Experimental Study of the Effect of Thermal Barrier Coating on Diesel Engine Performance

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Abstract - *The depletion of fossil fuel resources at a faster rate in the present world is demand for searching alternative fuels and the innovative methods to increase in efficiency of internal combustion engines. In this regard the use of thermal barrier coating materials in the automotive industry has been found to yield a significant effect on the efficiency of engines. Higher the operating temperature more will be the efficiency of the system. However, such higher temperatures demand for enhanced temperature resistant materials to be used. Yattria Stabilized Zirconia material is used as coating for the engine piston crown and cylinder liner by Plasma Spraying technique. The thermal barrier coating on the top piston surface decreases the thermal conductivity and increases the unburned charge oxidation, so that the metallic substrates will be exposed to lower peak temperature thereby reducing the thermal stress in engine components. Brake thermal efficiency and mechanical efficiency of coated piston are increased by the average value of 7.5% and 20% respectively. Specific fuel consumption was reduced by 5% with the coated piston. Also thermal barrier coatings on other elements of combustion chamber of internal combustion engine offer advantages including multi-fuel capacity and high power density.*

Key Words: **Thermal barrier coating, Diesel engine, Thermal efficiency, Plasma Spraying technique, Fuel consumption**

1. INTRODUCTION

Thermal barrier coatings (TBC) are ceramic layers deposited over metallic parts in order to provide their thermal insulation from the combustion gases. Thermal barrier coatings allow achieving higher efficiency of combustion engines (internal combustion engines and gas turbine engines) due to an increase of their operating temperature. Internal combustion engines are the integral part of every automotive, we come across in our day-to-day life. The reliability of IC Engines, especially petrol (gasoline) based; make them the most widely used prime mover in automobiles. However they are having very poor thermal efficiency. IC engines are constantly being modified in order to meet the rising demand for more efficient generation of power. The increasing pollution levels caused due to vehicular emissions also stress the need for intense research. It has been observed that there is an undesirable heat loss of more than 15% in an IC Engine through its combustion chamber walls and piston. This heat loss can be avoided by making use of TBC materials. Ceramics have a higher thermal durability than metals; therefore it is usually not necessary to cool them as fast as metals. Low thermal conductivity ceramics can be used to control temperature distribution and heat flow in a structure. Thermal barrier coatings (TBC) provide the potential for higher thermal efficiencies of the engine, improved combustion and reduced emissions. In addition, ceramics show better wear characteristics than conventional materials. Lower heat rejection from the combustion chamber through thermally insulated components causes an increase in available energy that would increase the in-cylinder work and the amount of energy carried by the exhaust gases, which could be also utilized. A lot of experimental study has been done to utilize these ceramic properties to improve thermal efficiency by reducing heat losses, and to improve mechanical efficiency by eliminating cooling systems. When cylinder-cooling losses are reduced, more of the heat is delivered to the exhaust system. This effective recovery of energy by exhaust improves the thermal efficiency of low heat rejection engine (LHR). [1] Thermal barrier coatings may increase the useful engine energy due to a reduction of the coolant energy.

The temperature of the combustion gases in a conventional diesel engine without thermal barrier coating is about 932°F (500°C). It may be increased up to 1472°F (800°C) by using ceramic coatings over the diesel combustion chamber surface. The coating thickness is of order of 0.04” (1 mm). Application of thermal barrier coatings in turbocharged diesel engines allows increasing the combustion gases temperature 2012°F (1100°C). At such high temperatures not only the engine efficiency is improved but also the content of the pollutants in the exhausting gases is reduced. [2] Krzysztof Z. Mandera in his journal explained the effects of plasma spray coating in Diesel engines [3]. In the present investigation, the cylinder liner was coated with CSZ ceramic material using a plasma spray coating. Plasma spraying is a thermal spray process that uses an inert plasma stream of high velocity to melt and propel the coating material on to the substrate. Thermal barrier coatings are duplex systems, consisting of a ceramic bond coat. The top coat consists of ceramic material whose function is to reduce the temperature of underlying, less heat resistant metal part. The bond coat is designed to protect the metallic substrate from oxidation and corrosion and promote the ceramic topcoat adherence.

In this article, we propose the use of thermal barrier coating materials in various components of IC Engine which could greatly improve the thermal efficiency and volumetric efficiency of the engine.

