FEA ANALYSIS OF CERAMIC COATED ALUMINIUM PISTON BY ANSYS

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Abstract: *In this study, the surface of piston in the engine is coated with different ceramic powders like chrome -oxide, Alumina, Titania, and Zirconia, Chromium Carbide, Tungsten Carbide by using Plasma-Spray technology, and their surface behaviour is analyzed subsequently. The main objective of this project is to explore tribological characteristics of surface coated piston in friction. In this, with or without coating piston is modeled and undergone analysis by using ANSYS. From the result, we found that coated specimens having improved mechanical and thermal properties in the diesel engine performance. The resultant shows structural and thermal distribution of coated and uncoated piston.*

Key words: **Ceramic Coating, Plasma Spray Technique, Wear resistance, Piston**

1. INTRODUCTION

Due to superior properties like hardness, chemical, corrosion resistance, thermal stability etc., Functionally Graded Materials are shown wide interest. 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 aero spacing, especially for thermal protection for components in gas turbines and diesel engines.

For Internal Combustion (IC) engine coatings is achieved by Thermal Barrier Coating (TBC), in which adiabatic changes is simulated for combustion chamber. 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 emission and brake specific fuel consumption. TBC application is to reduce heat loss to cooling jacket through surface which get exposed to heat. The insulation of the combustion chamber with ceramic coating affects the characteristics of engine improves. On other side, desire of increasing the thermal efficiency of reduce fuel consumption of engines lead to the adoption of higher compression ratios, in particular for diesel engines and recued in cylinder heat rejection. Mechanical and Thermal stresses of material is increased by both of these factors which is used in Combustion Chamber (CC).

Application of TBC to surface of these components enhance high temperature durability by reducing the heat transfer and lowering temperature of underlying metals. Typical TBC's failure is by spalling of the ceramic top coat from the bond coat. Overall performance and spalling of the coating were influenced by many factors. Life of coating system is influenced by two major factors known as oxidation and thermal mismatch. For atmospheric gases and liquid coating is permeable and which results to oxidation of bind coat and spalling. Therefore, for Conventional Thermal Barrier Coating alternative approaches are Thermal expansion and interfacial stresses.

In Internal Combustion engine, energy conservation and its energy efficiency are always a search to engineer's concern. Better Fuel Economy is generally obtained in diesel engine than counterpart of its petrol engine. Two-Third of heat energy of fuel are rejected by diesel engine, in which Coolant takes One-third, Exhaust takes One-third and One-Third as useful power output. In theoretical, if the heat rejected is reduced, then the tergal efficiency would be improved, at least up to the limit set by second law of thermodynamics. Low heat rejection aims by reducing heat loss to the coolant.

TBC in diesel engine leads to higher power density, fuel efficiency, multifuel capacity due to higher combustion chamber temperature and can increase engine power by 8% in decrease of specific fuel consumption by 20% and increases the exhaust gas temperature of 200k. Diesel engine with insulated combustion chamber with ceramic is referred as low heat rejection engine, which has improved fuel economy by eliminating the conventional cooling system and converting a part of increased exhaust energy into shaft work by using turbocharger system.

Number of studies were carried out in LHR engine based on performance, structure and durability. Kamo.R and Bryzik.K proposed a new concept of LHR engine 041 in combination with turbo component system, which leads to mixed investigation results, in which mostly concludes with insulation part reduces heat transfer rate in increases of thermal efficiency and energy availability in the exhaust. Most commonly used method in TBC (ceramic coating) is plasma spray technology for diesel applications which creates a splat structure with 10-20% of volume fraction voids and cracks, they make it an ideal choice for TBC due to high porosity structure. TBC's for diesel engine have generally been accepted to improve thermal efficiency and reduction in emission as well as special fuel consumption because of their ability to provide thermal insulation to component of engine. In general, we know the principle that in energy conversion system, increased operation temperature leads to increases in efficiency, fuel savings and reduction in emission of particles such as CO, HC and reduction of NOx emission.

2. LITERATURE SURVEY

For providing the best result in ceramic coating, a lot of technical and journals papers were studied. The following paper presents the grids which are referred during the project.

(1) A.Skopp et al., discussed that extended surface analysis shows the tribological induced of Magneli Ti_nO_{2n-1} type phase oxides which were tribological effects under dry friction up to high temperatures to reduce wear resistance. The friction coefficient still remains unchanged on a known level from SiC and Si_3N_4 ceramics. The ceramic composition of SiC-TiC, Si_3N_4 – TiN and TiMo,C,N + Ni tribo-chemiacl dominates mechanism which determines low wear rate under dry friction condition. Investing on wear tracks in low wear region exhibits occurrences of crystalline Magneli phases as well as some double oxides in it. These soft oxides phases with MeO_6 co-ordinates are mainly effective to reduces wear. TEM followed by small -spot XRD are the most appropriate analysis techniques to detect tribological oxidative formed crystalline Magneli type phases with planar defects.

(2) O.Maranho et al., discussed that high quality deposit of coating is possible by HVOF thermal spraying for multicomponent white cast iron alloy. In this coating is been prepared with low porosity and with excellent hardness which influences the spray parameters in coating quality. Particle size range, Spray distance and oxygen to propane ratio were critical in determine of coating properties. For set parameters utilized in this, a narrow particle size ranges of 20 and 45μm with spray distance of 200 mm and oxygen to the propane ratio of 4.6 are preferred as coating parameters in the analysis.

(3) V.A.D Souza et al., were discussed that WC-Co-Cr thermal spray coasting provides a good protection against wear and corrosion in liquid solid state when compared with stainless steels and benefits that offered are dependent. Corrosion and synergy were much important in this coating than the super stainless steel. Corrosion of small hard phase Particles can accelerate material loss under erosion and corrosion and synergy effect is one of the important features in it. Because of this play it's an important part of total damage and improves overall performance of erosion – corrosion in enhancing the behaviour of corrosion.

(4) M.H Staia et al., summarized Processing condition during reactive plasma spraying has an importance in coating microstructure, porosity and relative volume fractions of NiCr, Cr_2C_3 and in carbo-nitride phases. Coating deposited with higher pressure shows a clear record that areas of carbon enrichment within the carbide plus carbon-nitrade phases, has a highly ordered graphite structure and is determined by Raman Spectroscopy. Highest microhardness value was recorded for carbide phases contained in specimens which is produced at 1200m bar, which is sprayed at distance of 120mm and at substrate heating of 600^0C.

(5) J.Kopecki et al., were concluded plasma torch with microwave has the advantage of an electrodeless energy coupling which enables to produce thin films of PECVD like coatings by utilizing the plasma spray technique. Emission of silicon is processed by measuring their atomic emission lines of silicon in plasma and also gas temperature is determined for it. Several coatings of plasma were induced in rate sof 100-1000 nm/min and improves quality of coating with respect to photovoltaic properties.

