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Experimental Analysis of YSZ Coating on an IC Engine Piston

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ABSTRACT : *As per the second law of thermodynamics the IC (Internal Combustion) engine efficiency depends upon the extraction of work against the heat supplied. Minimization of heat rejection leads to increase the work. Heat rejection takes place through the engine piston, valves and cylinder heads to the surroundings. The aim of the study is to minimize this heat rejection to the surroundings. Heat transfer through the engine parts can minimize by applying the thermal barrier coating materials on the top surface of the engine piston, cylinder heads and valves. In this study an attempt is made to reduce the intensity of heat rejection by using a layer of the ceramic material, like Yttrium Stabilized Zirconia (YSZ) which has low thermal conductivity, high thermal resistance, chemical inertness, high resistance to erosion, corrosion and high strength was selected as a coating material for engine component. In this paper the experiments were carried out with 0.4mm YSZ coated piston and it is found that it has 1% total fuel consumption, 1.2% specific fuel consumption and 0.7% exhaust gas temperature less than the conventional engine with uncoated piston. It is also seen that 2.6% brake thermal efficiency, 2.14% indicated thermal efficiency and 1.35% mechanical efficiency more than the conventional engine with uncoated piston.*

Keywords : *Brake thermal efficiency, indicated thermal efficiency, Mechanical efficiency, Total fuel consumption, Yttrium stabilized zirconia*

I. INTRODUCTION

Energy conservation and efficiency have always been the quest of engineers concerned with internal combustion engines. Even the petrol engine rejects about two thirds of the heat energy of the fuel, one-third to the coolant, and one third to the exhaust, leaving only about one-third as useful power output. Theoretically if the heat rejected could be reduced, then the thermal efficiency would be improved. Low Heat Rejection engines aim to do this, by reducing the heat lost to the coolant. The energy flow through the reciprocating engine is considered. According to the first law of thermodynamics, energy can neither be created nor destroyed. It can only be converted from one form of energy to another form. In internal combustion engines, the chemical energy of the fuel is converted to thermal energy during combustion. The liberated thermal or heat energy cannot be fully utilized for driving the piston due to the losses. The losses are-loss through the engine exhaust, to the coolant and due to radiation. When fuel is supplied to the engine, heat is liberated and 30% of the heat supplied is lost through the engine exhaust, 30% of the heat supplied is lost to coolant. These heat losses need to be minimized to reduce the fuel consumption and to increase the efficiency of the engine. To achieve these goal different engine components like Piston, Combustion Chamber, Cylinder Head are coated. The Combustion Chamber is coated with low heat conducting ceramic materials, which indirectly increase the efficiency of the engine due to the increase of temperature and pressure inside the closed system. This also finds application as Thermal Barrier Coatings, which can improve the efficiency of the engine. The Emission can be reduced and Performance of the internal combustion engine can be increased by different coating methods. Catalytic Coating is done to speed up the reaction rates during combustion. Like Catalysts, various Catalytic surfaces enhance the chemical reaction and speed up the reaction rates. The petrol engine with its combustion chamber walls insulated by ceramics is referred to as Low Heat-Rejection (LHR) Engine. The LHR engine has been conceived basically to improve fuel economy by eliminating the conventional cooling system and converting part of the increased exhaust energy into shaft work using the turbocharged system. This study presents effect of Yttrium stabilised zirconia on the piston on the performance of the modified four stroke petrol engine and emission characteristics of the exhaust gas.

Karuppasamy et al [1] conducted experimental study where alumina-titania and nickel-chromia are used as thermal barrier materials. These materials are used to reduce the heat loss from engine. The Coating is performed by Plasma spraying technique. The results showed a reduction in specific fuel consumption. CO and HC emissions are slightly more than the conventional coated diesel engine at low and medium loads but lesser at higher loads whereas nitrogen oxide emissions are reduced. Results show increase in brake thermal efficiency after coating. Funatani et al [2] discussed about electroplated nickel ceramic composite coatings. The application of NCC coatings in two stroke motor cycles and diesel engines has resulted in some benefits. Reduction in emission and improved fuel economy are observed. Other benefits includes-Lowering of Cylinder Wall, Piston, Piston ring temperature, Lowering of Oil consumption, Thermal barrier protection on piston domes, Reduction on Carbon deposits on piston domes etc.

