Influence Of Thermal Barrier Coatings On S.I Engine Performance

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ABSTRACT

The thermal efficiency of most commercially used engine ranges from 38% to 42%, as nearly 58% to 62 % of energy is lost in the form of waste heat. Nearly 30% is retained in exhaust gas and the remaining is removed in cooling water/air, in order to save energy the hot parts are insulated thermally. This will lead to reduction in heat transfer through the engine, involving an increased efficiency. Change in combustion process due to insulation also affects emissions. Higher gas temperature should reduce the concentration of incomplete combustion products at the expense of an increase in nitrogen oxides ***(NOx).*** *However a decrease in carbon monoxide (CO) unburned hydrocarbons (HC) is observed. Also the highest temperature of any point on piston should not exceed 66% of the melting point temperature of the alloy. This limiting temperature of the piston alloy can be increased by using TBC. Ceramics have higher thermal durability than metals, therefore it is usually not necessary to cool them as fast as metals.*[6]

Thermal Barrier Coatings (TBC) *provides the potential for higher thermal efficiencies of the engine, improved combustion and reduced emissions. In addition ceramics show better wear characteristics than conventional materials.* *A lot of experimental study has to be done to utilize these ceramic prosperities to improve thermal efficiency by reducing heat loss, and to improve mechanical efficiency by eliminating cooling system.*[5]

Keywords : S.I Engine - Thermal Barrier Coatings (TBC) – Piston – Ceramics – Emissions - Heat Transfer – Combustion – Aluminium - Zirconium Dioxide - Titanium Dioxide.

1. INTRODUCTION

The rapid increase in fuel expenses, the decreasing supply of high grade fuels on the market and environment concerns stimulated research on more efficient engines with acceptable emission characteristics. The state of art thermal barrier coating (TBC) provides the potential for higher thermal efficiencies of the engine, improved combustion and reduced emission. In addition ceramic shows better wear characteristics than conventional material.

There are contradictory reports on the effect of TBC on engine performance. Obtained results depend on the type of the engine and conditions of test. Measurement of temperatures and heat flux is difficult, thermal problems often interfere with temperature distribution and materials used to construct them can catalyze the combustion process.

Ceramics have a higher thermal durability than metals. Therefore it is usually not necessary to cool them as fast as metals. 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 exhaust gases, which could also be utilized.

The engine selected for evaluation of the thermal barrier coating was a two-stroke, single cylinder, petrol engine. First this engine was tested as equipped with anair cooled at different speeds and loads condition without a coating. Then the surface of the engine's piston crown was coated with ceramic materials. The piston crown was coated with 0.35mm thickness of ZrO2 over a 0.15mm thick NiCrAl bond coat. The material used on the pistons was aluminium alloy. The coating process was performed using the plasma spray technique. Finally the ceramic-coated engine was tested again under the same operation conditions as the standard engine.[5]

2. IMPROVEMENT IN ENGINE PARAMETER'S

The primary objectives that we like to achieve by adiabatizing the engine cylinder by using Thermal Barrier Coatings (TBC) are as follows:

- To increase the thermal efficiency of the engine.
- To increase the temperature of combustion in the engine cylinder for complete combustion.
- To reduce the fuel consumption.
- To reduce the exhaust emission gases.
- To increase the performance of the engine.
- To find which coating among ZrO_2 and TiO_2 gives better adiabatization of the engine.

3. EXPERIMENTAL TESTING

1. Engine testing with and without coated piston.
2. Comparison of results with & without coating.
3. Tabulation and Generating graphical representations.

A two-stroke, single cylinder, and air-cooled petrol engine is selected to conduct the study. The engine is to be tested for its performance at various operating conditions without piston crown coating. Then the surface of the piston crown is coated with two different TBCs materials. Four pistons are selected for TBCs two pistons (P2, P3) are coated with ZrO_2 of various thicknesses as given in table. The other two pistons (P4, P5) are coated with TiO_2 of various thicknesses as given in table. The coating process is performed using the plasma spray technique. The engine is to be tested for its performance at various operating conditions. The results for both cases are to be analysed and then compared.

