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Effect of change in piston made of different materials on applying thermal and static loading conditions

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Abstract

As Automotive industry is showing its interest in improving its technology day by day. Keeping this scenario in mind a comparative study is performed on the piston using four different materials so as to find the results of performance of piston after changing its material. For this static structural and thermal analysis is performed on a automotive piston using two different materials i.e. Cast iron, Al –alloy, graphite, structural steel. graphite which is very light in weight as compared to other metals is chosen as the material for the piston as it is well known that it act as a self-lubricating material and can give better results when implemented with different components of engine. After this Static Structural and Thermal analysis is performed on both the pistons by using ANSYS 14.5 Software. The effect of new material on the Static and thermal behaviour of piston as compared to Cast iron and Al-alloy piston is observed.

The main objective of this study is to check the variations in stresses and thermal behaviour when replacing the piston material with of graphite material

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Keywords: - SI engine piston Static structural analysis, steady state thermal analysis, CATIA V5, ANSYS.

INTRODUCTION: Engine being the most important component of the power train of the vehicle and supplies energy to the different components after converting it into various forms. Engine consists of various mechanisms and components induced in it for different functioning. Piston is one of them which is connected to the cam shaft is responsible for all the strokes in an engine which includes intake, Compression, Expansion and exhaust. Piston of IC engine is used in today's industry is basically made up of Al-alloy. It is also a moving component that is contained by the cylinder. The main purpose of piston is to transfer force which is generated by the expanding gas to crankshaft through the connecting rod. The fatigue failure occurs in the piston by the effect of cyclic gas pressure and the inertia forces. Piston head is kept at a highest stress concentration Main reason for the fatigue failure is stress concentration.

In the thermal analysis the properties of material are studied with the change in temperature where as in static structural analysis stresses are calculated at certain static loading condition. For both the static structural and thermal analysis Finite element method is use.

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The efficiency of IC engine is greatly depended on design of piston as well as the material which is used in piston. The piston with the less weight is more efficient than the conventional one. In this study analysis is done on the piston with Cast iron, Al-alloy and graphite, structural steel.

PISTON DESIGN

The piston is designed according to the procedure and specification, given in Machine Design & design data hand book. The entire dimensions are in SI units. The parameters which are taken into consideration are following,

Pressure on piston head, temperature, heat flow, stresses, strain, diameter of piston, length of piston etc.

A. Design Consideration For a Piston

(1) Piston should have enough strength to withstand the high pressure.
(2) Piston should form proper oil sealing in the cylinder.
(3) Piston should have reciprocation speed high without making noise.
(4) For preventing undue wear, piston should provide sufficient bearing area.

B. Design procedure for piston

(1) Mechanical efficiency
(2) Indicated power
(3) Thickness of piston head
(4) Piston rings
(5) Width of top land & ring land
(6) Piston barrel
(7) Length of skirt
(8) Length of piston pin
(9) Piston pin diameter

(10)Heat flow through piston head

(1) $\eta_{mech} = \frac{BP}{IP}$

$$IP = \frac{BP}{0.8} = \frac{5.5}{0.8} = 6.875 \text{ KW}$$

Where: η= Mechanical efficiency
IP = Indicated Power

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BP= Break power

(2) $IP = \frac{P \times L \times A \times n}{60}$

$P_{me} = 1.244$ MPa

$P_{max} = 10 \times P = 12.44$ MPa

Where: P= pressure in MPa

L= Length of piston in mm

A= Area of piston in mm^2

(3) Thickness of piston head

$t_H = D \sqrt{\frac{3\,Pmax}{16\sigma t}}$

$t_H = 9.28$

empiricalformula

$t_n = 0.032D + 1.5 = 3.19$ mm

[$M_f = 45.493$ kg/kws]

$$\left[tn = \frac{[C \times HCV \times m \times BP] \times 10^6}{12.56 \times 150 \times 75 \times 3600} \right]$$

