Experimental Investigation on Improving Performance Of I.C. Engine by Varying Advance Piston Coating Materials

Mahesh M. Chudasama
Student M.E. (ICE & Auto)
Mechanical Engineering Depart.
L. D. C. E., Ahmedabad, Gujarat, India.
Gujarat Technological University

Prof. V. D. VORA
Associate Professor,
Mechanical Engineering Department
L. D. C. E., Ahmedabad, Gujarat, India.
Gujarat Technological University

ABSTRACT:

Experimental investigation is carried out under different loading conditions in a Single cylinder diesel engine with its piston crown were coated with NiAl (bond coat) of 50µm thickness and Chromium oxide (Top Coat) of 300µm thickness each by using Robotic Plasma spray coating technique to understand the influence of the thermal barrier coating (TBC) on performance and emission characteristics in comparison with baseline engine characteristics. Cr_2O_3 *is chosen as the candidate material for coating the piston crown because of its desirable physical properties such as high coefficient of thermal expansion, low thermal conductivity, high Poisson's ratio, and stable phase structure at higher temperature conditions. For the measurement of emission characteristics, ISO Mode testing cycle procedure is followed. Experimental results revealed that the thermal efficiency is increased by 16.8 % with reduction of brake specific fuel consumption by up to 6.9 %. Experimental results also revealed that Hydro carbon (HC) emission is reduced up to 18.95 %, carbon monoxide (CO) by up to 11.72 % and Carbon dioxide* (CO_2) *emission is increased by up to 21.5%.*

Keywords: *Thermal Barrier coating, piston crown, diesel engine, Chromium Oxide.*

I. INTRODUCTION

Diesel engines play a major role in the automotive industry. It has assumed a dominating role in both transport and agricultural industry due to its higher fuel economy and low running cost. However the heat carried away by the coolant and exhaust gases carry considerable amount of fuel energy from the combustion chamber even in diesel engines leaving only 30–40% of the total energy for conversion into useful work. The engine cooling system absorbs combustion and friction-generated heat energy and dissipates it to the surroundings to ensure engine temperature always remain below the safe level. The lubrication system and exhaust gases are the other sources which carry away the heat from the combustion chamber. Researchers are continuously striving to improve the performance and emission characteristics of the Internal Combustion engines due to the continuous demand from the industry for some technological and environmental requirements besides rapid increase in the cost of the fuel. On the other hand the improvements in engine materials become increasingly important by the introduction of new alternative fuels.

The consumption of hydrocarbon deposits at a faster rate in the present world the engine manufacturer as well as automobile industry is generating an essential demand for increase in efficiency of internal combustion engine. High speed Diesel Engine leads increasing temperature of combustion chamber. Engine life depends mainly on the part of the engine, service life increased by considering the part which dominates its major role in the working condition of the engine about one third heat loss such as friction , exhaust , cooling loss. However the heat carried away by the coolant and exhaust gases carry considerable amount of fuel energy from the combustion chamber. 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 presents applications of a variety of protective coatings for the piston crown of an I.C. Engine.

However, 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 applications of advance ceramic materials.

The developmental tendencies in obtaining high performance of I.C. engine are mainly related with an increase in the engine's capacity, its efficiency, lifetime, reliability, reduce emission and a decrease in the fuel consumption. These may be achieved with the development of ceramic coating for thermal insulation system for minimal heat rejection of heat and metal protection of hot gases faced in cylinder component is continued with emphasis on plasma spray.

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.

These may be achieved with the development of Advance coating material for thermal insulation system for minimal heat rejection of heat and metal protection of hot gases faced in cylinder component is continued with emphasis on plasma spray .

Need of coating

- In recent times, much attention has focused on achieving this goal by reducing energy lost to the coolant during th e power stroke of the cycle.
- So, For improving the design and performance have generated to low heat rejection (LHR) or insulated engines.
- Ceramic coatings are widely used in industry for providing valuable improvements against wear, corrosion and erosion. Coatings must maintain intended performance during their life cycles.
- Theoretically if the heat rejected could be reduced, then the thermal efficiency would be improved.
- Low Heat Rejection (LHR) engines aim to do this by reducing the heat lost to the coolant.
- Therefore, thermal barrier coating (TBC) technology is successfully applied to the internal combustion engines, in particular to the piston and combustion chamber.

