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INTERNATIONAL ADVANCED RESEARCHES and ENGINEERING JOURNAL

Journal homepage: www.dergipark.org.tr/en/pub/iarej

e-ISSN: 2618-575X

International Open Access

Volume 04
Issue 02

August, 2020

Research Article

The investigation of effect of the ceramic coatings with bond-layer coated on piston and valve surface on engine performance of a diesel engine

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ARTICLE INFO

Article history:
Received 02 Maech 2020
Revised 08 May 2020
Accepted 04 June 2020

Keywords:
Ceramic coating
Diesel engine
Engine performance
NiCr bond coat

ABSTRACT

The piston and valve surfaces of diesel engine have been coated with Cr_2O_3, Cr_2O_3+50%Al_2O_3 and Cr_2O_3 + 75% Al_2O_3 ceramic powders with bond coat (NiCr) by atmosferic plasma spray (APS) method. The engine performance of the coated engine were compared with the standard engine values by using that the engines tests were applyed repeat for each specimen in an electrical dynamometer in full power 1400 rpm, 1700 rpm, 2000 rpm, 2300 rpm, 2600 rpm, 2900 rpm and 3200 rpm engine speeds. In the results; it has been seen that engine power increased from 7% to 29%, engine torque from 7% to 23%, and exhaust gas temperatures from 6% to 17%, thermal brake efficiencyfrom 2.8% to 12.7% while specific fuel consumption decreased of 2.8% to 11.5%.

1. Introduction

In the automotive industry, diesel engines are used in the field of agricultural, transportation, shipping and many other fields like these which has made diesel engines become a basic necessity. Basically, businesses set up for profit-making like to benefit from the economicadvantages of these diesel engines for being strong and their less usage of fuel to provide customers with a low operating cost. Despite their advantages, diesel engines can have faultsmost especially with energy transfer. As seen clearly in literature, diesel engines only transfer40% of the total energy into useful work [1-3]. The internal combustion (IC) engine's energy is exhausted in 3 sections; energy used by the cooling liquid, energy used in attaining useful work and energy loss via the exhaust. Because of this, we can increase the output and general performance of an IC engine by the energy lost and gaining more energy fromuseful work [4]. In order to reduce thermal losses in the IC engines researchers coat combustion chamber elements with ceramic materials, thereby increasing fuel efficiency and improving engine performance by increasing the useful work achieved. In his study, Bahattin İşcan measured engine performance and emission values by covering the piston and valve surfaces with ZrO_2 ceramic powder to reduce the thermal losses of an internal combustion single cylinder air cooled diesel engine and by adding waste cotton oil into diesel fuel at different rates. As a result of his experiments, he declared that this reduces brake specific fuel consumption and significantly increases engine power and torque [5]. In another study carried out by Selman Aydin and Cenk Sayin, a thermal barrier was created by covering a combustion chamber with an internal combustion single cylinder air cooled diesel engine with 88% ZrO_2, 4% MgO and 8% Al_2O_3 materials, and in this engine, they studied engine performance and exhaust emissions using 20 bio-diesel - 80% diesel fuel (B20) and 50% bio-diesel - 50% diesel fuel (B50) mixtures. At the end of the study, it was observed that the engine power in biodiesel fuels did not change with the standard engine, and that the specific fuel consumption decreased, the thermal efficiency increased whereas the exhaust emissions decreased [6]. Kemal Masera and Abul Hossain [7] compiled the study results of the authors who investigated the effects of engine

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DOI: 10.35860/iarej.697009

performance and exhaust emissions using biodiesel in engines with thermal barrier coating in their work. In their study, they reported significant reductions in torque, 4.6% in power output, 7.8% in power output, 15.4% in brake specific energy consumption, 10.7% in brake thermal efficiency and exhaust emission values. Another study carried out by Shailesh Dhomne and Ashish M. Mahalle the properties of various thermal barrier coating (TBC) materials used in IC engines and their effects on engine performance, combustion and emission properties were investigated. At the end of their research, they declared that ZrO_2, Al_2O_3+TiO_2, CeO_2, TiO_2 etc. materials have a favorable effect on the engine performance and exhaust emission of IC engines, and new materials and specific coating powders that can be formed at different rates can achieve better results [8]. In conclusion of these studies, it is generally seen that ceramic coated materials are an important way to increase the performance of internal combustion engines. However, enough studies have not been carried out on improving engine performances with coatings made with ceramic powders mixed in different proportions.

