

FEA and Experimental Investigation on The Thermal Properties of the Ceramic Coating on Aluminium Piston

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ABSTRACT: In this study, the surface of a piston in a engine is coated with multi layer coating powder by the plasma-spray technique, and its surface behavior is subsequently analyzed. The purpose of this study is to analyze with mechanical and thermal effects of surface coating for a piston in frictional mechanism. In this related, with and without coated specimens were prepared, then the microstructure, hardness, corrosion test were carried out. From the obtained test and Ansys results, it is found that the coated specimen having improved properties in towards the diesel engine performance. The results show less deformation and fewer scratches due to wear on the multi layer coated piston as compared to uncoated one.

Also the aim of the investigation is to compare the mechanical, thermal properties and wear resistance of the piston with multi layer coating deposited on substrate material as Aluminium by Plasma spray technique. The surfaces topography and the structure of the plasma spray coatings is observe on the optical microscopy. The evaluation of the adhesion of coatings to the substrate is made using the hardness test also compare the thermal barrier properties. In case of the multi layer coating deposited onto the Aluminium a very good adhesion has been revealed to the substrate material in comparison to the Alumina - Titania coating deposited onto the heat treated hot work Aluminium. Taking into account the results of measurements, one can state that the lowest wear and thermal resistance at certain conditions at both room and elevated temperatures displays the multi layer coating deposited onto plasma spray coating.

KEYWORDS: Coatings; Structure; Adhesion; Wear resistance; Plasma Spray

I. INTRODUCTION

Functionally graded materials are of widespread interest because of their superior properties such as corrosion, erosion and 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.

Thermal barrier coatings 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 TBC 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. The insulation of the combustion chamber with ceramic coating affects the combustion process and, hence, the performance and exhaust emissions characteristics of the engines improve. On the other hand, the desire of increasing the thermal efficiency or reduce fuel consumption of engines lead to the adoption of higher compression ratios, in particular for diesel engines, and reduced incylinder heat rejection. Both of these factors cause increased mechanical and thermal stresses of

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materials used in combustion chamber.

The application of TBC to the surfaces of these components enhances high temperature durability by reducing the heat transfer and lowering temperature of the underlying metal. Typical TBCs failure is by spalling of the ceramic top coat from the bond coat. There are many factors that influence the overall performance of coatings and cause spalling of the coating.

However oxidation and thermal mismatch are identified as two major factors influencing the life of the coating system. The coatings are permeable to the atmospheric gases and liquids resulting in the oxidation of the bond coat and spalling of the coating. The functionally graded coatings were used to reduce the mismatch effect. Therefore the thermal expansion and interfacial stresses are an alternative approach to conventional thermal barrier coatings.

Energy conservation and efficiency have always been the quest of engineers concerned with internal combustion engines. The diesel engine generally offers better fuel economy than its counterpart petrol engine. Even the diesel engine rejects about two thirds of the heat energy of the fuel, one-third to the coolant, and one third to the exhaust, leaving only about one-third as useful power output. Theoretically if the heat rejected could be reduced, then the thermal efficiency would be improved, at least up to the limit set by the second law of thermodynamics. Low Heat Rejection engines aim to do this by reducing the heat lost to the coolant.

Thermal Barrier Coatings (TBCs) in diesel engines lead to advantages including higher power density, fuel efficiency, and multifuel capacity due to higher combustion chamber temperature. Using TBC can increase engine power by 8%, decrease the specific fuel consumption by 15-20% and increase the exhaust gas temperature 200K. Although several systems have been used as TBC for different purposes, yttria stabilized zirconia with 7-8 wt. % yttria has received the most attention. Several important factors playing important roles in TBC lifetimes including thermal conductivity, thermal, chemical stability at the service temperature, high thermo mechanical stability to the maximum service temperature and at last but not least the thermal expansion coefficient (TEC).