Methods to Produce Thermal Barrier Coatings

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

- 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)

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

- Alumina (Al_2O_3),
- Zirconia (ZrO_2),
- Magnesia (MgO),
- Barilla (BeO),
- Yttria (Y_2O_3) and non oxide ones.
- Garnets
- Spinel
- Mullite

Benefits of Ceramic Coated piston

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

- 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,
- Increased thermal 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
- Increase the life of component

A. LITERATURE SURVEY

Ashish jashvantlal Modi and dhiren patel[1] investigated the performance and emission characteristics of twin cylinder ceramic coated water cooled CI 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. Piston top surface (crown) and valve faces were coated with the Magnesium Zirconate (NIgZr03). An experimental investigation was conducted at medium speed with varying load to obtain actual driving condition experienced in most urban areas and measurements like fuel flow; exhaust temperature and smoke test were carried out. The results indicate that brake thermal efficiency of the LHR engine is found to be higher by 11-13% than the standard base line engine. The brake specific fuel consumption (BSFC) was 7-12% lower in LHR engine than that of the base engine at high load condition. Biodiesel also increased efficiency in reducing particulate emissions. The use of neem biodiesel resulted in lower emissions of unburned hydrocarbons, carbon monoxide, with some increase in emissions of oxides of nitrogen.

G. Sivakumar, S. Senthil Kumar, 2014[2] The aim of this paper is study of effect on performance and emissions results with yttria stabilized zirconia coated piston crown. The Experimental investigation is carried out under different loading conditions in a three cylinder diesel engine with its piston crown coated with Yttria Stabilized Zirconia to understand the influence of the thermal barrier coating on performance and emission characteristics in comparison with baseline engine characteristics. In this paper plasma spray method adopted in for experimental study. The main objective in plasma spraying was to constitute a thin layer that has high protection value over other exposed surfaces. Yttria Stabilized Zirconia (YSZ) is sprayed in powder form molten in ionized gas rapidly on the piston crown surface to form a 100 micron thin TBC coating. YSZ is chosen as the candidate material for coating the piston crown because of its desirable physical properties such as high coefficient of thermal expansion, low thermal conductivity, high Poisson's ratio, and stable phase structure at higher temperature conditions. Thermal efficiency of the engine increases. The 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 . Hydrocarbon emissions were reduced by 35.27% in the TBC coated engine, where Carbon monoxide emission is reduced by 2.7% and Carbon dioxide emission increased by 5.27%.

Ekrem Buyukkaya, Muhammet Cerit, 2007[3] The study of this paper investigated thermal analyses of conventional (uncoated) diesel piston made of aluminium silicon alloy and steel. Further thermal analyses are performed on pistons coated with MgO–ZrO2 material by means of using a commercial code, namely ANSYS. Finally, the results of four different pistons are compared with each other. The effects of coatings on the thermal behaviours of the pistons are investigated. It has been shown that the maximum surface temperature of the coated piston with material which has low thermal conductivity is improved approximately 48% for the AlSi alloy and 35% for the steel. The zirconia-based ceramic coatings are used as thermal barrier coatings owing to their low conductivity and their relatively high coefficients of thermal expansion, which reduce the detrimental interfacial stresses. Material properties of the MgZrO3, NiCrA1 and piston material made of AlSi alloy. Piston is coated with a 350 μm thickness of MgZrO3 over a 150 μm thickness of NiCrAl bond coat shows better result.

