Application of TBC Materials in IC Engine Combustion Chamber: A Review

Prof. Dipak C. Gosai[1] Mahesh M. Chudasama[2]
[1]Associate Professor [2]Lecturer
[1]Department of IC Engine & Automobile Engineering [2]Department of Automobile Engineering
[1]Shree S'ad Vidya Mandal Institute of Technology, Bharuch, Gujarat, India [2]Dr J N Mehta Govt. Poly, Amreli, Gujarat, INDIA

Abstract— Revolt fuel prices and more precise requirements in the field of the vehicle emissions such as nitrogen oxides, fine dust and carbon dioxide are increasing the pressure on the engine manufacturers to utilise technologies which contribute to a reduction in the emissions. In this study, a complete literatures review of Thermal barrier coating(TBCs) applications in Internal combustion engines Chamber performed to select a proper type and to find coating effects. The TBC coating technique has effects on the specific fuel consumption, the power and the combustion characteristic, pollution contents and the Thermal fatigue lifetime of engine components. Usually there are several beneficial influences by applying ceramic layers on the combustion chamber, including the piston, the cylinder head, the cylinder block, intake and exhaust valves by using a plasma thermal spray method. In this article, all effects, merits and demerits of TBCs are investigated based on presented articles.

Key words: Thermal Barrier Coating, Piston Crown, Diesel Engine

I. Introduction

Energy flows and energy efficiencies in the operation of a modern automobile are expressed in terms of simple empirical relations. The developmental tendencies in obtaining high performance of I.C. engine are chiefly connected with an increase in the engine's capacity, its efficiency, lifetime, reliability, reduce emission and a decrease in the fuel consumption. The overall energy use depends on two factors, vehicle load and power train efficiency. The former depends on speed acceleration and vehicle mass. The latter depends on heat-engine thermodynamic efficiency. Reductions in fuel consumption can be achieved by a variety of measures, including improved aerodynamics, weight reductions and hybrid power trains. Since the early stages of modern engine construction, their producers have been applying protective coating systems in order to enhance their durability and to maximize the exploitation of the properties of the used materials.

Modern engine constructions together with the technological advancement lead to the evolution of new coating types and to the improvement of the formerly used coatings. The present's applications of a variety of protective coatings for the piston crown of an I.C. Engine.

However, in the hot section of the engine, which includes piston , the combustion chamber area the thermal barrier coatings (TBCs) and high-temperature seal coatings are used. The hot operating temperature of the parts demands the application of Advance ceramic material.

Those materials need to be resistant to the high temperature of the gas stream, which may have a strong oxidizing, corroding or eroding impact. The influence of the destructive environment might be incredibly complex, depending on the engine construction, its working cycle, the used fuel and its operation site.

A. Thermal Barrier Coatings

TBCs have now been used extensively in the Automotive as well as gas turbine industry for over 50 years. Thermal barrier Coating are used in high temperature section components of the engine; these include the combustion chamber, turbine inlet guide vanes, Piston, turbine blades, Valve, turbine stator blades and afterburners. Parts insulated with a Thermal Barrier coating can be seen in figure 1:

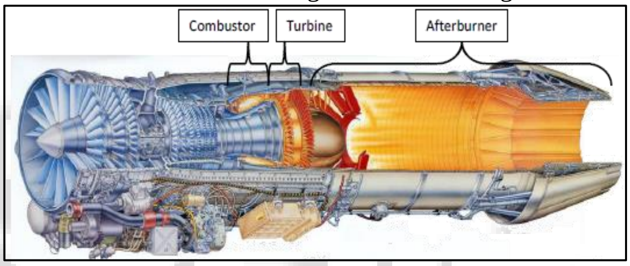

Fig. 1: Cross-section of RM-12 engine

The function of a TBC system is to allow higher temperature operating conditions than would be allowed by the metals used to make the engine

TBCs were first used towards the end of the 1950 as protection on duct work and rocket nozzles within experimental projects at NASA. TBC's began first in military service but progressed to civilian engines around the mid to late 70's. By the 21st century, thermal barrier coatings have become integral to almost every modern aero turbine and stationary gas turbine produced.

TBC's consist of at least three component layers; a diagram of a TBC system is shown in figure 2. The first layer is the bond coat applied onto the base component. An intermediate layer is formed during operation called the thermally grown oxide (TGO). The final layer is the ceramic top coat that provides the operating temperature increase. The ceramic material chosen has a very low thermal conductivity allowing up to 200K temperature drop across the coating [1]. Thicknesses for a bond coat can be in the range 100-200µm with a ceramic top coat layer of between 200µm and 1.5mm.

