (FEA). To promote combustion and improve the performance of SI engine, copper was coated on the piston crown and on the inner surface of the cylinder head. To emphasize the advantage of copper coating over uncoated components, finite element thermal analysis was done. The temperatures and heat flow rate across the component surfaces was found to be increasing along both axis and radius of piston and cylinder head of copper coated engine (CCE) over conventional (uncoated) engine(CE). The temperature of lubricating oil was also found to be increasing with CCE over CE but was found to be within the safe temperature limits to avoid deterioration.

Keywords: *Lubricating Oil, Temperature Distribution, Heat Flow Rate, FEA, Copper Coating, Conventional Engine*

1. Introduction

Many researchers adopted different theoretical techniques for predicting the temperatures and heat flux rate either in the conventional piston (Rammohan, 1995), (Li, 1982), (Esfahanian, *et al*, 2006) or on the cylinder head (Elisa, *et al*, 2011), (Elisa, *et al*, 2012) or both on piston and cylinder head (Mahdi Hamzehei. and Manochehr Rashidi, 2006). However, these researchers concentrated their efforts on the thermal analysis of conventional engine only, but not on the assembly of copper coated piston, liner and copper coated cylinder head (copper coated engine, CCE). The varying properties of copper coated crown, liner and copper coated cylinder head with differing boundary conditions call for accurate analysis for predicting temperature distribution and heat flow rate in the piston, liner and cylinder head. Very little literature is available for thermal analysis of different SI engine version (Ali Jafari and Siamak Kazemzadeh Hannani, 2006) and CI engine version (Muralikrishna, 2004), (Krishnamurthy, 2004). With advanced computer code like ANSYS, an attempt was made to predict the temperature distribution and heat flow rate using FEA. The prediction of temperatures and heat flow in these components is important which determines the efficient combustion by means of copper coating on the top surface of piston crown and over the inside surface of cylinder head. The values of temperature and heat flux along the axis and radius of each component was predicted to be higher for CCE over those of CE.

The present paper evaluated the temperature and the % increase in the heat flow rate along the axis and radius of each component of a copper coated combustion chamber (piston crown and inner surface of cylinder head being coated with copper) and compared with the uncoated base engine components.

2. Materials and methods

In the catalytic coated engine (CCE), initially a bond coating of nickel-cobalt-chromium was sprayed for a thickness of 0.1 mm on the piston crown and inner surface of cylinder head, over which, an alloy of copper (89.5%), aluminium (9.5%) and iron (1%) was coated for another 0.3 mm. Wear and tear was not reported from the engine life test carried out for 50 hours, (Dandapani, 1991).

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

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

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Thermal analysis is done in two broad stages as, i) Geometric modeling, and, ii) 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 (Georges Cailletaud, *website*).

Figure 1 shows the geometry created for the thermal analysis for CCE.

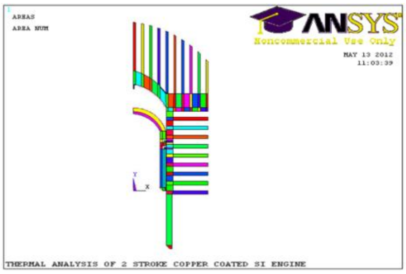

Fig. 1 Geometric model created for the thermal analysis for CCE

In the FEM, 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 piston and liner regions where variation of temperature is not much. Mesh is refined based on convergence requirements and the final mesh is shown in **Figure 2**, for CCE.

Fig. 2 Mesh employed in the thermal analysis for CCE

The methodology was obtained from (Esfahanian *et al*, 2006), (Elisa, *et al*, 2011), (Elisa, *et al*, 2012) 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 (Muralikrishna, 2004), (Krishnamurthy, 2004) 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 = 235 W/ m^2 K, T = 920 ^{0}C

3. Results and discussion

Figures 4(a) and **4(b)** shows the distribution of temperature and heat flux regions respectively, in the piston, liner and cylinder head from FEA in CE.

