CERAMIC COATED COMBUSTION CHAMBER FOR IMPROVING IC ENGINE PERFORMANCE

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Abstract

Thermal barrier coatings are becoming increasingly important in providing thermal insulation for heat engine components. Thermal insulation reduces in-cylinder heat transfer from the engine combustion chamber as well as reducing component structural temperatures. Containment of heat also contributes to increased in-cylinder work and offers higher exhaust temperatures for energy recovery. Lower component structural temperatures will result in greater durability. Advanced ceramic composite coatings also offer the unique properties that can provide reductions in friction and wear. Increased combustion temperature can increase the thermal efficiency of the engine and decreases the pollutants like HC, CO and (possibly) the NO_x emission rate. To reach the desirable operating temperature of 850-900^{0}C in the combustion chamber from the current conventional Engine temperature of 350-400^{0}C, a ceramic coating with a thickness of 0.25mm to is required.

Key words: Ceramic coating, thermal barrier, Structural Temperatures, Energy Recover

I. INTRODUCTION

The first use of *Thermal barrier coating* (TBC) was for aircraft engine performance. The concept of thermal barrier coating for diesel engines began in 1980s. The petroleum crisis and the subsequent increase in the cost of fuels, the improvement of fuels and the improvement of fuel economy of the I.C Engines has become a high priority to the researchers. Numerous investigations have modeled and analysed the effects of in-cylinder thermal insulation. Reducing heat rejection in reciprocating engines is a possible way of reducing fuel consumption [1]. This may be possible by eliminating a part of the cooling system and incorporating high-temperature insulting materials in the combustion chamber to withstand the higher combustion gas temperature. The advent of high temperature, high performance ceramics has tempted engine researchers to strive for higher operating temperatures with subsequent higher engine thermal efficiency by reducing fuel consumption.

Thermal Barrier Coatings (TBCs) in diesel engines offer advantages including higher power density, fuel efficiency, and multifuel capacity due to higher combustion chamber temperature (900C) [1,2]. Using TBCs can increase engine power by 8%, decrease the specific fuel consumption by 15-20% and increase the exhaust gas temperature by 200K [3]. Although several systems have been used as TBC for different purposes, Partially-Stabilized Zirconia has received the most attention. Plasma spray is the most common method of depositing TBCs for diesel engine applications.

With the problems experienced in the development of monolithic ceramic insulating component [3, 5] investigations began to look closer at thermal barrier coated alternatives. It was observed that the cyclic transient surface temperature swing on the combustion chamber component surfaces is dependent on the surface material properties such as heat capacity, thermal conductivity and density. It is also noted that in a true adiabatic combustion the surface temperature swing would be equal to and follow the cylinder gas temperature throughout the entire 4-stroke engine cycles (intake, compression, expansion and exhaust). In addition, it was observed that the surface temperature swing throughout the engine cycle penetrates only a small distance below the surface of the components and that the temperature through the remainder of the components changed linearly and behaved in a steady state manner.

II. THIN THERMAL BARRIER COATINGS

After reviewing the past experience with low heat rejection engines it was considered that the most effective, economical and reliable approach to improving fuel consumption benefits was to use a very thin thermal barrier coating with a thickness only slightly greater than the depth below the surface that experience transient thermal swings throughout the engine operating cycle. Analyses reported by Wong [2] considered combinations of coating thermal properties and coating thickness and predicted the resulting fuel consumption effects. Most coating for the piton and head face surfaces provided a maximum benefit at a thickness of about 0.004 inch and a loss with thickness over 0.012 inch.

The predicted maximum benefit in thermal performance ranged from 1 to 2%. It is predicted that PSZ coating on a liner with a thickness of 0.020 inch provided the optimum oil viscosity and a friction reduction to produce a engine performance improvement of 5% with less lubricating oil consumption.

A. Methods of Thermal barrier coating:

The inside surface of the cylinder head and piston crown were insulated by using partially stabilized Zirconia for a thickness of 0.25mm using plasma spray technique. The surface to be coated was first cleaned and degreased with a chemical solvent. A special adhesive bonding material was first coated. The material to be coated (partially stabilized Zirconia, ZrO_2) which is in the form of powder was fed to the melting zone. The molten material was further heated to a very high temperature leading to plasma stage. Then the plasma jet was impinged on the surface to be coated, the coating material flattened and sticks to the surface. It becomes very hard surface when it was cooled in inert gas atmosphere and sticks to the surface. As the cylinder wall surface is subjected to rubbing action and at the time of combustion only a small portion of the cylinder wall is exposed to hot gases, the cylinder wall (liner) is not coated with partially stabilized Zirconia. The advent of high temperature, high performance ceramics coating improved the higher engine operating temperatures with the subsequent higher engine thermal efficiency by reducing fuel consumption as reported by Andre L. Boehman et al[5].

