Experimental Investigation on Performance of Single Cylinder Diesel Engine with Mullite and Aluminium Titanate as Thermal Barrier Coating

S. Nandeeswaran[1], K. Sriram[*2]
[1]P.G.Student,Manufacturing Engineering, Dept of Manuf Engg,J K K Munirajah College of Technology, Anna University, Tamil Nadu, India
[2]Assistant professor, Dept of Mech Engg, J K K Munirajah College of Technology, Tamil Nadu, India

***Abstract* : The thermal efficiency of commercially used engine ranges from 38% to 42%, as nearly 58% to 62 % of energy is lost of heat. Nearly 30% is retained in exhaust gas and the remaining is removed in cooling water/air, in order to save that energy the hot parts are insulated TBC.TBC is that ceramic is better than the conventional materials. $CaZrO_3$, Mullite and Al_2O_3 –ZrO_2 are some of the ceramic materials used as TBC. A four stroke single cylinder Kirloskar diesel engine is selected for carrying out of the experiment. It is planned to use the TBC (Mullite + aluminum titanate) on the piston head by plasma spray process for the performance characteristics of the engine with and without TBC under various loading condition. The purpose of using these materials is to reduce the heat loss from engine. As the experimental investigation results of significant reduction in specific fuel consumption as 1.4% and effective improvement in brake thermal efficiency as 1.1%.**

***Keywords:* Mullite and Aluminum Titanate; Plasma spray; Diesel engine piston; Ceramic coating**

INTRODUCTION

One of the development for heat engines is improvement of their energy efficiency, as in the case of the C.I engine. The increase in fuel expenses, the decreasing supply of fuels in the market and environmental concerns necessitates engines with acceptable emission characteristics. In internal combustion engine, one of the ways to achieve the aim is engine adiabatization. The method to adibatize an engine is to cover the surfaces of the combustion chamber with a thermal barrier coating. The thermal insulation thus obtained is supposed to lead, according to the second law of thermodynamics, to an development in the engine's heat efficiency and a reduction in consumption. Higher temperature in the combustion chamber can also have a positive effect.

The thermal efficiency of commercially used engine ranges from 38% to 42%, as nearly 58% to 62 % of energy is lost of heat. Nearly 30% is retained in exhaust gas and the remaining is removed in cooling water/air, in order to save that energy the hot parts are insulated TBC. This will lead to reduction in heat transfer through the engine, involving an increased efficiency. The highest temperature of any point on piston should not exceed 66% of the melting point temperature of the alloy. This limiting temperature for the piston of aluminium alloy can be increased in TBC. Ceramics have higher thermal durability than conventional metals therefore it is usually not necessary to cool them as fast as metals. Thermal barrier coatings (TBC) provide higher thermal efficiencies of the engine, improved combustion and reduced emissions. In addition ceramic materials show better wear characteristics than conventional materials. A lot of experimental study has to be done to promote these ceramic prosperities to improve thermal efficiency by reducing heat loss, and to improve mechanical efficiency by eliminating cooling system.

Table.1.1 Properties of Ceramic Material

Properties/ Material	Young's modulus (GPa)	Poisson's ratio	Density (kg/m^3)	Specific heat (J/kg K)	Thermal expansion ($x10^{-6}k^{-1}$)	Thermal conductivity (W/mK)
Al alloy	80	0.28	2700	960	21	155
ZrO_2	200	0.27	3290	560	10.1	8
TiO_2	230	0.27	4000	560	9	11.7
NiCrAl	64.5	0.3	6290	460	10.3	3.88
$MgAl_2O_4$	276	0.26	3580	819	14	25
3Al2O3 SiO2	19	0.25	2710	760	5.1	1.29
Wc	686	0.22	15800	292	7.1	88

2. COATING MATERIALS

2.1 Mullite ($3Al_2O_3$; $2SiO_2$)

Mullite powder show in figure.2.1 is an important ceramic material because of its low density, high thermal stability, stability in severe biodegradable, low thermal conductivity and favourable strength and creep behaviour. Compared with yittria stabilized zirconia, mullite has a much lower coefficient of thermal expansion and higher thermal conductivity, and is much more oxygen-rebellious than yittria stabilized zirconia. The low thermal expansion coefficient of mullite is an advantage equitable to yittria stabilized zirconia in high thermal gradients and under thermal shock conditions. However, the large discrepancy in thermal expansion coefficient with metallic substrate leads to poor adhesion.