(4) Piston rings:-

(i) Radial thickness

$t_1 = D \sqrt{\frac{3\,Pw}{\sigma t}}$

$P_w = 0.025\text{-}0.042$ N/mm^2

σt= 85-110 MPa for cast iron rings

$t_1 = 1.688$mm

(ii) Axial Thickness

$t_2 = 0.7\, t_1 to t_2 = (0.7 \times 1.688) = 1.181$mm

Where: D = Diameter of Bore in mm

(5) Width of top land and Ring land

(i) Width of top land

$b_1 = t_H$ to $1.2\, t_H = 8.018$mm

Width of ring land

$b_2 = 0.75\, t_1$ to $t_2 = 1.266$mm

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(6) Piston Barrel

(i) Thickness of piston Barrel at top end

$t_3 = 0.03\,D + b + 4.5mm$

$t_3 = 0.03\times 53 + 2.088 + 4.5 = 8.178mm$

(ii) Thickness of piston Barrel at open end

$t_4 = (0.25\,t_3 \text{ to } 0.35\,t_3) = 2.022$ mm

(7) Length of skirt

$L_S = (0.6\,D \text{ to } 0.8\,D) = 31.8mm$

(8) Length of piston pin in on rod bushing

l_1 = 45% of piston dia. = 23.85

(9) Piston pin dia.

$d_p = (0.28\,D + 0.038\,D)$

$= 14.9mm$

Centre of pin should be 0.02 D to 0.04 D above piston skirt

- Heat flow through piston head

  $H = 12.56 \times t_H \times (T_c - T_E)$ KJ/sec

  $H = 744.368$ KJ/sec

  Where: Tc = temperature at the center of piston head in ºC

  T_E = temperature at the edges of the piston head in ºC

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Calculated parameters for piston

S. NO.	Parameter	Size in mm
1	Length of piston	42
2	Cylinder Bore	53
3	Axial thickness of ring	1.181
4	Radial thickness of ring	1.688
5	Maximum thickness of barrel	8.178
6	Width of the outer ring land	1.266
7	Width of the top land	8.018
8	Length of skirt	31.8
9	Piston pin Diameter	15.9

Modeling & Analysis

Modeling of Piston is done using CATIA V5. CATIA V5 is uses for specialized work of 3D model. The final product file is converted to .stp for importing in ANSYS then analysis is done.

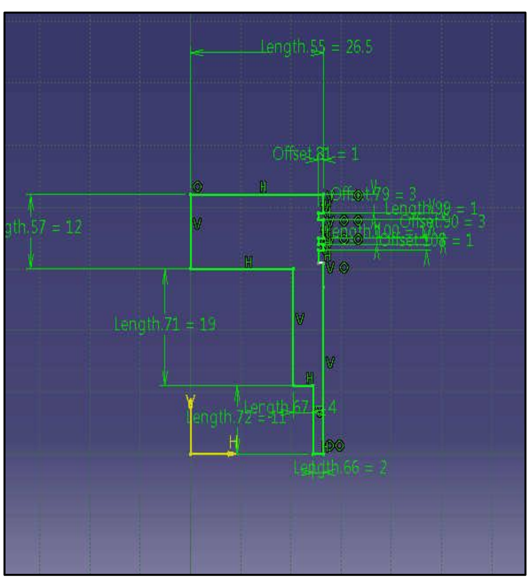
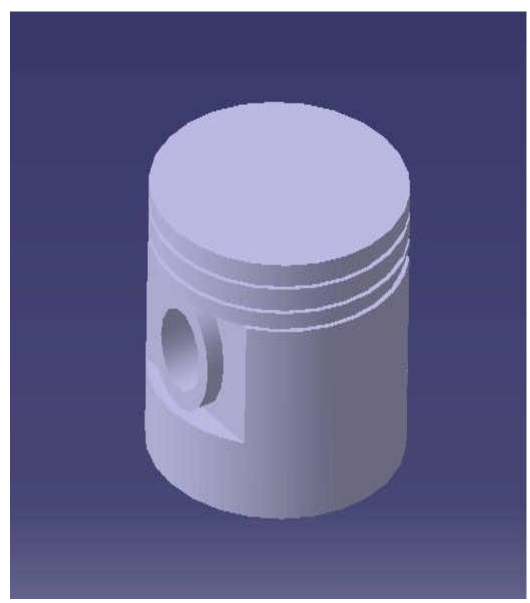


Fig: 1 Catia V5 Section of piston

Fig:2Catia V5 3D Model of piston



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ANSYS

ANSYS is a multi-Physics computing software falls under the category of CAE i.e. Computer Aided engineering analysis software used for providing the approximate solutions to the problems.