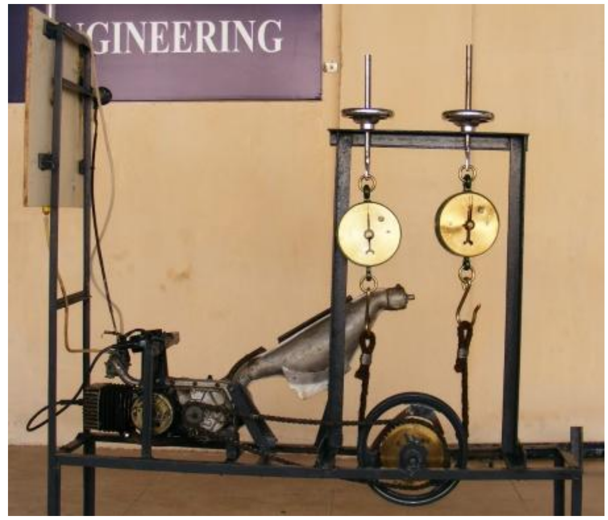

Fig.1: The Experimental Setup

Table.1: Coating Thickness of Materials Used

PISTON	(TBCs) MATERIALS	THICKNESS (mm)	BOND COAT & THICKNESS (mm)
Piston 1	Nil	Nil	Nil
Piston 2	ZrO2	0.250	NiCrAl & 0.15
Piston 3		0.20	
Piston 4	TiO2	0.250	
Piston 5		0.20	

3.1 PLASMA SPRAY PROCESS

The plasma spraying process uses a DC electric arc to generate a stream of high temperature ionised plasma gas, which acts as the spraying heat source. The coating material, in powder form, is carried in an inert gas stream into plasma jet where it is heated and propelled towards the substrate. Because of the high temperature and high thermal energy of plasma jet, material with high melting points can be sprayed.

Using the plasma spray process the TBC materials where sprayed on to the head of the piston at various thickness as mentioned in the above table.[2] [3]

4. PISTON& COATING MATERIALS

4.1 ALUMINIUM

The principleuses of aluminium are for aircraft, machinery, electrical conductors, and cooking utensils. Aluminium has largely created its own uses, and has not replaced steel in its traditional uses, as was once anticipated. The two principal structural metals are complementary more than competitive. Aluminium is very easy to work with in the shop, and has indeed replaced the more expensive brass in many applications. Aluminium, however, cannot be soldered, which is a severe disadvantage. It is very easy to make aluminium castings.[1]

4.2 ZIRCONIUM DIOXIDE (ZrO_2)

Pure zirconia exists in three crystal phases at different temperatures. At very high temperatures (>2370°C) the material has a cubic structure. At intermediate temperatures (1170 to 2370°C) it has a tetragonal structure. This behaviour destroys the mechanical properties of fabricated components during cooling and makes pure zirconia useless for any structural or mechanical application. Several oxides which dissolve in the zirconia crystal structure can slow down or eliminate these crystal structure changes. Commonly used effective additives are MgO, CaO, and Y_2O_3. With sufficient amounts added, the high temperature cubic structure can be maintained to room temperature. Cubic stabilized zirconia is a useful refractory and technical ceramic material because it does not go through destructive phase changes.

Zirconia is an extremely refractory material. It offers chemical and corrosion inertness to temperatures well above the melting point of alumina. The material has low thermal conductivity. It is electrically conductive above 600°C and is used in oxygen sensor cells and as the heater in high temperature induction furnaces. [1]

Fig.2: Zirconium Dioxide Coated Piston

4.3 TITANIUM DIOXIDE (TiO_2)

Titanium dioxide has its systematic name of Dioxotitanium. With its molecular formula of TiO2 and molecular weight of 79.87, it occurs in nature as well-known minerals rutile, anatase and brookite. Recently, Ries crater in Bavaria found two high pressure forms additionally, a monoclinic baddeleyite-like form and an orthorhombic α-PbO2-like form. But the most common form is rutile that is also the equilibrium phase at all temperatures. Titanium dioxide is insoluble in water and organic solvents, but slowly soluble in hydrofluoric acid and hot strong sulphuric acid. When you need to store it, it should be kept sealed in the cool, dry and well-ventilated place.

