Influence of Thermal Barrier Coatings on 4 Stroke Single Cylinder Diesel Engine Performance

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Abstract— Thermal barrier coating play a very significant role in the performance prediction. These prospects of improving the design and performance have generated impetus to active research on adiabatic or more appropriately, low heat rejection (LHR) or insulated engines. So with this aim, this experiment presents concept of thermal barrier ceramic coating in Internal Combustion engines. This experiment will aim to study effect on performance and emissions results of with & without coating for four stroke single cylinder diesel engine. The engine was thermally insulated by coating some parts of it, such as piston, exhaust and intake valves surfaces with TAFA95MXC material having 450µm thickness. The modified condition (coated parts) increase 2.12% thermal efficiency,fuel consumption decrease about 6.48%, exhaust gas temperature can be increase up to 11.42 %, CO reduced by 14.28%, HC reduced by 2.12% and NOx increased by 8.43 % compare to unmodified (original) condition.

Key words: Stroke Single Cylinder Diesel, consumption.

I. INTRODUCTION

The quest for increasing the efficiency of an internal combustion engine has been going on since the invention of this reliable workhorse of the automotive world. In recent times, much attention has focused on achieving this goal by reducing energy lost to the coolant during the power stroke of the cycle. A cursory look at the internal combustion engine heat balance indicates that the input energy is divided into to exhaust. This phenomenon, of course, should conform to some physical laws. The first law of thermodynamics is satisfied as long as energy is converted regardless of how that energy is apportioned between various categories. The second law stipulates that all the input energy cannot be converted into work; in other words, it is impossible to obtain 100% efficiency, so some heat has to be rejected, preferably at the lowest possible temperature to achieve highest possible efficiency. The reduction in the in cylinder heat transfer to either the coolant and/or the environment does not violate the second law of thermodynamics and, moreover, according to the first law, has the potential of producing more work. Added to this, another important advantage of the concept is the great reduction in parasitic losses due to reduction of cooling system, thus increasing the brake power of the engine. These prospects of improving the design and performance have generated impetus to active research on adiabatic or more appropriately, low heat rejection (LHR) or insulated engines. The coatings of insulation materials used in the LHR engine must have a high temperature strength, high expansion coefficient, low friction characteristics, good thermal shock resistance, light weight and durability roughly three equal parts: energy converted to useful work, energy transferred to coolant and energy lost. [16]

A. Introduction to Thermal Barrier Materials:

Thermal barrier famous materials are ceramic materials. Ceramics have been used since nearly at the beginning of low heat rejection engines. These materials have lower weight and heat transfer coefficient comparing with materials in conventional engines. Nowadays, important developments have been achieved in quantity and quality of ceramic materials. Also new materials named as "advanced technology ceramics" have been produced.

B. Properties of Thermal Barrier Ceramic Materials:

- High chemical stability
- Resistant to high temperatures
- High hardness values
- Low densities
- Can be found as raw material form in environment
- Resistant to wear
- Low heat conduction coefficient
- High compression strength

C. Different ceramic materials:

- Different ceramic materials available as listed below.
- Alumina (Al2O3),
- Magnesia (MgO),
- Barilla (BeO),
- Yttria (Y2O3) and non-oxide ones

D. Different Process or Technique Used For Coating:

- Plasma spray method
- High velocity oxygen fuel (HVOF) method
- Electrostatic laser spray
- Physical Vapour Deposition (PVD) method
- Rota plasma spray method
- Electroplating method

E. Benefits of Coating:

The transfer of heat is conducted through the combustion chamber elements, like valves, piston surfaces, and rings. Coating of these elements by a ceramic with low thermal conductivity keeps the heat in the chamber and hence increases the temperature. Ceramics, with their high temperature resistance, may offer an excellent coating surface to reduce the amount of degradation and to improve component durability of engines. Over the last 10 years there has been intensive development in methods to coat the cylinder bore, piston and valves for the automotive industry. [11]

The primary objectives that we like to achieve by adiabatizing the engine cylinder by using Thermal Barrier Coatings (TBC) are as follows:

- To increase the thermal efficiency of the engine.
- To increase the temperature of combustion in the engine cylinder for complete combustion.
- To reduce the fuel consumption.
- To reduce the exhaust emission gases.
- To increase the performance of the engine.
- To increase component durability of engines.

