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Comparison Studies on Effect of Thermal Spray Coating in Internal Combustion Engine

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The aim of the research outlined in this paper is to evaluate thermal spray processes like Atmospheric Plasma Spraying (APS) for the protection and upgrade of aluminium particularly for the low cost and flexible manufacture of automotive components. A great demand for automobile fuels due to increased rate of consumption and necessity of provide clean air environment in coming years. The automobile industry not only to find alternative fuel sources but also looking for fuel economic and eco friendly vehicles. Thermal spray coatings are depositions of materials which has been melted or plasticized immediately prior to projection onto the substrate. The thermal barrier coating is done on the piston for reducing the emission and thereby improving the efficiency of the internal combustion engine. The Alumina and Silicon Carbide particle were used as coating materials and the effect of the both on the emission and mileage is reported in this paper.

Keywords: Thermal spray coating, Al_2O_3, SiC, emission test.

1. Introduction

The petroleum and automotive industries are facing tough international competition, government regulations, and rapid technological changes. Coating is applied to improve the wear resistance and scuffing resistance at least as good as the cast iron liner they substitute. Fine grained tribologically functional ceramics such as Al_2O_3, SiC and Fe oxides present in a coating can improve surface related properties such as hardness, compressive strength, abrasion resistance and scuffing resistance [1]. Ever increasing government regulations require improved fuel economy and lower emissions from the automotive fuel and lubricant systems. Higher energy conserving engine oils and better fuel efficient vehicles will become increasingly important in the face of both the saving of natural resources and the lowering of engine friction. Depleting fossil fuel resources, economic competitiveness and environmental pollution has compelled to explore newer avenues to improve efficiency of automotive engines. In order to save weight and enhance heat transfer characteristics it is desirable to reduce the thickness of the cylinder lining. In aluminium engine block, every extra millimetre of cast iron or steel lining adds to the overall weight and reduces fuel economy. Previous attempts at manufacturing a sleeveless cylinder using a nickel-based liner deposited onto an aluminium substrate were employed by BMW and Jaguar [2]. The development of light weight internal combustion engines using materials such as cast aluminium alloys represents one of the most significant technological developments in automotive industry. Coating may be defined as a near surface region, having properties different from the bulk material it is deposited on. Thus the material system forms a composite, where one set of properties is obtained from the bulk substrate and another from the coating itself. The coatings should also possess good mechanical and thermal shock resistance, good adhesion and strain compliance with the aluminium alloy substrate to meet the engine durability requirements [3]. Thermal spraying is often considered as a potential alternative to traditional coating manufacturing techniques for the production of wear resistant coatings. Coatings can help to improve performance and life of automotive engine. Higher efficiency of engine is realized from various aspects of coatings as following conditions.

1. Reduced weight of the components.
2. Reduced friction between the components.
3. Thermal insulation in combustion chamber.

It is essential to have least frictional forces present in between mating and/or reciprocating components. High coefficient of friction leads to higher wear rate affecting the engine life [4]. Besides, mechanical friction has significant effect on the internal combustion (IC) engine fuel economy. In an IC engine, the major sources of frictions are valve train, piston system, crank and bearing system. Mechanical friction represents 10-15% of indicated mean effective pressure. Of the total frictional loss about 50-65% is accounted in piston system alone. Valve train system contributes 10-20% of friction loss and crank and bearing contributing the rest [5]. There is a pressing need to reduce these frictional losses to improve overall efficiency of the engine, reduce oil consumption and to increase life of engine.

2. Thermal spray coatings

Thermal spraying is a generic coating technique whereby droplets of molten or partially molten material are generated and projected at a surface to form a coating.

The droplets undergo little interaction with the substrate, merely adhering to the roughened surface through physical means to form an overlay coating. A variety of techniques have been designed for this process, varying in the manner in which they heat the material, the operating temperature and the velocity to which the droplets are accelerated. Through the range of operating conditions generated, any material that does not undergo sublimation or degradation upon heating can be applied as a coating [6]. Materials ranging from polymers through to metals, cermets and ceramics are routinely sprayed. In the generalized thermal spray process, the coating material in rod, wire or powder form is fed into a high temperature heat source, where it is heated close to, or in excess of, it's melting temperature [7]. A high velocity accelerating gas or combustion gas stream accelerates the droplets of material to the substrate, where they impact and spread across the surface to form a splat. The splat material deforms to match the surface topography, forming mechanical interlocking bonds as it undergoes rapid solidification (106 K/s) [8]. In melting of the particles may contribute to phase dissolution in multiphase materials. Rapid solidification generates non equilibrium metastable phases and amorphous structures in the splats. Conversely particles that are not sufficiently molten do not deform significantly upon impact, potentially generating voids and porosity within the coating.

