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DESIGN AND ANALYSIS OF I.C. ENGINE PISTON AND PISTON-RING USING CATIA AND ANSYS SOFTWARE

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ABSTRACT

In this present work a piston and piston ring are designed for a single cylinder four stroke petrol engine using CATIA V5R20 software. Complete design is imported to ANSYS 14.5 software then analysis is performed. Three different materials have been selected for structural and thermal analysis of piston. For piston ring two different materials are selected and structural and thermal analysis is performed using ANSYS 14.5 software. Results are shown and a comparison is made to find the most suited design.

Key words: Piston, Piston-Ring, CATIA, ANSYS.

INTRODUCTION

The modern trend is to develop IC Engine of increased power capacity. One of the design criteria is the endeavor to reduce the structures weight and thus to reduce fuel consumption. This has been made possible by improved engine design. These improvements include increased use of light-weight materials, such as advanced ultra-high tensile strength steels, aluminum and magnesium alloys, polymers, and carbon-fiber reinforced composite materials. The integration of lighter weight materials is especially important if more complex parts can be manufactured as a single unit. In the next 10–20 years, an additional 20–40% reduction in overall weight, without sacrificing safety, seems to be possible. Cuddy et al (1997) have reported that for every 10% weight reduction of the vehicle, an improvement in fuel consumption of 6–8% is expected. Improved engine design requires optimized engine components. Therefore sophisticated tools are needed to analyze engine components. Engine piston is one of the most analyzed components among all automotive or other industry field components. The engine can be called the heart of a automobile and the piston may be considered the most important part of an engine. Many sophisticated Aluminum piston analysis methods have been reported in the past years. Silva 2006 has analyzed fatigue damaged piston**.** Damages initiated at the crown, ring grooves, pin holes and skirt are assessed. An analysis of both thermal fatigue and mechanical fatigue damages is presented and analyzed in this work. A linear static stress analysis, using ‘‘cosmos works’’, is used to determine the stress distribution during the combustion. Stresses at the piston crown and pin holes, as well as stresses at the grooves and skirt as a function of land clearances are also presented. Buyukkaya et al (2007) has investigated a conventional (uncoated) diesel piston, made of aluminum silicon alloy and steel. He has performed thermal analyses on pistons, coated with MgO–ZrO_2 material by means of using a commercial code, namely ANSYS. Finally, the results of four different pistons are compared with each other. The effects of coatings on the thermal behaviors of the pistons are investigated. It has been shown that the maximum surface temperature of the coated piston with material which has low thermal conductivity is improved approximately 48% for the AlSi alloy and 35% for the steel. Saad et al. (2008) has done numerical analysis to analyze the stresses due to thermal cycle with different aluminum alloy of piston .Finite element method was used to evaluate the coupling field (thermal –stress) on the piston. ANSYS5.4 Finite element code is used to carry out the modeling process to determine the coupling stress .Two models with three dimensions are created .The first is used to evaluate the temperature distribution through the piston volume, and the second is used to evaluate the thermal stress distribution due to heat gradient and different materials. The result show the maximum range of temperatures is 4.3 °C and increases with decreasing of material thermal conductivity .Thermal stress is concentrated on the piston edges and depends on the material types. Gudimetal et al. (2009) has reported a CAD model of a damaged internal combustion (IC) engine piston and then has used the state-of-the-art ANSYS finite element analysis package to perform a linear static and a coupled thermal-structural analysis of the component. Further, a parametric evaluation of the material properties vis-à-vis operating conditions is carried out to generate a relational database for the piston to arrive at optimal design solutions under different operating conditions. Wang et al. (2010) has reported a solid model including piston and piston pin of a new designed piston by Pro/E software, and the finite element analysis model was also established by using ANSYS software. The thermo-mechanical coupling stress distribution and the deformation were firstly calculated. Considering the nonlinear material properties of piston and piston pin, the Newton-Raphson equilibrium iterative method is applied. Calculating results indicates that the maximum stress concentration is at the upper end of piston pin boss inner hole, and is mainly caused by the peak pressure of the fuel gas. Zeng et al. (2010) has setup a geometry model of a diesel engines piston in UG graphics. The temperature fields of the piston for burning diesel and DME separately are calculated using ANSYS 10.0. The result shows that the variation of the thermal load by substituting diesel with DME is still within the thermal strength of the material. The temperature of the DME fueled diesel engine decreases along the piston axis from top to bottom. The temperature of the piston of DME fueled engine increase as a whole comparing with burning diesel. However, the temperature field distribution has no significant change decreases and then increases from the combustion chamber center to the edge, and decreases again to the edge of the piston top. Durat. et al (2012) a steady-state thermal analysis was performed to evaluate the temperature gradients in the standard and two different partially stabilized ceramic coated pistons by using Abaqus© finite element (FE) software. A sharp increase in the temperature of the coated area of the piston was observed as a result of FE simulations. It is concluded that the annulus Y-PSZ coating may contribute better, as compared to Mg-PSZ, to decrease the cold start and steady state HC emissions without auto ignition, since the temperature in the area shows a local sharp increase. Junju et al. (2012) has tried to reduce the intensity of thermal and structural stresses by using the ceramic material Silicon Nitride as the material for piston crown (the top portion of the piston).As the crown material is brittle in nature and skirt material is ductile in nature. A ceramic reinforced fiber strip was introduced in between ceramic crown and Al alloy skirt to avoid failure of the ceramic crown due to its brittle nature when it is subjected to impact loads that are result of explosion of combustion gases. In this work Eutectic Al Alloy (Si 11-13%) was taken as piston material. Initially thermal and structural analysis was performed on Al Alloy piston without silicon nitride crown and then with silicon nitride crown using the software ANSYS. Then the results obtained are compared. The comparison of results indicated that the piston which is arranged by silicon nitride crown is better to withstand high thermal and structural stresses than the piston which is not arranged by silicon nitride crown. The present work has been undertaken with the following objective.