II. Coating Materials and Preparation of Coat

TAFA95MXC has been used as thermal barrier coating material on account of its lower thermal conductivity and higher coefficient of thermal expansion. The typical composition of material include, silicon (1.60 wt%), Chromium (29.0 wt%), Manganese (1.65 wt%), Boron (3.75 wt%), Iron (64.0 wt%). The engine components such as piston, valves were coated with TAFA95MXC by plasma spray coating technique.TAFA 95 MXC material having melting point 1204 °C, Bond strength 5775 psi, Density 6.7 gm/cm^2, thermal conductivity 5.1 W/m°k. Before commencing the coating with TAFA95MXC, the substrate material of piston, valves were subjected to grind up to 450 µm than after coated with 450 µm thickness. The photograph of the coated engine components has been shown in Fig. 1. Since the thickness of the coating duly affects the performance of the engine.

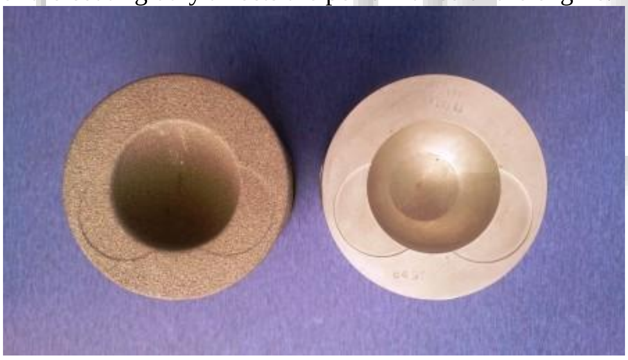

Fig. 1: Coated Piston with TAFA 95 MXC Material & Uncoated Piston

III. Experimental Setup and Arrangement

To evaluate the performance and emission characteristics, the specific type of engine is used in this project, single cylinder, water cooled, HSDI diesel engine used. Set up of the experimental engine is illustrated in fig 2 and its specifications are listed in Table I. The engine is coupled with an electrical dynamometer with load bank acting as a variable load system. Various instruments and gauges are used to obtain different measurements. The engine speed measure with the help of digital tachometer, fuel tank connected with calibrated glass burette to measure mass of fuel for experiment, engine intake air supply is connected to air box for measure mass of air consume during the experiment-type thermocouple with digital temperature indicator was used to measure exhaust temperature. In this engine using with/without the coated piston & valves to measure engine performance & emission in C.I engine.

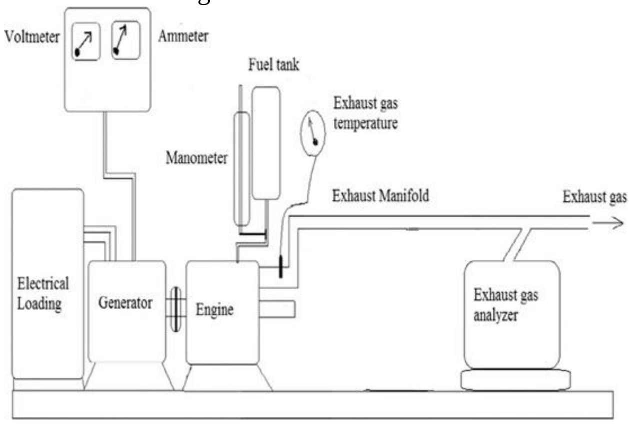

Fig. 2: Schematic Diagram of Experimental Set Up

Table I: Engine Specification

Parameters	Specification
Model	New JaiKishan diesel engine
RPM	1500
No. of cylinder	Single cylinder
No. of stroke	Four stroke
Engine Power	4.5 KW
Cylinder bore	85 mm
Stroke length	110.80 mm
Injection timing	26ºBTDC
Injection pressure	185 bar
Compression Ratio	18:1
Specific fuel consumption	250 gm/KWhr
Lubricating oil	Yantrol 32