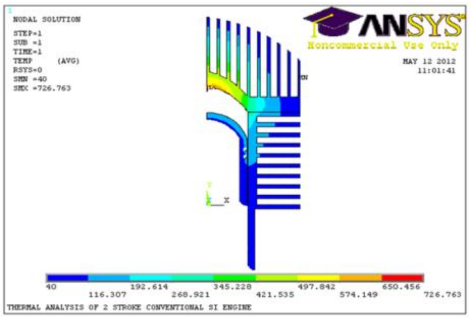

Fig. 4(a) Isotherms of thermal analysis for CE

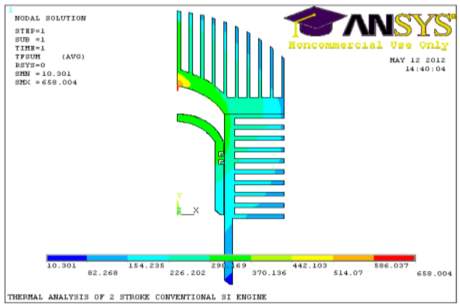

Fig. 4(b) Heat flow in the thermal analysis for CE

Figures 5(a) and **5(b)** shows the distribution of temperature and heat flux regions respectively, in the piston, liner and cylinder head from FEA in CCE.

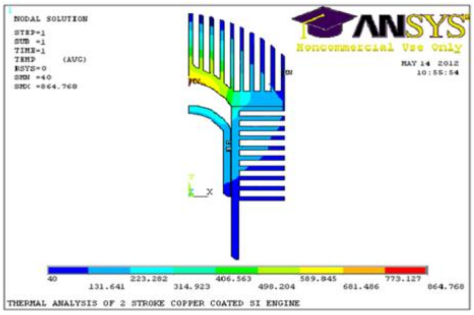

Fig. 5(a) Isotherms of thermal analysis for CE

Fig. 5(b) Heat flow in the thermal analysis for CCE

Figures 6(a), 6(b), 6(c) and 6(d) shows the comparative diagrams of variation of temperature and % increase in heat flux along the depth of piston and height of cylinder head of CC and CCE respectively.