Debasish Das, Gautam Majumdar, Rajat Shubra Sen, B. B. Ghosh, 2013[4] In this study, the comparative effect of combustion and emission of Standard diesel engine and partially stabilised zirconia coated piston were investigated. Single cylinder, water cooled DI diesel engine was used for the experimentation at constant speed, variable load. Primarily three piston crowns were coated with Al_2O_3 (bond coat) of 100μm thickness each by using Plasma spray coating technique. Then these piston crowns were coated with Partially Stabilized Zirconia with a thickness of 250μm, 350μm, 450μm respectively by using the same technique over the bond coat. Then these three coated and one uncoated piston inserted into the cylinder one by one of a single cylinder, water cooled DI diesel engine. 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. In this study piston crowns were coated with partially stabilized Zirconia can act like an insulator and prevent heat rejection from the engine produces. It produce more heat during combustion the engine with TBC coating having high brake thermal efficiency , more CO_2 produced, less O_2 which indicates better oxidation.

M Azadi, M. Baloo, 2013[5] The Objective of this experiment was to study effect on performance and emissions results of thermal barrier coating on diesel engine In this paper a complete literatures review of thermal barrier coating applications in diesel engines

is performed to select a proper type and to find coating effects. The coating system has effects on the fuel consumption, the power and the combustion efficiency, pollution contents and the 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. Several disadvantages such as producing nitrogen oxides also exist when a coating system is used. In this article, all effects, advantages and disadvantages of thermal barrier coatings are investigated based on presented articles. Modification NiCrAlY with 150 microns thickness and another layer made of ZrO2-8%Y2O3 with 300 microns thickness by using the plasma thermal spray method .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.
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Vinay Kumar Domakonda, Ravi Kumar Puli, 2012[6] 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. The 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 purpose of this paper is to explain the effect of insulation on engine performance, heat transfer characteristics, and combustion and emission characteristics.

Helmisyah Ahmad Jalaludin, Shahrir Abdullah, Mariyam Jameelah Ghazali, Bulan Abdullah, Nik Rosli Abdullah 2012[7] 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 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. Finally, the heat fluxes of all conditions of piston crown were calculated. 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. From the experiment, the average heat flux of YPSZ/NiCrAl coated piston crown exhibited 98% lower than the uncoated piston crowns. This might be due to the existence of lower conductivity of the ceramic coating. Current result may lead to contribution for the betterment of heat protection to the piston in CNGDI engine.

B. EXPERIMENTAL SETUP

To evaluate the performance and emission characteristics, the specific type of engine used in this project is a single cylinder water cooled HSDI diesel engine. Set-up of the experimental engine is illustrated in Figure. The engine is couple with a hydraulic dynamometer acting as a variable load system. Various instruments and gauges are used to obtain different measurements. The engine speed measure with the help of digital tachometer. K-Type thermocouple with digital temperature indicator was used to measure exhaust temperature, cooling water as well as lubrication oil temperature.

