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Comparative FE Thermal Analysis of Copper Coated 2-Stroke SI Engine Components over Conventional Engine

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Abstract — In SI engines, the engine performance can be improved by changing the composition of fuel (alcohol-gasoline blends) and by coating the engine components (Piston, Liner and Cylinder Head) with high thermal conductive material like copper. Copper coated engine (CCE) consists of copper coated piston, liner and copper coated cylinder head. The lubricating oil used in the engine should not be deteriorated, as the deterioration causes mechanical damage to the engine and decreases the efficiency. Hence, in a modified engine (CCE) with alcohol-gasoline blends, the performance of lubricating oil is to be checked. Across the components of CCE, the temperature distribution and heat flow rate along the axis (depth) and along the radius can be determined with the help of Finite element analysis (FEA) using ANSYS software package. FEA estimated an increase in the temperature and heat flow rate along the axis (depth) and along the outer radius of the catalytic coated piston, liner and cylinder head over conventional engine (CE) components.

Keywords — Alcohol-gasoline blends, ANSYS, Copper coating, FEA, Heat flow rate, Lubricating oil, Temperature distribution

I. INTRODUCTION

In order to understand the phenomena of heat flow through the piston, liner and cylinder head, the temperature distribution within these components will come handy for the designers. The transient nature of heat flow involving more than single variable, complicated method of measuring temperature across these components and ambiguous boundary conditions pose serious problems for the analysis of heat flow through the piston, liner and cylinder head of CCE. Added to this, the composite structure of the copper coated piston, liner and copper coated cylinder head consisting of a separate material for the piston crown, liner and cylinder head will bring in variation of material properties within these components. The piston ring grooves, 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 across the piston, liner and cylinder head.

In such complex situations with complex shape of the objects, the finite element analysis is best suited and hence the temperature distribution in copper coated piston, liner and cylinder head are studied by employing finite element based software using ANSYS programme.

The major difficulty faced by the users of the finite element analysis will be identifying the proper boundary conditions and choosing the appropriate type of mesh so that the results generated are not too far from the truth (experimental results). It is also well known that all computer predictions are to be validated on the basis of either experimental data or theoretical methods.

II. EXPERIMENTAL PROGRAMME

In the catalytically activated engine, by flame spraying technique, a high thermal conductive catalytic material like copper was coated on the cylinder head inside surface and top surface of piston crown. For 100µ thickness, nickel-cobalt-chromium bond coating was sprayed. On this coating, for another 300µ thickness, an alloy of copper (89.5%), aluminium (9.5%) and iron (1%) was coated with a METCO (Trade name of the company) flame spray gun. The bond strength of the coating was so high that it does not wear off even after operating it for 50 hrs continuously [1], [2], [3], [4].

Fig. 1 shows the Photographic view of copper coated piston, liner and copper coated cylinder head.

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

Fig. 2 shows the experimental set up for measuring the surface temperature of liner and cylinder head, while Fig. 3 shows the photographic view of the same.

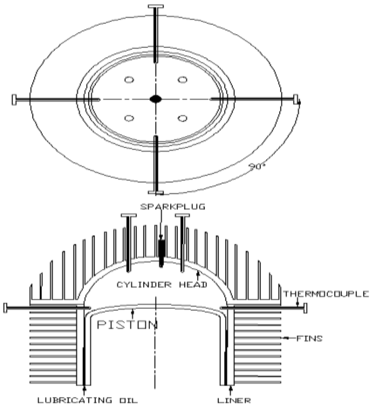

Fig. 2 Schematic diagram of the setup to measure the surface temperature of liner and cylinder head

Fig. 3 Photographic view of the set-up to measure the surface temperature of liner and cylinder head

Four holes of suitable diameter are drilled on the top portion of the liner and cylinder head and the thermocouples are inserted through these holes and are spot welded. These thermocouples are connected to temperature sensor.

Thermal analysis is done employing ANSYS software package to predict the temperature distribution and heat flux rate for different configurations of the piston, liner and cylinder head, in two broad stages as given below:

i. Geometric modeling

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-Fig. symmetric) 2-dimensional (acts as plane 55) elements [5] numbering up to 7456 consisting of 8276 nodes were used for accurate prediction of temperatures for piston, liner and cylinder head configurations.

Fig. 4 and Fig. 5 show the Geometric Model for the thermal analysis of the assembly of CE and CCE piston, liner and cylinder head respectively.