III. EXPERIMENTAL INVESTIGATION ON TBC ENGINE

The experimental investigation were carried out in base engine and Thermal barrier Coated engine. The engine components such as piston, combustion chamber were given Thermal barrier ceramic coating. The engine was operated with fossil diesel fuel. The performance data was then analyzed from the graphs recording power output, torque, specific fuel consumption and all emissions for all loads of the engine.

IV. TESTING METHODOLOGY

A. Experimental apparatus

The experimental set up consists of a four stroke, air cooled, single cylinder, direct injection diesel engine developing a power of 5.0 KW at 1500 rpm coupled with an electrical dynamometer. The engine has a bore of 87.5 mm and stroke of 110 mm. Compression ratios is 17.5:1.

A series of engine tests were conducted in the present study and reported here. Exhaustive engine tests were carried out on CI engine using a diesel and biodiesel blends separately as fuels at 1500rpm. The inlet valve opens at 4.5° BTDC and closes at 35.5° ABDC. The exhaust valve opens 35.5° BTDC. Performance and emission tests were conducted on various loads with base engine and TBC engine. Performance indices such as brake thermal efficiency and specific energy consumption were measured. The exhaust emissions like particulate matter, oxides of nitrogen, smoke density, hydrocarbon and carbon monoxide were measured by using AVL 5 Gas analyzer.

V. RESULTS AND DISCUSSION

A. Thermal Efficiency

The variation of brake thermal efficiency with power is shown in Fig. 1. for 'base engine' and TBC engine. The TBC Engine with diesel has shown better performance at higher loads and at lower loads respectively than the Base engine. Improved thermal efficiency was observed in TBC engine at all loads. The thermal efficiency was higher for TBC Engine (30.4%) where as for base engine it was 29.0%.

It can be observed from the results that Thermal Barrier coating in combustion chamber improves the thermal efficiency when compared with Base engine in Fig.1.

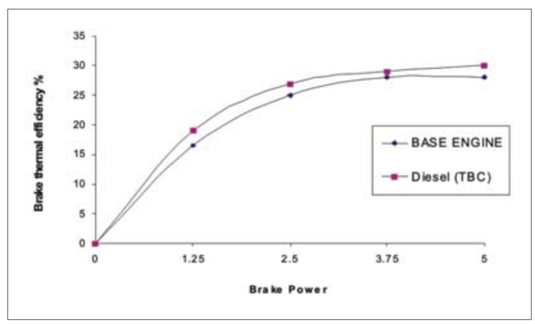

Fig. 1. Brake Power Vs Brake Thermal Efficiency for Various Blends

It is evident that the thermal Barrier coating ie Partially Stabilized Zirconium coating on piston crown and combustion chamber with a thin film of 250 micron prevents the heat loss from the walls to the surroundings. The thermal efficiency was increased due to the reduction in heat transfer from the gas to the walls during the combustion or expansion because of the higher wall temperatures. Thin thermal barrier coating shifts the combustion from premixed to diffusion stage.

B. Specific Fuel Consumption

The variation of brake specific fuel consumption with brake power is shown in Fig. 2.

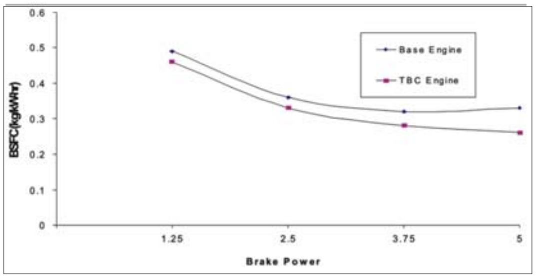

Fig. 2. Brake Power Vs BSFC (kg/kw-hr)

It shows that the specific fuel consumption verses brake power for Base engine and TBC engine. The higher brake specific fuel consumption values in the case of TBC engine. The increase in SFC is due to thermal Barrier Coating of combustion chamber. TBS acts as an insulator and increases the in-cylinder

VI. EMISSIONS

A. Unburned Hydrocarbon Emission

Normally SI engines are emitting more HC and CO emissions whereas the CI engines are not so. Fig. 3.

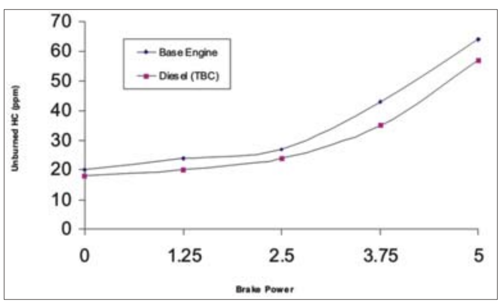

Fig. 3. Brake Power Vs Unburned HC for Various Blands

shows the variation of HC in the exhaust with brake power for Base engine and also for TBC engine. At 75% rated load the HC emission in TBC engine is 14 ppm where Base engine gives out slightly higher 22ppm HC emission.