Per this study, the surface of the combustion chamber elements (piston and valve) of the internal combustion diesel engine was coated with Cr_2O_3, Cr_2O_3+50%Al_2O_3 and Cr_2O_3+75%Al_2O_3 ceramic powders with NiCr bond coat using the atmospheric plasma spray (APS) coating method. The effects of coated engines on engine performance parameters were investigated by comparing them with the standard engine.

2. Material and Method

2.1 Coating Materials

The coating powders in this experiment are Cr_2O_3 and Al_2O_3 ceramic powders in 20 - 40 µm grain sizes belonging to the standards of Sulzer Metco. These powders are added to Cr_2O_3 with 50% and 75% by weight of Al_2O_3 and mixed homogeneously with a mechanical mixer for 30 minutes at 45 rpm. Using a spraying method, piston and valve surface of an internal combustion diesel engine are coated by the Cr_2O_3, Cr_2O_3+50%Al_2O_3 and Cr_2O_3+75%Al_2O_3 powders on simple surfacecoated with bond-coat (NiCr). The total coating thickness varies within the range of 0.0025 to 10 mm based on the stress limits of the sprayed material [9, 10]. Schematic image of the APS method is given in Figure 1 and coated pistons and valves are given in Figure 2.

Technical characteristics of single-cylinder diesel engine used in this study are given in Table 1. Diesel engine pistons and valves are made ready for the coating process. In order to keep the standard engines compression ratio constant with the value in the catalogue, sawdust has been removed from the aluminium piston and valve surfaces as much as the coating thickness. At a 200-300µm thickness, Cr_2O_3, Cr_2O_3+50%Al_2O_3 and CrO_3+Al_2O_3 ceramic powder (NiCr bond coat) with 3 pistons and valves (intake, exhaust) surfaces have been prepared by coating. The schematic picture of the coated piston is given in Figure3.

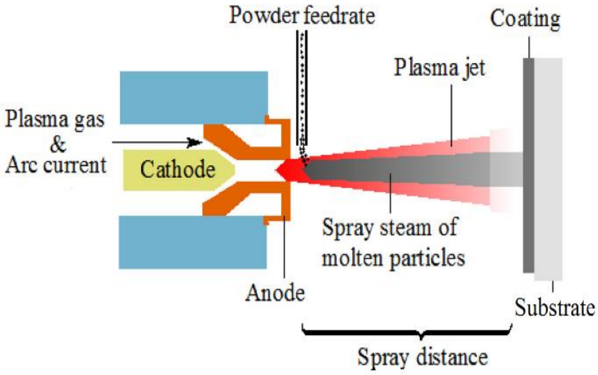

Figure 1. Schematic picture of the atmospheric plasma spray coating method [11]

Figure 2. Pistons and valves coated by APS

Table 1. Technical characteristics of the single cylinder diesel engine used in the experiment [12].

Power	5,5 HP/3600 rpm
Bore*Stroke [mm(in)]	78 x 62 mm
Dispiacement	296 cc
Operating Method	Starter and Rope
Engine Type	Four Stroke, Single cylinder, Air cooled, Direct injection
Fuel Consumption	285 gr/kWh
Fuel Tank Capacity	3,5 lt
Oil Capacity	1,1 lt
Oil Type	SAE 10W30 - 15W40
Fuel Type	Euro Diesel
Dimension	383×421×450 mm
Weight	38 kg

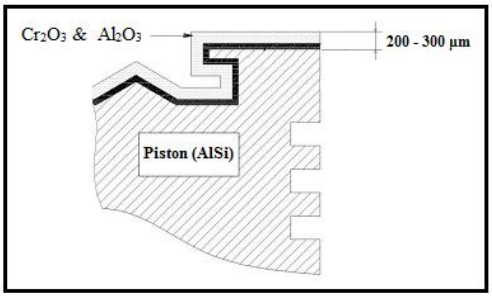

Figure 3. Schematic picture of coated piston

2.2. Engine Performance Tests

In the experiments, Netfren brand, 26 kW Hydrodynamic Dynamometer based on Föttinger Principle was used for performance measurements of the engine. Engine test dynamometer at 26 kW maximum measuring range, braking torque max. 83 Nm., Hydrodynamic Dynamometer based on Föttinger Principle with a weight of 90 kg and working at max. 5000 rpm. The test set can measure the speed, torque, and the power of the internal combustion engines and also the fuel consumption of the engines, and the measured data can be recorded to the computer in real-time. Figure 4 shows a schematic picture of the experiment set.

