Analysis of Ceramic Material For Diesel Engine By Finite Element Method

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Abstract- *About a third of the thermal energy is converted in to usable work in the internal combustion engine. Since the temperature of the flue gases does not correspond to the ambient temperature, there is a loss of heating energy with hot gases. The ceramic material is used in research in diesel engines to reduce heat loss through thermal conduction in the engine piston. The thermal insulation layer on selected diesel engine pistons should consist of the alloy materials NiCrAl and MgZrO3 as well as CaZrO3 as the upper ceramic layer in different thicknesses. The results show that the temperature at the top of the coated piston increases and the temperature of the uncoated piston decreases due to the low thermal conductivity of the coating materials.*

Keywords- Thermal barrier coating, Ceramic materials, Thickness of coating, ANSYS 14, Temperature distribution, Heat flux

I. INTRODUCTION

The selected diesel engine piston has a thermal insulation coating on its top to reduce heat conduction through the piston asthe ceramic material has low thermal conductivity. The aim of this research work is to create a finite element model of a thermal barrier coating system by simulating a diesel engine pistonto model the surface temperature profile. This analysis is performed in the "Steady State Thermal" elements of the ANSYS 14 Workbench. A steady-state analysis of the model is performed; no transient protection. However, the analysis took into account the temperature dependent creep properties of the following piston diamentions of the selected diesel engine:-

Diameter of piston D = 81mm
Height of piston H = 75 mm
Wall thickness of leading part = 3 mm Thickness of sealing part = 3 mm Distance of the first channel = 7 mm Hole diameter of piston pin = 23 mm
Diameter of thickening of piston pin = 38 mm Radial thickness of piston ring = 5 mm Thickness of crown = 7 mm

top coat and bond coat, the temperature dependent coefficient of thermal expansion of top coat and bond coat. With the help of most relevant papers on the subject will present a literature review of covering similar temperature profile and total heat flux. Also using of reviews theory of basic equations and boundary conditions utilized in solving problem, the material properties dependent on temperature and parameter definitions, the methodology, the set up using ANSYS and the results of theproject.

Objectives –

1. To study the Thermal Behavior of thermal coating ceramic material with different thickness coating.
2. Finite Element Analysis of coated piston model, used in C.I.Engine

Methodology - Model Description and Boundary Conditions

Piston is one of the main parts in the engine which is transfer of force from expanding gas in the cylinder to the crankshaft with help of connecting rod. Since the piston is the main reciprocating part of an engine, pistons are commonly made of a cast aluminum alloy light in weight. During heat is supplied the aluminum expands, so proper clearance must be provided to maintain free piston movement in the cylinder bore. Causes of insufficient clearance canpiston to seize in the cylinder and compression would loss of compression due to excessive clearance and increase in piston noise. Piston has the different features include the piston head, piston pin, piston pin bore, skirt, ring lands, ring grooves and piston rings.

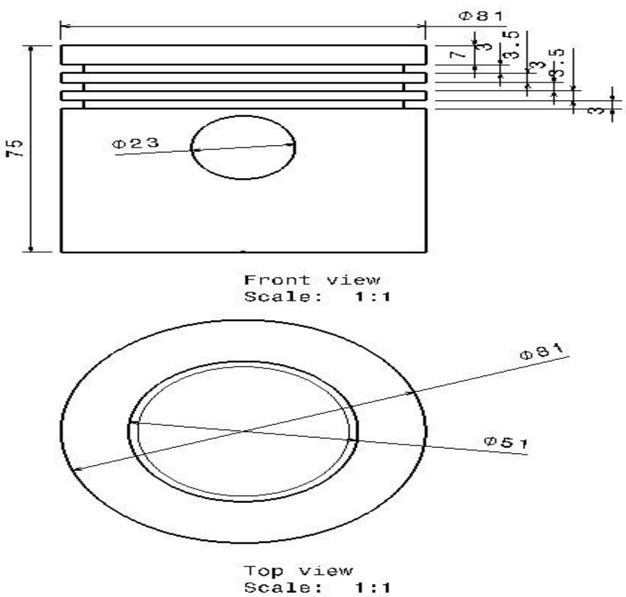

Fig.4.1 Piston

In this project we have taken structural steel material is used for piston and the piston head is the top surface (closest to the cylinder head) of the piston which has a thermal barrier coating (0.15 mm bond coat and 0.35 mm of top coating) is subjected to tremendous forces and heat during normal engine operation and also other model has thermal barrier coating (0.25 mm bond coat and 0.50 of top coating).[30]