3. PISTON

A Piston is a component being a part of reciprocating pumps, gas compressors and pneumatic cylinder, among alternative similar mechanisms. It's the moving component that's created gas-tight by piston rings. Its main purpose is to transfer force within the cylinder from gases that gets expands to the crankshaft. In a pump, the operation is reserved and force is transferred from the shaft to the piston for the focus of compressing or ejecting the fluid within the cylinder. In some engines the piston conjointly acts as a valve by covering and uncovering the ports of cylinder.

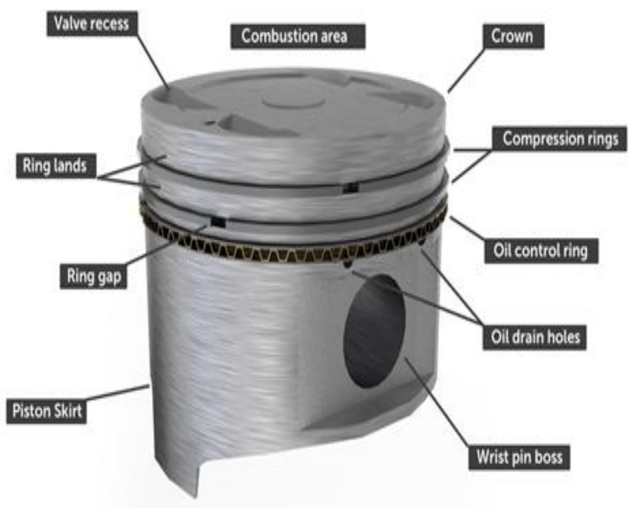


Fig.1 Piston Head Assembly

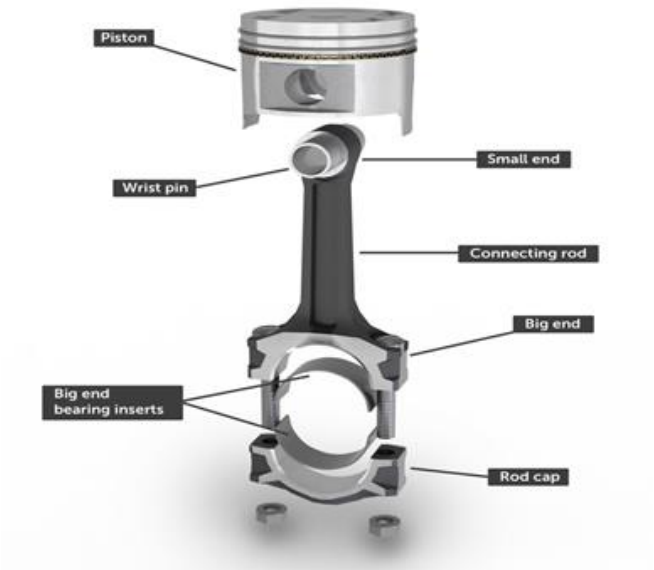


Fig.2 Piston

4. DIESEL ENGINE

Diesel engine is additionally called a compression – ignition or CI engine, is an internal combustion engine during which ignition of the fuel is caused by the elevated temperature of the air within the cylinder because of the mechanical compression. This contrasts with spark-ignition engines like a petrol engine or gas engine that use a spark plug to ignite an air-fuel mixture which enters into the cylinder through inlet valve.

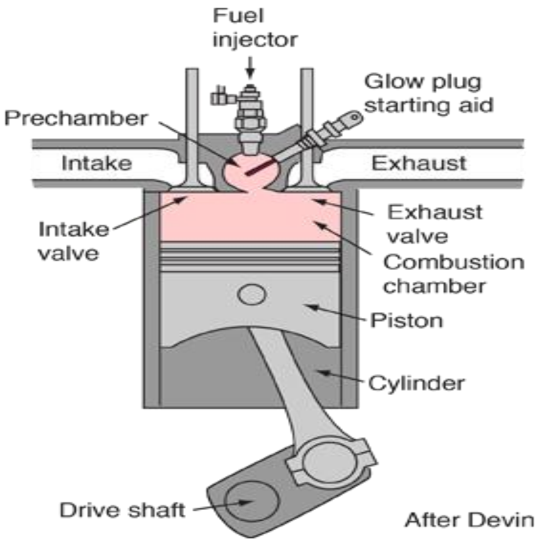


Fig.3 Diesel Engine

Diesel engine mainly works by compressing only air. Air temperature in the cylinder is raised to a high degree and atomized which directly injected into the chamber and fuel was fired spontaneously with air before combustion, this is known as a heterogenous air-fuel mixture. The torque of diesel engine is being controlled by manipulating air-fuel ratio, instead of throttling the intake air, the diesel engine relies on altering the amount of fuel injected and with high air-fuel ratio.

In our project we have been taken diesel engine because of their advantages which follows:

- Whether it's an internal or external combustion engine, high thermal efficiency is achieved due to high expansion ratio.
- Heat dissipation is triggered in excess air by lean burn.
- By Non-Direct Injection small efficiency is avoided.
- No Direct fuel intake or exhaust injection.
- 55% of effective efficiency can be reached in low speed diesel engines.

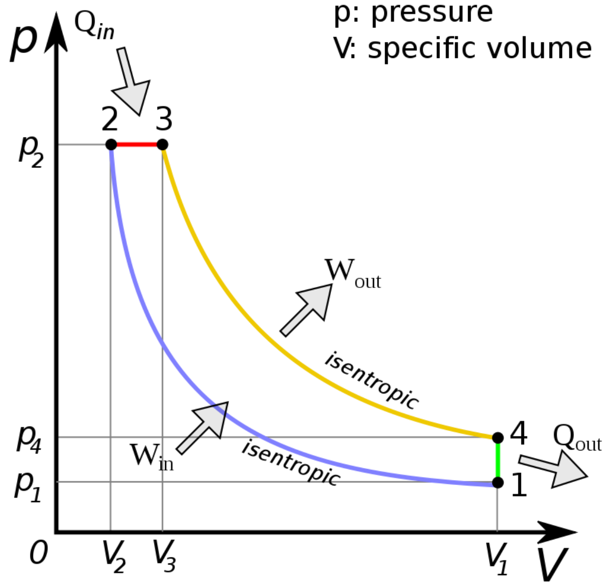


Fig.4 PV representation of Diesel Engine

4.1 Engine Specification

TABLE.1

ENGINE SPECIFICATION

ITEM	SPECIFICATION
Make	Kirloskar Engine.
Type of Engine	4-stroke with single cylinder, Naturally aspirated, Water cooled with constant engine speed.
Bore(mm)	80
Stroke(mm)	110
Compression Ratio	16.5:1
Rated Power	3.7 kW @ 1500 rpm
Type of Fuel	Diesel Fuel
Type of Injection	Direct Injection
Fuel Injection Pressure (bar)	200
No.of.Nozzle Holes	3

Nozzle Hole Diameter	0.26 mm
Inlet Valve Opens (IVO)	15 Bed
Inlet Valve Closes (IVC)	45 Abdc
Exhaust Valve Opens (EVO)	45 Bbdc
Exhaust Valve Closes (EVC)	10Atdc

5. COATING

It's a layer of covering that applied to an object and its aim is to improves surface properties of a bulk material usually referred to as a substrate. By coating one can improve materials appearance, adhesion, wettability, its corrosion resistance, its wear resistance, scratch resistance, etc., Coating may be applied as liquid, solid and gases. It can be measured and tested for materials which are properly opacity and also film thickness can be measured by using drawdown card. Various types of coating technologies are available but here in this project we are coating the material by using plasma spray technology in which high quality of coating can be achieved.

