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Thermal barrier coating on I.C engine cylinder liner

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ABSTRACT

Purpose: In this research, Cerium Stabilized Zirconia is coated on the I.C engine cylinder liner using Plasma Spray Coating technique. The coating system has effects on the fuel consumption, the power and the combustion efficiency, pollution contents. Their performance characteristics and results are studied and tabulated.

Design/methodology/approach: Thermal Barrier Coating (TBC) are used to achieve the reduced heat rejection in engine cylinders. It is known that the efficiency of internal combustion diesel engines changes 38-42%. It is about 60% of the fuel energy dismissed from combustion chamber.

Findings: The results showed that, increasing the brake thermal efficiency and decreasing the specific fuel consumption for the light heat rejection engine with thermal coated cylinder liner compared to that of standard engine. There was increasing the NO_x emission and O_2 for thermal barrier coated engine.

Practical implications: To save energy, combustion chamber component is coated with low thermal conduction materials. In this paper, we are giving idea to thermal barrier coating and ceramic materials which are used for making low heat released engines. It reduces the excessive heat transfer to the coolant and exhaust system, thus improves the mechanical and thermal efficiency

Keywords: Cerium stabilized zirconia; Diesel engine; Thermal barrier coating

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

The first use of Thermal Barrier Coating (TBC) was for aircraft engine performance. The concept of TBC in diesel engine begin in 1980s. The petroleum crisis and the subsequent increase in the cost of fuels, the improvement of the fuels and the improvement of fuel economy of the I.C engine has become a higher priority to the researchers.

The depletion of fossil fuel resources at a faster rate in the present world of economic competitiveness is generating an essential demand for increase in efficiency of internal combustion engines. The use of coating in the automotive industry has been found to yield a significant effect on the efficiency of engines.

Numerous investigation has modelled and analysed the effect of in-cylinder thermal insulation. Reducing heat

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rejection in I.C engine is possible way for reducing fuel consumption.

According to the First law of thermodynamics, thermal energy is conserved by reducing the heat flow to the cooling and exhaust systems, it's known that only one third of energy is converted to useful work, theoretically if rejection of heat is reduced then the thermal efficiency likely to be increased to a considerable extend. The application of TBC decreases the heat transfer to the cooling and exhaust system which ultimately results in high temperature gas and high temperature combustion chamber wall which reduces the level of smoke and hydrocarbon (HC) emission.

In particular, for the later, durability concerns for the materials and components in engine cylinders, which include piston, rings, liner, cylinder head, limit the allowable in-cylinder temperatures. The application of thin TBCs to the surface of these components enhance high temperature durability by reducing the heat transfer and lowering temperature of the underlying metal. In this article, the main emphasis is placed on investigating the effect of a TBC on the engine fuel consumption with support of detailed sampling of in-cylinder pressure. The optimization of the engine cycle and the exhaust waste heat recovery due to a possible increase in exhaust gas availability were not investigated. As a result, by considering the application of this kind of ceramic coating which is made on cylinder liner dependent on the diesel engine type, fuel consumption is reduced, power and combustion efficiency is increased, pollution content is decreased, and the fatigue lifetime of engine components is improved.

2. Literature review

The selection of TBC is restricted by some basic requirements:

1. High melting point,
2. No phase transformation between room temperature and operation temperature,
3. Low thermal conductivity,
4. Chemical inertness,
5. Thermal expansion match with the metallic substrate,
6. Good adherence to metallic substrate,
7. Low sintering rate of the porous microstructure.

Among those properties, thermal expansion coefficient and thermal conductivity seem to be the most important.

3. Materials

Zirconia PSZ are cream colored blends with approximately 10% MgO and are high in toughness, retaining this property to elevated temperatures. It retains many properties including corrosion resistance at extremely high temperatures, zirconia does exhibit structural changes that may limit its use to perhaps only 773 K. It also electrically conductive as this temperature is approached. Zirconia is commonly blended with MgO, CaO, or yttrium (3&4) as a stabilizer in order to facilitate transformation toughening. This includes a partial cubic crystal structure instead of fully tetragonal during initial firing, which remains metastable during cooling. Upon impact, the tetragonal precipitates undergo a stress induced phase transformation near an advancing crack tip.

From the research topic by [4], it is studied that this action expands the structure as it absorbs a great deal of energy, and is the cause of the high toughness of the material [4]. Reforming also occurs dramatically with elevated temperature and this negatively affects strength along with 3-7% dimensional expansion. PSZ is adopted.