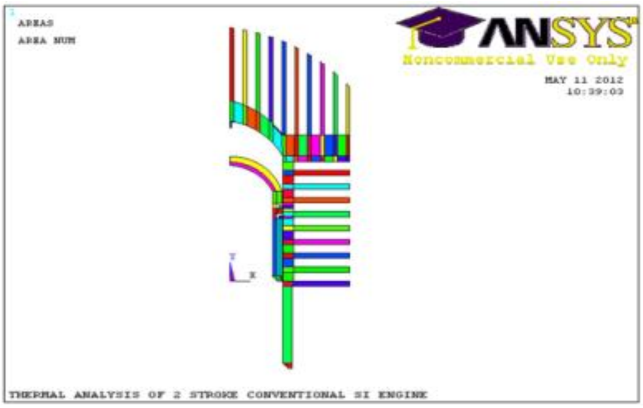

Fig. 4 Geometric model for the thermal analysis of the assembly of CE piston, liner and cylinder head

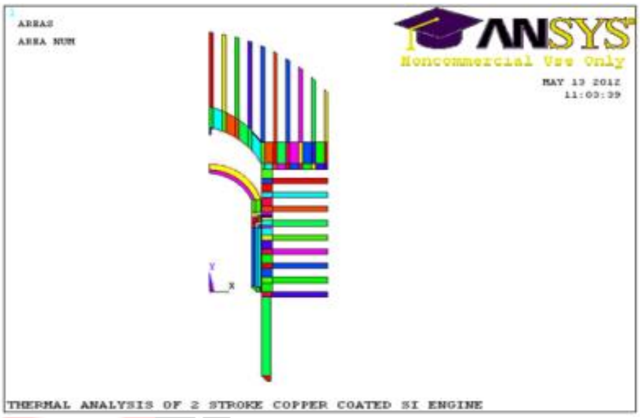

Fig. 5 Geometric model for the thermal analysis for the assembly of copper coated piston, liner and copper coated cylinder head

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 Fig. 6 for CE and Fig. 7 for CCE respectively.

Fig. 6 Mesh employed in the thermal analysis for the assembly of piston, liner and cylinder head of CE

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Fig. 7 Mesh employed in the thermal analysis for the assembly of copper coated piston, liner and copper coated cylinder head

The methodology was obtained from the References [6], [7], [8] for determining isotherms and heat flow 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 [9] and were given below:

1. Top surface of the 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

III. EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 8 shows the distribution of isotherms from finite element analysis in CE, while Fig. 9 represents the distribution of isotherms in CCE from finite element analysis.

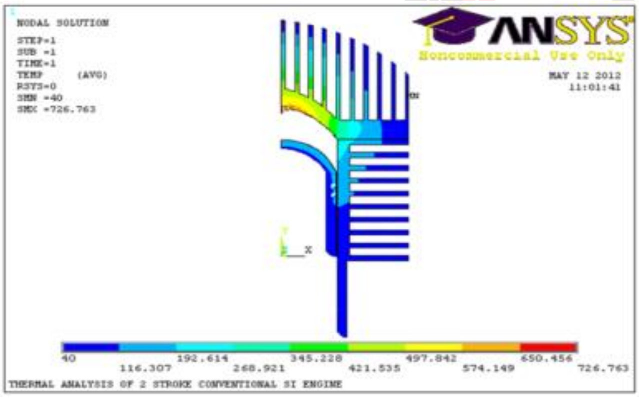

Fig. 8 Isotherms of thermal analysis for the assembly of piston, liner and cylinder head of CE

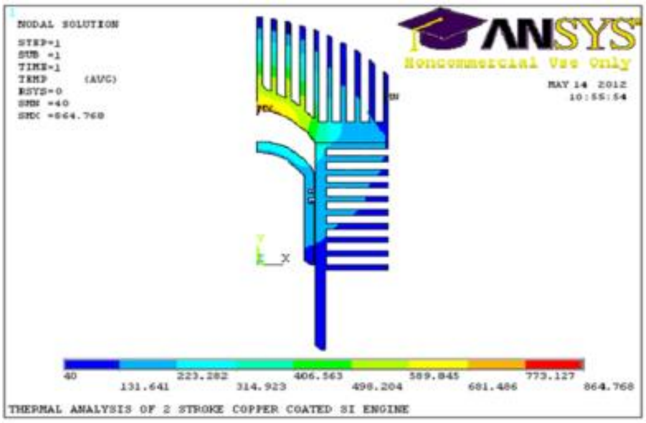

Fig. 9 Isotherms of thermal analysis for the assembly of piston, liner and cylinder head of CCE

Fig. 10 shows different heat flux regions in the piston, liner and cylinder head of CE, while Fig. 11 shows different heat flux regions in the piston, liner and cylinder head of CCE.