IV. Experimental Procedure

- The engine will be started by the mechanical lever. The fuel control lever was set towards higher fuel rate. The speed will be adjusted to 1500 RPM through fuel control lever.
- Before starting the test, the engine will run for 30 minutes to get stabilization and thereafter a stabilization period of 30 minutes will be allowed in subsequent testing.
- At first, the tests will conduct using uncoated (original) piston by varying the load from no load, 20%, 40%, 60%, 80% load and full load without any modification. This was base condition of engine.
- At second , the tests were conducted using neat constant speed (1500 RPM) and Coated piston by varied the loads (0%,20%,40%,60%,80% and 100%) condition.
- The performance and emission from the engine running on coated piston were evaluated and compared with uncoated piston.
- At constant speed and different load condition, measured the brake power, brake specific fuel consumption (BSFC) and brake thermal efficiency (BTE) measure for 50ml fuel consumption with Emission parameters such as

CO, NOx, and HC compared with and without modification condition.

V. RESULTS AND DISCUSSIONS

A. *Performance results:*

1) *Effect of Brake Power on Brake Thermal Efficiency:*

The brake thermal efficiency of the engine is one of the most important parameter for evaluating the performance of the engine. It indicates the combustion behavior of the engine to a greater extent. The variations of brake thermal efficiency with brake power of the engine with various condition are shown in Fig 3 and compared with the brake thermal efficiency observed with base data. It is noticed that the BTE of the engine increased with increasing loads.

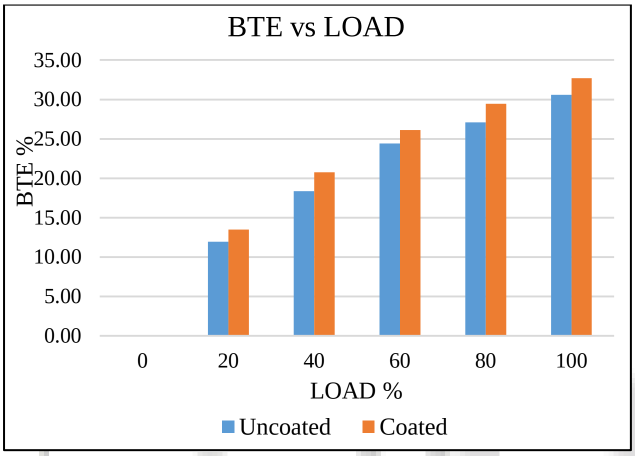

Fig. 3: Variation of Brake Thermal Efficiency with Brake Power

It can be observed from the figure that the thermal efficiency is highest for engine with coated piston. The brake thermal efficiency of original (unmodified) condition is 30.58% and of coated piston is about 32.70% hence increase 2.12% compares to original condition.

2) *Effect of Brake Power on Brake Specific Fuel Consumption:*

Figure 4 shows the variation in BSFC (brake specific fuel consumption) with respect to brake power. It can be seen from the Fig 4 that fuel consumption decreases with increase in load. One possible reason for this reduction is that the brake power increases in higher percentage compare to fuel consumption. Fuel consumption decreases about 6.48% compare to unmodified condition.