Rajasekaran et al [3] presented a paper and its main aim was to reduce the heat transfer to the surroundings. Heat transfer through the engine parts is minimized by applying the thermal barrier coating materials on the top surface of the engine piston, cylinder head and valves. Here Yttrium stabilized zirconia (YSZ) which has low thermal conductivity, high thermal resistance, chemical inertness, high resistance to erosion, corrosion and high strength was selected as a coating material for engine component. This study presents the effect of coating on the piston and the performance of modified four stroke petrol engine and the emission characteristics of the exhaust gas. Reduction of heat loss from the cylinder is observed. Therefore the efficiencies are increased and emissions are reduced.

Shrirao et al [4] intended to emphasis on energy balance and emission characteristic for standard engine (uncoated) and low heat rejection (LHR) engine with and without turbocharger. Tests were carried out at different engine load and engine speed conditions for standard and low heat rejection engine with and without turbocharger. The results showed that there was 2.18% decreasing on specific fuel consumption value of low heat rejection (LHR) engine with turbocharger compared to standard engine at full load. There was as much as 12% increasing on exhaust gas temperature of LHR engine with turbocharger compared to standard engine at full load. There was as much as 20.64% increasing on NOx emission of exhaust gas, 22.05% decreasing on CO emission of exhaust gas and 28.20% decreasing on HC emission of exhaust gas of LHR engine with turbocharger compared to standard engine at full load.

Azadi et al [5] showed the effects, advantages and disadvantages of thermal barrier coatings. In this article, effects of the TBC system on the engine performance and the components lifetime are reviewed in diesel engine applications. As a results, a proper type of the coating system could be created from two layers of coatings; including a layer made of NiCrAlY with 150 microns thickness and another layer made of ZrO2-8%Y2O3 with 300 microns thickness by using the plasma thermal spray method. An increase in combustion efficiency, engine power and reduction in fuel consumption are observed. An improvement in the fatigue lifetime of engine component (Cylinder Head) is also observed due to the reduction in surface temperature.

Ciniviz et al [6] studied, the effects of ceramic coating of combustion chamber of a turbocharged diesel engine to engine performance and exhaust emissions were investigated. Increasing mechanical energy by preventing heat losses to coolant and reducing cooling load, improving combustion by increasing wall temperatures and decreasing ignition delay, more power attaining in turbocharged engines by increasing exhaust gas temperatures and decreasing carbon monoxide and soot are aimed. For this aim, cylinder head, inlet and exhaust valves and pistons of the engine were coated with 0.5 mm zirconia by plasma spray coating. Then, the engine was tested for different brake loads and speeds at standard, ceramic coated engine one and ceramic coated engine 2 conditions. The results gained from the experimental setup were analyzed with computer software and presented with comparatively graphics. Specific fuel consumption was decreased 5- 9 percent, carbon monoxide emission was decreased 5 percent, and soot was decreased 28 percent for a specific power output value considering these positive results nitrogen oxide however was increased about 10 percent. By the development of exhaust catalysers, increase in nitrogen oxide becomes no more a problem for present day. When results are generally investigated, it was concluded that engine performance was clearly improved by zirconia ceramic coating.

Dhomne et al [7] presented a paper and in this study the performance of the engine is studied before and after the application of coating on the piston crown. Required modification has been done in the engine to increase the power and decrease the emission of CO & HC thereby making the engine environment friendly. Percentage increase in brake specific fuel consumption, brake thermal efficiency is observed. The performance of an externally scavenged engine will be improved with Ni-Cr-Ce Thermal Barrier Coating, as compared to normal piston & Ni-Cr coating. Therefore Ni-Cr-Ce Thermal Barrier Coating is an effective method to enhance performance of two strokes SI Engine. The engine with TBC piston helps in increasing the power of the engine. This is because complete combustion of the charge in the combustion chamber which leads to minimization of emission of carbon & hydrocarbon in the exhaust gases.

Sivakumar et al [8] In their experimental study, Piston crown coated with Yttria Stabilized Zirconia (YSZ). Experimental investigation is carried out under different loading conditions in a three cylinder diesel engine to understand the influence of Thermal Barrier Coating on performance and emission characteristics in comparison with baseline engine characteristics. For the measurement of emission characteristics, ISO 8178- 4 ‘‘C1’’ 8 Mode testing cycle procedure is followed. Experimental results revealed that the heat loss to the cooling water is reduced up to 5–10% and the thermal efficiency is increased by 3–5% with reduction of brake specific fuel consumption by up to 28.29%. Experimental results also revealed that Hydrocarbon (HC) emission is reduced up to 35.17%, carbon monoxide (CO) by up to 2.72% and Carbon di-oxide (CO2) emission is increased by up to 5.6%.

