Analysis of Piston and Cylinder Assembly by Using FEM

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Abstract— **In this present work a piston, piston ring and cylinder are designed for a single cylinder four stroke petrol engine using PRO-E Wildfire 5.0 software. Complete design is imported to ANSYS 14.0 software and then analysis is performed. There is three different materials have been selected for structural analysis of piston and for piston ring two different materials are selected and structural analysis is performed using ANSYS 14.0 software. Results are shown and a comparison is used to find the most suited design and most suited material for both piston and piston ring in order to improve the life and minimize the wear of the both.**

Key words: Piston, Piston-Ring, PRO-E, ANSYS.

I. Introduction

The engine can be called the heart of a automobile and the piston may be considered the most important part of an engine. Piston assembly consists of the piston rings mounted on the groove of the piston body while it is in motion, there are many contacting surfaces subjected to sliding with reasonable loads and speeds. Such a simultaneous action of sliding and reciprocation leads to the wear and tear of the ring, cylinder liner and piston. So it is necessary to improve the life and minimize the wear of the both. P.C. Mishra [1] have explained in the paper entitled " Finite Element Analysis for Coating Strength of a Piston Compression Ring in Contact with Cylinder Liner: A Tribodynamic analysis" he conclude that to reduce the wear and to enhance the ring and liner life, ceramic coatings are provided on the surface of such contact pairs. Paper uses a finite element method to analyze the coating strength of a compression ring at compression and power stroke transition, where peak combustion pressure is higher than other crank positions. Simon C. Tung, et.al. [2] have explained in the paper entitled "Modeling of Abrasive Wear in a Piston Ring and Engine Cylinder Bore System" Modeling of the wear progression of the piston ring/cylinder bore system is critical for advancing engine-related technologies. Based on a laboratory simulator, a three-body abrasive wear model has been developed to model the wear progression of the piston ring/cylinder bore system during steady-state operation. Isam Jasim Jaber.et.al. [3] have explained in the paper entitled "Design And Analysis Of I.C. Engine Piston And Piston-Ring Using Catia And Ansys Software" using CATIAV5R20 software design and modeling become easier. Only few steps are needed to make drawing in three dimensions. Same can be imported to ANSYS for analysis. Piston made of three different materials Al alloy 4032, AISI 4340 Alloy steel and Titanium Ti-6Al-4V (Grade 5) are analyzed. Bhavik b.hirapara, et.al [4].have explained in the paper entitled "A Technical Research on Piston Ring Coating of Single Cylinder Four Stroke SI Engine Fuelled with Compressed Natural Gas" Reducing exhaust emission and improving engine performance. The wear resistance of thermal sprayed molybdenum applicable to the piston ring is studied in this research. Wear resistance of molybdenum coated piston ring is high as compared to ordinary cast iron piston rings. Rahul D. Raut1, et.al [5].have explained in the paper entitled," Stress Optimization of S.I. Engine Piston" The performance of any automobile largely depends on its size and working in dynamic conditions. The piston is a "heart" of the engine and its working condition is the worst one of the key parts of the engine in the working environment. The good design of the piston optimization can lead to a mass reduction on the base of stress analysis satisfying the requirements of automobile specifications with cost and size effectiveness. M.Srinadh, et.al. [6]have explained in the paper entitled "Static and Thermal Analysis of Piston and Piston Rings " to designed a piston for 1300cc diesel engine car and taken 3 different profile rings .A 2D drawing is created from the calculations. The piston and piston rings are modeled using Pro/Engineer software; the stress and displacement are analyzed for the piston and piston rings by applying pressure on it in Structural analysis.

So this work represents three different materials have been selected for structural analysis of piston and for piston ring two different materials are selected and structural analysis is performed by using ANSYS 14.0 software. Results are shown and a comparison is used to find the most suited design and most suited material for both piston and piston ring in order to improve the life and minimize the wear of the both.

A. Objectives: Following are the objectives,

1- To design an IC engine (piston,piston ring and cylinder) by using theoretical design method.

2-To create a geometrical modeling and assembly by using modeling software PRO-E.

3- To perform the structural analysis (of piston and piston ring) using ANSYS14.0software.

4-To find out best suitable material for both piston and piston ring to improve its tribological properties.

