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Review of Ceramics Coating on the Engine Components

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Abstract: *The experimental research of ceramic coatings on engine components, as well as the evaluation of their performance, is discussed in this work. Engine efficiency, pollution, and combustion characteristics have also been studied in relation to the ceramic coatings on engine components. Furthermore, several ceramic coating materials and coating processes have been thoroughly studied. For a better understanding of the relevance of the ceramic coating, experimental findings of ceramic coated and non-coated engine components were compared. A few issues in emissions and engine performance have also been identified as areas where additional research is needed. The use of optimization techniques in ceramic coating on engines, as well as analysis of variance (ANOVA) to understand the major parameters impacting engine performance, has been explored.*

Keywords*: ceramic coatings, coating techniques, engine performance, ANOVA, optimization*

1. Introduction

Light-weight materials are in great demand, and light-duty vehicles are accountable for providing high efficiency [1]. In the design and construction of contemporary vehicles, light weighting has become one of the most significant factors to consider [2]. Progressed ceramic materials are used to work on the exhibition and discharge qualities of IC engines [3]. Ceramic materials are chemically inert [4] and stable at high temperatures [5]. Ceramic materials are an ideal choice for enhancing the properties of the engine [6-7]. Ceramic materials have greater benefits than metallic and polymeric materials because of their high hardness, low density, and outstanding thermal and corrosive resistance [8].

Modern automotive engineering sectors are facing a lot of challenges in identifying new materials to improve the performance of their engines, and materials like silicon nitride (Si_3N_4), zirconia (ZrO_2), and alumina (Al_2O_3) play an excellent role in the automotive sector [9-10]. The reason for this paper is to investigate cutting edge innovations in the illumination of new ceramic materials to upgrade the overall performance of the engine. Various materials in view of ceramics in engines have demonstrated their appropriateness and have been explored.

2. Materials and methods

Research works by various authors pertaining to the Ceramic coating on the engine components were meticulously chosen to review coating type, coating side temperature, coating thickness, coating bond thickness and error occurred with respect to DF, SS, Adj. MS, F, P, and Contribution ratio to obtain the results of ANOVA. The schematic sketch of experimental setup shown in Figure 1.

3. Result and discussions

3.1. Improvement of functional properties

Ceramic coatings of engine materials are emerging as the newest method of improving the engine's overall performance. Wear, abrasion, corrosion, and high-temperature deterioration are just a few of the consequences that ceramic coatings help to prevent [11-13]. Due to their low thermal conductivity, ceramic-based cylinder walls can withstand high thermal stresses. Ceramic coated piston is shown in Figure 2.

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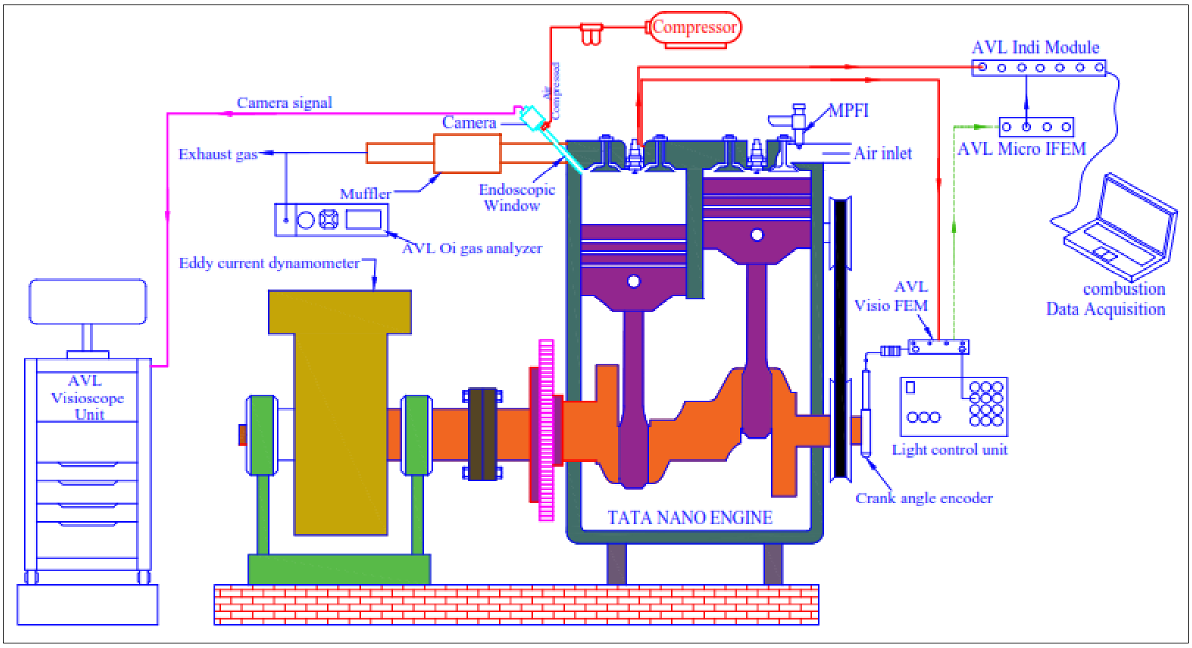

