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Review Paper on Experimental Investigation on Combined Effect of Thermal Barrier Coating and Blending on Stationary Four Stroke C.I Engine Performance and Emission Characteristics

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Abstract

Energy conservation and efficiency have been the quest of engineers concerned with internal combustion engines. The diesel engine generally offers about two thirds of the heat energy of the fuel out of which one-third to the coolant, and one-third to exhaust, leaving only about one third as useful power output. This paper reviews work of previous investigators to see the effect of coating of different ceramic material and blending on the engine performance and emission characteristics..The energy of the biodiesel can be released more efficiently with the concept of low heat rejection (LHR) engine. The main aim of this review work is to study the effect of different ceramic material and blends used in various researches done in past to improve engine performance and emission characteristics.

Keywords: *Thermal barrier coating, c.i engine, blending, engine performance, exhaust emission.*

1. Introduction

Thermal Barrier Coating

TBC→ Thermal Barrier Coating
Insulating the combustion chamber of an internal combustion engine theoretically results in improved Thermal efficiency according to the second law of thermodynamics.

A lot of experimental study has been done to utilize these ceramic properties to improve thermal efficiency by reducing heat losses, and to improve mechanical efficiency by eliminating cooling systems. When cylinder-cooling losses are reduced, more of the heat is delivered to the exhaust system. This effective recovery of energy by exhaust improves the thermal efficiency of low heat rejection engine (LHR).

Ceramic Coatings and Engine Performance

Ceramic thermal barrier coatings were originally developed and commercialized for gas turbine and jet engine applications. Many investigations have been conducted on various aspects of applying such coatings to the walls of combustion chamber in internal combustion engines. The prime objective which has been sought is to achieve higher thermal efficiencies by reduction of heat rejection from the combustion chamber. Experiments with diesel and gasoline engines suggest that thin coatings produce higher engine efficiency than thick coatings, in spite of being less effective as heat insulators.[11] This behaviour of ceramic coatings has not been satisfactorily explained. It is believed that some detailed heat transfer characteristics must have a more profound effect on thermodynamic efficiency than the overall heat rejection rate from the engine.
Several ceramic materials such as zirconium oxide, chromium oxide, aluminium oxide, and mullite have been investigated as in-cylinder engine coatings. Zirconia, thanks to its low thermal conductivity and its thermal expansion coefficient which is compatible with that of

metals, has become the preferred and most studied material. Ceramic coatings can be deposited by plasma spraying or from a ceramic slurry. The thermal spraying technique using a plasma torch has been used most extensively for this purpose. In the plasma spray process zirconia is fed as a powder into the plasma stream of the torch where it is melted at temperatures as high as 16,000°C. The high pressure plasma gas stream propels the molten particles onto the coated surface where they solidify. Powder and process parameters are used to control the structure and properties of the coating. The thickness of coatings can range from 0.05 to 2 mm. The optimal thickness of realistic materials is usually below 0.5 mm. Thin coatings were reported to exhibit both better performance and durability.

Besides improved thermal efficiency, advantages of ceramic coatings which have been proposed include improved engine durability, reduction in erosion and corrosion, less internal friction, lowered noise and reductions in exhaust emissions. A lot of work has been done on evaluating the effects of in-cylinder coatings on diesel engine performance and emissions. The results have been inconclusive and often contradictory. While most of published studies[12] [13] report potential emission benefits, some [14][15]claim that the coatings have detrimental effects on fuel mixing and combustion, thus, deteriorating the performance and emissions. There is a significant variability in the coating effect between different engine types. The emission benefit of coatings appears to be related to their enhancing effect on the thermal efficiency of the engine. Therefore, higher emission effectiveness of coatings may have been possible in older technology engines which were characterized by relatively low thermal efficiency.

2. Literature review

Imdat Taymaz (2007) evaluate " The effect of thermal barrier coating on the diesel engine performance".[1] The research engine was a four stroke, direct injection, six cylinder, turbo-charged and inter-cooled diesel engine. This engine was tested at different speeds and loads conditions without coating. Then, the combustion chamber surfaces, cylinder head, valves and piston crown faces were coated with ceramic materials. The layers were made of $CaZrO_3$ and $MgZrO_3$ and plasma coated onto the base of the NiCrAl bond coat. The results from this experiments showed that the results are for standard engine and ceramic-coated engine at 18° CA and 20° CA. At all load levels and engine speed, the results show a (2%–7%) decrease in bsfc for ceramic-coated engine in comparison to standard engine (without coating). the effective efficiency increases about 2% by using ceramic coating on the engine at low load. At medium load, it increases about 5%, while at full load it is obtained as 3%. The increase of the combustion temperature causes the effective efficiency to rise from 32% to 34% at medium load and from 37% to 39% at full load and medium engine speeds for ceramic-coated engine while it increases only from 26% to 27% at low load.