1- To design an IC engine (piston and piston ring) by using CATIA V5 R20 software

2- To perform the structural and thermal analysis (of piston and piston ring) using ANSYS 14.5 software.

Three different materials have been selected for piston and two different materials for piston rings.

MATERIALS AND THEIR PROPERTIES

For piston:

	Al alloy 4032	AISI4340 Alloy Steel	Titanium Ti-6Al-4V
Poisson ratio	0.35	0.28	0.342
Modulus of elasticity(GPa)	79	210	113.8
Thermal conductivity (w/m k)	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

For piston ring:

	Ductile Nodular Spheroidal cast iron	ASTM grade 50 (ISO grade 350, EN – JL 1060) Grey cast iron
Poisson ratio	0.275	0.26
Modulus of elasticity (GPa)	176	157
Thermal conductivity (w/m k)	33	46
Ultimate tensile strength MPa	414 – 827	362
Yield tensile strength (MPa)	240 – 621	228
DENSITY g/c.c	7.2	7.1

The piston and piston rings are designed according to procedures and specifications given in machine design and design data book. Dimensions are calculated and these are used for modeling the piston and piston ring in CATIA V5R20 as shown in Fig 1and Fig 2.

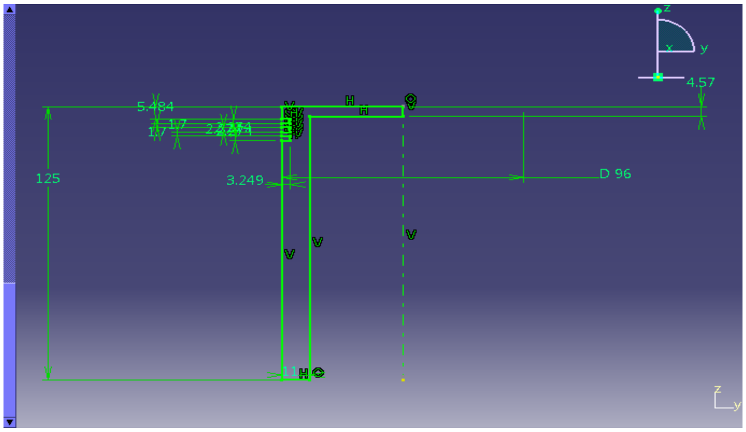

Fig.1 Piston Drawing and Dimensions

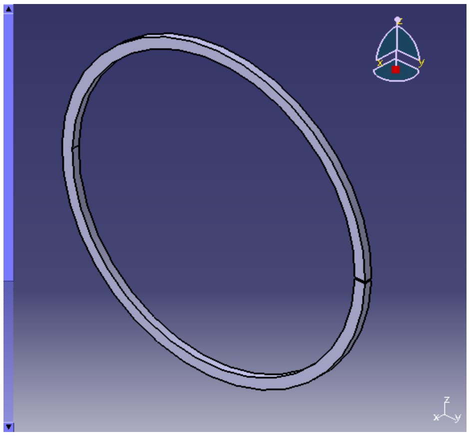

Fig. 2 Three D piston ring

These were then imported to ANSYS 14.5 for structural and thermal analysis. Structural analysis of piston is performed on ANSYS 14.5 mechanical APDL and thermal analysis is performed on ANSYS 14.5 workbench. Structural and thermal analysis of piston ring is performed on the ANSYS 14.5 workbench.

