Application of Energy Efficient Thermal Barrier Coatings for Internal Combustion Engines

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Abstract — I. C. engines used in transportation, energy, and defense sectors rely on high-temperature thermal-barrier coatings for improved efficiencies and power. Higher demands implementing stricter regulations on emission measure, high fuel prices, more precise requirements in the field of the vehicle emissions increasing the pressure on the engine manufacturers to utilise technologies which contribute to a reduction in air pollution, including limits on nitrogen oxides, particulate matter, greenhouse gases and require internal combustion engines to be optimized with respect to their frictional losses and wear. Meeting these standards can require complex and costly upgrades to diesel engines. In this article, Literature survey carried out on the basis of reference books, conference volume and Research paper. The details about Thermal Barrier coating, coating methods and researcher results and their conclusions are discussed in depth with facts and figure based on presented articles. The Thermal Barrier coating method has wide effects on the brake specific fuel consumption, brake power and the Emission characteristic, pollution contents and the Thermal fatigue lifetime of engine components. By using Air plasma thermal spray method there are several benefits by applying ceramic layers on the combustion chamber, including the piston, the cylinder head, the cylinder block, and intake and exhaust valves.

Keywords: Thermal Barrier Coatings, Coating Technique, Diesel Engine

I. Introduction

The energy balance analysis is recognized as a useful method for aiding the characterization of the performance and efficiency of internal combustion (IC) engines. As there is a high amount of heat loss in atmosphere due to which the efficiency is lower for the standard engine. From the total heat energy of the fuel offered by diesel engine about one-third goes to the coolant, about one-third to the exhaust and only remaining one-third of energy is available as useful power output. Theoretically if the heat rejected could be reduced, then the thermal efficiency would be improved, at least up to the limit set by the second law of thermodynamics. Low Heat Rejection engines aim to do this by reducing the heat lost to the coolant. The idea of a low heat rejection engine (Adiabatic engine) was extensively developed in the 1980s due to its potential in improving engine thermal efficiency via reducing the heat losses. From the first law of thermodynamics, it can be expected that any retained energy by reducing heat losses through the chamber walls can be converted to useful work and consequently improve the fuel conversion efficiency. In this study, the LHR operating condition is implemented by increasing the engine coolant temperature. The LHR engine has been conceived basically to improve fuel economy by eliminating the conventional cooling system and converting part of the increased exhaust energy into shaft work using the turbocharged system. A large number of studies on performance, structure and durability of the Thermal Barrier Coated (LHR) engine have been carried out the investigations have been concluded that insulation reduces heat transfer, improves thermal efficiency, and increases energy availability in the exhaust . An attempt will be made here to investigate and review the previous studies to look into future possibilities of the LHR engine from the viewpoint of combustion heat transfer and emission. There is one possible solution to reduce such problem i.e., converting the conventional CI engine in to the LHR engine.

A. *TBC Materials:*

The widespread utilization of ceramic thermal-barrier coatings in both energy and propulsion systems has, to a large extent, been enabled by the development of advanced deposition technologies. Thermal barrier coatings (TBCs) are highly advanced material systems mostly applied to metallic surfaces, such as gas turbine or aero-engine parts which operate at elevated temperatures, as a form of exhaust heat management [3]. The purpose of these coatings is to insulate components from large and prolonged heat loads by using thermally insulating materials which can sustain an appreciable temperature difference between the load-bearing alloys and the coating surface. The coatings of insulation materials used in the LHR engine must have a high temperature strength, high expansion coefficient, low friction characteristics, good thermal shock resistance, light weight and durability [18].The term ceramic now covers a very wide range of materials including building materials sanitary were, table, refractories, dielectrics, magnetic ceramics, insulators, etc. Materials that are used for engineering in its mechanical sense can be considered to be the stronger ones, usually specially developed for their fine grain size and high density. They can be divided conveniently into two groups: oxides and non-oxides. In the former group fall traditional Porcelains, alumina, magnesia and other refractory oxides. In the latter are silicon carbide, silicon nitride, boron carbide, boron nitride, molybdenum disilicide and other such compounds, of which the first three are probably the most important. The ceramic materials of principal interest for heat engine applications are silicon nitride, silicon carbide, zirconia and lithium aluminum Silicate (LAS). Although it has good thermal properties, LAS has very poor mechanical properties, so its use is limited to non-structural components. It's extremely low thermal expansion and excellent thermal shock resistance make it ideal for application like catalytic convertors, regenerators and flow separator housing where one side of the component may reach temperatures several hundred degrees higher than the other side. Although it is of higher density than Sic or Si3N4, there is still some uncertainty about its high temperature performance. The conditions for reversibility of the transformation toughening reaction may not be understood well enough yet to predict behavior under dynamic or repeated stress. However zirconia is an excellent insulator and has a thermal expansion equal to 80 % that of cast iron making it a suitable choice for a coating material for cylinder linear, piston caps and intake ports. In these its low coefficient of friction and good wear/corrosion resistance can also be exploited. Silicon carbide and silicon nitride are by far the materials most often considered for components to be subjected to the most severe thermal environments. Their superior room temperature and high temperature strength and oxidation resistance make them principal candidates for rotors and stators and rators and numerous other engine components. The ceramic coating which can also be considered for engine components are hot pressed silicon carbide (HPSC), hot pressed silicon nitride (HPSN) and stabilized zirconia (SZ). Fully stabilized zirconia coating performs very poorly in thermal cycling test. Yttria is used to partially stabilized zirconia, thus raising its mechanical strength and it resist to thermal shock and thermal fatigue.

