

Design and Analysis of Piston of Internal Combustion Engine on Different Materials Using CAE Tool ANSYS

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ABSTRACT: 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. In the internal combustion engine there are many reciprocating parts which are responsible for giving the motion to the engine. The piston is “Heart” of the engine and its working condition is the worst one of the key parts of engine in the working environment. So it is very important for design and structural analysis of the piston.

There are lots of research works proposing, for engine pistons, new geometries, materials and manufacturing techniques, and this evolution has undergone with a continuous improvement over the last decades and required thorough examination of the smallest details. Notwithstanding all these studies, there are a huge number of damaged pistons. Damage mechanisms have different origins and are mainly wear, temperature, and fatigue related.

In this study work the analysis of the piston consists of mainly design and analysis. Design the model of the piston in giving design specification on the modeling like PRO-E. Then giving it the constrains which are act on the working condition of the piston after the model of the piston into the analysis software ANSYS in IGES format. Then the analysis becomes completed on the different parameters (temperature, stress, deformation) and easily analysis the result. The different material Al alloy 4032, AISI4340 Alloy Steel & Titanium Ti-6Al-4V. After the analysis of the different material piston it analyzed that the Al alloy is suitable for I.C.Engine piston.

KEYWORDS: Design of Piston, Ansys, Pro-E.

I. INTRODUCTION

The piston reciprocates in the cylinder to complete the cyclic events and transmit gas pores to the crank shaft through the connecting rod. Piston is the most important component in an internal combustion engine. The working condition of piston in an internal combustion is so worst. During the combustion stroke the fuel get ignited with the help of spark plug. Due to this combustion of gases in the cylinder the thermal deformation and mechanical deformation causes piston cracks, tortuosity etc. It is very essential to check out or analyze the stress distribution, temperature distribution, heat transfer, thermal load, mechanical load in order to minimize the stress, minimize the thermal stress and different loads on working condition of the piston. The internal combustion engine piston is made of Al alloy. This creates difference between the running and design clearances. In this study firstly we draw the piston model in PRO-E software and finally the piston is analyzed in ANSYS software.

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The two steps involved in this study are:

1. To design an IC engine piston by using PRO-E software.
2. To perform the structural and thermal analysis of piston by using ANSYS software.

II. PISTON

Piston is a reciprocating component in an engine which converts the chemical energy after the burning of fuel into mechanical energy. The purpose of the piston is to transfer the energy to crankshaft via connecting rod. The piston ring is used to provide seal between the cylinder and piston. It must able to work with low friction, high explosive forces and high temperature around 2000°C to 2800°C. The piston is to be strong but its weight should be less to prevent inertia forces due to reciprocating motion.

III. FUNCTIONS OF PISTON

- To receive the thrust force generated by the chemical reaction of fuel in the cylinder and transmits to connecting rod.
- To reciprocate in the cylinder provide seal in suction, compression, expansion and exhaust stroke.

IV. PISTON MATERIALS

Generally pistons are made of Al alloy and cast iron. But the Al alloy is more preferable in comparison of cast iron because of its light weight which suitable for the reciprocating part. There are some drawbacks of Al alloys in comparison to cast iron that are the Al alloys are less in strength and in wearing qualities. The heat conductivity of Al is about of thrice of the cast iron. Al pistons are made thicker which is necessary for strength in order to give proper cooling.

V. DESIGN CONSIDERATION FOR A PISTON

In designing a piston, the following points should be taken into consideration:

1. It should have enormous strength to withstand the high gas pressure and inertia forces.
2. It should have minimum mass to minimize the inertia forces.
3. It should form an effective gas and oil sealing of the cylinder.
4. It should provide sufficient bearing area to prevent undue wear.
5. It should disperse the heat of combustion quickly to the cylinder walls.
6. It should have high speed reciprocation without noise.
7. It should be of sufficient rigid construction to withstand thermal and mechanical distortion.
8. It should have sufficient support for the piston pin.