Pure titanium dioxide does not occur in nature but is derived from ilmenite or leuxocene ores. It is also readily mined in one of the purest forms, rutile beach sand. These ores are the principal raw materials used in the manufacture of titanium dioxide pigment. The first step is to purify the ore, and is basically a refinement step. Either the sulphate process, which uses sulphuric acid as an extraction agent or the chloride process, which uses chlorine, may achieve this. After purification the powders may be treated (coated) to enhance their performance as pigments.[1]

Fig.3: Titanium Dioxide Coated Piston

4.4 NICKEL CHROMIUM ALLOY (NiCrAl) [BOND COAT]

The nickel-chromium system shows that chromium is quite soluble in nickel. This is a maximum at 47% at the eutectic temperature and drops off to about 30% at room temperature. A range of commercial alloys is based on this solid solution. Such alloys have excellent resistance to high temperature oxidation and corrosion and good wear resistance.

Increase in electrical resistivity is observed with increasing chromium additions. An addition level of 20% chromium is considered the optimum for electrical resistance wires suitable for heating elements. This composition combines good electrical properties with good strength and ductility, making it suitable for wire drawing. Small modifications of to this composition may be made to optimise it for particular applications. [1]

Table.2: Properties of Ceramic Materials Used [4]

Properties/ Material	Al alloy	ZrO_2	TiO_2	NiCrAl
Young's modulus (GPa)	72	200	230	90
Poisson's ratio	0.3	0.27	0.27	0.27
Density (kg/m³)	2700	3290	4000	7870
Specific heat (J/kg K)	960	560	560	764
Thermal expansion (1/k)x10^{-6}	21	10.1	9	12
Thermal conductivity (W/mK)	155	8	11.7	16.1

5. EXPERIMENTAL RESULTS

The following table shows the change in different efficiencies depending of the material used as TBC.

Table.3: Tabulation for Efficiency for Different TBC Materials

DATA	AL ALLOY	ZrO_2	TiO_2
Brake Thermal Efficiency	10.329%	12.223%	11.137%
Indicated Thermal Efficiency	24.604%	29.136%	26.278%
Mechanical Efficiency	41.980%	41.953%	42.381%
Volumetric Efficiency	47.663%	51.816%	49.783%
Air-Fuel Ratio	10.575	13.264	11.611

The following graphs show the change in efficiency and performance for different material used as TBC.

