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fea analysis and experimental investigation of ceramic coating on aluminium piston material by plasma spray coating

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ABSTRACT
In this study,the surface of a piston in an engine is coated with multi layer coating powder using the plasma-spraying approach and the surface behaviour of the piston is then examined. The goal of this research is to analyze the mechanical and thermal impacts of a piston in a frictional mechanism. Microstructure, hardness, and corrosion tests had been carried out on each coated and uncoated specimens. according to the findings of the tests and Ansys, the coated specimen has better qualities in terms of diesel engine performance. when as compared to an uncoated piston, the multilayer coated piston shows less distortion and fewer scratches because of wear.

The experiment also objectives to compare the mechanical, thermal, and wear resistance of the piston with a multi layer coating formed on an aluminium substrate using a plasma spray process. Optical microscopy is used to examine the topography and structure of plasma spray coatings. The hardness test is used to evaluate the adherence of coatings to the substrate and to compare the thermal barrier qualities. In comparison to the Alumina - Titania coating placed onto the heat treated hot work Aluminium, the multi layer coating applied onto the Aluminium demonstrated a very good adherence to the substrate material. Using the results of the testing, it can be concluded that the multi layer coating put upon plasma spray coating has the lowest wear and heat resistance under specified situations at both room and increased temperatures.

KEYWORD- Plasma Spray Coating, Wear Resistence, Structure,Adhesion.

I. INTRODUCTION

The piston absorbs the majority of the heat generated during the combustion process in Internal Combustion Engines. This is the piston's direct heat loss. This lowers

the indicated power and, as a result, the Internal Combustion Engine's performance. In diesel engines, an engine coating with a ceramic thermal barrier can be used to increase dependability and durability of performance and efficiency. About 30% of the total energy in a standard diesel engine is lost to the coolant, and it has been suggested that an engine coating could be a useful solution. Some of the key benefits of the engine coating concept were improved fuel economy, reduced hydrocarbon, smoke, and carbon monoxide emissions, and reduced noise due to a lower rate of pressure increase and high energy in exhaust gases. Plasma spraying is commonly used to apply thermal barrier coatings to the cylinder head, piston, and valves. Wear, friction, heating, corrosion, and oxidation are all reduced when these parts are coated with ceramic. In a theoretical diesel cycle analysis, it was also discovered that as the heat transfer diminishes, the efficiency of the engine declines. Plasma spraying is commonly used to apply thermal barrier coatings to the cylinder head, piston, and valves. Wear, friction, heating, corrosion, and oxidation are all reduced when these parts are coated with ceramic. a theoretical diesel cycle analysis, it was also discovered that the lower the heat transfer, the less energy is lost, resulting in increased work output and thermal efficiency. In another study, engine coating was found to result in increased engine power and lower specific fuel consumption, as well as considerable reductions in exhaust gas emissions and smoke density when compared to an uncoated engine. The required temperature in the combustion chamber will be maintained due to the coated piston. This will lessen the piston's heat loss. This decrease in heat loss will be used to burn the unburned gases, resulting in fewer polluting exhaust gases.

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Because of their exceptional qualities such as corrosion, erosion, and oxidation resistance, high hardness, and chemical and thermal stability at cryogenic and high temperatures, functionally graded materials are gaining popularity.Thermal Barrier Coating (TBC) on metallic substrates used at high temperatures in the domains of aircraft and aerospace, especially for thermal protection of components in gas turbines and diesel engines, is one of their many applications. In order to imitate adiabatic changes, thermal barrier coatings have been successfully applied to internal combustion engines, particularly the combustion chamber. The goals are not just to reduce in-cylinder heat rejection and preserve underlying metallic surfaces from thermal fatigue, but also to reduce engine emissions and brake specific fuel consumption.The use of TBC lowers heat loss to the engine cooling jacket by reducing heat transmission through surfaces such as the cylinder head, liner, piston crown, and piston rings.The use of ceramic coating to insulate the combustion chamber improves the combustion process and, as a result, the engine's performance and emissions characteristics. On the other hand, the aim to improve thermal efficiency or reduce fuel consumption of engines has resulted in the adoption of higher compression ratios, particularly for diesel engines, as well as lower in-cylinder heat rejection. Both of these characteristics result in increased mechanical and thermal stresses in combustion chamber materials. TBC on these components' surfaces improves high-temperature endurance by decreasing heat transmission and lowering the temperature of the underlying metal. Spalling of the ceramic top coat from the bond coat is a common TBCs failure. Many factors influence the overall performance of coatings and contribute to coating spalling. However, oxidation and thermal mismatch are two important issues that influence the coating system's longevity. The coatings are permeable to ambient gases and liquids, causing the bond coat to oxidise and the coating to spall. To lessen the mismatch effect, functionally graded coatings were utilised.As a result, thermal expansion and interfacial strains can be used as an alternative to traditional thermal barrier coatings.

Engineers working on internal combustion engines have always strived for energy saving and efficiency. The fuel economy of a diesel engine is generally better than that of a petrol engine. Even the diesel engine rejects over two-thirds of the fuel's thermal energy, one-third to the coolant, and one-third to the exhaust, leaving only approximately one-third as useful power production.The thermal efficiency might theoretically be enhanced if the heat rejected could be minimised, at least up to the limit established by the second law of thermodynamics. Low Heat Rejection engines try to achieve this by reducing the amount of heat that escapes into the coolant. The investigation of thermal behaviour of functionally graded coatings generated using a commercial code, ANSYS, on aluminium and steel piston surfaces is the focus of this paper, and the results are supported by numerical and experimental testing.

