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DESIGN AND PERFORMANCE ANALYSIS ON PISTON RING

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ABSTRACT- The main objective of this work is to study the wear characteristics that govern on the piston ring pack inside the piston assembly of an engine. Among several methods, most profitable method is to provide a coating layer on the piston ring pack. Since, ring seal is essential to the performance of the engine, it is must be a perfect seal between the ring pack and cylinder wall. In this phase, existing material of the piston ring material were considered and studied, a model corresponding to its dimensions were prepared and analysis were done on them in static conditions. Also, Mathematical calculations were performed in designing the ring pack for modelling. The study on coating materials were made and suitable materials were chosen for coating.

KEYWORDS: Piston Ring design, Nano Coating, Thermal Analysis, Static analysis, High Speed Steel, Silicon di Oxide, Calcium stabilized Zirconium oxide,

1. INTRODUCTION

Nano technology is an engineering functional system at the molecular scale. It involves the creation and/or manipulation of materials at the nanometer (nm) scale either by scaling up from single groups of atoms or by refining or reducing bulk materials. A nanometer is 1×10^{-9} m or one millionth of a millimeter. To give a sense of this scale, a human hair is of the order of 10,000 to 50,000 nm. Two main approaches are used in Nano technology. In the “bottom-up” approach, materials and devices are built from molecular components which assemble themselves chemically by principles of molecular recognition. In the “top-down” approach, Nano objects are constructed from larger entities without atomic level control.

2. NANO COATING

Nano coating is a surface modification technique to create the Nano layer on the surface to improve the physical and mechanical performances.

- Increase the hardness.
- Superior wear resistance.
- Oxidation resistance
- Friction resistances

This coating is widely used for cutting and forming tools, bearings, I.C engine components, seals, valves, glass etc.Nano-layered multilayer coatings have periodic structures of layer with proper control of the layers composition and structure. Chemical vapor deposition (CVD) was the first technology used, which advanced from single layer to current multilayer types combining, TiC, TiN, TiCN and Al_2O_3. The coatings with very low electronic conductance, such as SiO_2 TiO_2, non-conducting coatings Al_2O_3 or mix-oxides coating of TiO2, SiO2, and Al_2O_3 have been reported as the wear protections in the literatures.

3. PISTON RING

The function of a piston ring is to seal off the combustion pressure, to distribute and control the oil to transfer heat, and to stabilize the piston. The piston is designed for thermal expansion, with a desired gap between the piston surface and linear wall.

The piston rings have three types:

- Top Compression ring
- 2nd Compression ring

Oil Scratch ring

Top and 2nd compression rings seal the combustion chamber perfectly to avoid the escape of combustible rich mixture from the chamber. Oil ring helps in removing the lubricant oil from the surface of the cylinder wall and reduces the combustion of lubricant oil.

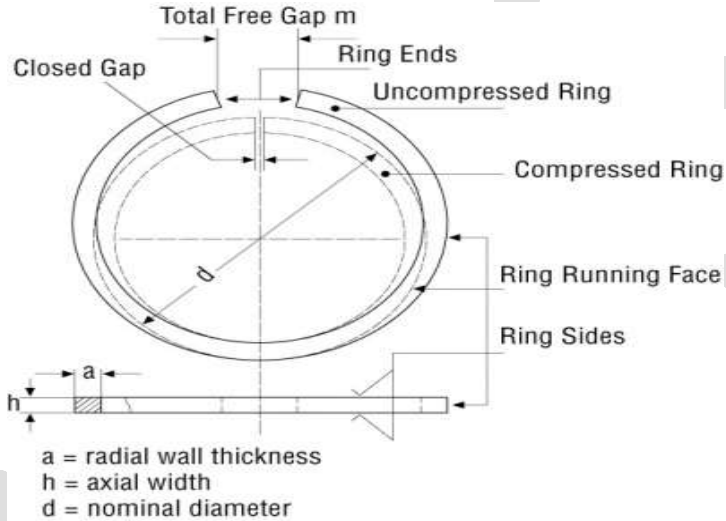

FIGURE 3.1 NOMENCLATURE OF PISTON RING

4. MATERIALS AND COATING METHOD

4.1 HIGH SPEED STEEL (HSS OR HS)

HSS is a subset of tool steels, commonly used in tool bits and cutting tools. This property allows HSS to cut faster than high carbon steel. To increase the life of high speed steel, tools are sometimes coated. Most coatings generally increase a tool's hardness and/or lubricity. The coating also helps to decrease the temperature associated with the cutting process and increase the life of the tool.

Table 4.1- Composition of AISI440C Steel

Grade440C		
Ingredients	Min.	Max.
Carbon	0.95	1.20
Manganese	-	1.00
Silicon	-	1.00
Phosphorus	-	0.040
Sulphur	-	0.030

Chromium	16.00	18.00
Molybdenum	-	0.75
Iron	Balance	

4.2 SILICON DI-OXIDE (SiO_2)

Silicon dioxide, also known as Silica is natural compound of oxide of silicon. Silicon dioxide has many advantageous properties such as Low electrical conductor and thermal insulator.