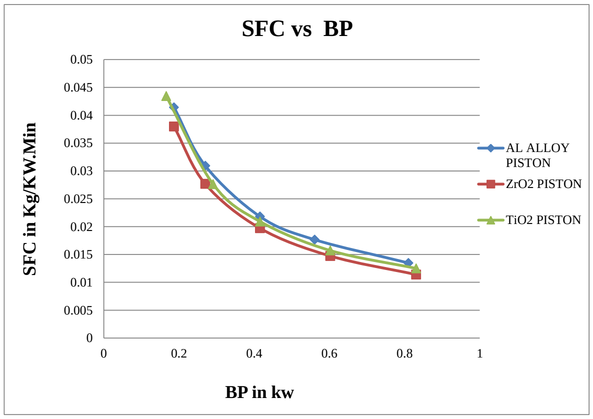

Fig.4: Specific Fuel Consumption vs Brake Power

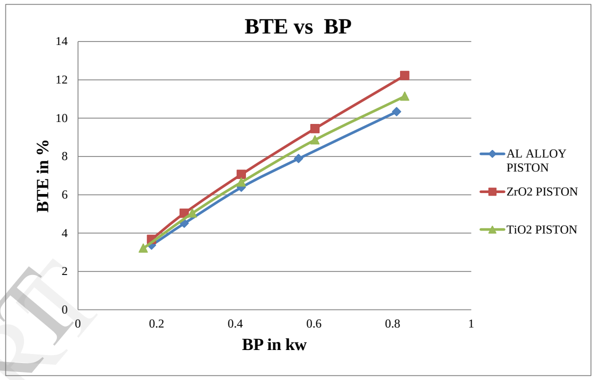

Fig.5: Brake Thermal Efficiency vs Brake Power

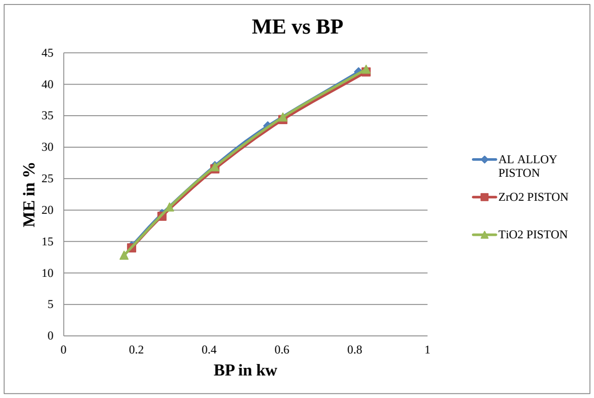

Fig.6: Mechanical Efficiency vs Brake Power

The following tables give the change is emission observed when different material are used as TBC.

Table.4: Tabulation for Al Alloy Piston

SL NO	BP in Kw	Load in kg	CO	CO_2	HC	NOX
			in ppm			
1	0.18701	0.8	8.02	1.6	4385	43
2	0.27013	1.4	8.82	1.82	3766	39
3	0.41558	2.2	9.3	2.1	3448	36
4	0.56104	2.9	9.37	2.29	3136	33
5	0.81039	3.7	9.58	2.38	3112	31

Table.5: Tabulation for Zirconium Dioxide Coated Piston

SL NO	BP in Kw	Load in kg	CO	CO2	HC	NOX
			in ppm			
1	0.1870	0.75	2.02	2.3	1694	26
2	0.2701	1.5	3.2	3.34	1495	45
3	0.4155	2.25	4.05	4.55	1428	54
4	0.6026	3	4.79	5.42	1380	61
5	0.8311	3.75	5.09	5.81	1350	67

Table.6: Tabulation for Titanium Di Oxide Coated Piston

SL NO	BP in Kw	Load in kg	CO	CO2	HC	NOX
			in ppm			
1	0.166235	0.9	2.13	3.53	2586	28
2	0.290912	1.5	4.65	4.45	2365	40
3	0.415588	2.3	5.86	4.92	2112	47
4	0.602603	2.85	7.10	5.21	1986	53
5	0.831176	3.85	7.11	5.07	1852	58

The following graphs show the change in emissions for different material used as TBC.