The diesel engine with its combustion chamber walls insulated by ceramics is referred to as Low Heat-Rejection (LHR) engine. The LHR engine has been conceived basically to improve fuel economy by eliminating the conventional cooling system and converting part of the increased exhaust energy into shaft work using the turbocharged system.

A large number of studies on performance, structure and durability of the LHR engine have been carried out since Kamo and Bryzik presented a new concept of the LHR engine 041 combined with the turbo compound system. Although promising the results of the investigations have been somewhat mixed. Most have concluded that insulation reduces heat transfer, improves thermal efficiency, and increases energy availability in the exhaust. However contrary to the above expectations some experimental studies have indicated almost no improvement in thermal efficiency and claim that exhaust emissions deteriorated as compared to those of the conventional water-cooled engines.

Plasma spray is the most common method of depositing TBCs for diesel applications. It creates a splat structure with 10-20 % volume fraction of voids and cracks. High porosity of this structure makes it an ideal choice for TBC. Widespread application has been limited by insufficient lifetimes and the cost.

TBCs for diesel engines have generally been accepted to improve engine thermal efficiency and reduce emissions as well as specific fuel consumption because of their ability to provide thermal insulation to the engine components. The generally known principle that increased operation temperatures in energy conversion systems lead to an increase in efficiency, fuel savings and reduced emissions as particles, carbon monoxides (CO), hydrocarbons (HC) and limited reductions of NO_x emissions have, over many decades, promoted R&D activities in the field of TBCs development.

II. OBJECTIVE

In this project, the main emphasis is placed on the study of thermal behaviour of functionally graded coatings obtained by means of using a commercial code, ANSYS on Aluminium piston surfaces and the results are verified with

numerical and experimental works.

III. PISTON

A piston is a component of reciprocating engines, pumps and gas compressors. It is located in a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder. In some engines, the piston also acts as a valve by covering and uncovering ports in the cylinder wall.

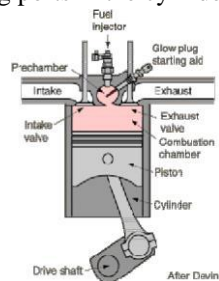


Fig 1: Components of Diesel engine

IV. COATING

Coating is a covering that is applied to an object. The aim of applying coatings is to improve surface properties of a bulk material usually referred to as a substrate. One can improve appearance, adhesion, wettability, corrosion resistance, wear resistance, scratch resistance, etc.. They may be applied as liquids, gases or solids. Coatings can be measured and tested for proper opacity and film thickness by using a Drawdown card.

NANO COATING:

Nano-coating is a recently developed technology used for coating any kind of material in hard coating and low friction coating both in which coating is done at nano scale that is of the order of 10^{-9} . The two major types of nano-coating are

1. Physical vapour deposition (PVD)
2. Chemical vapour deposition (CVD) FUNCTIONALLY GRADED COATING:

Functionally Graded Coatings are typically ceramic composites based on zirconia, alumina, and titanium. The high hardness, wear resistance and good chemical stability of TBCs make them very desirable in cutting tool applications. Functionally Graded Coating provides good resistance against the corrosive, high temperature environment of aircraft engines as well. Wear resistance can increase between 200 to 500% with the addition of a Functionally Graded Coatings to a material. Chemical vapor deposition (CVD), plasma vapour deposition (PVD), and electron beam physical vapor deposition (EBPVD) are the primary deposition methods for these coatings.

V. METHODOLOGY

- o Design of the Piston in CATIA V5 – 2D
- o Modelling of the Piston in CATIA V5– 3D
- o Thermal Analysis of Uncoated Piston

Alumina Coated Piston

Titania Coated Piston

Zirconia Coated Piston o CFD Analysis of the Piston o CFD Results imported to FEA o FEA Results based on CFD Results