3. Experimental Results and Discussions

3.1. Microstructure of Coating Layers

Figure 5 demonstrates the SEM picture of the coating surfaces of the coated materials. Piston materials are hardened parts sensitive to temperature. Tribological systems in these parts; It works depending on factors such as contact pressure, contact temperature, lubrication or leanness, wear rate and friction loss. Thermal barrier coatings applied to the engines prevent these surface deformations that may occur, preventing high temperature, pressure and chemical wear (corrosion) taking place during the combustion event by directly touching the main material surface, improve the engine performance by protecting the combustion energy with the high temperatures they create [13]. When the images are examined, it is seen that there is no gap between the coating layers and the backing material and it creates a good coating.

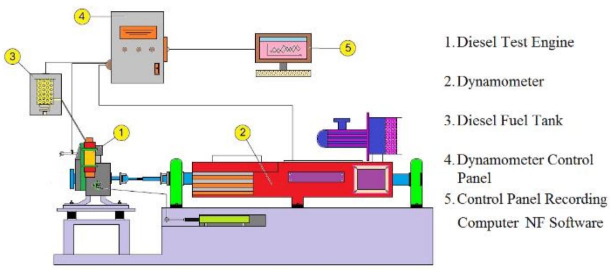

Figure 4. Schematic representation of the engine test equipment

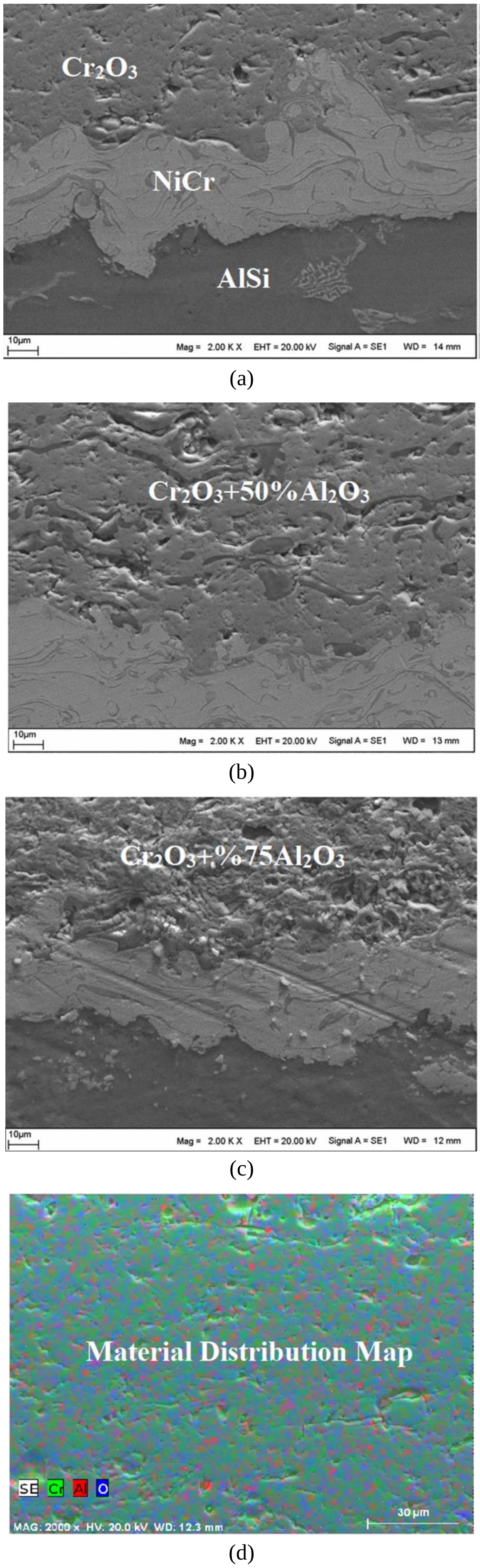

Figure 5. SEM microstructure of coating layers

3.2. Engine Performance of Coated Engine

The change of engine power according to an engine speed of engines coated with Cr_2O_3 ceramic powders with Al_2O_3 addition is given in Figure 6. The factor that creates the engine power in IC engines is calculated by the useful study obtained as a result of the combustion of the fuel taken into the cylinders, and the useful operation in the cylinders is measured by the average index pressure and the Netfren Brand Dynamometer control software directly calculates this value.