II. METHOD

A) PISTON

A piston can be found in reciprocating engines, reciprocating pumps, gas compressors, and pneumatic cylinders, among other things. It's the moving part that's confined by a cylinder and sealed shut by piston rings. The purpose of a piston rod and/or connecting rod in an engine is to transfer force from expanding gas in the cylinder to the crankshaft. The function is reversed in a pump, with force transferred from the crankshaft to the piston to compress or discharge the fluid in the cylinder. The piston can also operate as a valve in some engines by covering and uncovering openings in the cylinder wall. The petrol enters the cylinder, the piston travels upwards, the spark plug produces a spark, the petrol catches fire, and the energy produced drives the piston downwards.

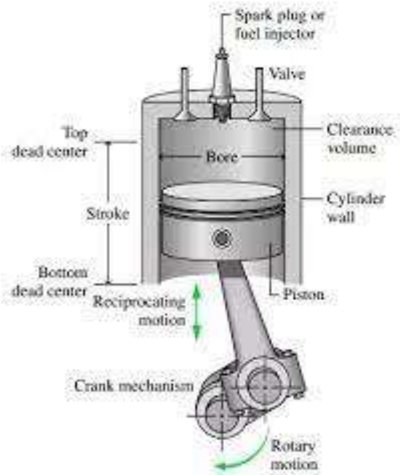

Fig1: Piston Assembly

B) COATING:

A coating is a thin layer of paint or varnish applied to an object. Coatings are used to improve the surface qualities of a bulk material, commonly referred to as a substrate. The appearance, adhesion, wetability, corrosion resistance, wear resistance, scratch resistance, and other properties can all be improved. They can take the form of liquids, gases, or solids. A Drawdown card can be used to quantify and evaluate coatings for correct opacity and film thickness.

C) THERMAL SPRAYING TECHNIQUE:

Thermal spraying techniques are coating methods that include spraying melted (or heated) materials onto a surface. Electrical (plasma or arc) or chemical techniques are used to heat the "feedstock" (coating precursor) (combustion flame).When compared to other coating methods such as electroplating, physical, and chemical vapour deposition, thermal spraying can create thick coatings over a large surface at a high rate of deposition . Metals, alloys, ceramics, polymers, and composites are among the coating materials accessible for thermal spraying.

They are fed in powder or wire, heated to a molten or semi-molten state, and accelerated as micrometer-sized particles towards substrates. Thermal spraying often uses combustion or electrical arc discharge as a source of energy. The aggregation of many sprayed particles results in coating formation. The surface may not heat up much, allowing combustible compounds to be coated.

The porosity, oxide content, macro and micro-hardness, bond strength, and surface roughness of a coating are routinely measured to determine its quality. In general, as particle velocities increase, the coating quality improves.

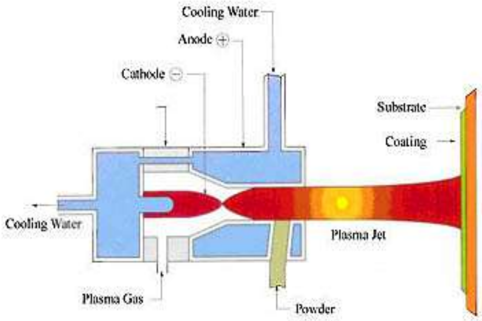

Fig2: Thermal Spray Technique

D) PLASMA COATING

In order to form a coating, the Plasma Spray Process requires spraying molten or heat softened material onto a surface. Powdered material is fed into a plasma flame with a very high temperature, where it is rapidly heated and propelled to a high velocity. The heated material collides with the substrate and cools quickly, forming a coating. This plasma spray technique is referred to as a "cold process" (relative to the substrate material being coated) because the substrate temperature may be kept low during processing, preventing damage, metallurgical changes, and deformation. A copper anode and tungsten cathode, both water cooled, are used in the plasma spray cannon.

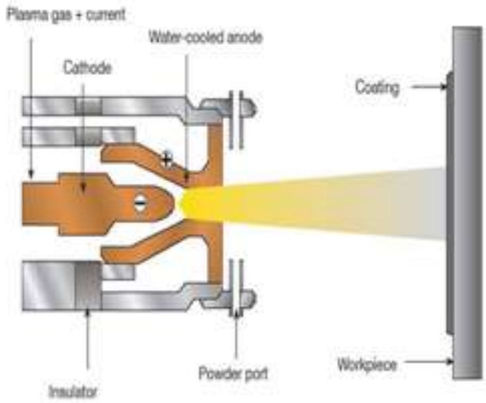

Fig3: Plasma Spraying

Plasma gas (argon, nitrogen, hydrogen, helium) travels around the cathode and through the constricting nozzle-shaped anode. A high-voltage discharge causes localised ionisation and creates a conductive channel for a DC arc to form between the cathode and anode, which initiates the plasma.. Due to the arc's resistance heating, the gas reaches extreme temperatures, dissociates, and ionises, forming plasma. The plasma leaves the anode nozzle as a free or neutral plasma flame, as opposed to the Plasma Transferred Arc coating process, where the arc extends to the surface to be coated (plasma that does not carry electric current). Instead of shorting out to the anode nozzle's nearest edge when the plasma is stabilised for spraying, the electric arc extends down the nozzle. The arc is stretching due to a thermal squeeze effect. Because the cold gas around the water-cooled anode nozzle is electrically non-conductive, it constricts the plasma arc, increasing its temperature and velocity. The most frequent method of feeding powder into the plasma flame is through an external powder port located near the anode nozzle exit. Spray distances of 25 to 150 mm are possible since the powder is heated and propelled so quickly. The plasma spray method, often known as APS, is most commonly employed in normal atmospheric circumstances. Some plasma spraying is done in a safe setting with vacuum chambers that are generally back filled with a gas.VPS or LPPS refers to a protective gas at low pressure. Unlike combustion methods, plasma spraying has the benefit of being able to spray materials with very high melting points, such as refractory metals like tungsten and ceramics like zirconia.

