DESIGN AND THERMAL ANALYSIS OF CERAMIC COATING ON PISTON FOR AUTOMOTIVE ENGINE BY FINITE ELEMENT SOFTWARE

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Abstract

Using a technique known as plasma spray, the surface of the piston in the engine is coated with a variety of ceramic powders such as Alumina, Titania, and Zirconia for the purpose of this numerical analysis. Thereafter, the behaviour of these coated surfaces is investigated. The primary purpose of this study is to investigate the thermal characteristics of a surface-coated piston that is subjected to friction. ANSYS was utilised in order to model both the piston with and without a coating so that it could be analysed. As a result of our investigation, we discovered that coated specimens had enhanced mechanical and thermal properties, which contributed to better diesel engine performance. The final product reveals the structural and thermal distribution of both coated and uncoated pistons.

INTRODUCTION

The exceptional qualities of functionally graded materials, such as corrosion, erosion, and oxidation resistance, high hardness, chemical and thermal stability at cryogenic and high temperatures, have made them a popular topic of study. Thermal Barrier Coating (TBC) on metallic substrates used at high temperatures in the aircraft and aerospace industries, especially for the thermal protection of components in gas turbines and diesel engines, benefit from these qualities. To imitate adiabatic fluctuations, thermal barrier coatings have been added to the combustion chamber of the internal combustion engine. Thermal fatigue protection of metallic surfaces, as well as prospective reductions in engine emissions and brake specific fuel consumption are among the goals. A TBC application lowers heat loss to the engine cooling jacket through the exposed surfaces such as the piston crown and piston rings. B limiting heat transfer and lowering the temperature of the underlying metal, TBC applied to these components' surfaces improves their high temperature durability. When a TBC fails, the ceramic topcoat peels away from the bond coat. Several factors influence the overall performance of coatings and lead to the formation of flaking. Thermal mismatch and oxidation, on the other hand, are both known to shorten the coating system's life expectancy. The bond coat oxidises and spalls because the coatings are susceptible to ambient gases and liquids. The functionally graded coatings were employed to minimise the mismatch impact. Because of this, thermal expansion and interfacial tensions can be used as an alternative to conventional thermal barriers.

1. LITERATURE SURVEY

Mass loss and wear mechanisms of HVOF sprayed multi-component white cast iron coatings O. Maranho et al, The HVOF thermal spray process was used to apply multi-component white cast iron instead of the more traditional manufacturing methods. Rubber wheel apparatus in compliance with ASTM G-65 was used to investigate the impact of substrate type, substrate preheating, and coating heat treatment on mass loss. Scanning electron microscopy research was also used to examine the effect of heat treatment on the wear mechanisms of the coating. Compared to as-prayed coatings, heat treated coatings had a mass loss of three times less. Micro-cutting and cracks around unmelted particles and pores are also wear processes of as-sprayed coatings. Sintering causes less mass loss in heat-treated coatings. Aspects of microstructure on the synergy and overall material loss of thermal spray coatings in erosion– corrosion environments. **V.A.D. Souza** et al, When WC– Co–Cr coatings are Electrochemical tests were conducted on titanium coatings generated by RPS using a controlled atmosphere plasma spray system (CAPS) to determine their corrosion resistance. A neutral 0.5 M NaCl solution and an acidic 0.5 M NaCl q1 M HCl solution were both used. Corrosion resistance has been studied in relation to porosity and nitrogen content. Coated samples, detachable coatings, AISI304 substrate and commercially pure titanium grade 2, are also given and discussed in the polarization curves. Optimizing the plasma spraying parameters is essential to provide wear and corrosion resistant deposits, since the corrosion resistance of coated samples was found to be mostly reliant on porosity values. Deposited using the High Velocity Oxy- Fuel (HVOF) and the Super Detonation-Gun (D-Gun) methods, the effect of microstructure on overall material loss is examined. When two different microstructures are created, this study aims to understand the synergy impact (here defined as the amplification of erosion due to corrosion processes) on material loss. For example, HVOF coatings have a lower corrosion resistance than D-Gun coatings, but they have a greater total erosion–corrosion resistance than D-Gun coatings. Because the microstructures of HVOF and Super D-Gun coatings differ based on the circumstances of application, the findings provided in this work cannot be generalized. When distinct microstructures are generated in the WC–Co–Cr coating, a link between the composition of the coating, its microstructure, and its erosion–corrosion performance is established.