Zirconia ceramic is a ceramic material consisting of at least 90% of Zirconium Oxide (ZrO_2). Zirconium Oxide is produced from natural minerals such as Baddeleyite or Zirconium silicate sand. Pure zirconia changes its crystal structure depending on the temperature: At temperatures below 2138°F (1170°C) monoclinic structure transforms to cubic structure at 4300°F (2370°C). Tetragonal crystal structure transforms to cubic structure at 4300°F (2370°C). Structure transformations are accompanied by volume changes which may cause cracking if cooling/heating is rapid and non-uniform and structural failure3 of any ceramic coating. Additions of some oxides (MgO, CaO, Y_2O_3) to pure zirconia depress allotropic transformations (crystal structure changes) and allow to stabilize either cubic or tetragonal structure of the material at any temperature. The most popular stabilizing addition to zirconia is yttrium (Y_2O_3), which is added and uniformly distributed in proportion of 5.15%.

4. Experimental setup and operation

A fully instrumented CI engine was mounted on a computer-controlled engine dynamometer. Table 1 tabulates the specification of the engine, while Figure 1 shows the schematic of the overall arrangement of the engine test bed.

Table 1.
Specification of computerized test rig

Type	Vertical 4 stroke single cylinder water cooled diesel engine
Combustion chamber	Direct injection
Bore	87.5 mm
Stroke	110 mm
Displacement	661 cc
Compression ratio	17.5
Power	5.2 Kw @ 1500 rpm
Piezo sensor	Range 5000 psi
Crank angle sensor	Resolution 1º

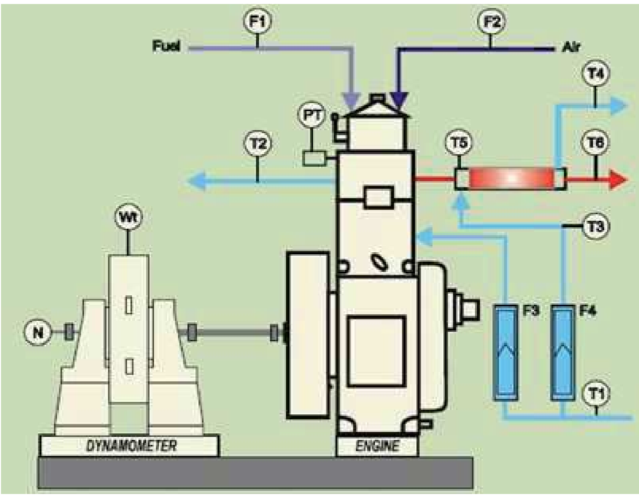

Fig. 1. Schematic of the overall arrangement of the engine test bed

To appreciate the effect of a TBC on engine performance, in particular fuel consumption, obtaining engine indicator diagrams is necessary. A 10-mm water cooled piezoelectric transducer was used to measure the dynamic cylinder pressure. Unfortunately, the transducer of this size to be directly mounted on it because no fill space is available for such installation. To fix the transducer, an adapter mounting was fabricated. To draw the pressurized gas out of the combustion chamber, a 1.3 mm through hole was drilled into the third cylinder at the rear of the cylinder head (Fig. 1), the only place suitable for the mounting of the adapter and bypassing of the water jacket of the cylinder head. In addition to pressure measurement, a crank shaft encoder was used to trigger the acquisition of the pressure signal and also to provide crank position information. The shaft encoder provides a resolution of 0.1° crank angle; however, the data acquisition was set at a sampling rate of 0.2°crank angle.

In this experiment, a non-dispersive infrared (NDIR) analyzer and flame ionization detector (FID) measure concentrations of carbon monoxide and unburned hydrocarbons (HCs), respectively.

4.1. Plasma spray 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. Krzysztof Z. Mandera in his journal explained the effects of plasma spray coating in Diesel engines [1]. 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.

5. Performance and characteristics

Table 2 and Figures 2-4 shows the results obtained from the I.C engine without coating.

Table 2.
Experimental results

Speed (rpm)	Load (kg)	BP (Kw)	BSFC (kg/kwh)	BTh.eff (%)
1576	0.17	0.05	6.89	1.24
1550	3.8	1.03	0.63	19.869
1534	6.86	2.32	0.42	24.08
1508	11.33	3.52	0.33	26.88

5.1. Load vs. brake power

According to the graph, as the load increases the brake power increases, thus the load is proportional to the brake power. But after coating for the same load the brake. Power will be more effective than latter.

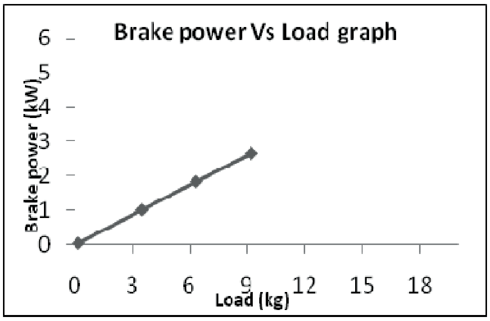

Fig. 2. Results from the I.C engine without coating

5.2. Load vs. BSFC

This graph shows that for a given load the brake specific fuel consumption decreases as the load increases. But after coating for a same load the brake specific fuel consumption further decreases.