5.1 Plasma Spray Techniques

Plasma spray process is basically spraying the molten or heat softened material in a surface to provide a coating. Material which is ready for coating should be in powder from which is injected into a very high temperature plasma flame, where it can be rapidly heated and accelerated to a high velocity. The hot material impacts on substrate's surface and cooldown rapidly which forms a coating. Plasma spray can be carried out in cold process by keeping the surface temperature of substrate in low during the process in order to avoid damages, metallurgical changes and distortion to the substrate material.

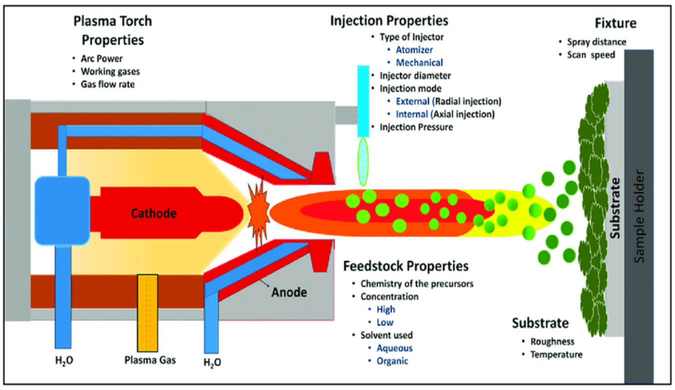


Fig.5 Plasma Spray Technology

Plasma spray gun is composed of copper anode and tungsten cathode, which are cooled by using water coolant which is easily available in the environment. Plasma gases like Nitrogen, Hydrogen, Helium, Argon flows around cathode and through anode which is shaped by a constricting nozzle. By a high voltage discharge plasma is initiated which causes local ionisation and a conductive path for a DC arc to form between anode and cathode. Resistance heating from the arc causes gas to reach extreme temperatures, dissociate and ionise to form a plasma. This exits the anode nozzle as a free which is different to plasma transferred arc coating process where the arc extends to the surface to be coated.

When Plasma is ready and stabilized for spraying the electric arc extends down to the nozzle. This stretching of arc is due to thermal pinch effect. Cold gas around the surface of water-cooled anode nozzle being electrically non – conductive constricts the plasma arc, raising its temperature and velocity. Powder is fed into plasma flame most commonly via an external powder port mounted near anode nozzle exit. The powder is so rapidly heated and accelerated the spray distances can be in the order of 25 to 150 mm.

5.2 Advantages of Plasma Spray technology

- Spray can be at very high melting point materials such as refectory metals like tungsten and ceramics like zirconia unlike combustion processes.
- They are much denser, stronger and cleaner than other thermal spray processes.
- Widest range of thermal spray coatings and applications and makes process the most versatile.
- Atmospheric Operation.

5.3 Parameters of Plasma Spraying

- Substrate: Al – specimen
- Coating Material: Ceramic Coating (Zirconia, Titania, Alumina. Chrome-oxide)

TABLE.2

PARAMTERS OF PLASMA SPRAY PROCESS

PARAMETER	RANGE
Torch Input Power	10-20 KW
Plasma gas flow rate (Ar-Argon) (slpm)	100 – 200 ± 5%
Secondary gas flow rate (N_2 – Nitrogen) (slpm)	100 ± 5%
Feed Rate (Ceramic Powder) (g/min)	40 -50
Powder Carrier gas flow rate (m/s)	Up to 450
Torch (Base Diameter) (mm)	76 -126 ± 10%
Anode (Nozzle Diameter) (mm)	8
Arc Current (Amps)	240 - 450
Plasma Gas Injection	Radial injection (by nozzle near exit)
Powder Injection	Vortex

6. PROPERTIES OF COATING MATERIAL

TABLE.3

Properties of Coating Materials

Properties	Titania (TiO_2)	Alumina (Al_2O_3)	Zirconia (ZrO_2)	Chromium Carbide (Cr_3C_2)	Tungsten Carbide (WC)
Atomic Volume (m^3/K.mol)	0.007	0.0058	0.0021		0.0064
Density (mg/m^3)	4.05	3.98	6.15	6.68	15.88
Bulk Modulus (GPa)	218.1	324	212		400
Hardness (MPa)	10290	22050	15750	1019	36000
Poisson's Ratio	0.29	0.33	0.32		0.22
Shear Modulus (GPa)	112.5	165	86.4		283
Tensile Strength (MPa)	367.5	665	330		530
Young's Modulus (GPa)	288	413	250	373.13	686
Melting Point (k)	2123	2369	2715	1895	3193
Specific Heat (J/Kg.k)	697	955	540		292
Thermal Conductivity (W/m.k)	11.8	38.5	2.7	189.77	88
Thermal Expansion (10^{-6}/k)	11.8	10.9	12.2		7.1

7. ANSYS

ANSYS is a software used for analysing in worldwide. By using ANSYS we can analysis structural, Thermal, Fluid (CFD), Electromagnetic. In ANSYS three steps are involved

- Pre-Processor
- Solver
- Post-Processor

After modelling, Piston model is imported in ANSYS by IGES file format and meshing is done. Here were are using triangular meshing in which meshing is done with accuracy. Analysis result can be most accurate and smooth solution is obtained.

7.1 ANSYS result – Aluminium Piston

7.1.1. Alumina Coating

- Structural Analysis – Stress, Strain, Total Deformation
- Thermal Analysis – Temperature, Heat Flux

