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Effect of Titanium Dioxide(TiO_2) as a Thermal Barrier Coating on the Piston Crown of CI Engine

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ABSTRACT:- *In a normal diesel engine, about one third of the energy is lost as heat. Thermal Barrier Coating (TBC) is the material which is used to reduce the wastage of heat transfer to water cooling jacket and exhaust system. Thus improves the overall mechanical efficiency. Based on the availability, cost and ease of coating in the piston, titanium dioxide (TiO2) was selected as a coating material in my work. Piston crown of a single cylinder four stroke diesel engine is coated with Titanium Dioxide and Performance test is carried out for the comparative analysis of Performance variation in TBC Coated as well as a base engine. The results indicate a reduction in specific fuel consumption and an increase in brake thermal efficiency for titanium dioxide coated piston.*

Keywords:- *Heat loss, Mechanical Efficiency, Thermal Barrier Coating, Specific fuel consumption.*

I. INTRODUCTION

An engine is basically designed to convert energy into useful mechanical work. It's known that only one third of energy is converted into useful work in all CI engines.Theoretically if rejection of heat is reduced then the thermal efficiency may be increases to a considerable extend.Ceramic Coatings have historically been developed to surface properties of the substrate such as appearance, corrosion resistance, wear resistance etc

Researchers are continuously striving to enhance the performance level of internal combustion engines due to the high demand from industries for some technological requirements to increase the efficiency and to decrease the specific fuel consumption for overcoming the problem of rapid increase in the cost of fuel. In automobile field also higher Brake Thermal Efficiency with less fuel consumption is one of the essential requirement and continuous researches is going on for that to satisfy the above requirement. The application of TBC decreases the heat transfer to the cooling and exhaust system.. Thermal barrier coating (TBC) technology is successfully applied to the IC engines, in particular to the combustion chamber. Insulation of the combustion chamber components of low heat rejection (LHR) engines can reduce theheattransfer between the gases in the cylinder and the cylinder wall and thus increase the combustion temperature. The LHR engine concept is based on suppressing this heat rejection to the coolant and recovering the energy in the form of useful work. The Efficiency of most commonly available engines can able to enhance by coating the piston head with an insulating ceramic material such as Titanium Dioxide. The main requirements of a thermal barrier coating material include high melting point, low thermal conductivity, chemical inertness, Thermal expansion coefficient match with piston material, No phase transformation between room temperature and operating temperature.

Usually Stabilised Zirconia like Yittria-Stabilised Zirconia (7-8 wt % Y2O3-ZrO2) or Magnesium Stabilised Zirconia (MgO-ZrO2), Millite (3Al2O3-2SiO2) etc is used as TBC Material. Stabilised Zirconia is used instead of Pure Zirconia because Pure Zirconia (ZrO2) undergo phase transformation if the temperature increased above 500 deg Celsius.The results of MesutDurat [1] says that the usage of Mg-ZrO2 as TBC material caused Knocking at engines on higher load condition when compared to Y-ZrO2.

Lots of Ceramic materials are available which satisfies the requirements of TBC Material. Titanium Dioxide or Titanium Oxide is comparatively cheap when compared to Stabilised Zirconia. It also satisfied the basic property requirements of a TBC coating material. Because of its easy availability and also low rate my objective of this study was to investigate the effects of Titanium Dioxide as the Thermal barrier coating on the piston head of a diesel engine using plasma spray coating process.

II. THERMAL BARRIER COATING

Thermal barrier coatings (TBC) are highly advanced materials systems usually applied to metallic surfaces, such as on gas turbine or aero-engine parts, operating at elevated temperatures, as a form of exhaust heat management. These coatings serve to insulate components from large and prolonged heat loads by utilizing thermally insulating materials which can sustain an appreciable temperature difference between the load-bearing alloys and the coating surface. In doing so, these coatings can allow for higher operating temperatures while limiting the thermal exposure of structural components, extending part life by reducing oxidation and thermal fatigue. In conjunction with active film cooling, TBCs permit working fluid temperatures higher than the melting point of the metal air foil in some turbine applications. There are many applications for Thermal Barrier Coating and Fig 1 and Fig 2 shows two of them.