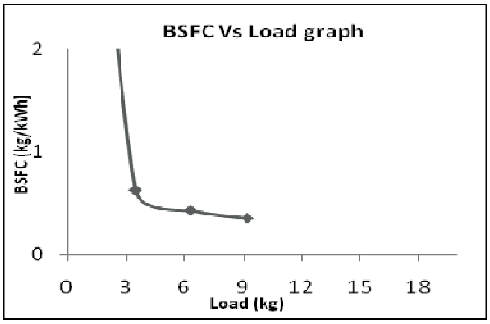

Fig. 3. Results from the I.C engine without coating

5.3. Load vs. brake thermal efficiency

The rejection of heat flow to the water cool jackets and the exhaust system which ensures a better combustion engine than the baseline engine. The decrease in the fuel consumption level which also indicates a better thermal efficiency in the coated I.C engine.

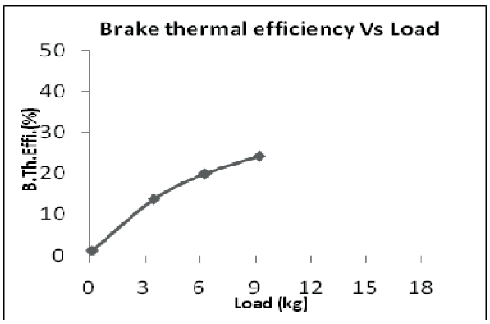

Fig. 4. Results from the I.C engine without coating

6. Exhaust emission

The emission test was conducted in AVL GAS ANALYSER and the results are calibrated (Table 3).

Table 3.
Emission test results

Gas\Load	No load	25%Load	50%Load	75%Load
CO, %vol	0.02	0.03	0.03	0.04
HC, ppm	14	30	34	40
CO_2, %vol	1.90	2.70	3.90	5.00
O_2, %vol	18.11	16.87	15.97	13.77
NOx	102	224	465	750

6.1. Hydrocarbons

The level of emission of unburned hydrocarbon(UHC) is considerably decreased due to reduction of flow of heat to the water cool jackets and exhaust system.

6.2. Carbon monoxide

The higher temperatures both in the gases and at the combustion chamber walls of the diesel engine assist in permitting the oxidation of CO. The higher temperature causes complete combustion of CO emission.

6.3. Nitrogen oxides

NOx is formed by chain reactions involving Nitrogen and Oxygen in the air. These reactions are highly temperature dependent. Since diesel engines always operate with excess air, NOx emissions are mainly a function of gas temperature and residence time. These NOx can be reduced by hydrolysis by 30% of Carbamide mixed with 70% of water.

7. Conclusions

The results showed that, increasing the brake thermal efficiency and decreasing the specific fuel consumption for the light heat rejection engine with thermal coated cylinder liner compared to that of standard engine. There was increasing the NOx emission and O_2 for thermal barrier coated engine.

The following conclusions can be drawn.

- The TBC, using CSZ applied to the combustion chamber of the internal combustion engine showed some improvement in fuel economy with a maximum of up to 4% at low engine power.

- The peak cylinder pressure was increased by a magnitude of eight to ten bars in the TBC coated cylinder liner, in particular at high engine power outputs, though the exhaust gas temperatures were generally lower, indicating good gas expansion in the power stroke.
- The unburned hydrocarbon concentration was increased most seriously at low engine speed and/or low engine power output with TBC coated engine. The authors suspected that this could be due to the porous quenching effect of the rough TBC cylinder liner, where oxidation of hydrocarbons was unable to be achieved by the combustion air.
- Sampling of cylinder pressures in the cylinders showed that the ignition point of the TBC coated engine advanced slightly relative to the baseline engine, indicating the improvement in ignitability and heat release before top dead centre, which caused the peak cylinder pressure to raise.

References

[1] K.Z. Mandera, Effects of Plasma Sprayed Zirconia Coatings on Diesel Engine Heat release, Journal of KONES Internal Combustion Engines 7/1-2 (2000) 431-437.

[2] P.N. Shrirao, A.N. Pawar, Evaluation of performance and Emission characteristics of Turbocharged Diesel Engine with YSZ as Thermal Barrier Coating, International Journal of Engineering and Technology 3/3 (2011) 256-262.

[3] H. Samadi, T.W. Coyle, Alternative Thermal Barrier Coating for Diesel Engines, Proceedings of the 5th Congress of Iran Ceramic Society, Iranian Ceramic Society, Tehran, Iran, 2004.

[4] R. Kamo, W. Bryzik, Ceramics In Heat Engines, SAE International, 1979.

[5] S.H. Chan, K.A. Khor, The effect of thermal barrier coated piston crown on engine characteristics, Journal of Materials Engineering and performance 9/1 (2000) 103-109.