When the graph in Figure 6 is examined, it is seen that the engine power is more in ceramic coatings. As the rate of Al_2O_3 ceramic coating in Cr_2O_3 increases, the increase in engine power is higher than other uncoated engines. Since the fuel that creates the pressure inside the cylinder is caused by the end of combustion temperature and the sudden increase in temperature inside the cylinder, it is thought that the power of Al_2O_3 coated engines increases by creating higher temperatures in the combustion chamber. With the speed increasing, there is a tendency to decrease the power of all engines at 2600 rpm. The reason for this was that with the increase in speed, excessive heat was generated, causing knock and a decrease in engine power. It was stated that the increase in effective power was slowed with the increase in speed, while the increase in speed was effective when the literature sources were examined [14]. When the engines coated with the standard engine are examined during all revolutions, the lowest engine power is seen in the standard engine, while the highest engine power is detected in Cr_2O_3+75%Al_2O_3 coated engine. When compared to the average power at all revolutions with standard engine and coated engines, it was found that there was an increase of 7.18% in Cr_2O_3 coated engine, 21.08% in Cr_2O_3 + 50% Al_2O_3 coated engine and 29.3% in Cr_2O_3+75%Al_2O_3 coated engine.

The graph giving the change of engine torque according to an engine speed of engines coated with Cr_2O_3 ceramic powders with Al_2O_3 addition is given in Figure 7. Torque is an important measurement criterion for a specific engine's energy, but its size relies on engine dimensions. Much more useful relative engine performance measurement criteria are found by dividing the work by revolutions. The parameter determined in this way is expressed in the unit of force applied to the unit area [15].

Looking at the graph in Figure 7, it is seen that all engines with ceramic coating increase the engine torque compared to the standard engine. As the engine speed in internal combustion rises, a rise in engine torque is seen. This increment passes through the maximum point and causes a decrease again [16]. In Figure 7 also, a decrease is seen after 2600 rpm, friction losses increase with the speed of the beating engine, the engine torque is decreased after 2600 rpm due to the decrease in the volumetric efficiency as the fuel-air mixture time gets shorter. This is also observed in similar studies [17]. When the engine torque is compared with the standard engine and the thermal barrier coated engines, it has been determined that there is an increase of 7.86% in the Cr_2O_3 coated engine, 13.93% in the Cr_2O_3+50%Al_2O_3 coated engine and 23.13% in the Cr_2O_3+75% Al_2O_3 coated engine.

The graph giving the BSFC change according to the engine speed of the engines coated with Cr_2O_3 ceramic powders with Al_2O_3 addition is given in Figure 8. The amount of fuel that the engine needs to be burned to get one kW of useful work in one hour is called BSFC.

As seen in the graph in Figure 8, the lowest values of BSFC were measured around 2600 rpm. The reason for this situation is that the engines operating temperature is low at low revolutions together with the efficiency of combustion being low. BSFC values decrease with increasing engine combustion efficiency which reaches the ideal operating temperature by approaching medium revolutions.

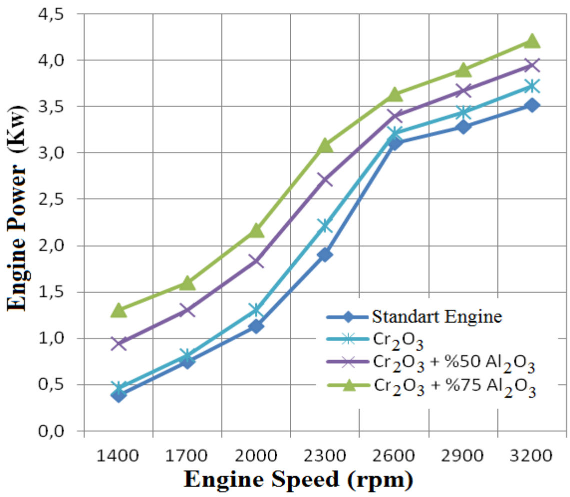

Figure 6. Engine power changes under different speed.

