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Design and Analysis of I.C. Engine Piston Using Finite Element Analysis (Ansys)

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Abstract-

Now a days, due to the increased use of automobile demands of engine is increased. Due to which the demands of engine component is high. Piston is one of the most important component of engine. In this we study to design a piston of suitable design using three different materials and then structural analysis is performed to analyse the stress distribution over the piston using FEA (finite element analysis). Three pistons of different materials are designed using materials properties on CATIA and then the whole design is imported to ANSYS software where the structural analysis of the piston is performed by applying the boundary conditions i.e pressure. After this the equivalent stress, strain and deformation are analysed at the real engine conditions. These materials are Al 6061, Al 4032 and Cast iron FG200. The main objective is to investigate and analyse the stress distribution over the piston at real engine condition during combustion process.

KEYWORDS- CATIA; ANSYS; WORKBENCH; Piston; Boundary Conditions; Stress; Pressure.

I. INTRODUCTION

Developing IC Engine is not something rare in the industry but the modern trend is to develop engines with high power capacity. This can be achieved when the weight is less and the fuel consumption is low.It has been reported by Cuddy et al that 10% weight reduction of the vehicle contributes 6-8% reduction in fuel consumption. That simply means that the engine designs should be improved. When we say about improving engine design we also mean to improve the design of its component. Piston is the one of the most important component of the engine. Hence, we should use light weight material like aluminium, titanium to design the piston so as to reduce the weight because improved engine designs require optimised engine components. Along with less weight of the piston enormous strength must also be ensured so as it can withstand the pressure generated by the combustion in the cylinder. After the materials are selected the piston dimensions are calculated according to the procedures and specifications given in the machine design and data book. Once the dimensions are obtained, the piston is designed on CATIA V5R20. Finite element analysis FEA is used for stress analysis by making the piston pin hole fixed and applying the boundary conditions. Pressure is applied at the piston head and the deformation and stress distribution is analysed. If the stress obtained is less than the theoretical stress (calculated at specific factor of safety) then our design is safe. But if it is more then the design is unsafe and the factor of safety needs to be changed.

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The present task undertaken is:-

1. To design an IC Engine piston according to the procedures and specifications given in machine design and data book on CATIA V5R20.
2. To perform the structural analysis using ANSYS 12
3. .

II. MATERIAL USED AND ITS PROPERTIES:-

	AL ALLOY 6061	AL ALLOY 4032	CAST IRON FG200
Poisson's Ratio	0.33	0.33	0.33
Modulus of Elasticity(Gpa)	71	70-80	100
Thermal Conductivity (w/mk)	174.15	155	46.6
Ultimate Tensile Strength(Mpa)	310	380	200
Density(g/cc)	2.77	2.69	7.1

III. PISTON DESIGN

1.) Design considerations for piston

- It should have minimum weight so that it can withstand the inertia forces.
- It should have enormous strength to withstand the combustion pressure.
- It should reciprocate at desired speed without much noise.
- It should have sufficient support for the piston pin.
- It should have sufficient strength to withstand the mechanical distortion.

2.) Piston design parameters

(i) Thickness of Piston Head (t_H)

The piston thickness of piston head calculated using the following Grashoff's formula,

$$t_H = D\sqrt{\frac{3 \times P}{16\sigma_t}}$$

Where

P= maximum pressure in N/mm²
D= cylinder bore/outside diameter of the piston in mm.
σ_t = permissible tensile stress for the material of the piston.

(ii) Radial Thickness of Ring (t_1)

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$$t = D\sqrt{\frac{3 \times P_w}{\sigma_t}}$$

Where,
D = cylinder bore in mm
P_w= pressure of fuel on cylinder wall in N/mm². Its value is limited from 0.025N/mm² to 0.042N/mm².

(iii)Axial Thickness of Ring (t_2)

The thickness of the rings may be taken as

$t_2 = 0.7t_1$ to t_1

(iv) Width of the top land (b_1)

The width of the top land varies from
$\mathbf{b_1 = t_H \text{ to } 1.2 \times t_H}$

(v)Width of other lands (b2)

Width of other ring lands varies from

$\mathbf{b_2 = 0.75 \times t_2 \text{ to } t_2}$

(vi)Maximum Thickness of Barrel (t_3)

$\mathbf{t_3 = 0.03 \times D + b + 4.5 \text{ mm}}$

Where,
b = Radial depth of piston ring groove
$b = t_1+0.4$

(vii) Number of piston rings (n_r)