Boundary Conditions for Structural Analysis of Piston

Combustion of gases in the combustion chamber exerts pressure on the head of the piston during power stroke. The pressure force will be taken as boundary condition in structural analysis using ANSYS mechanical APDL. Fixed support has 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 = 3.3 N/mm^2 as shown in Fig.3.

Boundary Condition for Thermal Analysis of Piston

The thermal boundary conditions consist of applying a convection heat transfer coefficient and the bulk temperature, and they are applied to the piston crown, land sides, piston skirt shown in Fig. 4

Maximum on piston head temperature = 859.7 ^{0}C , Bulk temperature = 25^{0}C, Heat transfer coefficient on piston surface =3200 W/m^{2}K, Maximum temperature at edges piston = 482.7 ^{0}C, Heat transfer coefficient on edge piston = 2400 W/m^{2}K, Heat transfer coefficient on lands rings =1600 W/m^{2}K, Heat transfer coefficient on piston skirt = 1000 W/m^{2}K.

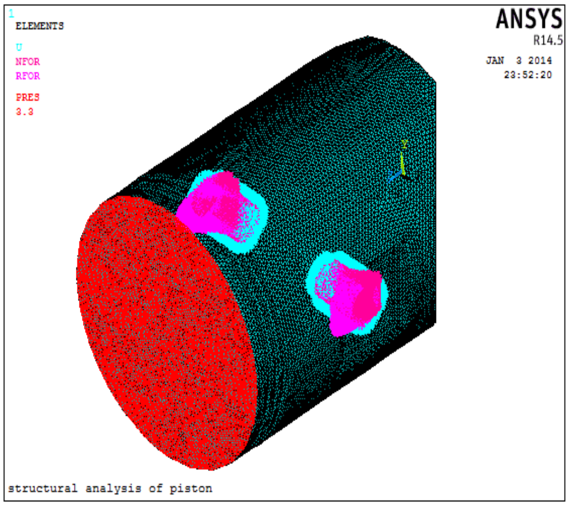

Fig.3 boundary condition of structural analysis

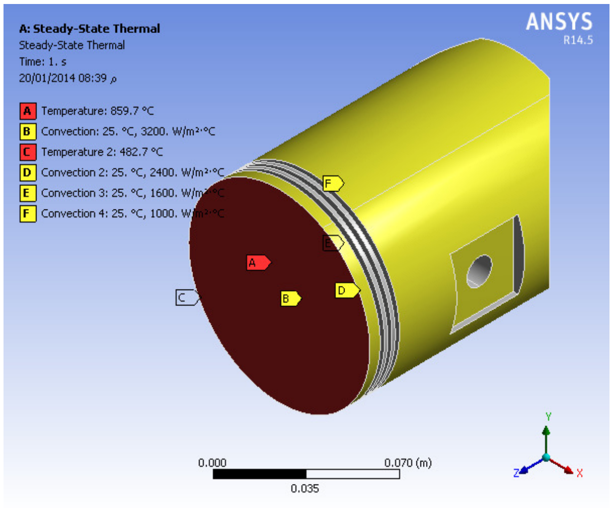

Fig.4 boundary condition for thermal analysis

Boundary Condition for Structural and Thermal Analysis of Piston Ring

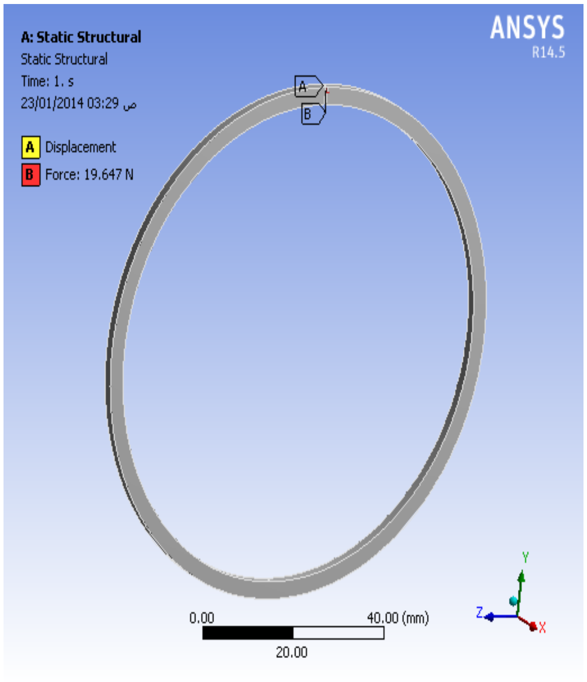

Fig.5 boundary condition for structural analysis

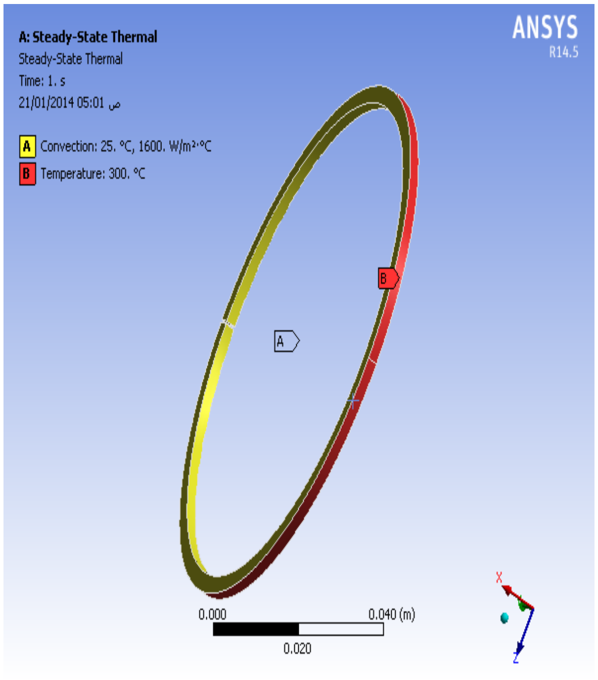

Fig.6 boundary condition for thermal analysis

RESULTS AND DISCUSSION

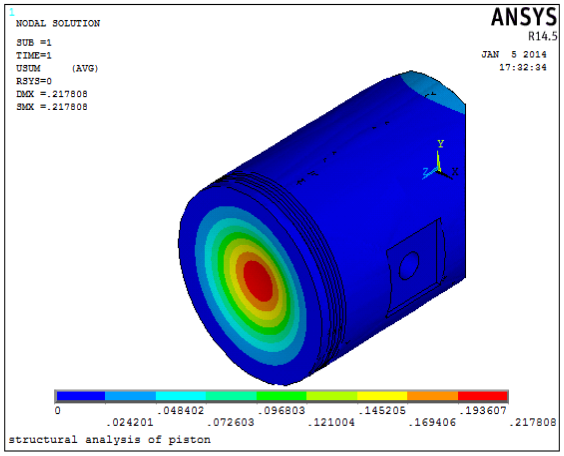

Fig. 7 Displacement vector sum for Al Alloy 4032

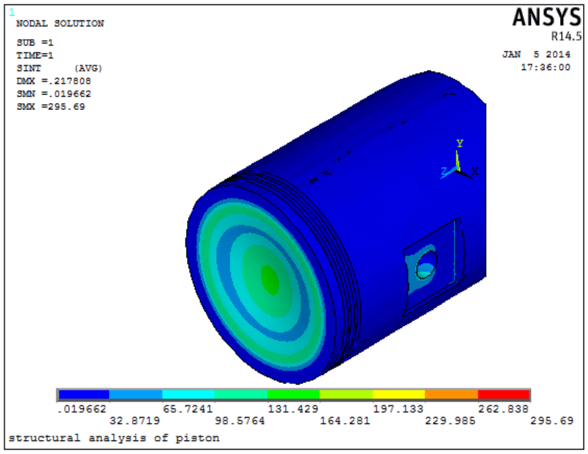

Fig .8 Stress intensity for Al Alloy 4032

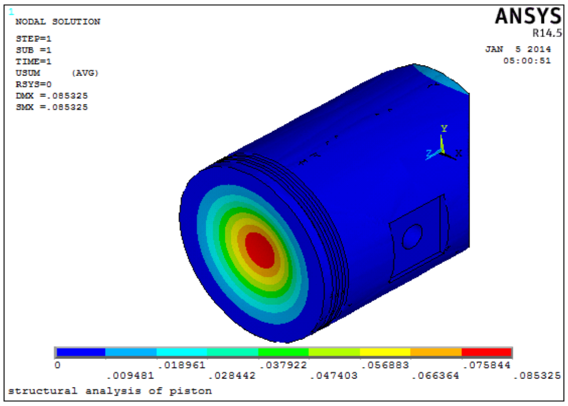

Fig.9 Displacement vector sum for Alloy Steel 4340

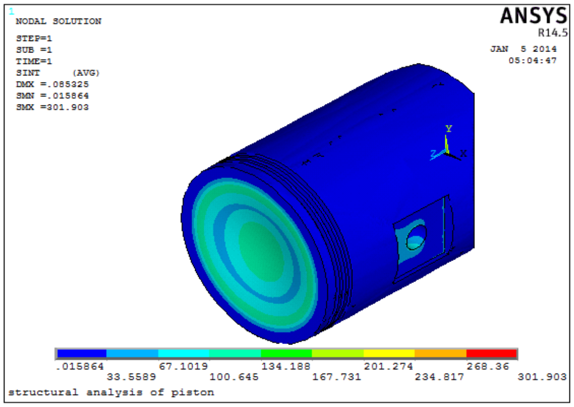

Fig.10 Stress intensity for Alloy Steel 4340

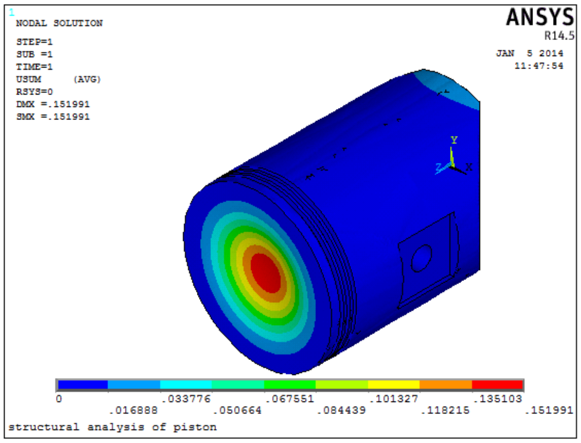

Fig.11 Displacement vector sum for Titanium Ti-6Al-4V

