Coating and Performance of Nano Structured Yttria Partially Stabilized Zirconia (composite) as Thermal Barrier in I.C. Engines

PRESENTED BY

MENTA BHARATH PAVAN KUMAR
S.SHRI HARI

Email: mbpk12629@gmail.com
Contact no: 9629759543
ABSTRACT:

The knowledge of the heat transfer in the parts of internal combustion engine is most important in order to ascertain the points of high temperature variation and hence to determine the optimum conditions where the parts of the engine are subject to high thermal load. Among the components exposed to heat load, piston of internal combustion engine is subject to maximum thermal stress. The large temperature gradient in the piston will cause structural deformation, deterioration of lubricant and decrease the clearance between the cylinder liner and piston, thereby causing more noise, vibration and decrease in the engine service life. The non-uniform temperature gradient arise owing damage of piston especially in the crown region.

Experimental study is conducted on single cylinder 5hp diesel engine in order to find an improved performance, when a ceramic coating is given at nano phase to the piston crown by vacuum plasma spray process. The ceramic coating gives mechanical support to the piston. Among the ceramics, nano phased Yttria partially stabilized Zirconia (YPSZ) is being favored for diesel engines since its co-efficient of thermal expansion is close to those of metals used in piston. This avoids problems relating to difference in thermal expansion between metallic and thermal parts which also increases its durability. Compared to the conventional engine (without coating over the piston crown), the modified engine (with ceramic coating over the piston crown) neither produces any observable knock in the engine, nor any significant wear of piston crown. It also retains the heat produced in the combustion chamber thereby ensuring complete combustion and minimizing the emissions. Various graphs are drawn to check the improved performance of the engine when it is with and without the ceramic thermal barrier coating on the piston crown, and found that there is 5-6% decrease in SFC, 4-5% increase in brake thermal efficiency and 8-9% increase in mechanical efficiency.

KEY WORDS

Nano phased Yttria partially stabilized Zirconia, Thermal Barrier Coating, Vacuum Plasma Spray.

INTRODUCTION:

In general, conventional diesel engines are fed up with problems like emission, incomplete combustion, thermal wear, mechanical wear, etc. These problems can be solved by the application of thermal barrier coating (TBC) to the piston crown, cylinder walls, cylinder heads and valve heads. The material which best suits for the above application is nano structured yttria partially stabilized zirconia. Coating process and performance evaluation is done in this paper.

Coating process includes cleaning, bond coating and top thermal barrier coating. Robotic vacuum plasma spray process is used here to coat the top coat over the prepared bond coat at the
piston crown surface. Thickness is maintained at a controlled rate for optimum performance.

**COATING MATERIAL PROPERTIES:**

The basic requirements of the ceramic coat materials are that the co-efficient of thermal expansion of the material should be of the same order of the base structures, so that under the wide range of cyclic temperature variation, the coating materials should adhere to the metallic surface without any significant interface stresses. In addition they should have low thermal conductivity, high specific heat and high thermal strength.

The material which best caters the above needs is nano structured yttria partially stabilized zirconia. In this material zirconia (ZrO₂) is usually stabilized with about 8% of yttria (Y₂O₃) to get the required composite. The micro hardness of this nano material is 8.6mpa which is 1.6 times larger than the hardness achieved by conventional coating. The region of maximum test lifetime correlates with the presence of maximum amounts of non equilibrium, non transformable tetragonal phase.

**COATING PROCESS:**

The process of coating involves the following steps:

1. Surface preparation
2. Bond coating
3. Thermal barrier coating

**SURFACE PREPARATION:**

The surface to be coated is initially prepared by cleaning process. This is done usually to get rid of foreign materials bound to the substrate. First the substrate surface is mechanically cleaned by conventional dry cleaning process using compressed air. Then it is grit blasted to get rough surface for effective bonding with the bond coat. This is followed by ultrasonic cleaning.

**BOND COATING:**

The prepared surface is then coated with an adhesive elastic bond coat by physical vapor deposition. Usually MCrAIY material is used as the bond coat. In the metallic MCrAIY bond coat M is selected from Ni, Co, Fe or a combination thereof. The thickness of this bond coat is maintained between 0.075mm to 0.125mm for effective adhesion. The bond coat is then grit blasted for effective adhesion with top coat.

