Stress Analysis of Piston at Different Pressure Load

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Abstract - *Internal combustion engines have been, and will remain for the foreseeable future, a vital and active area of engineering education and research. Most of the researches in internal combustion engines are operating performance and fuel performance oriented. Every mechanical component is designed for a particular structural and thermal strength. Piston seizure and cylinder block melting are typical problems when thermal and structural loads on the components exceed the design strengths. Piston is a cylindrical component fitted into the cylinder and forms the moving boundary of the combustion system. It fits perfectly into the cylinder providing gas tight space with the help of piston rings and lubricant. These pistons are made of two different types of materials aluminum alloy and cast iron. Structural and thermal analysis will be carried out on problem made up of these materials using simulation software ANSYS 16.0. This FEM study can be extended to engine valves.*

1. INTRODUCTION

A piston is a component of reciprocating IC-engines. Piston is the component which is moving that is contained by a cylinder and was made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod. Nowdays Piston mainly endures the cyclic gas pressure and the inertial forces at working, and this working condition may cause the fatigue damage of piston. Piston in an IC engine must possess the good mechanical and thermal characteristics. The result found show that the maximum stress and critical region on the aluminum alloy pistons using FEA. It is important to locate the area which is critical about concentrated stress for appropriate modifications. Static and thermal stress analysis is performed by using ANSYS 16.0. Automobile components have great demand now days because of increased use of automobiles. The increased demand is due to improved performance and reduced cost of these components R&D and testing engineers should develop critical components in shortest possible time to minimize launch time for new products. This necessitates understanding of new technologies and quick absorption in the development of new products. [4]

1.1 OBJECTIVES

- To determine the stress distribution of aluminum alloy piston by using Finite Element Method.
- To determine the maximum stress and critical region on the aluminum alloy piston by using Finite Element Method.
- To determine the stress distribution of Cast Iron piston by using Finite Element Method.
- To determine the maximum stress and critical region on the Cast Iron piston by using Finite Element Method.

1.2 SCOPE

- The result of this work could be useful for the design of the piston which bears the pressure conditions of system.
- This result also helpful for the designer for understanding the behavior of piston in details.

2. LITERATURE REVIEW

2.1 Design the Piston of Internal Combustion Engine by Pro\Engeer.

Author: Shuoguo Zhao Mechatronics Department Handan Polytechnic College,Handan Hebei
Overview: 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. So it is very important for structural analysis of the piston. This paper analies and calculates the piston by Pro\ENGEER software to gain a result, which improves and optimizes the structure of the piston.[6]

2.2 Thermal Analysis and Optimization of I.C. Engine Piston Using Finite Element Method.

Author: 1M.Tech Student Heat Power Engineering, Mechanical Engineering Department, KITS College of Engineering Nagpur,2.Asso.Professor, Mechanical Engineering Department, KITS College of Engineering Nagpur.
Overview: In this paper the stress distribution of the seizure on piston four stroke engine by using FEA. The finite element analysis is performed by using computer aided design (CAD) software. The objectives of author to analyze the thermal stress distribution of piston, during combustion process, at the real engine condition. The paper describes the mesh optimization by using finite element analysis technique to

predict the higher stress and critical region on the component. To reduce the stress concentration on the upper end of the piston the optimization is carried out i.e (piston head/crown and piston skirt and sleeve). By using computer aided design (CAD), Pro/ENGINEER software the model of a piston will be developed. Furthermore, ANSYS software is used to analyse the finite element.

2.3 Finite Element Analysis of Ic Engine Connecting Rod By ANSYS.

Author: R A Savanoor, Abhishek Patil, Rakesh Patil and Amit Rodagi
Overview: Connecting rod is the intermediate link between the piston and the crank. In this research we came to know that to transmit the push and pull from the piston pin to crank pin Connecting rod is responsible, thus it converts the reciprocating motion of the piston to rotary motion of the crank. Generally carbon steel is being used in manufacturing of connecting rod and in recent days aluminum alloys are finding its application in connecting rod. Here we are comparing the von mises stress and total deformation of 2different aluminium alloys with the forged steel. We had obtained the parameters like von misses stress and displacement from ANSYS software. Then compared the aluminium alloys with the forged steel. Then Al5083 alloy found to have less weight. It resulted in reduction of 63.19% of weight.[5]

3. PISTON DESIGN

The design of piston is done according to the procedure and specification which are given in machine design and data hand books. The dimensions are calculated in terms of SI Units. The pressure applied on piston head, temperatures of various areas of the piston, heat flow, stresses, strains, length, diameter of piston and hole, thicknesses, etc., parameters are taken into consideration

3.1 Design Considerations for a Piston

In design of piston for an engine, the following points should be taken into consideration:

- It should have enormous strength to withstand the high pressure.
- It should have minimum weight to withstand the inertia forces.
- It should form effective oil sealing in the cylinder.
- It should provide sufficient bearing area to prevent undue wear.
- It should have high speed reciprocation without noise.
- It should be of rigid construction to withstand both thermal and mechanical distortions.
- It should have sufficient support for the piston pin.

