CERAMIC COATING OF PISTON TOP SURFACE THROUGH HVOF TECHNIQUE USING FE ANALYSIS

R. BHASKAR REDDY
Lecturer
Mechanical Engineering
SKIT/JNTUA,
Srikalahast, Chittoor dist,
A.P - 517640, INDIA
E-Mail: rkbreddy111@gmail.com

Dr. B. JAYACHANDRAIAH
Professor
Mechanical Engineering
SKIT/JNTUA,
Srikalahasti, Chittoor dist,
A.P - 517640, INDIA
E-Mail:bjcskit2011@gmail.com

ABSTRACT

The strive to intensification of the engine efficiency in terms of fuel consumption and lower emissions have lead to higher demands. The piston is made up of Al- Alloy. An attempt is made the present paper to analyse with mechanical effects of surface coating for a piston movement commencing top dead centre bottom dead centre or vice-versa. The proper material for the insulated piston is not an easy task to evaluate mechanical properties. In Adiabatic process there is no heat added or removed from an isolated system. The conventionally the top surface of piston is coated with different ceramic powder like Alumina, Titania and Zirconia by High velocity oxidizing flame (HVOF) technique Then the with and without coated piston are modelled in CATIA v5 software and analysis are done by using ANSYS software. And analysis is carried-out to find the preferable coating powder like Alumina, Titania and Zirconia etc. It is recognized from the analysis the coated Aluminium-Titania piston having improved mechanical properties like hardness, microstructure, and corrosion résistance. Further it is observed that total heat flux, total deformation and Heat transfer have been decreased with increase of hardness compared to uncoated piston material.

Keywords: *Coatings, Deformation, HVOF technique, Microstructure, Temperature, Wear resistance.*

1. INTRODUCTION OF COATING TECHNIQUE

Coating is a process of applying an additional metal on to the required surface to get required mechanical properties. They may be pragmatic as liquids, gases or solids.

i) Thermal Spray Technique

It is a surface treatment process that the refined and detached metal or non-metallic coating material. Thermal spray material is heated to a plastic or molten state and accelerated. While these elements hitting the substrate surface, these are reformate due to pressure and adhere to the substrate surface. They continuously accumulate and eventually form a layered coating. By changing coating materials, the functions can be comprehended such as erosion resistance, abrasion resistance, heat insulation, ceramic insulation and so on. Today, in high-tech method, thermal spray has been widely used in aerospace, automotive, energy, metallurgy, paper making, machinery maintenance, municipal construction and other areas.

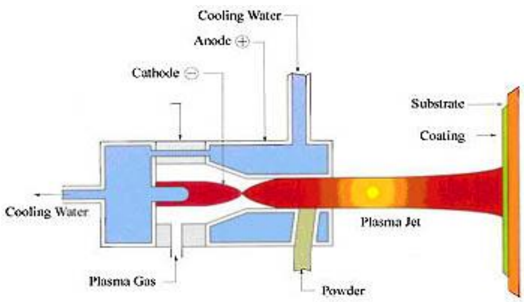


Fig.1. Thermal Spray Technique

In engineering and mechanical surface treatment areas, thermal spray technology is the most effective, economic and direct process to enhance the surface functions and parameters. Through the use of thermal spray technique, it can improve the life of equipment or spare parts, improve the surface performance, as well as reduce production and maintenance costs.

ii) Plasma Coating Process

In all thermal spray procedure, plasma spray is the very malleable one as it can influence an appropriate heat to melt any material, so the coating material are almost unlimited. Plasma spray gun is composed of a small chamber with a cathode (electrode) and an anode (nozzle).

Damaged by high-intensity bow, the gas through the chamber possesses plasma substance, and releases huge extent of heat, which can reach the temperature of 6000 ℃ ~ 16000 ℃. When the varnish material is high-speedily added hooked on the gas flame, it is melted and impacts on the substrate surface.

The wide range of coatings can be applied including ceramics, ZiO_2, YiO_2, chrome carbides & tungsten carbide and used in many applications including seal diameters, machines spindles & print rollers.