Sharma et al [9] presented a paper which deals with the study of different ceramic coatings to understand stresses in coatings, porosity and crack penetration by applying thermal shock tests and thermal torch experiment. Also the best ceramic coating material has been suggested suitable as thermal barrier coating for application in internal combustion engines. In literature, piston crown surface, cylinder cover and valve parts are coated with ceramics. Beside these, piston rings and cylinder liner are coated with ceramics. Zirconia is observed with best thermal shock and thermal punching experiments. Domakonda et al [10] showed the application of Thermal Barrier Coatings in Diesel engines. The paper explains the effect of insulation on engine performance and emission characteristics. The factors that influence thermal efficiency, exhaust emission are also discussed. The higher temperatures of the combustion chamber surfaces of LHR Engine deteriorate properties of lubricating oil. Hence one of the main directions of the research in adiabatic engines should be development of lubricating oils capable of retaining satisfactory viscosity at the higher temperatures encountered in the engine.

From the literature survey it is clear that the Thermal Barrier Coating on piston have significant effect on thermal efficiency. In this study an attempt is made to reduce the intensity of thermal by using a layer of the ceramic material, like Yttrium Stabilized Zirconia (YSZ) which has low thermal conductivity, high thermal resistance, chemical inertness, high resistance to erosion, corrosion and high strength was selected as a coating material for engine component. The experiments were carried out with 0.4mm YSZ coated piston and the results were discussed.

II. EXPERIMENTAL SETUP

A TVS STAR CITY engine is tested with brake drum load. Table 1 tabulates the specification of the engine.

Table 1: Specification of the engine

TYPE	4 STROKE, AIR COOLED OHC SI ENGINE
ENGINE DISPLACEMENT (cc)	109.7cc
BORE×STROKE	53.5mm×48.8mm
MAXIMUM POWER	6.1KW @ 7500rpm
MAXIMUM TORQUE	8.1N-m @ 5000rpm
TRANSMISSION	4 SPEED CONSTANT MESH

The engine tests were conducted in single cylinder, air cooled spark ignition engine at constant speed of 1500 rpm. The schematic diagram of the experimental setup is shown in the figure 1.Two types of test were conducted namely base line test and coated piston test by the following procedure. The load was given as 20%, 40%, 60%, and 80% and full load and the readings were taken. For each load the time taken for 10CC of fuel was measured. The exhaust emission and smoke parameter will be measured by Exhaust gas analyzer and smoke meter. Initially readings will be taken with normal (uncoated) piston. After taking the readings, the engine parts will be dismantled. Piston Crown is coated with YSZ. Same procedure was repeated to predict the performance of the engine with the coating.

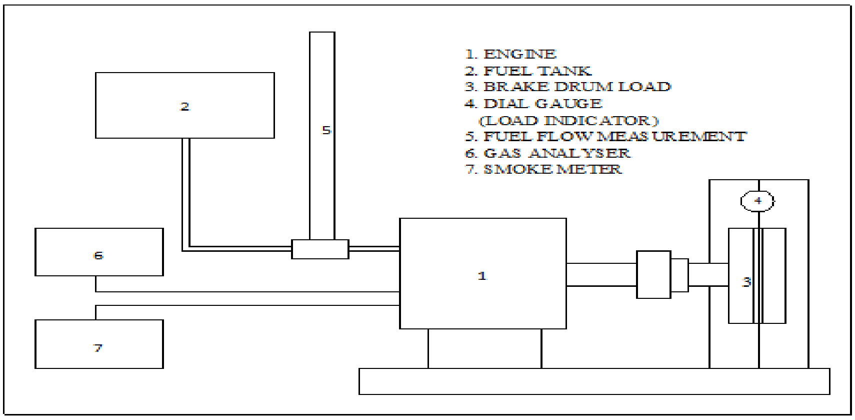

Figure 1: Schematic diagram of the experimental set up

The figure 2 shows the uncoated piston of Tvs star city engine. The experiments were carried with the uncoated piston and the engine is dismantled for coating the piston with YSZ. Numerical simulations are carried out in gambit and fluent to determine the location, thickness for coating.

