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Investigation of Thermal Barrier Coating on I.C Engine Piston

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Abstract: Thermal Barrier Coating(TBC) are used to stimulate the reduced heat rejection in engine cylinders. It reduces the heat transfer to the water cooling jacket and exhaust system. Thus improves the mechanical efficiency. In this operation Zirconia Ceramic is coated on the I.C engine piston using Plasma arc technique. Their performance characteristics and results are studied and tabulated.

I. INTRODUCTION

According to the First law of thermo dynamics, 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 into 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 the high temperature gas and high temperature combustion chamber wall which reduces the level of smoke and hydrocarbon(HC) emission.

In particular, for the latter, durability concerns for the materials and components in the engine cylinders, which include piston, rings, liner, and cylinder head, limit the allowable in-cylinder temperatures. The application of thin TBCs to the surfaces of these components enhances high-temperature durability by reducing the heat transfer and lowering temperatures 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 the 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 in this study.

II. LITERATURE REVIEW

The selection of TBC materials 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 the metallic substrate and

(7) Low sintering rate of the porous microstructure.

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

III. 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 500 °C. It also becomes electrically conductive as this temperature is approached. Zirconia is commonly blended with MgO, CaO, or Yttria (3&4) as a stabilizer in order to facilitate transformation toughening. This induces 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.

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

Type	Horizontal 4 stroke single cylinder water cooled diesel engine
Combustion chamber	Direct injection
`Bore	95 mm
Stroke	95 mm
Displacement	673.4 cc
Compression ratio	18:1
Max. torque	4.2 kg- /1900 rpm
Max. HP	13 HP@2400 rpm
S.F.C	192 g/ Hp / hr
Cooling system	Condenser type thermo siphon cooling system
Lighting system	12 volts / 35 watts
Std. pulley (DIA)	100 mm/optional 120mm

Table1

Zirconia Ceramic is a ceramic material consisting of at least 90% of Zirconium Dioxide (ZrO_2). Zirconium Oxide is produced from natural minerals such as Baddeleyite (zirconium oxide) or zirconium silicate sand. Pure zirconia changes its crystal structure depending on the temperature: At temperatures below 2138 ºF (1170ºC) zirconia exists in monoclinic form. At temperature of 2138ºF (1170ºC) monoclinic structure transforms to tetragonal form which is stable up to 4300ºF (2370ºC). Tetragonal crystal structure transforms to cubic structure at 4300ºF (2370 ºC). Structure transformations are accompanied by volume changes which may cause cracking if cooling/heating is rapid and non-uniform and structural failure 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 yttria (Y_2O_3), which is added and uniformly distributed in proportion of 5.15%.

IV. EXPERIMENTAL SETUP AND OPERATION

A fully instrumented CI engine was mounted on a computer-controlled engine dynamometer. Table 1 tabulates the specifications of the engine, while figure shows the 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 pressure 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. 2), 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 positional information. The shaft encoder possessed a resolution of 0.1° crank angle (°CA); however, the data acquisition was set at a sampling rate of 0.2 °CA. In this experiment, a non-dispersive infrared (NDIR) analyser and flame ionization detector (FID) measured concentrations of carbon monoxide and unburned

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hydrocarbons (HCs), respectively. The TBC was examined with scanning electron microscopy (SEM) after the tests had been conducted, and the chemical composition was analysed with an energy dispersive x-ray (EDX) unit

A. Plasma spraying technique:

In the various ceramic materials, partially stabilized zirconia (PSZ) 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. PSZ has been widely used as a thermal barrier coating in the combustion chambers of diesel engines.(6) Hence, in the present work, PSZ was chosen as the material for the thermal barrier coating in the piston crown. In the present investigation,(5) the piston crown was coated with the PSZ ceramic material, using a plasma spraying technique. 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.(1)

V. PERFOMANCES AND CHARTERISTICS

Figures compares the results obtained from both the baseline and TBC piston tests. In general, the TBC piston tests showed lower exhaust gas temperatures, which, combined with the results shown in Figure, positively indicated that the performance of the engine would be improved.(2)