B. Methodology

1. Theoretical Design calculation of piston, Piston ring and cylinder.
2. Create a 3D model and assembly of piston, piston ring and cylinder for two stroke engine using PRO-E software
3. Develop a Finite Element Model by using ANSYS 14.0
4. Analyze piston, piston ring and cylinder using static structural analysis method and optimize the model for wear reduction.

II. GEOMETRICAL MODELING

Theoretical design is done by using a book of Machine design by R.S.Khurmi ,J.K.Gupta and V.B.Bhandari book, dimensions are calculated and these are used for modeling .The piston, piston rings and cylinder with assembly were modeled by using solid modeling software PRO-E as shown in Fig 1,2and 3 respectively and designed dimensions are shown in table -I[3]and table II shows designed dimensions of cylinder.

TABLE I-Designed dimensions of piston and piston ring

Sr. No.	Design- Dimensions	Size in mm
1	Length of the Piston (L)	70
2	Cylinder bore / Outside diameter of the piston (D)	60
3	Radial thickness of the ring (t1)	2.1
4	Axial thickness of the ring (t2)	2
5	Maximum thickness of barrel (t3)	8.8
6	Thickness of piston head or crown (tH)	5.8
7	Width of the top land (b1)	5.8
8	Width of other ring lands (b2)	1.5

TABLE II- Designed dimensions of Cylinder

Sr. No.	Design- Dimensions	Size in mm
1	Inner diameter	60
2	Outside diameter of the cylinder (D)	66.8
3	Length of cylinder	100
4	Collar diameter	68
5	Collar width	10

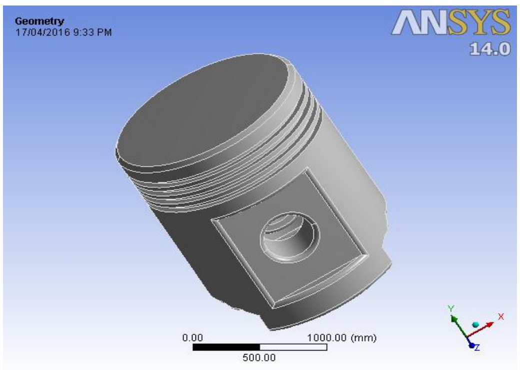

Fig.1. PRO-E Model of Piston

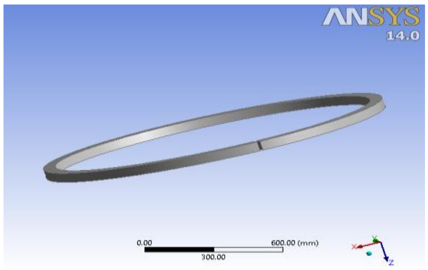

Fig. 2. PRO-e Model of Piston ring

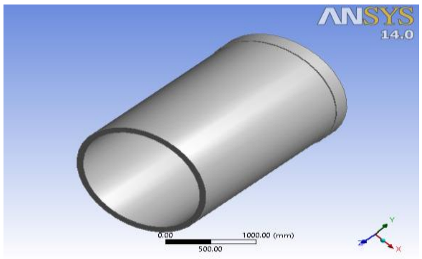

Fig.3.PRO-E Model of Cylinder

All these are assembled in PRO-Esoftware and same copy is saved into .igs format and then it is imported to ANSYS 14.0 for structural analysis. Structural analysis of piston and piston ring assembled with cylinder is performed on ANSYS 14.0 workbench.

III. FINITE ELEMENT ANALYSIS

A) Material Properties-

1) For Piston

TABLE III-Piston Material properties

Properties	Al Alloy 4032	AISI 4340 Alloy steel	Titanium Ti6AL4V
Poissons ratio	0.35	0.28	0.342
Thermal Conductivity w/mk	155	44.5	6.7
Ultimate tensile strength(Mpa)	380	745	950
Yield tensile strength MPa	315	470	880
Density g/cc	2.68	7.8	4.43
Modulus of elasticity(GPa)	79	210	113.8

2) For piston Ring

TABLE IV-Piston ring Material properties

Properties	Ductile nodular spheroidal cast iron	ASTM grade 50 ISO Grey cast iron
Poissons ratio	0.275	0.26
Modulus of elasticity(GPa)	176	157
Thermal Conductivity w/mk	380	46
Ultimate tensile strength(Mpa)	414-827	362
Yield tensile strength MPa	240 – 621	228
Density g/cc	7.2	7.1