Figure 1. Schematic diagram of Experimental Setup

Figure 2. Ceramic coated piston [13]

Balu et al. [14] coated engine components with zirconia in order to reduce thermal conductivity and increase thermal efficiency. Using zirconia coatings on the cylinder wall and piston, heat transfer was minimized. The engine was converted to a low heat rejection diesel engine (LHR) that reduced the emissions of carbon monoxide and unburned hydrocarbons. By reducing the heat loss, they were able to increase the efficiency of the ethanol-fuelled engine. Figure 3 depict the when coating of cylinder and combustion chamber by plasma coating procedure.

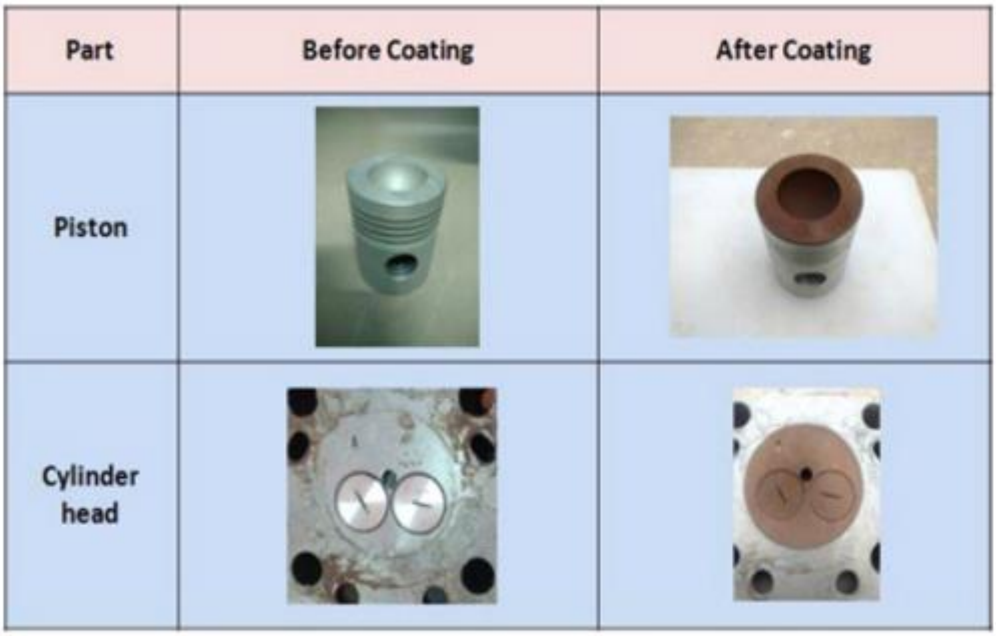

Figure 3. Piston, and Combustion chamber coated by plasma coating technique [24]

Saravanan et al. [15] explored the adequacy of CI engine which utilize waste plastic oil as fuel. To some extent partially stabilized zirconia covered engine parts were dissected and with standard diesel fuel. Ceramic coatings bring about higher thermal effectiveness with lower NOx, and the presence of unburnt hydrocarbons is decreased when contrasted with standard diesel fuel.