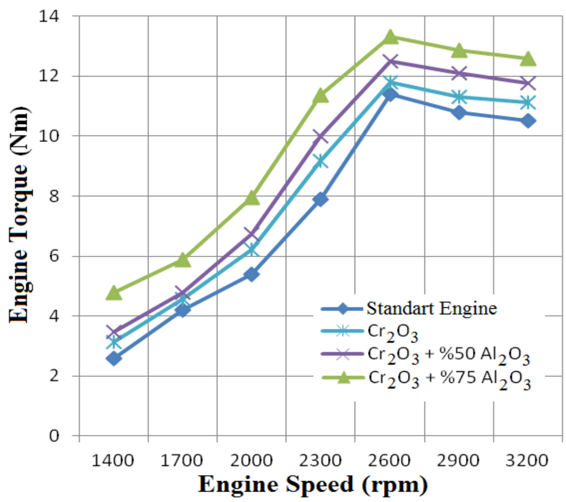

Figure 7. Engine torque changes under different speed

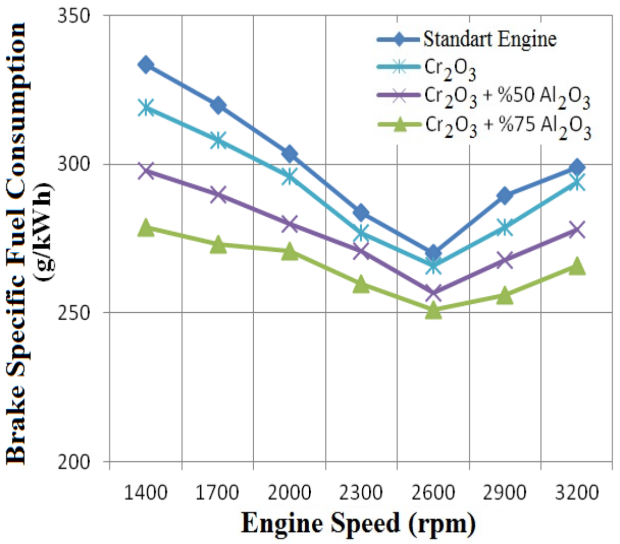

Figure 8. BSFC changes under different speed

Also, the fact that the fuel/air mixture is much closer to the stoichiometric ratio in the engine medium revs is seen as another factor that decreases BSFC values. When high revolutions are attained, the time required for combustion reactions negatively affects combustion and reduces combustion efficiency. Due to the reduced combustion efficiency, the engine needs to transfer more fuel to the combustion chamber to produce the same power and therefore causes an increase in BSFC values. The results of the study are similar to those in the literature [18-20]. When BSFC was compared between standard engine and Thermal barrier coated engines, it was found that there was a decrease of 2.85% in Cr_2O_3 coated engine, 7.47% in Cr_2O_3+50%Al_2O_3 coated engine and 11.57% in Cr_2O_3+75% Al_2O_3 coated engine.

The graph that gives the change of exhaust gas temperature according to the engine speed of the engines coated with Cr_2O_3 ceramic powders with Al_2O_3 addition is given in Figure 9. The exhaust gas temperature can be referred to as the temperatures of the burning fuel in the cylinders, the gases discharged as combustion products at the end of combustion. The exhaust gas temperature is an indicator of the end of the combustion temperature in the cylinder [21].

When the graph in Figure 9 is examined, it is seen that all engines with ceramic coating have higher exhaust gas temperature compared to the standard engine. This is the desired result because it is concluded that there is a thermal barrier coating inside the cylinder with the ceramic coating. Since the thermal conductivity coefficients of Cr_2O_3 and Al_2O_3 materials are lower than the standard combustion chamber of the engine (AlSi), it traps the temperatures in the cylinder, there by increasing the end of combustion temperatures inside the cylinder [22-26].

