The Behavior of Temperature on Insulated(MgZrO₃) 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 (MgZrO₂) 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 MgZrO₂ as a top ceramic coating, and in this paper conclude that increases thickness of coating causes increase top piston surface temperature.

Keywords—Thermal barrier coating, thickness of coating, ANSYS 14 and Temperature distribution.

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. The bond coat is applied on the substrate because adhesion of ceramic material. NiCrAl used as a bond coat which has oxidant resistant property. It consist multiple layers for some cases.

The thermal barrier coating consists of ceramic top coat (MgZrO₃) as well as (CaZrO₃) and bond coat NiCrAl. The porous top coat, which is bonded to the bulk material via the bond coat, can protect the underlying air cooled material by significantly reducing the operating temperature. The metallic bind coat serves also to protect the material from oxidation and corrosion. The bond coat has been used to improve the corrosion resistance and prolong the lifetime of nickel-based super alloy at high operating temperature. [1] Thermal barrier coating mostly ZrO₂ and ZrO₂-based thick and thin films are used because properties of these materials such as oxidation, erosions and corrosions resistance, high hardness, thermal and chemical stability at cryogenic and high temperatures [2]. All these properties make suitable for uses in different applications on metallic substrates in aerospace and aircraft at high temperature environment, also used in the reduction of heat loss in diesel engines and gas turbines. Mostly applications of thermal barrier coating successfully to internal combustion engine, particularly in combustion chamber to simulate adiabatic engines. Thermal barrier coating is not only reduced temperature and thermal fatigue, but also reduction emissions of engines and brake specific fuel consumption [3]. The ceramic coating insulation on the combustion chamber affects performances, combustion process and also improves emissions characteristics of engines [4]. Other hand, increasing thermal efficiency or reduction fuel consumption of engines leads to higher compression ratio for diesel engines, and reduced in-cylinder heat rejection. Causes of both factors increased thermal stresses and mechanical stress of materials used in the combustion chamber. Due to durability concerns all components of engines limit the maximum in-cylinder temperature. The applied thermal barrier coating to components increases high temperature durability with heat reduction and temperature of substrate [5]. The failure of thermal barrier coating occurs due to spalling of ceramic coating from bond coat. Many factors which influences the life of coating. Thermal mismatch and oxidation are major factors effect on the life of thermal barrier coating.
The micro-cracked and highly porous structure of thermal barrier coating decreases its thermal conductivity [6] [7]. Many experimental have been studied to improve thermal efficiency of diesel engine with utilization of thermal barrier coating by reducing heat losses and increases mechanical efficiency by eliminating cooling systems. Reduced heat losses through cylinder in cooling system delivered in heat in exhaust gases. The recovery exhaust gas heat increases thermal efficiency of engines. Without heat recovery system, some part of heat converted to piston work and increases thermal efficiency [8] [9]. With application of thermal barrier coating in diesel engines increases fuel efficiency, higher power density and multi fuel capacity due to higher combustion chamber temperature [10]. The insulation coating on diesel engine must have a low friction coefficient, high temperature strength, and good thermal shock resistance, durable and light weight. The insulating material such as silicon nitride in combustion chamber which improvement 7% in performance [11]. Experimental results of developed semi-adiaotic engine improvement 30% heat reduction in cylinder heat rejection and improvement 5-9% in specific fuel consumption [12].

II. FINITE ELEMENT METHOD

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 paper 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 MgZrO3 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 [13]. 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.

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. [7].

<table>
<thead>
<tr>
<th>Piston position</th>
<th>Environment Temperature (T) °C</th>
<th>Convective heat transfer coefficient (h) W/m²°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion chamber</td>
<td>650</td>
<td>800</td>
</tr>
<tr>
<td>Lateral surface temperature</td>
<td>300</td>
<td>230</td>
</tr>
<tr>
<td>Ring temperature</td>
<td>160</td>
<td>200</td>
</tr>
<tr>
<td>Piston skirt and pin temperatures</td>
<td>85</td>
<td>60</td>
</tr>
</tbody>
</table>

Properties of materials

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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>79</td>
<td>12.2</td>
<td>7870</td>
<td>0.3</td>
</tr>
<tr>
<td>MgZrO$_3$</td>
<td>0.8</td>
<td>8</td>
<td>5600</td>
<td>0.2</td>
</tr>
<tr>
<td>NiCrAl</td>
<td>16.1</td>
<td>12</td>
<td>7870</td>
<td>0.27</td>
</tr>
</tbody>
</table>

### 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 I**

<table>
<thead>
<tr>
<th>A: Steady-State Thermal</th>
<th>Type: Temperature</th>
<th>Unit °C</th>
<th>Time: 1</th>
<th>1/05/2013 0:55 AM</th>
</tr>
</thead>
<tbody>
<tr>
<td>471.85 Max</td>
<td>445.16</td>
<td>413.1</td>
<td>360.15</td>
<td>308.48</td>
</tr>
</tbody>
</table>

Fig 1 Temperature profile on non coated piston

**Case II**

Fig 2 Temperature profile on ceramic 0.35 mm coated piston

**Case III**

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 °C and 191 °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 503 °C, 522 °C and minimum value 205 °C, 200 °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 6% increases in case 2 and 9.59 % 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.

REFERENCES