In other word its main purpose is to perform finite element Analysis for finding the approximate numerical solutions of Mechanical problems. Finite element analysis basically refers to dividing the component or the part into finite number of elements. For analysis of piston ANSYS 14.5 is used.

Modeling of piston is done in CATIA V5 R20 software and it is imported in ANSYS 14.5for further analysis.

Methodology, Boundary and loading Conditions

After the 3D modeling of piston by using CATIA V5 the procedure for the analysis of the 3D modal is following,

1-Firstly generating the Computer model

2-Assign the property of material for component

3. Applying boundary conditions.

4. Applying load 12440N.

5. Mesh generation.

6. Solving for obtaining results.

7. Creating the job to get output data file.

THERMAL & GEOMETRIC PROPERTIES OF PISTON MATERIAL

For controlling the thermal stresses and deformation, it is more important to calculate the piston temperature distribution. Approximately 50% of power loss is generated by the piston ring. If the clearance which is filled by the lubricating oil has a small value, because of which the frictional losses increases.

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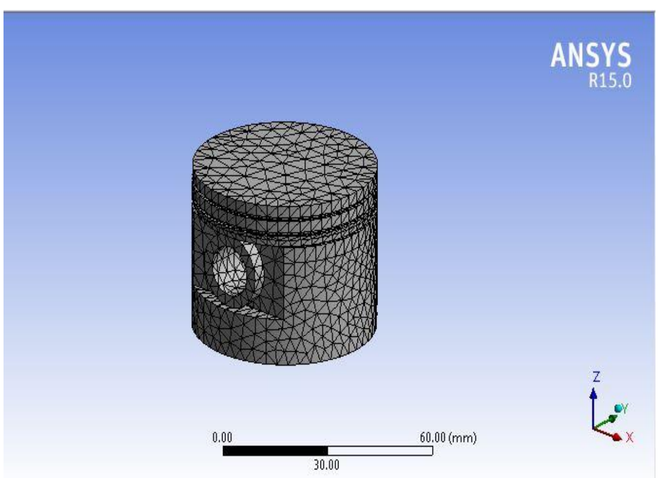
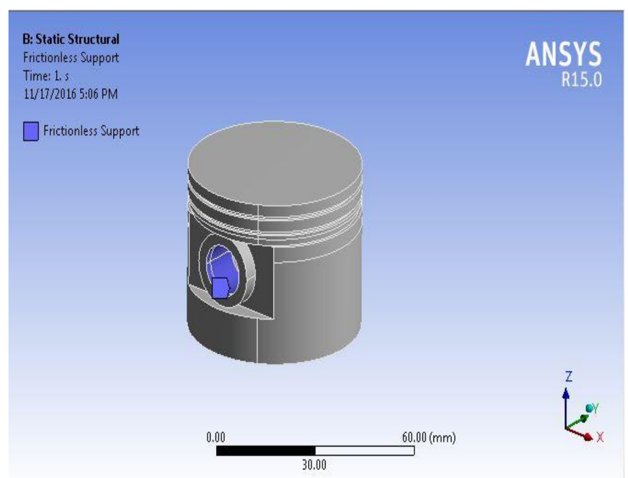
S.NO.	Property	AL-Alloy	Cast iron	Structural steel	Graphite
1	Poisson Ratio	0.33	0.28	0.33	0.23
2	Young's Modulus	7.1E+10	1.1E+11	2E+11	2.76E+10
3	Thermal conductivity	64	52	60.5	24
4	Co efficient of thermal Expansion	2.3E-05	1.1E+05	1.2E-05	1.2E+06

In most of the IC Engine thermal expansion co efficient of piston material is 80% higher than the cylinder bore material.