Uncoated Piston

Alumina Coated Piston

Titania Coated Piston

Zirconia Coated Piston

VI.THERMAL ANALYSIS OF PISTON

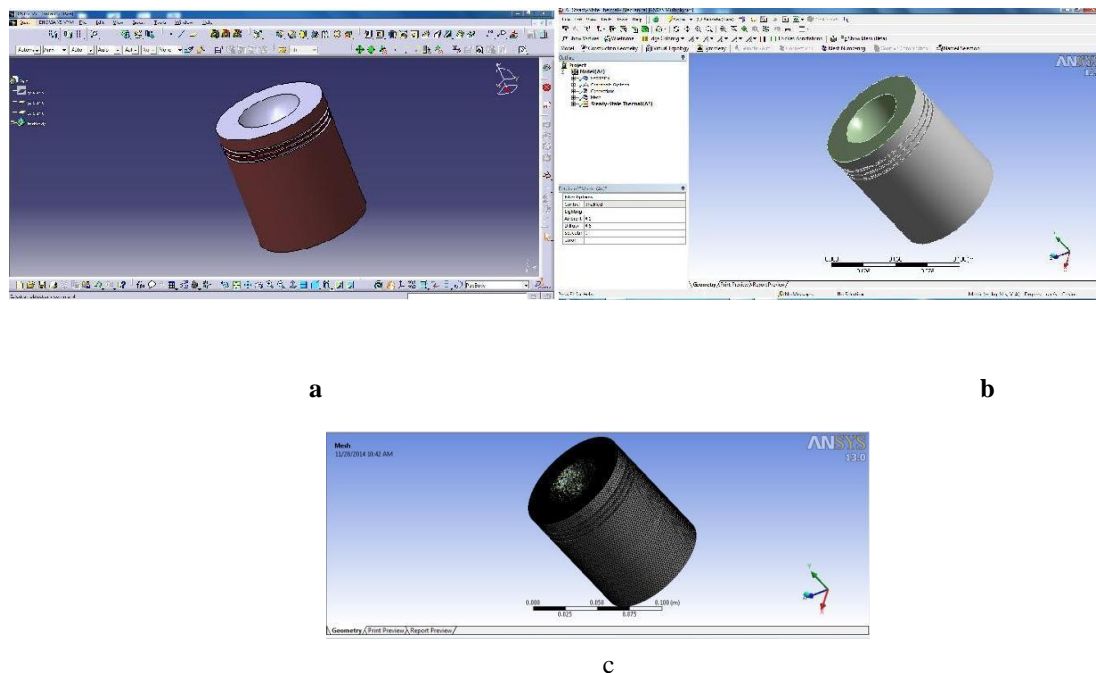


Fig 2 : Models of Piston (a) 3D Model of Piston in CATIA V5 (b) 3D Model of Piston in ANSYS (c) Meshed Model of Piston in ANSYS

The basis for thermal analysis in ANSYS is a heat balance equation obtained from the principle of conservation of energy. The finite element solution is performed via ANSYS which calculates nodal temperatures, and then uses the nodal temperatures to obtain the other thermal quantities. The ANSYS program handles all three primary modes of heat transfer: conduction, convection, and radiation. The Material Properties of Aluminium used are as follows:

Table1: Material properties of Aluminium

Material properties	Values
Young's modulus	70 GPa
Poisson's ratio	0.31 (no unit)
Coeff of thermal expansion	23 e-6 /K
Coeff of thermal conductivity	234 W/mK

INPUTS GIVEN

- Type of Analysis – Thermal Analysis – Steady State Thermal
- Temp at Robin Boundary Conditions
- Top Surface = 873K
- Convection Film Co efficient – 1500 W/Sq mC
- No of Nodes – 392339
- No of Elements – 232582
- Mesh quality Skewness – 0.3961

