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Effect of Aluminum Oxide (Al_2O_3) Coating on Piston Crown on the Performance of a Gasoline Engine –Experimental Analysis

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Abstract- Internal combustion (IC) engines play an important role in the area of the automotive industry. An IC engine discards approximately two-thirds of fuel energy to the atmosphere through exhaust valves and combustion chamber walls while only one-third is used as a power output. The chief goal of ceramic thermal barrier coating (TBC) is to drop fuel consumption as well as improve the thermal efficiency (TE) of IC engines. In this article, the experimental investigation was performed on a single-cylinder gasoline engine. The piston crown was coated with Aluminum Oxide (Al_2O_3) to analyze the effect of ceramic TBC on the engine performance and its results compared with the conventional engine piston. Al_2O_3 ceramic was used for TBC because of its appropriate physical properties such as a high coefficient of thermal expansion, low thermal conductivity, and stable phase structure against high temperatures. The results were obtained on a baseline engine and ceramic TBC Aluminum Oxide piston engine which were coated with thicknesses of 300 µm. TE of the LHR engine was improved by 2-3% over the uncoated engine. Fuel consumption and volumetric efficiency were reduced by 5-8% and 4-6%, respectively, over the baseline engine. The findings are applicable for the optimized performance of the IC engine at bench and commercial scales.

Keywords- Al2O3, LHR, Engine Performance, Thermal Efficiency, TBC

I. INTRODUCTION

The engine is a major part of the automotive industry and plays a significant role in the transport and agricultural industry. The increasing fuel demand along with the limited resources of fossil fuels and heat losses in the engine requires an improved insulation system to minimize thermal losses and enhance its efficiency. Many researchers worked on engine material to improve engine performance, they introduced metallic coatings which are sustainable under high temperatures and pressure. Now the trend is to enhance engine performance and ability using advanced materials and better cooling systems with different operating conditions. The introduction of ceramic coatings has brought a revolution in the automobile industry [1]. Fig. 1 displays the energy balance between a conventional and ceramic-coated diesel engine [2].
Many researchers used metallic coating technique that is sustainable under high temperatures and pressure for the improvement in engine performance. Recently, investigators [3-5] using advanced materials and better cooling systems with different operating conditions have become an interesting and effective trend of research for the enhancement of engine performance. Ceramic coating is one of the most emerging and revolutionary areas of research in the automobile industry. Literature shows that these techniques improve various engine constraints such as fuel utilization and brake thermal efficiency (BTE)

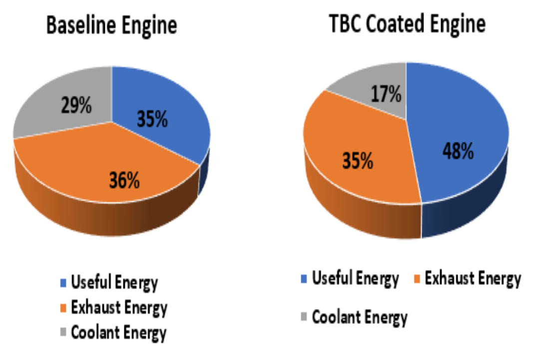

Fig. 1: Energy balance of the conventional and ceramic TBC engines.

Whereas reducing exhaust emissions [6]. In an experimental study by Rupangudi, et al. [7] the piston of a diesel engine was layered with Titanium dioxide by atmospheric PST. Results reflected that Brake specific fuel consumption (BSFC) decreased, BTE increased up to 3% and ITE improved by 3% over a conventional engine. Mechanical efficiency (ME) of the coated piston is increased by 2% when estimated with the baseline engine. Effect of TBC was investigated on the execution, combustion as well as exhaust emission characteristics compared with a conventional engine. The thermally insulated piston had high TE, ME, and BP compared with the baseline engine. Test results showed that BTE was increased with ZrO_2-Al_2O_3 coated piston compared with uncoated piston engine [8].