Comparison of HVOF and plasma- sprayed Alumina Titania coatings microstructure, mechanical properties and abrasion behaviour.

Yourong Liu , et al, Nano and micro structured powders were used in HVOF and PS procedures to test the mechanical characteristics, abrasion wear resistance, and microstructure of Alumina Titania ceramic coatings. The mechanical characteristics and abrasion resistance of the coatings are heavily influenced by the deposition guns, although this is not true of the powders. An advantage with this element type is that you can stack several elements to model more than 250 layers to allow through-the-thickness deformation slope discontinuities. The user-input constitutive matrix option is also available. SOLID46 adjusts the material properties in the transverse direction permitting constant stresses in the transverse direction. In comparison to the 8-node shells, SOLID46 is a lower order element and finer meshes may be required for shell applications to provide the same accuracy as SHELL91 or SHELL99. As a result of this process, used to account for the impact of porosity on the abrasion resistance. **Corrosion resistance properties of reactive Plasma-sprayed titanium composite coatings** HVOF coatings are two to three times more resistant to abrasion. Modified Evans–Marshall equation is **composite coatings** HVOF coatings are two to three times more resistant to abrasion. Modified Evans–Marshall equation is

T. Valente et al, Reactive plasma spraying (RPS) techniques can be used to create protective coatings or free- standing components in the thermal spraying process. Nitrogen or methane can be used to generate hard nitride or carbide phases in reactive metals like Ti, Cr, or Al by reacting with these metals.

Plasma Spraying Technique for the Deposition Of a-Si/µc-Si.

J. Kopecki et al, Using plasma spraying, thin coatings can be applied at high rates using low- cost precursors. As a result of its electrodeless energy coupling, our microwave plasma source has a major advantage over conventional plasma spraying sources, which use electrodes made of copper or tungsten. Thin films with high purity can be deposited since the precursor is unpolluted and therefore suitable for photoactive coatings like amorphous and microcrystalline silicon (a-Si and cSi).A plasma is used to melt and evaporate the intrinsic silicon powder, resulting in films of between 100 and 1000 nanometers in thickness.

2. PISTON DETAILS

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. Components of Diesel engine, (E) Exhaust camshaft, (C) Crankshaft, (W) Water jacket for coolant flow, (I) Intake camshaft, (S) Fuel Injector, (V) Valves, (P) Piston, (R) Connecting rod, (W) Water jacket for coolant flow.

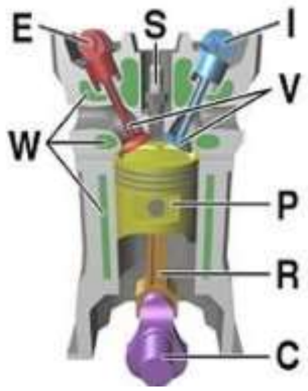


Fig.2.1 Components of Diesel Engine

COATING TECHNIQUE

A coating is a material used to cover anything. Surface qualities can be improved by applying a coating, which is sometimes known as a "substrate." It is possible to enhance the appearance, adhesion, wetting, corrosion resistance, wear resistance, scratch resistance, and other properties of the material. As a liquid, gas or solid, they can be used in many different ways. A Drawdown card can be used to measure and assess the opacity and film thickness of coatings.

