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Research Article

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The effect of thermal barrier coating material in CI engine using higher fraction ethanol diesel blend

***V. Gnanamoorthi[1] and G. Devaradjane[2]**

[1]Department of Mechanical Engineering, University College of Engineering Villupuram, Villupuram, India
[2]Department of Automobile Engineering, M. I. T., Anna University, Chennai, India

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ABSTRACT

This paper investigates the effect of semi thermal barrier coating (TBC) onTorodial (re-entrant) piston bowl geometry combustion chamber at a higher compression ratio of 19.5:1 in an internal combustion engine. The tests were performed on a single cylinder, four stroke, direct injection, diesel engine using E50 ethanol diesel blend. The engine's piston crown was coated with variousTBC materials in different composition ratios such as Aluminium oxide (Al2O3) + Molybdenum (Mo) + Titanium oxide(TiO2) (40%+30%+30%), over a 150μm thickness of NiCrAlY bond coat. The maximum thickness of coating is about 300 μm.The engine with and without coating has been tested with the test fuels and diesel fuel in the same operating conditions.The test resultshows that they coated engine has areduction in brake specific fuel consumption (BSFC) and an increase in brake thermal efficiency (BTE) of about 6%. It is also observed that there is a considerable increase in NO_x of about 4.32 % and reduction in CO and HC emission. The analyses of the results were carried out using scanning electron microscope (SEM) and EDX.

Keywords : Thermal barrier, Ethanol, Toroidal, Coating, Pistion.

INTRODUCTION

The diesel engine is undergoing continuous technologicalprogressionto become an Adiabatic Engine improvement in performance and durability of IC engine. A major breakthrough in diesel engine technology to make it adiabatic can be achieved by coating the various parts like the cylinder wall, combustion chamber, cylinder head, piston body, valves etc., with ceramic materials having very low thermal conductivity [1]. The coating material of the adiabatic engine must have a high temperature resistance, low thermal expansion coefficient, low friction characteristics, good thermal shock resistance, high strain tolerance, low sintering rate of the porous microstructure, lightweight and durability[3, 2]. It is observed that exhaust temperature of the low heat rejection engine was increased up to 25% depending on the compression ratio and load compared to that of STD engine[4].Increasing temperature level in the combustion chamber decreased the ignition delay and decreased the fuel burnt during the pre-mixed combustion phase. There will be an increase in NO_xemission with increase in temperature [5]. Using SEM image coating material transfer form of the metal piston surface was observed where a bulk ceramic bond rubbed against metal [6].Toughness tends to be smaller for brittle material because elastic limit and plastic deformations allow materials to absorb large amount of energy.Molybdenum in the top surface of the piston reduces the crack formation due to high heat directly applied on the surface, resulting in increasing thermal expansion co-efficient and important thermal properties of piston [7].Nano technology and structured coatings would be expected to increase life of ceramic coating is very longer, showed superior mechanical properties of crack resistance, adhesive strength, spoliation resistance, abrasive wear resistance and sliding wear residence Lower component structural temperatures will results in greater durability to increase of engine life [8].Anhydrous ethanol and hydrous ethanol are provided for automotive application where anhydrous ethanol possesses a maximum of 0.7 % of water on weight basis and hydrous ethanol will have water content about 7.4 % of weight basis at 20^0 C. In ethanol, diesel blend or emulsion, ethanol, diesel blend will not be a homogeneous mixture for longer period without an additive (emulsifier)[9]. The thermal efficiency of the engine depends on the stability of the ethanol diesel blend and property of fuel blend compared to pure diesel[10].Ethanol blend will be evaporated in a TBC engine easily due to high cylinder temperature. This will result in proper combustion of ethanol in a TBC engine [11].By Increase the ethanol blend,oxygen percentage also increases resulting in decreeing adiabatic flame temperature consequently the NOxemission decrease even at thermal barrier coated engine [12].

The main scope of this work is to reduce the wear and tear on the engine and to increase the life span of the coated parts of the engine using a thermal barrier coating (TBC) technology. The coating preserves the coated part whatever it may be in the engine by acting as Thermal Barrier. Using top coated on the piston alloys of Aluminium oxide (Al2O3) + Molybdenum (Mo) + Titanium oxide(TiO2) (40%+30%+30%) are coated on the piston. The best performance can be obtained by combining the chosen materials and its own properties combines to create better performance.