4.3 CALCIUM STABILIZED ZIRCONIUM OXIDE (CSZ)

Zirconium oxide is one of the sub products of zirconium. It is in white color and it is a crystalline oxide of zirconium. Zirconium oxides were known for their thermal stability and high wear resistance.

4.4 DIAMOND LIKE CARBON (DLC)

Diamond like carbon (DLC) is a class of amorphous carbon material which displays some similar properties of diamond. DLC is usually applied as coatings to other materials such as steels, brass, copper etc .DLC exists in three forms:

- Amorphous
- Crystalline
- Monolithic

5. MODELLING AND MESHING

5.1 DESIGN CONSIDERATIONS FOR PISTON RING

Design considerations for designing the piston ring were:

- Must form a perfect seal with cylinder wall
- Must maintain constant blow-by and lock the chamber pressure
- Addition in weight of piston rings was acceptable.
- Ring pack must be rigid to withstand thermal and shock loads.
- Oil ring must remove excess lubricant from the cylinder wall.
- Rings must also act as a fin structure to remove heat from the engine chamber.
- It must have resistance over heat and pressure.

6. PROCEDURE FOR PISTON RING DESIGN

6.1 CALCULATING MAXIMUM PRESSURE

Considering Mechanical efficiency = 0.8

Brake Power BP = $(T*2*\pi* N)/60$

Indicated Power, IP = Brake Power/Mechanical efficiency

= $(P*\pi*D^2*L*N)/2$

Where,

P - Maximum Pressure in N/mm^2

N	-	Engine Speed in rpm
D	-	Cylinder bore in mm
L	-	Length of stroke in mm

6.2 RADIAL THICKNESS OF THE RING

$T_1 = D\sqrt{((3*P_w)/S_t)}$

Where,

P_w = Wall pressure on the ring

= 0.025 N/mm^2 to 0.042 N/mm^2

S_t = Tensile stress of the steel ring

= 745 N/mm^2

6.3 AXIAL THICKNESS OF THE RING

$T_2 = 0.7*T_1$ TO T_1

Where,

T_1 = Radial thickness of ring in mm

6.4 ANGLE OF CIRCUMFERENCIAL GAP

Circumferential gap, C = $0.02*(\pi*D)$

Angle of circumferential gap, θ = $(C/R)*(180°/\pi)$

Where,

C = Circumferential gap in mm

R = Radius of the ring in mm

7. GEOMETRY MODEL

From the above calculations, dimensions of the piston ring were designed using any modelling software such as CATIA V5. In this design, we have considered the cross section of top compression ring as rectangular one with dimensions of 3.5mm*2.5mm. As far the oil ring is considered, cross section is considered to be a C-Section. Here, we have considered the thickness of oil ring is much greater than the compression ring. When coating is provided, the sealing is considered to be a perfect one with reduced blow-by gas escape and better lubrication under dry conditions.

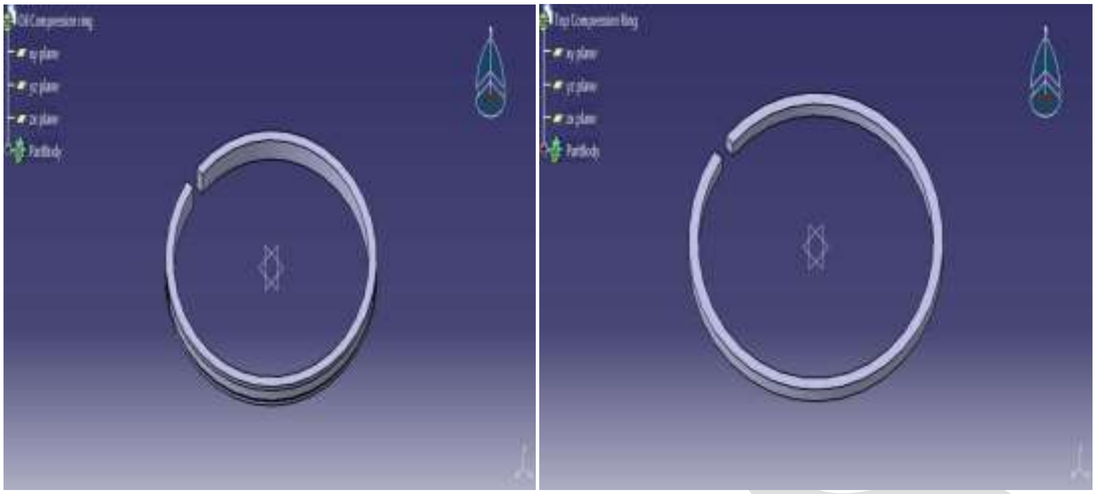

FIGURE 7.1 GEOMETRY MODEL OF PISTON RING PACK

7.1 MESHING

After the model is created according to the dimensions, we import the geometry file using ANSYS V12. In this analysis, we have achieved fine number of meshing constraints, with values up to 45970 numbers of nodes.