B. Carbon Monoxide (CO) Emissions

Emissions of carbon monoxide from a D1 diesel engine mainly depend upon the fuel physical and chemical properties. The reduction in CO in case of TBC engine is lower when compared with Base engine. At 3.75 KW load the Base engine emits 0.085% CO emission which is much higher when compared TBC engine Fig. 4 since it gives out only 0.069% at this load. The high in-cylinder operating temperature reduces the CO emission to a lower level. As a whole the TBC engine reduces the CO emission to a considerable value at the higher operating temperature.

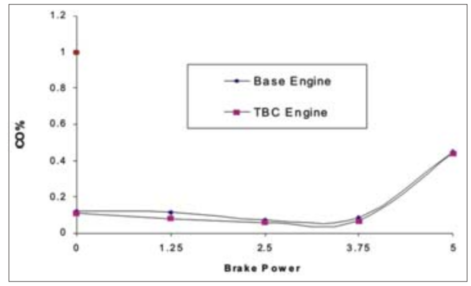

Fig. 4. Brake Power Vs CO for Various Blends

C. Smoke Emissions

Fig. 5 shows the variation of smoke with power for different configured engines. The smoke emissions of TBC engine was comparatively lesser than the Base engine at 75% of the rated load of 3.75 KW. It was found that from the results the thin Thermal barrier Coating reduced the smoke emissions for all the configuration of the engine. This was due to higher gas temperatures and enhancement in oxidation, which resulted in reduction of soot particles.

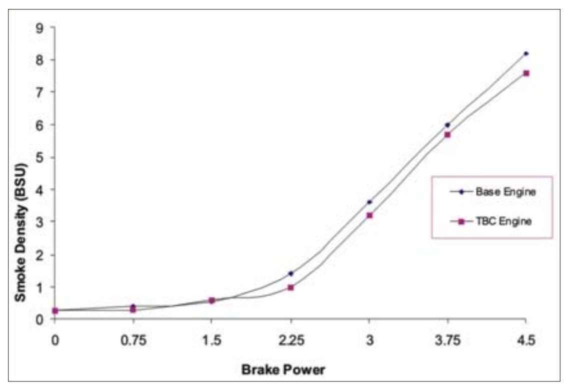

Fig. 5. Brake Power Vs Smoke Density (BSU) for Various Blends

VII. CONCLUSION

- The engine exhaust temperature has increased in the case of TBC engine (from 410° C to 428°C) which promotes better energy recovery.
- Reduction in HC, CO and PM emissions were observed with the use of TBC engine.
- Reduced smoke levels from 4.4 to 4.13 BSU.
- The insulation of the combustion chamber with this ceramic coating influences the performance and exhaust emissions of the CI engine. The insulation modifies the boundary conditions for the combustion process which in turn shortens the ignition delay period hence lowers the fuel consumption, reduces the heat loss and increases the exhaust temperature

which in turn influences the engine performance and emissions.

- Advanced high performance ceramic coatings have opened for new opportunities.
- Ceramic coatings provide potential for higher engine thermal efficiencies, longer life and higher reliability of engine components.
- Thermal barrier coatings offer the possibility of reducing particulate emissions
- Thermal barrier coatings decrease the amount of condensable hydrocarbons.
- Under low load and speed conditions the base engines produces plate like particles, the TBC engine produces smaller spherule particles.

VIII. FUTURE SCOPE

1. The costliest new bimodal YSZ coating may offer improved thermo- mechanical performance.
2. Nano-Technology structured coatings (Al2O3-TiO2) showed superior mechanical properties, including indentation crack resistance, adhesive strength, spoliation resistance, abrasive wear resistance and sliding wear residence.
3. Nano structured coatings would be expected to show better thermal resistance and reduced thermal conductivity compared to Partially Stabilised Zirconia's coatings.

IX. LIMITATIONS

1. Coating of aluminium with Partially Stabilised Zirconia is very difficult due to the large difference in coefficient of thermal expansion.
2. At present PSZ coating is very costlier.
3. Life of ceramic coating is very short.
4. The inelastic behaviour of the TBC ceramic material and its micro structure determines the failure mechanism.
5. Due to the mismatch in thermo mechanical properties on the top of TBC develops cracking and declamation.

REFERENCES

[1] B.B. Goash., T.K.Banerjee., "Experimental investigations on some performance parameters of a diesel engine using ceramic coatings on the top of the piston". SAE paper No. 970207.

[2] Wong, Roy kamo, Melvin Woods., "Coatings for improving Engine Performance"., SAE Paper No. 970204.

[3] Fairbanks, J.W.,"Thermal Barrier Coating Applications".U,S Department of Energy, office of Environmental Management (1995).

[4] Kamo, R. Assanis, D.N. Bryzik, W., " Thin Thermal Barrier coating for Engines" SAE Technical paper No. 890143 (1989).

[5] Debra A, Marks and Andre L. Boehman., " The influence of Thermal Barrier Coatings on morphology and Composition of Diesel Particulates". SAE Paper No. 970756

[6] Noboru Miyamoto., Teruyoshi Arima., " improvent of Diesel combustion and emissions with addition of various oxygenated agents to Diesel fuels". SAE Paper No. 962115 Page 193-199

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