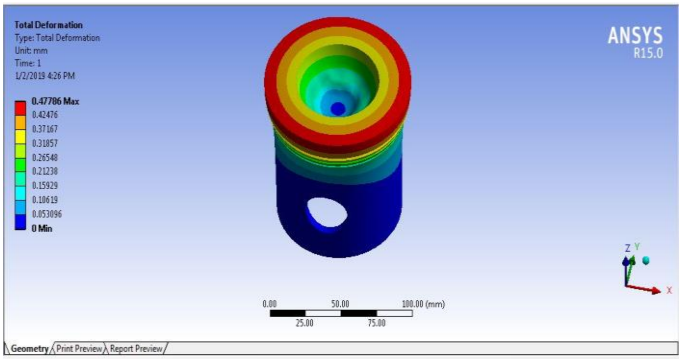


Fig.6 Total Deformation for Alumina Coating

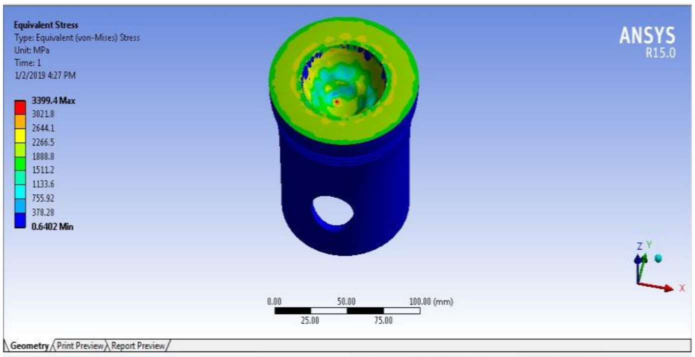


Fig. 7 Equivalent Stress for Alumina Coating

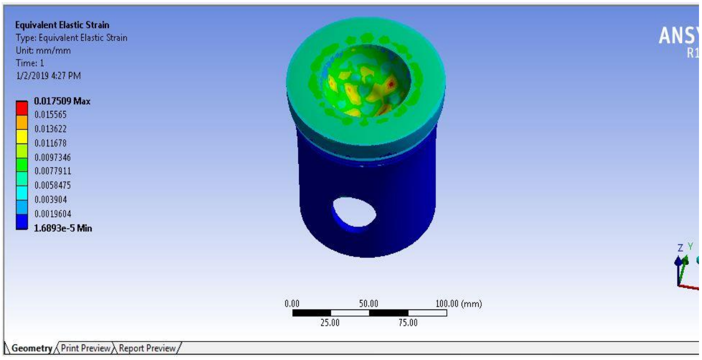


Fig.8 Equivalent Elastic Strain for Alumina Coating

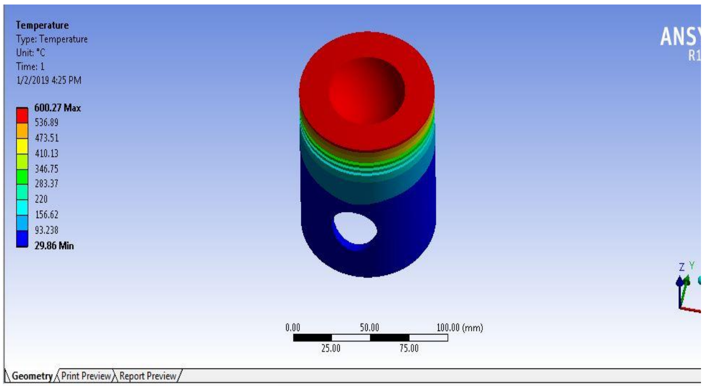


Fig.9 Temperature for Alumina Coating

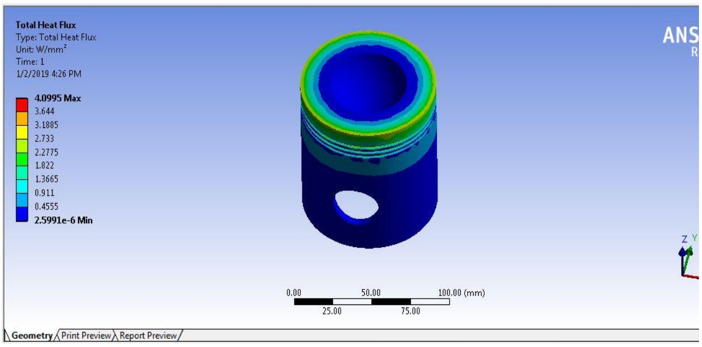


Fig.10 Total Heat Flux for Alumina Coating

7.1.2. Chromium Carbide Coating

- Structural Analysis – Stress, Strain, Total Deformation
- Thermal Analysis – Temperature, Heat Flux