Thermal & geometric properties are:



Meshing of Piston with tetrahedron mesh



Frictionless support on gudgeon pin

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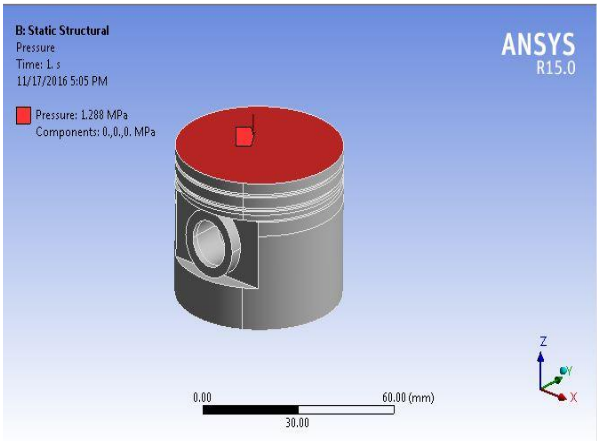
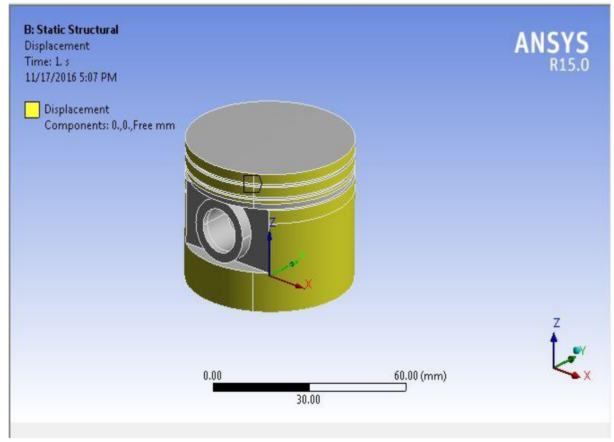


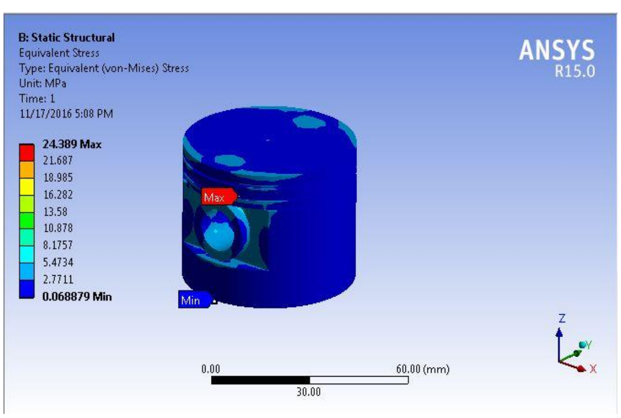


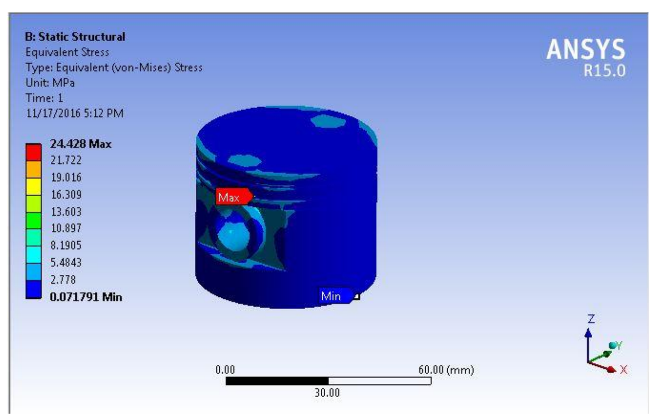
Pressure Load On Piston

Displacement of piston constrained in Z direction

Procedure Explained: After assigning the Material to the model in ANSYS Workbench Meshing of component is done taking the tetrahedron mesh of element size 1 mm resulting in 8466Elements and 15212Nodes. Then after meshing Suitable boundary conditions are assigned in the ANSYS Workbench following the working Principles of Piston i.e. Load (Pressure of 12.44 MPa) is applied on the piston head, Frictionless support is provided on the gudgeon pin on both side, And the boundary condition for thedisplacement in only Z direction is assigned keeping the displacement in X and Y axis constantly Zero.