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E) PLASMA SPRAYING PARAMETER
SUBSTRATE ALUMINIUM SPEIMEN
COATING MATERIAL: CERAMIC POWDER (Zirconia)
Parameter: Plasma Spraying

Parameter	Range
Torch input power	10-18 Kw
Plasma gas(Ar) flow Rate	100–200 ± 5% (1/min)
Secondary gas(N2) flow rate	100 ± 5% (1/min)
Powder feed rate	40-50 g/min
Powder carrier gas flow rate	Up to 450 (m/s)
Torch to base Distance	76.2 - 127 ± 10 mm
Anode nozzle Diameter	8 mm
Arc current	250-450 amperes
Powder injection	Radial injectionthrough nozzle (near the exit)
Plasma gas injection	Vortex injection

Table-1 Plasma Spraying Parameter

F) COATING MATERIAL
Titania
Alumina
Zirconia

III. DESIGN AND ANALYSIS

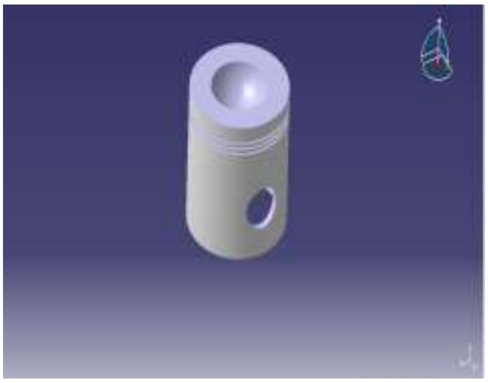

Fig4: Piston model in ansys

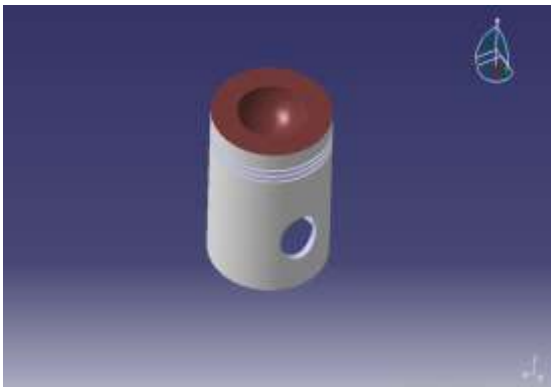

Fig5: Piston coating

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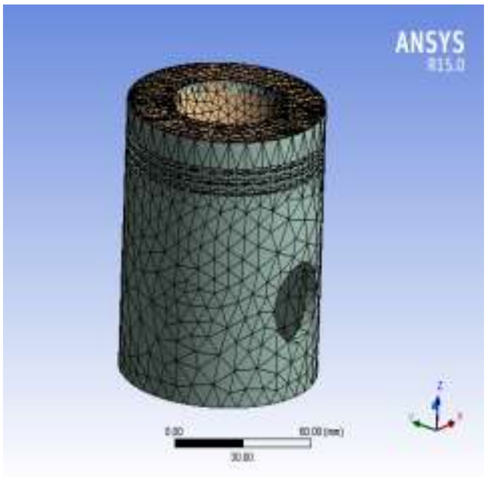

Fig6: Piston coating meshing

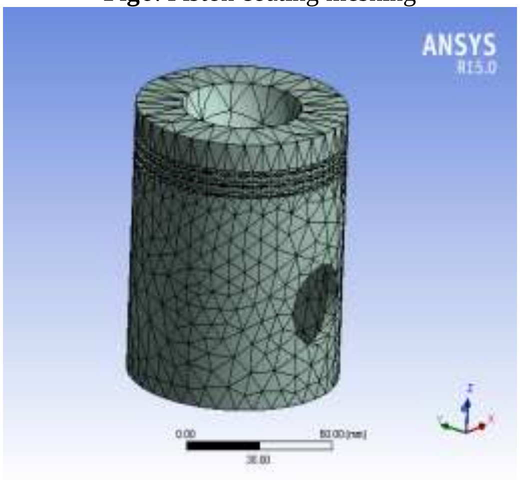

Fig7: Piston meshing

UNCOATED

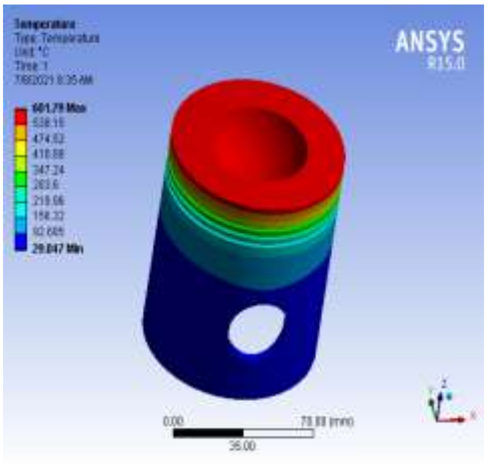

Fig8: Temperature (uncoated)