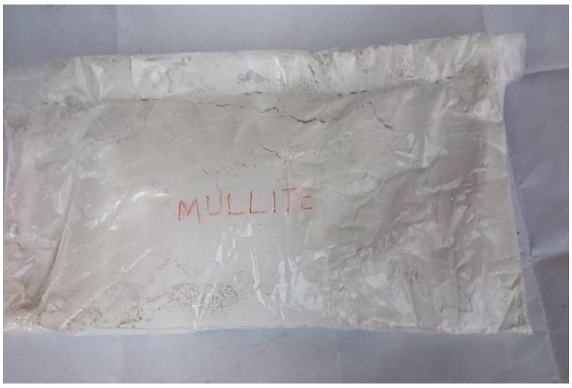

Fig.2.1 Mullite Powder

2.2 Aluminum Titanate (Al_2TiO_5)

Aluminum titanate is a ceramic powder material show in figure.2.2 it's consisting of a mixture of alumina and Titania forming solid solution with stoichiometric proportion of the components: Al2TiO5.Aluminium titanate is prepared by heating of a mixture of alumina and Titania at temperature above 2460°F. Pure Aluminum Titanate is unstable at the temperatures above 1380°F when the solid solution disintegrates into two separate phasesAl2O3 and TiO2. Aluminum Titanate ceramics are doped with MgO, SiO2 and ZrO2 in order to assist the solid solution structure. The distinctive property of Aluminum Titanate ceramics is their high thermal shock defiance which is a result of very low coefficient of thermal expansion.

Fig.2.2 Aluminum Titanate Powder

3. EXPERIMENTAL WORK

3.1 Plasma spray process

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

Plasma spraying produces a high quality coating by combination of a high temperature, high energy heat source, corresponding inert spraying medium and high particle velocities, typically 200-300m.sec-1. However, some air becomes appropriated in the spray stream and oxidation of the spray material may occur. The neighbouring atmosphere also cools and slows the spray stream. Vacuum plasma (VPS) or low pressure plasma spraying (LPPS). Reduce these problems by spraying in pressure, inert gas environment. Plasma spraying is widely applied in the production of high quality sprayed coating. The plasma spray gun comprises a copper anode and tungsten cathode, both of which are water cooled. Plasma gas (argon, nitrogen, hydrogen, helium) flows around the cathode and through the anode which is shaped as a compressing nozzle. The plasma is initiated by a high voltage discharge which causes localized ionization and a consecutive path for a DC arc to form between cathode and anode. The resistance heating from the arc causes the gas to reach extreme temperatures disengage and ionizes to form plasma.

3.2 Technical Specifications of Diesel Engine

- Make : Kirloskar
- Stroke : 110 mm
- Bore : 80 mm
- Speed : 1500 rpm
- No of cylinder: One
- BHP : 5.0
- Orifice diameter : 20 mm
- Type of ignition : Compression ignition
- Method of cooling : Water cooled
- Method of loading : Rope brake dynamometer

Fig.3.1 Ceramic Coated Piston

4. EXPERIMENTAL RESULT

A long term experimental study has been regulated on a single cylinder, direct injection Diesel engine. Both the standard engine (without TBC) and its LHR adaptation have been used in the experiments. For LHR engine a reciprocating compressor has been connected between air box and engine to upgrade the air pressure and to maintain constant Air Fuel ratio (A/F) as in standard engine. A comparative calculation for both cases has been made based upon engine performance; brake specific fuel consumption; exhaust gas temperature and energy balance.