1) *Characteristics of TBC*

- High melting point
- Low thermal conductivity:
- Low density
- High thermal shock resistance
- Resistance to oxidation and chemical environment
- High surface emissivity:
- Resistance to mechanical erosion

2) *Advantages of Ceramic Coated engine*

When Engine performance of Compression Ignition engine & Spark Ignition engine takes place with ceramic coated engine parts by experiment and finite element analysis, it offers the following advantages:

It show increase the thermal efficiency of the engine.

- To lower the fuel consumption.
- Increase the temperature of combustion inside engine cylinder for complete combustion.
- It show reduce in exhaust gases emission.
- To increase the performance of the engine.
- Durability of engine component increase
- It reduce the friction between engine components.
- Low cetane fuels can be burnt.
- Improvements occur at emissions.
- Waste exhaust gases are used to produce useful shaft work
- Increased effective efficiency,

II. Existing Literature

Dhiren Patel, A J Modi, , 2015[1] investigated the performance and emission characteristics of twin cylinder ceramic coated water cooled Diesel engine using blends of diesel and neem bio diesel. In this work they prepared bio - diesel in laboratory from non-edible vegetable oil (neem oil) by transesterification process with methanol, where potassium hydroxide (KOH) was used as a catalyst and Combustion chamber inner wall. Air Plasma spray Technology was used to coat Magnesium Zirconate on inner wall of Combustion chamber, Piston crown and valve faces. Results Shows that brake thermal efficiency of the Lower Heat Rejection engine is found to be higher by 11-13% and brake specific fuel consumption was 7-12% lower in LHR engine than that of the Standard engine at extreme load condition.

R. G. Telrandhe, Parag C. Thanare , 2015[2] investigated and analyze the thermal stress distribution of piston, piston rings at the real engine condition during combustion process. With application of the thermal barrier coating results indicate on piston crown the thermal stress 10 -15% decreases because low thermal conductivity of coating material Magnesium Zirconate ($MgZrO_3$) & Titanium Alloys

K. Komali, Nagarjuna Jana, 2015[3] enhanced piston model using ANSYS for thermal distribution in functionally Graded Material Coated Piston. Temperature distribution on the piston's top surface and substrate surface is examined by using finite element based software called ANSYS. The functionally graded material whose properties are varied along the thickness of the coating is considered. The FGM is actually a layer of ceramic consisting of zirconium with different proportions of nickel-chromium aluminum alloy bond coat applied along its thickness using the HVOF process.

G. Sivakumar, S. Senthil Kumar, 2014[4] investigated the effect of air plasma spraying technique on the piston crown surface to form a 100 micron Yttria Stabilized Zirconia thin TBC coating layer. Result indicates heat loss to the cooling system is reduced up to 5–10% Brake Specific Fuel Consumption is reduced by 3.38% and 28.59% at high load and 25% of the full load conditions respectively. Particulate Emissions in the exhaust were also reduced by 35.27% in the Thermal Barrier coated engine, where CO emission is reduced by 2.7% and CO2 emission increased by 5.27%.