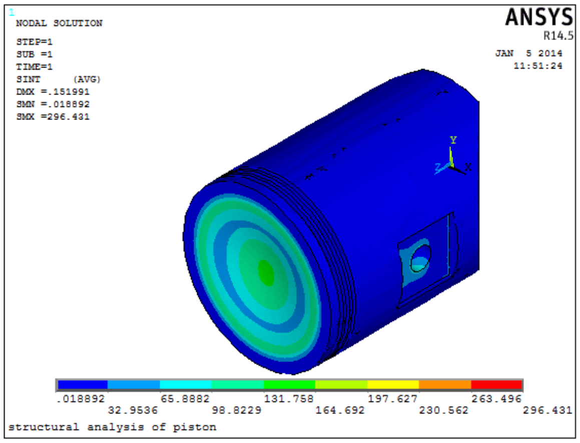

Fig.12 Stress intensity for Titanium Ti-6Al-4V

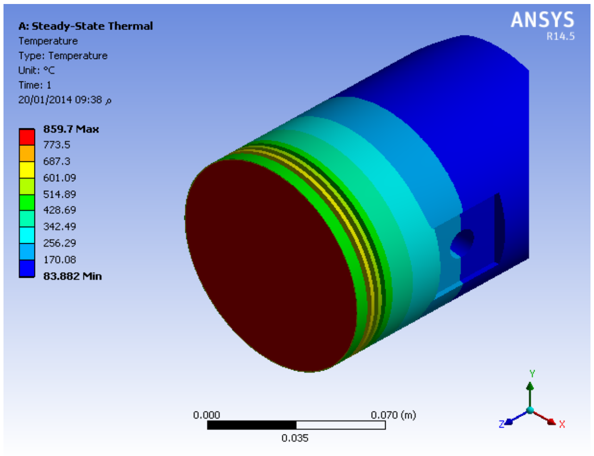

Fig.13 temperture for Al Alloy 4032

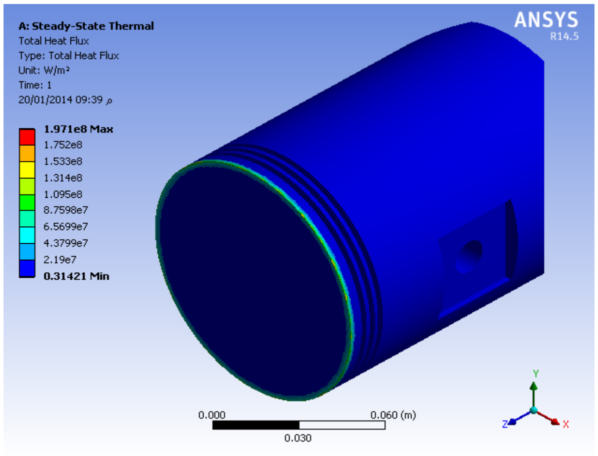

Fig.14 Heat flux for Al Alloy 4032

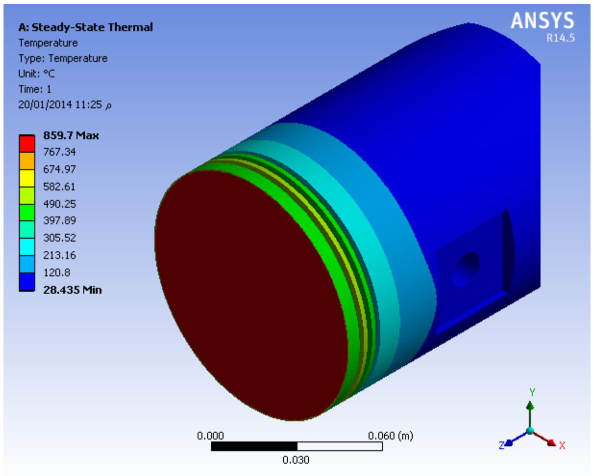

Fig.15 temperture for AISI Alloy Steel 4340

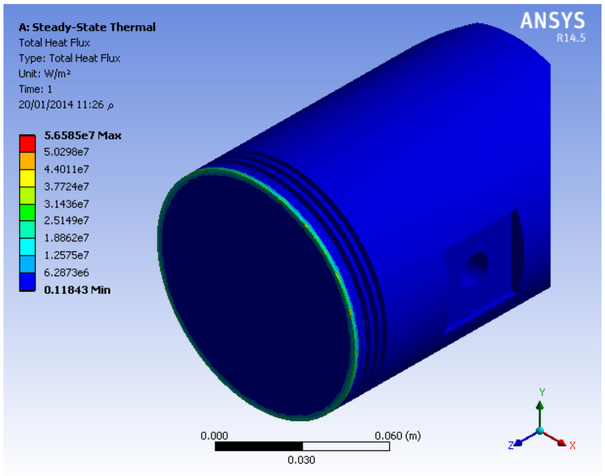

Fig.16 Heat flux for AISI Alloy Steel 4340

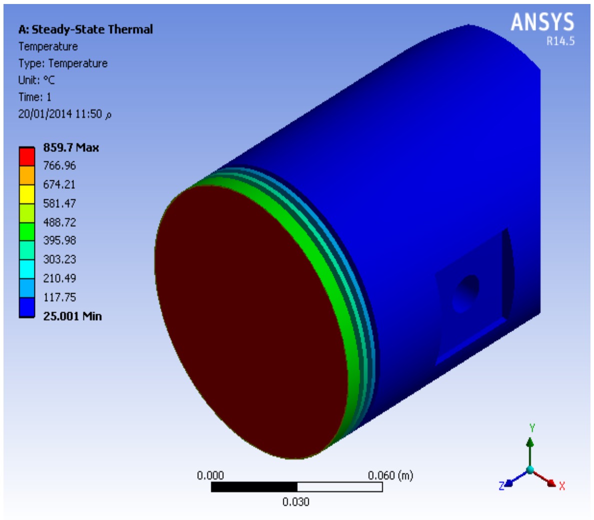

Fig.17 temperture for Titanium Ti-6Al-4V

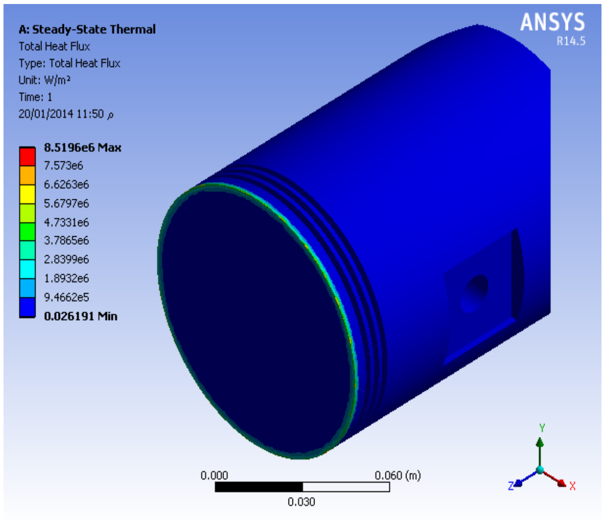

Fig.18 Heat flux for Titanium Ti-6Al-4V

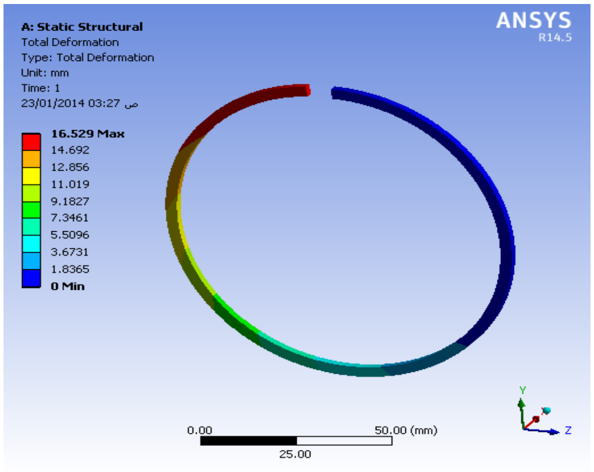

Fig.19 total deformation for Nodular Spheroidal cast iron

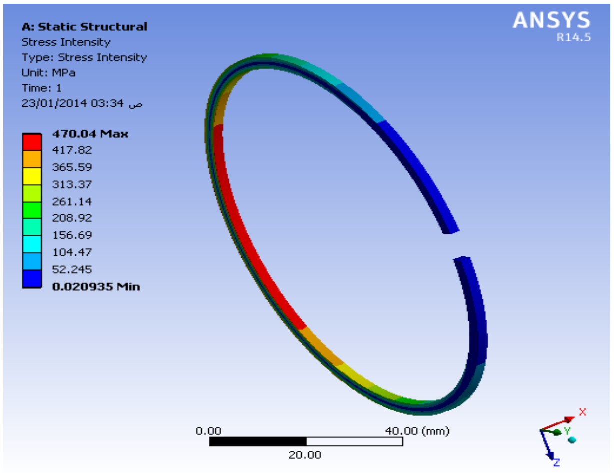

Fig.20 Stress intensity for Nodular Spheroidal cast iron

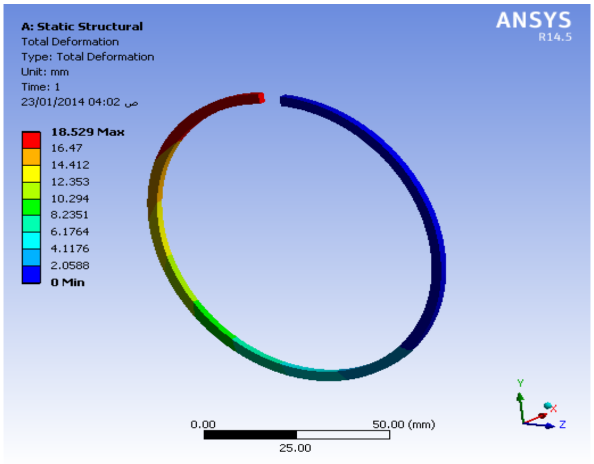

Fig.21 total deformation for grey cast iron

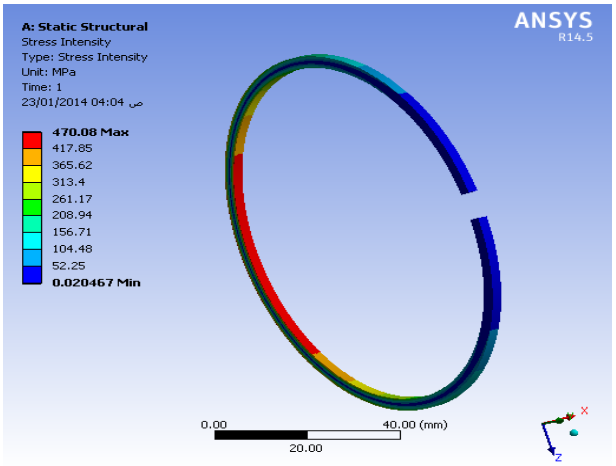

Fig.22 Stress intensity for grey cast iron