$t_2 = \frac{D}{10 \times n_r}$

Where t_2= Maximum axial thickness

(vii) Piston Pin Diameter (d_o)

d_o= 0.03D

IV. Theoretical Stress Calculations

$$\sigma_b = P_{ZMax} \times \left(\frac{r_i}{\delta}\right)^2$$

σ_b = Max. Allowable Stress

P_{ZMax} =Max. Gas Pressure (5 MPa)

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r_i =Crown Inner Radius

$$r_i = \left[\frac{D}{2} - (s + t_1 + dt)\right]$$

s =Thickness of Sealing Part

s =0.05×D

dt= Radial clearance between piston ring and channel

δ =Thickness of Piston Crown

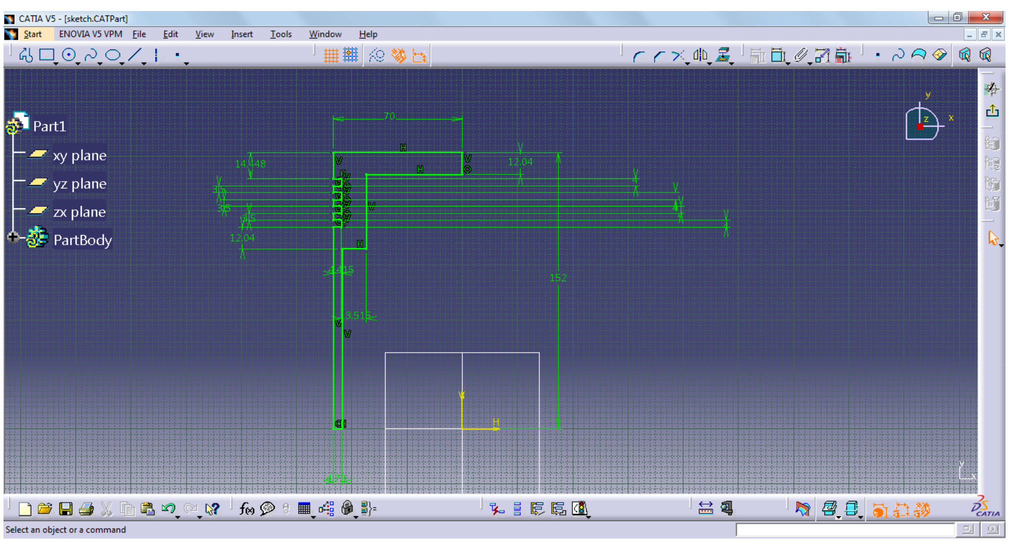
$\delta = (0.08\ to\ 0.1) \times D$

V. DIMENSIONS CALCULATED

	Al Alloy 4032	Al Alloy 6061	Cast Iron FG200
Thickness of Piston Head (t_H)	12.040	12.170	11.730
Radial Thickness of Ring (t_1)	4.415	4.862	4.300
Axial Thickness of Ring (t_2)	4.000	4.000	4.000
Width of the top land (b_1)	14.418	14.607	14.000
Width of other lands (b2)	3.500	4.200	3.500
Maximum Thickness of Barrel (t_3)	13.600	13.500	13.400

VI. Designing the model using CATIA

By considering the dimensions calculated above the piston is designed on CATIA V5R20. The below design is of AL 6061 alloy piston.



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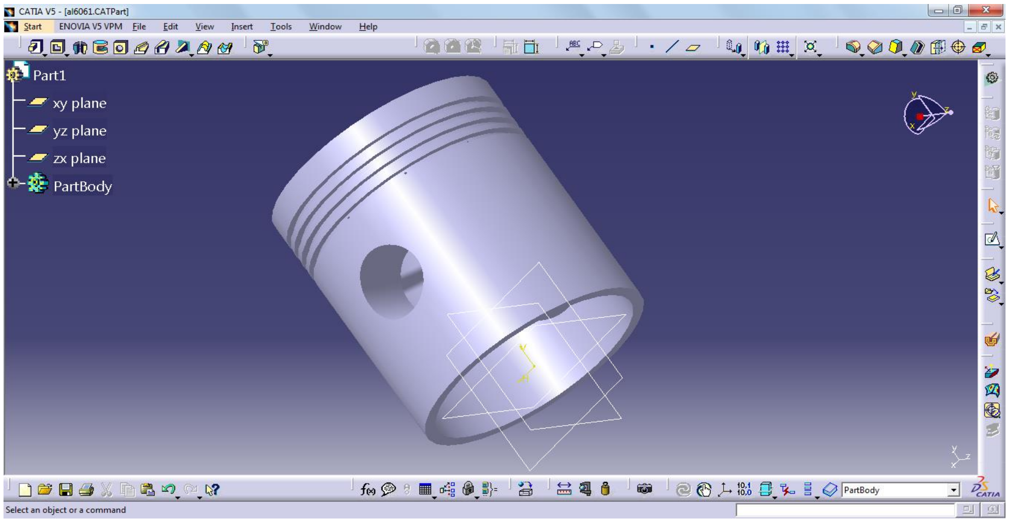