Material	Thermal conductivity [W/m0C]	Thermal expansion n 10-6[1/0C]	Density [Kg/m3]	Specific heat [J/Kg0C]	Poisson's ratio	Young's modulus [GPa]
Structural Steel	79	12.2	7870	500	0.3	200
MgZrO3	0.8	8	5600	650	0.2	46
NiCrAl	16.1	12	7870	764	0.27	90
CaZrO3	0.6	3.2	5110		0.25	100

Table 4.1 Properties of piston materials

On the basis of above specifications, first making the geometric model of diesel piston without top coating and with coating is developed by help of 2D drawing and generated in 3D model in CATIA V5. The non-coated piston as one part and for coated piston three parts are designed first main piston, second bond coat and third is top coating shown in fig. 4.2(a) and fig 4.2(b) respectively. The thickness of bond coat is 0.15 mm and 0.35 mm; similarly thickness of bond coat is 0.25 mm and top coat 0.35 mm for other model. The all parts of models are assembled in assembly design shown in fig 4.2(c).

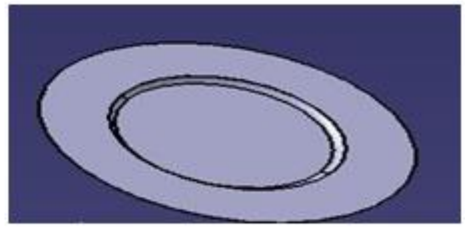

Fig.4.2 (a) Layer of bond coat

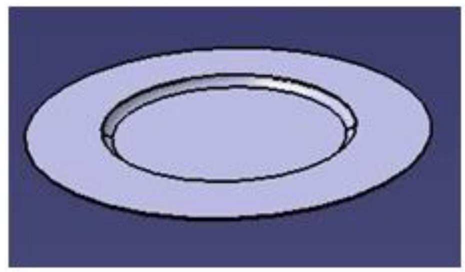

Fig.4.2 (b) Layer of ceramic top coating

Boundary conditions

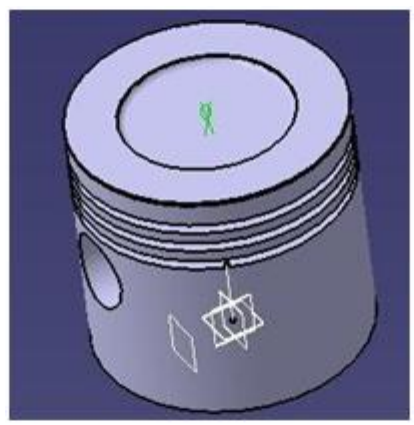

Fig 4.2 (c) Model of assembled piston

In the numerical performed a diesel engine piston made of structural steel, is taken on the basis of the simulation. 3D finite element thermal analysis is carried out on conventional and ceramic coated engine piston. Piston thermal boundary conditions consist of the piston pin thermal boundary condition, skirt and ring land thermal boundary condition, underside thermal boundary condition, combustion side thermal boundary condition.[7]

Thermal circuit method is used to model the heat transfer in the ring land and skirt region with the following assumptions:

- Piston motion effect on heat transfer isneglected.
- There is no cavitation's effect of oil on ring and pistonskirt
- Do not twist thering,
- Neglecting the conductive heat transfer inoil.

The reasonable boundary conditions are given to calculate heat transfer with finite element method of diesel engine piston. [7]

Piston position	Environment Temperature (T) 0C	Convective heat transfer coefficient (h) W/m2 0C
Combustion chamber	650	800
Lateral surface temperature	300	230
Ring temperature	160	200
Piston skirt and pin temperatures	85	60

Table 4.2 Boundary Condition for Piston

Results

In the Steady State Thermal Analysis, the solution section is selected, and a temperature solution is inserted as well as a heat flux solution. This is because part of the scope of this thesis is to study the temperature gradient in the piston model with thermal barrier coating layers and also heat flux through piston.