VI. DESIGN PROCEDURE

The design procedure of piston consists of the following parameters:

- Thickness of piston head (t_H)
- Heat flows through the piston head (H)
- Radial thickness of the ring (t_1)
- Axial thickness of the ring (t_2)
- Width of the top land (b_1)
- Width of other ring lands (b_2)
- Maximum Thickness of Barrel (t_3)

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- Piston wall thickness towards the open end
- Piston pin

Here we are assuming the diameter of the piston according to your requirements.

1. Thickness of Piston Head (t_h):

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

$$t_h = D \sqrt{\frac{3PD^2}{16\sigma_t}}$$

Where,

P= maximum pressure in N/mm².

D= cylinder bore/outside diameter of the piston in mm.

D = 50mm.

σ_t = permissible tensile stress for the material of the piston.

2. Heat Flow Through the Piston Head (H):

The heat flow through the piston head is calculated using the formula

$$H = C * HCV * M * BP$$

$$t_h = \frac{H}{12.56 * K * (T_c - T_e)}$$

Where,

H= Heat flow through the piston head.

C=Constant heat supplied to engine(C=0.05).

HCV= Higher calorific value of petrol (HCV=47000 KJ/Kg).

M= Mass of fuel used per cycle (M=0.069 Kw/hr).

BP= Brake power (BP=7.5W).

K= Thermal conductivity of material which is 174.15W/mk.

T_c = Temperature at centre of piston head in °C.

T_e = Temperature at edges of piston head in °C.

3. Radial Thickness of Ring (t_1):

$$t_1 = D \sqrt{\frac{3P_w}{\sigma_t}}$$

Where,

D = Cylinder bore.

D = 50mm.

P_w= Pressure of gas on the cylinder wall (nearly taken as 0.025 Mpa to 0.042Mpa).

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σ_t = Allowable bending tensile stress (84 Mpa to 112Mpa for cast iron).

4. Axial Thickness of Ring (t_2):

The thickness of the rings may be taken as

$$t_2 = 0.7t_1 \text{ to } t_1$$

5. Width of the Top Land (b_1):

The width of the top land varies from

$$b_1 = t_H \text{ to } 1.2t_H$$

6. Width of other Lands (b_2):

Width of other ring lands varies from

$$b_2 = 0.75t_2 \text{ to } 3$$

7. Maximum Thickness of Barrel (t_3):

$$t_3 = 0.03D + b + 4.5$$

Where,

b = radial depth of piston ring groove.