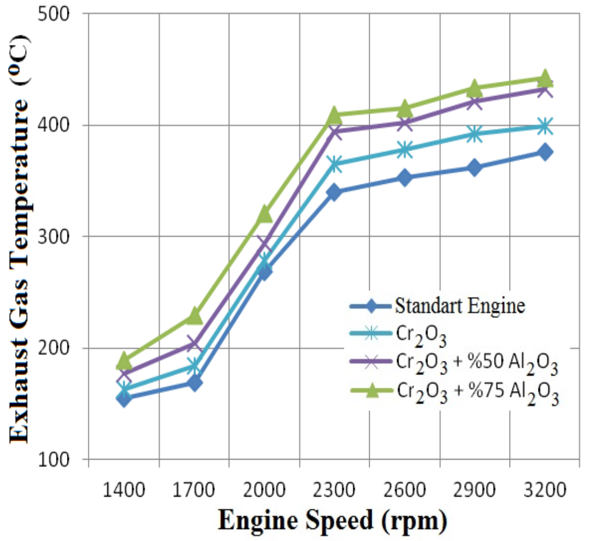

Figure 9. Exhaust gas temperaturechanges under different speed

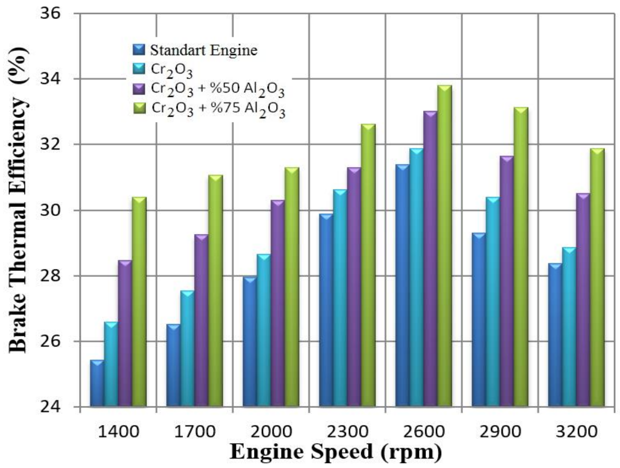

Figure 10. Brake thermal efficiency changes under different speed

When the exhaust gas temperatures were compared between the standard engine and the thermal barrier lined engines, it was found that there was an increase of 6.29% in the Cr_2O_3 coated engine, 12.95% in the Cr_2O_3+50%Al_2O_3 coated engine and 17.02% in the Cr_2O_3+75%Al_2O_3 coated engine.

In Figure 10, the graph shows the change in thermal brake efficiency according to the speed of the engine. Important brake parameters affecting thermal efficiency are ignition delay, a chemical, physical property of fuel and combustion temperature. The TBC coated engines also increase the combustion temperatures due to the temperatures where they lock the combustion chamber [27]. In this case, the thermal brake directly affects efficiency. When the graph is examined, it's been seen that the thermal brake efficiency of the ceramic coated engines rises. Thermal brake efficiency; Compared between the standard engine and thermal barrier coated engines, it was found that there was an increase of 2.84% in Cr_2O_3 coated engine, 7.83% in Cr_2O_3+50%Al_2O_3

coated engine and 12.73% in Cr_2O_3+75%Al_2O_3 coated engine.

4. Conclusions

In this study, it has been determined that an internal combustion diesel engine piston can be coated with Al_2O_3 added Cr_2O_3 ceramic powders by using an intermediate bond (NiCr) material and these engines can be investigated for performance tests. When the performance results of the coated engines with the standard engine are examined, the following results are obtained.

- The lowest value in engine power was observed in the standard engine during all revolutions and it was found that there was an increase of 1.58% in the Cr_2O_3 coated engine, 9.41% in the Cr_2O_3+50%Al_2O_3 coated engine and 21.38% in the Cr_2O_3 + 75% Al_2O_3 coated engine.
- The least value was observed in the standard engine during all revolutions of the engine torque and it was found that there was an increase of 1.51% in the Cr_2O_3 coated engine, 9.40% in the Cr_2O_3+50%Al_2O_3 coated engine and 21.36% in the Cr_2O_3+75%Al_2O_3 coated engine.
- The highest value was observed in the standard engine during all cycles in brake specific fuel consumption, it was determined that there was a 4.9% decrease in Cr_2O_3 coated engine, 7.75% in Cr_2O_3+50%Al_2O_3 coated engine and 9.39% in Cr_2O_3+75%Al_2O_3 coated engine.
- The lowest value of exhaust gas temperature was observed in the standard engine during all cycles and an increase of 2.17% in Cr_2O_3 coated engine, 6.62% in Cr_2O_3+50%Al_2O_3 coated engine and 10.018% in Cr_2O_3+75%Al_2O_3coated engine was detected.
- The least value in brake thermal efficiency was observed in the standard engine during all revolutions and it was found that there was an increase of 1.58% in the Cr_2O_3 coated engine, 9.41% in the Cr_2O_3+50%Al_2O_3 coated engine and 21.38% in the Cr_2O_3+75%Al_2O_3 coated engine.

In general, all engines with Al_2O_3 addition Cr_2O_3 coating give better results in terms of performance compared to the standard engine. To improve this study, performance researches can be conducted on internal combustion engines by using more specific advanced technological ceramic materials.

Declaration

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The author(s) also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required.

Acknowledgment

I would like to express my gratitude to this noble institution, Bitlis Eren University Scientific Research Project Unit within the scope of No: BEBAP-2014.15 project for its gross support. Moreover, part of this study was presented at the "IATENS2019 Conference", Seydisehir / Konya, Turkey.

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