Once this is completed, the Steady State Thermal Analysis part of the model is ready to be solved. Once the analysis set up is complete, the Finite element Analysis is ready to be run.

Description

The evolution of the thermal behavior of non-coated piston and coated piston with different ceramic materials and different thickness, at the interface of bond coat and top coating, using Finite Element Analysis of a steady state modelisstudied.Inthismodelutilizeslineartemperaturedependent material properties for each layer of thermal barrier coating system. The ceramic top coating and bond coat layer on piston was studied of thermal behavior, the effects of variation of ceramic materials with different thickness on thermal behavior. The thermal barrier coating system utilized the top coat is CaZrO3 with 0.5 mm. The model environment of combustion chamber with a hot convection coefficient of 800 W/m2K and temperature is 650 0C.

Temperature Distribution

The first group analysis of temperature distribution of non-coated piston and thermal barrier coating system of different materials with different thickness given below are:

Case-1

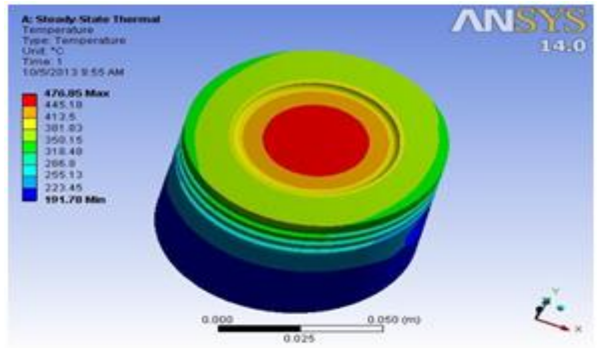

Fig. 1 The temperature distribution of non-coated piston

Case-2

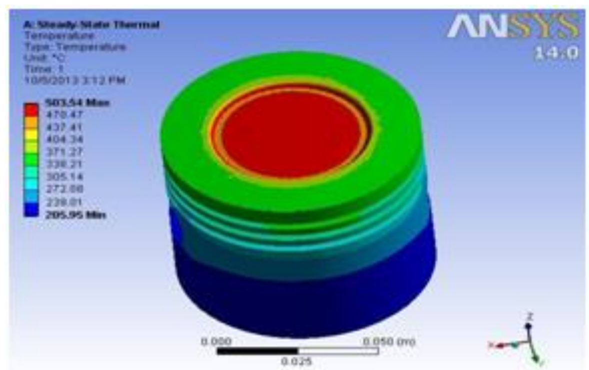

Fig. 2.. Temperature distribution of MgZrO3 coated piston with 0.35 mm thickness

Case-3

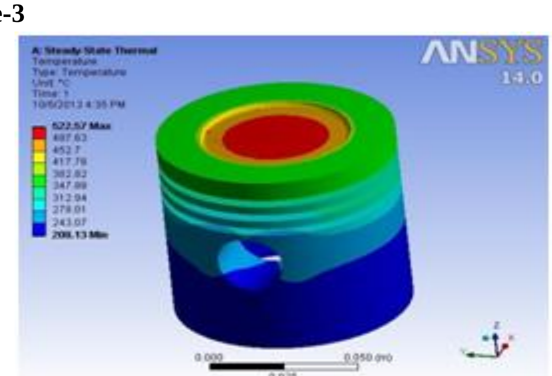

Fig. 3. Temperature distribution of MgZrO3 coated piston with 0.50 mm thickness

Case-4

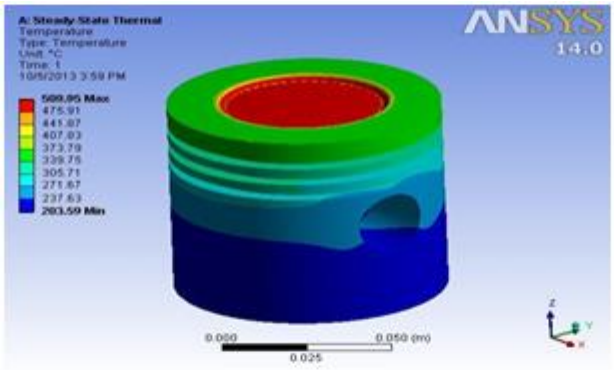

Fig. 4.. Temperature distribution of $CaZrO_3$ coated piston with 0.35 mm thickness