$$b = t_1 + 0.4$$

8. Piston Wall Thickness Towards the Open End:

$$t_4 = 0.25t_3 \text{ to } 0.35t_3$$

9. Piston Pin:

Load on pin due to bearing pressure = $P_b * d_o * t_1$

Where, $t_1 = 0.45D$

Maximum load on piston due to gas pressure = $\frac{\pi}{4} * D^2 * P$

Inside diameter of piston pin

$$d_1 = 0.6d_o$$

VII. CALCULATIONS

1. Thickness of Piston Head (t_h):

$$t_h = D \sqrt{\frac{3PD^2}{16\sigma_t}}$$

$$= 50 \sqrt{\frac{3 * 91.95 * 50^2}{16 * 469}}$$

$$t_h = 9.58 \text{ mm}$$

2. Heat Flow through the Piston Head (H):

$$H = C * HCV * M * BP$$

$$= 0.05 * 47000 * 10^3 * 0.069 * 7.5$$

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$$= 1216125$$

$$t_h = \frac{1216125}{H}$$

$$= \frac{1216125}{12.56 \times K \times (T_c - T_e)}$$

$$= \frac{1216125}{12.56 \times 174.75 \times 75}$$

$$t_h = 7.3 \text{ mm}$$

3. Radial Thickness of Ring (t_1):

$$t_1 = D \sqrt{\frac{3P_w}{\sigma_t}}$$

$$= 50 \sqrt{\frac{3 \times 0.04}{112}}$$

$$t_1 = 1.63 \text{ mm}$$

4. Axial Thickness of Ring (t_2):

$$t_2 = 0.7t_1 \text{ to } t_1$$

$$= 0.7 \times 1.63 \text{ to } 1.63$$

$$= 1.14 \text{ to } 1.63 \text{ mm}$$

5. Width of the Top Land (b_1):

$$b_1 = t_H \text{ to } 1.2t_H$$

$$= 7.3 \text{ to } 1.2 \times 7.3$$

$$b_1 = 7.3 \text{ to } 8.76 \text{ mm}$$

6. Width of other Lands (b_2):

$$b_2 = 0.75t_2 \text{ to } 3$$

$$= 0.75 \times 1.63 \text{ to } 3$$

$$b_2 = 1.22 \text{ to } 3 \text{ mm}$$

7. Maximum Thickness of Barrel (t_3):

$$t_3 = 0.03D + b + 4.5$$

$$= 0.03 \times 50 + 2.03 + 4.5$$

$$t_3 = 8.03 \text{ mm}$$

$$b = t_1 + 0.4$$

$$= 1.63 + 0.4$$

$$b = 2.03 \text{ mm}$$

8. Piston Wall Thickness Towards the Open End:

$$t_4 = 0.25t_3 \text{ to } 0.35t_3$$

$$= 0.25 \times 8.03 \text{ to } 0.35 \times 8.03$$

$$t_4 = 2.01 \text{ to } 2.81 \text{ mm}$$

9. Piston Pin:

$$\text{Load on pin due to bearing pressure} = P_b \times d_o \times t_1$$

$$= 35 \times d_o \times 0.45 \times 50$$

$$= 787.5d_o$$

$$\text{Maximum load on piston due to gas pressure} = \frac{\pi}{4} \times D^2 \times P$$

$$= \frac{\pi}{4} \times 50^2 \times 5$$

$$= 9817.44$$

Load on pin due to bearing pressure = maximum load on piston due to gas pressure

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$$787.5d_o = 9817.44$$

$$d_o = 13\text{mm}$$

Outside diameter of piston pin $d_o = 13\text{mm}$

Inside diameter of piston pin

$$\begin{aligned} d_1 &= 0.6d_o \\ &= 0.6 * 13 \\ &= 8\text{mm} \end{aligned}$$

Designing of Piston

The following are the sequence of steps in which the piston is modeled.

- Drawing half portion of piston by using sketcher.
- Generating the model by using revolve command.
- Removing the inner material by using extrude command.
- Create a piston pin hole.
- Save this model into IGES format.

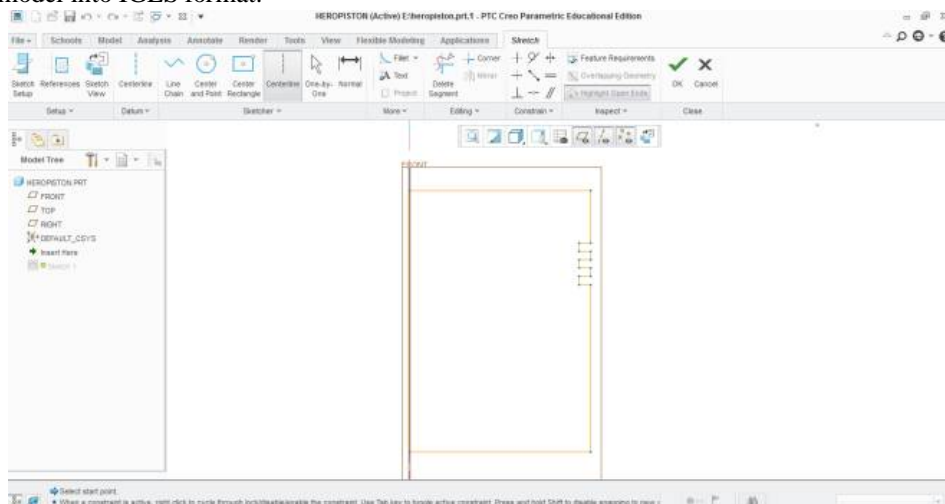


Fig 1: Piston design in PRO-E

VIII. RESULT AND ANALYSIS

Aluminium 4032:

Temperature Distribution:

Here we are applying the temperature on the piston head and on the walls of the piston. On the piston head 500°C is applied and on the piston walls 300°C is applied. The below figure shows the temperature distribution of piston.

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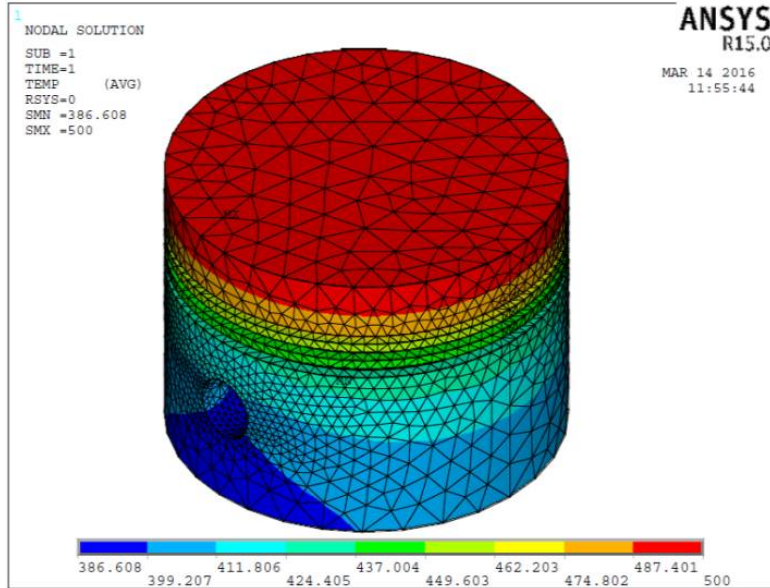


Fig 2: Aluminium temperature deflection

Deformation due to Pressure:

Here we apply the pressure on the top of the piston of 3Mpa and Applying the All DOF on the piston pin rings by which we can find out the deflection in piston.

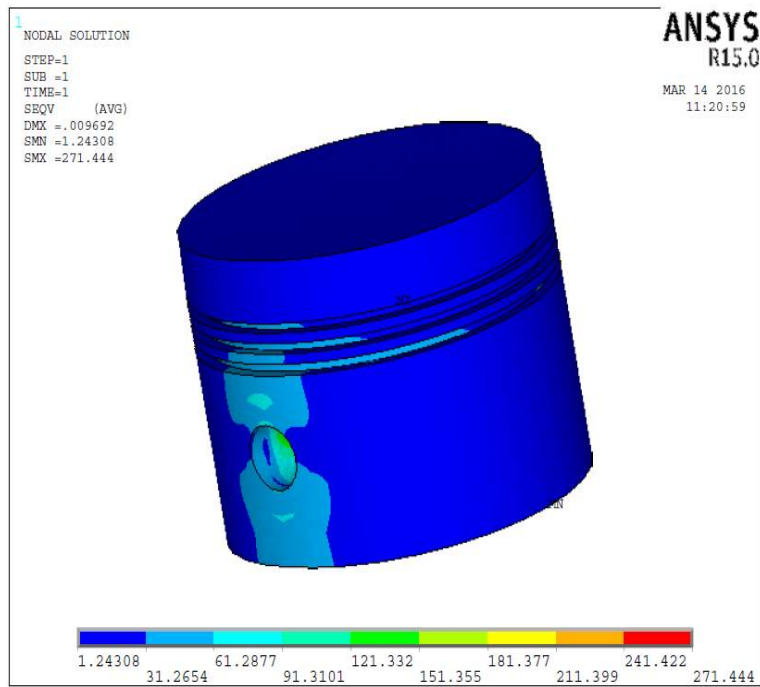


Fig 3: Deformation due to pressure

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AISI 4340:

Temperature Distribution:

Same amount of temperature is applied on the piston which is made of AISI 4340 material. The below figure shows the temperature distribution of AISI 4340 material.