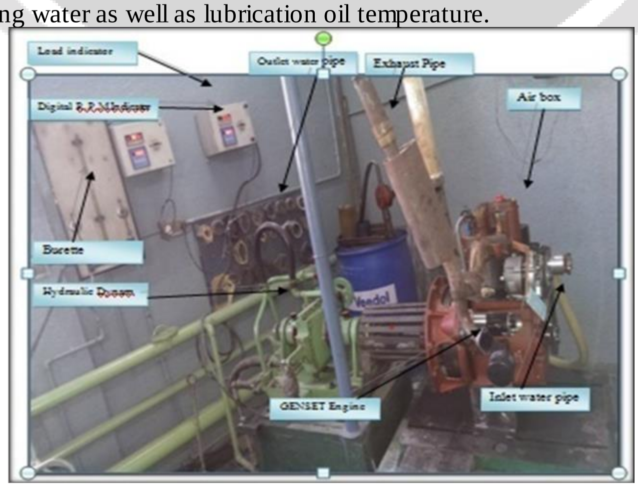


Figure 1 Photographic View of Tested Engine

B. Technical Specification of Field marshal Diesel Engine

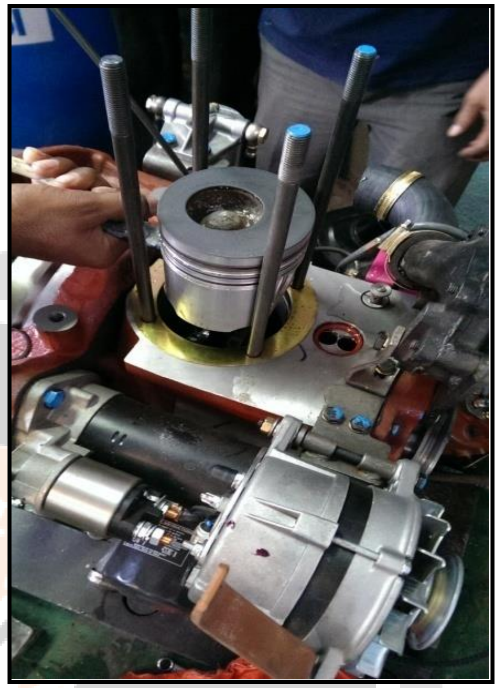
Fieldmarshal®	
P. M. DIESELS PVT. LTD. RAJKOT	
Technical Specification of Field marshal Diesel Engine	
MODEL :- FMGS - 75	
Bore (mm)	**100**
Stroke (mm)	**114**
Displacement (cm^3)	**895**
No. of cylinder	**1**
Compression ratio	**18:1**
Engine R.P.M.	**1500**
Injection method	**Direct Injection**
Fuel consumption (gm/kWh)	**260gm/kwh**
Engine power H.P	**11.6**
Method of starting	**ELECTRIC**
Engine dimension	
Length(mm) Width(mm) Height(mm)	**537** **526** **790**
Oil sump capacity (liter)	**2.5**
Grade of oil	**SAE20W40**

Table 1 Engine Technical Specification

C. Detail of Existing Piston and Modified piston (Coated with chromium Oxide)

Material	Aluminium
Bore	**100mm**
Stroke	**114mm**

Detail Existing Diesel Engine piston



Material	Aluminium
Bore	**100mm**
Stroke	**114.35mm**
Bond coat	**NiAl – 50 micron**
Top coat	**Cr_2O_3 – 300 micron**

Detail Modified Diesel Engine piston

D. PISTON COATING SPECIFICATION

Thermal Spray Coatings are applied by Robot for accurate control of coating properties and thickness and for process repeatability. Advanced process control systems to ensure that the quality of the coatings is optimized. Thermal spray coatings can also be because of its better wear resistance, low thermal conductivity, high thermal shock resistance and high melting points. Plasma process parameters for chromium oxide are:

Coating parameter	Specification
Coating system	Plasma Spray Method
Plasma gun	3 MB plasma spray gun
Nozzle	GH Type
Pressure of argon gas	100-120 PSI
Flow rate of argon gas	80 – 90 LPM
Pressure of Hydrogen gas	50 PSI
Flow rate of Hydrogen gas	15 -18 LDM
Powder feed rate	40 – 45 g per min
Spray distance	3-4 in
Particle size in Mesh size	20 mesh
Air Pressure	6 kg/cm^2
Air quality	Dry
Blasting distance	200-500 mm
Bond coat	NiAl 50 micron
Top coat	cr_2o_3 300 micron