Case-5

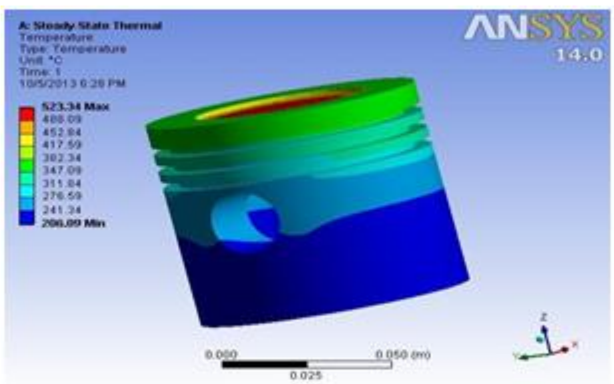

Fig.5..Temperature distribution of $CaZrO_3$ coated piston with 0.50 mm thickness

In above cases temperature is varying in all direction of model. In this study two thermal barrier coating system used and compare each other. The thermal barrier coating of $MgZrO_3$ with thickness of 0.35 mm and 0.50 mm, similarly other thermal barrier coating of$CaZrO_3$ with 0.35 mm and 0.50mm.In both Conduction.

The fig. 6.2 and fig. 6.3 are cases of thermal barrier coating of $MgZrO_3$ with different thickness of 0.50 and 0.75 respectively which shows highest at top and lower at bottom, but fig. 6.2 have maximum value 503 0C and 205 0C is minimum value. Similarly, The fig.6.4 and 6.5 is cases of the fig.6.3 have maximum value of temperature is 522 0C and 288 0C respectively. The temperature difference in both systems is due to different thickness of top coating and bond coat. The conduction of heat decreases with increases of Systems NiCrAl bond coat used but thickness is different. The fig 6.1 shows highest temperature at top face of non-coated piston and decreases with height in down. The maximum temperature at top is 476 0C and 191 0C at bottom of piston model. So the heat loss in piston due to temperature difference with Thickness of thermal barrier coating. Other thermal barrier coating system of $CaZrO_3$ with different thickness of same above 0.50 and 0.75. Similarly, fig.6.4 have maximum and minimum values are 5090C, 203 0C respectively. The fig. 6.5 show maximum and minimum values are 523 0C, 206 0C respectively; it has highest value of temperature due larger thickness of thermal barrier coating on selected piston model.

The above same results are shown in graphical representation below of all cases respectively:

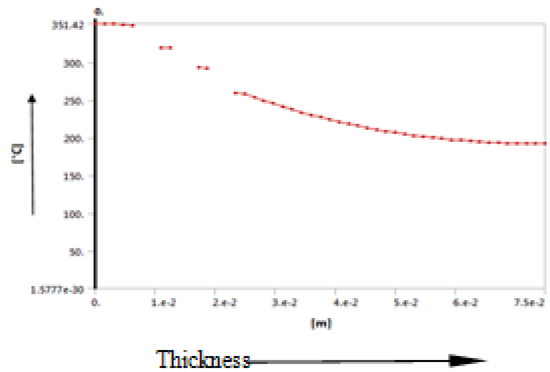

Fig. .6 Graphical representation of temperature non-coated model (Case-1)