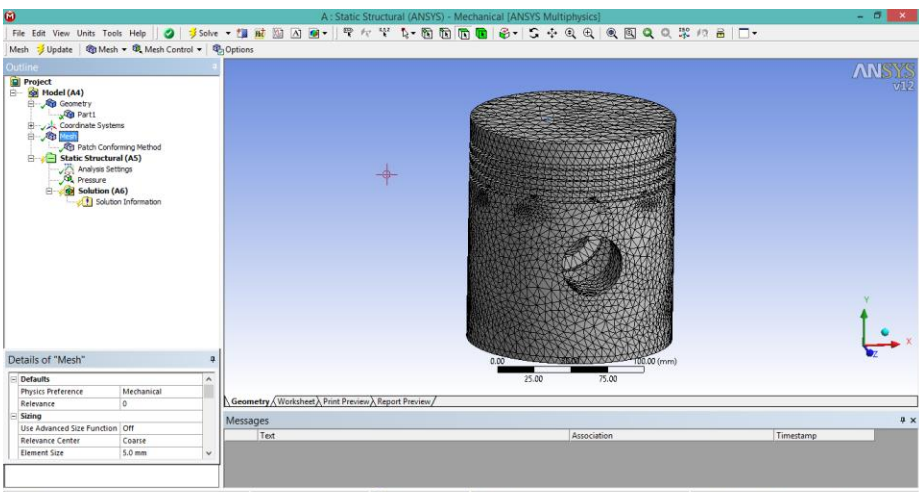
VII. STRUCTURAL ANALYSIS

Boundary conditions for structural Analysis of Piston

Pressure is exerted on the top of the piston i.e. on the piston head during the combustion process. Due to which the piston moves from TDC to BDC. Fixed support is given at the pin hole because of which the piston moves from TDC to BDC. The pressure acting on the top of the piston is taken as boundary condition. In case of aluminium alloys piston the pressure is between 2Mpa to 5Mpa. Whereas in case of cast iron alloys it can be upto 8Mpa. Here we take the pressure as 5Mpa for all the three materials.

MESH GENERATION

In mesh generation, the element used is tetrahedron. The element size is 5mm. The total nodes in the meshed model are 68637 and the total elements are 39480.



VIII. STATIC STRUCTURAL ANALYSIS

After the mesh is generated, fixed support is applied at the two piston pin holes. Pressure of 5MPa is applied at the top of the piston head and then deformation and stress is analyzed on the piston.