Result and Discussion of Static Structural Analysis





Von mises stress for graphite piston

Von mises for structural steel

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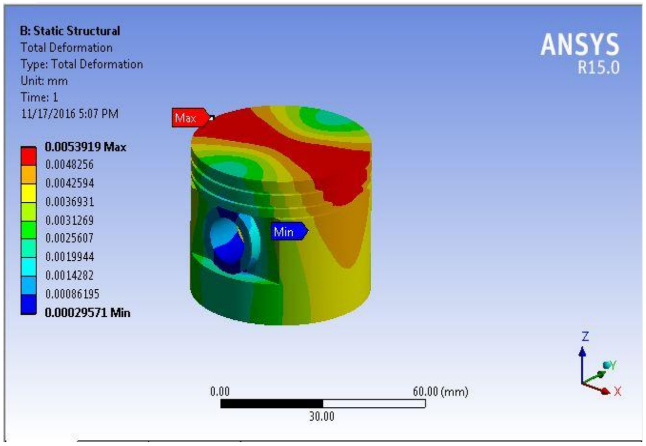
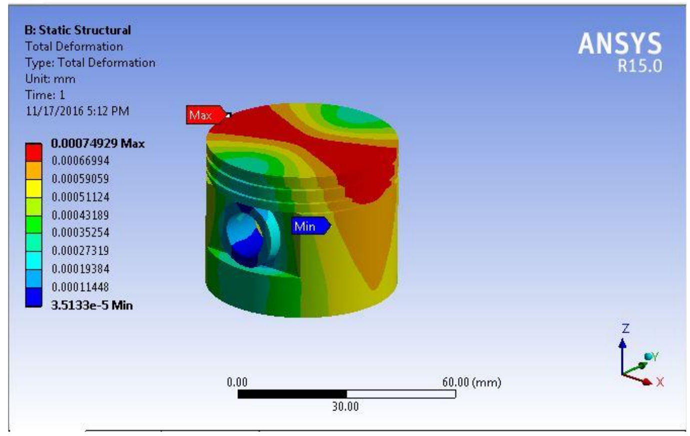
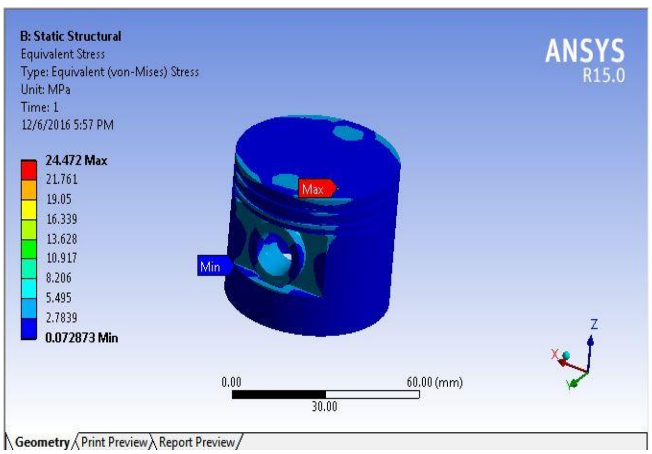


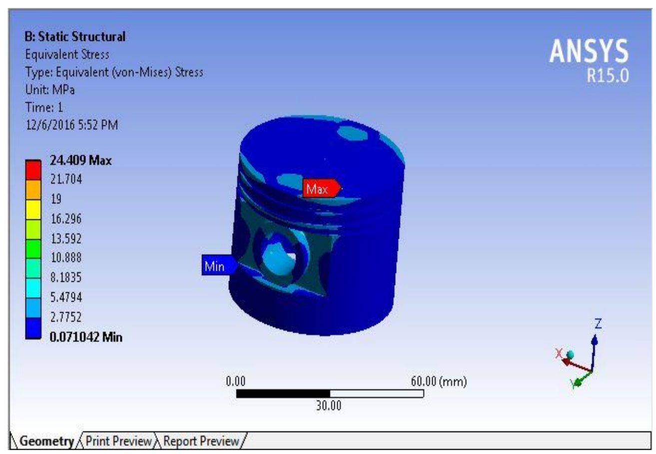
Total deformation for graphite piston



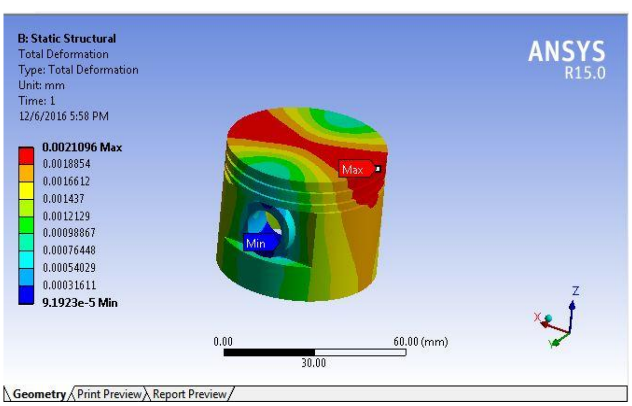
Total deformation for structural steel piston