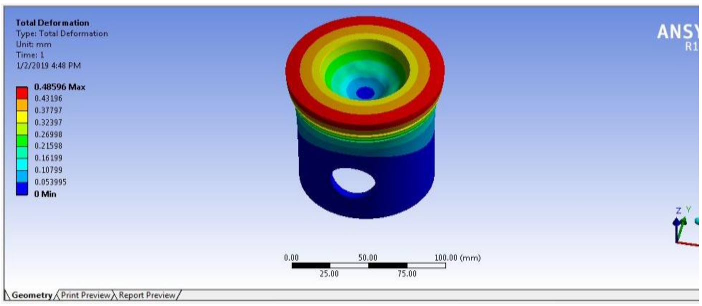


Fig.11 Total Deformation for Chromium Carbide Coating

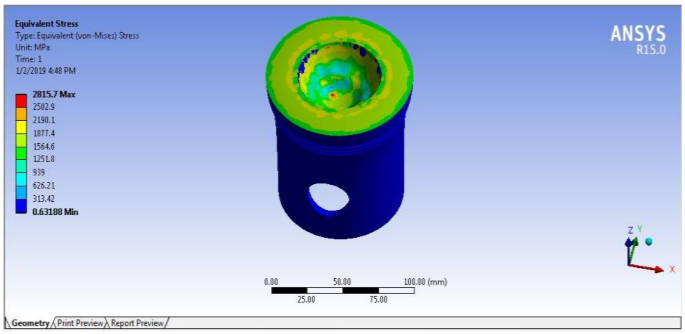


Fig.12 Equivalent Stress for Chromium Carbide Coating

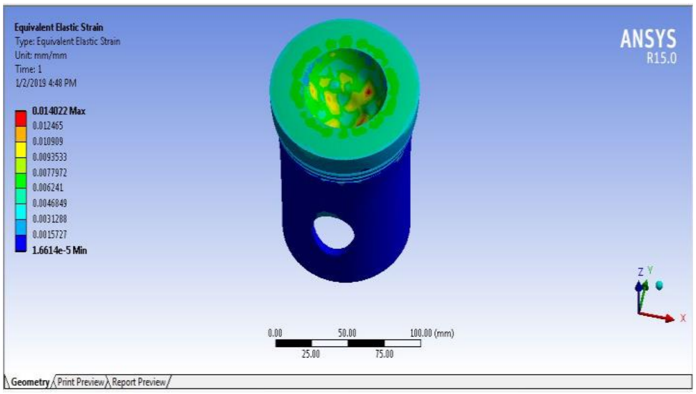


Fig.13 Equivalent Strain for Chromium Carbide Coating

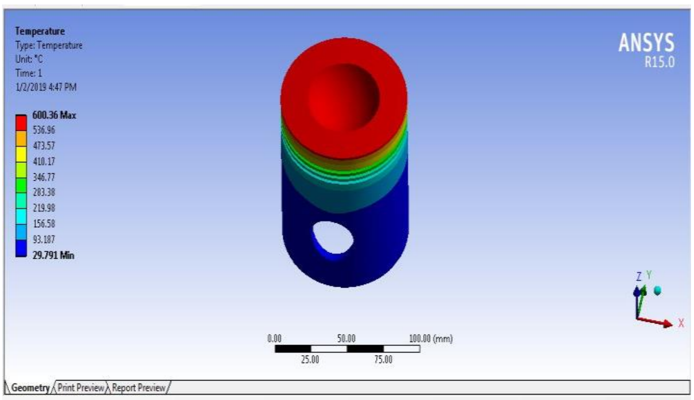


Fig.14 Temperature for Chromium Carbide Coating

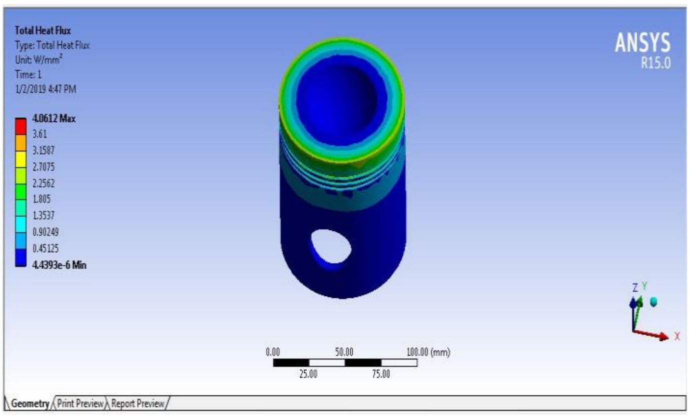


Fig.15 Total Heat Flux for Chromium Carbide Coating

7.1.3. Titania Coating

- Structural Analysis – Stress, Strain, Total Deformation
- Thermal Analysis – Temperature, Heat Flux

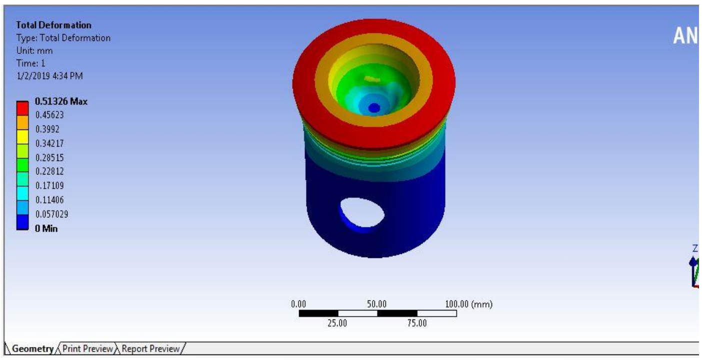


Fig.16 Total Deformation for Titania Coating

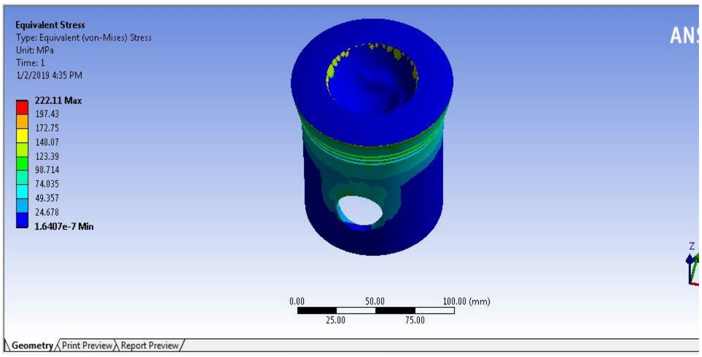


Fig.17 Equivalent Stress for Titania Coating

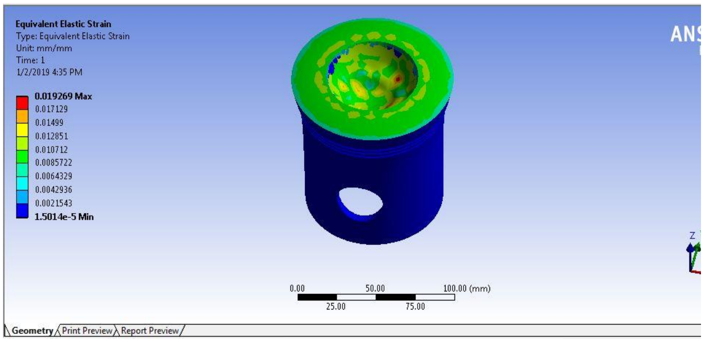


Fig.18 Equivalent Strain for Titania Coating

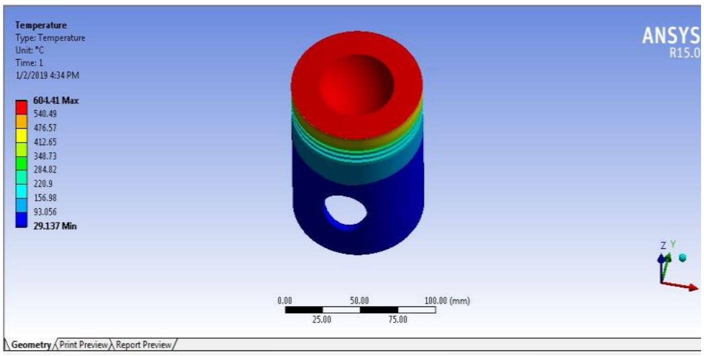


Fig.19 Temperature for Titania Coating

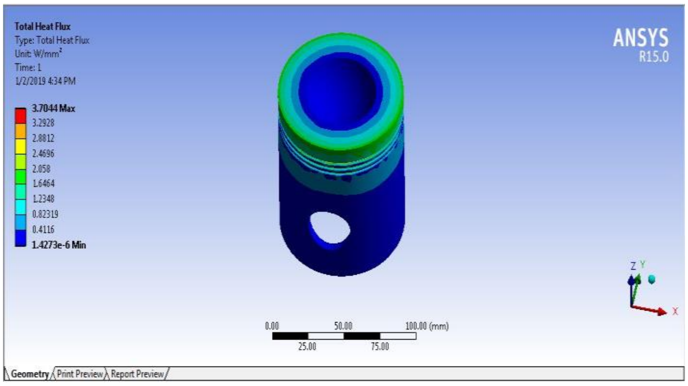


Fig.20 Total Heat Flux for Titania Coating

7.1.4. Tungsten Coating

- Structural Analysis – Stress, Strain, Total Deformation
- Thermal Analysis – Temperature, Heat Flux