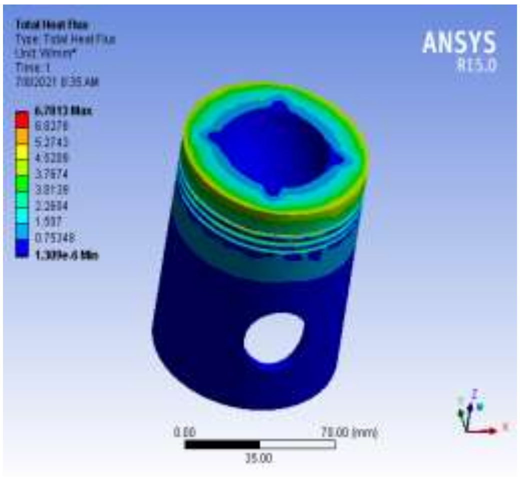

Fig9: Total heat flux (uncoated)

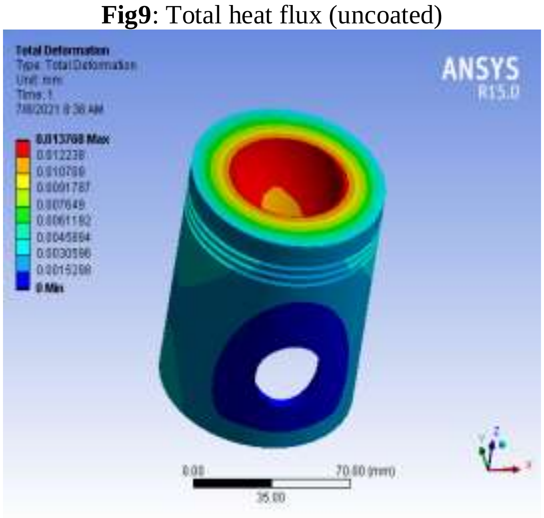

Fig10: Total deformation (uncoated)

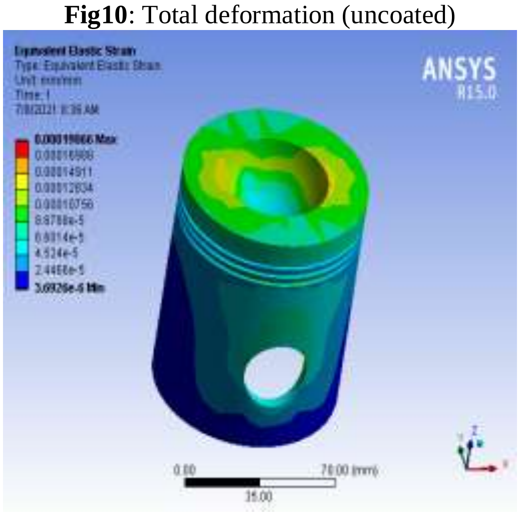

Fig11: Equivalent elastic strain (uncoated)

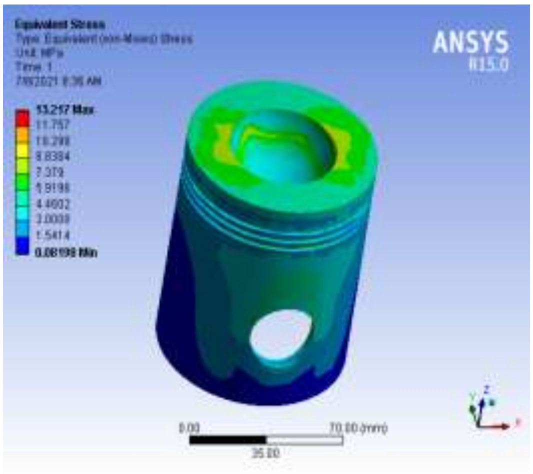

Fig12: Equivalent stress (uncoated)

Alumina

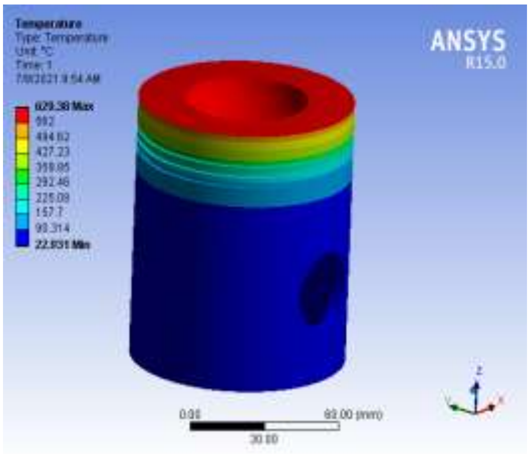

Fig13: Temperature (Alumina)

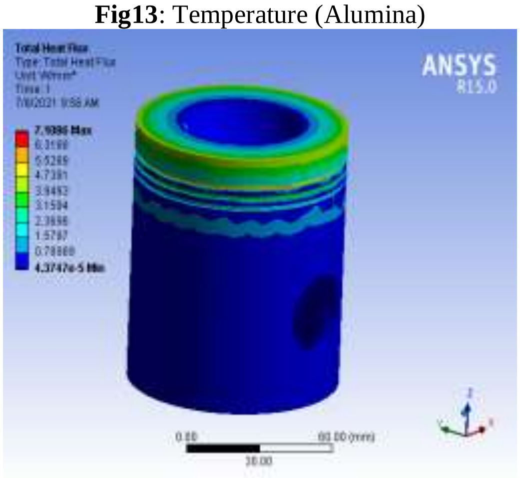

Fig14: Total heat flux (Alumina)