Figure 2: Uncoated Piston

The figure 3 shows the Piston coated with Yttrium Stabilised Zirconia (YSZ) on the crown. The simulation results shows better result when coating on the entire crown of the piston. The piston after coated is fitted back to the engine to carry out the second experiment.

Figure 3: Coated Piston

III. RESULTS AND DISCUSSIONS

The low heat rejection (LHR) engine concept is based on minimising the heat rejection to the coolant and recovering the energy in the form of useful work. Zirconia is a low thermal conductivity material. It will act as a barrier for the heat transfer to the surroundings from the engine's combustion chamber and reduces the heat loss from the engine. The engine with coated and uncoated pistons was tested for its performance characteristics.
The Graphs shows comparison of efficiencies for uncoated and coated piston of the same dimension.

Figure 4 shows the variations of total fuel consumption of the standard engine and compared with coated piston. It is clear that the total fuel consumption of the engine after coating is reduced. For a brake power of 0.026KW the total fuel consumption for engine with YSZ coated piston is 1% less than that of engine uncoated.

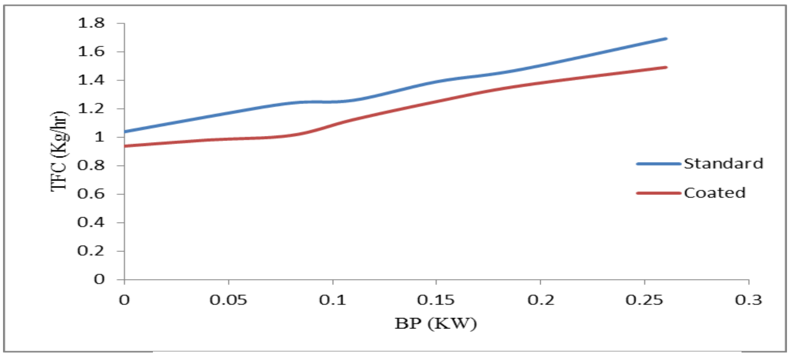

Figure 4: Variation of Brake power with Total fuel Consumption

From Figure 5 it is clear that SFC is high for low loads and it is decreasing when the load increases. Moreover same for coated and uncoated pistons, but at the higher loads a significant change in SFC occurs in coated pistons. For a brake power of 0.026KW the specific fuel consumption for engine with YSZ coated piston is 1.2% less than that of engine uncoated.

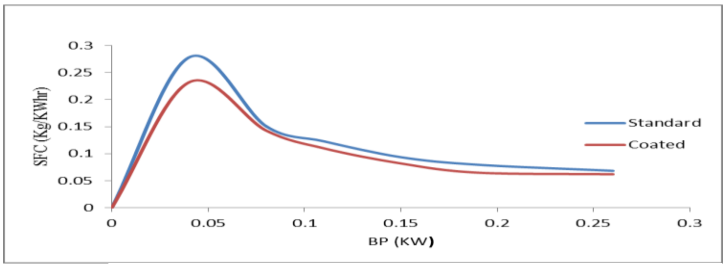

Figure 5: Variation of Brake power with Specific fuel consumption

Figure 6 shows that brake thermal efficiency is low for the both the cases, because of the low brake power at low loads. Then it is increases due to the brake power increases. A significant improvement is observed at the full load conditions, the brake thermal efficiency is increases above 3% in the coated piston. For a brake power of 0.026KW the brake thermal efficiency for engine with YSZ coated piston is 2.6% more than that of engine uncoated.

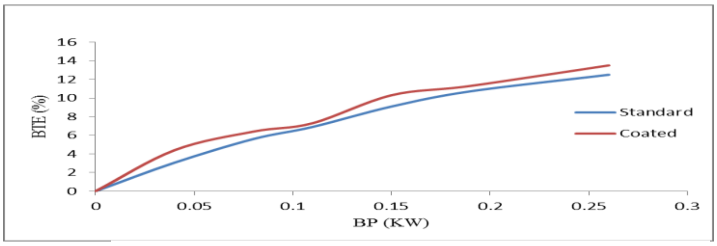

Figure 6: Variation of Brake power with Brake thermal efficiency

Figure 7 shows the variation of Indicated thermal efficiencies of the Standard and Coated engine. It is seen that the Indicated thermal efficiency is greater for Engine with Coated engine than with the engine with standard piston. For a brake power of 0.026KW the indicated thermal efficiency for engine with YSZ coated piston is 2.14% more than that of engine uncoated.