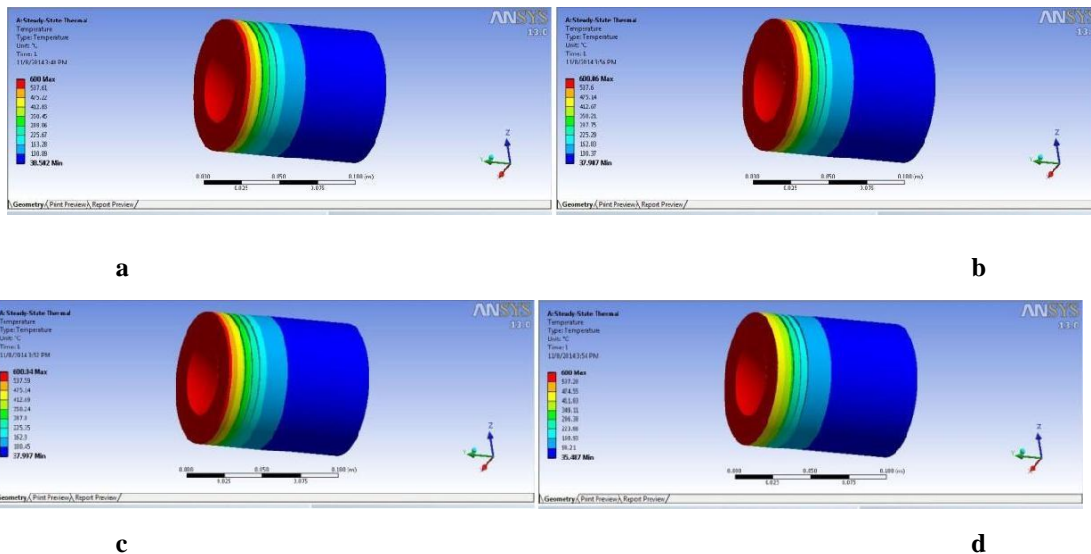


Fig 3 : Thermal Analysis of Piston (a) Uncoated Piston (b) Alumina Coated Piston (c) Titania Coated Piston (d) Zirconia Coated Piston

VILCFD RESULTS CFD ANALYSIS

- Fluent Turbulence Model – Navi’s Stoke equation
- RNGKe Equation
- Mt/1 - Gasoline Vapour
- Boundary Condition-
- Inlet – 5 m/s
- Wall2 – 0.08 Heat Flux
- Equation – Semi Implicit Pressure Linked Equation

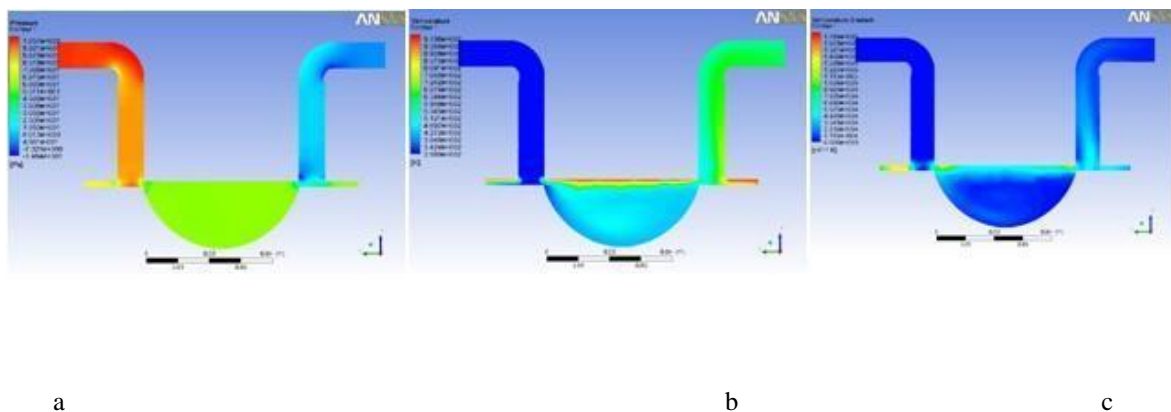
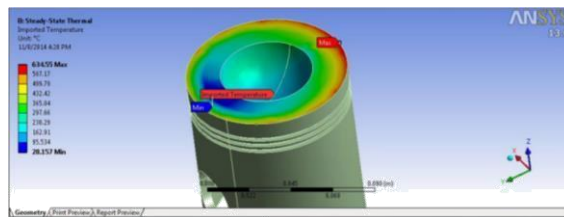