EXPERIMENTAL SECTION

A four stroke, direct injected, water cooled single cylinder diesel engine was used for experimental work. The Engine tests conducted with variable loads at a constant engine speed were directly coupled with eddy current dynamometer. Using data acquisition system connected to a piezoelectric pressure transducer was mounted with cylinder head surface to measure the in cylinder pressure. It is also provided with temperature sensors for the measurement of inlet and exhaust gas temperatures. An encoder is fixed for crank angle record. The signals from these sensors interface with a computer to an engine indicator to display P-ϴ, P-V, mass fraction burnt and heat release versus crank angle plots. The combustion chamber insulation with 300µm thickness is applied on the piston crown using atmospheric plasma spraying coating with different composition such as Aluminium oxide (Al2O3) + Molybdenum (Mo) + Titanium oxide (TiO2) (40%+30%+30%). Over a thickness of Ni-Crbond coat. The thermal barrier coated piston engine was compared with the standard engine. The prepared specimen dimensions 10x10x4 mm with similar coating surface were examined by means of scanning electron microscope (SEM) and Energy dispersive X-ray spectroscopy (EDX) Analysis. Fig. 1 shows the coated and uncoated specimens of the piston crown.

Fig. 1. Pistion crown for coated and uncoated and specimens

RESULT AND DISCUSSION

SCANNING ELECTRON MICROSCOPE (SEM) ANALYSIS

Properties of the piston top coated with TBC and bond coat were analyzed by using SEM and EDX. The coating thickness achieved for both plasma sprayed top coat of Al_2O_3+TiO_2+Mo and bond coating of Ni-Cr were in the thickness of 300µm,where optimum compositional and structural conditions of the coating component were analyzed. The micro graph of the fracture surface of the Al_2O_3+TiO_2+Mo coated pistons crown samples is shown in Fig. 2. And micrograph of the fracture surface of Ni-Cr bond coating is shown in Fig. 3 and The structure exhibited particles of both materials were deformed on impact during the plasma spraying process and melted on the piston crown surface. The overall performance of the coating was helpful to identify the micro cracks, oxidation, thermal mismatch and porosity are compared. When comparing these defects of $Al_2O_3$with Ni-Cr bond coating on the piston, it is observed bigger dense splat and a few of the bigger voids. Which in turn showed lower porosity compared with coating material.The structure of the surface shows fine particles with a lot of small voids which shows a high porosity causes increase in thermal cycling life of the coating.

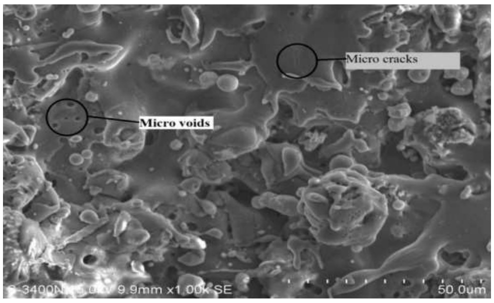

Fig.2.SEM Micrographs of Al_2O_3+TiO_2+Mo coated surface

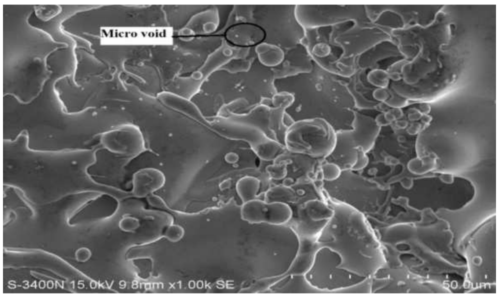

Fig. 3. SEM Micrographs of Ni-Cr bond, coated surface

The structure of the top layer of Al_2O_3+TiO_2+Mo layer exhibited high porosity, number of small voids,oxides inclusion, unmelted particles and cracks of micro size. High porosity characteristics of Al_2O_3+TiO_2+Mo contributed to the brittleness of the structure. The coating was still perfect and adhered to the bond coat. A significant difference was observed between the microstructure of the coating material and bond coating. This might be a reason on low thermal conductivity that leads to heat transfer reduction. This may be the reason for poor thermal efficiency and in this condition of several micro cracks the heat will be lost through the cracks of the coated part of the engine. This will spoil the purpose of coating.

