Temperature Distribution on $CaZrO_3$ Coated Diesel Engine Piston with ANSYS

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Abstract : In an internal combustion engine, the heat energy approximately one third of total fuel input energy is converted to useful work. Since the exhaust gas temperature is not equal environmental temperature, so lot of heat energy lost with hot gases. Also heat energy is lost in cooling of engine. If we recovered heat energy which lost in cooling instead on crankshaft as useful work, then increase the efficiency of engine and improvement in fuel economy. Many researchers have done work on design improvement to increase efficiency of engine. Some researchers worked on other alternative which is thermal barrier coating on different parts of engine like as piston, liner, valves and head of cylinder. In this paper ceramic material ($CaZrO_3$) with different coating thickness 0.35 mm and 0.50 mm are used to reduction of heat losses through conduction in piston of engine. With the application of thermal barrier coating on engine parts increase thermal efficiency, fuel combustion process and emissions controls. Here thermal barrier coating is to be done on selected piston of diesel engine with NiCrAl is bond coat material and $CaZrO_3$ as a top ceramic coating, and in this paper conclude that increases thickness of coating causes increase top piston surface temperature.

I. INTRODUCTION

Thermal barrier coatings can be applied in the IC engine to insulate combustion chamber surfaces. The coating is applied to the piston of diesel engine which increases the temperature of top surface during combustion of fuel, so decrease the temperature difference between piston surface and gas to reduce heat transfer. Some of the additional heat energy in the cylinder can be converted into useful work, increasing power and efficiency. Reducing heat transfer also increases exhaust gas temperatures, providing greater potential for energy recovery with a turbocharger. Additional benefits include protection of metal combustion chamber components from thermal stresses and reduced cooling requirements. There are using of many materials of ceramics Cr_2O_3 and CeO_2, m-Zro_2, Al_2 O_3-Tio_2, $MgZrO_3$, $BaO{\cdot}ZrO_2$, $SrO{\cdot}ZrO_2$, and $Al_2O_3.SiO_2.MgO$. etc, we know that thermal conductivity of insulated ceramics materials must be low but materials also able to sustain high thermal environments. Although many types of thermal barrier coating system have been used for different condition and requirements, yttria-stablized zirconia with 7-8 wt% yttria has received the most attention[1] several factor play important roles in overall thermal barrier coating effectiveness like as good thermal insulation, thermodynamically compatible with the bond coat, micro structural and chemically stability at the operating parameter, creep, high melting point, appropriate thermal expansion coefficient to reduce the thermal stress. In the coating of non homogeneous system the thermal shock resistance behavior is most important to understand that engine combustion chamber temperature is high, and thermal and residual stress is also high which causes problems of reliability and durability in coating system are arisen. The major limiting factor for coating in fluctuating thermal environments is reduction of strength for lifetime performance. Transiently dependent on time and materials system is especially non homogeneous are problems of system because mechanical and thermal loading cracking and coating is spalling can occurs [2]. Experiments were conducted to determine the thermal shock resistance of thermal coating [3-4]. Computational fatigue analysis was made for cyclic thermal shock in notched specimens [5]. Cracking behavior in a thermal barrier coating upon thermal shock loading was numerically analyzed [6]. With different experimental observation and theoretical study based suggestion is that multiple cracks may occurs due to rapidly changes in temperature in homogeneous and non homogeneous materials [7].Furthermore, the material properties exhibit significant temperature –dependence under high temperature environments. We studied type of coating like as thin thermal barrier coating and thick thermal barrier coating which depend on the application of coating. Thin thermal barrier coating up to 0.5 mm and thick thermal barrier coating up to 5-6 mm layer. There are different types of coating process are (1) Thermal spray coating: Plasma spray, wire flame spray and powder flame spray, electrical arc spray, detonation gun technique and high speed oxy fuel system. (2) Chemical ceramic coating: Sole-gel, slurry, chemical vapour sedimentation, physical vapour sedimentation, hard coating. (3) Laser coating. (4) Arc spark alloying. (5) Ion enrichment method (Yaşar, 1997; Kamo ., 1989) [8]. In diesel engine used as thick layer coating by plasma spray and flame spray coatings are generally utilized (Kamo ., 1989). Plasma spraying is the most common method for depositing coating materials in diesel engine [1].