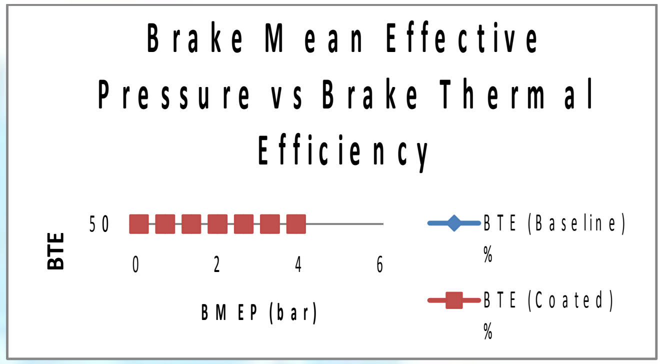
Swept vol	Speed	Voltage	Current	Power	FC	FC	FC	SFC	BMEP	CV	Fuel Energ	Efficiency
cu.m	rpm	V	A	kW	s/5cc	g/hr	kg/s	g/(kW.hr)	bar	kJ/kg	kW	%
0.000673	1500	230	0	0	28.13	537.5044	0.000149	-	0	42500	6.345539	0
0.000673	1500	230	2	0.541176	23.38	646.7066	0.00018	1195.001	0.642937	42500	7.634731	7.088351
0.000673	1500	230	4	1.082353	18.57	814.2165	0.000226	752.2652	1.285873	42500	9.612278	11.26011
0.000673	1500	230	6	1.623529	17.31	873.4835	0.000243	538.0152	1.92881	42500	10.31196	15.74414
0.000673	1500	230	8	2.164706	15.87	952.741	0.000265	440.1249	2.571747	42500	11.24764	19.24587
0.000673	1500	230	10	2.705882	12.31	1228.27	0.000341	453.9258	3.214683	42500	14.50041	18.66073
0.000673	1500	230	12	3.247059	11.86	1274.874	0.000354	392.6241	3.85762	42500	15.05059	21.5743

BASE LINE ENGINE VS COATED ENGINE

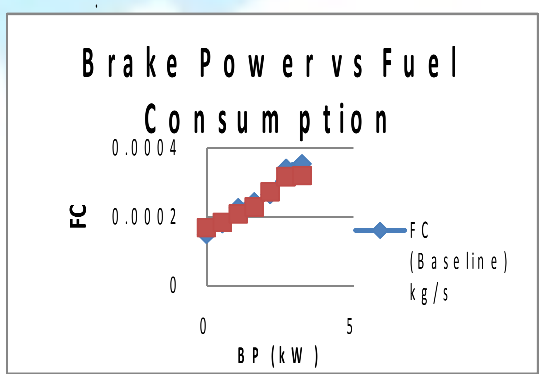
Swept vol	Speed	Voltage	Current	Power	FC	FC	FC	SFC	BMEP	CV	Fuel Energ	Efficiency
cu.m	rpm	V	A	kW	s/5cc	g/hr	kg/s	g/(kW.hr)	bar	kJ/kg	kW	%
0.000673	1500	230	0	0	24.86	608.206	0.000169	#DIV/0!	0	42500	7.180209	0
0.000673	1500	230	2	0.541176	22.85	661.7068	0.000184	1222.719	0.642937	42500	7.811816	6.927665
0.000673	1500	230	4	1.082353	20.12	751.4911	0.000209	694.3124	1.285873	42500	8.871769	12.19997
0.000673	1500	230	6	1.623529	18.38	822.6333	0.000229	506.6944	1.92881	42500	9.711643	16.71735
0.000673	1500	230	8	2.164706	15.37	983.7345	0.000273	454.4426	2.571747	42500	11.61353	18.63951
0.000673	1500	230	10	2.705882	13.27	1139.412	0.000317	421.0871	3.214683	42500	13.45139	20.116
0.000673	1500	230	12	3.247059	13.13	1151.561	0.00032	354.6475	3.85762	42500	13.59482	23.88453

A.THERMAL EFFICIENCY ON FUEL CONSUMPTION:

The rejection of heat flow to the water cool jackets and the exhaust system which ensures a better combustion in a 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



In the emission measurements, the tailpipe uHC and CO concentrations were conducted. It was discovered that the CO did not vary much in either the baseline or TBC test. The variations were more or less within the resolution of the NDIR analyzer, which was ±0.1 vol.% concentration,(21) whereas the resolution of the FID used was ± 1 ppm. Figure 6 compares the brake specific fuel consumption between the baseline and TBC piston tests. Results show that, in general, the fuel consumption was lower in the TBC piston tests for the same operating condition, with an improvement of up to 6% at lower engine power. The self-optimized cycle efficiency due to the altered ignition characteristics in the TBC piston engine outnumbered the slightly reduced combustion efficiency with an overall improvement in thermal efficiency as a whole. The level of improvement that has been predicted ranged from 2 to 12 %. They attribute this to insulation of in-cylinder components