2. METHODOLOGY

A thermal barrier coating is generally composed of two layers:

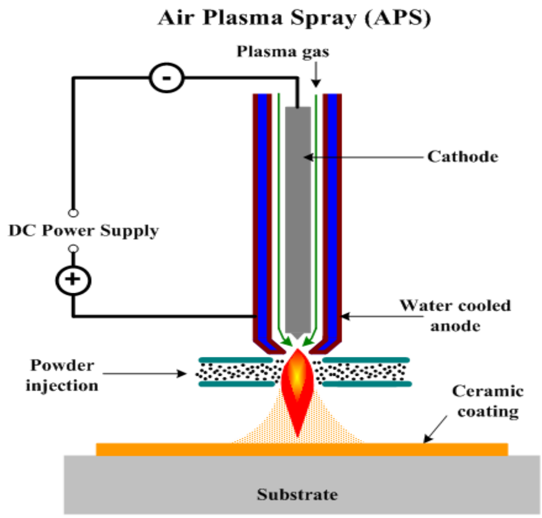
Metallic Bond Coat with a thickness of about 0.004" (0.1 mm). The alloy of the bond coating is MCrAlY, where M is Ni, Fe or Co. The bond coat is an intermediate layer providing strong adhesion of the outer ceramic layer to the substrate surface. The bond coat also inhibits the diffusion of the substrate and the ceramic coating components. Aluminum in the amount of about 10% in the bond diffusing from the combustion gases throghout the ceramic layer. The oxide layer is composed of α-Al2O3.

Outer ceramic layer (Top Coat) Commonly 6-9% yttria (Y2O3) stabilized zirconia (ZrO2) with tetragonal crystal structure is used for building the outer ceramic layer. Yattria is added to zirconia in order to stabilize the tetragonal structure. Without a stabilizing agent tetragonal zirconia transforms to monoclinic allotrope stable at low temperatures. The volume change (about 8%) resulting from the tetragonal-monoclinic transformation causes internal stresses and cracking. Monoclinic zirconia is also undesirable because of its low Coefficient of Thermal Expansion and poor mechanical properties. Tetragonal zirconia is characterized by:

- Low thermal conductivity (about 2 W/(m*K))
- High Coefficient of Thermal Expansion which allows reducing thermal stresses at the boundary with the metallic substrate
- Relatively high Fracture Toughness
- High thermal shock resistance.

Method of depositing thermal barrier coatings:
Air Plasma Spraying (APS):

The method utilizes an electrical arc ionizing Argon flowing through it and converting into hot plasma at a temperature of about 15,000°F (8,300°C). The ceramic material in powdered form is injected into the plasma jet where the ceramic grains melt and move in the stream of the hot gas towards the substrate surface. When the molten particles impact the substrate surface they solidify in form of splats (flattened discs). The resulting microstructure is composed of the grains and elongated pores stretched in the direction parallel to the substrate surface.



Air Plasma Spraying Technique

In the various ceramic materials, cerium stabilized zirconia (CSZ) has excellent toughness, hot strength, and thermal shock resistance, low thermal conductivity and a thermal expansion coefficient close to those of steel and cast iron. CSZ was chosen as the material for the thermal barrier coating in the cylinder liner.

TBC COATING IN CYLINDER LINER

At present TBCs are applied to combustion components of IC engines, mainly for pistons crow, valves, cylinder cover, and cylinder liner. However, the extended application of TBC to cylinder liner has not been explored practically. Cylinder liner is one of the important components of IC engine which severely under goes wear and tear due to reciprocating motion of piston. At the same time, linear as subjected to thermal stresses caused by hot gasses of combustion.

TBC in the place of linear has to play very important role in minimizing wear and tear, heat transfer from cylinder to surroundings. The problem presently faced in implementing of TBC as engine cylinder is thermal mismatch which mainly occurs due to improper adhesion and difference in thermal expansion coefficient between bond coat and cylinder materials. TBC must also withstand wear and tear.

EXPERIMENTAL SETUP

Experiments were conducted with single cylinder, four stroke diesel engine in IC engine lab. The specifications of the engine are tabulated. Performance parameters were evaluated for standard diesel engine and piston coated diesel engine.

Fig. Single cylinder, four stroke diesel engine

Engine Specifications

Engine made	Kirloskar
Type	Single cylinder, four stroke diesel engine
Bore	80 mm
Stroke	110 mm
Rated power	5 HP
Speed	1500 RPM
Compression ratio	16:1
Capacity	250

3. EXPERIMENTAL RESULTS

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

SFC

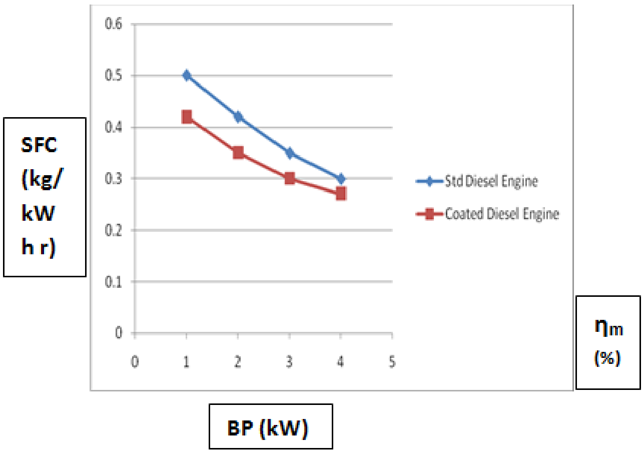


Fig. 1: Specific Fuel Consumption v/s Brake power

The graph shows the variation of SFC with BP. When the conventional diesel engine is tested without ceramic coating the maximum SFC has been found to be 0.5 Kg/hr/KW. For the same engine with ceramic coated parts the SFC comes down to 0.42 Kg/hr/KW .It was observed that specific fuel consumption for a modified engine decreases by 16%.