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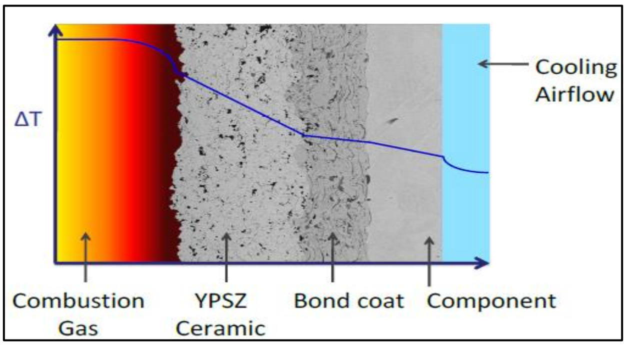

Fig. 2: Diagram of a TBC system with temperature drop illustrated across the coating cross-section

B. Methods of coating process

Figure 3 indicate the different technique of catalytic coating process. Spray coating technique is ergonomic, economical and environmentally friendly prescribed by many researchers.

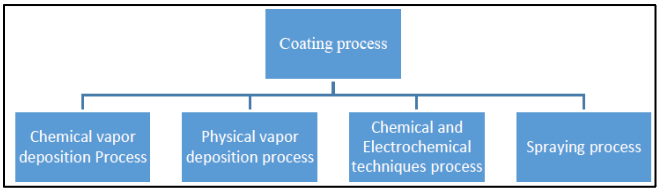

Fig. 3: Types of catalytic coating process

Thermal Barrier Coatings can be produced in industries by the following technique:

- Air Plasma Spray (APS)
- Electron Beam Physical Vapour Deposition (EBPVD)
- High Velocity Oxygen Fuel (HVOF)
- Electrostatic Spray Assisted Vapour Deposition (ESAVD) and
- Direct Vapour Deposition (DVD)

The Air Plasma Spray and EBPVD method are widely used in industries whereas Direct Vapour Deposition(DVD), ESAVD and HVOF processes are less frequently used. Two processes are explained below.

Air Plasma Spray coating: From the above coating methods Air plasma coating is one of the important coating method prescribed by many researchers to achieve the above said objective. Figure.4 shows the plasma spray process is basically the spraying of molten or heat softened material onto a surface to provide a coating. Material in the form of powder is injected into a very high temperature plasma flame, where it is rapidly heated and accelerated to a high velocity. The hot material impacts on the substrate surface and rapidly cools forming a coating.

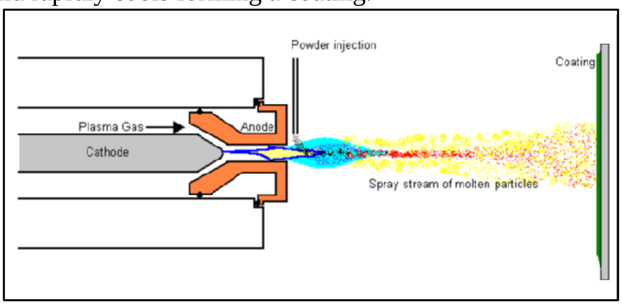

Fig. 4: Show diagram of the plasma spray Process

Electron Beam Physical Vapour Deposition (EBPVD): This deposition is a method applied in the semiconductor industry to grow electronics materials, in the space craft industry to form high temperature and chemical barrier coatings to protect surfaces against corrosive environments, in optics to impart the desired reflective and transmissive properties to a substrate and elsewhere in industry to modify surfaces to have a variety of desired properties. The deposition process can be broadly classified into physical vapor deposition (PVD) and chemical vapor deposition (CVD). In CVD, the film growth takes place at high temperatures, leading to the formation of corrosive gaseous products, and it may leave impurities in the film. The PVD process can be carried out at lower deposition temperatures and without corrosive products, but deposition rates are typically lower. Electron-beam physical vapor deposition, however, yields a high deposition rate from 0.1 to 100 μm/min at relatively low substrate temperatures, with very high material utilization efficiency. The schematic of an EBPVD system is shown in Fig

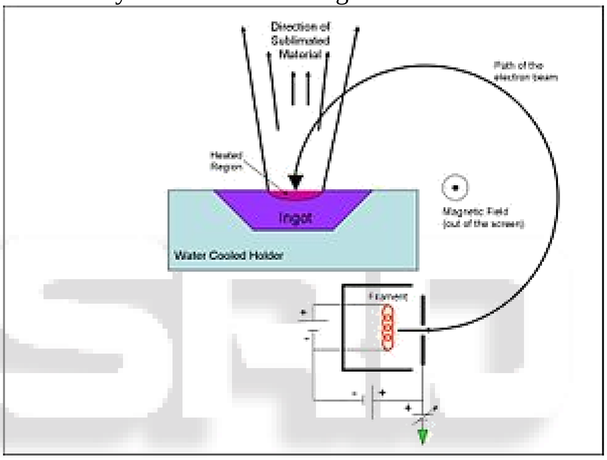

Fig. 5: shows the schematic diagram of an EBPVD system

Advanced technology ceramics consist of pure oxides and type of Ceramic material:

The choice of manufacturing process depends not only on the chemistry of the material to be produced, but also the product's target goals, resulting coating characteristics and properties, and the application economics (deposition rate vs. product cost).