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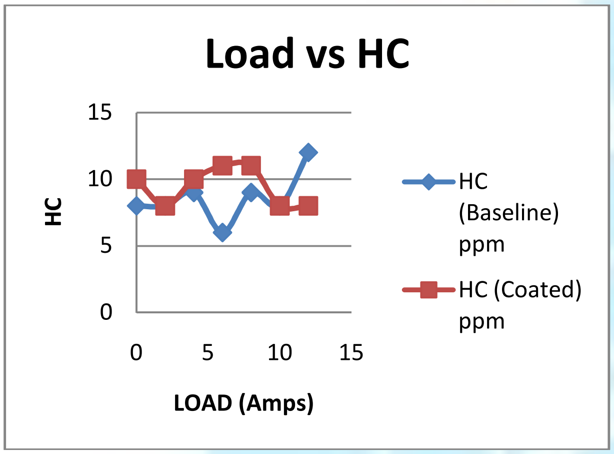
EXHAUST EMISSION:

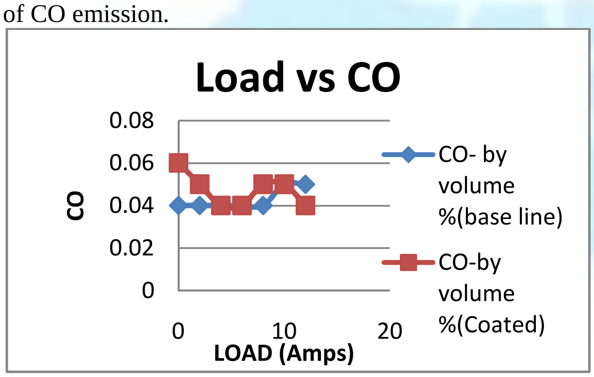
A.HYDROCARBONS:

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.But due to high temperature gas and high temperature combustion wall which contributes combustion of lubricating oil,which ultimately leads to emission of unburned hydrocarbon.



B. Carbon monoxide(CO):

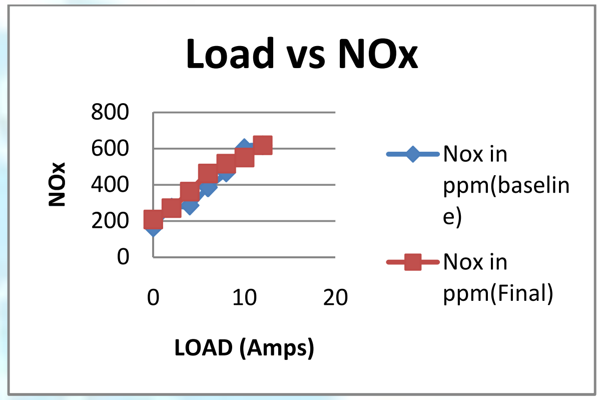
The higher temperatures both in the gases and at the combustion chamber walls of the LHR engine assist in permitting the oxidation of CO.The higher temperature causes complete combustion of carbon which results in combustion of CO emission.



C. 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. Most of the earlier investigations show that NOx emission from LHR engines is generally higher than that in water-cooled engines. They say this is due to higher combustion temperature and longer combustion duration. . Reference reports an increase in the LHR engine NOx emissions and concluded that diffusion burning is the controlling factor for the production of NOx. Almost equal number of investigations report declining trend in the level of emission of NOx. Reference indicates reduction in NOx level. They reason this to the shortening of the ignition delay that decreases the proportion of the premixed combustion.

Load vs NOx



Few drawbacks with TBCs

During operation TBCs are exposed to various thermal and mechanical loads such as thermal cycling, high and low cycle fatigue, hot corrosion and high temperature erosion. Currently, because of reliability problems, the thickness of TBCs is limited, in most applications, to 500µm. Increasing coating thickness increases the risk of coating failure and leads to a reduced coating lifetime. The failure mechanisms that cause TTBC coating spallation differ in some degree from that of the traditional thinner coatings. A major reason for traditional TBC failure and coating spallation in gas turbines is typically bond coat oxidation. When the thickness of the thermally grown oxide (TGO) exceeds a certain limit, it induces the critical stress for coating failure. Thicker coatings have higher temperature gradients through the coating and thus have higher internal stresses.

Although the coefficient of thermal expansion (CTE) of 8Y2O3-ZrO2 is close to that of the substrate material, the CTE difference between the substrate and coating induces stresses at high temperatures at the coating interface. The strain tolerance of TTBC has to be managed by controlling the coating microstructure.

Use of thicker coatings generally leads to higher coating surface temperatures that can be detrimental if certain limits are exceeded. In the long run, the phase structure of yettria stabilized zirconia (8Y2O3-ZrO2) is not stable above 1250°C. Also the strain tolerance of the coating can be lost rapidly by sintering if too high surface temperatures are allowed.