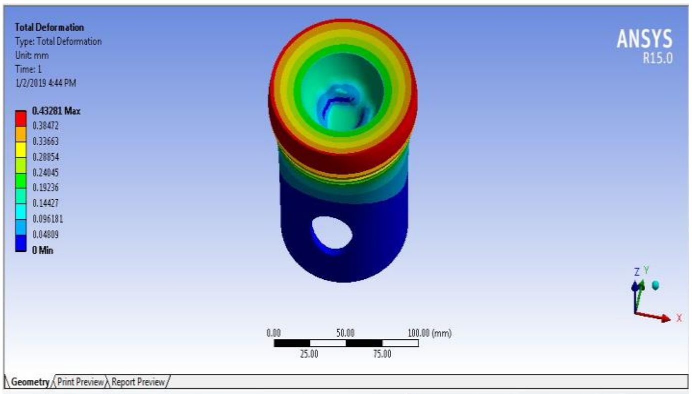


Fig.21 Total Deformation for Tungsten Carbide Coating

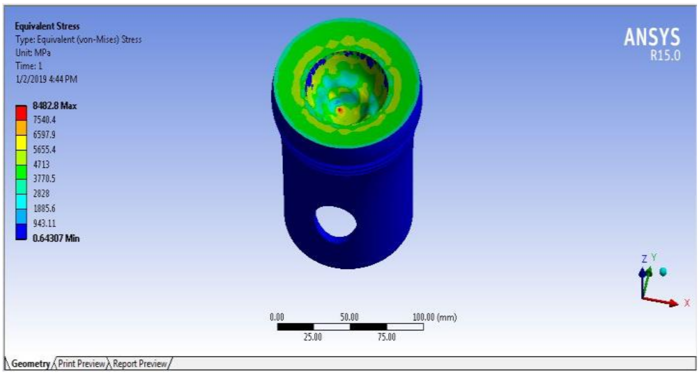


Fig.22 Equivalent Stress for Tungsten Carbide Coating

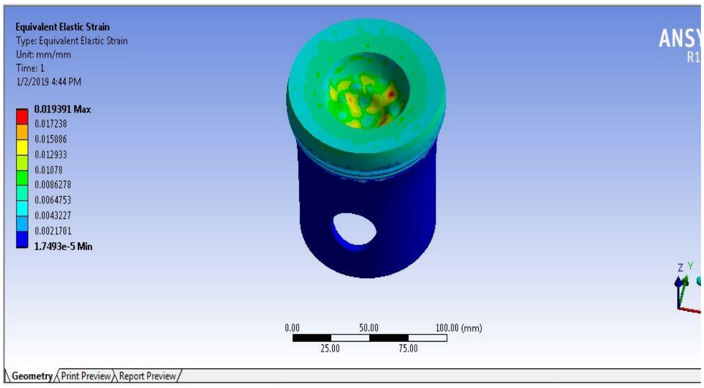
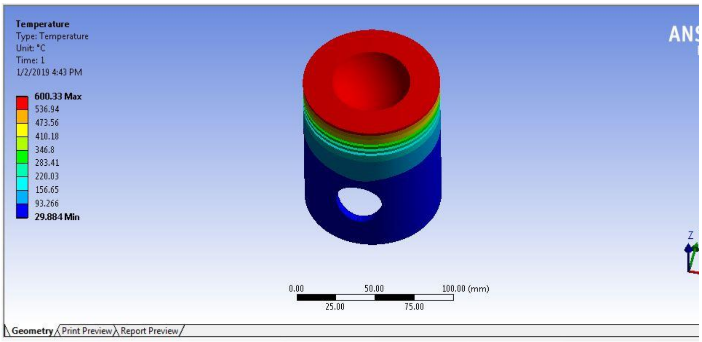


Fig.23 Equivalent Strain for Tungsten Carbide Coating



Fig,24 Temperature for Tungsten Carbide Coating

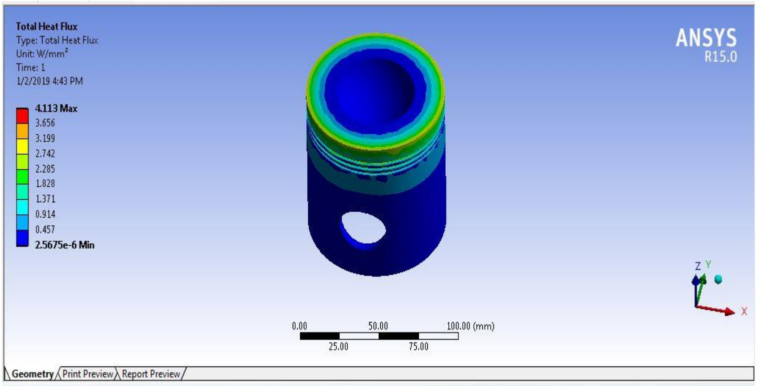


Fig.25 Total Heat Flux for Tungsten Carbide Coating

7.1.5. Zirconia Coating

- Structural Analysis – Stress, Strain, Total Deformation
- Thermal Analysis – Temperature, Heat Flux

