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Finite Element Analysis and Experimental Investigation of Multi Layer Coating (Al_2O_3-TiO_2 and Cr_2C_3) on Aluminium Piston by Plasma Spray Technique

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ABSTRACT:

In this study, the surface of a piston in an engine is coated with multilayer coating powder by the plasma-spray technique, and its surface behaviour is subsequently analyzed. The purpose of this study is to analyze with mechanical and thermal effects of surface coating for a piston. In this, with and without coated specimens were prepared, then the microstructure, hardness, corrosion test were carried out. From the obtained test and analyzed results, it is found that the coated specimen having improved properties may contribute towards improved diesel engine performance. The results show less deformation after getting analyzed on ANSYS on the multilayer coated piston as compared to uncoated one.

KEYWORDS:

Finite element analysis; Plasma spray technique; Multilayer coating; Aluminium piston; Hardness

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1. Introduction

Functionally graded materials are of widespread interest because of their superior properties such as corrosion, oxidation resistance, high hardness, chemical and thermal stability at cryogenic and high temperatures. These properties make them useful for many applications, including Thermal Barrier Coating (TBC) on metallic substrates used at high temperatures in the fields of aircraft and aerospace, especially for thermal protection of components in gas turbines and diesel engines [1-4]. TBCs have been successfully applied to the internal combustion engine in particular the combustion chamber in order to simulate adiabatic changes. The objectives are not only for reduced in-cylinder heat rejection and thermal fatigue protection of underlying metallic surfaces, but also for possible reduction of engine emissions and brake specific fuel consumption. The application of TBCs reduces the heat loss to the engine cooling-jacket through the surface exposed to the heat transfer such as the cylinder head, liner, piston crown and piston rings.

Chromium carbide is a ceramic compound that exists in several different chemical compositions. It is extremely hard and corrosion resistance. Chromium carbide is useful in the surface treatment of metal components. It is an excellent refractory ceramic material known for its hardness. Chromium belongs to block D, period 4 while carbon belongs to block P, Period 2 of the periodic table. Its nano particles appear in the form of gray crystals with an orthorhombic structure. All this properties makes it useful as an additive to metal alloys. Thermal spraying methods are a well established processes and preferred technique for deposition of corrosion, wear resistance, and TBC. Composites of Alumina and Titania are known for their high toughness, low thermal conductivity, and low expansion. These properties make Alumina-Titania composites desirable materials of construction and coatings for high performance application where thermal barriers are required [5-9].

When Titania is added to Al_2O_3 wear resistance increases, adhesion strength increases and toughness of the coating improves without changing the hardness. The insulation of the combustion chamber with Alumina-Titania and Chrome carbide coating affects the combustion process [10]. Hence, the performance and exhaust emissions characteristics of the engines improve. In this the nickel bond material of 50 microns, bottom layer is of Alumina-Titania (60%-40%) of 125 microns and top layer is Chrome carbide material of 125 microns are coated on the specimen. Total 300 microns are coated on the specimen.

2. Design of piston

Fig. 1 represents the plan and side views of the piston with key dimensions. Thermal analyses of un-coated and coated piston are carried out using ANSYS finite element analysis software. Fig. 2 shows the temperature fringe of un-coated piston with the minimum heat dissipation value of 35.021, which is having the more heat dissipation value than the coated one. Fig. 3 shows the temperature fringe of the piston coated with single layer of Chrome carbide which is having the minimum heat dissipation of 34.958. This shows that the piston coated with Cr_2C_3 having better properties than the uncoated piston. Fig. 4 shows the temperature fringe of the multi-layer coated piston with Alumina-Titania and Chrome carbide which is having the minimum heat dissipation value of 34.665. This shows that the multilayer coated piston is having better properties than the uncoated and Cr_3C_2 coated piston.