- Abradables and Polymer Fillers
- MCrAlY Alloys
- Carbides
- Cermets
- Alumina (Al_2O_3),
- Magnesia (MgO),
- Zirconia (ZrO_2),
- Mullite
- Garnets
- Yttria (Y_2O_3) and non oxide ones.
- Barilla (BeO),
- Spinel

Benefits of Ceramic Coated engine

When performance of C.I. engine & S.I. engine takes place with ceramic coated engine parts by experiment and finite element analysis, it offers the following advantages:

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- To increase the thermal efficiency of the engine.
- To reduce the fuel consumption.
- To increase the temperature of combustion in the engine cylinder for complete combustion.
- To reduce the exhaust emission gases.
- To increase the performance of the engine.
- To increase component durability of engine
- Reduction in friction
- Low cetane fuels can be burnt.
- Improvements occur at emissions .
- Waste exhaust gases are used to produce useful shaft work,
- Increased effective efficiency,
- Using lower-quality fuels within a wider distillation range,
- The ignition delay of the fuel is considerably reduced,
- The faster vaporization and the better mixing of the fuel,
- Reduced specific fuel consumption,
- Lighter weight,
- Decreased the heat removed by the cooling system,
- The first start of engine on cold days will be easier,
- Decreasing knocking and noise caused by combustion

II. EXISTING LITERATURE

A J Modi, Dhiren Patel, 2015[4] investigated the performance and emission characteristics of twin cylinder ceramic coated water cooled CI engine using blends of diesel and neem bio diesel. Plasma spray Technique was used to coat Magnesium Zirconate (MgZr03) on Combustion chamber inner wall, Piston top surface and valve faces. Results indicate that brake thermal efficiency of the LHR 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 base engine at high load condition.

Parag C. Thanare , R. G. Telrandhe, 2015[5] 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 on piston head the stress 10 -15% decreases because low thermal conductivity of coating material $MgZrO_3$ & Titanium Alloys

Nagarjuna Jana , K. Komali, 2015[6] developed piston model using ANSYS code for temperature distribution in functionally Graded Material Coated Piston. 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 NiCrAl bond coat doping along its thickness.

G. Sivakumar, S. Senthil Kumar, 2014[7] examined the effect of plasma spraying technique on the piston crown surface to form a 100 micron Yttria Stabilized Zirconia thin TBC coating layer. Result shows heat loss to the cooling water is reduced up to 5–10% BSFC is reduced by 3.38% and 28.59% at full load and 25% of the full load conditions respectively. Emissions were also reduced by 35.27% in the TBC coated engine, where CO emission is reduced by 2.7% and CO2 emission increased by 5.27%.

Ekrem Buyukkaya, Muhammet Cerit, 2007[8] carried out the thermal analysis of a ceramic coating MgO-ZrO2 diesel engine piston by 3-D finite element method and compared the results of four different pistons. Thermal barrier coatings (TBC) have the capacity to give higher thermal efficiency , improves combustion and reduces emissions. Ceramics used as TBC have more thermal durability than metals and display improved wear characteristics than conventional materials. It was observed that surface temperature (maximum) in the coated piston having material with less thermal conductivity improved by 48% for AlSi alloy and 35% in case of steel.

Y. Sureshbabu, P. Ashoka Varthanan , 2014[9] In this paper coating materials on the engine piston and their performances are studies and its clear that the catalyst coating on the piston, combustion chamber gives the maximum brake thermal efficiency. The objective of this paper is to study the efficiency of the engines coated with different materials based on earlier researchers. This study analyses the work of other researchers who used various catalyst as coating materials. This study also aims to identify the best coating material for spark ignition engine.

Debasish Das, Gautam Majumdar, Rajat Shubra Sen, B. B. Ghosh, 2013[10] In this study, three piston crowns were coated with Al_2O_3 (bond coat) of 100µm thickness & Partially Stabilized Zirconia (Top coat) with a thickness of 250µm, 350µm, 450µm respectively by using the same technique over the bond coat by using 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 also observed that coated piston engine increases the cylinder pressure and better heat release rate due to complete combustion.