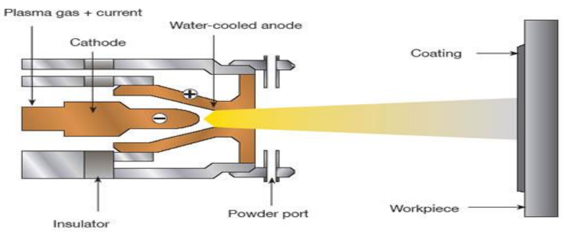


Fig.2. Plasma Spraying

iii) Flame Spray Processes

Flame spraying includes low-velocity powder flame, rod flame, and wire flame processes and high-velocity processes such as HVOF and the explosion gun (E-Gun) process (D-Gun is a registered trademark of Praxair Surface Technologies Inc.). Particle speed is relatively low (<100 m/s), and connection strength of the deposits is generally lower than the higher velocity processes. Porosity can be high and cohesive strength is also generally lower.

Spray rates are usually in the 0.5 to 9 kg/hour (one - 20 lb/hour) range for all but the lower melting point materials, which stem at significantly higher rates.. Wire Flame. In wire flame spraying, the primary function of the flame is to melt the feedstock material. A stream of air then atomizes the High-Velocity Oxy fuel. In HVOF, a fuel gas (such as hydrogen, propane, or propylene) and oxygen are used to create a combustion jet at temperatures of 2500 to 3100 °C (4500 to 5600 °F). The combustion takes place internally at very high chamber pressures, exiting through a small-diameter (typically 8 to 9 mm, or 0.31 to 0.35 in.) barrel to generate a supersonic gas jet with very high particle speeds. The process results in extremely dense, coatings, making it attractive for many applications. Either powder or wire feedstock can be sprayed, at typical rates of 2.3 to 14 kg/h (5 to 30 lb/h).

1.1 HVOF SPRAYING PARAMETER

SUBSTRATE: ALUMINIUM / CAST IRON

COATINGMATERIAL: CERAMIC POWDERS

Table-1 HVOF Spraying Parameter

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
Current	250-450 amperes
Powder injection	Circular injection through nozzle
Plasma gas injection	Vortex injection

1.1. PISTON MATERIALS

The following materials are used to manufacturing of piston material.

a) Aluminum Material

The properties of aluminium include low density and therefore low weight, high strength, superior malleability, easy machining, excellent corrosion resistance and good thermal and electrical conductivity are amongst aluminum's most important properties. Aluminium is also very easy to recycle.

b) Cast Iron Material

Cast iron is a group of iron-carbon alloys with carbon content greater than 2%. Its usefulness derives from its low melt temperature. The alloy constituents affect its colour when fractured white cast iron has carbide impurities which allow cracks to pass straight through grey cast iron has graphite flakes which deflect a passing crack and initiate countless new cracks as the material breaks.

Cast iron tends to be brittle, except for malleable cast irons. With its relatively low melting point, good fluidity, castability, excellent machinability, resistance to deformation and wear resistance, cast irons have become an engineering material with a wide range of applications and are used in pipes, machines and automotive industry parts, such as cylinder heads, cylinder blocks and gearbox cases .It is resistant to destruction and weakening by oxidation .

c) Steel Material

Steel is an alloy of iron and other elements, primarily carbon, widely used in construction and other applications because of its high tensile strength and low cost. The base metal, iron, is able to take on two crystalline forms, body centered cubic (BCC) and face centered cubic (FCC), depending on its temperature. It is the interaction of those allotropes with the alloying elements, primarily carbon, that gives steel and cast iron their great range of unique properties. The carbon in typical steel alloys may contribute up to 2.1% of its weight. Varying the amount of alloying elements, their presence in the steel either as solute elements, or as precipitated phases, retards the movement of those dislocations that make iron comparatively ductile and weak, or thus controls its qualities such as the hardness, ductility, and tensile strength of the resulting steel.

2. DESIGN MODEL OF PISTON

The below figure shows the 2-D modelling of piston and represents the dimensions required for modelling of piston in CATIA V5.

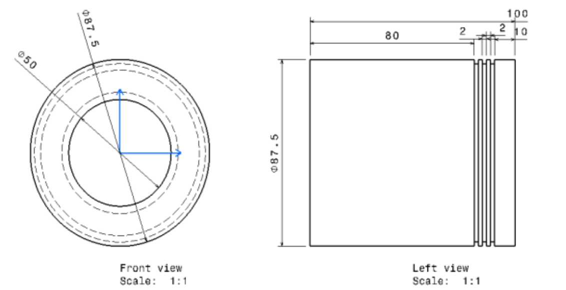


Fig.3. 2-D model of piston

The below figure shows the line drawing of piston. The dimensions are taken from the 2-D Model of the piston and it is imported into 3-D model of line drawing.