The performance analysis and emission of the TBC engine with YSZ coating in the combustion chamber were studied by Gosai, et al. [9] and compared with the baseline engine. Results show that BSFC is decreased while TE is increased. A similar study by Büyükkaya et al. performed experimental analysis by using a 6-cylinder DI turbocharged diesel engine. The piston crown was layered with 0.150 mm of NiCrAl as a bond coat and 0.350 mm of $MgZrO_3$ as a top coat. The outcome showed a 1-8% reduction in BSFC, and a 65 ºC rise in EGT, for the LHR engine with turbocharger over the baseline engine [10]. The thermal barrier coating of Al_2O_3-TiO_2 and ZrO_2-Y_2O_3 with NiCrAl bond coat affected the temperature and stress distribution on the piston crown. Increased temperature because of the coated surface increased engine performance by approximately 8% [11]. The zrO_2-Y_2O_3 coating increases the engine performance, reduces pollution, and rises the fatigue life of the engine [12]. The thin coating of ceramic material to the aluminum alloy piston reduces the thermal waste of energy and increases efficiency. TBC of ceramic decreases consumption by around 4.12%, and increases BTE up to 12% while SFC decreases by around 2.65% along with a substantial decrease in emissions [13]. Pandian, et al. [14] have performed 3D finite element (FE) structural and thermal analysis on a couple of uncoated and functionally graded (FG) TBC pistons by using ANSYS. The extreme surface temperate of the ceramic-coated piston is about 7% improved than the conventional piston. Experiments were performed by Mittal, et al. [15] by using YSZ. Two diverse fuel mixtures (10% and 15% butanol in gasoline) were examined on a ceramic-insulated engine and a standard engine. The valves as well as the cylinder head were covered using 100 µm NiCrAl as a bond coat and 200 µm ZrO_2 (including 8% Y_2O_3) as a top coat. When the engine was loaded at minor and full load, the BTE improvements of 3.8% and 6% were predicted, respectively, in the LHR engine over the baseline engine. Having an open literature review, it is revealed that coating ceramic materials on engines decreases SFC, increases TE, and improves emission characteristics. Numerous scientists [3-18] work on diesel engines to reduce heat losses, while on gasoline engines still much work is to be done.

This is an experimental study carried out on a 4-stroke, overhead valve (OHV), inclined cylinder with 25 degrees, horizontal shaft, single cylinder, gasoline engine using a coating of Al_2O_3 to decrease heat losses, to enhance thermal efficiency and to minimize harmful exhaust gases as compared to the conventional engine.

II. Coating Material and Process

In this investigation, the plasma spray technique (PST) was used because it offers adaptable and relatively reasonable methods for creating coated parts of an engine. Robin EX17D four-stroke gasoline engine piston was coated with Al_2O_3 material by utilizing the plasma technique. Trichloroethylene was utilized for cleaning the piston crown and eliminating all sand particles. On the base metal, a NiCrAlY bond layer of 100 µm in thickness was coated, and a binder layer was connected to assure a decent bond to the coating material. At that point, Al_2O_3 powder was drizzled utilizing a gun onto the head of the piston crown to a thickness of 200 µm. Many ceramic materials can be used for the coating of the piston, herein Al_2O_3 was adopted because it is the best for the engine performance results and the availability of the materials for the coating. The benefits and drawbacks of Al_2O_3 are presented in Table 1, and the coating material properties are revealed in Table 2. The illustration of PST for piston coating is exposed in Fig. 2.

Table 1: The Characteristics of coating material Al_2O_3.

Sr. No	Advantages	Disadvantages
1	Resistant to high temperatures	Transformation of phase at 1273K
2	Resistant to erosion and corrosion	Costly machining process
3	High wettability	Brittle
4	High hardness value	Lower coefficient of thermal expansion

Table 2: Properties of Al_2O_3.

Properties	Value
Hardness (kg/m^2)	1300
Density (g/cm^3)	3.96
Fracture Toughness (MPa $\sqrt{m}$)	4.5
Melting Temperature (ºC)	2050
Modulus of elasticity (GPa)	36-40
Strength (MPa)	250-300

Piston crown coating the proper estimation apparatus, their arrangement, and functioning conditions knowingly affect investigational results. The nomenclature of the coated materials is given in Table 3.