The viability of two distinct ceramics coating thicknesses in CI engine was concentrated by Narad et al. [16]. They noticed the impact of bio fuel by contrasting the outcomes acquired for the tests led with diesel as a fuel for both covered and non-covered cylinders. The thermal efficiency (BTE) increments by around 6% for 250 m and by 8% for 500 m as the coating thickness increments. Conversely, fuel utilization falls by generally 18% for 250 m and 20% for 500 m. CO (carbon monoxide), HC (hydrocarbon), and smoke outflows were diminished by 23-40%, 17-42%, and 11-35%, separately. However, NOx (nitrogen oxides) tends to rise from 15 to 180 ppm.

3.2. Abrasion resistance

Kamo et al. [17] used ceramic coatings to a Direct injection diesel engine, and the outcomes were 6 percent better at maximum load (2600 RPM) and 3.5 percent better for 1600 RPM when compared to the regular metallic engine. The engine with the thinner thermal barrier coating had a higher heat release rate. Abrasion resistance was also shown to be stronger in the coated engine than in the uncoated engine. Titanium nitride and molybdenum nitride were considered as the most common representations of wear resistant coatings based on nitrides to increase the abrasion resistance of engine components [18]. Wear resistance and corrosion resistance are both improved by chromium carbide. Burkov and Kulik [19] employed electric spark deposition to cover engine components with chromium carbide coatings. The coatings' micro hardness was increased from 8.2 till 9.8 GPa. Coatings have a wear resistance that was more than 50 times higher than that of steel. Coatings also decreased the potential of corrosion considerably. They proved that the application of coatings on steel 35 improved the endurances of its surfaces to a gas erosion at high temperature.

3.3. Emission reduction

Abbas et al. [20] coated the piston's outer surface with PSZ/Al_2O_3 ceramic material. Their objective was to minimize heat transfer from the combustion compartment to the rest of the engine. Researchers compared the results of a coated diesel engine with those of a non-coated diesel engine. With the insulation of the engine, peak pressure was increased, thermal efficiency was enhanced, exhaust gas temperatures climbed, and NOx emissions decreased. Karthickeyan [21] assessed the impact of thermal barrier coating (TBC) on the DI diesel engine. He explored the presentation qualities of kapok oil biodiesel combined with ordinary diesel in a DI diesel engine. yttria-settled zirconia were used to cover the engine components. As per the eventual outcomes, the covered engine delivers less CO, HC, and smoke than the untreated engine.

Venkadesan and Muthusamy [22] evaluated the Al_2O_3/8YSZ, CeO_2/8YSZ, TBC-coated, and uncoated conventional diesel engines performance and combustion characteristics. In comparison to the Al_2O_3/8YSZ based TBC, their test findings indicated that the CeO_2/8YSZ based TBC had good thermal cycling behaviour. When they compared to a regular diesel engine, Both TBC-coated engines had lower HC, CO, and smoke emissions and greater NOx emissions.

Surfaces of engine parts can be hardened using the microarc oxidation (MAO) method to enhance their anti-friction characteristics [23]. The MAO coating process creates a ceramic oxide layer on the base metal. The oxide coating allows the piston to withstand high temperatures and pressures and reduces the piston's heat rejection in the cylinder [24]. Figure 4 illustrates a schematic view of the ceramic coating using the MAO method. The micro-arc oxidation (MAO) method was used by Dudareva et al. [25] to coat aluminum-alloy pistons with ceramic coatings to increase IC engine reliability. Using a piston head with a MAO layer, the efficiency of thermal protection was examined experimentally. Tests were conducted on pistons with MAO coating thicknesses of 76 and 106 μm. They used ANSYS multiphysics for simulating the thermal state of the piston. They concluded that MAO coating on the piston head reduced the temperature of the piston by 45...78°C.

3.4. Performance improvement through optimization

In order to increase the engine's thermal efficiency, the effects of coatings on combustion, emissions, and engine performance were studied. To enhance the performance of the engine, Yessian & Varthanan [26] used characteristics such as load, speed, and fuel. To increase the performance of IC engines and reduce emissions, they employed the Grey Relational Analysis Optimization (GRA) approach in collaboration with the Taguchi design of research.

When contrasted with a normal un-coated cylinder type engine, their outcomes uncover that a changed copper chromium zirconium (CuCr1Zr) reactant covered cylinder creates less toxins and upgrades execution. Utilizing the Taguchi with GRA technique, the results of the trials were compared to those of an uncoated engine, and optimal parameters for catalytic coated modified IC engines were identified.