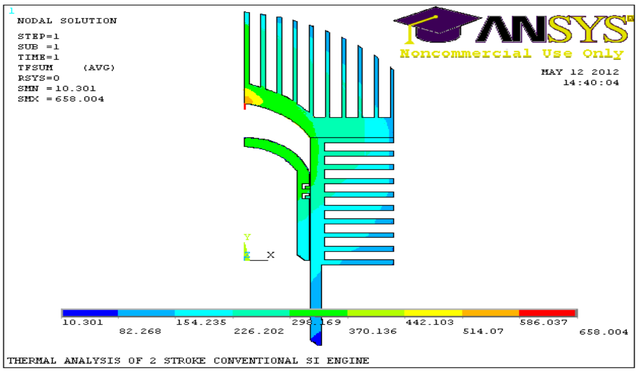

Fig. 10 Heat flux in the assembly of piston, liner and cylinder head of CE

Fig. 11 Heat flux in the assembly of piston, liner and cylinder head of CCE

Table I shows the surface temperature of piston along the depth (axis) and along the radius predicted by FEA.

TABLE. I
Surface temperature (^{0} C) of Piston predicted by FEA

Component	Location	Conventional Engine (CE)	Copper Coated Engine (CCE)	Deviation in CCE over CE
Piston	Along the axis (depth)			
	Top surface (Crown)	183	236	+53
	Bottom surface	105	206	+101
	Along the radius			
	Outer periphery	164	217	+53

From the Table I, it was noted that, the surface temperature of the piston of CCE is greater than that of CE along the depth of the piston. As the radius of piston increases, crown temperature of the piston decreases marginally for both CE and CCE. This was due to copper coating done on the piston crown. Because copper has high thermal conductivity, it increases the temperature, as it absorbs heat from the vicinity of the piston. The temperature decreases at the outer periphery of the piston, as it is cooled by means of lubricating oil and also with the presence of fins. The temperature drop for the piston of CCE from the crown to the outer periphery was less as the piston is coated with copper, which has high thermal conductivity and hence thermal resistance was less.

Table II shows the surface temperature of liner along the depth (axis) and along the radius.

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TABLE. II
Surface temperature (^{0} C) of Liner

Component	Engine version	Measured experimentally	Predicted by FEA	Deviation
Liner	Along the axis (depth)			
	CE	---	61	+21
	CCE	---	82	
	Along the radius (Inner wall)			
	CE	215	228	+13
	CCE	230	244	+14
	Along the outer radius			
	CE	---	123	+18
	CCE	---	141	

From the Table. II, it was noticed that, the temperature experienced in the liner of CCE is higher than that of CE. This was due to the liner absorbs heat from the copper coated piston and copper coated cylinder head. The central portion of the liner is exposed to combustion and hence higher temperatures are experienced while the end portions are subjected to the cooling of fins and lubricating oil. Therefore, the temperatures are lower at the end portions of the liner.

Table III shows the surface temperature of cylinder head along the height (axis) and along the radius.

TABLE. III
Surface temperature (^{0} C) of cylinder head

Component	Engine version	Measured experimentally	Predicted by FEA	Deviation
Cylinder head	Along the axis (height) : Inner surface (bottom)			
	CE	602	634	+32
	CCE	668	703	+35
	Along the axis (height) : Top surface			
	CE	---	429	+77
	CCE	---	506	
	Along the outer radius			
	CE	---	311	+84
	CCE	---	395	

From the Table III, it was noticed that, as the height of the cylinder head increases, the surface temperature of the cylinder head decreases for both CE and CCE. This is due to the resistance offered by the material against the heat flow and hence temperature drops. However, the temperature of the cylinder head for CCE is greater than that of CE at different heights of cylinder head. CCE exhibits high temperatures, as the cylinder head is coated with copper. The spark plug is located at the base of the cylinder head and the temperatures encountered at the base were high for the cylinder head of conventional engine and copper coated engine. As the radius of the cylinder head increases, the surface temperature decreases for both CE and CCE. This is due to the copper coating done on the cylinder head with which temperature increases.

Table IV shows the percentage (%) increase in the heat flow rate (heat flux) along the axis and radius of Piston, Liner and Cylinder Head predicted by FEA.