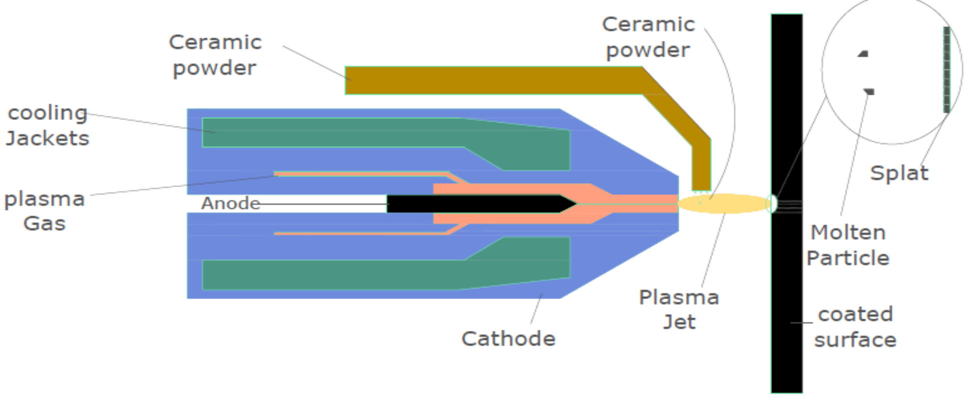

Fig. 2:

Illustration of plasma spray technique (PST).

Illustrations of baseline and ceramic-coated piston and coating descriptions are shown in Fig. 3 and Fig. 4.

Table 3: Nomenclature of the coated materials.

Type of Coat	**Top Coat**	**Bond Coat**
Material	Al_2O_3	NiCrAlY
Thickness	200 µm	100 µm

(a) Bassline piston (b) Ceramic coated piston

Fig. 3: Illustration of baseline and ceramic-coated pistons.

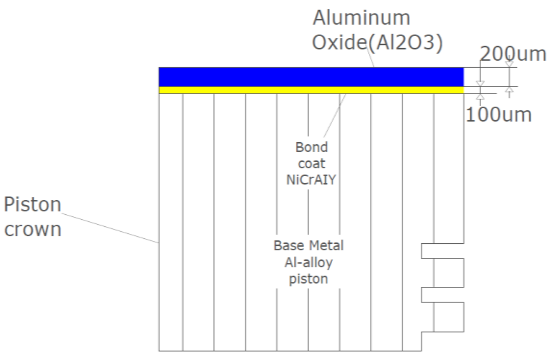

Fig. 4: Binder and coated material thickness on the piston crown.

III. Experimental Setup and Procedure

Robin EX17D gasoline, four-stroke, single-cylinder, air-cooled engine with 50 mm bore and 50 mm stroke was utilized for experiments. The engine is studied at 3.5 kW (4.8 HP) and 3600 r/min. The engine performance examination of the coated piston, as well as the conventional piston, was analyzed. The experiments were conducted at diverse engine speeds (rpm) and dissimilar applied loads. The same procedure is applied for both a conventional engine and a ceramic TBC piston engine. Experimental estimations ordinarily include fuel utilization, torque, air utilization, speed, cooling flow rate, motor, surrounding temperature, dampness, weight, exhaust gas temperature, and inlet and outlet cooling. The specifications of a conventional engine are revealed in Table 4. The test setup of the engine bed is exposed in Fig. 5.

Table 4: Experimental engine specifications.

Compression Ratio	9.0:1
Dimension (H x W x L) mm	346 x 362 x 312
Displacement (cm^3)	163
Dry Weight (Kg)	15.1
Maximum net torque Nm (kgfm) / (rpm)	10.3 (1.05) / 2500
Continued rated Power kW (H.P) / (rpm) KW (H.P) / (rpm)	2.5 (3.4) / 3000 2.9 (3.9) / 3600
Fuel Tank Capacity (Liter)	3.1
Engine Type	4-stroke single-cylinder OVH petrol engine
Net Power KW (H.P) / (rpm)	3.6 (.8) / 3600
Bore x Stroke (mm)	68 x 45
Engine Oil Capacity (Liter)	0.6