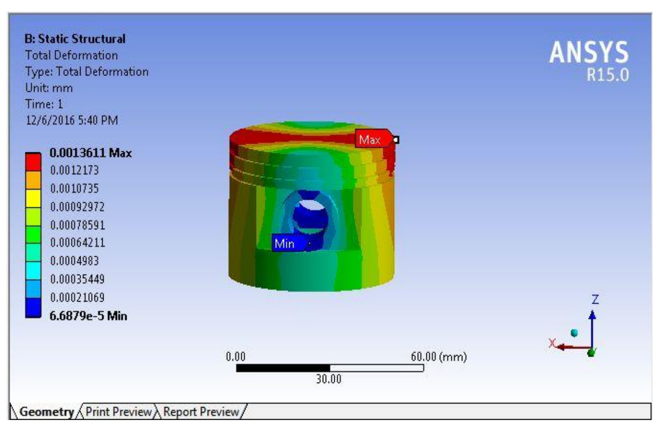
Von mises stress for Al-alloy



Von mises stress for Cast-iron



Total deformation for Al-alloy



Total deformation for Cast-iron

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After assigning the Boundary conditions results for Von-mises stress and deformation are calculated for AL-Alloy and Cast iron. On performing the analysis Max. Equivalent stress for al-alloy 24.472 and for Cast iron is 24.409MPa. Andgraphite is 24.389 and structural steel is 24.428. In the same manner results were calculated for total deformation also in which max. Deformation for al-alloy is 2.1096mm for cast iron is1.3611mm.and structural steel 7.4929mm for graphite 5.3919mm.

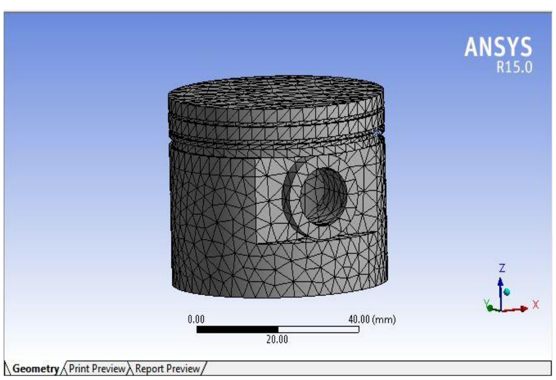
Methodology, Loading and Boundary Conditions for Steady State Thermal Analysis:

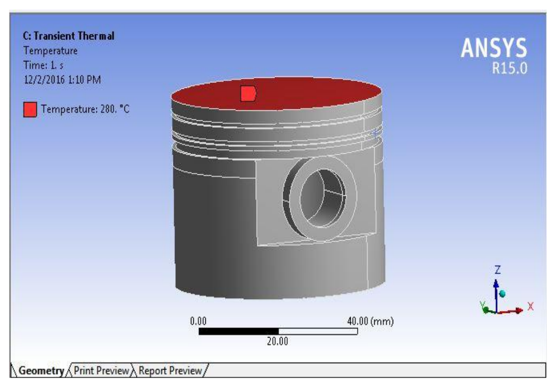
After the 3D modelling of piston by using CATIA V5 the procedure for the analysis of the 3D modal is following,

1. Firstly Importing the CAD model
2. Assign the property of material for component
3. Applying boundary conditions
4. Mesh generation
5. Solving for obtaining results
6. Creating the job to get output data file

MATERIAL PROPERTIES OF PISTON MATERIAL

With reference to the static structural analysis same material properties are applied on the component in steady state thermal analysis also