The heat energy presented in the internal combustion engine is addition of all different types of energy which satisfy the first law of thermodynamics. But according to the second law of thermodynamics, we cannot get 100% efficiency because some heat loss has to be rejected; higher engine efficiency can obtain at law environmental temperature. Second law of thermodynamics states that all input energy cannot be converted into work done [9].The amount of work done increases with controlling of heat loss in cylinder wall either coolant and environments which is application of first law and also does not violation of second law. Furthermore, most important advantage is great reduction of losses in coolant system, thus increase the brake horsepower of internal combustion engine. The prospects of the improving the design and performance have generated impetus to active research on adiabatic or more appropriately, low heat rejecting (LHR) or insulated engines. Prasad used partially stabilized zirconia (PSZ) as insulated ceramics materials, on the piston crown and reduction of heat about 19% through piston [10]. Performance was improved 7% used the insulated material is silicon nitride on different surfaces of combustion chamber by Kamo and bryzik [11]. Morel. by experimental results has shown higher temperature of insulated engine because reductions of heat through cylinder wall of the engine according to the knowledge of convective heat transfer [12]. From past of years the development of insulated ceramics materials diesel engine as a low heat rejection engine, coating on the combustion chamber (piston, cylinder, valve). Insulating engine by reducing the heat trough cylinder increasing efficiency of engine also eliminates requirements of cooling system, reducing cost of cooling system, also reducing weight and reducing the complexity of engine. By the insulated engine temperature of hot gases increased, so this heat energy into mechanical energy using turbo arrangement in engine. In this study has shown by Imdat Taymaz [9] evaluate the energy balance at different engine load and speed with and without coated ceramic engine. The result showed a reduction in heat losses to the oil, ambient temperature and cooling system of ceramic coated engine. Thermal coating in diesel engine lead to advantage including higher power density, fuel efficiency, multi fuel capacity due to the possibility of higher combustion chamber temperature (900 ^{0}C vs. 650 ^{0}C). The increased operating temperature when using thermal barrier coating can increased engine power by 8%, decrease the fuel consumption by 15-20% and increased the gas temperature 200 K [1].

II. FINITE ELEMENT ANALYSIS

The selected piston of diesel engine has thermal barrier coating on top surface to reduction of heat transfer through piston with conduction because ceramic material has low thermal conductivity. In this project is to generate a finite element model of a thermal barrier coating system, simulating a piston of diesel engine such that the evolution of temperature profile at surface. This analysis is performed in ANSYS 14 Workbench "Steady State Thermal" elements. The steady state analysis of the model is performed; without cover of transient effects. However, the analysis takes into consideration the temperature dependent creep properties of the 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. 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 the selected piston. In this paper 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 coating of $CaZrO_3$ with 0.35 mm and 0.50 mm, and 0.15 mm bond coat (NiCrAl) for each coating. 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. The model is then imported to ANSYS Workbench Simulation, where after the definition of boundary conditions and temperature distributions in the piston are calculated. Initially conventional piston (structural steel) model was prepared then ceramic crown piston model was prepared using modeling.

A. Properties of Materials

The following properties are taken from literature which is essential for analysis.

Material	Thermal conductivity [W/m^{0}C]	Thermal expansion 10^{-6} [1/^{0}C]	Density [Kg/m^3]	Poisson's ratio	Young's modulus [GPa]
Steel	79	12.2	7870	0.3	200
$CaZrO_3$	0.6	3.2	5110	0.25	100
NiCrAl	16.1	12	7870	0.27	90

Table 1 Properties of ceramic material

B. Boundary Conditions :

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.

The reasonable boundary conditions are given to calculate heat transfer with finite element method of diesel engine piston. [13].