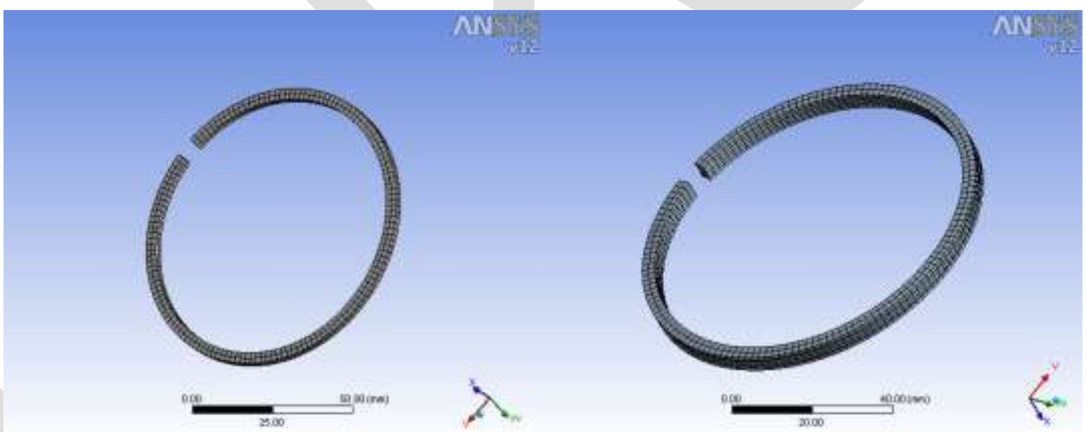

FIGURE 7.2 MESHED MODEL OF PISTON RING PACK

8. COMPUTATIONAL ANALYSIS

8.1 STATIC ANALYSIS

Static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads.

Typical structural quantities are:

1. Total Deformation
2. Equivalent Stress
3. Equivalent Strain

8.2 BOUNDARY CONDITIONS

The maximum pressure of about **14.95 MPa** is applied on the top surface of the ring structure. Both the coated and uncoated structures were recommended to use constant pressure for this analysis.