ENERGY DISPERSIVE X-RAYSPECTROSCOPY (EDX) ANALYSIS:

The effect of EDX is investigated and taken from the microstructure given in for TBC coat and bond coating is shown in Fig.4 &5. It Illustrate the composition consisting of Ni-Cr phases in the matrix made up of Al2O3+TiO_2+Mo composite phase predominantly. Oxygen is observed in the matrix. The chemical composition of the coating would be in the range of Al_2O_3(40%)+TiO_2(30%)+Mo(30%). It can be seen from the fig that some oxygen is present in the composition in the coating. The oxygen is probably imported from the air atmosphere to the coating during the process, because the coating process has been carried out in air atmosphere without any vacuum.

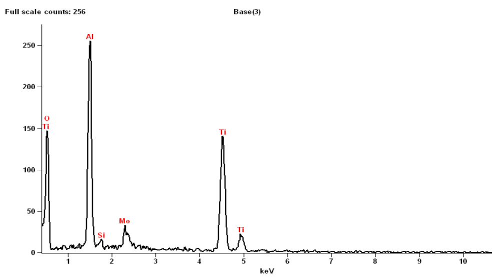

Fig. 4. EDX analysis of Al_2O_3+TiO_2+Mo coated surface

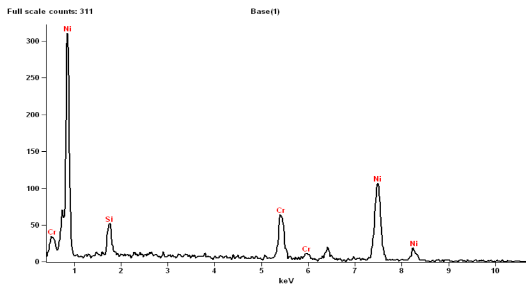

Fig. 5. EDX analysis of Ni-Cr bond, coated surface

PERFORMANCE ANALYSIS

Brake Thermal Efficiency

The variation of brake thermal efficiency with brake power is shown in Fig.6. It can be observed from the results that the Thermal Barrier Coated in piston decreases BSEC and improves the thermal efficiency when compared with uncoated engine. This may be due to increased temperature of the piston crown which increases the temperature of cylinder gas and wall results in higher temperature at combustion chamber. The combustion conditions become more favorable which results in shortening ignition delay time in coated engine affecting both the chemical and physical reactions positively. It is believed that this situation contributes to decrease BSFC when compared to uncoated engine. The ceramic coating has low thermal conductivity which enhances higher operating temperature of the engine. The efficiency was increased due to the reduction in heat transfer from the cylinder wall during the combustion or expansion, from the graph BSEC of thermal Barrier coating Engine is compared to uncoated engine. Which results in decrease of BSFC by 6.55 Kg/KW-hr and BTE is increased by 4.90%

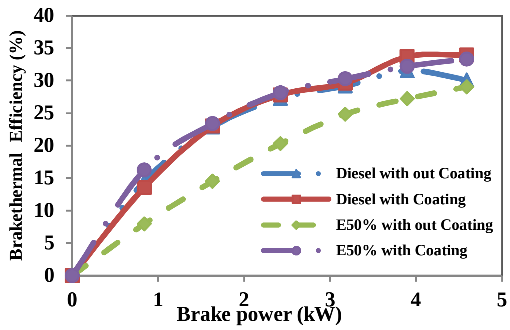

Fig. 6. Variation of BTE for neat diesel and Ethanol-Diesel blends in uncoated and coated engine

EMISSION ANALYSIS

Hydrocarbon Emission

Fig.7. Shows the hydrocarbon emission with brake power. It can be observed from the results that Thermal Barrier Coating in piston crown decreasing HC when compared with uncoated engine. The unburned hydrocarbon emission is reduced, when the engine runs with TB coating. The ethanol has the high latent heat of vaporization and lower cetane, which reduces the cylinder temperature and boosts the more cooling effect on the cylinder wall, slower evaporation of cool flame and reduces chemical kinetics. The HC emission rises evident with the increasing content of ethanol uncoated combustion chamber retards the ignition delay with more flame quenching. The HC emission reduces because of an increase in residual gas temperature in the cylinder at higher load in the engine. The main reason for this is, reduction in the un burned HC emissions is that higher in cylinder temperatures results, decrease the flame quenching thickness, the engine will have sufficient amount of oxygen in ethanol. As a result of this, the HC will split into H and C which mixes with O_2 thereby reducing the HC emissions. From the graph HC emission of thermal barrier coated engine compared to uncoated engine