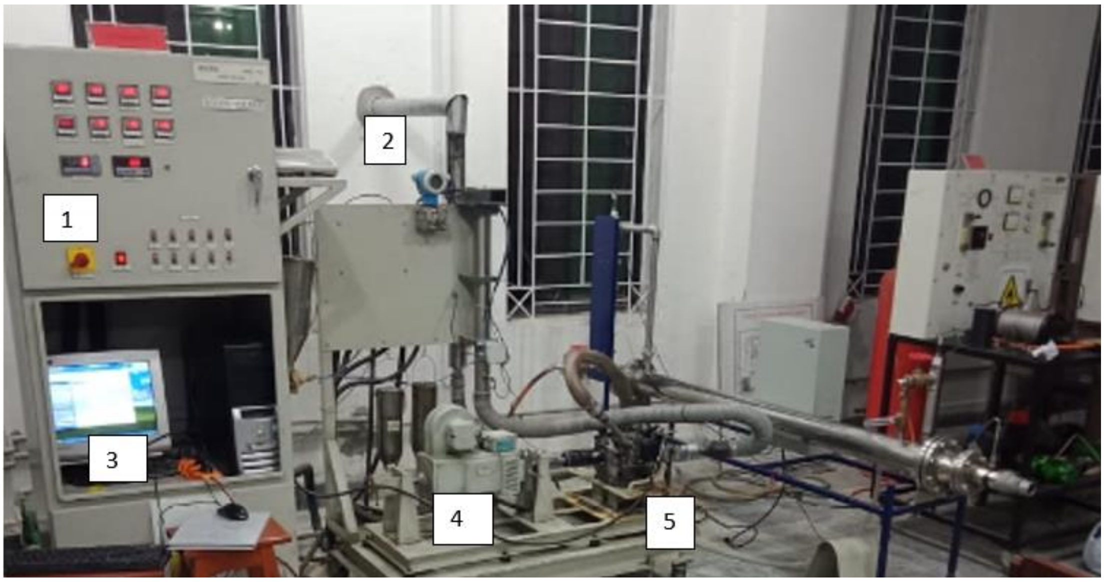

Fig. 5**:** Engine Test Bed
1. Control panel 2. Exhaust 3. Computer system 4. Dynamometer 5. Test Engine

Furthermore, experiments were performed at four levels of speed such as 2000, 2500, 3000, and 3500 r/min, and various parameters such as air-fuel ratio, mechanical efficiency (ME), BSFC, ITE, EGT, and brake thermal efficiency (BTE) were noted for all four levels of speed.

IV. Results and Discussion

A. Thermal efficiency

TE is the quantity of heat that is being transformed to work output. Fig. 6 represents the evaluation of the thermal efficiency of a conventional engine as well as the Al_2O_3 TBC piston engine. The experimental result displays that as the brake power

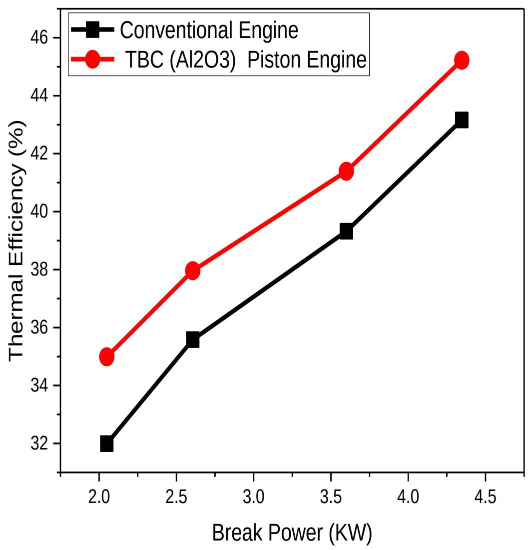

Fig. 6: Discrepancy of TE of TBC Conventional engine under diverse break powers

Conventional engine under diverse break powers of the engine rises the TE of both conventional and TBC piston engines increases. TE of the coated engine enlarged due to a drop in heat losses as well as the accessibility of additional heat in the combustion chamber of the IC engine. There was 2-3% enhancement in TE was predicted in the TBC piston engine over the uncoated piston engine and also similar results of increasing in thermal efficiency were found in previous research, Reddy [3], Jagtap [5], Mittal [15], Ali, [19], and many others [20].