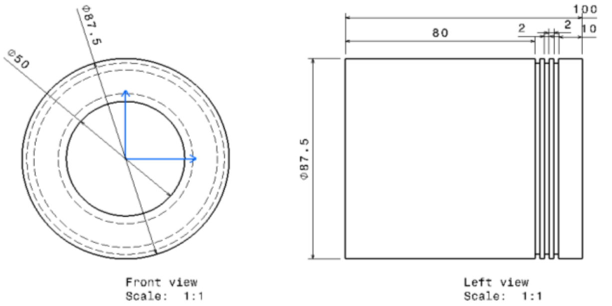

Fig. 1: Arial view of the piston with dimensions

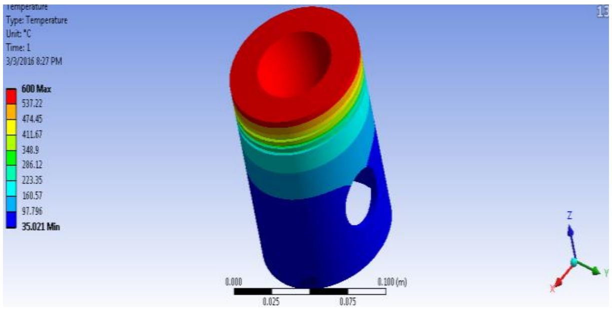

Fig. 2: Un-coated piston: Temperature fringe plot

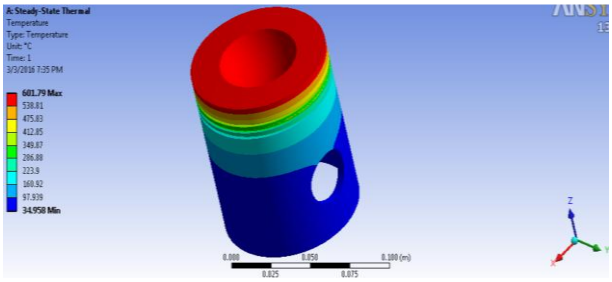

Fig. 3: Chrome carbide coated piston: Temperature fringe plot

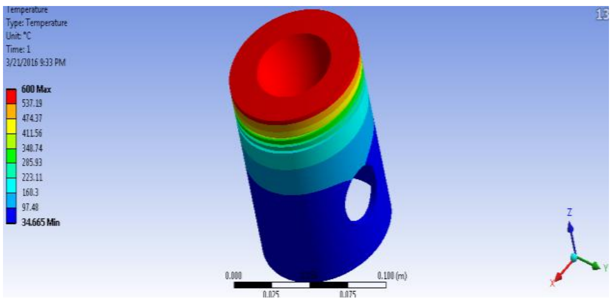

Fig. 4: Alumina-Titania & Chrome carbide coated piston - Temperature fringe plot

Fig. 5 represents the bar diagram of dissipated temperature of un-coated piston vs. coated piston. High performance engine produce a lot of heat in the combustion chamber compared to a normal. The pistons for these engines should absorb as little heat as possible for the engine to allow operating efficiently. A coated piston absorbs less heat than an uncoated piston which results in lower piston temperature. An Al_2O_3-TiO_2 & Cr_3C_2 coated piston is stronger than an uncoated piston as less stress is induced in a coated piston. This implies that coated pistons can allow engines to operate at even higher temperatures improving their efficiency and power output.

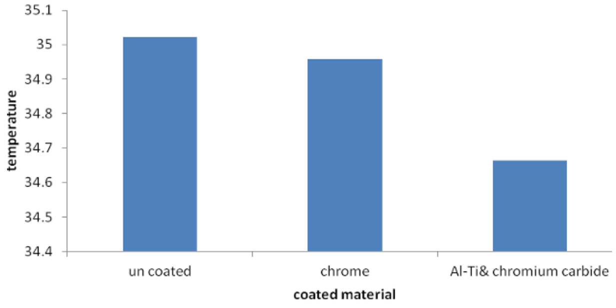

Fig. 5: Temperature (°C) vs. coated material

3. Experimentation results

From the analysis results the multilayer coating of Alumina-Titania & Chrome carbide was considered as the best coating material as it has good temperature withstanding capabilities and low total heat flux coefficient value. An aluminium specimen of 25×25× 10mm dimension specimen was made and Alumina-Titania & Chrome carbide material was coated on specimen using plasma spray coating process for a thickness of 300 microns. The chemical composition of substrate material aluminium for the plate specimen were machine-ground and ultrasonically before being grift blasted by Alumina abrasive to ensure good adhesion of coating layer to the substrate. Prior to the spray coating a Ni-Al composite was applied as a bond coat to enhance adhesion and reduce thermal expansion mismatch between the substrate and coating layer. Since coatings can provide high corrosion resistance it is necessary to check the corrosion resistance for the coated specimen. Salt spray test is a standardized method used to check corrosion resistance and the test duration depends on the coating, the longer the duration showing no signs of corrosion indicates coating material is effective. From Table 1, it is clear that coated specimen has shown no evidence of corrosion up to 12 hours.