The extent, to which the material phases in the powder are retained in the coating, and the coating density, are critically dependent upon the deposition technique and spray parameters. The highest quality coatings are generated by high velocity particles, heated to a low temperature sufficient for deformation and spreading upon impact [9]. In this technique, a mixture of inert gases, typically based on Ar or N_2 with additions of H_2 and He [10], is passed through a direct current arc generated between a central throated tungsten cathode and radial copper anode. The ionized gas undergoes rapid expansion and accelerates out through the nozzle of the gun. The typical temperature distribution of this expanding gas is 2700-12000°C [11]. The resulting gas velocity, ranging from 200-400 m/s [12] up to 600-800 m/s or higher [13], is dependent upon the nozzle design and operating parameters. The D-Gun consists of a water cooled barrel approximately one meter long, with an internal diameter of 25 mm [14]. Pulses of the combustion gases, oxygen and acetylene are injected into the end of the barrel, along with a charge of powder entrained in a carrier gas. The entrained powder is heated and accelerated to speeds of 750-800 m/s [15] in the D-Gun and 900 m/s in the Super D–Gun processes respectively. The barrel is purged with nitrogen prior to the next firing, which occurs 1-15 times per second [16]. Each shot of powder generates a circular disc of material on the substrate, made up of multiple overlapping splats. Successive firings overlap the discs of deposited material to build up the coating. This combination of attributes results in these coatings being extensively used to mitigate the effects of wear, erosion and abrasion. As a feedstock for thermal spraying these materials are formed into powders of typically 5-53 μm by combining carbide and alloy matrix powders through mechanical blending, agglomerating and sintering, fusing and crushing, or spray drying and sintering. Some powder production routes incorporate additional flame or plasma treatments to spheroidise and/or densify the particles to improve flowability and reduce internal particle porosity [11]. The make up of these powders in terms of carbide size, distribution and morphology, the composition of the binder and the overall mass ratio of carbide to binder d by the requirements of the coating application. A typical system of plasma spray coating process is shown in Fig. 1. During thermal spraying deposition, however, the composite particles are prone to oxidation, phase dissolution and decarburization, which significantly affect the coating composition, phase concentration and carbide morphology [18].

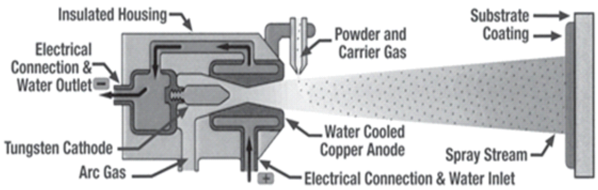

Figure 1 Typical system of atmospheric plasma spray process

Mechanical and elastic properties of the phosphate sealed and laser-glazed $8Y_2O_3$-ZrO_2 and 22MgO-ZrO_2 thick thermal barrier coatings (TBCs) were determined by erosion and abrasion experiments and the elastic properties were evaluated by four–point bending (4PB) tests [17]. Phosphate based sealing treatments improved significantly the erosion and abrasion resistance of the coatings and also increased the coating micro hardness, bending strength and stiffness. The improvements of mechanical properties in the phosphate sealed coatings were caused by the lamellae bonding, due to the sealant. This class of ceramic has a very low thermal conductivity, effectively insulating the underlying super alloy substrate from the high temperature environment. Lowering of thermal conductance of TBCs can be approached three ways [20]:

1. Lowering the thermal conductivity of the coating material.
2. Lowering the thermal conductivity by increasing the porosity of the coating.
3. Increasing the thickness of the coating.

When tailoring the low thermal conductance TBCs, all these ways should be considered. For heat engines applications, the thickness of the TBC will be in the range of 0.13-0.15 mm [9]. At this thickness range, for hot sections operating at temperature around 1000°C, the surface of the insulated super alloy component can be reduced by approximately 100°C, enabling extended lifetime at the engines operating temperature or allowing the engine to function at a higher more efficient temperature [19].