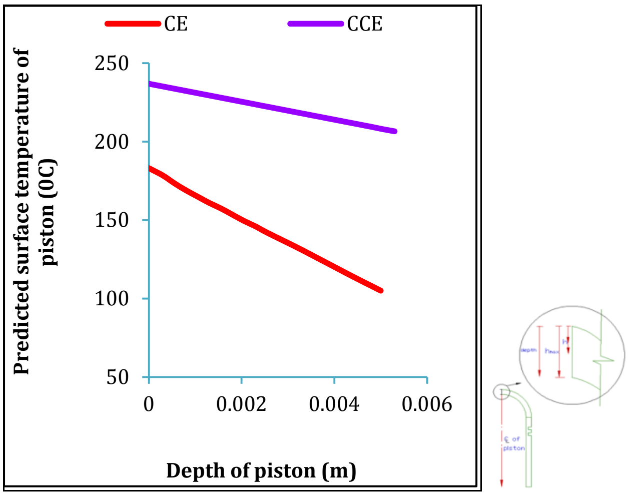

Fig. 6(a) Variation of temperature along piston depth

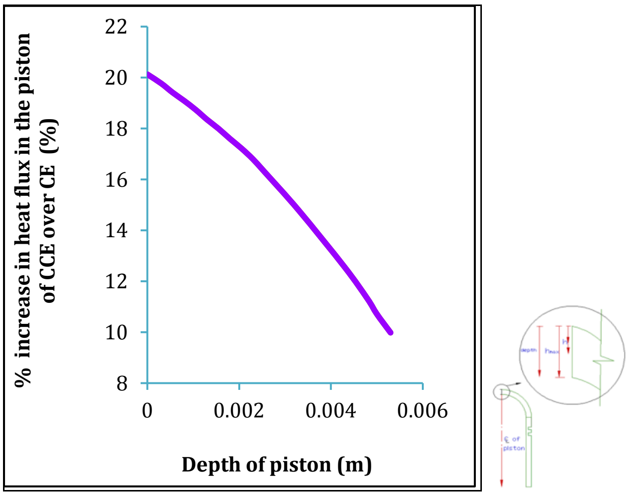

Fig. 6(b) Variation of % increase in heat flux along piston depth

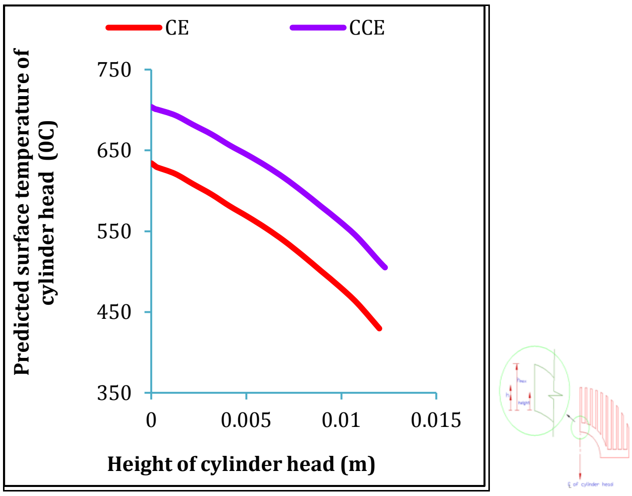

Fig. 6(c) Variation of temperature along the height of cylinder head

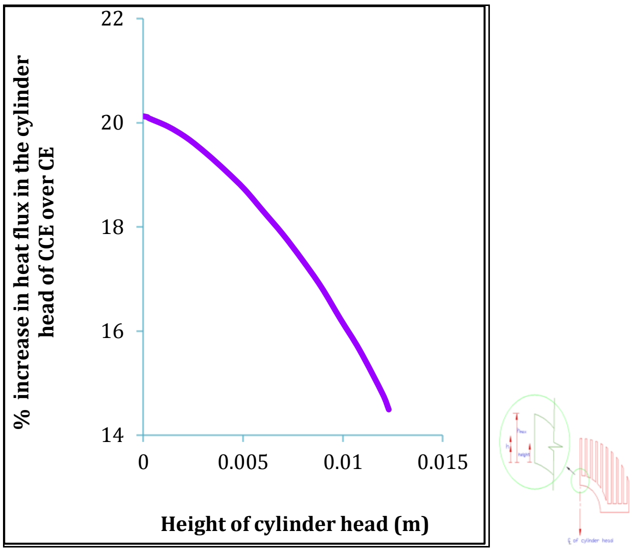

Fig. 6(d) Variation of % increase in heat flux along the height of cylinder head

As it is observed from the **Figures 6(a), 6(b), 6(c)** and **6(d)**, the surface temperature of the piston of CCE is greater than that of CE along the depth of the piston and height of cylinder head. This is due to copper coating done on the piston crown and on the inner surface of cylinder head. As copper is a good conductor of heat, it increases the temperature, as it absorbs heat from the vicinity of the piston and cylinder head and hence heat flux also increases. However, at the top of the cylinder head, the percentage (%) increase in heat flux decreases due to the resistance offered by the material against heat flow.

Figures 7(a), 7(b), 7(c) and 7(d) shows the comparative diagrams of variation o temperature and % increase in heat flux along the radius of piston and cylinder head respectively.