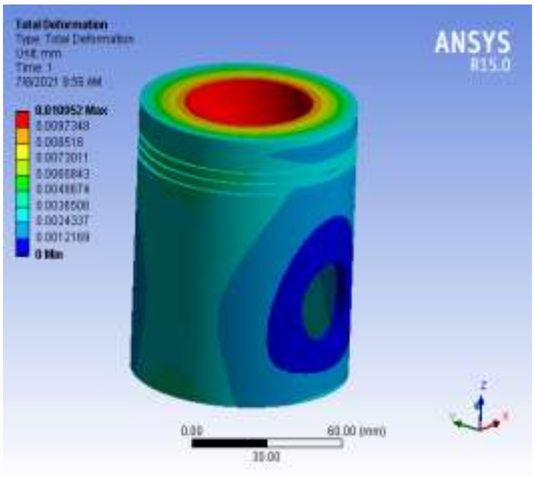

Fig15: Total deformation (Alumina)

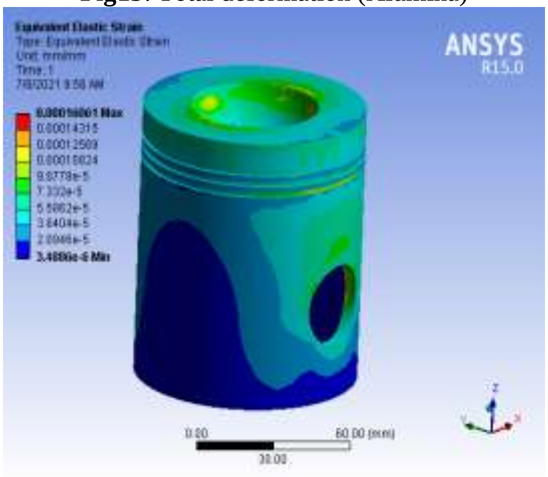

Fig16: Equivalent elastic strain (Alumina)

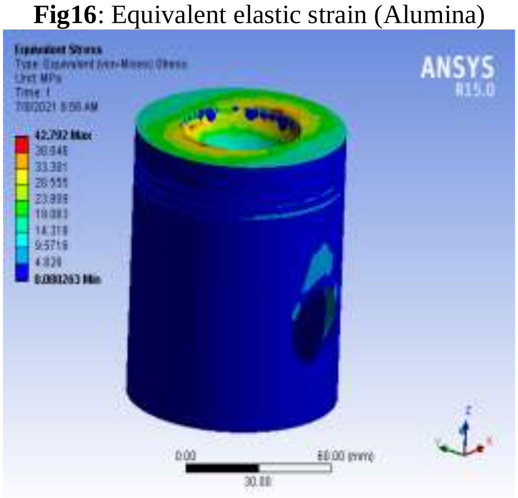

Fig17: Equivalent stress (Alumina)

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Titanium

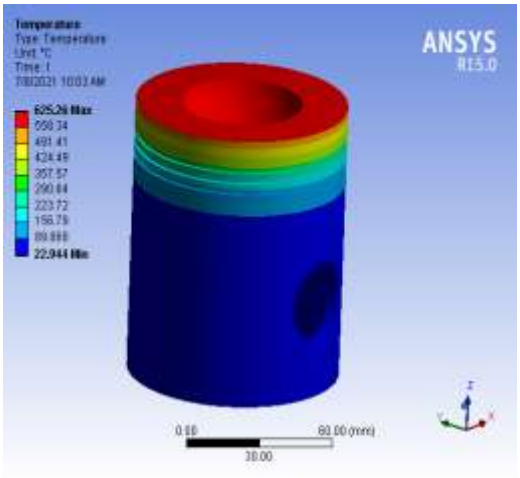

Fig18: Temperature (Titanium)

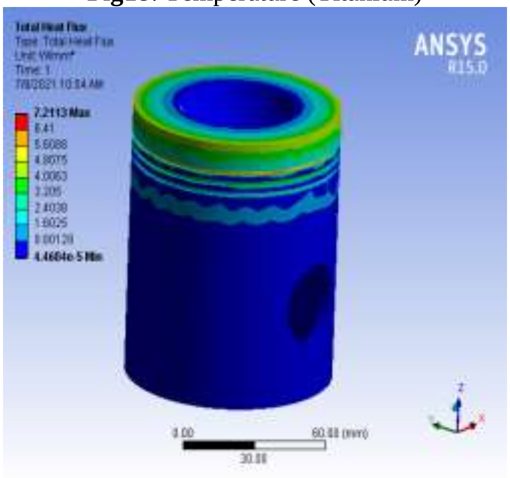

Fig19: Total heat flux (Titanium)

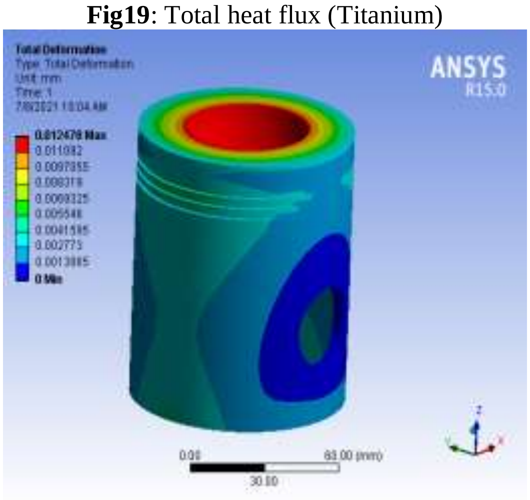

Fig20: Total deformation (Titanium)