3) For Cylinder

TABLE V-Cylinder Material properties

Properties	Grey Cast Iron
Poissons ratio	0.28
Modulus of elasticity(GPa)	110
Thermal Conductivity w/mk	380
Ultimate tensile strength(Mpa)	240
Yield tensile strength MPa	200
Density g/cc	7.2

B. Connections-

Along with piston, piston ring is sliding in contact with cylinder liner so it is need to define the contact region between piston ring and cylinder liner, so fig 4. Represents there is frictional sliding contact between outer periphery of the ring and inner wall of cylinder.

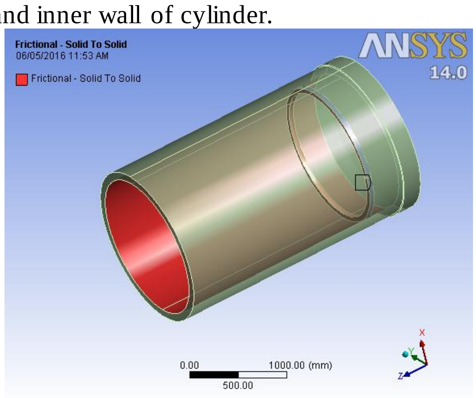

Fig.4. Frictional contact

C. Meshing-

Mesh generation is called pre-processing for finite element method. Use automatically generates finite element mesh.

Technical details of meshed as given in table VI, and mesh models of piston, piston ring and cylinder as shown in figure 5, 6 and 7 respectively.

TABLE VI-Mesh details

Details	Types/numbers
Physical preference	mechanical
Sizing	fine mesh generated
Smoothing	medium
Transition	fast
Span angle method	coarse
Minimum edge length	50.80mm
Inflation	smooth
Transition ratio	0.272
Maximum layer	5
Growth rate	1.2
Total nodes	36698
Total elements	18974

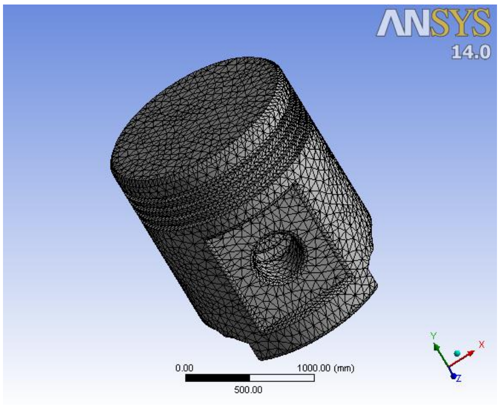

Fig.5. Meshed Model of Piston

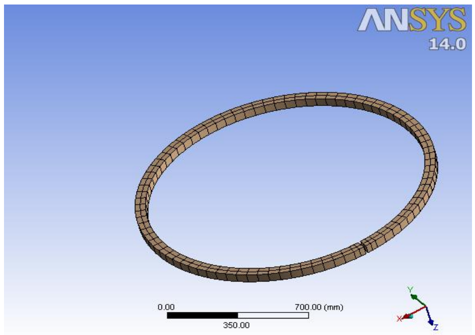

Fig.6. Meshed Model of Piston ring

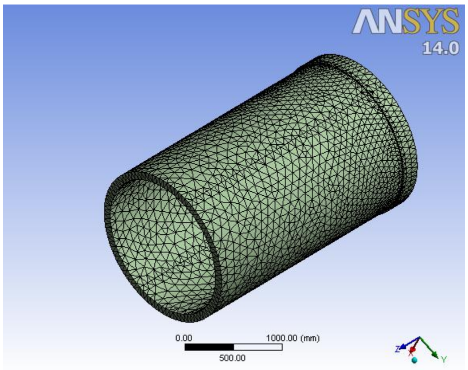

Fig. 7. Meshed Model of cylinder

D. Boundary Conditions

1. for Piston

Combustion of gases during the combustion in combustion chamber will exert pressure on the head of the piston during power stroke. The pressure force will be taken as boundary condition in structural analysis using ANSYS workbench. Fixed support has been given at surface of pin hole. because the piston will move from TDC to BDC with the help of fixed support at pin hole. So whatever the load is applying on piston due to gas explosion that force causes to failure of piston pin (inducing bending stresses). Pressure acting on piston = 1.84 N/mm^2 as shown in Fig.8. [3],[4],[6]