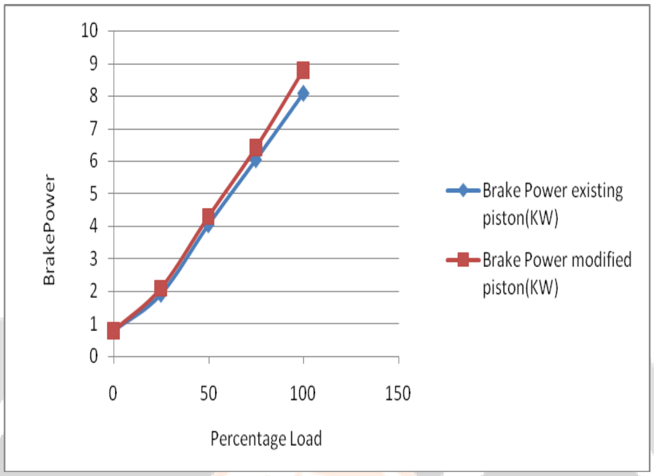
Table 2 Engine Technical Specification

D. RESULT AND DISCUSSION

ENGINE PERFORMANCE TEST PARAMETER

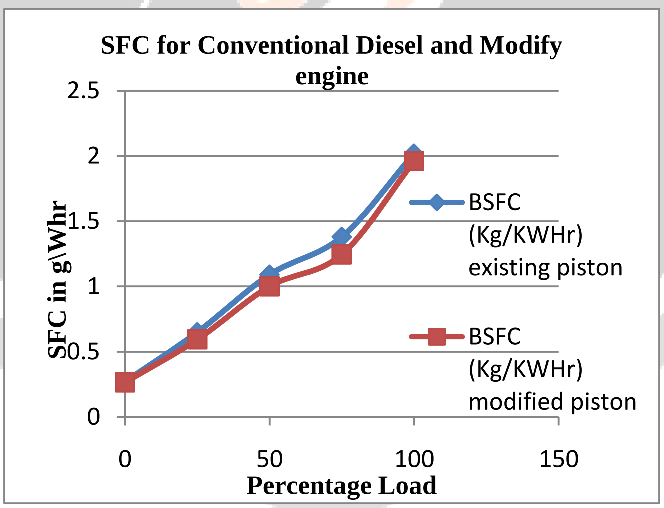
I. BRAKE POWER

Graph 1Shows the comparison of brake power as a function of engine load for conventional and LHR (Chromium coated) diesel engines. It is found that, the values of brake power are slightly higher for LHR (Chromium coated) engine as compared to conventional engine. This is due to fact that effect of insulation; the heat free flow is restricted, which results in reduction in heat transfer in case of LHR engine. The reduction in heat transfer leads to increase in combustion temperature, which results in better combustion. The higher combustion temperature will lead to more expansion work. The increase of combustion temperature causes the brake power to increase with LHR engine at full engine load condition compared to conventional engine.



Graph 1 Variation in brake Power with percentage load

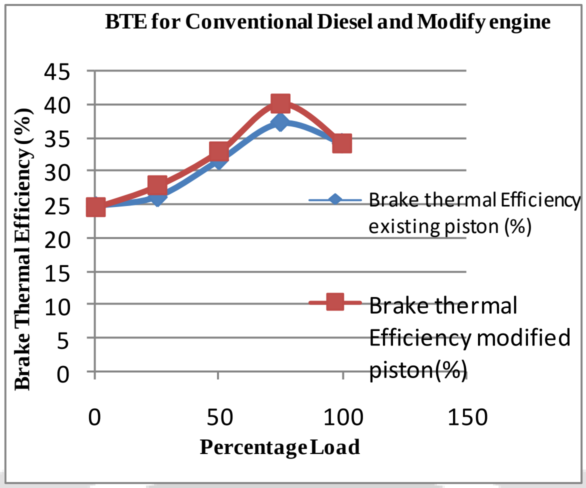
II. Specific Fuel Consumption



Graph 2 Variation in Specific Fuel consumption with percentage load

A comparison of BSFC for conventional and LHR engine at various loads is as shown in Graph 2 Because of higher surface temperature of combustion chamber of LHR engine as compared to conventional engine, the BSFC values of LHR engine is less than those of conventional engine. The improvement in fuel economy observed in LHR engine may be due to: higher pre mixed combustion, reduced heat transfer loss, lower diffused combustion and higher rate of heat release in the main portion of combustion chamber. It is found that BSFC value is decreased by 6.9 % for LHR (Chromium Oxide) engine as compared to conventional engine at full engine load.