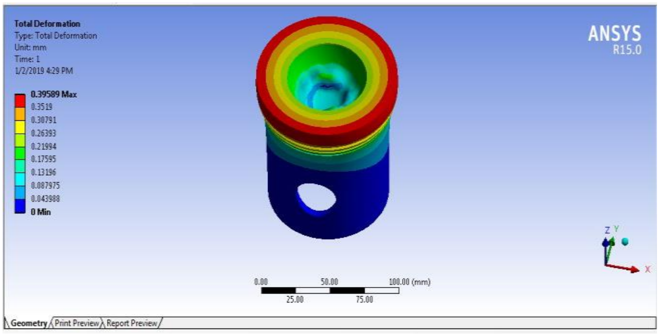


Fig.26 Total Deformation for Zirconia Coating

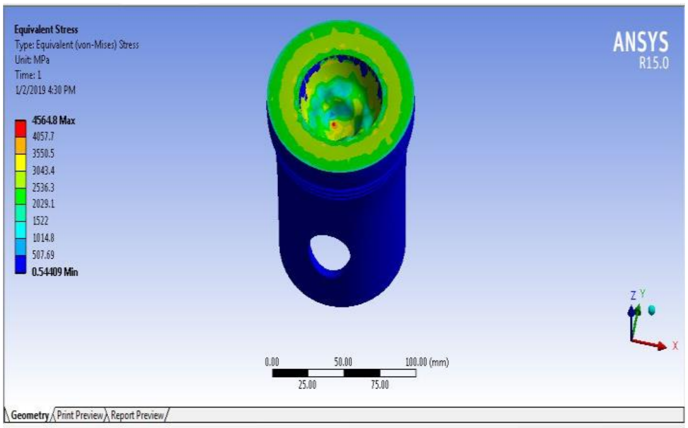


Fig.27 Equivalent Stress for Zirconia Coating

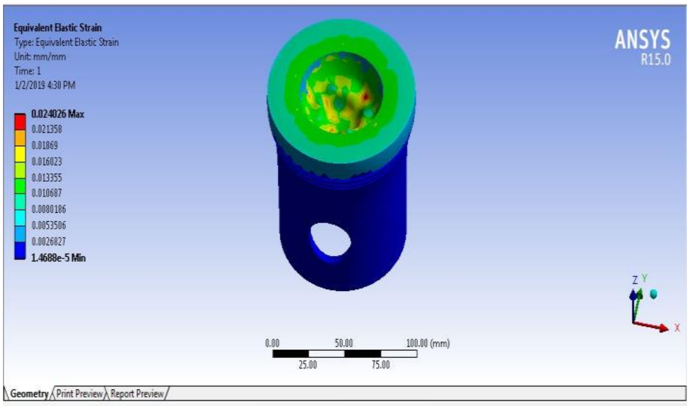


Fig.28 Equivalent Strain for Zirconia Coating

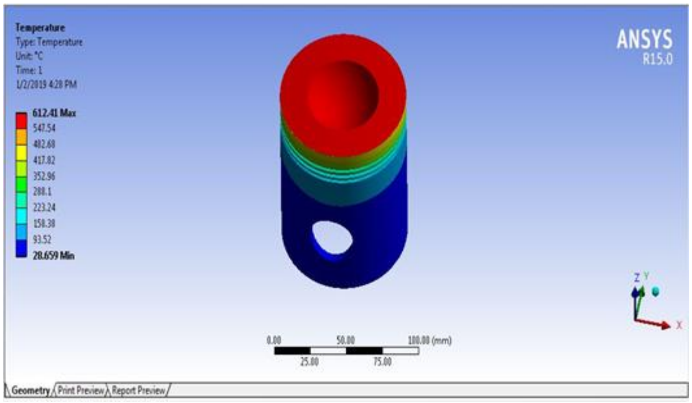
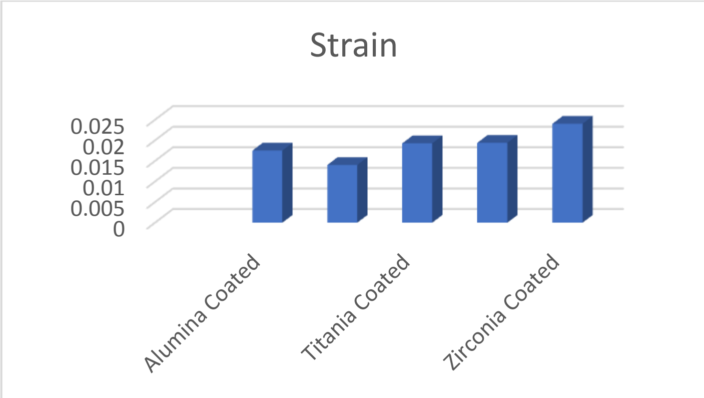


Fig.29 Temperature for Zirconia Coating



Graph.1 Ceramic Coating Vs Equivalent Strain

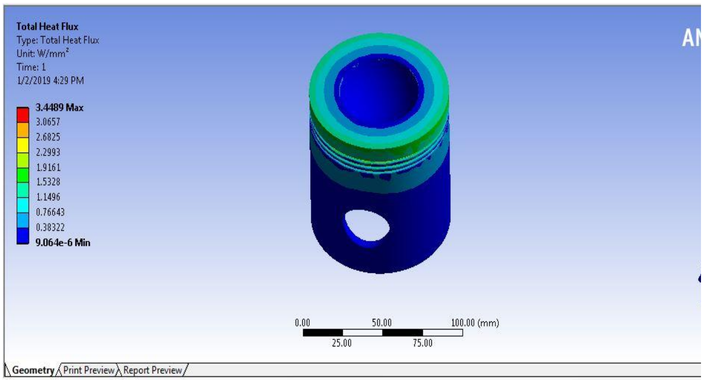
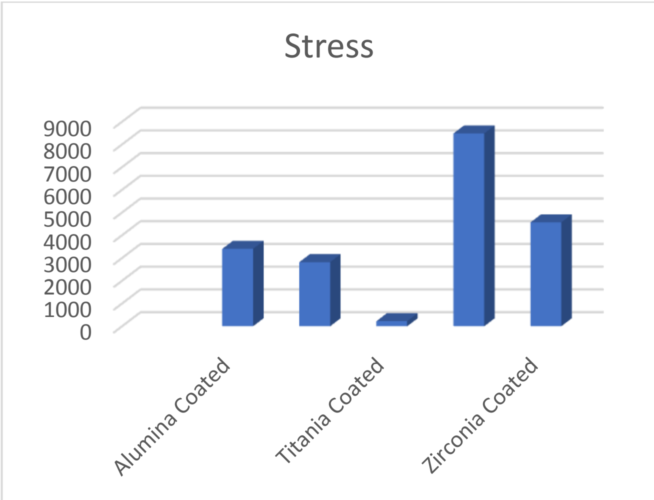


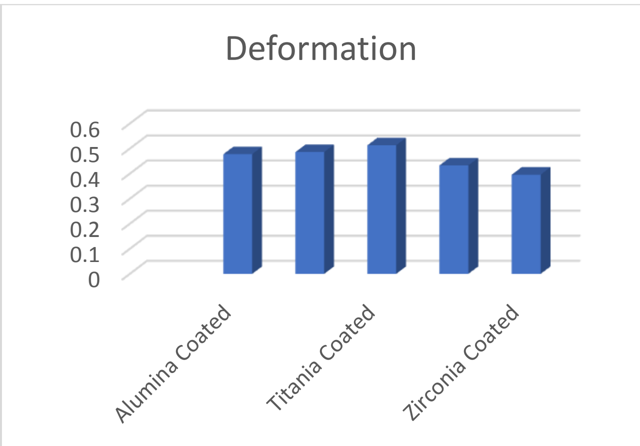
Fig.30 Total Heat Flux for Zirconia Coating



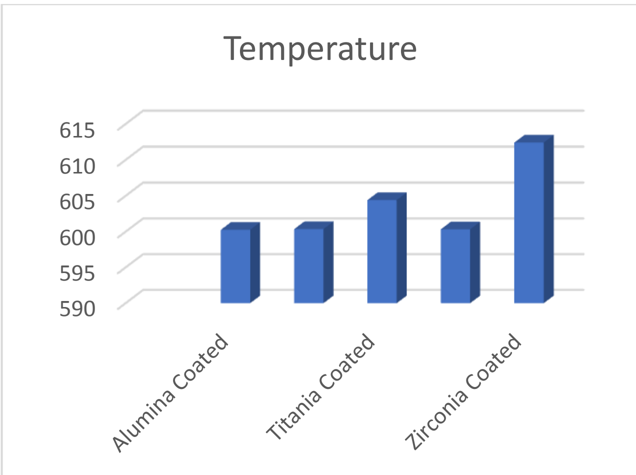
Graph.2 Ceramic Coating Vs Equivalent Stress

7.2. ANSYS Result Comparison

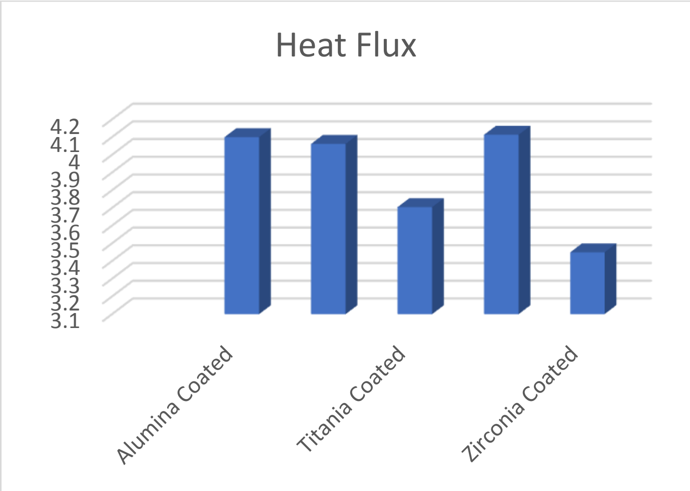
By Comparing Ansys result we can conclude that specimen with Zirconia Coating shows high results when compared with other coatings and further Hardness, Corrosion and Microstructure test were carried out with Zirconia Ceramic Coating in Aluminium Specimen.