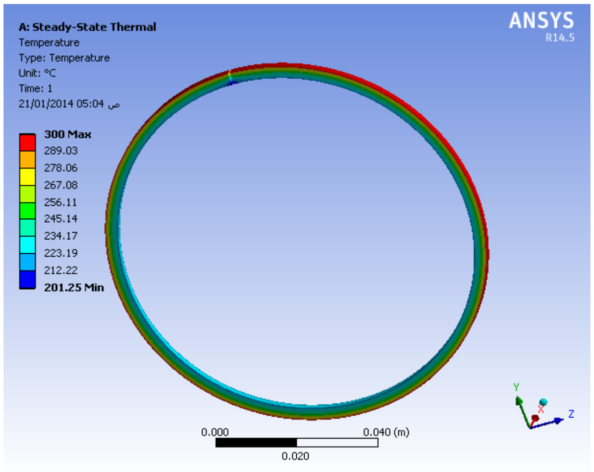

Fig.23 Temperature for Nodular Spheroidal cast iron

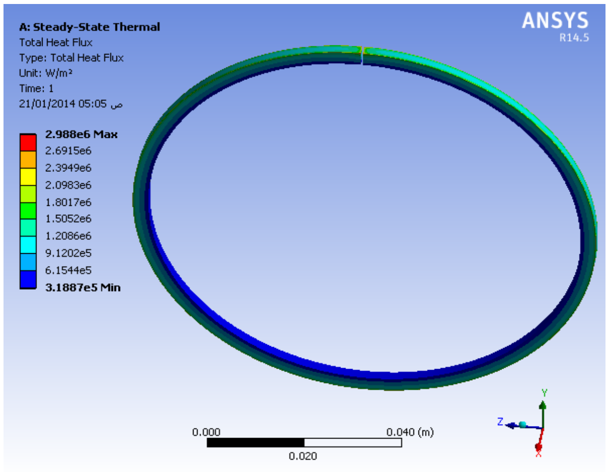

Fig.24 Total heat flux for Nodular Spheroidal cast iron

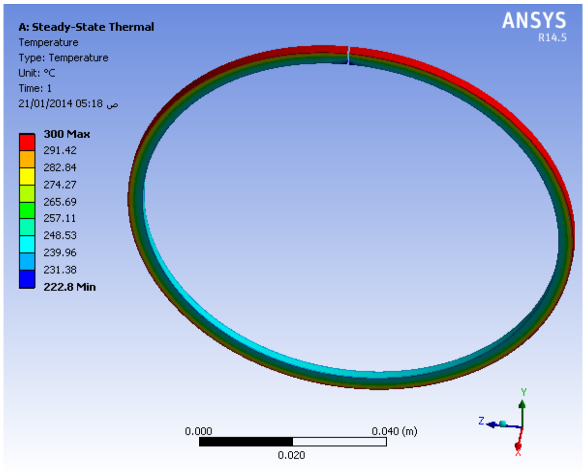

Fig. 25 Temperature for grey cast iron

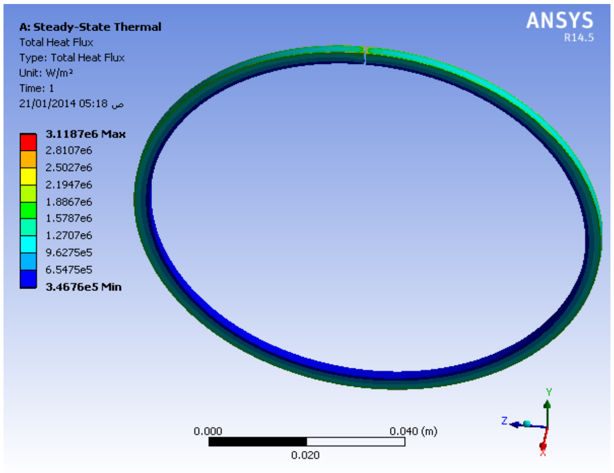

Fig. 26 Total heat flux for grey cast iron

RESULTS AND DISCUSSION

It is clear from figure 7, 9 and 11 that the maximum displacement is observed in the piston made of Al alloy 4032 and minimum in AlSl 4340 alloy steel. As it is expected maximum displacement is observed at the top of the centre of the piston. It is shown in the figure 8, 10 & 12 that the maximum stress intensity is observed in AlSl 4340 with 301.903 MPa MPa and minimum in Al alloy 4032 with 295.69 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.