8.3 TOTAL DEFORMATION

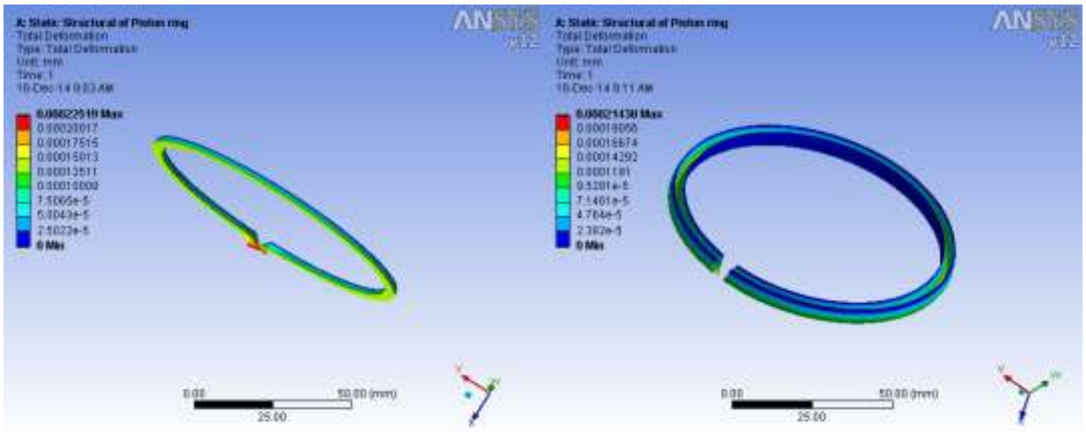

FIGURE 8.1 TOTAL DEFORMATION OF UNCOATED PISTON RINGS

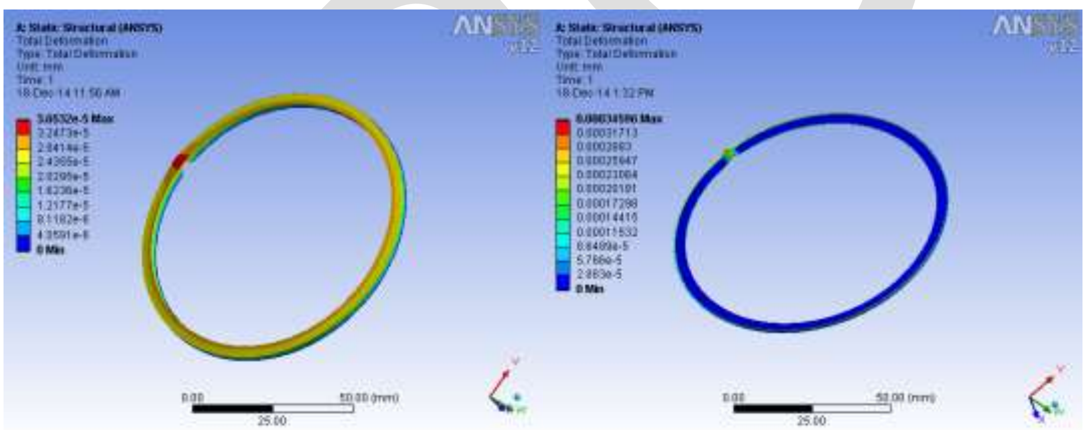

FIGURE 8.2 TOTAL DEFORMATION OF COATED PISTON RINGS

8.4 EQUIVALENT STRAIN

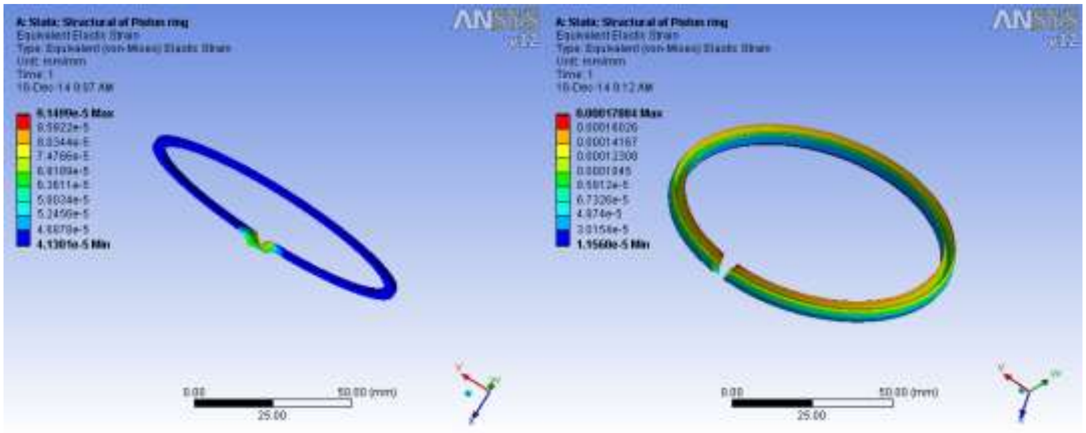

FIGURE 8.3 STRAIN IN UNCOATED PISTON RINGS

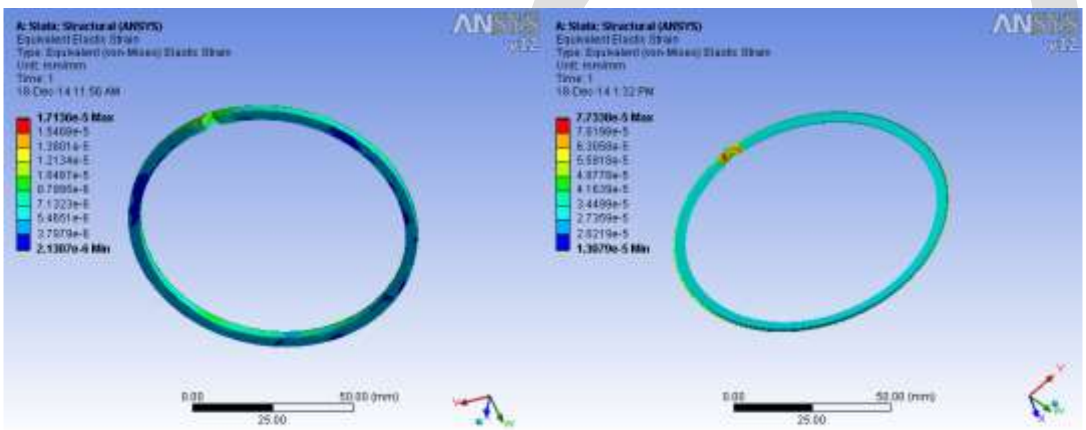

FIGURE 8.4 STRAIN IN COATED PISTON RINGS

8.5 EQUIVALENT STRESS

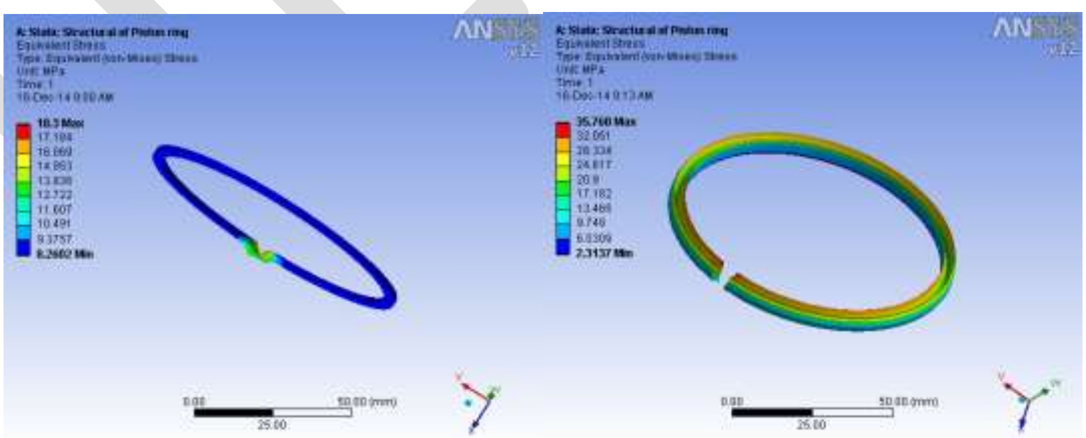

FIGURE 8.5 STRESS ACTING ON UNCOATED PISTON RING