3.2 Procedure for Piston Design

The procedure for piston designs mainly consists of the following steps:

- 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)

The above steps are explained as below:
Thickness of Piston Head (th)
The piston thickness of piston head calculated using the following Grashoff's formula,

$$t_H = \sqrt{(3pD2)/\ (16\sigma_t)} \text{ in mm}$$

Where
P= maximum pressure in N/mm^2
D= cylinder bore/outside diameter of the piston in mm.
σ_t=permissible tensile stress for the material of the piston. Here the material is a particular grade of AL-Si alloy whose permissible stress is in range of 50 Mpa-90Mpa.
Before calculating thickness of piston head, the diameter of the piston has to be specified. The piston has been considered here has L*D specified as 152*140.

Heat Flow through the Piston Head (H)
The heat flow through the piston head is calculated using the formula

$$H = 12.56*tH * K * (Tc-Te) \text{ Kj/sec}$$

Where
K=thermal conductivity of material which is 174.15W/mk
Tc = temperature at center of piston head in °C.
Te = temperature at edges of piston head in °C.

Radial Thickness of Ring (t_1)

$$t_1 = \sqrt{D3pw/\sigma t}$$

Where D = cylinder bore in mm
Pw= pressure of fuel on cylinder wall in N/mm^2. Its value is limited from 0.025N/mm^2 to 0.042N/mm^2. For present material, σ_t is 90Mpa.

Axial Thickness of Ring (t2)
The thickness of the rings may be taken as

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

Let assume t_2 =5mm
Minimum axial thickness (t2)

$$= D/(\ 10*nr\ )$$

Where nr = number of rings

Width of the top land (b_1)
The width of the top land varies from

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

Width of other lands (b_2)

Width of other ring lands varies from

$b_2 = 0.75t_2$ to t_2

Maximum Thickness of Barrel (t_3)

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

Where

b = Radial depth of piston ring groove

Thus, the dimensions for the piston are calculated and these are used for modeling the piston in CATIA V5R16.[1]

4. METHODOLOGY

4.1 FEA Methodology

The Finite Element Method is mainly a product of electronic digital computer age. Though the approach shares many features common to the numerical approximations, it possesses some advantages with the special facilities offered by the high speed computers. In particular, the method can be systematically programmed to accommodate such complex and difficult problems as nonhomogeneous materials, nonlinear stress-strain behavior and complicated boundary conditions. It is difficult to accommodate these difficulties in the least square method or Ritz method and etc. an advantage of Finite Element Method is the variety of levels at which we may develop an understanding of technique.

4.2 CAD Modeling

The below image shows the geometry of piston imported into the simulation software for Analysis.

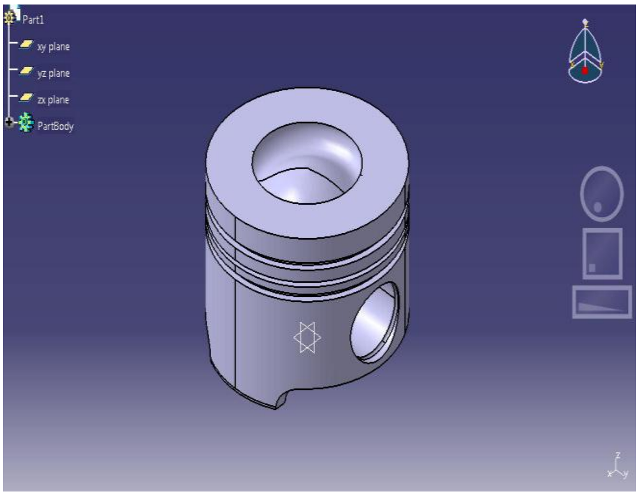


Fig 1: Piston created by CAD model

Before going to import a geometrical model of piston which can be prepared by modeling software's like Autodesk Inventor. The geometrical modeling can also done in the analysis software's like ANSYS