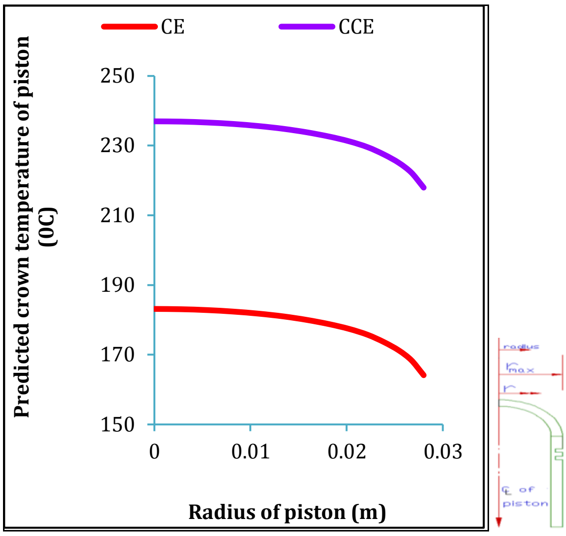

Fig. 7(a) Variation of temperature along piston radius

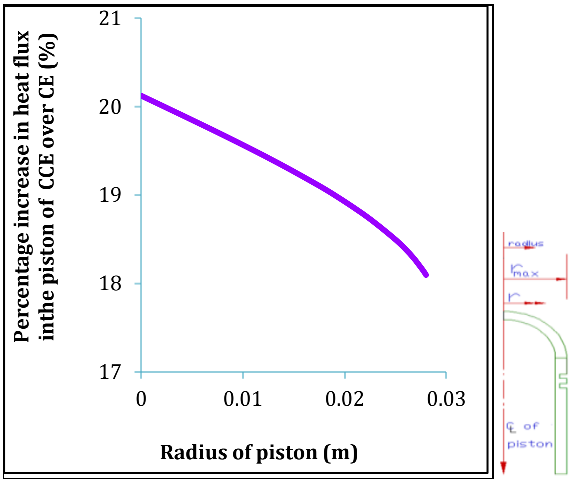

Fig. 7(b) Variation of % increase in heat flux along piston radius

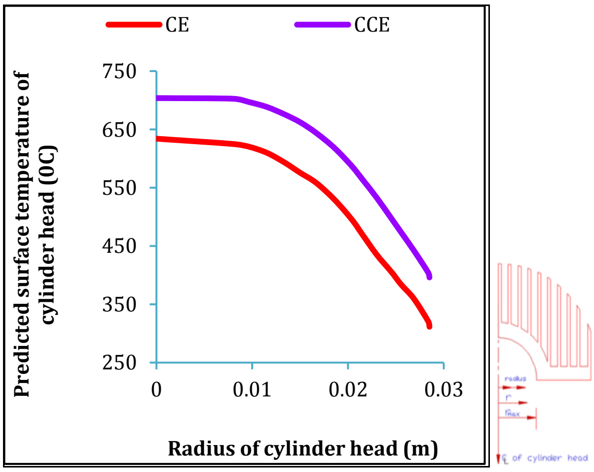

Fig. 7(c) Variation of temperature along the radius of cylinder head

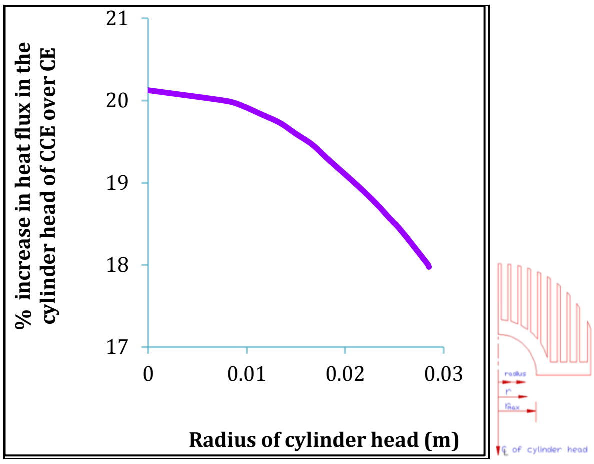

Fig. 7(d) Variation of % increase in heat flux along the radius of cylinder head

As it is noticed from the **Figures 7(a), 7(b), 7(c)** and **7(d)**, at the outer radius of the piston, the temperature and heat flux are marginally lower, as the outer periphery of the piston is subjected to cooling by means of lubricating oil and fins. High temperatures are encountered in the cylinder head of CCE in comparison with CE, due to the copper coating done at the inner surface of the cylinder head. Since inner surface of the cylinder head (bottom of cylinder head) is coated with copper, uniform heat flux is obtained through the radius of the cylinder head and not much variation in the heat flux is observed along the radius of the cylinder head, as it has got higher thermal conductivity and lower thermal resistance.

Conclusions

1) The surface temperature and the heat flux along the depth and radius of piston are increased by copper coating on the piston crown in comparison with the uncoated piston in conventional engine.
2) Compared to the uncoated cylinder head in conventional engine, copper coating on its inner surface resulted in the increase of the temperature and heat flow along its height and radius.
3) The lubricating oil temperature varied between 106^{0}C to 150^{0}C for the conventional engine, while it varied between 127^{0}C to 172^{0}C for the copper coated engine and was within the limits (Ali Jafari and Siamak Kazemzadeh Hannani, 2006), (Heywood, 1988).

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