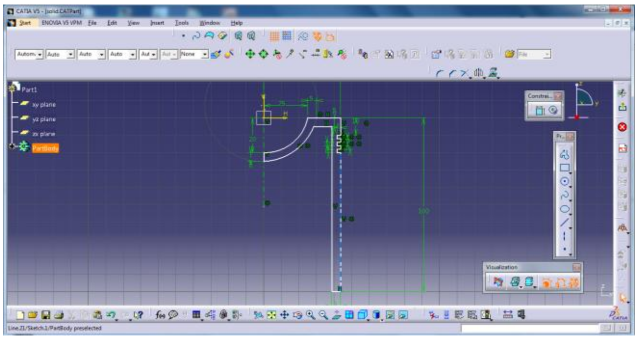


Fig.4. Line drawing of Piston

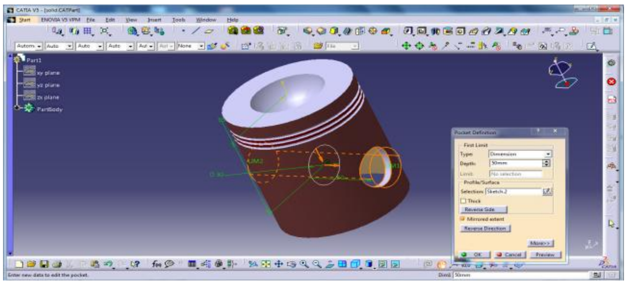


Fig.5. 3-D model of without coating piston

The above figure shows the final 3-D model of without coating final piston. After the line drawing and by using several tools like pad, revolve, etc the final 3-D model is obtained.

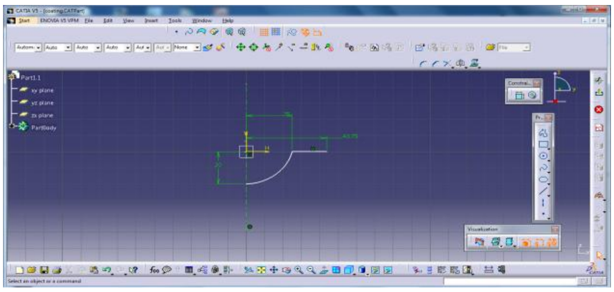


Fig.6. Line diagram of coating part

The fig.6 shows the line diagram of coating part which is the top most part of the piston. During the line diagram the thickness of the coating part is given depending on the quantity of thickness required.

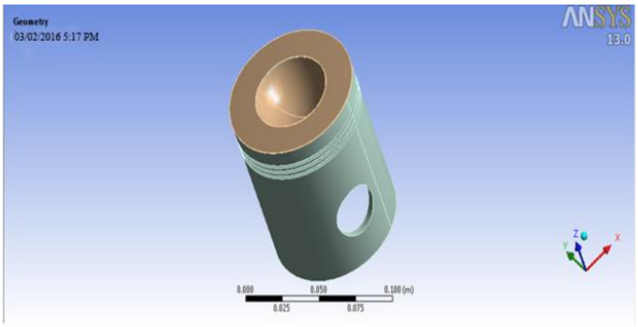


Fig.7. Assembly Model of with coating piston

3. 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. Such as Structural, Thermal, Fluid (CFD) and Low & High-Frequency Electromagnetic. Every analysis involves three main steps:

Pre-processor, Solver & post processor

3.1 ANSYS RESULTS OF UNCOATED PISTON MATERIAL

The component is subjected to the influence of heat conduction at the top of the piston and heat convection to side lands etc. The following images are shown for resulted deformation and vonmisses stresses before and after optimization.

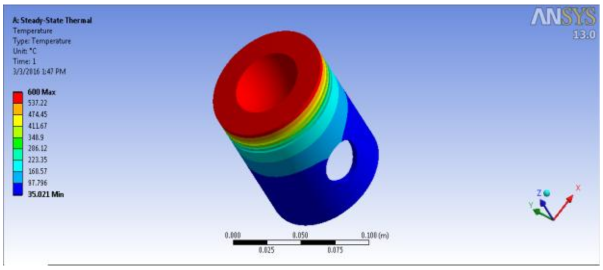


Fig.9. Temperature

In the fig.9, maximum temperature up to 600°C at the bowl especially at the top of the piston bowl which indicates at a maximum temperature of 600°C at maximum red colour, then the temperature further distributed along the piston parts,348.9°C at the middle portion and finally reaches at 35.021°C at the bottom surfaces.