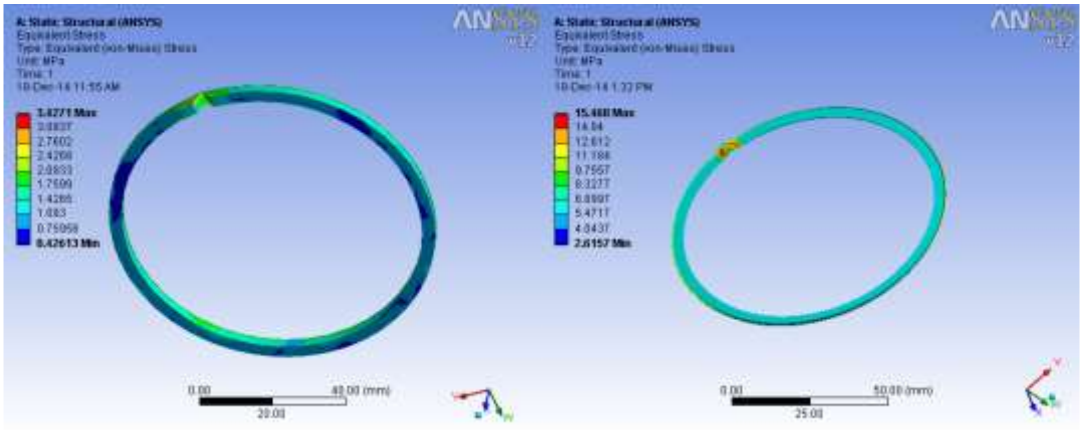

FIGURE 8.5 STRESS ACTING ON COATED PISTON RINGS

8.6 THERMAL ANALYSIS

A thermal analysis calculates the temperature distribution and related thermal quantities in a system or component. Typical thermal quantities are:

1. The temperature distributions.
2. Thermal fluxes
3. Thermal error.

8.7 BOUNDARY CONDITIONS

Engine temperature of 1100°C is produced on the rings as convection heat transfer and thermal coefficient were given for all the sides of the ring. The results obtained by this analysis were shown below.