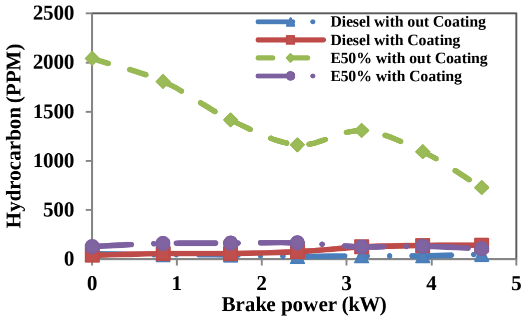

Fig. 7. Variation of HC emission for neat diesel and Ethanol-Diesel blends in uncoated and coated engine

Carbon Monoxide Emission

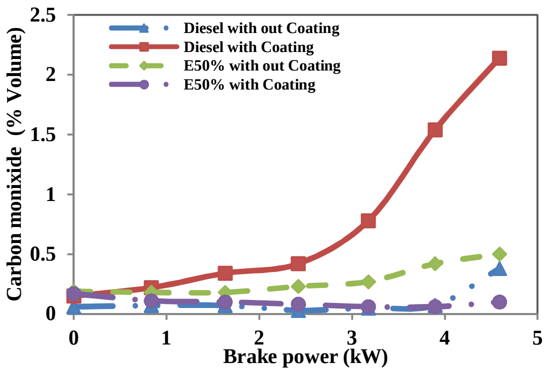

Fig. 8. Variation of CO emission for neat diesel and Ethanol-Diesel blends in uncoated and coated engine

Fig.8 shows the variation of CO with brake power. The carbon monoxide arises mainly due to incomplete combustion, is a way to measure efficiency of combustion. Generally, oxygen availability in diesel is high.So at high temperature carbon easily combines with oxygen and reduces the CO emission. From the graph CO emission of different thermal barrier coated engine compared with uncoated engine. For Mo+Al_2O_3+TiO_2, the CO is decreased by 4% of its volume.

Oxides of NitrogenEmission (NO_x)

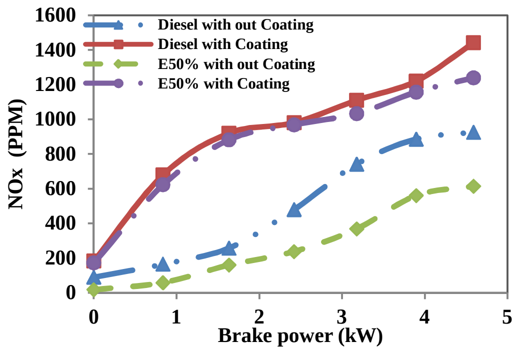

Fig. 9. Variation of NO_x emission for neat diesel and Ethanol-Diesel blends in uncoated and coated engine

Fig. 9 shows the variation of NOx with brake power. The increase of NO_x in the thermal barrier coated engine may be the result of an increase in after combustion temperature due to the ceramic coating.Mo+Al_2O_3+Ti_2O_3TBC coated engine shows a decrease in NO_x emission when compared with uncoated engine.Availability of oxygen is high but the availability of nitrogen is very less because of the presence of impurities. Generally, oxygen availability in diesel is high, so at high temperature nitrogen easily combines with oxygen, but availability of nitrogen in very less due to coating and forms less NO_x.

Smoke Emission

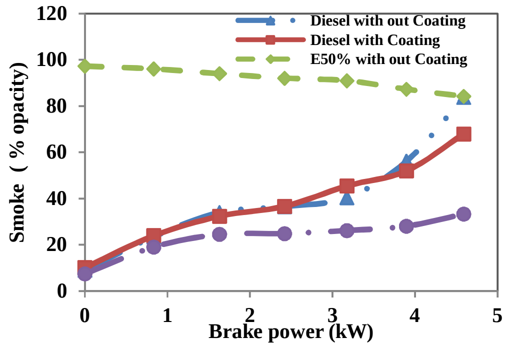

Fig. 10. Variation of Smoke emission for neat diesel and Ethanol-Diesel blends in uncoated and coated engine