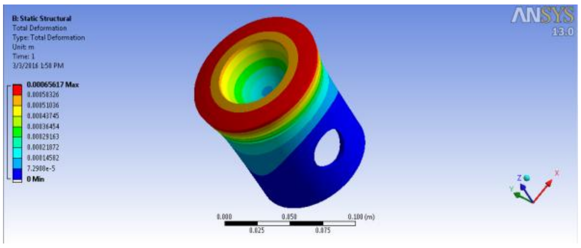


Fig.10 Total Deformation

The total deformation of the piston is essential to know the resistance of the piston material on working condition. The total deformation occurred into piston is 0.00065617 mm. The deformation in the piston is shown in figure 10.

The fig.11 shown above gives the thermal flux distribution over the volume of the piston at steady state after the application of thermal loads. The maximum heat flux occurs at the first ring of the piston. A MAX symbol on the heat flux distribution chart shows the maximum heat flux point. The minimum heat flux occurs at the bottom, it is indicated by MIN.

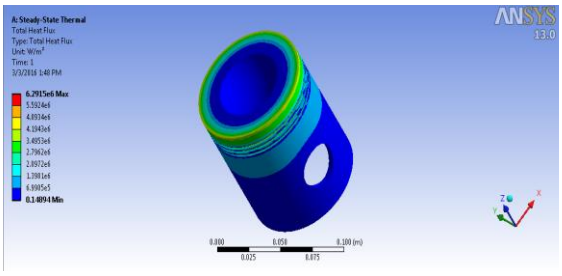


Fig.11 Total Heat Flux

3.2 ANSYS RESULTS OF ALUMINA-TITANIA COATED PISTON MATERIAL

The ansys results of Alumina-Titania coated piston material are shown below.

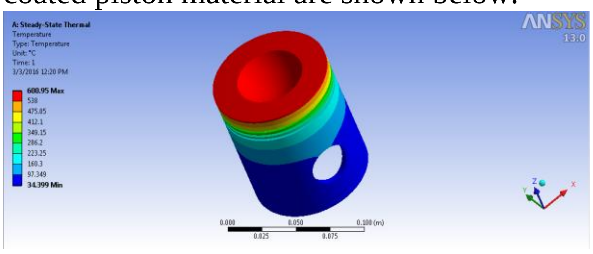


Fig.12 Temperature

In the figure 12 maximum temperature up to 600°C at the bowl especially at the top of the piston bowl which indicates at a maximum temperature of 600°C at maximum red colour, then the temperature further distributed along the piston parts,349.15°C at the middle portion and finally reaches at 34.399°C at the bottom surfaces.

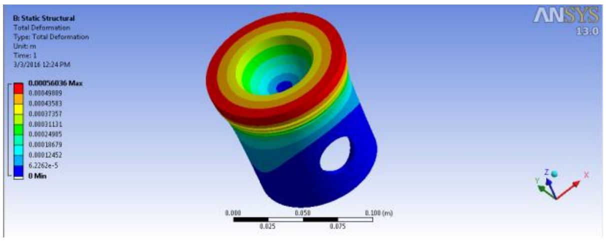


Fig.13 Total Deformation

The total deformation of the piston is essential to know the resistance of the piston material on working condition. The total deformation occurred into piston is 0.00056036mm.The deformation in the piston is shown in figure 13.

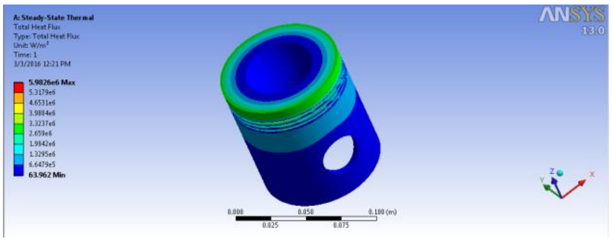


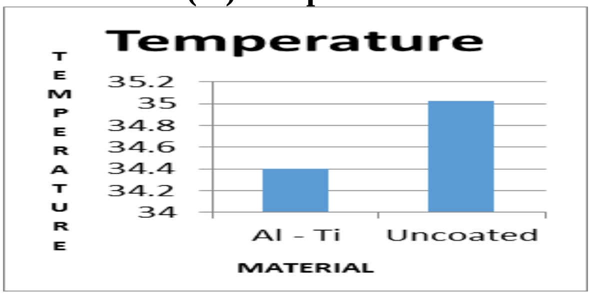
Fig.14 Total Heat Flux

The fig.14 shown above gives the thermal flux distribution over the volume of the piston at steady state after the application of thermal loads. The maximum heat flux occurs at the first ring of the piston. A MAX symbol on the heat flux distribution chart shows the maximum heat flux point. The minimum heat flux occurs at the bottom, it is indicated by MIN.