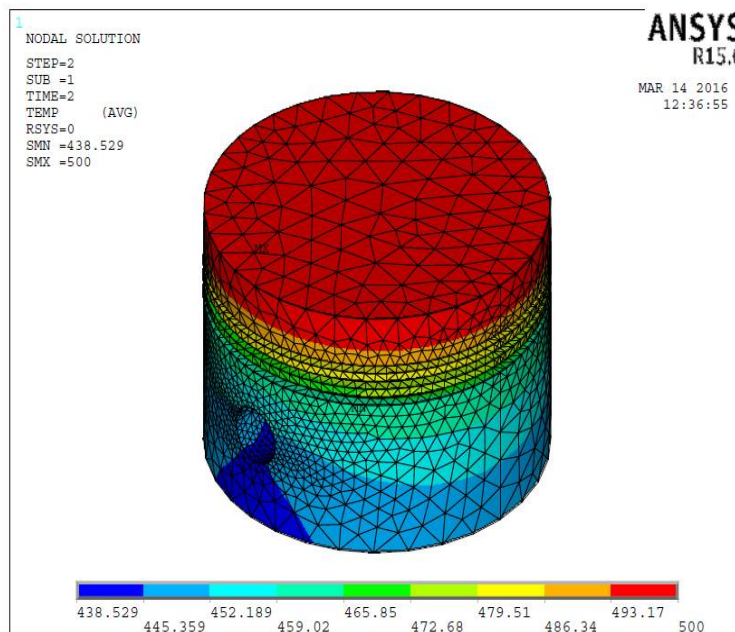


Fig 4: AISI 4340 Temperature Distribution

Deformation due to Pressure:

Here we are applying the pressure on the piston which is made of AISI 4340, on the piston head 3Mpa of pressure is applied and Applying the All DOF on the piston pin rings.

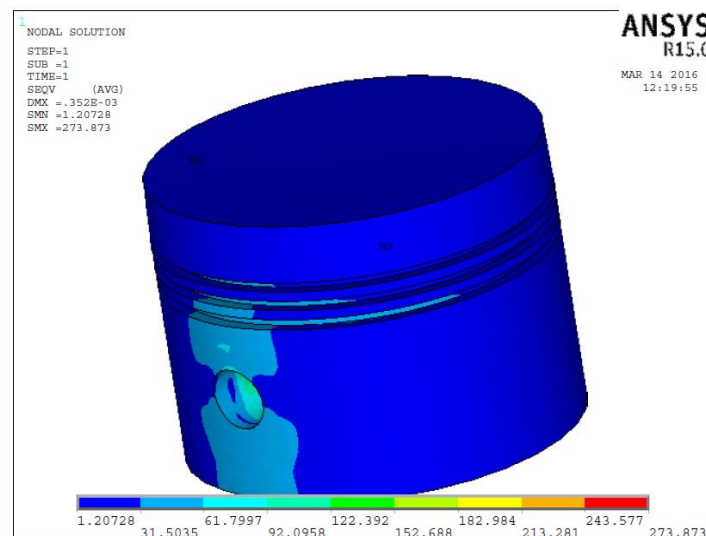


Fig 5: Deformation due to pressure

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IX. CONCLUSION

It is concluded from the above study the piston is designed using PRO-E software and analyzing the piston using the ANSYS software. Only few steps are needed to make drawing in three dimensions. The piston model is imported to ANSYS for analysis. Piston made of two different materials Al alloy 4032 & AISI 4340 Alloy steel 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. 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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