B. Fuel consumption

The rate at which an engine uses fuel is said to be the fuel consumption of the engine. Fig.7 represents the contrast in the fuel consumption of the engine between conventional and Al_2O_3 TBC piston engines. The fuel intake of the coated engine was lesser as contrasted to the conventional engine. Fuel consumption of TBC engines is decreased because of higher operating temperature and improving combustion characteristics. This may be because of boosted temperature walls of the combustion chamber, which raises the temperature of the fuel delivering as of the heated fuel injection nozzle causing the decreased fuel viscosity as well as enhanced combustion of the fuel. Fuel consumption was reduced by up to 5-8% as compared to the conventional piston engine and similar results were found by previous researchers Reddy [3], Mittal [15], and some others [21-22].

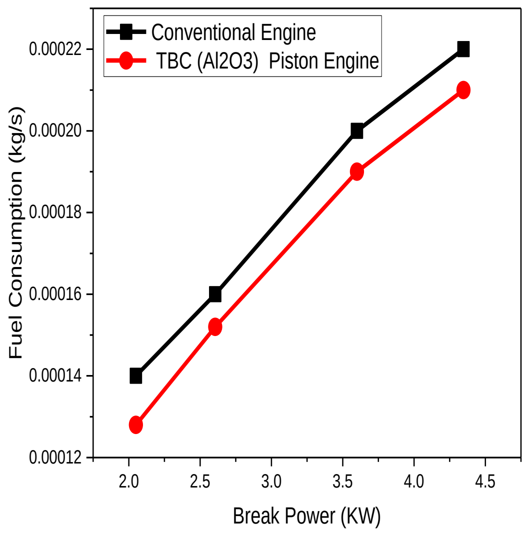

Fig. 7: Discrepancy of fuel consumption of TBC engine and conventional engine under diverse break powers.

C. Effect of brake mean effective pressure on thermal efficiency

Thermal efficiency is the ratio of power generated at the shaft to the fuel energy consumed per second. BMEP is the actual power of the IC engine on the crankshaft. Average effective braking pressure considers engine efficiency. The evaluation of the thermal efficiency of the petrol engine between conventional as well as Al_2O_3 coated piston engines are represented in Fig. 8. Thermal efficiency of the coated piston was greater than that of the conventional engine.

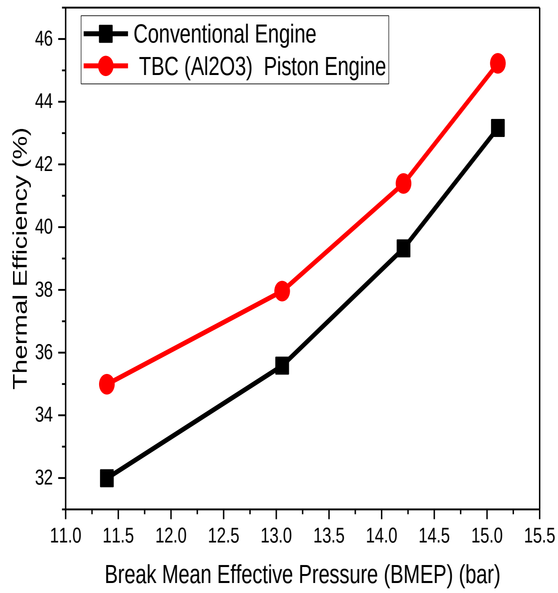

Fig. 8: Discrepancy of TE of TBC engine and conventional engine under diverse BMEP.

D. Volumetric efficiency

The engine's volumetric efficiency (VE) characterizes its capacity to place air into its cylinder. Fig. 9 shows the contrast of the VE of the gasoline engine between conventional and Al_2O_3-coated piston engines. As the brake power of the engine increased the VE of the engine gradually decreased in both conventional and TBC engines. The VE of a coated engine is decreased as contrasted to the conventional engine; the result of VE is exposed in Fig. 9. VE was decreased because of the high temperature within the engine cylinder. Due to the higher temperature within the cylinder, the density of the air was reduced, and less air entered the combustion chamber because of this VE of the TBC engine declined. The VE of the TBC engine decreased by almost 4-6% as compared with conventional engines. The researchers Ramu et al. [8], Chan, et al. [12], and Binder, et al. [23] show a similar reduction in VE in the case of the LHR engine.