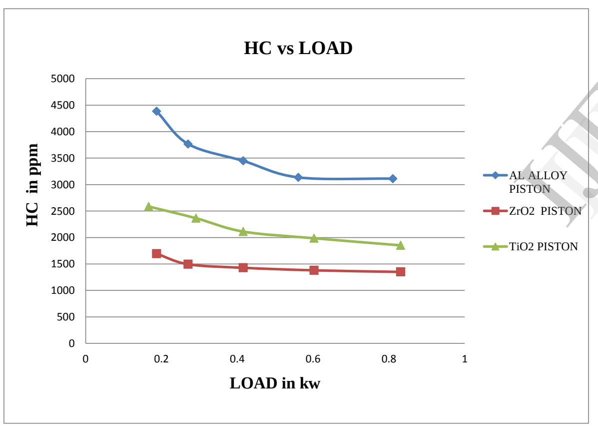

Fig.7: HC vs LOAD

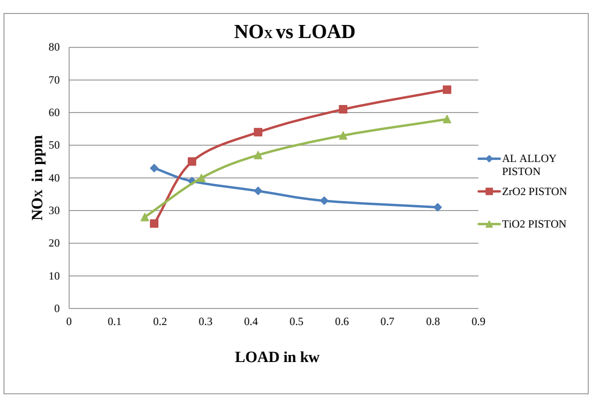

Fig.8: NO_X vs LOAD

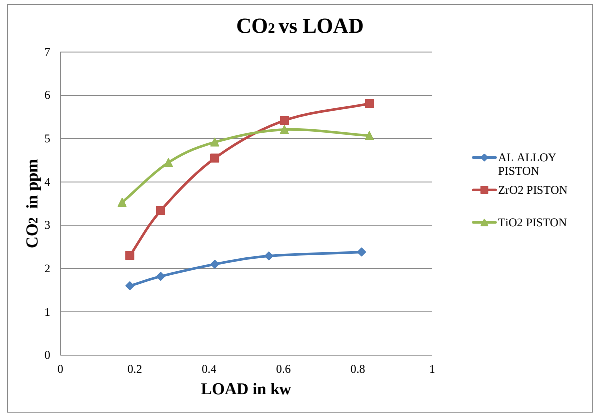

Fig.9: CO_2 vs LOAD

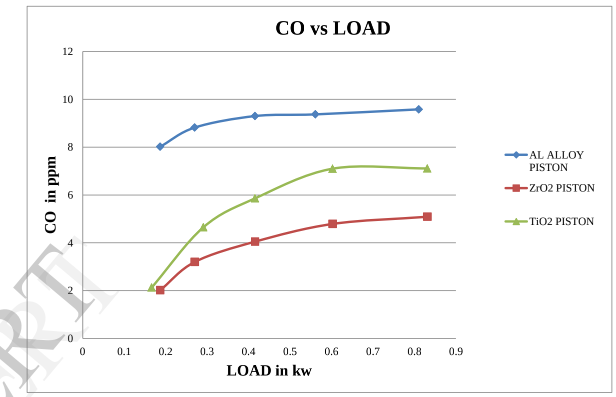

Fig.10: CO vs LOAD

6. RESULT ANALYSIS

Two sets of experiments were conducted with conventional and TBC coating of zirconiumdioxide **(ZrO_2)** and titanium dioxide **(TiO_2)** coated pistonon the piston crown. In each set of tests, readings of engine speed, load torque, engine power, fuel consumption, exhaust gas temperature, gas emission concentration, readings were taken with various engine loads and various engine speeds (1000 to 4500rpm).

Total fuel consumption has comparatively reduced in TBC over conventional AL Alloy piston and also increase in brake thermal efficiency,Indicated thermal efficiency and also increase in volumetric efficiency. ZrO_2has a better performance over TiO_2 and AL Alloy piston.

When comparing piston coated with ZrO_2 and piston coated with TiO_2 it was found that the piston with

ZrO_2 coating provided better results than the TiO_2 coated piston. The piston with ZrO_2 coating provides better efficiency and performance when compared with the TiO_2 coated piston. The difference in the efficiency between ZrO_2 coated piston and TiO_2 coated piston was in the range of 1% to 2%. In the case of air-fuel ratio it was found that ZrO_2 coated piston had an air-fuel ratio of 13.26. But the air-fuel ratio of TiO_2 coated piston was 11.61. The engine with ZrO_2 coated piston also shows better result in fuel consumption when compared with TiO_2 coated piston.

In the case of emissions it was found that the ZrO_2 coated piston emits less CO and HC when compared with TiO_2 coated piston. But it is to be noted that both ZrO_2 and TiO_2 coated piston showed an increase in NOx and CO_2 when compared with plain AL alloy piston. The ZrO_2 coated piston engine showed a slight increase in NOx and CO_2 emissions when compared with TiO_2 coated piston engine.

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8. CONCLUSION

Experimental investigation of the effect of ceramic coating on petrol engine performance and exhaust emissions was conducted.

- The TBC, using ZrO_2 and TiO_2 applied on the piston crown of internal combustion engine showed some improvement in fuel economy
- The unburned hydrocarbon concentration was increased mostly at low engine speed or low engine power output with a TBC piston engine.
- CO emission and HC were lower in the coated engine.
- The specific fuel consumption shows a 1% decrease in the engine with TBC
- Significant increase in engine performance was observed.
- The performance of thermally coated engine was found to be satisfactory.
- The NOX and CO_2 can be reduced by using catalytic converter or EGR systems.

9. REFERENCES

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