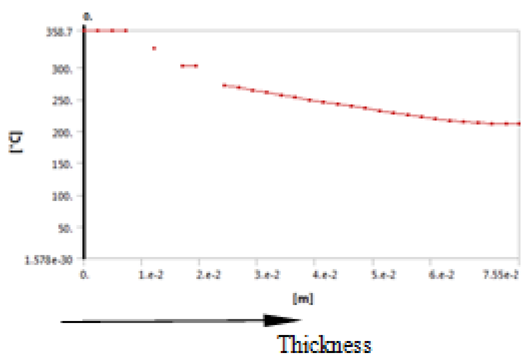

Fig. 07.. Graphical representation of temperature $MgZrO_3$ with 0.35 mm (Case-2)

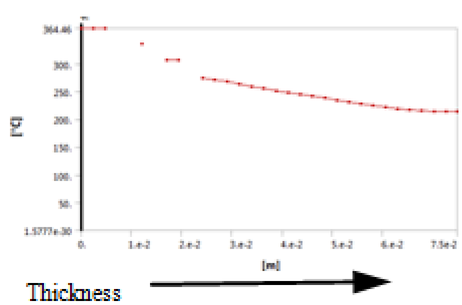

Fig..8 Graphical representation of temperature $MgZrO_3$ with 0.5 mm (Case-3)

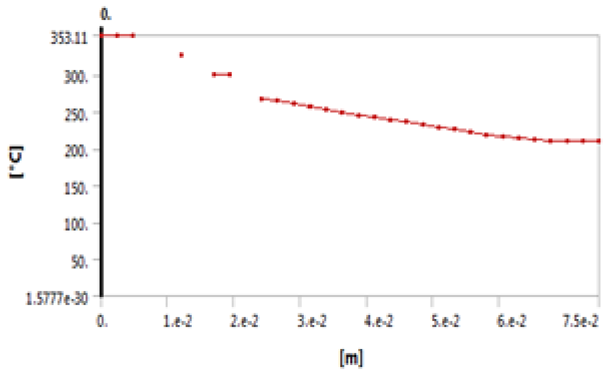

Fig .9 Graphical representation of temperature CaZrO3 with 0.35 mm (Case-4)

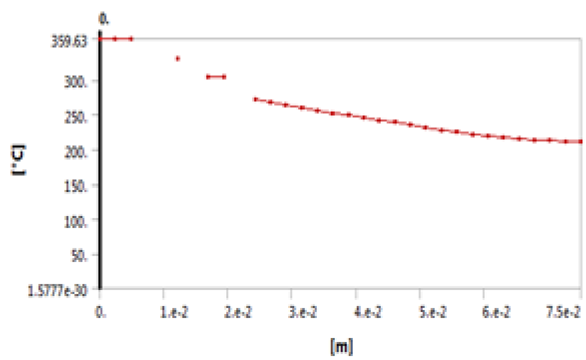

Fig.10 Graphical representation of temperature CaZrO3 with 0.50 mm (Case-5)

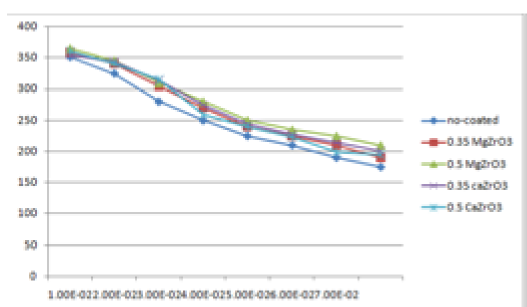

Fig.11 Comparison of all of temperature distribution

Heat Flux

At the same above environment the distribution of heat flux through the piston model at different material with different thickness of thermal barrier coating. The following results are:-

The fig. 6.12 shows the total heat flux maximum at top of the piston model 5.5021×10^5 W/m2 and minimum heat flux at bottom of piston is 138.66 W/m2. The heat flux is decreases through height.

The fig 6.13 shows the heat flux of thermal barrier coated system of MgZrO3 with thickness of top coating 0.35 mm shows maximum 4.2553×10^5 W/m2 and minimum at bottom is 201.96 W/m2. Thefig.6.14 shows the total heat flux maximum 8.3002×10^5 W/m2 and minimum 58.66 W/m2. The fig 6.15 and fig. 6.16 gives the comparison of total heat flux same material but different thickness of coating 0.50 mm and 0.75 mm maximum at top is 9.2483×10^5 w/m2 and minimum at bottom of piston 58.339 w/m2, this model have same topcoat material like fig. 6.9 but thicknessis 0.75 mm. The fig. shows different results at same boundary conditions and same materials due to different thickness of top coating materials.