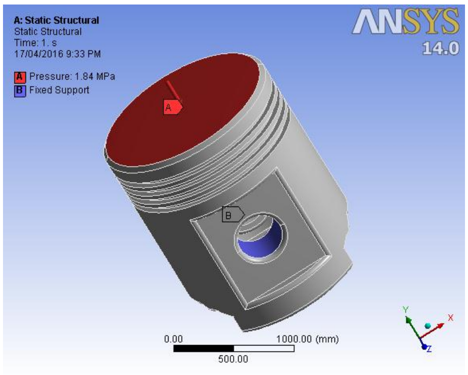

Fig. 8.Boundary conditions of Piston

2. for Piston Ring

After combustion of gases it will also act the pressure on top side on the piston ring and also some gas are passing through inner side of the ring and exerts the pressure against the cylinder liner. As the piston ring moves with piston from TDC to BDC so displacement is also given at the outer periphery of the piston ring as sown in fig. 9.

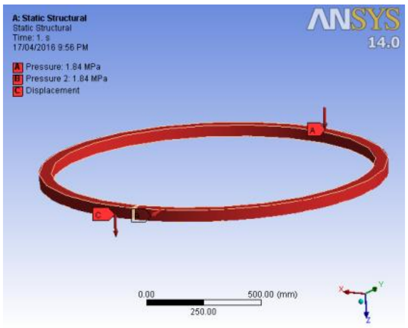

Fig.9. Boundary conditions for piston ring

3. for cylinder

As the piston is moved inside the cylinder from TDC to BDC so cylinder is fixed hence fixed support is given on all outer faces of the cylinder as a boundary condition as shown in fig.10

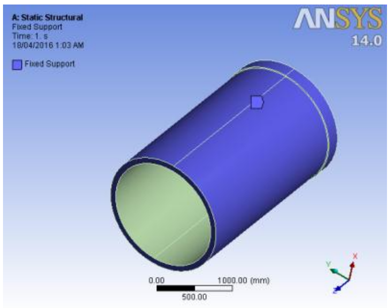

Fig. 10. Boundary conditions for cylinder

IV. RESULTS AND DISCUSSION

It is clear from fig. 11, 14 and 17 that the maximum total deformation is observed in the piston made of Al alloy 4032 i.e 0.3392mm and minimum in AlSl 4340 alloy steel i.e. 0.0144mm. As it is expected maximum deformations is observed at the top of the centre of the piston. It is shown in the figure 11, 14 & 17 that the maximum stress intensity is observed in AlSl 4340 alloy steel with 31.825 MPa and minimum in Al alloy 4032 with 31.394 MPa. It is observed that the maximum stress intensity is on the bottom surface of the all piston crown and along the edges. Again in piston made of titanium alloy moderate stress intensity is found. Whereas the yield strength of the piston is very high in Titanium alloy piston followed by AISI4340 steel and Al alloy 4032.