Graph.3 Ceramic Coating Vs Total Deformation



Graph.4 Ceramic Coating Vs Temperature



Graph.5 Ceramic Coating Vs Total Heat Flux

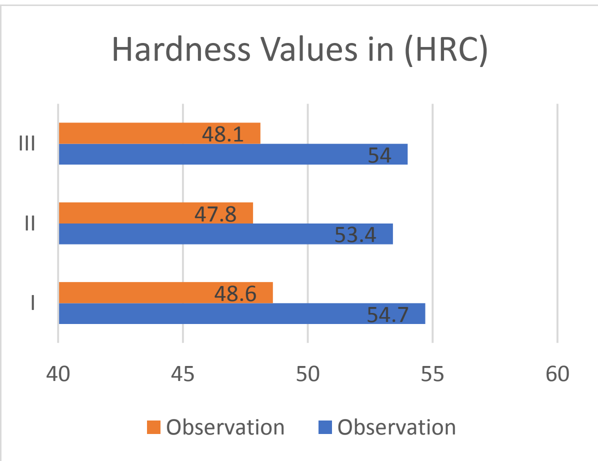
8.EXPERIMETAL RESULT

8.1. Hardness Test

- Testing Equipment – Vickers's Hardness Test

TABLE.IV
RESULT OF COATED AND UNCOATED SPECIMENS

HARDNESS VALUES in HRC	**OBSERVATION**	
Sample ID 3798 A	**With Zirconia Coating**	**Without Zirconia Coating**
I	54.7	48.6
II	53.4	47.8
III	54	48.1



Graph.6 With Zirconia Coating Vs Without Zirconia Coating

8.2. Salt Spray Test

- Testing Equipment – A Salt Spray Camber

	Sample I With Zirconia Coating	**Sample II Without Zirconia Coating**
Chamber Temperature (^0C)	34.5 – 35.5	34.5 – 35.5
pH Values	6.65 – 6.85	6.65 – 6.85
Volume of Salt Solution Collected	1.00 – 1.50 %	1.00 – 1.50 %
Concentration of Solution	4.80 – 5.30 %	4.80 – 5.30 %
Air Pressure (Psi)	14 – 18	14 – 18
Component Loading in the chamber Position	$< 30^0$	$< 30^0$
Observation	No rust formed. Noticed up to 12 hours.	No rust formed. Noticed up to 12 hours.

8.3. Microstructure

- Testing Equipment – Optical Microscopy

(i) Specimen with Zirconia Coating, Microscopic View = 200µm

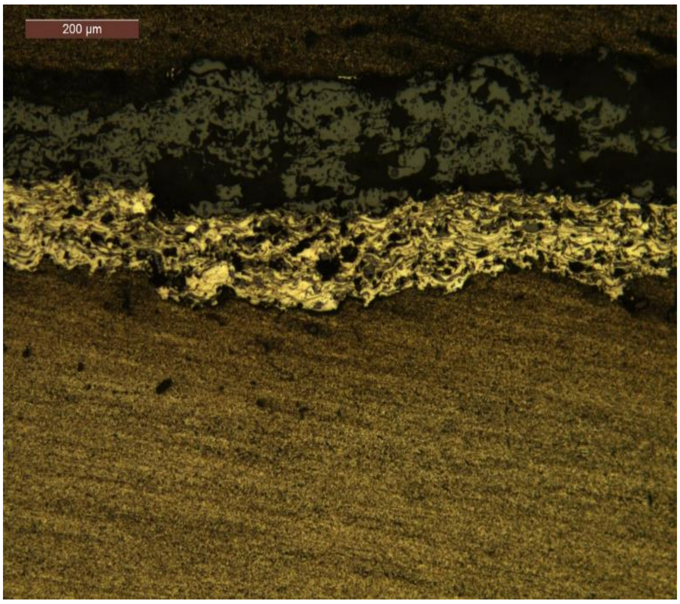


Fig.31 Microstructure of Coated Specimen for Mag.100X

(i) Specimen without Zirconia Coating, Microscopic View = 50µm, 200µm

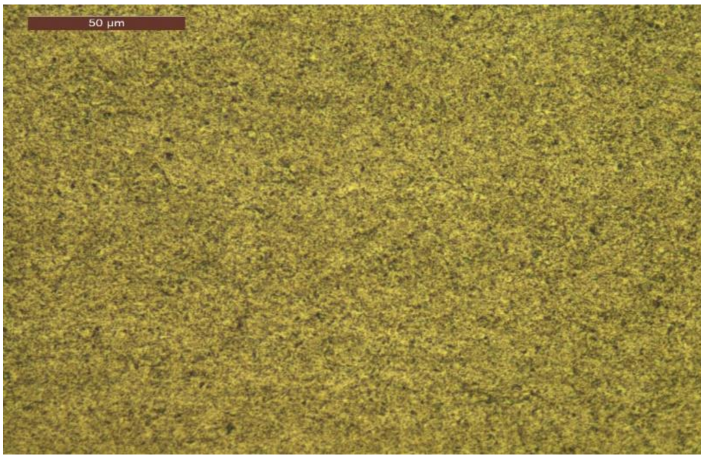


Fig.32 Microstructure of Uncoated Specimen for Mag.100X

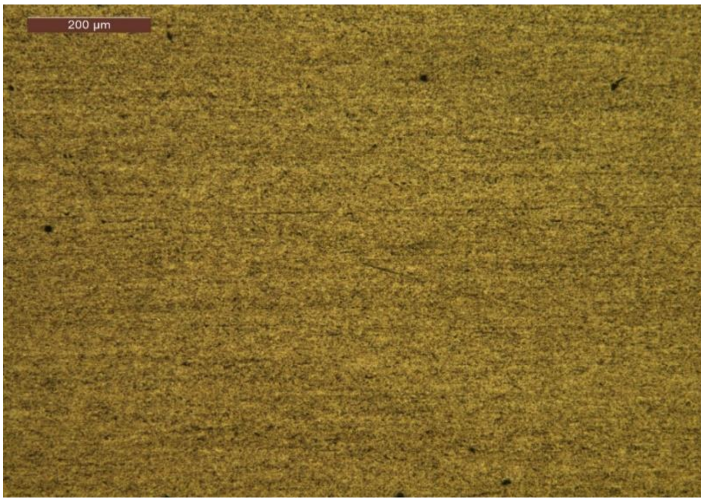


Fig.33 Microstructure of Uncoated Specimen for Mag.500X

9. CONCLUSIONS

From the result it is obtained that

- Coating on Aluminium material improves Hardness, Structural grains and Thermal Properties.
- Zirconia coating shows the improvement over coated and uncoated surfaces.
- In engine, high temperatures and chemical diffusion are driven for their life. For lower temperature applications, coating offers a better performance due to crystal refinement, which provides a smooth surface and crack arresting provides a tough coating.
- Zirconia increases corrosion resistance, reduction of wear rate during combustion were obtained.

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