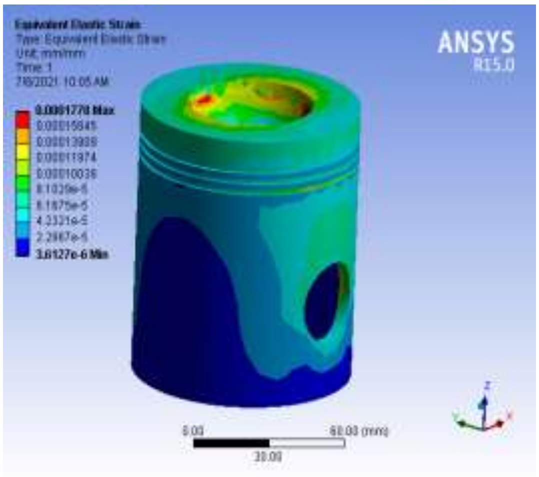

Fig21: Equivalent elastic strain (Titanium)

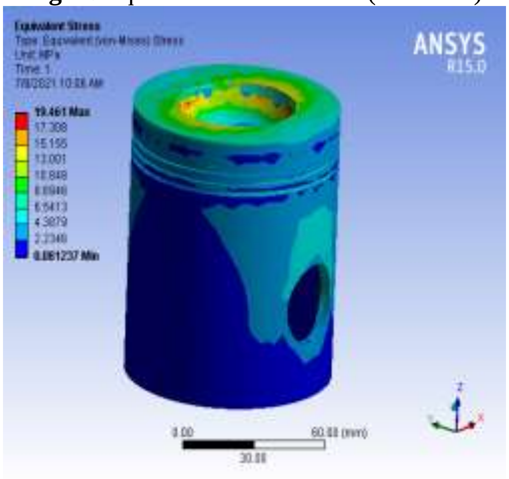

Fig22: Equivalent stress (Titanium)

Zirconia

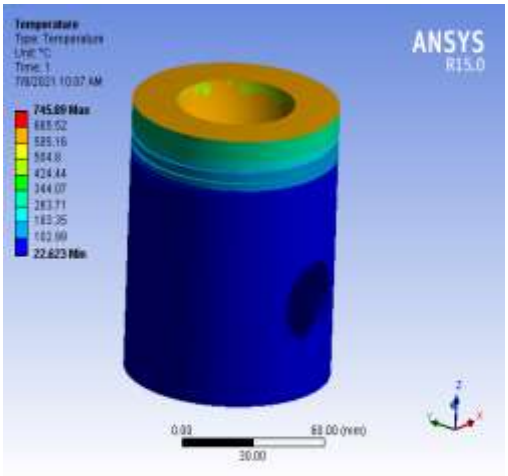

Fig23: Temperature (Zirconia)

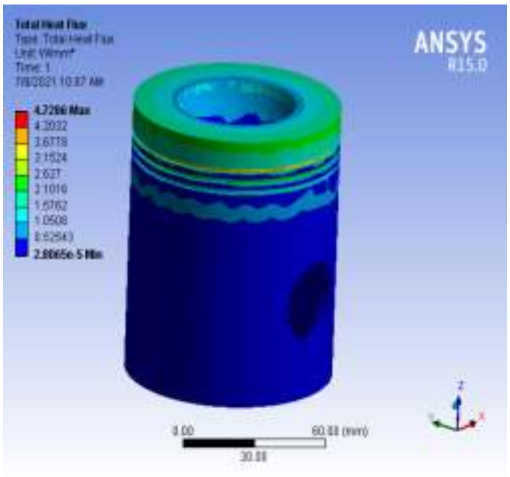

Fig24: Total heat flux (Zirconia)

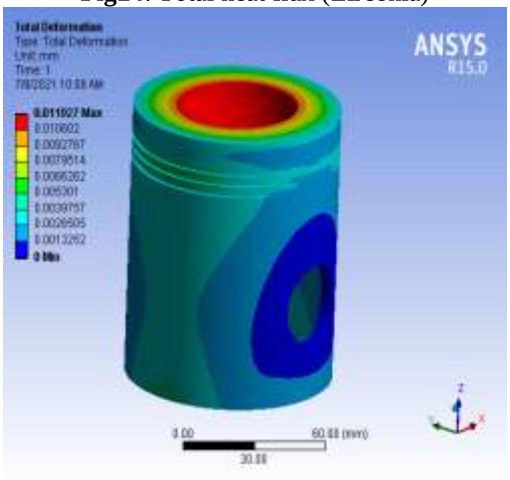

Fig25: Total deformation (Zirconia)

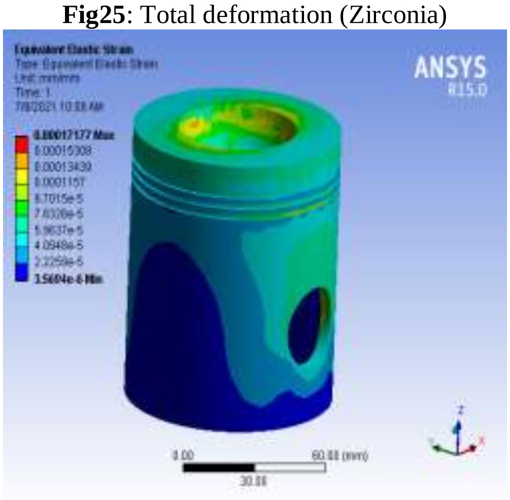

Fig26: Equivalent elastic strain (Zirconia)