Meshing of piston with Triangular element

Temperature applied on piston head

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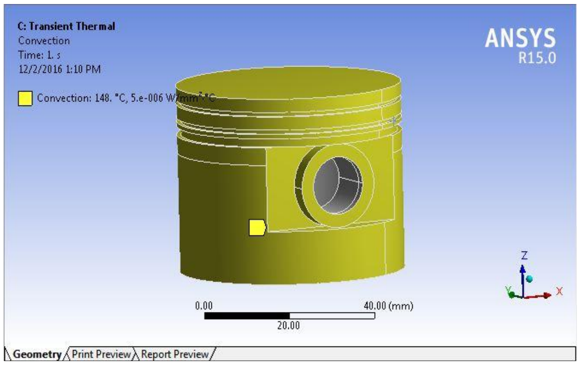
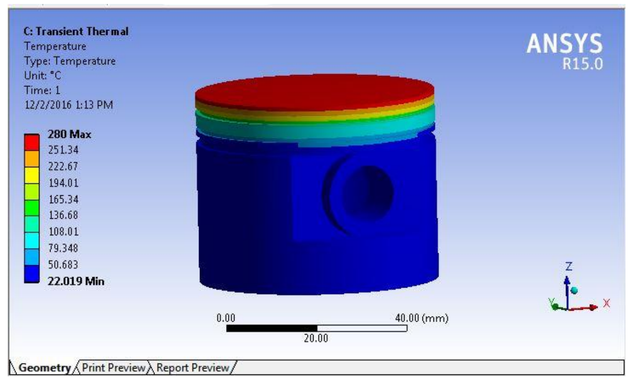
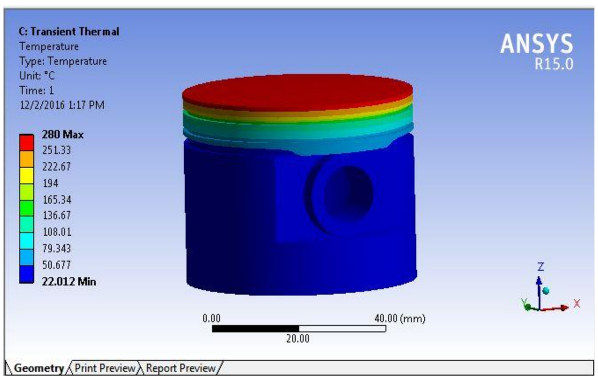


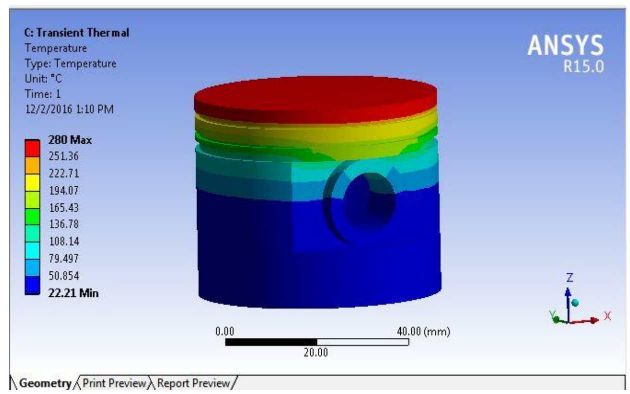
Convection applied on piston side wall



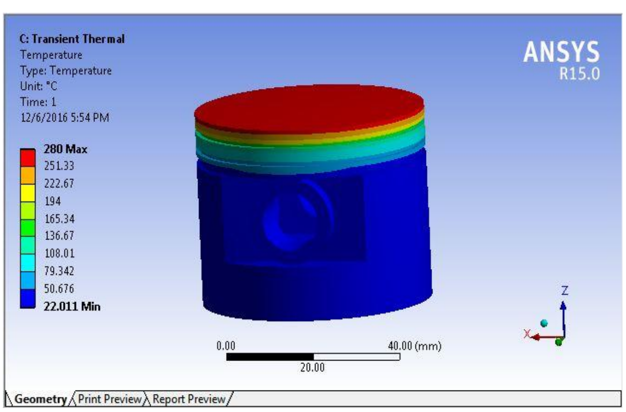
Max. Temperature for graphite piston



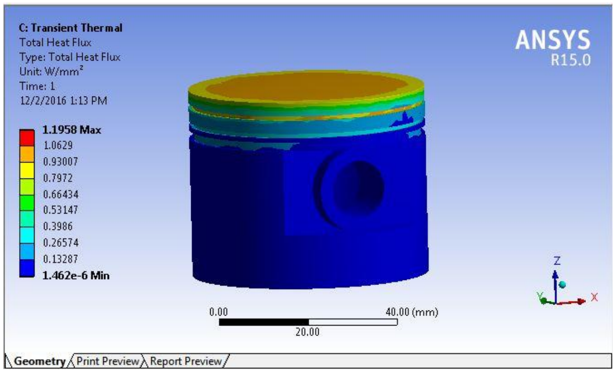
Max. Temperature for structural steel piston.