M Azadi, M. Baloo, 2013[11] shows the effect on performance and emissions results of thermal barrier coating on diesel engine , 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 conclude that thermal Efficiency increases & Emission result is also improved. BSFC decreased by 12%. 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[12] In this paper a review of research on low heat rejection engines, to incorporate various systems of ceramic materials in intermittent combustion engines, and on the use of ceramics in these engines is presented. The reduction of heat loss from the combustion chamber of diesel engines improves fuel efficiency only by 3 or 4 per cent. Some other gains may be possible from a smaller cooling system, recovery of exhaust energy, and improvements in aerodynamics.

Helmisyah Ahmad Jalaludin, Shahrir Abdullah, Mariyam Jameelah Ghazali, Bulan Abdullah, Nik Rosli Abdullah 2012[13] In this study , bonding layer NiCrAl and ceramic based yttria partially stabilized zirconia (YPSZ) were plasma sprayed onto AC8A aluminum alloy CNGDI piston crowns and normal CamPro piston crowns in order to minimize thermal stresses. Several samples were deposited

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with NiCrAl bonding layers prior to coating of YPSZ for comparison purpose with the uncoated piston. The performance of the coating against high temperature was tested using a burner rig. The temperatures on the top of piston crown and piston underside were measured. In short, the YPSZ/ NiCrAl coated CNGDI piston crown experienced the least heat fluxes than the uncoated piston crowns and the coated CamPro piston crown, giving extra protection during combustion operation.

Ramaswamy P, Seetharamu S, Verma K, Raman N, Rao K.[14] examined the effect of 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[15] 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[16] 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.

Muhammet Ceritet. Al[17] determine 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[18]. 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[19]. 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[20] 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[21] 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[22]. 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[23] 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.[24] 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.

M. Mohamed Musthafa[25] Development of performance and emission characteristics on partially stabilized zirconia (PSZ) coated diesel engine fuelled by biodiesel with cetane number enhancing additive of Di-tertiary-butyl peroxide (DTBP). partially stabilized zirconia (PSZ) coated diesel engine fuelled by biodiesel with cetane number Biodiesel with additive and petroleum diesel were used as the test fuels. There was no significant improvement on performance and emissions (except HC and CO) of uncoated engine running on biodiesel with additive fuel

B. Dhinesha, R.KrishnaMoorthy[26] Effectively utilize the biofuel along with nano additive)powered with a coated and uncoated diesel engine YSZ was coated on the engine piston, valves and cylinder head by plasma spray coating technique, simulation study using FEA, Thermal Analysis thermal efficiency of the engine was enhanced by 1.75%fuel-based emissions such as hydrocarbon; carbon monoxide and smoke were reduced with a penalty of increased oxides of nitrogen emission.

Gosai D.C, Nagarsheth H.[27] investigated the performance of a ceramic coated engine through modification in engine component such Piston top surface, cylinder head and liners with Partially Stabilized Zirconia and compared with base line engine. Results indicate improved fuel economy and reduced pollution levels for the Thermal Barrier Coated engine

Gosai D.C, Nagarsheth H.[28] carried out test with engine coating materials MgZrO3 and YSZ engine combustion chamber components like piston’s top surface, engine heads, valves and liners valves from observation they concluded that better combustion is found in MgZrO3 type ceramic TBC material diesel engine.

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Selman Aydin[29] carried out test with engine coating materials of 88% ZrO2, 4% MgO and 8% Al2O3 coated for 400µm on piston bowl, cylinder head and valves from observation he concluded that partial improvement in fuel economy, brake thermal efficiency, CO, HC and smoke emission.

III. CONCLUSION

Research or innovation regarding any of the subject can be made possible only through the knowledge of past work related to the same field. So, work carried out by the eminent personalities will always be the stepping-stone for the future revelations. Required preparation 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.

Coating materials continues to be successfully applied for aerospace and IGT applications. Material reliability and process versatility give the product a long history of success. Partially stabilized zirconia and MgZrO3 can be 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.

This chapter presents the detailed literature review on Combustion chamber Analysis with mechanical parameter and effect of piston crown coating on the performance of engine thus following conclusions have been made:

Low thermal conductivity Coating materials such as Abradables , Polymer Fillers, MCrAlY Alloys , Carbides Cermets on the engine piston , combustion chamber gives the maximum thermal efficiency in Engine an reduce the emission from engine.

Nickel Chromium has good resistant against hot oxidizing and corrosive gases, and prevents scaling on carbon and low alloy steels

Inconel type used for repair of superalloy components and protection for less noble substrates, Excellent high temperature oxidation & corrosion resistance

There are some of the areas where more work can be done to improve the performance of an I.C. Engine by nanostructured APS coating, oxidation behaviour under real operating conditions, Optimizing Coating thickness variation for Piston Piston crown profile, thus thermal efficiency increase.

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