Figure 1. Thermal barrier coating applied onto automotive exhaust system

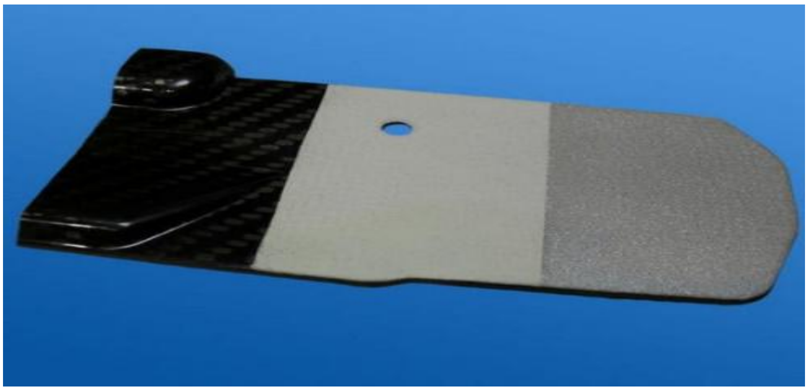


Figure 2. Thermal barrier coating applied onto carbon composite

Essential Property requirements for the selection of a TBC material

1) Low Thermal conductivity
2) High melting point
3) Chemical inertness
4) No phase transformation between room temperature and operating temperature
5) Thermal expansion coefficients match with metallic substance.
6) Good adhesion to the metallic substance.

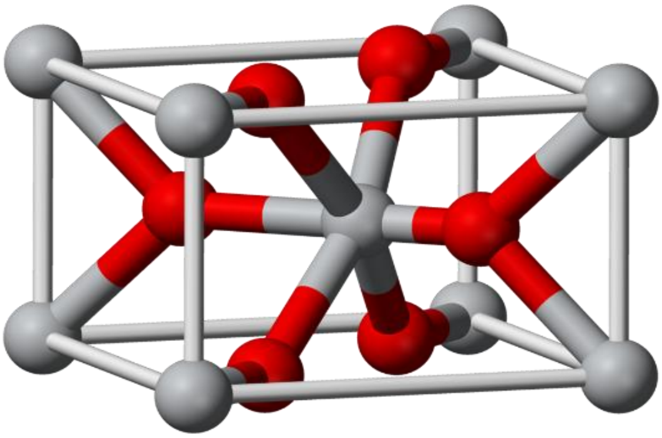
III. SELECTION OF MATERIAL FOR COATING

Based on the availability and ease of coating, Titanium dioxide was selected as the coating material. Titanium dioxide, also known as Titanium Oxide or Titania, with its molecular formula TiO2 and molecular weight 79.87 g/mol, is a kind of white powder. It is a soft solid powder and melts at 1800 Degrees Celsius. It has special performance, such as insulation, corrosion, flags, etc. It has a wide range of applications, from paint to sunscreen to food colouring. When used as a food colouring and the other most important application areas are paints and varnishes as well as paper and plastics, which account for about 80% of the world's titanium dioxide consumption. Other pigment applications such as printing inks, fibers, rubber, cosmetic products and foodstuffs account for another 8%. It is polymorphous and it exists in three types of crystal structures: (a) rutile, (b)anatase and (c) brookite. Only rutile is used commercially and the structure is shown in the Fig.3

Table 1: Properties of Titanium Dioxide

Chemical Formula	TiO2
Density	4.23 g/cm3 (Rutile)
Molar Mass	79.866 g/mole
Melting Point	1,843 °C (3,34 to 9 °F; 2,116 K)
Thermal Conductivity	1.8 to 2.2 w/m k
Flash point	Non Flammable