**ROBOTIC VACCUM PLASMA SPRAYING:**

Vacuum Plasma arc spraying is chosen over other conventional process for the following reasons:

1. It has lower degrees of oxide formation when compared to the conventional ones.

2. Only in plasma arc spraying, coating thickness in the range of 0.125mm to 0.375 mm could be achieved with good bond strength.

The plasma spraying uses coating materials in the form of powders, which are melted with plasma heat source. Plasma is an
excited gas, often considered to be fourth state of matter, consisting of an equal ratio of free electrons and positive ions. This forms an electrically neutral flame.

**EQUIPMENT AND PROCESS:**

The equipment used in the process has three basic components: the plasma spray gun, an automatic - controlled console and power feed unit. Ancillary equipment has been evolved simultaneously to mechanize the operation of the guns and to ensure accurate metered supplies of process gas and coating powders.

**PLASMA GUN:**

A plasma arc gun is a water-cooled device, which has an open ended chamber in which the plasma is formed. The compact gun in its most practical form contains a central tungsten electrode or cathode mounted concentrically relative to a narrow circular orifice of about 9mm diameter in a copper anode.

**WORKING:**

The arc is initiated between the two electrodes of the plasma gun either by touching them together or preferably by means of a high frequency spark from a high frequency arc starter. Once discharge is initiated, the plasma can conduct currents as high as 2000A direct current, with voltage potentials ranging from approximately 30 to 80V. The exit gas velocity is high enough to force the arc beyond the anode orifice. The forced high temperature gas breaks the yttria partially stabilized zirconia into nano structured grains and adheres it to the bond surface. This coating is performed in vacuum and hence the name. The powder level, pressure and flow of the arc gases and the rate of flow of powder and carrier gas are controlled at the robotic console of the system. The spray gun position and gun to work distance are usually preset.

Spraying at reduced pressure or vacuum is generally preferred so as to obtain a dense structure devoid of internal oxidation. Using an inert gas shroud at atmospheric pressure can also help to diminish oxidation during spraying. Regardless of how the bond coat is applied it must be sufficiently rough to promote ceramic layer attachment. However, excess roughness may eventually contribute spallation or failure of the coating.

**VACUUM PLASMA SPRAY PROCESS**
EXPERIMENTAL INVESTIGATIONS:

ENGINE:

A single cylinder water cooled Kirloskar engine is used for our analysis. The piston is coated with nano structured YPSZ by Robotic vacuum plasma spray process. The water at room temperature is allowed to pass through the water jacket in the engine. The specification of the engine is given as follows.

<table>
<thead>
<tr>
<th>Engine name</th>
<th>Kirloskar engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Single cylinder vertical diesel engine.</td>
</tr>
<tr>
<td>Rated rpm</td>
<td>1500</td>
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<tr>
<td>Bore</td>
<td>79.9</td>
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<tr>
<td>Stroke</td>
<td>110 mm</td>
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<tr>
<td>Capacity</td>
<td>553 cc</td>
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<tr>
<td>Compression</td>
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<tr>
<td>Ignition</td>
<td>CI</td>
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<tr>
<td>Power</td>
<td>5 Hp</td>
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</table>

FUEL MEASUREMENT:

To measure the fuel, a burette is used. A provision to cut fuel from the fuel tank and allow the fuel flow from the burette is made for easy and accurate measurement. Using a stop watch, the time taken for a known amount of fuel (10 cc) consumed can be noted.

PERFORMANCE TEST:

The load is applied to the engine with the help of rope and weight mechanism. The rope is wound over the brake drum. One end of the rope is connected to a string balance and to the other end the weights are attached. Using this arrangement the brake horse power is calculated. The rated horse power at certain speed does not give enough information. The necessary information is obtained by plotting the performance curves. In the same diagram, some additional characteristic curves are plotted such as torque, fuel consumption per horse power per hour and mechanical efficiency. All these data must be obtained from the actual tests conducted on the engine.

The performance tests were conducted at constant speed throughout the entire load. In every test, sufficient number of runs had been made so that the results when plotted indicated the shape and characteristic of the operational curve. A run had been made at a steady speed at which the engine operates.