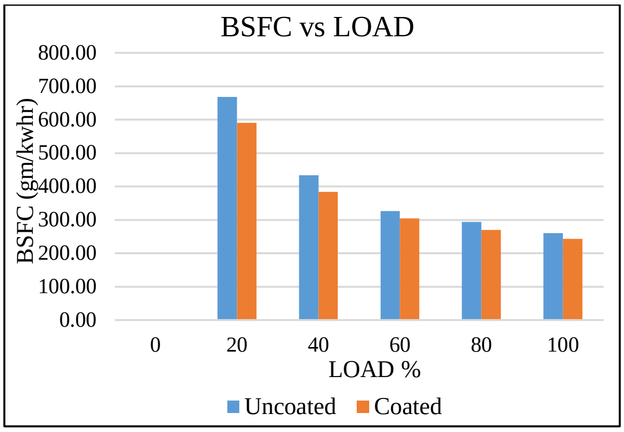

Fig. 4: Variation of BSFC with Brake Power

3) *Effect of Brake Power on Exhaust Gas Temperature:*

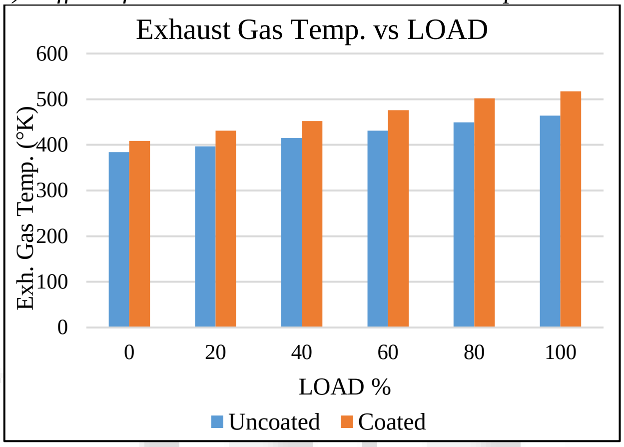

Fig. 5: Variation of Exhaust Gas Temperature with Brake Power

Figure 5 compares the brake power and exhaust gas temperature. The exhaust gas temperature of the engine is the indication of conversion of heat into work. With increase in fuel consumption so the temperature in the combustion chamber increases. By modifying the normal engine with newly designed coated piston exhaust gas temperature can be increase up to 11.42 %.

B. *Emission parameters*

1) *Effect of Brake Power on Carbon Monoxide (CO):*

Carbon monoxide emissions from internal combustion engines are controlled mainly by the fuel/air equivalence ratio. Usually diesel engines work with lean mixtures, but local conditions may be rich and lead to the formation of CO. The emission of carbon monoxide for different loads and also for different condition has been shown in Fig 6. CO is the outcome of poor atomization and incomplete combustion. Fig 6 compares the CO emission of engine at varying brake power and at different conditions. It is seen that, CO emission decreases with increase in load for any condition and also different values at even same load. The CO emission is 0.07% at unmodified condition and 0.06% at coated piston condition hence it is reduced by 14.28% at full load.

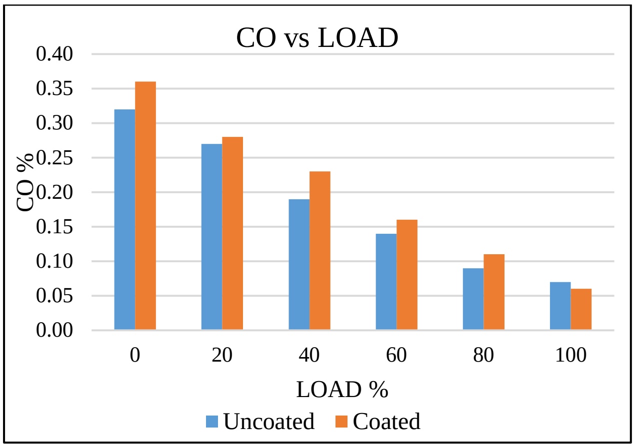

Fig. 6: Variation of Carbon Monoxide (CO) with Brake Power

2) Effect of Brake Power on Hydrocarbons (HC):

Hydrocarbon emissions from diesel engines vary widely with different operating conditions; different HC formation mechanisms are likely to be most important at different operating modes.