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

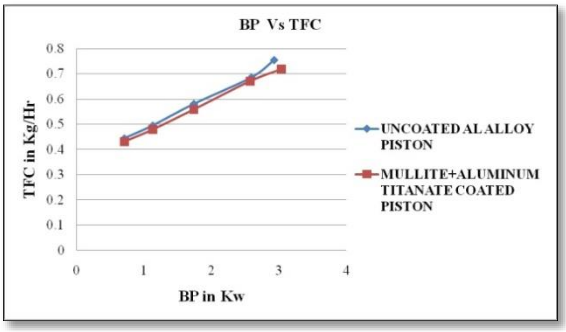

Fig.4.1 Brake Power Vs Total Fuel Consumption

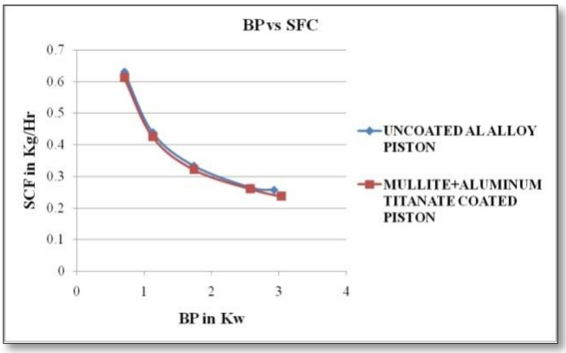

Fig.4.2 Brake Power Vs Specific Fuel Consumption

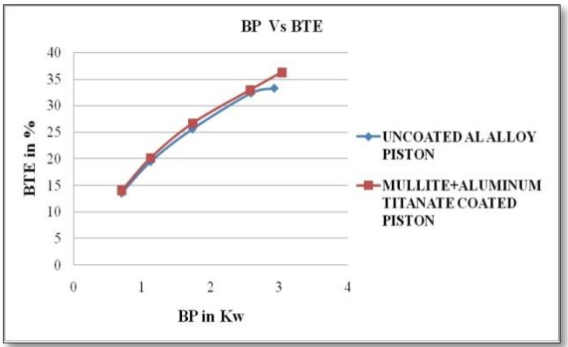

Fig.4.3 Brake Power Vs Brake Thermal Efficiency

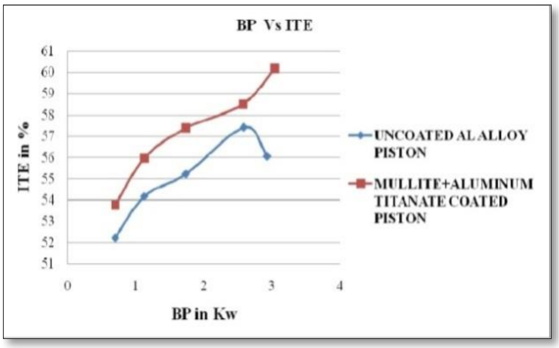

Fig.4.4. Brake Power Vs Indicated Thermal Efficiency

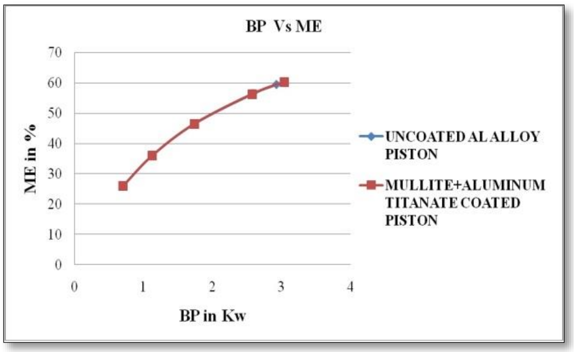

Fig.4.5 Brake Power Vs Mechanical Efficiency

5. RESULT AND CONCLUSION

The main conclusions drawn from present experimental investigation on (Mullite + aluminum titanate coated) and conventional diesel engines are as follows.

Coated engine with 0.35mm of Mullite+ aluminum titanate insulation coating on piston crown of diesel engine models lower brake specific fuel Consumption than the conventional diesel engine. This insulation coating exhibits the brake specific fuel consumption very close to conventional engine with deviation by about 1.4% higher at full engine load. This is due to effect of insulation; the heat free flow is prescribed, which leads to cutback in heat transfer in case of LHR engine. The Reduction in heat transfer margins to increase in combustion temperature, which leads to Better combustion. The higher combustion temperature will start to more expansion Work.

Coated engine with 0.35 mm of Mullite+ aluminum titanate insulation coating on piston Crown of diesel gives marginal rise in brake thermal Efficiency when compared with conventional diesel engine. The brake thermal efficiency for LHR engine is higher by about 1.1 % than the conventional diesel engine at full engine load level. The insulation coating reduces the heat loss through combustion chamber resulting in increase in the charge temperature. This higher charge temperature leads to better combustion. Finally the combustion chamber temperature increases the thermal efficiency of the engine also increases.

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