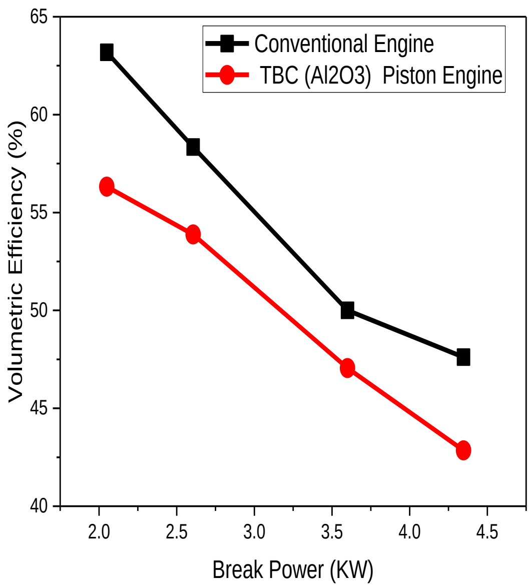

Fig. 9: Discrepancy of VE of TBC engine and conventional engine under diverse break powers.

E. Exhaust gas temperature

The temperature at which the exhaust gases discharged from the engine. Fig. 10 demonstrates the correlation of exhaust gas temperature (EGT) of gasoline engines among conventional and coated piston engines. There was a significant increment in the EGT of ceramic Al_2O_3-coated engines; much of the heat produced remained within the combustion chamber subsequently improving in EGT. This increment was because of higher ignition temperature as well as diminished heat loss to the coolant. The EGT of the TBC piston engine improved up to 5-8% as contrasted to the conventional engine. Similar behavior was found in the investigations of Sivakumar, et al. [24], Penny, [25], Fei, [26], and Uchida [27].

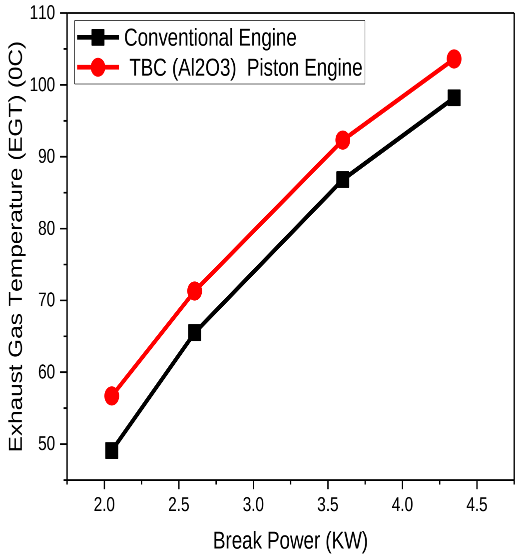

Fig. 10: Discrepancy of EGT of TBC engine and conventional engine under diverse break powers.

V. CONCLUSION

A single-cylinder, 4-stroke, the gasoline engine was transformed over the LHR engine by coating its piston crown with using 300 µm layer of ceramic Al_2O_3 by using the PST. The ceramic TBC piston engine represents higher BTE and improved BSFC as contrasted to the uncoated engine. From the experimental outcomes, the following conclusions can be drawn.

i. Performance analysis of the modified engine is better as compared to the uncoated engine. BTE was increased at all engine speeds and load conditions in TBC piston engines. The BTE was improved up to 2-3%.
ii. TBC piston engines decrease the specific fuel consumption by 5.5-8% at all engine loads and speeds as associated with the uncoated engine.
iii. The TE is increasing for the both uncoated engine and Al_2O_3 coated engine with increasing the BMEP.
iv. The heat energy released from the fuel in TBC engine is higher as associated with that of without the coated engine.
v. The EGT was greater in the engine with TBC piston by 5-8% as contrasted to the conventional piston engine.
vi. The VE of the TBC piston engine reduces by up to 4-6% as contrasted to the conventional engine.

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