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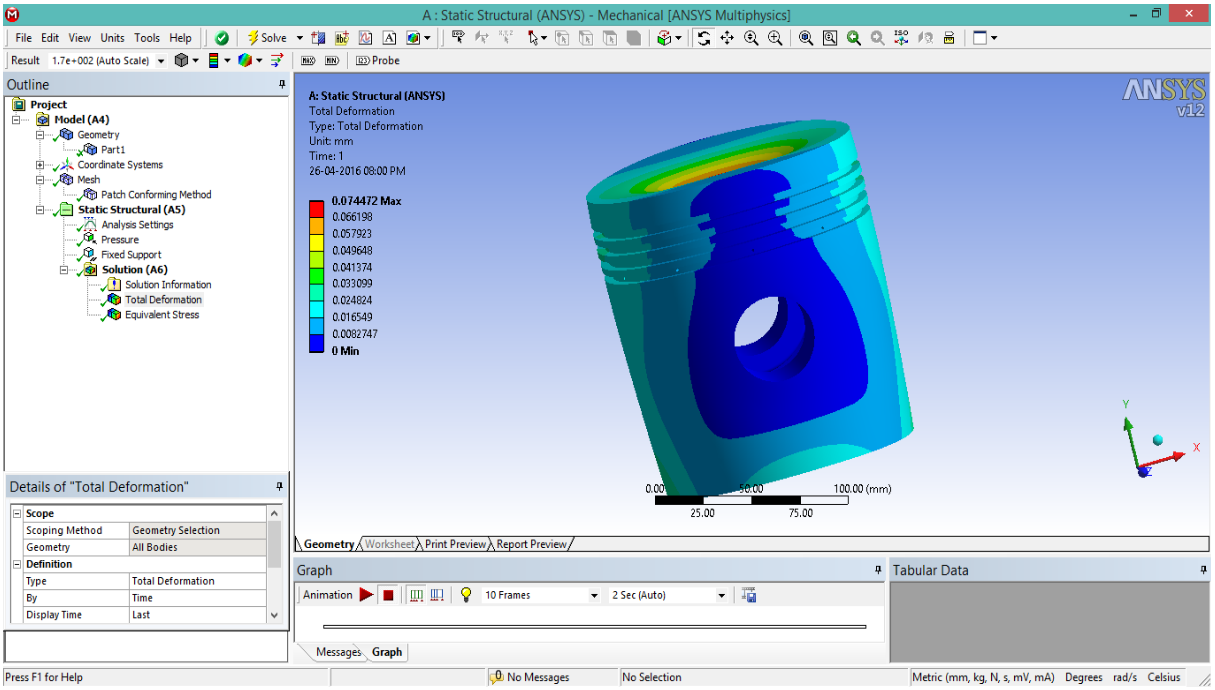
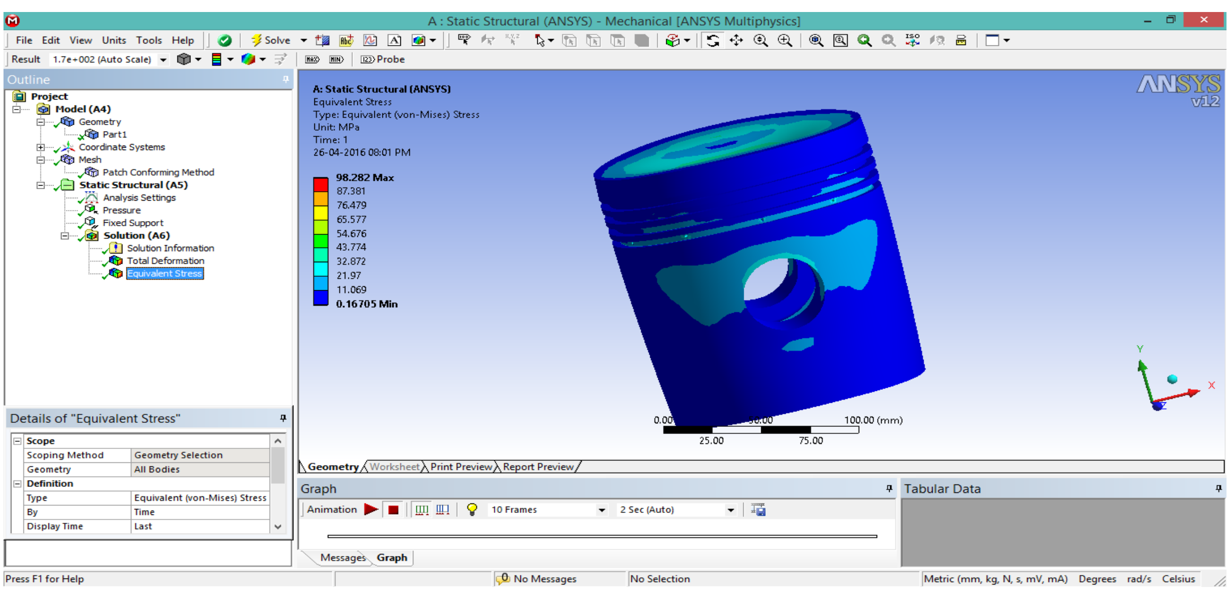
Deformation



Stress Distribution

The obtained stress is 98.282 MPa which is less than the maximum allowable stress 124 MPa. This means the design of the piston is safe.



The same analysis process is done for other two materials and the results are obtained.

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IX. RESULTS

	AL 6061	AL 4032	CAST IRON FG 200
Deformation(mm)	0.074472	0.0685	0.0546
Stress(MPa)	98.282	110.64	118.79

All of the obtained stresses of the repective material is well below the maximum allowable stress. Deformation of the CAST IRON FG200 is minimum among all the three materials. Hence, CAST IRON FG200 is the best suited material.

X. CONCLUSIONS

While performing the animation after the analysis the piston skirt may appear deformation at work. As a result of this the cracks may appear on the upper end of the piston head. Due to which the stress concentration will be more. Therfore, the piston head should have enough stiffness to reduce the deformation.

- Out of all the three materials CAST IRON FG200 is best suited material as it is subjected to minimum deformation.
- When the stress is contant, material whose modulus of elasticity is more its deformation will be more.

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