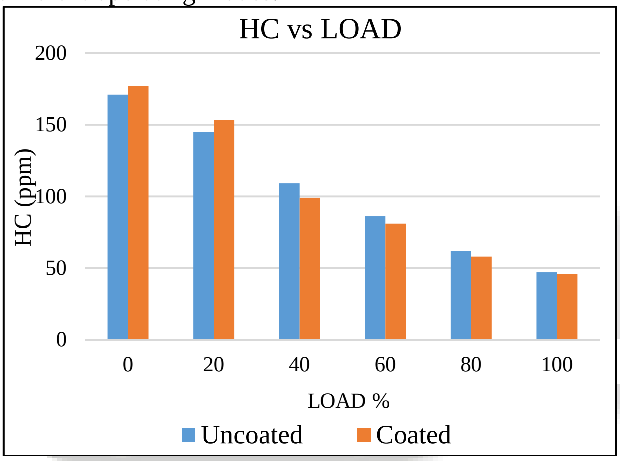

Fig.7: Variation of Hydrocarbons (HC) with Brake Power

Under idling or light load operation, the engine produces higher amounts of HC than under full load conditions. But when the engine is over fueled, HC emissions also increase. HC is a function of over-mixing (mixture is too lean), under-mixing (mixture is too rich), and cylinder wall temperature, which suggests that wall quenching is important. Fig 7 shows the variation of hydrocarbon exhaust emission for different load and for different condition. Hydrocarbons are due to incomplete combustion of carbon compounds in the fuel. In order to maintain low levels of HC, ignition delay time has to be as short as possible, and cylinder content temperature should be high enough to enable acceleration of thermal oxidation reactions that will consume formed HC.

As the load increases, fuel consumption is increased. As the mixture strength reaches a certain level, the combustion duration of the gas becomes shorter and the flame spread speed increases result in lower HC emission at higher load. HC is decreased from 47 ppm to 46 ppm compare original condition to coated piston at full load hence HC reduced by 2.12%.

3) Effect of Brake Power on Oxides of Nitrogen (nox):

Nitrogen oxides are known as an air contaminants formed through the combustion of fossil fuels and other fuels that contain nitrogen. Combustion of nitrogen-free fuels at high temperatures in the presence of air oxidizes the nitrogen in the air, producing nitricoxide. When nitric oxide reaches the air, it oxidizes into nitrogen dioxide, which gives smog its brown color. The mixture of nitric oxide and nitrogen dioxide is referred to as NOx. High temperature and high oxygen concentration results in high NO formation. As shown in fig 8 NOx formation is highest with coated piston. In coated piston temperature of combustion chamber increasing hence increases. NOx level is increased from 557 ppm to 604 ppm compare to unmodified (original) condition and coated piston at full load which is increased by 8.43 %.

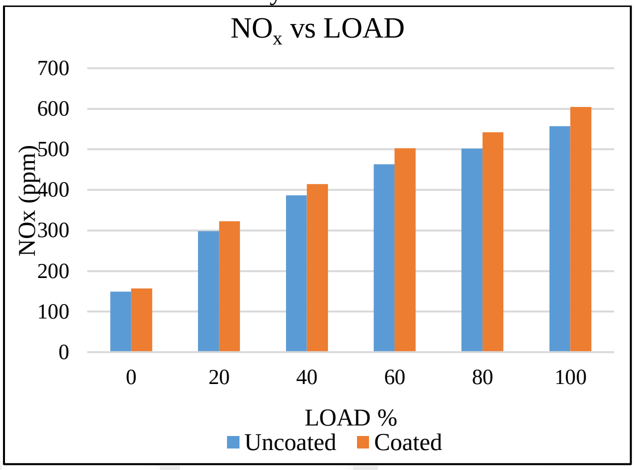

Fig. 8: Variation of Nitrogen Oxide (Nox) with Brake Power

VI. Conclusion

- Brake Thermal Efficiency increased by 2.12 % with respect to uncoated condition.
- Fuel consumption decreases about 6.48% compare to unmodified condition.
- By modifying the normal engine with newly designed coated piston exhaust gas temperature can be increase up to 11.42 %.
- The CO emission is 0.07% at unmodified condition and 0.06% at coated piston condition hence it is reduced by 14.28% at full load.
- HC is decreased from 47 ppm to 46 ppm compare original condition to coated piston at full load hence HC reduced by 2.12%.
- NO_X level is increased from 557 ppm to 604 ppm compare to unmodified (original) condition and coated piston at full load which is increased by 8.43 %.

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