8.8 TEMPURATURE DISTRIBUTION

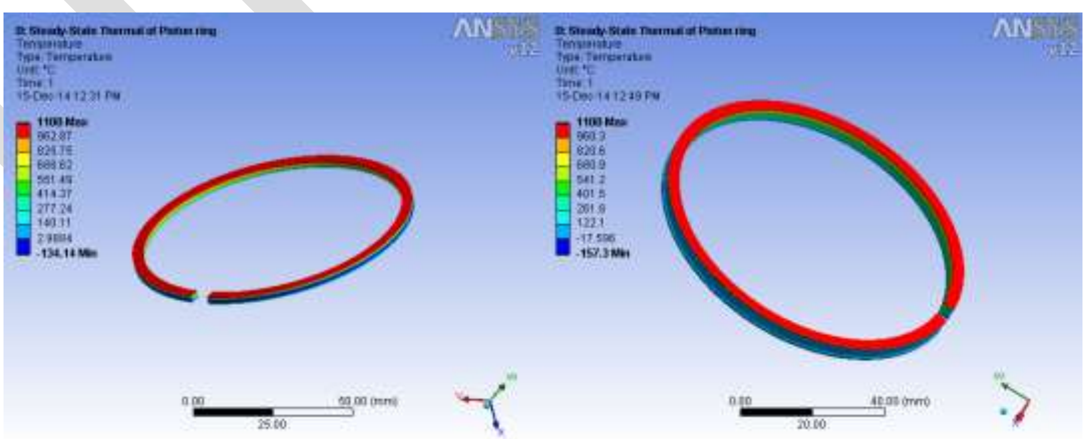

FIGURE 8.6 TEMPURATURE DISTRIBUTION OF UNCOATED RINGS

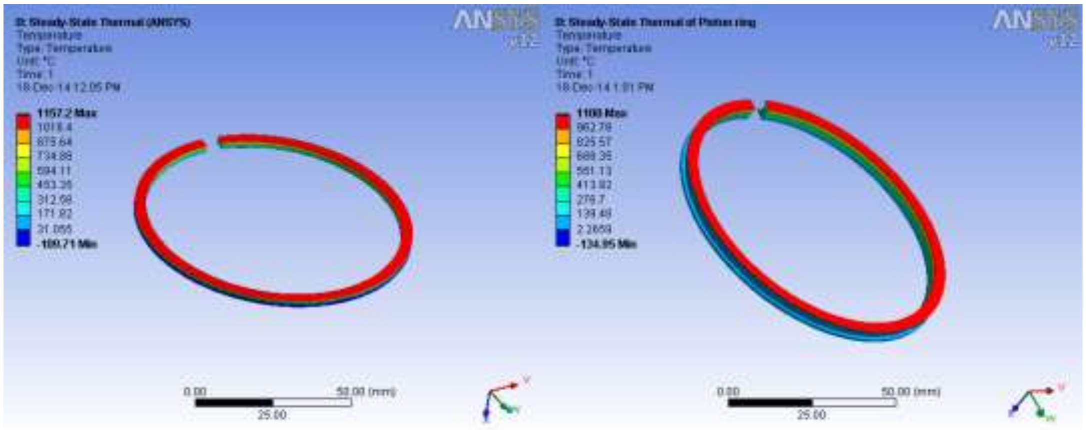

FIGURE 8.6 TEMPURATURE DISTRIBUTION OF COATED PISTON RINGS

8.9 TOTAL HEAT FLUX

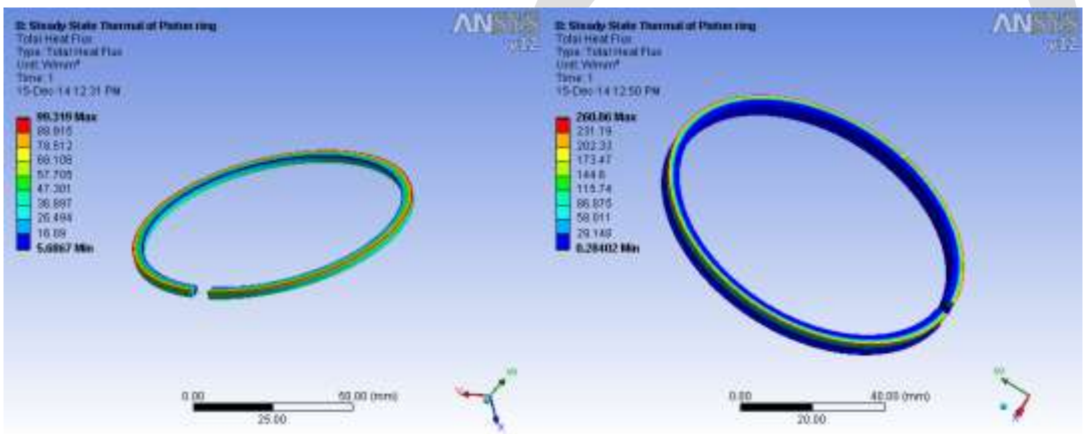

FIGURE 8.7 TOTAL HEAT FLUX DISTRIBUTION ON UNCOATED PISTON RINGS

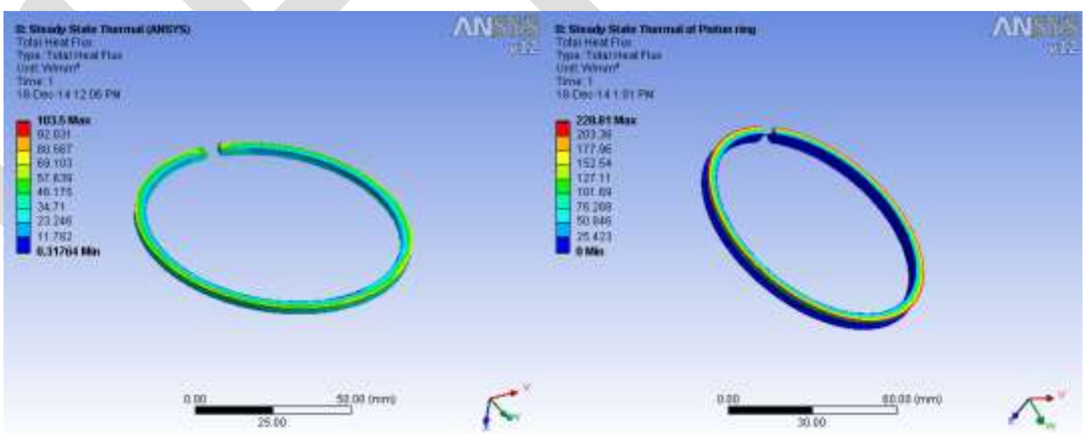

FIGURE 8.8 TOTAL HEAT FLUX DISTRIBUTION ON COATED PISTON RINGS

9. MODAL ANALYSIS

This analysis is used to determine the vibration characteristics (natural frequencies and modal shapes) of a structure during the design stage itself.