A. Parlak et al.(2005) evaluate " the effects of injection timing on NOx emissions of a low heat rejection indirect diesel injection engine".[2] The engine tests were conducted in a single cylinder, indirect injection Ricardo E6-MS/128/76 type diesel engine. In this study to see the injection timing is varied to see the effect on NOx emission. The tests were conducted with variable loads at engine speeds of 1000, 1400, 1800 and 2200 rpm and at the static injection timing of 38°, 36°, 34° and 32° CA. After the load tests were conducted for STD diesel engine, same test order was adopted for LHR engine and the test result were compared with each other. Optimum injection timing was found with 4 crank angle (34° CA)retarded before top dead centre (BTDC) in LHR diesel engine in comparison to that of STD diesel engine (38°CA BTDC). When the LHR engine was operated with the injection timing of the 38° crank angle, which is the optimum value of the STD engine, it was shown that NOx emission increased about 15%. However, when the injection timing was retarded to 34°CA in the LHR case, it was observed a decrease on the NOx emissions with about 40% and the brake specific fuel consumption (BSFC) with about 6% compared to that of the standard case. Thus, by retarding the injection timing, an additional 1.5% saving in fuel consumption was obtained.

E. Buyukkaya et al. (2006).In this study the "Effects of thermal barrier coating on gas emissions and performance of a LHR engine with different injection timings and valve adjustments".[3] Tests were performed on a six cylinder, direct injection, turbocharged Diesel engine whose pistons were coated with a 350 µm thickness of $MgZrO_3$ over a 150 µm thickness of NiCrAl bond coat. $CaZrO_3$ was employed as the coating material for the cylinder head and valves. The working conditions for the standard engine (uncovered) and low heat rejection (LHR) engine were kept exactly the same to ensure a realistic comparison between the two configurations of the engine. Comparisons between the standard engine and its LHR version were made based on engine performance, exhaust gas emissions, injection timing and valve adjustment. The results showed that 1–8% reduction in brake specific fuel consumption could be achieved by the combined effect of the thermal barrier coating (TBC) and injection timing. On the other hand, NOx emissions were obtained below those of the base engine by 11% for 18° BTDC injection timing. BSFC lover in coated engine but at full load and high speed there is slightly increase in BSFC. Nearly 40% reduction in particulate emission, The higher NOx emissions from the LHR engine, in comparison to the standard engine. For 18° BTDC injection delay timing, a relative reduction of 1–2% in the specific fuel consumption was recorded.

Hanbey Hazar (2010) investigated on the effect of "Cotton methyl ester usage in a diesel engine equipped with insulated combustion chamber". [4] Investigated on the effect of the usage of the cotton methyl ester made from vegetable oil. In this study as it is obvious that the direct use of these fuel without modification is not possible as the viscosity of methyl ester is quite high and calorific value is lower. So to overcome this difficulty surfaces of cylinder head, piston, exhaust and inlet valve of a four-stroke, direct injection, single cylinder diesel engine were coated with molybdenum (Mo) by plasma spray method. Thus, thermal barrier characteristic was brought to these parts. Variances in performance and emission values of cotton methyl ester and 2D fuel mixtures were studied in the ceramic coated and uncoated engines under the same running conditions. Performance (up to 2.2–2.3% for engine power, up to 3.5– 5.6% for specific fuel consumption) and emission values (up to 17–22% for CO, up to 5.2–10% for smoke) of the test fuels were improved in the coated engine compared with the uncoated engine. However, because the coated engine ran at higher temperatures compared with the uncoated engine, an increase (up to 6.5–7.4%) was seen in NOx emission in cases of all test fuels.

T. Hejwowski, A. Weronski (2002) In this experiment "The effect of the Thermal Barrier Coating on the diesel engine performance". [5] the ceramic material like the NiCrAl bond coat 0.15mm thick(Al_2O_3–40% TiO_2) 0.35mm thick; NiCrAl bond coat 0.15mm thick, ZrO2–8% Y_2O_3 0.3mm thick; NiCrMo bond coat 0.15mm thick, Al_2O_3–40%.Finite element method (FEM) calculations to evaluate stress and temperature distributions in pistons with crowns covered with the TBC. All the systems were examined. Engine trials on base line engine and the engine with pistons covered with TBC. Durability tests and road test. Results of FEM calculations showed that the optimum thickness of the TBC is slightly below 0.5 mm. It was found in tests performed on a naturally aspirated diesel engine with pistons covered with TBCs, that specific fuel consumption was lower by 15–20%. Significant increase in engine performance was found at high engine speeds power increased by approx. 8% and brake moment by 6%. Exhaust gas temperature was found to be 200K higher than in the engine with metal pistons.