TABLE. IV
Percentage (%) increase in the heat flow rate predicted by FEA

Component	Location	% increase in heat flux in CCE over CE
Piston	Top surface (Crown)	20.2%
	Bottom surface	10.1%
	Outer periphery	18.2%
Liner	Along the axis (depth)	7.8%
	Along the radius (Inner wall)	15.4%
	Along the outer radius	11.9%
Cylinder Head	Along the axis (height) : Inner surface (bottom)	20.2%
	Along the axis (height) : Top surface	14.6%
	Along the outer radius	18.1%

It was noticed from the Table. IV that, as the depth of the piston increases, heat flux decreases. This was due to the thermal resistance offered by the piston material against heat flow. As the radius of the piston increases, a marginal decrease in the heat flux was noticed, as the outer periphery of the piston is subjected to cooling by means of lubricating oil and fins. An increase in the depth of liner decreases percentage (%) increase of heat flux. As the radius of the liner increases, the % increase in heat flux decreases. At the inner radius, the liner is subjected to hot gases and products of combustion and at the outer radius, the liner is subjected to cooling by means of fins. As the height of the cylinder head increases, the % increase in the heat flux decreases in CCE over CE. Because the cylinder head has copper coating over the inside surface and that, copper being a good conductor of heat, absorbs heat from the surroundings. Hence heat flux increases in the cylinder head of CCE over CE at the bottom of cylinder head. With the increase in the radius of cylinder head, the percentage (%) increases in heat flux decreases marginally. Since inner surface of the cylinder head (bottom of cylinder head) is coated with copper, uniform heat flux is obtained throughout the radius of the cylinder head and not much variation in the heat flux was observed along its radius because of its higher thermal conductivity and lower thermal resistance.

Fig. 12 shows the isotherms in the lubricating oil between the liner and piston of CE, while Fig. 13 shows those of CCE from the Finite Element Analysis.

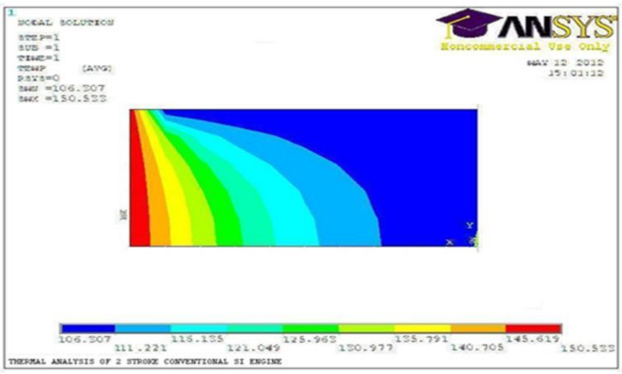

Fig. 12 Isotherms from the finite element analysis in the lubricating oil between piston and inner surface of liner for CE

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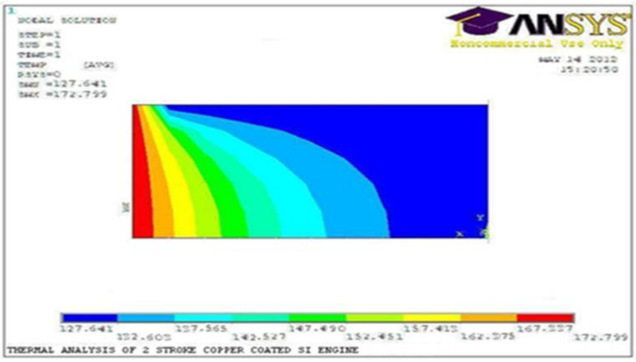

Fig. 13 Isotherms from the finite element analysis in the lubricating oil between piston and inner surface of liner for CCE

Table V shows the temperature of Lubricating oil predicted by FEA.

TABLE. V Temperature (^{0}C) of Lubricating oil predicted by FEA

Component	Location	Conventional Engine (CE)	Copper Coated Engine (CCE)
Lubricating oil	Between outer radius of piston and inner wall surface of liner	106 - 150	127 - 172

From the Fig. 12, it was observed that, the lubricating oil temperature varied between 106^{0}C to 150^{0}C for CE, while it varied between 127^{0}C to 172^{0}C for CCE as seen from Fig. 13. This was reflected in the Table V. It can be found that, the lubricating oil temperatures are within the limits, as the safe temperature limit (to avoid deterioration) of lubricating oil was 180^{0}C [10], [11]. Hence, it was mentioned that, catalytic coated engine will not result in the deterioration of lubricating oil.