Performance had been obtained at stabilized operating conditions. These general principles govern the length of the experimental run.

1. No data shall be taken until load, speed and temperature have been stabilized.
2. Recorded data shall be the average sustained values over a period of at least one minute with no significant change occurring during that time.
3. Fuel consumption shall not be taken for time intervals of less than 60 seconds. All specific fuel consumption figures shall be based on observed brake horsepower.
The readings were taken and tabulated. The performance graphs were drawn.

**PERFORMANCE TEST WITHOUT COATING**

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Brake load in Kg</th>
<th>Brake load in N</th>
<th>Time for 10 cc of fuel consumption</th>
<th>Brake power in KW</th>
<th>Total fuel consumption kg/hr</th>
<th>Specific fuel consumption Kg/KWhr</th>
<th>Indicated power in kW</th>
<th>Indicated efficiency %</th>
<th>Brake thermal efficiency %</th>
<th>Mechanical efficiency %</th>
<th>Indicated thermal efficiency %</th>
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<td></td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSIONS:**

The results obtained are analyzed for the following characteristics.

1. Brake horse power
2. Specific fuel consumption
3. Brake thermal efficiency
4. Mechanical efficiency

**BRAKE HORSE POWER:**

When the conventional diesel engine is tested without ceramic coating, the maximum brake horse power was found to be 5hp. For the same engine with ceramic coated parts the maximum brake horse power was found to be the same.

**SPECIFIC FUEL CONSUMPTION:**

When the conventional diesel engine is tested without ceramic coating the maximum SFC has been found to be 0.51 Kg/hr/KW. For the same engine with ceramic coated parts the SFC comes down to 0.45 Kg/hr/KW.

**BRAKE THERMAL EFFICIENCY:**

For the conventional diesel engine, if tested without ceramic coating, the maximum brake thermal efficiency has been found to be 16%

For the same diesel engine if tested with ceramic coating, the maximum brake thermal efficiency has been found to be 20.4%. It results in an increase of 4.4% when compared with the engine without ceramic coating.

**MECHANICAL EFFICIENCY:**

Based on the performance test conducted on the engine without coating and with ceramic coating, the following results have been arrived.

For the conventional diesel engine, if tested without ceramic coating, the maximum mechanical efficiency has been found to be 48.2%. For the same engine with ceramic coated
piston crown, the maximum mechanical efficiency has been found to be 56.6%. This results in an increase in mechanical efficiency by 8.4% when compared with the engine without ceramic coating.

**ENVIRONMENTAL BENEFITS:**

1. **Reduced fuel consumption:**
   
   The diesel engine of today converts only about 30 to 40 percent of heat generated by the fuel into useful work. The remaining heat is dissipated to the surrounding through conduction and radiation. Hence the reduction of this heat loss to the coolant system has always been of considerable interest to engine designers.

   The ceramic nano YPSZ coating insulates the combustion zone components with materials having low thermal conductivity against high temperature oxidation and corrosion. The coating also reduces the heat absorbed by the components via radiation, help convert more heat into useful energy. The use of the engine parts coated with TBC’s causes two significant beneficial changes in the combustion process, ignition delay or the time between the start of the fuel injection and its ignition is reduced and there is a large drop in the height of combustion spikes. Additional power and improved efficiency of the diesel engine is
possible, because thermal energy, normally lost to the cooling water and exhaust gas, is utilized to enhance complete combustion and hence converted to useful power. Hence there is a considerable decrease in the fuel consumption of the coated engine.

**B) Exhaust emission control:**

This nano coating reduces the heat radiation through the piston at the end of power stroke and thus retains the heat produced in the combustion chamber. As a result, it lowers the level of NOx and unburned hydrocarbon emissions. It also facilitates complete oxidation of the soot and reduces exhaust smoke thus controlling the emission.

**CONCLUSION**

This nano structured thermal barrier coating over the piston crown is a problem solving technology. By using the correct surfacing material where it is best suited, thermal barrier coating allows engineers to improve product and performance, reduce maintenance time, cost, save energy and reduce production cost. Hence there is potential for improvements in the performance, fuel versatility, operating life and maintenance requirements of the I.C. engines.

**REFERENCES**

4. www.inframat.com
5. www.tms.org