BRAKE THERMAL EFFICIENCY:

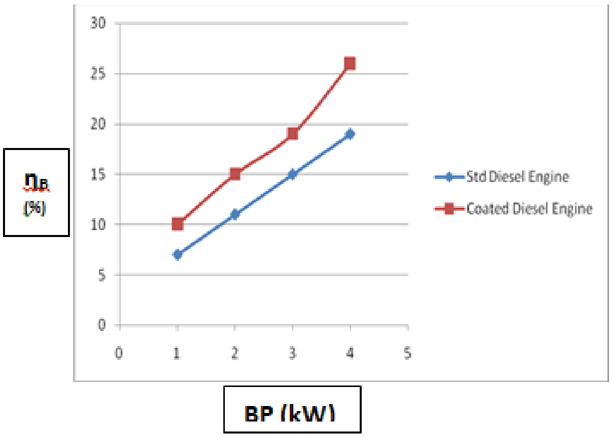


Fig. 1: Brake Thermal Efficiency v/s Brake power

For the conventional diesel engine, if tested without ceramic coating, the maximum brake thermal efficiency has been found to be 19% For the same diesel engine if tested with ceramic coating, the maximum brake thermal efficiency has been found to be 26%. It results in an increase of 7% when compared with the engine without ceramic coating. This increase in efficiency is due to low heat rejection in engine cylinder because of thermal barrier coating.

MECHANICAL EFFICIENCY

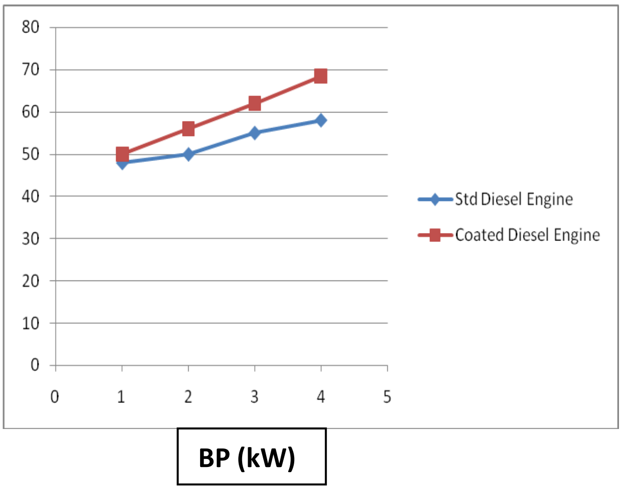


Fig. 1: Mechanical Efficiency v/s Brake power

For the conventional diesel engine, if tested without ceramic coating, the maximum mechanical efficiency has been found to be 58%. For the same engine with ceramic coated piston crown, the maximum mechanical efficiency has been found to be 68.5%. This results in an increase in mechanical efficiency by 10.5% when compared with the engine without ceramic coating.

4. CONCLUSION

The applications of thermal barrier coatings to various components of combustion zone of an engine such as piston and cylinder liner has produced significant improvements in thermal and mechanical efficiency and other performance parameters of the engine like specific fuel consumption. Thus this paper explores various aspects, effect and application of thermal barrier coating in piston, cylinder liner and Diesel engine performance. So this paper serves as a complete reference guide for the researches who work on improvement of diesel engine performance.

REFERENCES

[1] Winkler M.F., Parker D.W. and Bonar J.A.,1992, "Thermal barrier coatings for dieselengines: ten years of experience", SAEInternational, Paper No. 922438.

[2] Sridhar K,Reji Kumar R,Narasimha M, 2013 "Thermal barrier Analysis in Diesel" International Journal of Modern Engineering Research (IJMER) Vol.3, Issue.3, pp-1435-1441.

[3] Gumus M and Akcay M,2010 "Thermal barrier coatings for diesel engines", international scientific conference, Gabrovo.

[4] Ilker Turgut Yilmaz, "Thermal barrier coatings for diesel engines", International scientific conference 19 – 20 November 2010.

[5] Abdullah Uzun, I.smet Çevik , Mustafa Akçil , "Effects of thermal barrier coating on a turbocharged diesel engine performance", Surface and Coatings Technology 116–119 , 1999, 505–507.