Thermal analysis of piston shows that the value of maximum temperature is same for all the materials at the top surface of the piston crown, but minimum value of temperature in the piston made of titanium alloy. The highest value of minimum temperature is found in the piston of Al alloy. This is due to thermal conductivity of the materials. Minimum temperature is in the skirt of the piston is observed as shown in figure 13, 15 & 17.

Figure 14, 16 & 18 shows that max total heat flux is observed in piston of Al alloy and piston of titanium alloy shows the lowest value of max total heat flux along the edges.

Piston rings are made of Nodular Spheroidal Cast Iron & Grey Cast Iron. GCI Piston Rings show more deformation than in NSCI. Stress intensity is equal in both. Maximum temperature is equal in both materials, where minimum temperature is higher in GCI, which is 222.8^{o}C. Here, maximum total heat flux is observed in GCI piston rings & minimum value in NSCI piston rings.

CONCLUSION

It is concluded from the above study that 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. Their structural analysis shows that the maximum stress intensity is on the bottom surface of the piston crown in all the materials, but stress intensity is close to the yield strength of Al alloy piston. Maximum temperature is found at the centre of the top surface of the piston crown. This is equal for all materials. Depending on the thermal conductivity of the materials, heat transfer rate is found maximum in Al alloy piston and minimum in

Ti alloy piston. For the given loading conditions, Al alloy piston is found most suitable. But when the loading pattern changes, other materials may be considered. With the advancement in material science, very light weight materials with good thermal and mechanical properties can be used for fail safe design of the I.C.engine. This will reduce the fuel consumption and protect the environment.

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