Ekrem Buyukkaya, Muhammet Cerit, 2007[5] analysed the thermal analysis of a ceramic coating MgO-ZrO2 Compression ignition engine piston by 3-D finite element method and investigated thermal analyses of uncoated diesel piston made of aluminium silicon alloy and steel. A Ceramic coating has the capacity to give maximum thermal efficiency, improves combustion and reduces emissions. Compared to conventional materials, Ceramics used as thermal barrier coating have more thermal durability than metals and display improved wear characteristics. It was observed that Piston is coated with a 350 µm thickness of MgZrO3 over a 150 µm thickness of NiCrAl bond coat shows better result with less thermal conductivity improved by 48% for AlSi alloy and 35% in case of steel.

Y. Sureshbabu, P. Ashoka Varthanan, 2014[6] recognized that the catalyst coating on the piston, combustion chamber gives the maximum brake thermal efficiency. This study aims to identify the best coating material for spark ignition engine. Among the different catalysts investigated, copper is very effective in reducing HC and CO emissions for SI engines and hence proved that copper coating is most suitable for SI engines. In future copper coating thickness will be optimized for better results.

Debasish Das, Gautam Majumdar, Rajat Shubra Sen, B. B. Ghosh, 2013[7] coated three piston crowns with Al_2O_3 as bond coat of 100µm thickness & Partially Stabilized

Zirconia with top coat of 250µm, 350µm, 450µm respectively by Plasma spray coating technique. Performance shows that on the application PSZ as a ceramic coating increased oxidation, which increases the generation of CO2. It has been observed that coated piston engine increases the cylinder pressure and better heat release rate due to complete combustion. Partially stabilized Zirconia can act like an insulator and prevent heat rejection from the engine.

M Azadi, M. Baloo, 2013[8] studied effect of thermal barrier coating on diesel engine, it shows that performance and emissions characteristic of engine improve. In this presented paper they compare the coated NiCrAlY with 150 microns thickness and another layer made of ZrO2-8%Y2O3 with 300 microns thickness by using the plasma thermal spray method with uncoated engine. Hence they examined that thermal efficiency increases & emission parameter is also improved. Brake Specific Fuel consumption decreased by 12% with increase in Engine lifetime, Engine power, Valves lifetime compared with the uncoated piston is 20%, 10% and 300% respectively.

Vinay Kumar Domakonda, Ravi Kumar Puli, 2012[9] presented the paper that show effect of ceramic material on performance parameter of engine, heat transfer characteristics, combustion characteristics and emission characteristics. Research on low heat rejection engines was carried out , it's show increase in the in-cylinder temperatures helped in better release of energy in the case of biodiesel fuels thereby reducing emissions at almost the same performance as the diesel fuel. The reduction of heat loss from the combustion chamber of diesel engines improves fuel economy by 3% to 4%.

Helmisyah Ahmad Jalaludin, Shahrir Abdullah, Mariyam Jameelah Ghazali, Bulan Abdullah, Nik Rosli Abdullah 2012[10] carried out test experimental investigation on ceramic coated piston crown with CNG DI engine with bonding layer NiCrAl and ceramic based yttria partially stabilized zirconia were air plasma sprayed onto AC8A aluminum alloy CNGDI piston crowns and normal CamPro piston crowns in order to reduce thermal distortion. The performance of the coating against high temperature was tested using a burner rig and temperatures on the top of piston crown and piston underside were measured. Hence, they concluded that the YPSZ/ NiCrAl coated CNGDI piston crown experienced the least heat fluxes than the uncoated piston crowns.

Ramaswamy P, Seetharamu S, Verma K, Raman N, Rao K.[11] examined the effect of atmospheric plasma spraying technique on the piston crown surface to form a 100 micron NiCrAlY thin TBC bond coating layer and 260 micron ZrO2–8%Y2O3 top coating layer. Result shows BSFC decreases by 6–7% for YSZ in the TBC coated engine.

Parlak A, Yasar H, Eldogan O[12] examined the effect of Atmospheric plasma spraying technique on Cylinder head and valve with CaO–ZrO2 (0.35 mm) under Variable loads and constant speed result shows BSFC decreases by 6%

T. Karthikeya Sharma[13] investigates the effects of using argon (Ar) gas to mitigate the spark ignition engine intake air to enhance the performance and cut down the emissions mainly nitrogen oxides result Shows A 55% reduction in NOx emissions was observed in the engine emissions by the replacement of N2 by Ar and increase in air fuel ratio.