Plasma spray was utilised by Ozel et al. [27] studied the ceramic coating on the surfaces of the valves and piston. The effects of coated layers on torque, power, and brake-specific fuel consumption were investigated (BSFC). Engine torque and BSFC reached their greatest values when Al_2O_3 + 13% TiO_2 was employed at 2600 rpm, according to their research. They utilized the L16 (42) Orthogonal array (OA) for the Taguchi examination.

Yunus et al. [28] established the tribological attributes of ceramics coating and they enhanced their coating with the assistance of Taguchi with GRA (T-GRA). With T-GRA, they were able to reduce wear, increase TBC life, and reduce friction coefficient. ANOVA helped them to support their findings. Most significant parameters affecting the thermal efficiencies can be found out using ANOVA results. In the Table 1, Coating type played a significant role (72%) when compared to other parameters have been identified using ANOVA. Also P value is less than 0.05 and hence it proves that the result is statistically significant. Thus the exact results of thermal characteristics (TC) are being analyzed for the characterization ceramic coating. In general, most of the attempts have been done for optimizing the control factors using Taguchi design of experiment combined with GRA [29-32]. Nirmala et al. [33] explored the ceramic covered diesel engine and they applied Particle Swarm Optimization and Genetic Algorithm (PSO-GA) for working on the durability as well as limiting the expense.

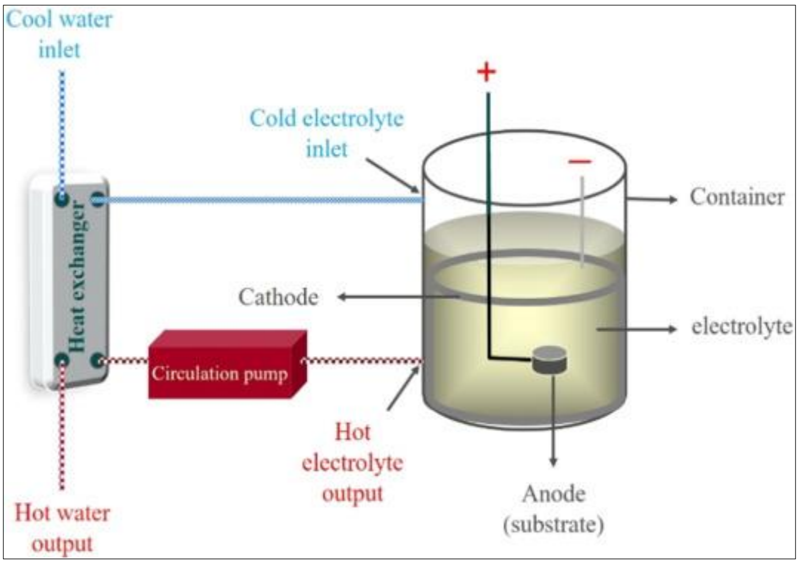

Figure 4. Ceramic coatings using micro arc oxidation method [23]

Table 1. Results of ANOVA [27]

Parameters	DF	SS	Adj. MS	F	P	Contribution ratio
Coating type	3	0.376542	0.125514	23.71	0.014	72.98
Coating side temperature, °C	3	0.12243	0.004081	0.77	0.582	2.37
Coating thickness, μm	3	0.095492	0.031831	6.01	0.087	18.51
Bond coat thickness, μm	3	0.015810	0.005270	1.00	0.501	3.064
Error	3	0.015883	0.005924	-	-	3.078
Total	**15**	**0.515969**	-	-	-	**100**

4. Conclusions

The coatings on engine components, as well as their performance evaluation, are examined in this paper. The ceramic coatings on engine components have also been studied in connection to engine efficiency and combustion characteristics. The different advanced ceramic coating materials and coating processes utilised to improve thermal efficiency were examined in depth. The ceramic coating is an excellent alternative for increasing the performance of engine components, as ceramic materials have a high hardness and excellent thermal and corrosive resistance, as evidenced by the review.
However, finding new ceramic coating materials that may improve engine performance while lowering NOx emissions remains a challenging task. Optimization techniques were additionally provided to have a superior comprehension of the significance of the interaction boundaries that impact the ceramic coating. In the future, ceramic coating research should focus on extending the life of engine components while lowering processing costs.

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