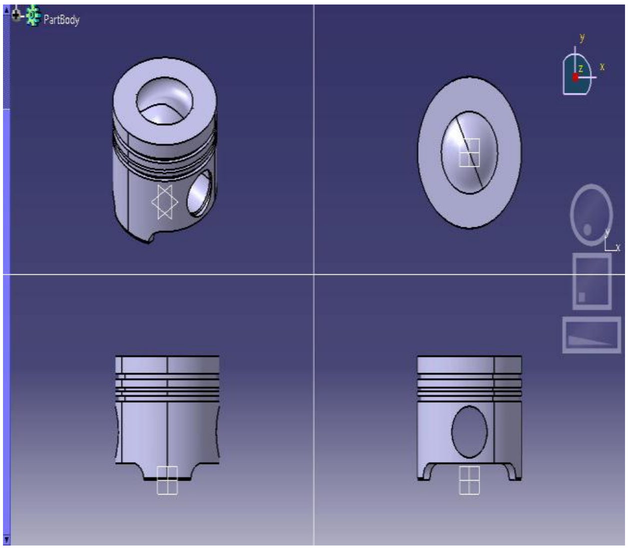


Fig 2: all views of piston

4.3 Meshing Geometry

Meshing of of Piston Model Solid 187 (10-Node Tetrahedral Element) of which Meshing Type is Fine and the Number of is 27194 and Number of Node is 48852

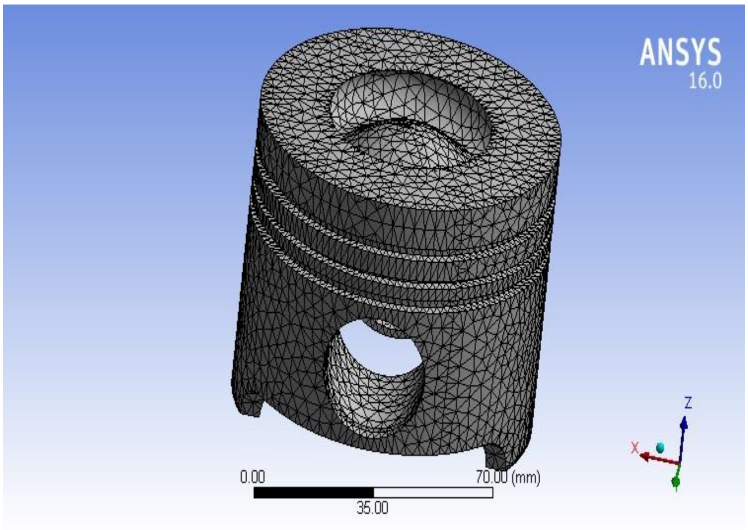


Fig 3: Meshing of Piston Model

Following table shows Mechanical properties of both the material Cast Iron and Aluminum Alloy.

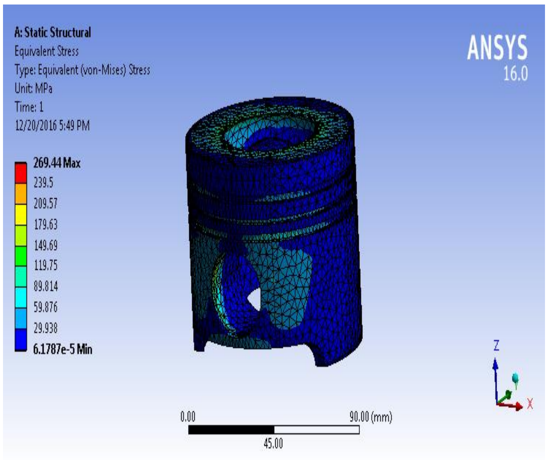
Table 1: Mechanical properties of material

Parameters	Unit	Cast Iron	Aluminum Alloy
Modulus of Elasticity	MPa	100×10^3	70×10^3
Poisson's Ratio	--	0.28	0.33
Tensile Yield Strength	MPa	--	280
Tensile Ultimate Strength	MPa	240	310
Density	Kg/m^3	7200	2700
Coefficient of Thermal Expansion	$m/^0C$	0.1×10^{-6}	0.24×10^{-6}
Heat Conductivity	$W/m/^0C$	44.7	174.75
Shear Modulus	MPa	45×10^3	25×10^3

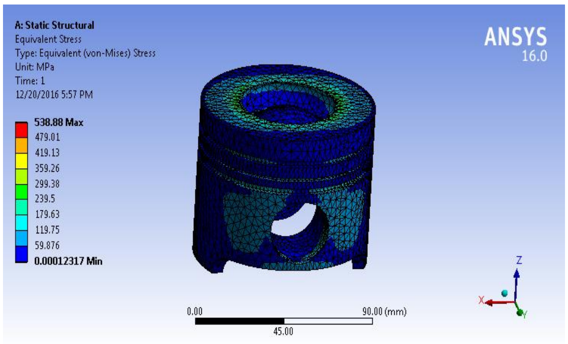
5. RESULTS

By providing suitable boundary conditions at different pressures we get the following results for Equivalent Stress