Piston position	Environment Temperature (T) ^{0}C	Convective heat transfer coefficient (h) W/m^2 ^{0}C
Combustion chamber	650	800
Lateral surface temperature	300	230
Ring temperature	160	200
Piston skirt and pin temperatures	85	60

Table 2 Boundary conditions

III. RESULT AND DESCRIPTION

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. The reasonable boundary conditions are given to calculate temperature distribution with finite element method of diesel engine piston.

Case 1

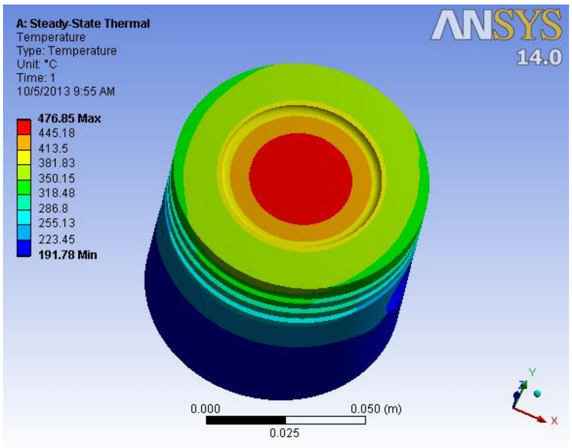

Fig.1 Temperature profile on non coated piston

Case 2

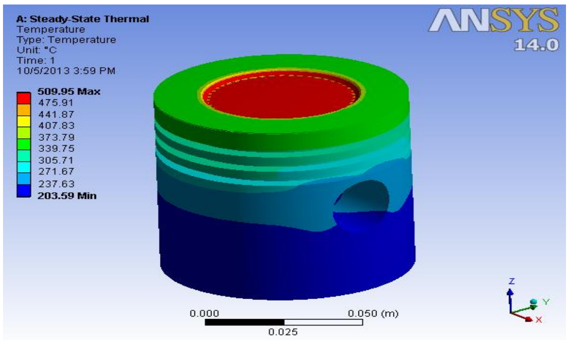

Fig.2 Temperature profile on ceramic 0.35 mm coated piston

Case 3

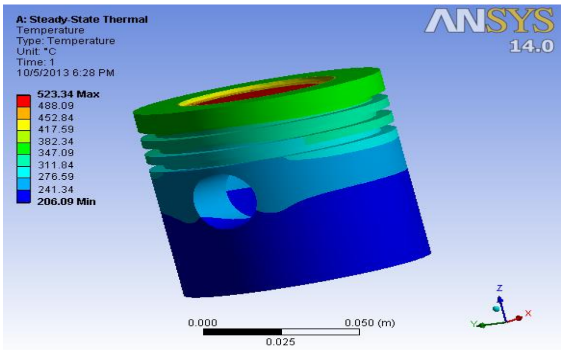

Fig.3 Temperature profile on ceramic 0.50 mm coated piston

In above cases temperature is varying in all direction of model. The fig 1 shows highest temperature at top face of non coated piston and decreases with height in down. The maximum temperature at top is 476 ^{0}C and 191 ^{0}C at bottom of piston model. So the heat loss in piston due to temperature difference with conduction. Similarly, the thermal barrier coated pistons in fig 2 and fig 3 have maximum value 509 ^{0}C, 523 ^{0}C and minimum value 203 ^{0}C, 206 ^{0}C respectively. The results shows increases the thickness of coating, increases the top surface temperature of piston.

IV. CONCLUSION

On the basis of the above results conclude that with application of the thermal barrier coating on piston of diesel engine the temperature of the top surface of piston increases and temperature of steel piston decreases because low thermal conductivity of coating materials. The temperature of piston surface 7% increases in case 2 and 9.75 % increases in case 3 due to application of thermal barrier coating. Here conclude that increases thickness of top coating increases temperature of piston but cannot more thickness because volumetric efficiency of engine will be decreases. 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.

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