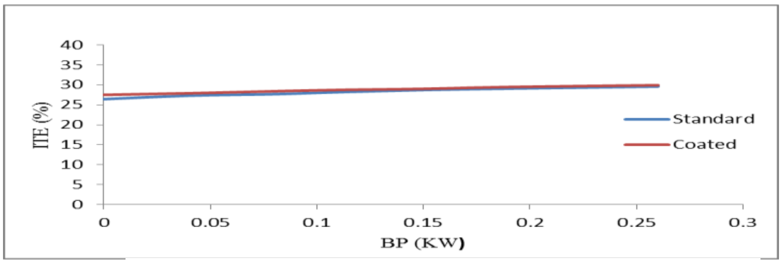

Figure 7: Variation of Brake power with Indicated thermal efficiency

From figure 8 it is observed that the mechanical efficiency is slightly increasing for the coated piston from low load conditions to a higher load conditions. The efficiency is always slightly higher in the coated piston from low load to a higher load due to the small increases of indicated power in the coated piston when compared with uncoated piston. Therefore the mechanical efficiency is always higher in the case of coated piston. For a brake power of 0.026KW the mechanical efficiency for engine with YSZ coated piston is 1.35% more than that of engine uncoated.

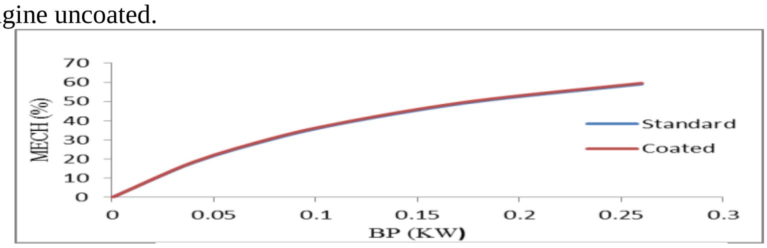

Figure 8: Variation of Brake power with Mechanical efficiency

From figure 9 it is observed that the temperature of the exhaust gas for the uncoated engine is greater than the coated engine. For a brake power of 0.026KW the Exhaust gas temperature for engine with YSZ coated piston is 0.7% less than that of engine uncoated.

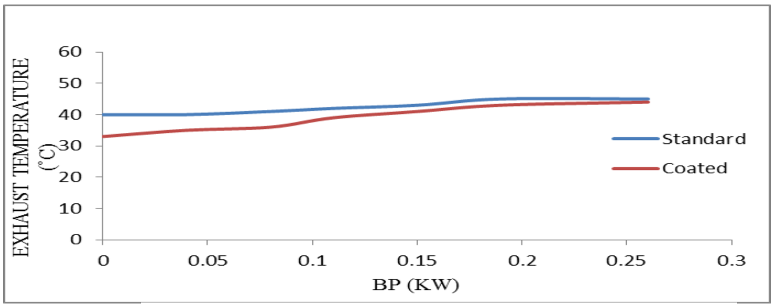

Figure 9: Variation of Brake power with Exhaust gas temperature

IV. CONCLUSION

The applications of thermal barrier coatings to various components of combustion zone of an engine such as piston has produced significant improvements in thermal and mechanical efficiency and other performance parameters of the engine like specific fuel consumption and reduce exhaust emission. As the zirconia is a low thermal conductivity material, it reduces the heat loss from the cylinder to the surroundings. Therefore the efficiencies are increased and the emissions are reduced because of various chemical reactions takes place inside the cylinder at high temperature. By doing the experiments on coated and uncoated pistons of same dimensions, the following conclusions were made

- For a brake power of 0.026KW the total fuel consumption for engine with YSZ coated piston is 1% less than that of engine uncoated.
- For a brake power of 0.026KW the specific fuel consumption for engine with YSZ coated piston is 1.2% less than that of engine uncoated.
- For a brake power of 0.026KW the brake thermal efficiency for engine with YSZ coated piston is 2.6% more than that of engine uncoated.
- For a brake power of 0.026KW the indicated thermal efficiency for engine with YSZ coated piston is 2.14% more than that of engine uncoated.
- For a brake power of 0.026KW the mechanical efficiency for engine with YSZ coated piston is 1.35% more than that of engine uncoated.
- For a brake power of 0.026KW the Exhaust gas temperature for engine with YSZ coated piston is 0.7% less than that of engine uncoated.

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