Case-A

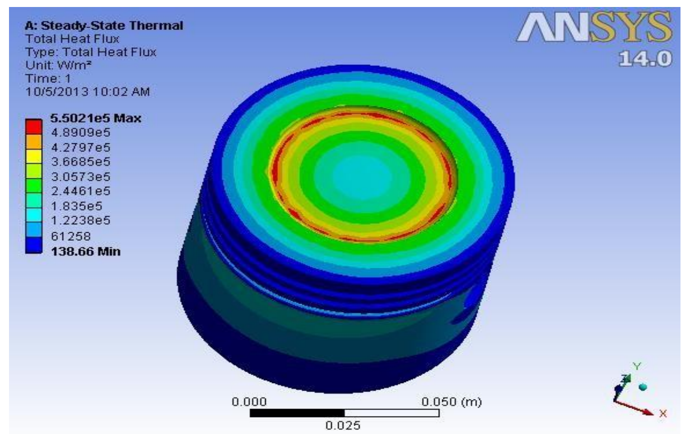

Fig 6.12 Total heat flux of non-coated piston

Case-B

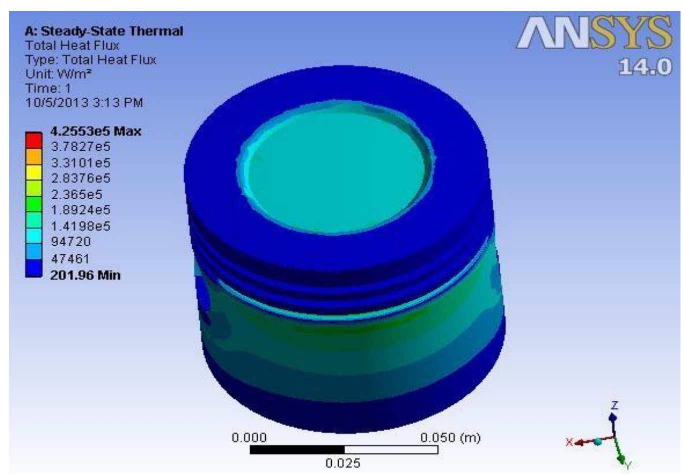

Fig 6.13 Total heat flux of MgZrO3 with 0.35 mm thickness

Case-C

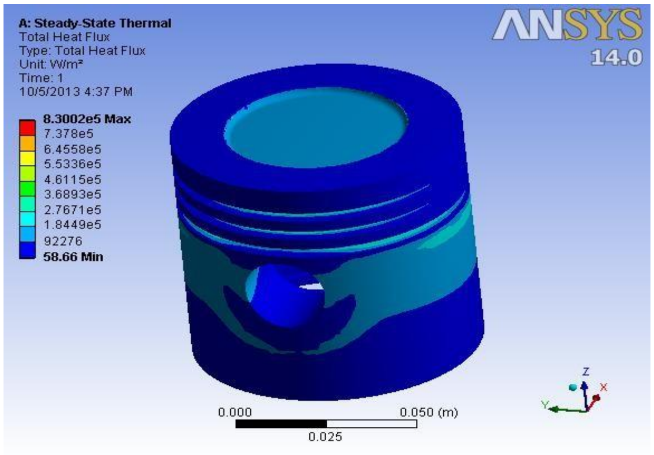

Fig 6.14 Total heat flux of MgZrO3 with 0.50 mm thickness

Case-D

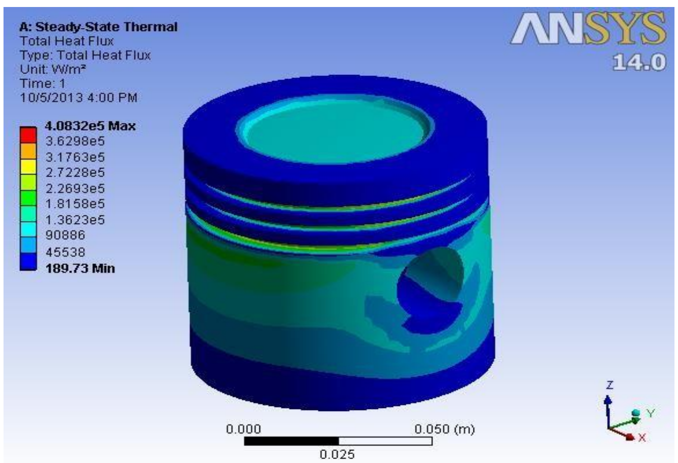

Fig. 6.15 Total heat flux of CaZrO3 with 0.35 mm thickness

Case-E

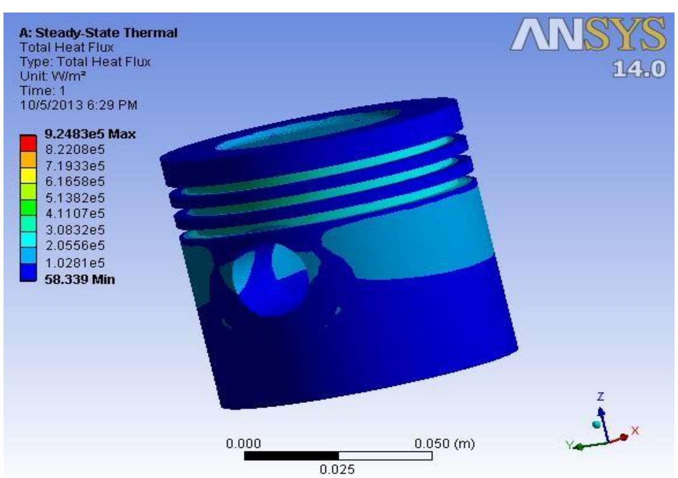

Fig6.16 Total heat flux of CaZrO3 with 0.50 mm thickness

The fig. 6.9 shows the total heatflux maximum at top of piston coated with CaZrO3 of 0.35 mm thickness is 4.0832×10^5 w/m2 and minimum at bottom of piston is 189.73w/m2. Similarly, fig 6.10 shows total heat flux maximum at top is 9.2483×10^5 w/m2 and minimum at bottom of piston 58.339 w/m2, this model have same topcoat material like fig. 6.9 but thicknessis 0.75 mm. The fig. shows different results at same boundary conditions and same materials due to different thickness of top coating materials.

CONCLUSION

On the basis of the above research study conclude that temperature increases on the top surface of ceramic coated piston and decreases on non-coated steel piston because low thermal conductivity of coating materials.

1. The temperature of piston surface 6% increases in case-2, 9.59% increases in case-3, 7% increases in case-4 and 9.75% in case-5 than non-coated piston model, due to this effect conductive heat transfer through the piston is reduced.
2. The heat flux on non-coated piston is 5.5x105w/m2 in case-A, the heat flux reduces in both cases B and D 4.2x105 and 4.08 x 105w/m2 respectively. Further, with increases thickness of thermal barrier coating the heat flux in cases C and E are 8.3x105w/m2 and 9.24 x 105 w/m2 respectively.
3. Hence additional energy is available in the combustion chamber of engine that can be utilized in useful work done, increases the exhaust gas temperature and can reduce the complexity of cooling system in engine. Also can utilized available high energy in exhaust gases with compounding of turbine.
4. The efficiency of engine becomes increased and combustion of engine improved, so well emissions control of exhaust gases but NOx amount is Increased compared to conventional engine.
5. The steady state model, however, does not take into consideration any transient effects such as timed heating up. However, the steady state thermal analysis using the MgZrO3 material as top coating with different thickness increases temperature of piston model and decreases the total heat flux, more result give positive response with increases of thickness of thermal barrier coating. But the thickness of thermal barrier coating cannot increases more, because the volumetric efficiency of engine will be decreases.
6. Similarly, the same concept is applicable on the CaZrO3 thermal barrier coating but the results are different due to both materials having different thermal conductivity.

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