II. **Effect of Load on BTE for Conventional Diesel and Modify engine:**



Graph 3 Variation in Brake Thermal Efficiency with percentage load

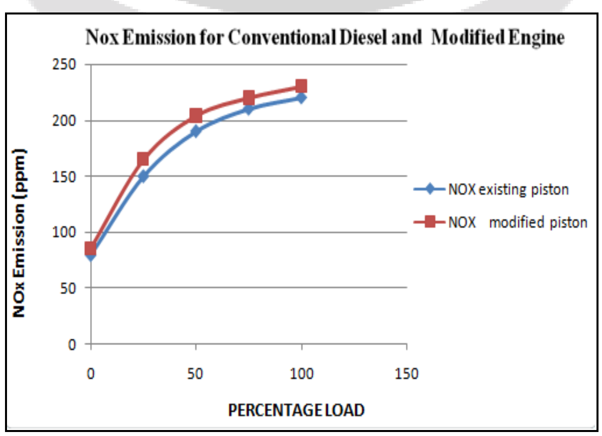
It is observed from Graph 3 that, the amount of increase in thermal efficiency for LHR engine is 16.8% compared to conventional engine at full engine load while at low and medium loads thermal efficiency shows less variation for LHR engine when compared to the conventional engine. This is because that heat recovered by insulation which is generally lost to the cooling, is converted into useful work (indicated work). But all the heat recovered by the insulation may or may not be able to get converted into some useful work. Therefore, the rate of increasing thermal efficiency for LHR engine is minor compared to conventional engine.

ENGINE EMISSION PARAMETERS

Comparisons of experimental results such as engine exhaust emissions of the conventional (without coating) and LHR (chromium coated) diesel engines under identical conditions.

I. NO_X emissions

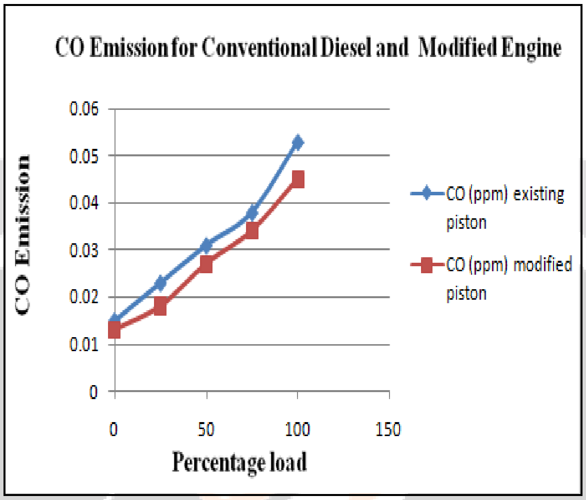
Graph 4 shows the comparison of NOx variations as a function of engine load for conventional and LHR engine. It is found that the NOx emission for LHR engine is more as compared to conventional engine. The NOx emission for LHR engine at full engine load is 8.16 % higher than conventional engine. The increase of NOx emission for in the LHR engine may be due increase in after-combustion temperature due to the chromium coating. This is due to higher combustion temperature and having longer combustion duration.



Graph 4 Variation in NO_X Emission with percentage load

II. CO emissions

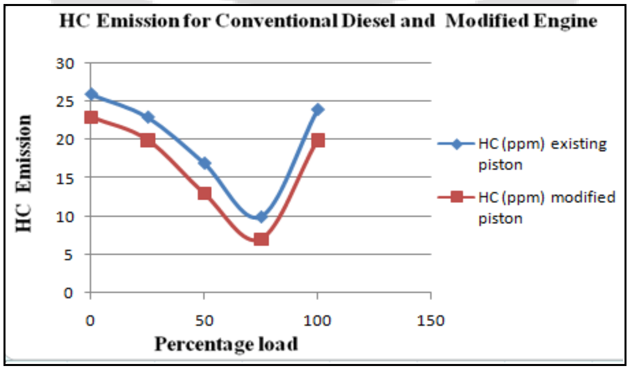
Graph 5 shows the comparison of CO emissions variations as a function of engine load for conventional and LHR engines. Carbon monoxide (CO) emission is 11.70 % lower in the LHR engine compared with the conventional engine. This is due to the fact that, because of ceramic coating which bears the thermal barrier property, which results in increase in combustion temperature for LHR engine. The decrease in the amount of heat rejected to the cooling water system which results in an increase in combustion temperature. Increase in combustion temperature increases the time for CO oxidation, which results in decreasing CO emission for LHR engine.