3. Experimental works

A typical chemical composition and properties of cermet powders are presented in Tab. 1. Thermal barrier coatings, cermet's such as silicon carbide, alumina are applied by plasma spray process to the substrate. Before coating the independently controllable predominant plasma spray processes were to be identified to carryout experimental work and to develop the empirical relationships. Trial runs are to be conducted to find out the working limits of plasma spraying using Ion Arc 40 kW Atmospheric Plasma Spray (APS) machine (Fig. 2) available at CEMAJOR Annamalai University and coating has carried under the following conditions (Plasma current (C) - 440 Amps, Powder feed rate (R) - 60 g/min., and Stand off distance (S) - 120 mm). In Fig. 3 shows schematic of plasma plume laden with molten particles spray from torch gun. In atmospheric plasma spray coating process to obtain reasonable bond strength of the sprayed coating on the substrate, the surface must be activated shortly before the spray operation. Traditionally, grit blasting (Fig. 4b) with based materials (Fig. 4a) is used for this operation. However, grit blasting leads to contamination of the interface with embedded particles. Thermal barrier crown coating is applied to the piston 0.13 mm (Fig. 4c) thickness.

Table 1 The chemical composition & properties of cermets

Chemical composition (wt. %)					Real Density kg/m^3	Melting Point °C	Average Size of Particles
Al_2O_3	SiO_2	Fe_2O_3		Na_2O	3980	2072	40-60 m
9.5	0.04	0.04		0.06			
SiC	SiO_2	Si	Fe	C	3170	2730	
98.8	0.41	0.3	0.09	0.3			

Overspray can be avoided through the use of masking which can be applied under production conditions using an automatic placement system, with the optimal particle size distribution of coating. Good bond strength can be obtained; however, the values depend strongly on the surface roughness, on the sprayed material, on the spray parameters, and of the coating thickness.

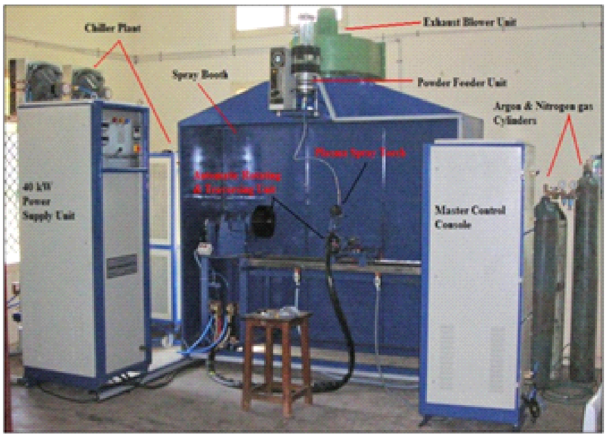

Figure 2 Experimental setup of atmospheric plasma spray process

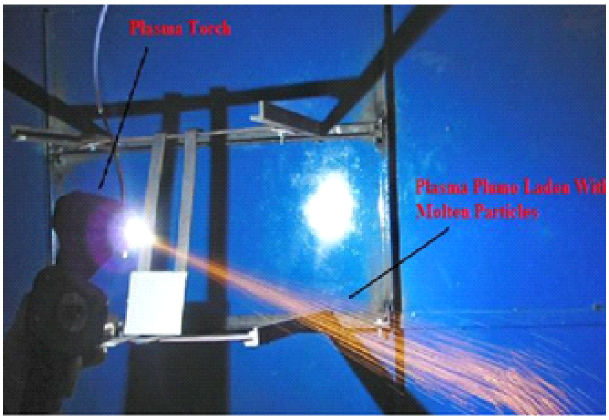

Figure 3 Schematic of plasma plume laden with molten particles

Performance evaluation of automotive engines is a great importance for running the vehicle under economic condition. The method for assessing the performance includes the determination of engine economic speed, kilometre test, and emission test. The test is carried on a plain road under steady speed. The observations of a road test conducted by the author1 using a TVS 50 XL with coating on piston at various speeds are analyzed. The exhaust emission has harmful effect on our environment/public health. In order to ensure a clean environment the government has enforced regulations to control automobile exhaust emission. As per the central motor vehicle rule (CMVR) 1989, in case of two wheelers (petrol driven) the idling CO emission (by vol.) should be less than 3.5%. So emission to be checked by authorized agencies at least once in every three months and to get the PUC certificate. In order to access the emission level of the engine without coating and with Al2O3 and SiC coating, emission test was carried. The emission test conducted PRIYA ENTERPRISES (Authorized Auto exhaust analyzing centre), Perambalur.