A. For Piston Material (Al Alloy4032)

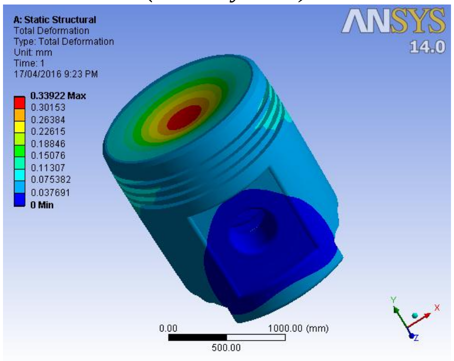

Figure 11-Total deformation for Al Alloy 4032

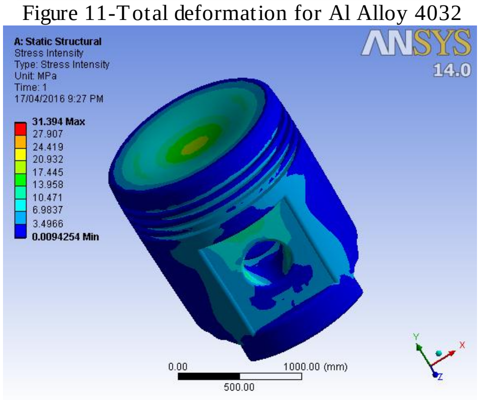

Fig. 12.Stress intensity for Al Alloy 4032

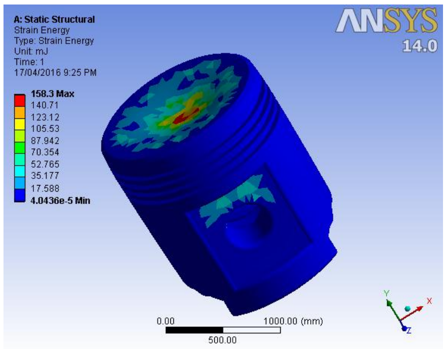

Fig. 13.Strain energy for Al Alloy 4032

B. For Piston Material (AISI 4340 Alloy Steel)

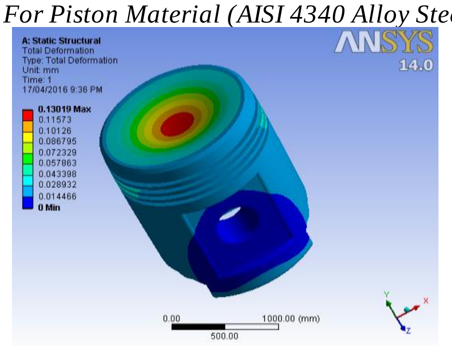

Fig. 14.Total deformation for AISI 4340 Alloy Steel

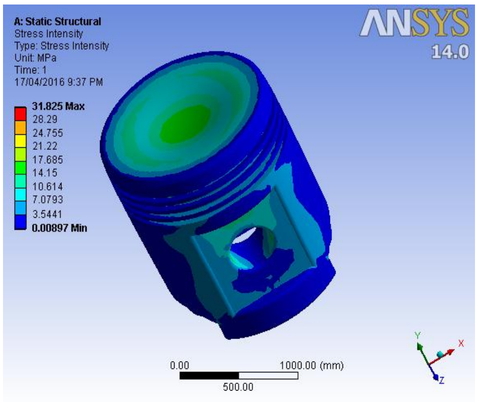

Fig. 15.Stress intensity for AISI 4340 Alloy Steel

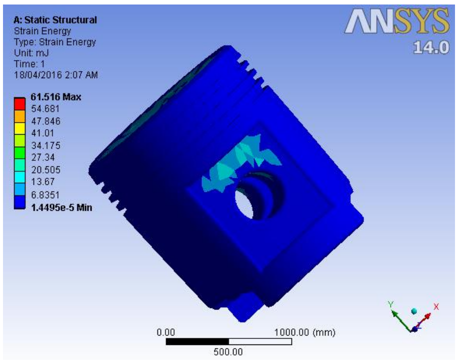

Fig. 16.Strain energy for AISI 4340 Alloy Steel

C. For Piston Material (Titanium Ti6Al4V)

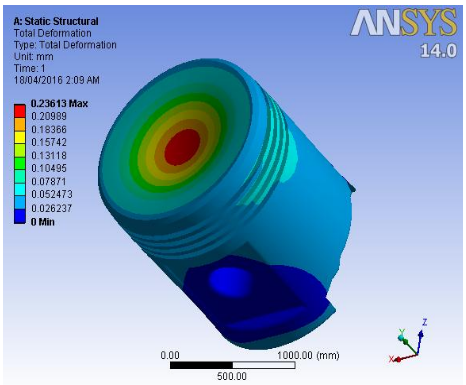

Fig. 17.Total deformation for Titanium Ti6Al4V

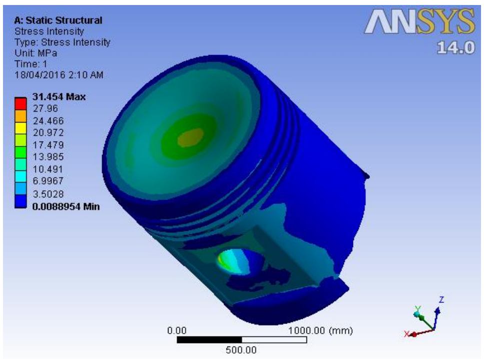

Fig. 18.Stress intensity for Titanium Ti6Al4V

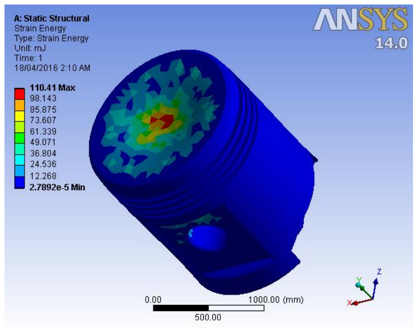

Fig. 19.Strain energy for Titanium Ti6Al4V

D. for Piston ring Material Ductile nodular spheroidal cast iron

From fig. 20 and 25 maximum total deformation is observed in piston ring having material ASTM grade 50 ISO Grey cast iron i.e. 0.19mm whereas minimum deformation observed in ring having material Ductile nodular spheroidal cast iron i.e. 0.002 mm and corresponding wear maximum for Ductile nodular spheroidal cast iron is 0.33mm and minimum wear observed in ASTM grade 50 ISO Grey cast iron is 0.016mm.