Graph 5 Variation in CO Emission with percentage load

III. HC emissions

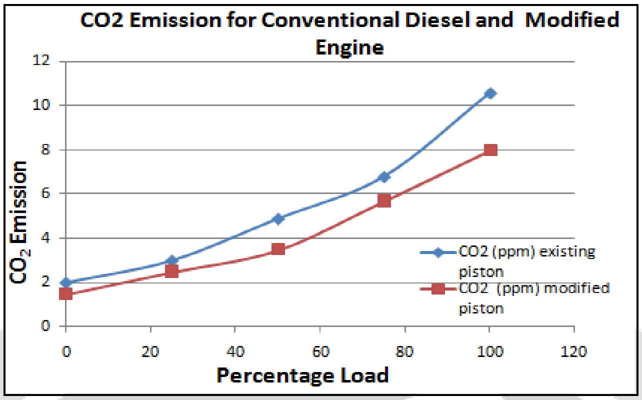
Graph 6 shows the comparison of HC emission variations as a function of engine load for conventional and LHR engines. Hydrocarbon emission is 18.16 % lower in the Low Heat rejection engine compared to conventional engine. The decrease in Hydrocarbon emission in the Low Heat rejection (LHR) engine may be due to an increase in after-combustion temperature as a result of the decrease in heat losses going to cooling and also outside due to the ceramic coating, creating more unburned Hydrocarbon (HC) to be added to the combustion. The result clearly shows that the ceramic coating improves local conditions such as cylinder gas pressure, cylinder gas temperature, and makes the combustion continuous in diesel engines. The higher temperatures in the gases and at the combustion chamber walls of the LHR engine allows the oxidation reactions to close to completion results in decreasing the Hydrocarbon (HC) emissions.



Graph 6 Variation in HC Emission with percentage load

IV. CO2 emissions

As shown in Graph 7 the experimental results it is known that carbon dioxide emission is lower in TBC coated engine compared to standard engine as it is well known that better fuel.



Graph 7 Variation in CO_2 Emission with percentage load

CONCLUSIONS

A conventional Single cylinder diesel engine was converted to a LHR Engine by coating its piston crowns by a NiAl 50µm of bond layer and Chromium oxide (Top Coat) of 300µm thickness each by using Robotic Plasma spray coating method. Engine parameters, namely brake thermal efficiency, brake specific fuel consumption, power and emission characteristics were measured to investigate the effects of Cr_2O_3 on its performance and emission characteristics of the engine. The following conclusions can be drawn from the experimental results.

- The brake specific fuel consumption (BSFC) was 6.9 % lower in LHR engine than that of the base engine at Medium load condition.
- Improvement in engine brake thermal efficiency at all load LHR engine. The brake thermal efficiency of the LHR engine is found be higher by 16.8% than the standard base line engine. This is due to reduced loss of heat in coolant and high heat flux in the combustion chamber.
- NO_x emission found to 8.16 % higher than the standard baseline engine. This could be due to the higher combustion temperature and longer combustion duration. Due to the better combustion of the air–fuel mixture in the TBC coated engine, the combustion temperature is higher. An increase in after-combustion temperature causes an increase in No_x emission level. All factor facilitating and accelerating the reaction between oxygen and nitrogen increases No_x formation at higher temperature.
- Experimental results show that the combustion temperature in the TBC coated engine is high. Hydrocarbon emissions were reduced drastically by 18.16 % in the TBC coated engine, whereas Carbon monoxide emission is reduced by 11.72 % and Carbon dioxide emission. Carbon dioxide emission is decreased by 21.5%.