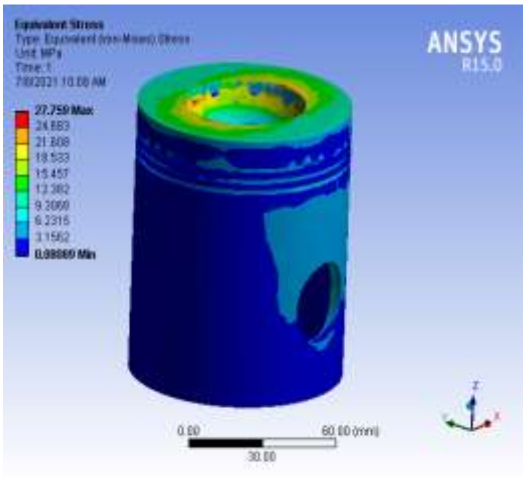

Fig27: Equivalent stress (Zirconia)

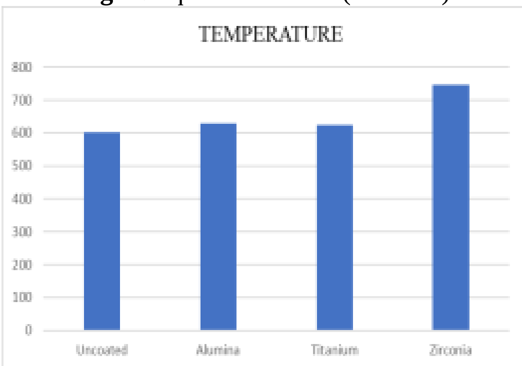

Fig28: Temperature graph

Uncoated	601.79
Alumina	629.38
Titanium	625.26
Zirconia	745.89

Table-2: Temperature table

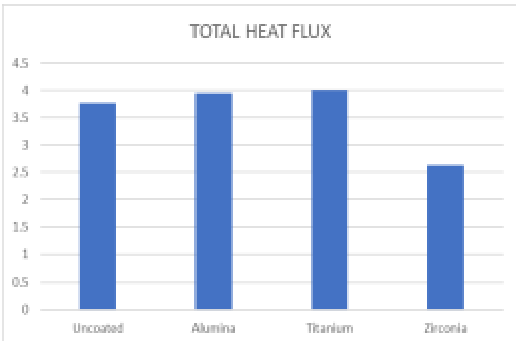

Fig29: Total heat flux graph

Uncoated	3.7674
Alumina	3.9493
Titanium	4.0063

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Zirconia	2.627

Table-3: Total heat flux table

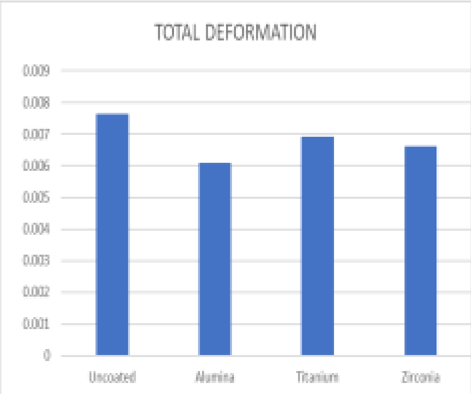

Fig30: Total deformation

Uncoated	0.007649
Alumina	0.0060843
Titanium	0.0069325
Zirconia	0.0066262

Table-4: Total deformation table

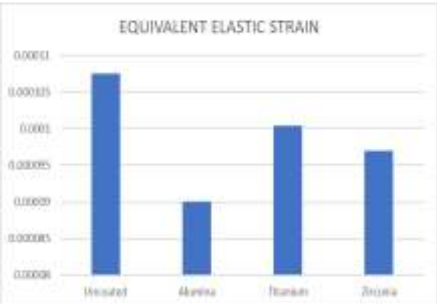

Fig31: Equivalent elastic strain

Uncoated	0.00010756
Alumina	9.01E-05
Titanium	0.00010038
Zirconia	9.70E-05

Table-5: Equivalent elastic strain table

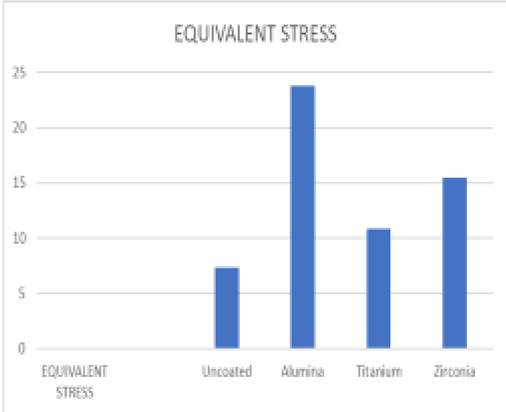

Fig32: Equivalent stress

Uncoated	7.379
Alumina	2.38E+01
Titanium	10.848
Zirconia	1.55E+01

Table-6: Equivalent stress

1) MICRO-STRUCTURE IMAGES
A) UN-COATED

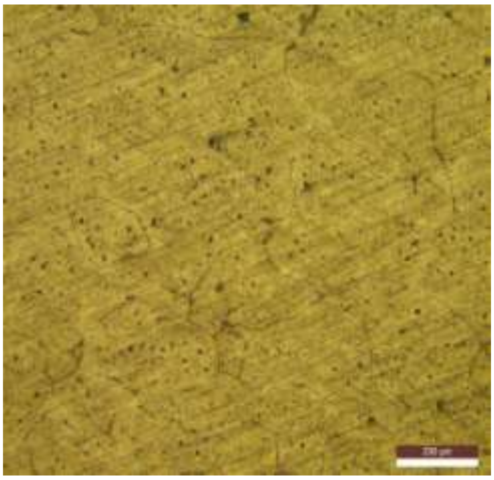

Fig33: micro-structure-1 uncoated

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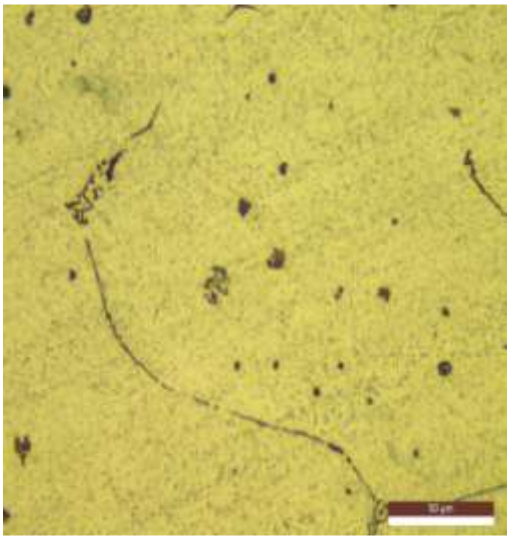

Fig34: micro-structure uncoated-2

COATED

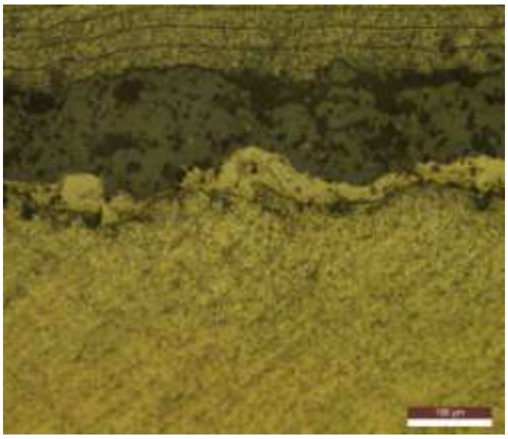

Fig35: micro-structure-1 coated

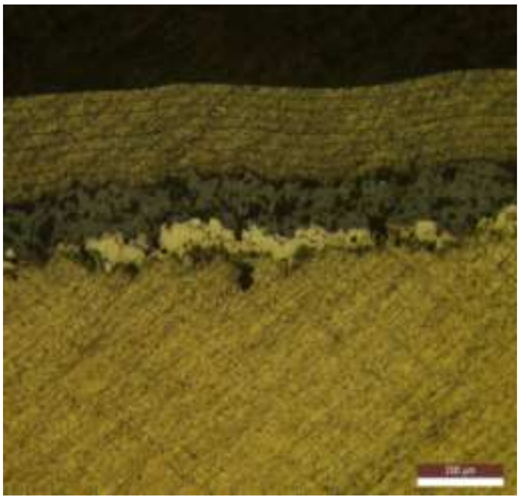

Fig36: micro-structure-2 coated

CORROSSION – RESULTS
SALT SPRAY TEST

Chamber temperature : 34.5 – 35.5
pH Value : 6.65 – 6.85
Vol ume of salt solution collected : 1.00-1.50 ml/hr
Concentration of solution : 4.80-5.30% of NACL
Air pressure : 14-18 Psi