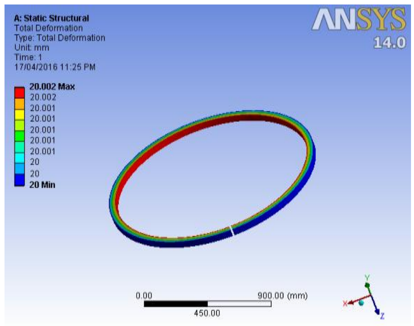

Fig. 20.Total deformation for Ductile nodular spheroidal cast iron

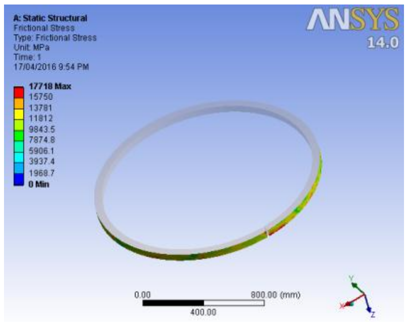

Fig. 21.Frictional stress for Ductile nodular spheroidal cast iron

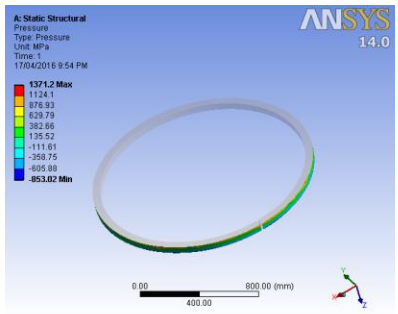

Fig. 22.Pressure distribution for Ductile nodular spheroidal cast iron

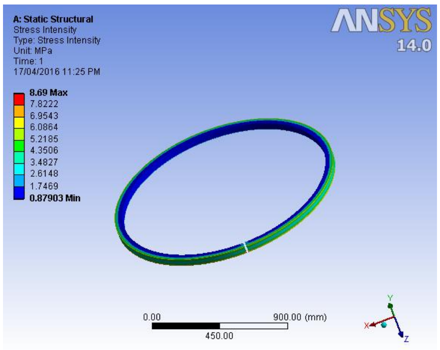

Fig. 23.Stress intensity for Ductile nodular spheroidal cast iron

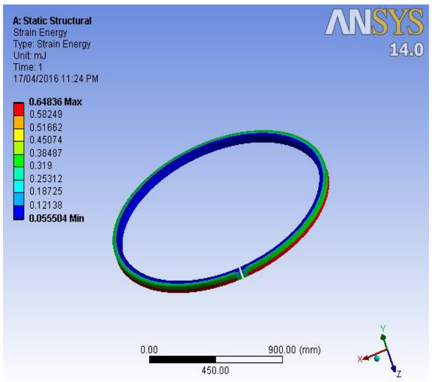

Fig. 24.Strain energy for Ductile nodular spheroidal cast iron

E. for Piston ring Material ASTM grade 50 ISO Grey cast iron

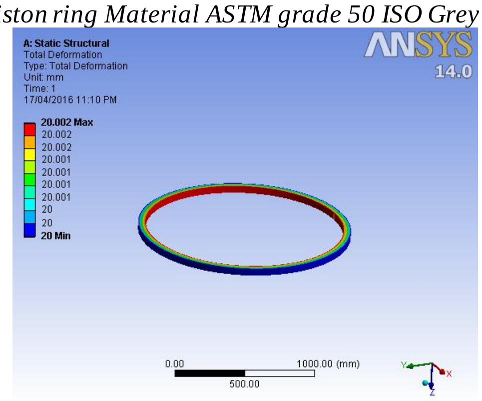

Fig. 25.Total deformation for ASTM grade 50 ISO Grey cast iron

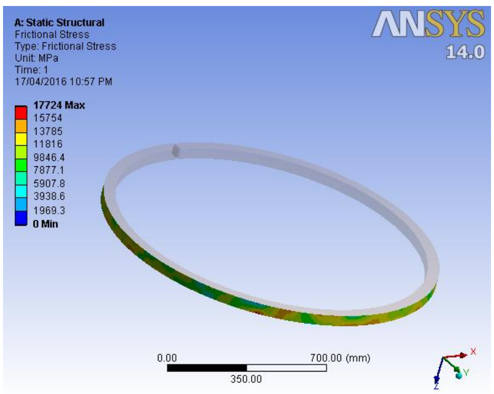

Fig. 26.Frictional stress for ASTM grade 50 ISO Grey cast iron