Ekrem Buyukkaya, Muhammet Cerit, 2007[14] carried out both temperature and thermal stress distributions to improve the performance of a diesel engine. He modified the standard baseline engine with Magnesia-stabilized zirconia coating on an aluminum piston using different coating thickness. Concluded with increases in Thermal efficiency of the engine. Identified maximum temperature at the crown center, compared with the uncoated piston is 32.7%, 55.8%, 72.5% and 84.8% for 0.4 mm, 0.8 mm, 1.2 mm and 1.6 mm thick coating, respectively

Hitesh Buhecha et. Al[15]. study effect on performance and emissions results of LPG fuelled Engine with Alumina coating.he modified baseline engine with Coating of Al_2O_3 on SI engine, thickness around 200 µm and used LPG as fuel and found that BSFC is 29% lower at 50% loads and 12% reduces at maximum loads.CO is reduced maximum 0.03% at 50% load & at full loads it rescues 0.02%.

Susumu Uozato et. Al[16] investigated the wear and corrosion resistance with newly developed ferrous powder, Fe–C–Ni–Cr–Cu–V–B is using particle sizes of 200–300 µm using Rota-Plasma spray coating , its showed excellent wear performance compared with liner bulk materials currently used in actual engines and Weight loss of the coating was about 2%.

Hanbey Hazar[17] performed test on the uncoated engine and compared with Coated engine with modification of Al_2O_3-TiO_2 thickness of 250 µm over 50 µm thickness of NiAl bond coat using plasma spray method. He conclude that improve in engine power and specific fuel consumption, as well as significant improvements in exhaust gas emissions.

D. N. Assanis[18] described the application of a computer simulation of the turbocharged turbo compound diesel engine system to study the effect of combustion chamber insulation on the performance of various LHR system configurations he conclude that coating of sprayed zirconia can result in a substantial (43%) reduction in heat loss. The lower the thermal conductivity and the lower the thermal capacity of the material, the higher the wall surface temperature variations, the smaller the degradation in volumetric efficiency and thus the better the thermal efficiency of the overall system.

Hitesh Buhecha et. Al[19] study effect on performance and emissions of LPG fuelled Engine with Alumina coating. Modified LPG fuel engine with thickness around 200 µm Al_2O_3 on SI engine shows thermal Efficiency increases & Emission result is also improved. it conclude that BSFC is 29% lower at 50% loads and 12% reduces at maximum loads.CO is reduced maximum 0.03% at 50% load & at full loads it rescues 0.02% .

K.Thiruselvam[20] Study of effect of thermal barrier coating in internal combustion engine. TBC coating in cylinder liner and piston. SFC for all test fuels decreases in coated condition Gasoline in ceramic coated engine showed 3.8% rise in break thermal efficiency at lower loads and peaks to 6% at maximum load.

Cengiz Oner et. al.[21] The wear behaviors of the engine with CrN coated cylinder and with uncoated, cast iron cylinder were compared. Chromium nitride (CrN) coatings doing with physical vapor deposition (PVD) process

Improved hardness, microstructure and roughness values of the surface present a longer life for the cylinder.

III. CONCLUSION

Research regarding any of the subject or course can be made possible only through the knowledge of previous work related to the same branch. So, following work carried out by the eminent personalities will always be the stepping-stone for the future revelations. Required deep knowledge before carrying research work can be made well by discussing the previous work carried out by the researchers in the various fields which are related to topic.

Thermal Barrier coating material continues to be successfully applied for Gas Turbine engine used in transportation, Aerospace and IGT applications. Material improved effiecieny, power, reliability and process versatility give the product a long history of success.

Y_2O_3 stabilized ZrO_2 ceramics and MgZrO3 can be an air plasma-sprayed with APS Technology application hardware to meet engineered design coating criteria using either mass flow control or volumetric flow meters. By changing parameters, it has been demonstrated that coatings can be altered with great latitude while maintaining efficiency.

These articles are introduced, together with a discussion of the major challenges to improved coating development, Combustion chamber Analysis with mechanical parameter and effect of piston crown coating on the performance of engine thus following conclusions have been made. This chapter presents the detailed literature review on

Coating materials properties such as low thermal conductivity, high melting point, resistance to sintering, a demonstrated manufacturing capability for depositing it with constant composition, and long life in the resulting TBCs

Coating materials such as Nickel chromium and alloys has Corrosion resistance, Melting point, Hardness and prevents scaling on carbon and low alloy steels.

There are some of the areas where more work on the experimental side can be done to for adequate methods for measuring and characterizing the mechanical and thermal properties of coatings at high temperatures, improve the performance of an I.C. Engine by nanostructure APS coating, oxidation behaviour under real operating conditions thus thermal efficiency increase.

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