Components loading in the chamber position : 30 Degree Angle

Aluminium Alloy Specimen without coated	**Aluminium ALLOY specimens with coated**
White- rust formation	No white rust

BRINELL HARDNESS

Aluminium Alloy Specimen without coated	**Aluminium Alloy specimens with coated**
41.4	45.8

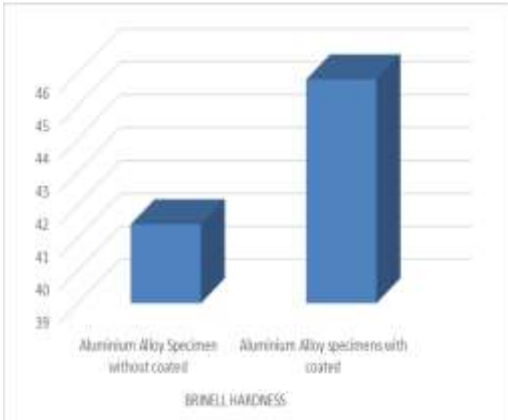

Fig37: Brinell hardness result

IV. CONCLUSION

The coating of piston materials such as aluminium specimens by thermal spray coatings was explored based on the findings of the obtained analysis and experimental work. The surface morphologies of the major and minor faces differed significantly. The mechanical and thermal characterisation of aluminium materials will improve as a result of the coating. Hardness, structural grains, and thermal characteristics will all improve as a result of this. In engine component applications where failure mechanisms caused by high temperatures and chemical diffusion are significant, Zirconia coatings exhibited the most dramatic advantages over other coatings and uncoated components. The coating will still operate better at lower temperatures (lower speeds, discontinuous contact) due to the effects of crystallite refinement, which create a smoother surface and second phase fracture arresting or deflection mechanisms, which make the coating stronger. The hardness of aluminium materials coated with zirconia was enhanced, resulting in a lower wear rate throughout the combustion process. The corrosion resistance was also improved thanks to the zirconia coating.

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