Fig 4 : CFD Results (a) Pressure (b) Temperature (c) Temperature Gradient

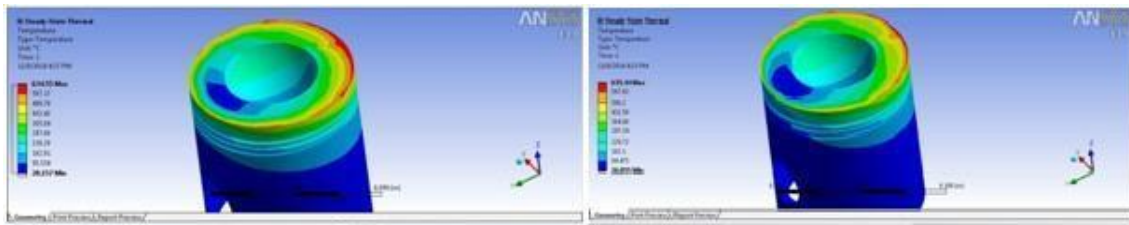
VIII. FEA RESULTS BASED ON CFD

CFD Results are imported to FEA to Steady State Thermal and FEA is done. Results are tabulated. Thermal Conductivity Values

- Alumina – 18 W/mK
- Aluminium – 205 W/mK
- Titania – 21.9 W/mK
- Zirconia – 2 W/Mk

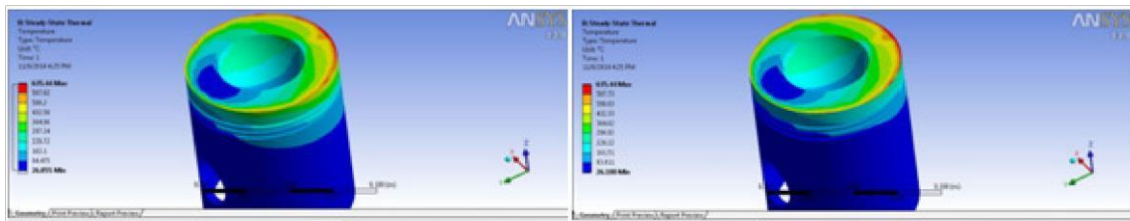


a



b

c



d

e

Fig 5 : Thermal Analysis Results based on CFD (a) Imported Temperature (b) Uncoated Piston (c) Alumina Coating (d) Titania Coating (e) Zirconia Coating

IX.RESULTS TABULATION THERMAL ANALYSIS

RESULTS

Temperature given as Input at Top Surface = 600 Deg.Celsius

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Table2: Thermal Analysis Results

Coating	Temperature at Bottom Surface Deg Celsius, C
Uncoated	38.502
Alumina	37.907
Titania	37.997
Zirconia	35.487

THERMAL ANALYSIS RESULTS BASED ON CFD

Table3: Thermal Analysis based on CFD Results

Coating	Temperature at Bottom Surface Deg Celsius, C
Uncoated	28.157
Alumina	26.855
Titania	26.855
Zirconia	26.108

X. CONCLUSION

From the obtained Ansys results the strengthening point of view the Zirconia coated piston strength will be higher than the all other coated piston. So that the tribological property will be increased in terms of wear and thermal barrier also, this will improve the further overall engine efficiency due to the good combustion takes place. Due to more strengthening of the Zirconia coated piston surface, the corrosion and wear properties also improved. This will be further helpful for the incomplete combustion. Also from the obtained Ansys result, the normal shear and shear stress was lower than the other coated piston like Titaniaia and Alumina. Then the temperature distribution is higher for the Zirconia coated piston than the other pistons, this will improve the combustion properties and reduces the emissions.

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XI.FUTURE SCOPE

The Study can be extended to Real Time Experimental work – applying coating on Aluminium Piston by Plasma Spray Technique and then studying the results.

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