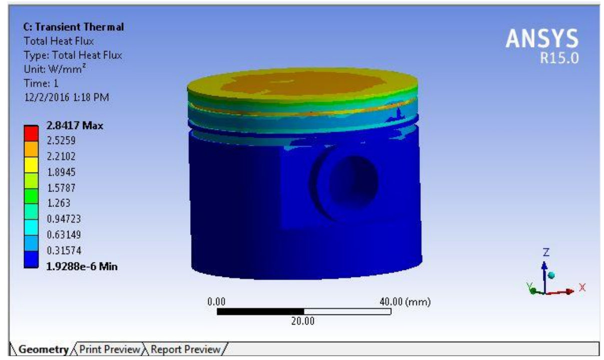
Max. Temperature for Al-alloy



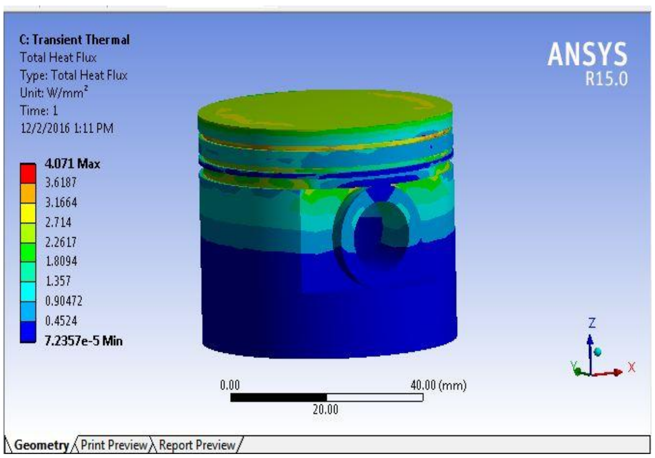
Max Temperature for Cast -iron



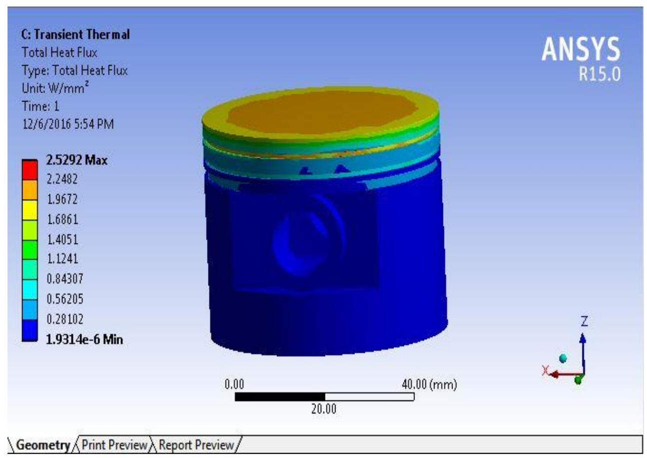
Max. Heat flux for Graphite piston



Max. heat flux for structural steel



Max. Heat flux for Al-alloy



Max. Heat flux for Cast-iron

After assigning the Boundary conditions results for Max.Temperature and Max. Heat Flux is calculated for graphite piston 22.019 and structural steel Piston is 22.012. On performing the analysis Max. Temperature Value ranges from 22.21 to 280ºC for al-alloy and for cast ironit ranges from 22.011ºC to 280ºC. In the same manner results were calculated for total heat Flux also in which Max. Heat Flux for Al-alloy was 4.071W/mm2and for cast iron was 2.5295 W/mm2and graphite 4.071W/mm2 and structural steel 2.8417 W/mm2.

CONCLUSION

From the Above Results of Static Structural and Steady State Thermal Analysis it is concluded that the graphite piston shows outstanding results in both the analysis procedures with the additional weight Reduction of 20% and is a good indication to replace the al-alloy Piston, cast iron piston and structural steel piston in Automotive Industry.

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