IV. Conclusions

1. The temperature at the top surface of the piston crown was increased from 183^{0}C with the base engine to 236^{0}C with the catalytic coated engine.

2. At the outer periphery of the piston, the temperature was increased from 164^{0}C with the base engine to 217^{0}C with the catalytically activated engine.

3. The temperature at the inner wall of the liner in contact with lubricating oil was increased from 228^{0}C with the base engine to 244^{0}C with the copper coated engine.

4. At the bottom of the cylinder head the temperature was increased from 634^{0}C in the base engine to 703^{0}C in the catalytic coated engine.

5. Along the radius of piston, liner and cylinder head, the heat flux increased by 18-20%, 12-15% and 18-20% respectively for the catalytically activated engine over that of base engine.

6. In comparison with base engine, the heat flux was higher by 10-20%, 8-15% and 14.5-20% respectively along the axis of piston, liner and cylinder head of the copper coated engine.

8. The values of temperature predicted by FEM analysis at the inner surface of the liner of the base engine and catalytically activated engine showed an increase of 13^{0}C and 14^{0}C respectively over the experimental data.

9. FEM analysis predicted the values of temperature at the inner surface of cylinder head of the base engine and catalytic coated engine at 32^{0}C and 35^{0}C respectively higher than the values of experimentation.

7. The lubricating oil temperature varied between 106^{0}C to 150^{0}C for the base engine, while it varied between 127^{0}C to 172^{0}C for the catalytic coated engine and was within the limits [10-11], as the safe temperature limit (to avoid deterioration) of lubricating oil was 180^{0}C [10-11]. Hence, it was mentioned that, catalytic coated engine will not result in the deterioration of lubricating oil.

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References

[1] Dhanpani, "Theoretical and Experimental Investigation of Catalytically Activated Lean Burn Combustion", *Ph. D. Thesis*, IIT, Madras, 1991

[2] Nedunchezhian, N. and S. Dhandapani, "Experimental Investigation of Cyclic Variation of Combustion Parameters in a Catalytically Activated Two Stroke SI Engine Combustion Chamber", *SAE paper*, number-990014, 1999.

[3] N. Nedunchezhian and S. Dhanpani, "Experimental Investigation of Cyclic Variation of Combustion Parameters in a Catalytically Activated Two Stroke SI Engine Combustion Chamber", *Engineering Today*, ISSN: 0974-8377, Vol.2, pp. 11-18, 2000.

[4] P. Govindasamy and S. Dhanpani, Performance and Emissions Achievements by Magnetic Energizer with a Single Cylinder Two Stroke Catalytic Coated Spark Ignition Engine", *Journal of Scientific and Industrial Research*, Vol. 66, pp. 457-463, 2007.

[5] Georges Cailletaud, "Finite Lement: Matrix Formulation", *Ecole des Mines de Paris, Centre des Mat'eriaux*, UMR CNRS 7633.

[6] V. Esfahanian, A. Javaheri and M. Ghaffarpour, "Thermal Analysis of an SI Engine Piston using Different Combustion Boundary Condition

 DOI : 10.35291/2454-9150.2020.0478

Treatments", *Applied Thermal Engineering*, Vol. 26, pp. 277-287, 2006.

[7] Elisa Carvajal Trujillo., J. Francisco, Jiménez-Espadafor., José A. Becerra Villanueva. and Miguel Torres García., "Methodology for the Estimation of Cylinder Inner Surface Temperature in an Air-cooled Engine", *Applied Thermal Engineering*, Vol. 31, pp. 1474 – 1481, 2011.

[8] Elisa Carvajal Trujillo., J. Francisco, Jiménez-Espadafor., José A. Becerra Villanueva. and Miguel Torres García, "Methodology for the estimation of head inner surface temperature in an air-cooled engine", *Applied Thermal Engineering*, Volume-35, 202-211, 2012.

[9] M.V.S. Murali Krishna, "Performance Evaluation of Low Heat Rejection (LHR) Diesel Engine with Alternative Fuels", *Ph. D. Thesis*, JNT University, Hyderabad, 2004

[10] Ali Jafari. and Siamak Kazemzadeh Hannani., "Effect of Fuel and Engine Operational Characteristics on the Heat Loss from Combustion Chamber Surfaces of SI Engines", *International Communications in Heat and Mass Transfer*, Vol. 33, pp. 122-134, 2006.

[11] J.B. Heywood, "Internal Combustion Engine Fundamentals, Thermo-chemistry of fuel air mixtures, Properties of working fluids", *McGraw-Hill Book Company*, New York, 1988.

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