4. RESULTS AND DISCUSIONS

The comparison of ANSYS results of with and without coated piston material is shown under the following graphs.

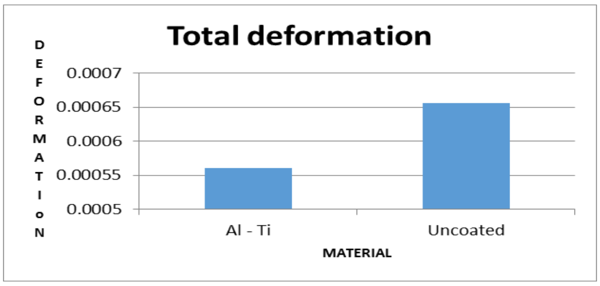
4.1. Material (vs) Temperature



Graph-1 Material (vs) Temperature

The above graph-1 shows Material (vs) Temperature. In this, X-axis is taken as material and Y-axis taken as temperature distribution. From the graph we analyze that Al-Ti coating material receives less temperature compared to uncoated piston material. Hence 1.7% of the receiving temperature has been reduced in Al-Ti material compared to uncoated piston material.

4.2 Material (Vs) Total Deformation

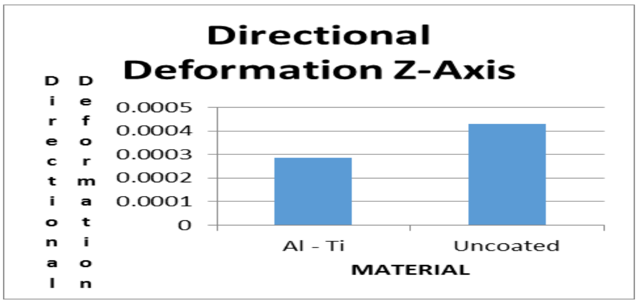


Graph-2 Material (vs) Total Deformation

The above graph-2 shows Material (vs) Total deformation. In this X-axis represents material and Y-axis represents Total deformation, the graph it is clearly observed that Al-Ti coating material gives less total deformation when compared to uncoated piston material. Hence 16% of the total deformation has been reduced in Al-Ti material compared to uncoated piston material.

4.3 Material (vs) Directional Deformation

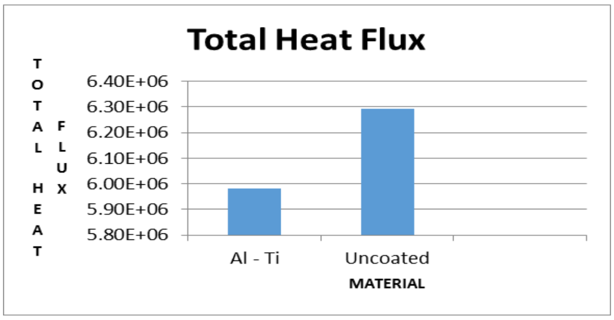
The graph-3 show Material (vs) Directional Deformation in Z-direction In this X-axis is indicates material and Y-axis indicates Directional Deformation. From the graph we analyze that Al-Ti coating material gives less Directional Deformation compared to uncoated piston material. Hence 5% of the Directional Deformation has been reduced in Al-Ti material compared to uncoated piston material.



Graph-3 Material (vs) Directional Deformation

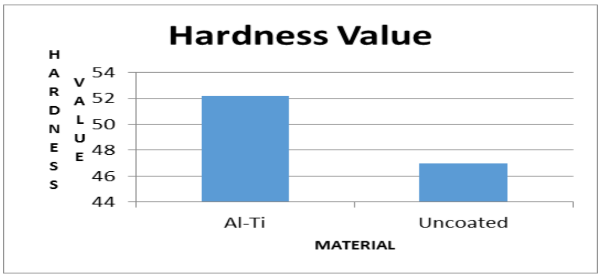
4.4 Material (vs) Total Heat Flux

The above graph-4 shows Material (vs) Total Heat Flux. In this X-axis is represented as material and Y-axis represented as Total Heat Flux. From the graph we analyze that Al-Ti coating material receives less Total Heat Flux compared to uncoated piston material. Hence 1.7% of the Total Heat Flux has been reduced in Al-Ti material compared to uncoated piston material.