THERMAL SPRAY TECHNIQUE

As the metal or non-metallic coating material melts or is semi-molten, it is sprayed onto the substrate surface to form a thin deposited layer known as a thermal spray. Material is heated to a plastic or molten state and then accelerated to produce a thermal spray effect. These particles are distorted by pressure and create a layered sheet as they strike the substrate, where they stick. They build up over time, forming a thick covering

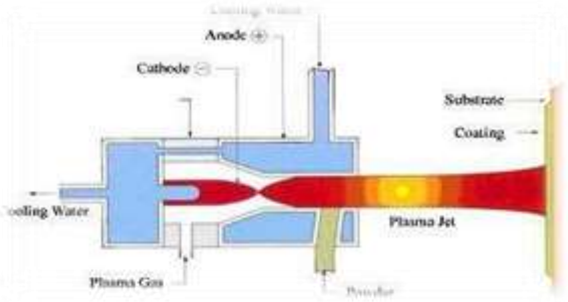


Fig.2.2 Thermal Spray Technique

PLASMA COATING PROCESS

Plasma spray is the most adaptable of all thermal spray techniques because it can reach temperatures high enough to melt or heat virtually any material. Cathode and anode are electrodes in a tiny chamber called a plasma spray cannon (nozzle). Plasma is formed when high-intensity arc breaks down the gas in the chamber, releasing a tremendous amount of heat that can reach temperatures of 6000 °C to 16000 °C. Melting of the coating material occurs when it is rapidly introduced into the gas flame

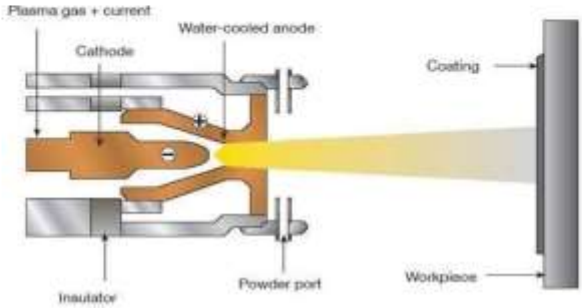


Fig.2.3 Plasma Spraying

3. SOFTWARE OVERVIEW

ANSYS EVALUATION

ANSYS is a complete FEA simulation software package developed by ANSYS Inc – USA. It is used by engineers worldwide in virtually all fields of engineering. Structural, Thermal Fluid, (CFD), Low-and High-Frequency Electromagnetic.

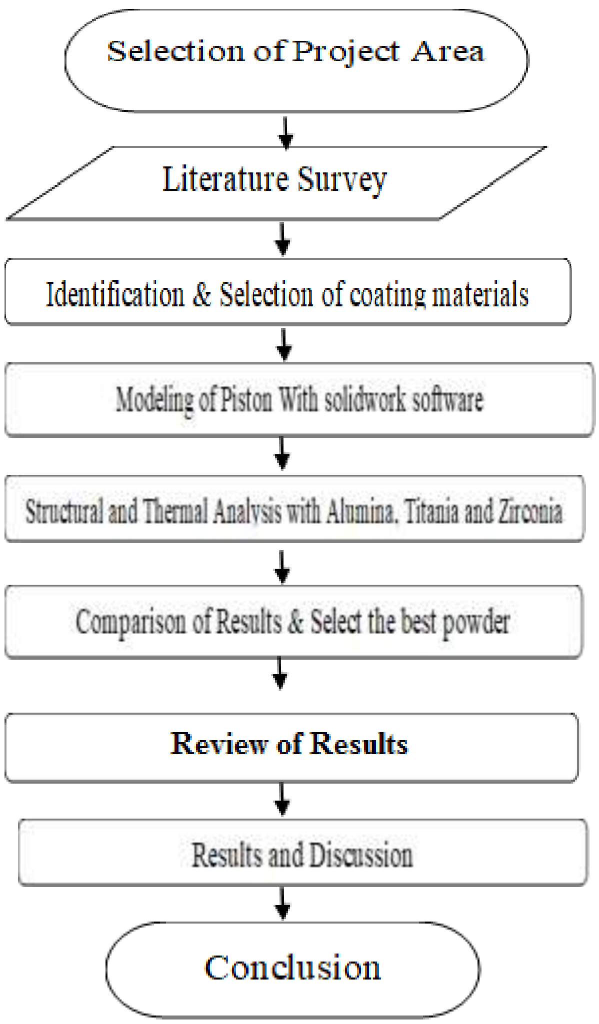
PROCEDURE

Every analysis involves three main steps:

Pre-processor Solver

Post processor

4. METHODOLOGY



5. PROPERTIES OF ALUMINA

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al2O3. It is the most commonly occurring of several aluminium oxides, and specifically identified as aluminium(III) oxide. It is commonly called alumina, and may also be called aloxide, or alundum depending on particular forms or applications. It commonly occurs in its crystalline polymorphic phase α-Al_2O_3, in which it comprises the mineral corundum, varieties of which Form the precious gemstones ruby and sapphire. Al_2O_3 is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point Al_2O_3 is an electrical insulator but has a relatively high thermal conductivity (30 $Wm^{-1}K^{-1}$) for a ceramic material. Aluminium oxide is insoluble in water. In its most commonly occurring crystalline form, called corundum or α-aluminium oxide, its hardness makes it suitable for use as an abrasive and as a component in cutting tools. Aluminium oxide is responsible for the resistance of metallic aluminium to weathering. Metallic aluminium is very reactive with atmospheric oxygen, and a thin passivation layer of aluminium oxide (4 nm thickness) forms on any exposed aluminium surface . his layer protects the metal from further oxidation.The thickness and properties of this oxide layer can be enhanced using a process called anodising. A number of alloys, such as aluminium bronzes, exploit this property by including a proportion of aluminium in the alloy to enhance corrosion resistance. The aluminium oxide generated by anodising is typically amorphous, but discharge assisted oxidation processes such as plasma electrolytic oxidation result in a significant proportion of crystalline aluminium oxide in the coating, enhancing its hardness.

6. PROPERTIES OF TITANIA

Titanium dioxide, also known as titanium (IV) oxide or titania is the naturally occurring oxide of titanium, chemical formula TiO_2. When used as a pigment, it is called titanium white, Pigment White 6 (PW6), or CI 77891. Generally it is sourced from ilmenite, rutile and anatase. It has a wide range of applications, from paint to sunscreen to food colouring. Titanium dioxide occurs in nature as well-known minerals rutile, anatase and brookite, and additionally as two high pressure forms, a monoclinic baddeleyite-like form and an orthorhombic α-PbO_2-like form, both found recently at the Riesc rater in Bavaria. It is mainly sourced from ilmenite ore. This is the most wide spread form of titanium dioxide- bearing ore around the world. Rutile is the next most abundant and contains around 98% titanium dioxide in the ore. The metastable anatase and brookite phases convert irreversibly to the equilibrium rutile phase upon heating above temperatures in the range 600°800 °C. Titanium dioxide has eight modifications – in addition to rutile, anatase, and brookite, three metastable phases can be produced synthetically (monoclinic, tetragonal and orthorombic), and five high-pressure forms (α-PbO_2-like, baddeleyitelike, cotunnite- like, orthorhombic OI, and cubic phases)

7. PROPERTIES OF ALUMINUM ALLOY

Aluminum alloy is a type of metal alloy made by mixing aluminum with one or more other metals or non-metals, such as copper, magnesium, zinc, silicon, or manganese. These alloys are used in a variety of industries, including aerospace, automotive, construction, and electronics, due to their high strength-to-weight ratio, corrosion resistance, and other desirable properties. Aluminum alloys are classified based on their composition, with each type having different properties and applications. For example, 2024 aluminum alloy is commonly used in aircraft structural components due to its high strength and fatigue resistance, while 6061 aluminum alloy is often used in bicycle frames and other consumer products due to its good strength and weldability. Overall, aluminum alloys have become an increasingly important material due to their lightweight and versatile nature, making them a popular choice in many modern applications.