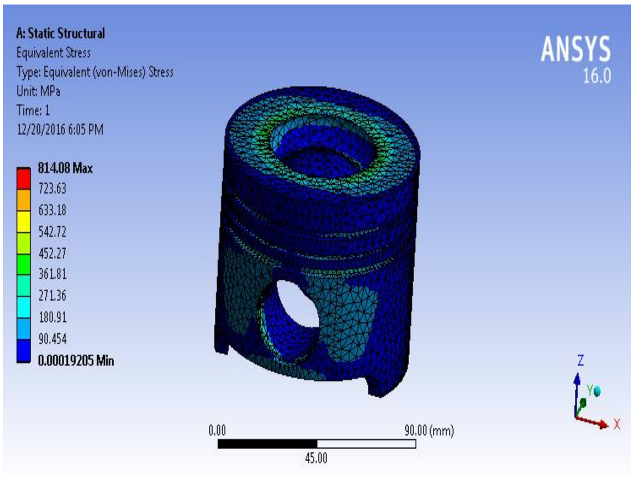
Case 1: For pressure = 5 N/mm^2 (For Aluminum)



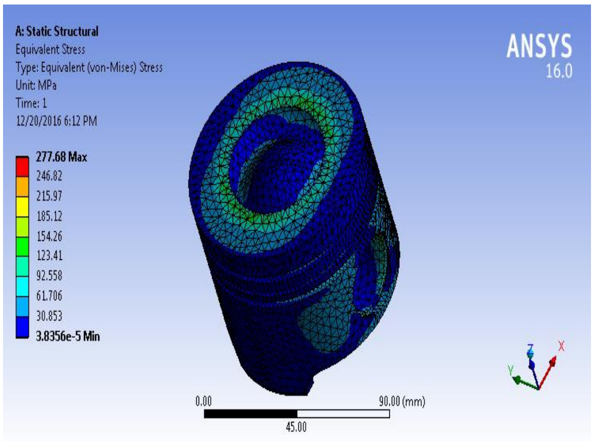
CASE 2: For pressure = 10 N/mm^2 (For Aluminum)



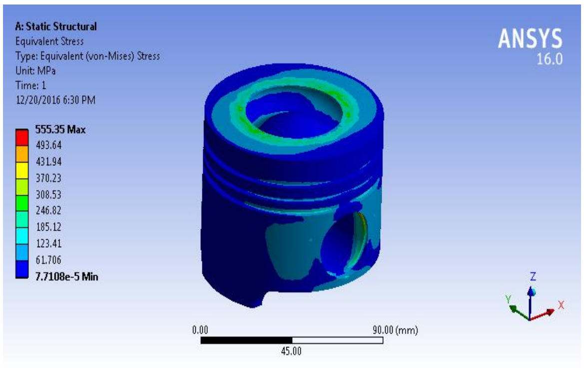
CASE 3: For pressure = 15 N/mm^2 (For Aluminum)



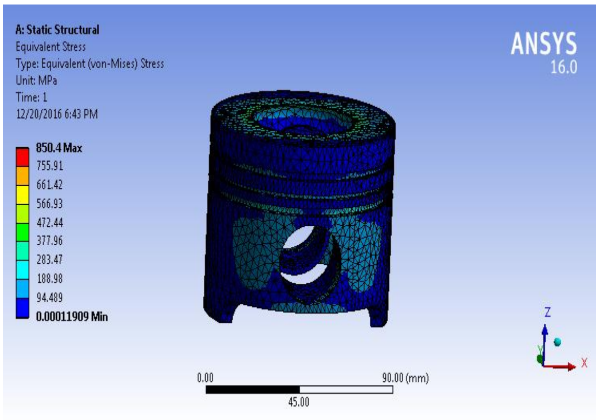
Case 4: For pressure = 5 N/mm^2 (For Cast Iron)



Case 5: For pressure = 10 N/mm² (For Cast Iron)



Case 6: For pressure = 15 N/mm² (For Cast Iron)



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6. CONCLUSIONS

1. In this way by means of using FEA analysis we can easily determine the stress distribution of aluminum alloy piston by using Finite Element Method.

2. The result of this work could be useful for the design of the piston which bears the stresses and pressure conditions of system. This result also helpful for the designer for understanding the behavior of piston in details.

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