Table 1: Corrosion resistance test results

Process	Un-coated	Coated
Chamber temperature	34.5-35.5°C	34.5-35.5°C
pH value	6.65-6.85	6.65-6.85
Volume of salt solution collected	1.0-1.5 ml/hr.	1.0-1.5 ml/hr.
Concentration of solution	4.80-5.30%of NaCl	4.80-5.30%of NaCl
Air pressure	14-18 Psi	14-18 Psi
Components loading in the chamber position	30° angle	30° angle
Results	White rust formation noticed up to 12 hours	No white rust formation noticed up to 12 hours

The micro hardness of the coatings was measured using a Vickers micro hardness tester. The indentations were made with 5kg load for 10sec along the axis of coating thickness. Fig. 6 represents the hardness value vs. specimen. Alumina-Titania & Chrome carbide coated specimen has high hardness value.

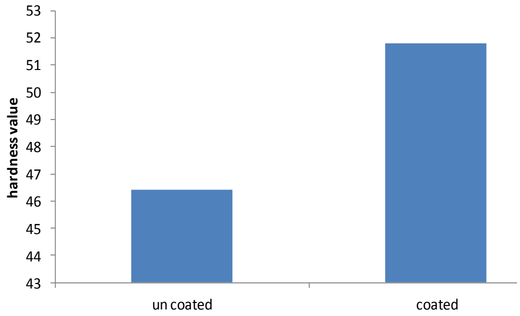

Fig. 6: Hardness value vs. Specimen

Microstructure is the small scale structure of a material, defined as the structure of a prepared surface of material as revealed by a microscope above ×25 magnification. The optical microscope, often referred to as light microscope, is a type of microscope which uses visible light and a system of lenses to magnify images of small samples. The image from an optical microscope can be captured by normal light-sensitive cameras to generate a micrograph. Figs. 7 and 8 illustrate the cross-sectional microstructure of plasma-sprayed coating and higher magnification of coating as revealed by SEM photography. Grain structure having larger thickness is observed in coated SEM than uncoated. In the uncoated SEM, pores and inter lamellar cracks were observed.

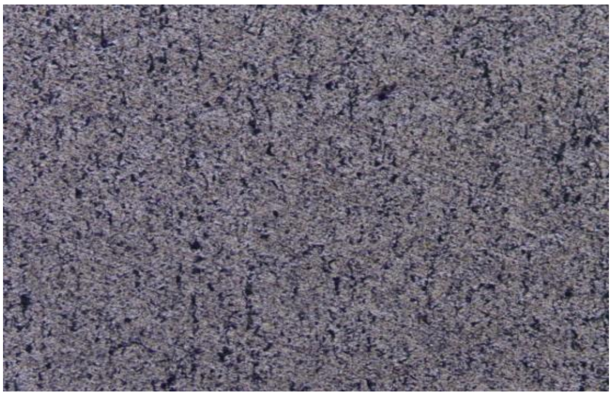

Fig. 7: Microstructure of un-coated specimen with ×100 magnification

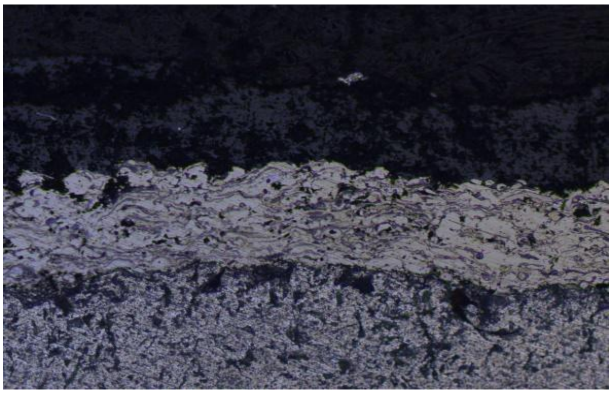

Fig. 8: Microstructure of coated specimen with ×200 magnification

4. Conclusion

From the obtained finite element simulation and experimental analysis result, it was found that the values of stresses produced in cylinder liner due to application of temperature and pressure are within permissible limit. It can be concluded that the baseline design of piston is safe with coated materials with the reference of pressure and temperature basis. With help of coating on piston and other automotive components having thermal barrier and wear resistance also found that due to the coating, thermal distribution will improved.

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