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REFERENCES

[1] Ashish Jashvantlal Modi and Dhiren Patel ,Experimental Study on Diesel Engine Performance with Blends of Diesel and Neem biodiesel, SAE International , January 2015, pp 1-8

[2] G. Sivakumar, S. Senthil Kumar "Investigation on effect B coated piston crown on performance and emission characteristics of a diesel engine" - Alexandria Engineering Journal 53, ,2014, pp 787–794

[3] Ekrem Buyukkaya, "Thermal Analysis of functionally graded coating AlSi alloy and steel pistons", Surface and coatings technology, 2007, pp 1-6

[4] Debasish Das, Gautam Majumdar, Rajat Shubra Sen, B. B. Ghosh "Evaluation of combustion and emission characteristics on diesel engine with varying thickness of PSZ coated piston crown" , International Journal of Innovative Research in Science, Engineering and Technology, October – 2013, pp 4858-4865

[5] M Azadi M. Baloo . H. Farrahi S. M. Mirsalim "A review of thermal barrier coating effects ondiesel engine performance and components lifetime" International Journal of Automotive Engineering ,March 2013, pp 305-317

[6] Vinay Kumar Domakonda, Ravi Kumar Puli presents on "Application of Thermal Barrier Coatings in Diesel" Energy and Power, 2012, pp 9-17

[7] Helmisyah Ahmad Jalaludin, Shahrir Abdullah, Mariyam Jameelah Ghazali, Bulan Abdullah, Nik Rosli Abdullah "Experimental Study of Ceramic Coated Piston Crown For Compressed Natural Gas Direct Injection Engines" AIJSTPME ,2012,pp 73-77

[8] F. Roach, "Aluminium Automotive Manual" European Aluminium Association, 2011, pp 1-13

[9] R. S. Khurmi., J. K. Gupta," A Text Book of Machine Design", 14^{TH} Edition , Eurasia Publishing House , New Delhi, 2005, pp 1132

[10] Jaume Anguera Llort, Master's Thesis Engineering, "Designing and Modeling of Piston in Combustion Engines" , Cracow University of Technology, July 2014, pp 22

[11] Parag C. Thanare, R. G. Telrandhe " Design And Analysis Of Piston Head With Different Coat" International Journal of Scientific Research and Engineering Studies, IJSRES , May 2015,pp 15-18

[12] Nagarjuna. Jana, K. Komali "Design and Analysis on a Ceramic Coated Diesel Engine Piston using ANSYS" IJSETR, January 2015, pp 16-19

[13] Parvezalam Shaikh and S.P. Yeole "An Experimental Investigation on Engine Performance of a Low heat rejection (mullite coated) Single cylinder diesel engine with and without" International Journal of Mechanical Engineering and Technology (IJMET) Volume 6, Issue 11, Nov 2015, pp. 132-144

[14] Y.Sureshbabu, P.AshokaVarthanan "Study the emission characteristics of catalytic coated piston and combustion chamber of a four stroke spark ignition (SI) engine" Journal of Chemical and Pharmaceutical Sciences, Dec2014, pp 126-127

[15] K. Sridhar, 1 R. Reji Kumar, 2 M. Narasimha3, "Thermal barrier Analysis in Diesel" IJMER, Vol.3, Issue.3, May-June. 2013 pp-1435-1441

[16] I.Taymaz, K. Cakir, M. Gur, A. Mimaroglu, "Experimental investigation of heat losses in a ceramic coated dieselEngine". Surface and coatings technology 169-170, 2003, pp168-170

[17] T. Hejwowski, A. Weronski, "The effect of thermal barrier coatings on diesel engine performance" Vacuum 65 ,2002, pp 427–432

[18] Naveen.P, C.R. Rajeshekhar, C.Umashankar &Vinayaka Rajashek harkiragi, Coating on Performance Characteristics of Bio-Diesel (Honge) Fuelled C.I.Engine"Vol.2, Issue.4, July-Aug 2012, pp-2825-2828.