VI. CONCLUSIONS

The results showed that, increasing the brake thermal efficiency and decreasing the specific fuel consumption for Light heat Rejection engine with thermal coated piston compared to the standard engine. There was increasing the NOx emission and O_2 for thermal barrier coated engine. However there was decreasing the CO and HC emissions for thermal coated piston engine compared to the standard engine.

The following conclusions can be drawn.

- The TBC, using PSZ, 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 pressures were increased by a magnitude of eight to ten bars in the TBC piston engine, 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 concentrations were increased most seriously at low engine speed and/or low engine power output with a TBC piston engine. The authors suspected that this could be due to the porous quenching effect of the rough TBC piston crowns, 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 piston engine advanced slightly relative to the baseline engine, indicating the improvement in ignitability and heat release before the top dead center, which caused the peak cylinder pressure to raise.

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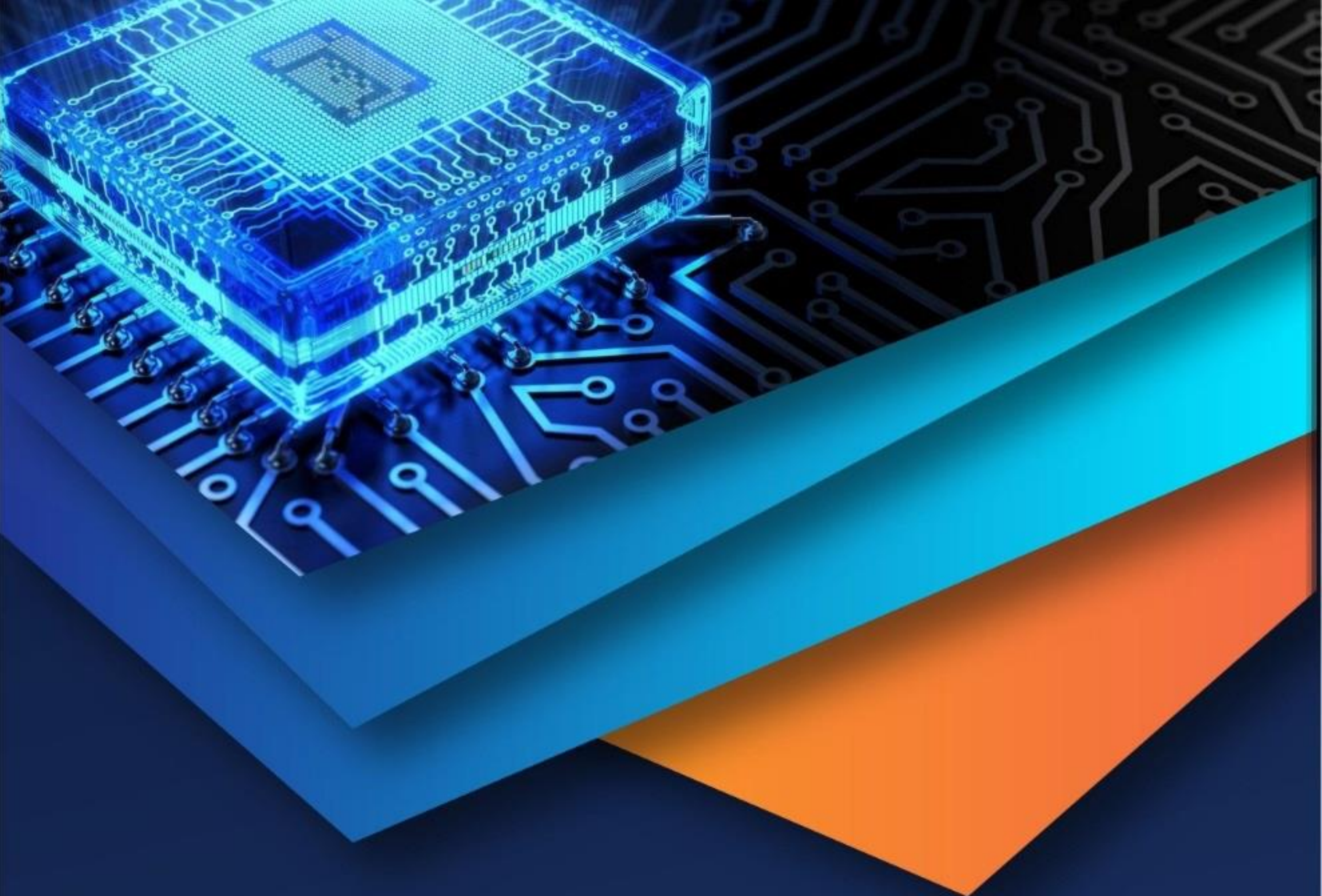

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