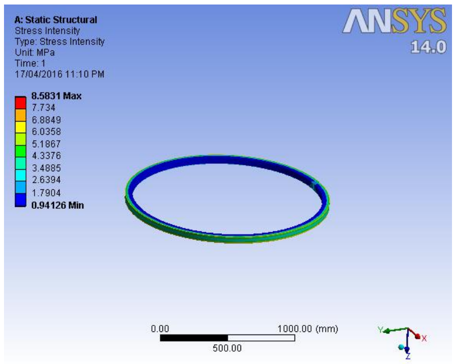

Fig. 27.Stress intensity for ASTM grade 50 ISO Grey cast iron

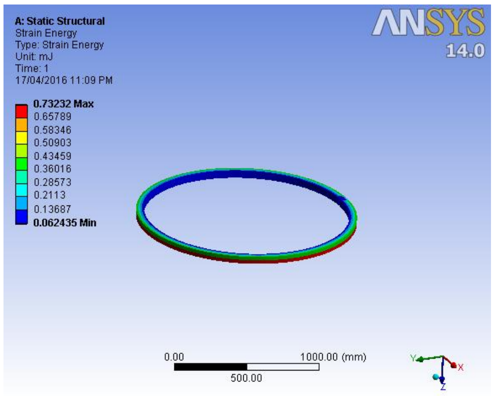

Fig. 28.Strain energy for for ASTM grade 50 ISO Grey cast iron

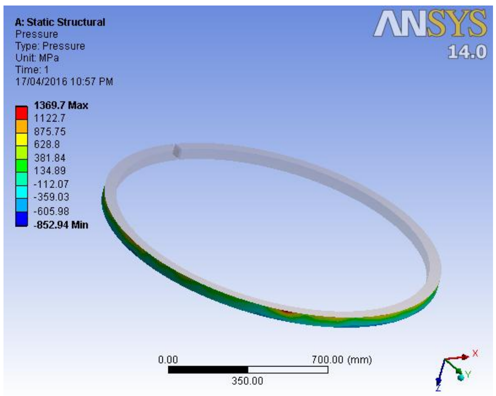

Fig. 29.Pressure distribution for for ASTM grade 50 ISO Grey cast iron

From fig. 22 and 29 we are getting the value of pressure distribution on frictional contact region i.e Ductile nodular spheroidal cast iron material shows maximum pressure of 13.71 Mpa and ASTM grade 50 ISO Grey cast iron shows minimum pressure of 6.05 Mpa from above value of pressure we can calculate wear response as below, According to Archard's Wear equation. [10]

Response Wear(d∂)=k.Pc.Ds (1)

d∂ = incremental change insurface position due to wear in the direction perpendicular to the contact surface