Figure 3. Structure of Titanium



IV. PLASMA SPRAY COATING

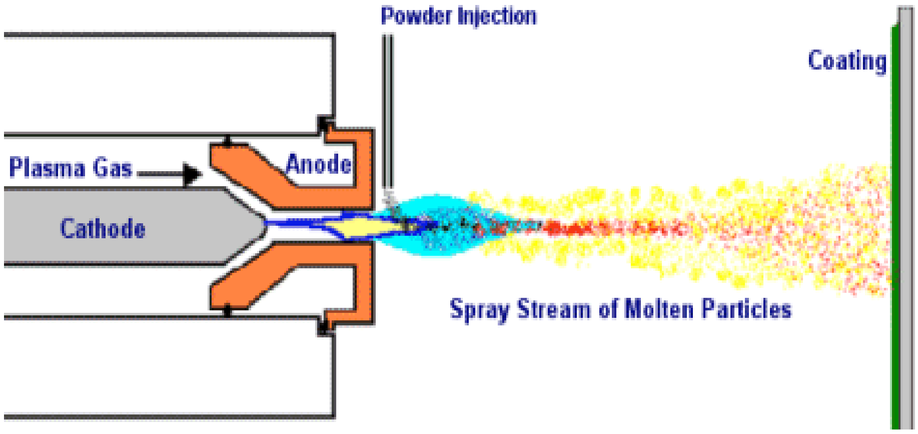


Figure 4.Plasma spray process

Piston head is coated by the process of plasma spraying.Plasma spray is the most versatile of the thermal spray processes. Plasma is capable of spraying all the materials that are considered sprayable. In plasma spray devices Fig 4, an arc is formed in between two electrodes in a plasma forming gas, which usually consists of either argon/hydrogen or argon/helium. As the plasma gas is heated by the arc, it expands and is accelerated through a shaped nozzle, creating velocities up to MACH 2. Temperatures in the arc zone approach 36,000°F (20,000°K). Temperatures in the plasma jet are still 18,000°F (10,000°K) several centi meters form the exit of the nozzle.

Nozzle designs and flexibility of powder injection schemes, along with the ability to generate very high process temperatures, enables the plasma spray technique to utilize a wide range of coatings. The range goes from low melting point polymers such as nylon, to very high temperature melting materials such as refractory materials including tungsten, tantalum, ceramic oxides like Titanium Oxide, Zirconium Oxide etc and other refractory materials

Figure 5.Plasma Spray Process

Table 2 . Plasma Spray Coating Specifications

Coating parameters	Specifications
Plasma gun	3MB plasma spray gun
Nozzle	GH Type nozzle
Pressure of organ gas	100-120 PSI
Flow rate of organ gas	80-90 LPM
Pressure of hydrogen gas	50 PSI
Flow rate of hydrogen gas	15-18 LPM
Power feed rate	40-45 g per minute
Spraying distance	3-4 in.

There are a large number of technological parameters that influence the interaction of the particles with plasma jet and the substrate and therefore the deposit properties. These parameters include feedstock type, plasma gas composition and flow rate, energy input, torch offset distance, substrate cooling. Sandblasting in Fig. 6is the process before plasma spray coating by propelling very fine bits of material at high-velocity to clean or etch the piston surface

Figure 6: Sand Blasting Process

The end result is absolute clean bare metal, which is ready to be prepared for alteration or surface coating such as powdercoating. Sandblasting also leaves a uniform course profile on the substrate, which allows for maximum adhesion between the coating and the substrate that is coated. Skilled operators manually control the sandblasting process.

Figure 7: TiO2 Coated Piston head

V. EXPERIMENTAL SETUP

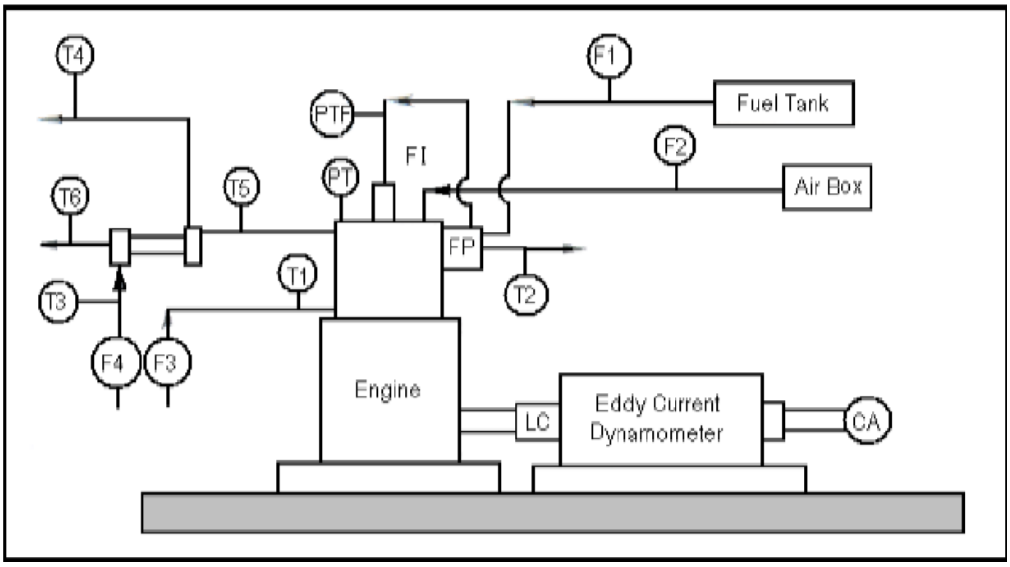


Figure 8: Diagram

Nomenclature:

T1: Jacket Water Inlet Temperature T2: Jacket Water Outlet Temperature
T3: Inlet Water Temperature at Calorimeter T4: Outlet Water Temperature at Calorimeter
T5: Exhaust Gas Temperature before calorimeterT6: Exhaust Gas Temperature after calorimeter
FI: Fuel InjectorF2 : Air Flow Rate
F3: Jacket water flow rateF4 : Calorimeter water flow rate
LC : Load CellCA : Crank Angle Encoder
PTF: Fuel Injection Pressure SensorEGC: Exhaust Gas Calorimeter

A four stroke and direct injected single cylinder diesel engine is used for the experiment. Specification of the engine is represented in Table 3. The schematic experimental set up is shown in Fig 8. Engine torque was measured by eddy current dynamometer. The engine is a conventional fuel injection system. A piezoelectric pressure transducer was mounted with a cylinder head surface for measuringthe cylinder pressure. It is also provided with temperature sensors for the measurement of jacket water, calorimeter water, and calorimeter exhaust gas inlet and outlet temperatures. An encoder is fixed for crank angle record.

The signals from these sensors are interfaced with a computer to engine indicator for displaying P-θ, P-V, mass fraction burnt and heat release versus crank angle plots. The provision is also made for the measurement of volumetric fuel flow. Preset Programme in the in the system calculates indicated power, brake power, thermal efficiency, volumetric efficiency and heat balance. The software package is fully configurable and averaged P-θ diagram, P-V plot and other diagram is obtained for various operating conditions. Initially standard piston (without coating) was tested. The tests were performed at different loads. Then the Piston head was coated with thermal barrier material. The piston head was coated with a 300 μm Titanium dioxide (TiO2) using plasma spray technique. After that replaced the normal piston with Titanium Dioxide coated piston and conduct the performance tests with a compression ratio of 17.5:1 and injection pressure of 200 bar. After that analysis is done by comparing the performance variation of both base engine and coated piston engine.

Table 3: Engine Specification

Cylinders	1
Strokes	4
Bore	80mm
Stroke	110mm
Compression Ratio	16.5 : 1
Max Engine Power	3.7 KW
Max Engine Speed	1500 rpm
Specific Fuel Consumption	175 g/Kwh
Cubic capacity	533 cc
Cooling Type	Water
Engine Type	Kirloskar

VI. RESULTS AND DISCUSSION

Test engine used here in a 5 HP, four stroke, and single cylinder diesel engine.

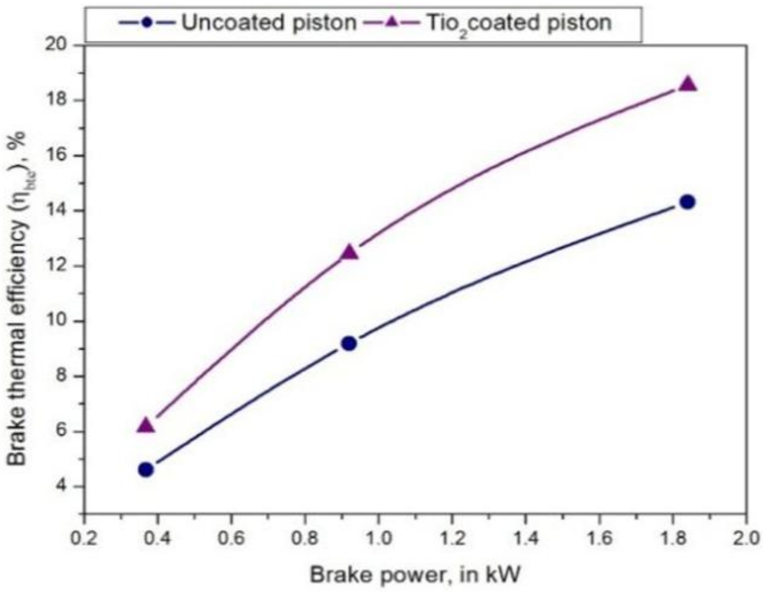


Figure 9:BP Vs BTE

Fig 9 shows the variation of Brake Thermal Efficiency with Brake power for Diesel engine with Titanium oxide coated piston and base piston. We can see that when the load increases the Bth also increases. In the above fig we don't find much difference only a slight increase in the Bth for the coated piston. This is because of the titanium oxide which acts as catalyst to enhance the combustion and also due to the thermal barrier coating which heat transfer. Thatswhy we can say that the Bth of the coated piston is better than base piston.