Graph-4 Material (vs) Total Heat Flux

4.5 Material (vs) Hardness Value



Graph-5 Material (vs) Hardness Value

The above graph-5 shows Material (vs) Hardness Value. In this X-axis is taken as material and Y-axis taken as Hardness Value. From the graph we analyze that Al-Ti coating material has more Hardness Value compared to uncoated piston material. Hence 9.6% of the Hardness Value has been increased in Al-Ti material compared to uncoated piston material.

5. CONCLUSIONS

From the obtained experimental work it was found that, the coating on piston material like aluminium specimens by thermal spray coatings were investigated. The surface morphologies of the major and the minor faces were considerably different from each other. Due the coating on aluminium, materials will improve the mechanical and thermal characterization. This will further improve the hardness, structural grains and thermal properties. Also the Alumina-Titania coatings will provide the most dramatic improvements over other coating and un coated, in engine component applications where failure mechanisms that are driven by high temperatures and chemical diffusion are important for life. In lower temperature applications (lower speeds, discontinuous contact) the coating will still offer improved performance due to the effects of crystallite refinement, which provide a smoother surface and second phase crack arresting or deflection mechanisms that make the coating tougher. Due to alumina-Titania coated on aluminium specimens the hardness and corrosion resistance was increased.

6. FUTURE SCOPE

This work will further extend towards the engine performance in Direct Injected Diesel Engine (DI). Also the emission and performance characteristics will be analysed. The different coated pistons like mono layer, multilayer and composite coating powder will be used for this analysis

Much more work will be required to determine the optimum level of coating to maximize performances. This optimization includes the various types of coating used & its thickness.

The Study can be extended to Real Time Experimental work applying coating on Aluminium Piston by various coating techniques and then studying the results

7. REFERENCES

1. ZumGahr KH, Bundschuh W, Zimmerlin B. Effect of grain size on friction and sliding wear of oxide ceramics. Wear (1993);162–164:269–79.

2. Wang D, Mao Z. Abrasive wear of tetragonal zirconia poly crystal ceramics. J Chin Ceram Soc (1995);23(5):518–24.

3. He Y, Winnubst L, Burggraaf AJ, Verweij H, Vander varstPGTh, de with B. Grain-size dependence of sliding wear in tetragonal zirconia poly crystals. J Am Ceram Soc (1996);79(12):3090–6.

4. J.S. Lee, T. Matsubara, T. Sei, T. Tsuchiya, J. Mater, Preparation and properties of Y2O3 doped ZrO2 thin films by the sol–gel process, Surface Coating Technology (1997).

5. M. Foy, M. Marchese, G. Jacucci, Engineering plasma spray films by knowledge based simulations proceedings of IFIP conference on, in: Arthur B. Baskin, etal.(Eds.)Cooperative Knowledge Processing for Engineering Design, Kluwer Academic Publishers, The Netherlands,(1999), p. 289. 6. Moulzolf SC, Lad RJ, Blau PJ. Microstructural effects on the friction and wear of zirconia films in unlubricated sliding contact. Thin Solid Films(1999);347:220

7. Reinhold H. Dauskardt, "THERMAL BARRIER COATINGS" (1999).

8. Zhang T, Xu L, Xiong W, et al. Experimental research on the thermal contact resistance between Cu-Cu in vacuum and low temperature. Cryogenics, (1999). www.azom.com "Functionally Graded Materials (FGM) and Their Production Methods".

9. Yang CT, Wei WJ. Effects of material properties and testing parameters on wear properties of fine-grain zirconia (TZP). Wear (2000); 242:97–104.

10.D. Robinson, R. Palaninathan. Thermal analysis of piston using 3D finite element method. (2001) Elsevier B.V

11.EkremBuyukkaya, "Thermal Analysis of functionally graded coating AlSi alloy and steel pistons", Surface and coatings technology (2007)

12.A.R. Bhagwat, Y.M. Jibhakate. Thermal Analysis of I.C Engine Piston Using Finite element method(IJMER)Vol.2, Issue4, July-Aug (2012).