Pc=Contact pressure in KN/m2,Ds=sliding distance in mm

K= Wear coefficient

By using equation 1,

Sample calculation for wear

$d\partial = k.Pc.Ds$
$= 0.2*137.1*12.04$
$= 0.330mm$

V. RESULT TABLE

A. For Piston

TABLE VII –Structural analysis of piston

Properties	Total deformation (mm)		Stress intensity (Mpa)		Strain energy (MJ)	
materials	Max.	Min.	Max.	Min.	Max.	Min.
Al Alloy 4032	0.3392	0.037691	31.394	0.00942	158.3	$4.04*10^{-5}$
AISI 4340 Alloy steel	0.13019	0.014466	31.825	0.00897	61.516	$1.44*10^{-5}$
Titanium Ti6Al4V	0.23613	0.026237	31.454	0.008894	`110.41	$2.79*10^{-5}$

B. For Piston Ring

TABLE VIII- Structural analysis of piston ring

Properties	Total deformation (mm)		Stress intensity (Mpa)		Wear (mm)	
Materials	Max.	Min.	Max.	Min.	Max.	Min.
Ductile nodular spheroidal cast iron	0.19	0	8.58	0.94	0.330	0.0161
ASTM grade 50 ISO	0.022	0	8.69	0.87	0.320	0.016

Same results are plotted on graph showing deformation vs different materials for piston Fig. 30 shows maximum deformation observed in Al Alloy while minimum deformation on material AISI 4340 Alloy steel .

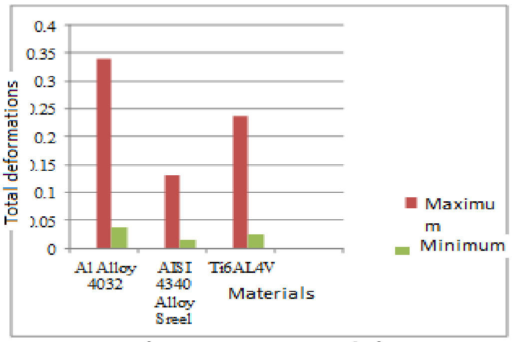

Fig. 30 Deformations vs. materials for Piston

Fig. 31 showing deformation vs different materials for piston ring shows maximum deformation observed in material Ductile nodular cast iron while minimum deformation on material ASTM G50 grey CI.

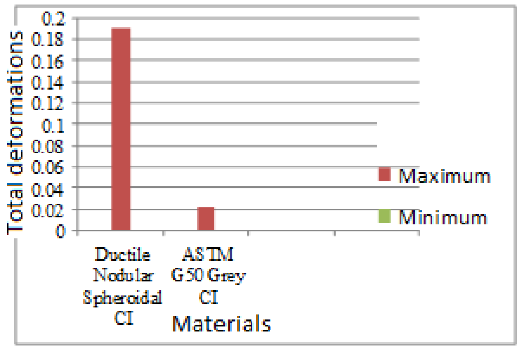

Fig. 31 Deformations vs. materials for Piston ring

Fig.32 showing Wear vs. different materials for piston ring shows maximum wear observed in material Ductile nodular cast iron while minimum wear on material ASTM G50 grey CI.

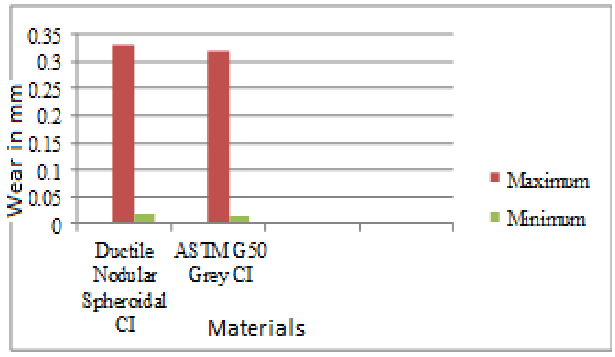

Fig. 32 -Wear vs. materials for Piston Ring

VI. CONCLUSIONS

1. From above work it is concluded that the most suitable material for piston is Al Alloy because the same material shows the minimum stress intensity for considered pressure.
2. Most suitable material for piston ring is ASTM grade 50 grey cast iron shows minimum wear value.
3. Piston made of three different materials Al alloy 4032, AISI 4340 Alloy steel and Titanium Ti-6Al-4V (Grade 5) are analyzed. Their structural analysis shows that the maximum total deformation and stresses is on the top surface of the piston.

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