ZIRCONIA

Zirconia can be found in three crystal structure. These are monolithic (m), tetragonal (t) and cubic (c) structures. Monolithic structure is stable between room temperature and 1170 0C while it turns to tetragonal structure above 1170 0C. Tetragonal structure is stable up to 2379 0C and above this temperature, the structure turns to cubic structure. Zirconia (ZrO_2) is a ceramic material with adequate mechanical properties for manufacturing of medical devices. Zirconia stabilized with Y_2O_3 has the best properties for these applications. When a stress occurs on a ZrO_2

surface, a crystalline modification opposes the propagation of cracks. Compression resistance of ZrO_2 is about 2000 MPa. Zirconia is a crystalline dioxide of zirconium. Its mechanical properties are very similar to those of metals and its color is similar to tooth color.

Background

The fundamental properties of zirconia ceramics which are of interest to the engineer or designer

Are:

- High strength,
- High fracture toughness,
- High hardness,
- Wear resistance,
- Good frictional behaviour,
- Non-magnetic,
- Electrical insulation,
- Low thermal conductivity,
- Corrosion resistance in acids and alkalis,
- Modulus of elasticity similar to steel,
- Coefficient of thermal expansion similar to iron.

Types of Zirconias

There are many different types of zirconias. These have evolved as researchers and manufacturers sought to exploit the different properties of the various phases. Some of the phases are stable at high temperatures and need to be "frozen" in such that they can be used at room temperatures, while others exploit toughening mechanisms that are only found in these and few other materials. Some of these materials are listed below along with their typical abbreviations.

- Tetragonal Zirconia Polycrystals TZP
- Partially Stabilised Zirconia PSZ
- Fully Stabilised Zirconia FSZ
- Transformation Toughened Ceramics TTC
- Zirconia Toughened Alumina ZTA
- Transformation Toughened Zirconia TTZ

Materials (oxides) added to stabilise or toughen the zirconia will also be noted as a prefix to the abbreviations listed in table 1. They will sometimes be used in conjunction with numbers which indicate the amount of the stabilising agent added. Typical examples include Y, Ce, Mg and A which correspond to yttria (Y_2O_3), ceria (CeO_2), magnesia (MgO) and alumina (Al_2O_3) respectively. So a material denoted as 3Y- TZP would tetragonal zirconia polycrystal with an addition of 3mol% Y_2O_3 as a stabiliser.

Property Comparison

Lists properties for various grades of zirconia and has been compiled from a variety of sources. However, as with most ceramic materials properties are dependent on many factors such as starting powders and fabrication techniques. Most ceramic fabrication techniques have been applied to zirconias such as dry pressing, isostatic pressing, injection moulding, extrusion and tape casting. Addition of impurities during processing may also introduce flaws and degrade properties.

8. CONCLUSION

The FEA and comparison investigation of an aluminium alloy piston coated with alumina, titania, and zirconia using ANSYS revealed the benefits and drawbacks of each coating material. According to the results, alumina coatings are best for high- performance engines because they are thermally stable and resist wear. Titania coating is resistant to high temperatures and wear, but it cracks more easily than other coatings when subjected to extreme pressure. When compared to alumina and titania coatings, zirconia has poorer wear resistance but better heat insulation and lower friction characteristics.

Maximum surface stress and deformation are both reduced with any of the three coatings relative to an uncoated piston. This suggests that the coatings have the potential to increase the piston's durability and service life. The results of the study indicate that the coating material used on an aluminium alloy piston must be tailored to the needs of the individual application and the working environment. The choice of coating should be based on a compromise between wear resistance, thermal stability, and other criteria including cost and availability.

By comparing all the findings from the study, the ceramic coating of Zirconia delivers the greatest performance than other two coatings. It can endure the temperature of 808oc than other two coatings. The total heat flux travel rate per unit area is significantly smaller in Zirconia coating, which leads to the insulation of thermal than Alumina and Titania. To conclude, Zirconia is the ideal ceramic coating for the application of piston.

9. REFRENCE

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