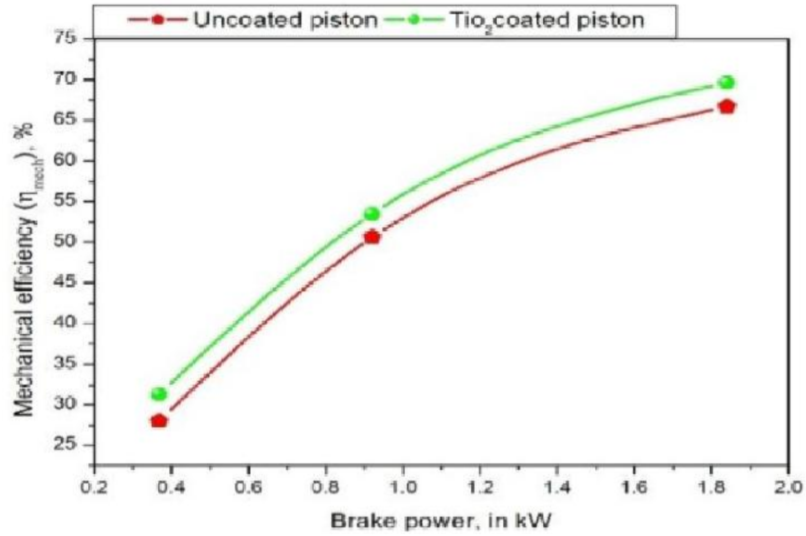


Figure 10:BP Vs ME

Mechanical Efficiency is increased as 6-7 % for the TiO2 coated piston when compared to uncoated piston for the change in pressure of 900 lb/in2 .

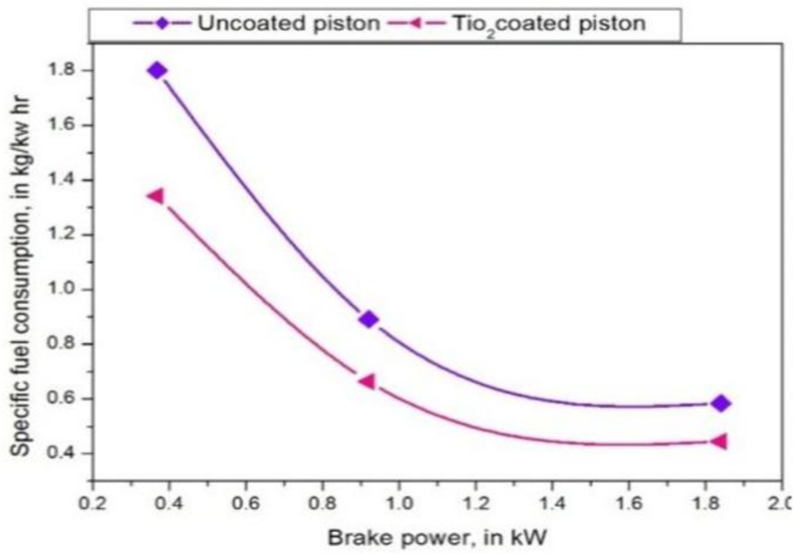


Fig 11:BP Vs SFC

From the comparitive study for the load applied for coated and uncoated piston, We can observe that the S.F.C for coated piston for all the fuels is low when compared to base piston. This is because of better combustion of the fuel due to high temperature in the combustion chamber because of thermal resistance due to coated material and also due to composition of titanium dioxide which acts as catalyst for enhancing combustion and thus reduces the fuel consumption for titanium oxide coated piston.

VII. CONCLUSION

The following conclusion is made for the performance of TiO2 coated piston and uncoated pistons.The results showed that, increasing the brake thermal efficiency and decreasing the specific fuel consumption for Light heat Rejection engine with thermal coated piston compared to the standard engine TiO2 believed to be a low thermal conductive material results in improved efficiency when coated over the parts of the engine. The efficiency is said to be increase to 5% for coated than uncoated piston for varied injection pressure.Coating results in decreased fuel consumption as 0.3 kg/kW hr thus shows that maximum utilization of fuel takes place inside the combustion chamber of the diesel engine.

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