1. Total Deformation

9.1 Boundary Conditions

The Boundary conditions given for the Thermal Analysis of the Piston are as follows:

- Friction less support for the inner and outer sides of the ring pack in order to study the mode of frequency generated during this analysis

TOTAL DEFORMATION

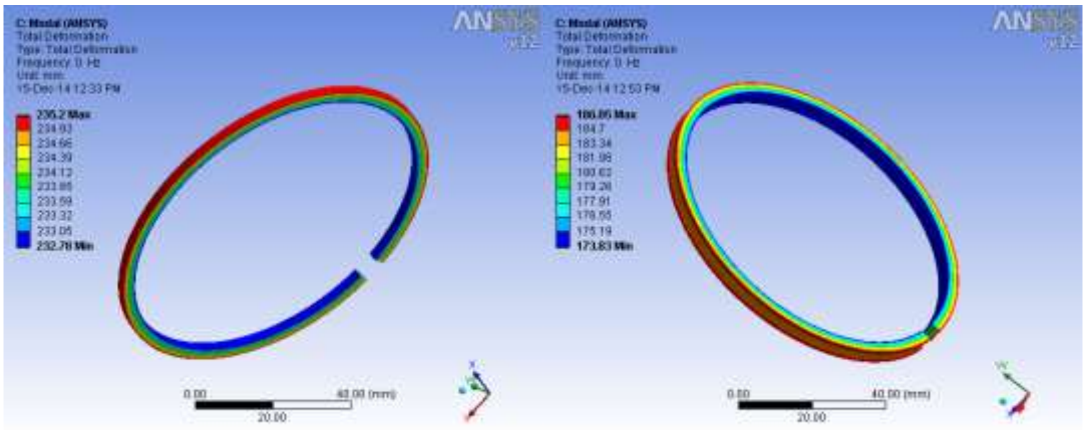

FIGURE 8.9 TOTAL DEFORMATION IN UNCOATED PISTON RINGS

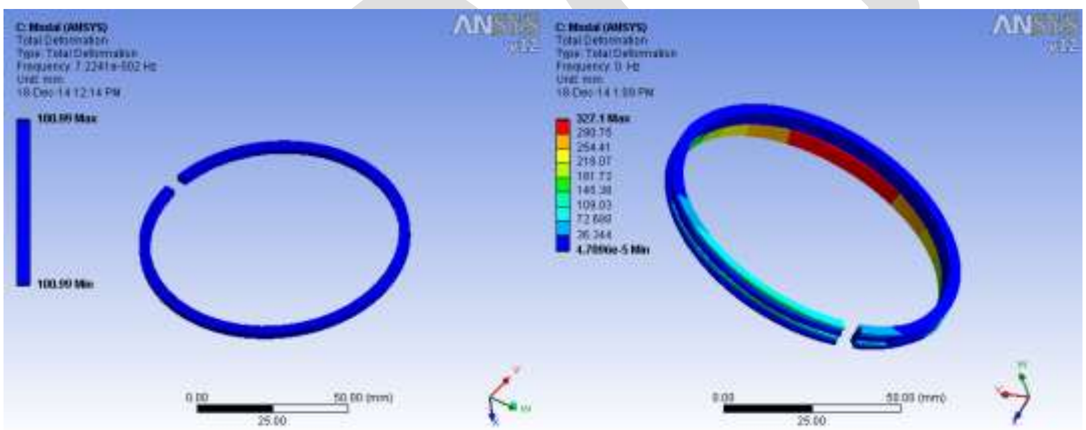

FIGURE 8.10 TOTAL DEFORMATION IN COATED PISTON RINGS

10. COMPARISON OF RESULTS

Based on the pressure load, friction less support, convection are applied on the piston after applying thermal loads, the Von Mises stresses, deformation, on mises strain, vibration and displacement values are calculated and compare between the results of uncoated and coated piston ring pack. The graphs plotted below contain the values obtained from the analysis. Plotting makes us easy to understand and prioritize the requirement.