Figure 4 a) Uncoated pistons b) Sand blasted pistons c) Al_2O_3, SiC coated pistons

4. Results and discussion

Figs 5 and 6 shows the graphical representation between the speed in KMPH and distance in Km for both solo rider a as well as pillion rider. From the Figs 5 and 6, it clearly indicates that, the distance travelled per litre of the vehicle is more when the piston is coated with silicon carbide for both solo rider a as well as pillion rider. The result shows the economic speed of running the vehicle is at 30 KMPH based on fuel consumption. Under this condition the KMPL(kilometre per litre) is observed as economical with solo as well as with pillion rider driving. Also during the economic speed of running the vehicle, the KMPL is observed. The result shows that KMPL is more in the case of coating with silicon carbide, alumina coating and without coating. The analysis of emission level shows in figure 7 and 8, CO and HC emission levels are also reduced in the case of silicon carbide coating. The performance of the engine is considerably increased with silicon carbide coating then without coating.

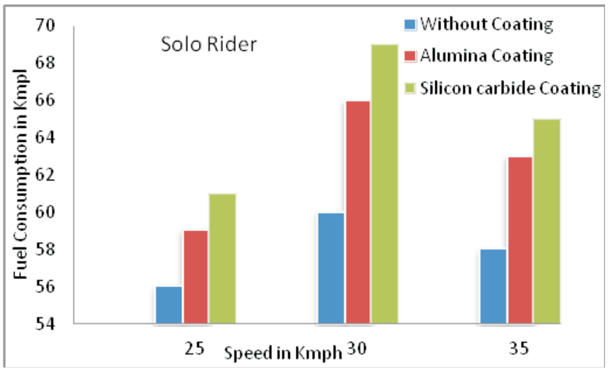

Figure 5 KM running test at solo rider

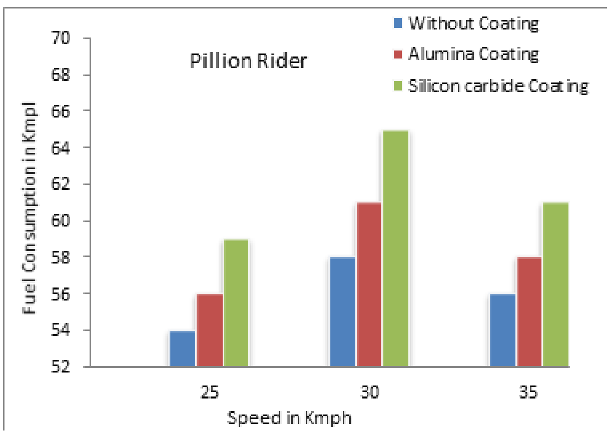

Figure 6 KM running test at pillion rider

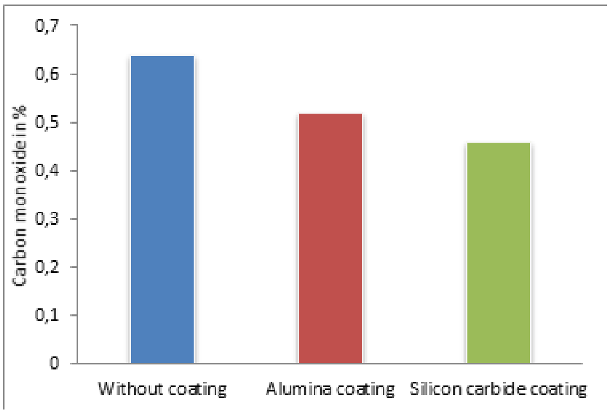

Figure 7 Analysis of CO emissions level

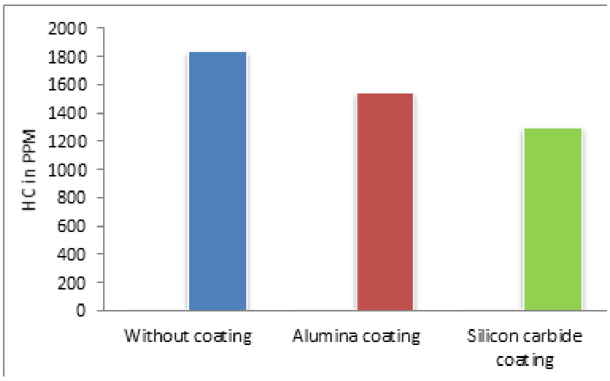

Figure 8 Analysis of HC emissions level

5. Conclusion

1. The present investigations show that, Kmpl is improved when the piston is coated with silicon carbide.

2. The same results are obtained for both solo riding and pillion riding. The emission test analysis shows an emission level reduction of 0.18% in the case of silicon carbide coating.

3. There is an improvement in the performance as well as good emission control when the piston is coated with Alumina when compare with piston without coating and it is lesser for the silicon carbide coating.

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