E. Buyukkaya , M. Cerit (2007) In this study "Thermal analysis of a ceramic coating diesel engine piston using 3-D finite element method".[6] is observed. In order to analyse the behaviour firstly, thermal analyses are investigated on a conventional (uncoated) diesel piston, made of aluminum silicon alloy and steel. Secondly, thermal analyses are performed on pistons, coated with MgO–ZrO_2 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.

Huseyin Aydin (2013) examined the" Combined effects of thermal barrier coating and blending with diesel fuel on usability of vegetable oils in diesel engines". [7] The possibility of using pure vegetable oils in a thermally insulated diesel engine has been experimentally investigated. Initially, the standard diesel fuel was tested in the engine, as base experiment for comparison. Then the engine was thermally insulated by coating some parts of it, such as piston, exhaust and intake valves surfaces with zirconium oxide (ZrO_2). The main purpose of engine coating was to reduce heat rejection from the walls of combustion chamber and to increase thermal efficiency and thus to increase performance of the engine that using vegetable oil blends. Another aim of the study was to improve the usability of pure vegetable oils in diesel engines without performing any fuel treatments such as pyrolysis, emulsification and transesterification. Pure inedible cottonseed oil and sunflower oil were blended with diesel fuel. Blends and diesel fuel were then tested in the coated diesel engine. Experimental results proved that the main purpose of this study was achieved as the engine performance parameters such as power and torque were increased with simultaneous decrease in fuel consumption (bsfc). Furthermore, exhaust emission parameters such as CO, HC, and Smoke opacity were decreased .Also, sunflower oil blends presented better performance and emission parameters than cottonseed oil blends.

H. Hazar, U. Ozturk (2010) "The effect of Al_2O_3-TiO_2 coating in a diesel engine on performance and emission of corn oil methyl ester".[8] Evaluate from the study, the piston, cylinder head, exhaust and inlet valves of a diesel engine were coated with the ceramic material Al_2O_3-TiO_2 by the plasma spray method. Thus, a thermal barrier was provided for the parts of the combustion chamber with these coatings. The effects of corn oil methyl ester that produced by the transesterification method, and ASTM No. D2 fuels' performance and exhaust emissions' rate were studied by using equal in every respect coated and uncoated engines. Tests were performed on the uncoated engine, and then repeated on the coated engine and the results were compared. A decrease in engine power and specific fuel consumption, as well as significant improvements in exhaust gas emissions (except NOx), were observed for all test fuels used in the coated engine compared with that of the uncoated engine.

M. Cerit et al. (2011) developed "Thermal analysis of the partially ceramic coated piston: Effect on cold start HC emission in a spark ignition engine".[9] In this work was carried out on the single cylinder water cooled engine in order to study the effect on the cold start HC emission in a spark ignition engine coated with Ceramic material ($MgZrO_3$). The tests were conducted at two stages. At the first stage, cold start HC emission was measured for the first 180 s. Secondly, the performance characteristics were measured under full load condition (WOT) at the engine speeds of 1400, 1600, 1800, 2000,2200, 2400, 2600 and 2800 rpm. and also In this study, a steady-state thermal analysis was carried out to evaluate temperature gradients in the standard and partially coated pistons by using a finite element (FE) code called ANSYS. Cold start HC emissions of the standard engine are compared to those of the engine with partially coated piston for the first 180 s. In the case of coated piston, significant reductions in HC emission were observed at 1200 rpm engine speed. This reduction in HC emission ranges from8.1% to 43.2% for the first 20 s, from10.8% to 26.4% for the rest of the time. The results indicate that TBL cause an increase in engine torque for all engine speeds. Maximum increase in the engine torque was 3.57%. Although volumetric efficiency slightly decreases, the engine performance has been improved when TBL was applied on piston . It is concluded that TBL causes an increase in combustion efficiency compared to that of the uncoated engine. Maximum decrease in HC emissions was 43.2% compared to the standard engine.

E. Buyukkaya (2008) investigated the "Thermal analysis of functionally graded coating AlSi alloy and steel piston". [10] In this study thermal behaviour of functional graded coatings on AlSi and steel piston materials was investigated by means of using a commercial code, namely ANSYS. Thermal analyses were employed to deposit metallic, cermet and ceramic powders such as NiCrAl, NiCrAl+$MgZrO_3$ and $MgZrO_3$ on the substrate. The numerical results of AlSi and steel pistons are compared with each other. It was shown that the maximum surface temperature of the functional graded coating AlSi alloy and steel pistons was increased by 28% and 17%, respectively.

Conclusion

This review work is carried out to review the research and development work carried out by the previous researchers in order to understand the effect of thermal barrier coating and blending on the C.I engine performance and emission characteristics. Based on this review work, it is concluded that there is scope for reduce emission and increase performance characteristics by applying thermal barrier coating of $MgZrO_3$ to different parts exposing in combustion chamber like piston, valves with the combination of bio fuel derived from neem oil.

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