STATIC STRUCTURAL ANALYSIS

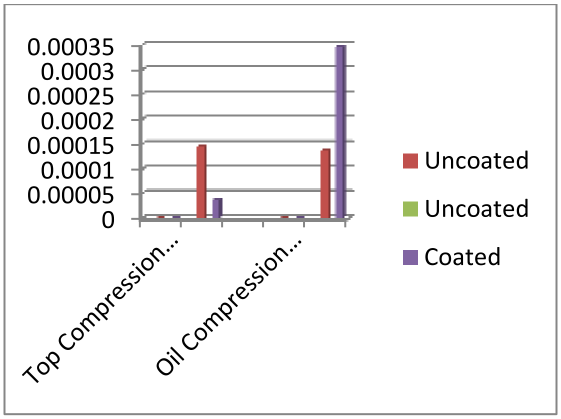

FIGURE 10.1 DEFORMATION IN THE COATED AND UNCOATED RING PACKS

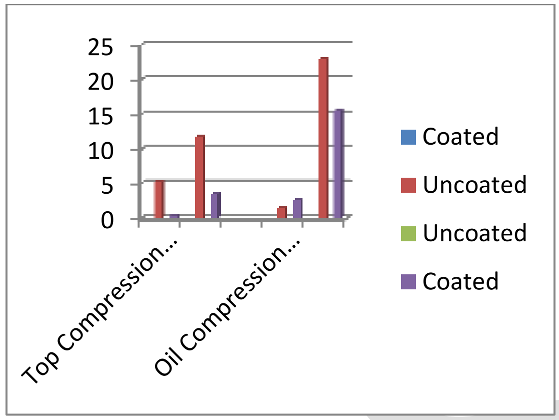

FIGURE 10.2 STRESS DISTRIBUTIONS IN UNCOATED AND COATED RING PACKS

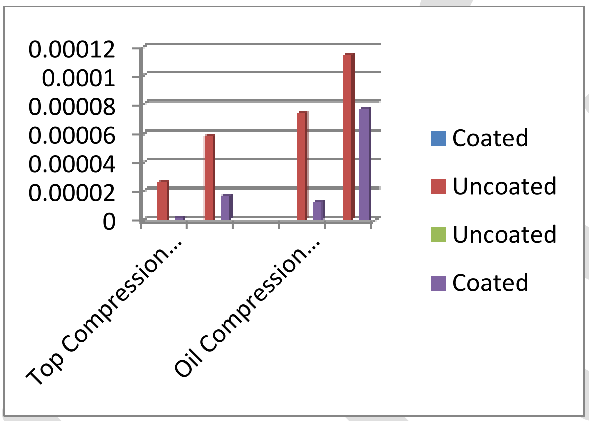

FIGURE 10.3 STRAIN CONCENTRATION IN UNCOATED AND COATED RING PACKS

THERMAL ANALYSIS

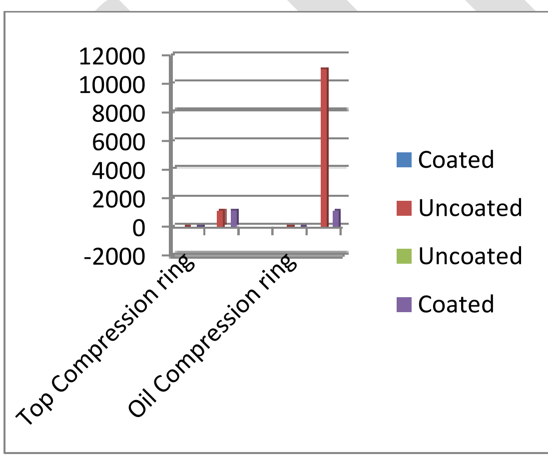

FIGURE 10.4 TEMPURATURE DISTRIBUTIONS IN UNCOATED AND COATED RING PACKS

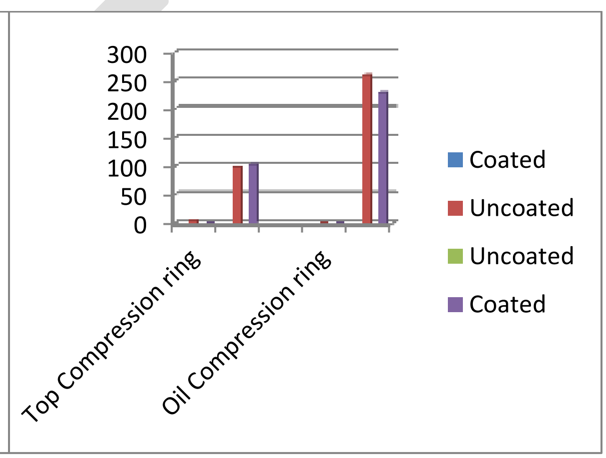

FIGURE 10.5 TOTAL HEAT FLUX PRODUCED ON UNCOATED AND COATED RING PACKS

MODAL ANALYSIS

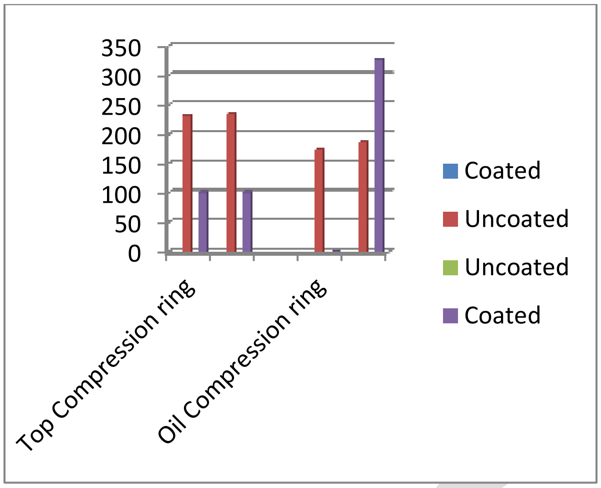

FIGURE 10.6 DEFORMATION PRODUCED ON UNCOATED AND COATED RING PACKS

11. CONCLUSION

From the above analysis and plotted graphs, we can achieve some results based on it. Some are:

- It is observed that maximum deformation occurs on the top face and sides of the piston rings. This is due to scuffing and wear losses that occur during running conditions.
- Tempurature distribution in the piston ring shows that maximum tempurature occur on the face towards the chamber and next tempurature occur on the sides which are in contact with cylinder wall.

Thus, high refractoriness and high lubricancy is nessasary for the coating which we are about to be prepared on it. Multilayer coating consisting Calcia-Partially Stabilized Zirconia, Magnesia-Partially Stabilized Zirconia, Silicon Dioxide, Diamond like carbon which sounds to be effective under such extreme conditions.

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