The Fig. 10 shows the emitted smoke opacity .This can be observed that smoke for thermal barrier coated ethanol, diesel blends were significantly lower than the subsequent neat diesel fuel in uncoated.The thermal barrier coated engine smoke reduces due to holding more combustion temperature in the combustion chamber. Decrease in latent heat of vaporization of ethanol causes decrease in the ignition delay. Therefore the resulting temperature is higher at combustion chamber smoke opacity reduced for TBC engine. The ethanol blends poor ignition characteristics due to its low cetane number, higher latent heat of vaporization and high ignition temperature are required for auto ignition. Using thermal barrier coated engine it will overcome this problem the smoke opacity improves substantially with the introduction of TBC produced in the diffusion burn.

CONCLUSION

The coating material has been applied successfully to the engine piston as the thermal barrier coating of a diesel engine prevents excessive heat loss during combustion. Due to this coating, the heat loss through the piston is reduced and the temperature inside the combustion chamber is increased. This leads to increase in the effective efficiency of the ethanol diesel blend engine. The temperature inside the combustion chamber increases and so the volumetric efficiency also increase. The TBC technique is very much useful to reduce the waste heat rejection and hence the efficiency of the engine is slightly increased through this project. If the coating is applied to the inner surfaces of the combustion chamber like cylinder head, combustion chamber wall, valves and piston also, there will be a bright chance to increase the efficiency by reducing heat loss.

- The brake thermal efficiency was increased in TBC engine mainly depends upon the thermal conductivity of the material. For $Mo+Al_2O_3+TiO_2$, The BTE is increased by 4.90%
- The brake specific fuel consumption was decreased in TBC engine. For $Mo+Al_2O_3+TiO_2$, the BSFC is decreased by 6.55 Kg/KW.hr
- The carbon monoxide was decreased in the TBC engine by 4% of volume.
- The hydrocarbon emission was decreased in the TBC engine by 6 ppm.
- Thermal barrier coating in piston crown increases NOx emission by 28ppm.

REFERENCES

[1] RR.Sekar and R. Kamo, Advanced adiabatic diesel engine for passenger cars. SAE Paper 840434.
[2] Pawar, A., Jajoo, B., and Nandagoankar, M., Combustion Analysis and Performance of Low Heat Rejection Diesel Engine with Different Thermal insulation coating, SAE Technical Paper: **2004**, 12.
[3] Hui Dai, XinghuaZhong, Jiayan Li and et al., *Surface & Coatings Technology*, **2006**, 2527 – 2533.
[4] MuhammetCerit, *Surface & Coatings Technology*, **2011**, 3499 – 3505.
[5] S. Henningsen, Evaluation of Emissions and Heat Release Characteristics from a Stimulated Low Heat Rejection Engines, SAE Paper No.871616.

[6] RajendraPrasath, P. Tamilporai, mohd. F. Shabir and T. Senthil Kumar, Simulation and Analysis of Combustion, Performance and Emission Characteristics of Biodiesel Fueled Low Heat Rejection Direct Injection Diesel Engine, SAE Technical Paper: **2007**-32-0094.

[7] Nadir Yilmaz, A. Burl Donaldson and Andy Johns, Some Perspective on Alcohol Utilization in a Compression Ignition Engine, SAE Technical Paper: **2005**-01-3135.

[8] Alberto Boretti , *Applied Thermal Engineering*, **2012** , 44, 1-9.

[9] Avinash Kumar Agarwal, *Progress in Energy and Combustion Science*, **2007**, 33, 233-271.

[10] Uzun, I. Cevik, and M. Akcil, *Surf. Coat.Technol*. **1999**, 505, 116–119.

[11] Roy Kamo, Walter Bryzik and Michael Reid, Melvin Woods, Coatings for Improving Engine Performance, SAE paper 970204.

[12] Tadeusz Hejwowski, *Vacuum*, **2010** , 85,610-616.

[13] PH. Havstad, IJ. Gervin, and WR. Wade, A ceramic insert un cooled diesel engine. SAE Paper 860447..

[14] K. Toyama, T. Yoshimitsu, and T. Nishiyama, Heat insulated turbo compound engine, SAE Transactions, 92, **1983**.

[15] M.Cerit, V.Ayhan and et al., *Applied thermal Engineering* ,**2011**, 31, 336-341.