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Research Article

Design Analysis of Piston for Four Stroke Single Cylinder Engine Using ANSYS

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Abstract

In this study, structural analysis is investigated on conventional piston made of Al alloy A2618. Secondly analysis are performed on piston made of Al-GHY1250 and Al-GHS1300.The material used for the design of piston should have light weight, low cost, structurally and thermally withstand at very high pressure and temperature condition that will occur in combustion process. In this project, it has been decided to study a particular piston design and its capability for maximum gas pressure. In this work, initial planning is to make piston model using solid modeling software Creo / Pro 5.0. It has been decided to mesh the geometry analyze using ANSYS. For the analysis of piston input conditions and process of analysis, a lot of literature survey has been done. High combustion gas pressures will act as a mechanical loads and causes major stresses in the critical region of the piston. Detailed static structural analysis is carried out for various loading conditions like maximum gas pressure load. Comparative study is done to select best material.

Keywords: *A2618, Al-GHY1250, Al-GHS1300, Creo/ Pro 5.0.*

1. Introduction

Piston is one of the most important components in internal combustion engine which reciprocates within the cylinder. The main function of the piston is to transfer force from gas in the cylinder to the crank shaft through connecting rod. It is very important to calculate temperature distribution on the piston in order to control thermal stresses and deformation in working condition, Piston produces stresses and deformation due to periodic load effects which produces from high gas pressure, high speed reciprocating motion of inertia force. Lateral force by the chemical reaction of burning the gas high pressure generates which make the piston expand which generates thermal stresses and thermal deformation. The thermal and mechanical deformation causes piston cracks. Swati S. Chougule *et. al* (2013). Therefore it is very essential to analyses the stress distribution, temperature distribution, heat transfer, mechanical load in order to minimize the stress at different load on piston.

1.1 Piston

Piston is one of the most important components in I.C. engine which reciprocates within the cylinder. The main function of the piston of an internal combustion engine is to transfer force from expanding gas in the cylinder to the crank shaft through connecting rod. Ch. Venkata Rajam *et. al* (2013).

Following are the main parts of piston

1) Piston Head or crown: It is flat, convex or concave depending on design of combustion chamber. It withstands pressure of gas in the cylinder.
2) Piston rings: It is used to seal the cylinder in order to prevent leakage of gas past the piston.
3) Skirt: It act as bearing for the side thrust of connecting rod on the walls of cylinder.
4) Piston pin: It is also called gudgeon pin or wrist pin. It is used to connect the piston to the connecting rod.

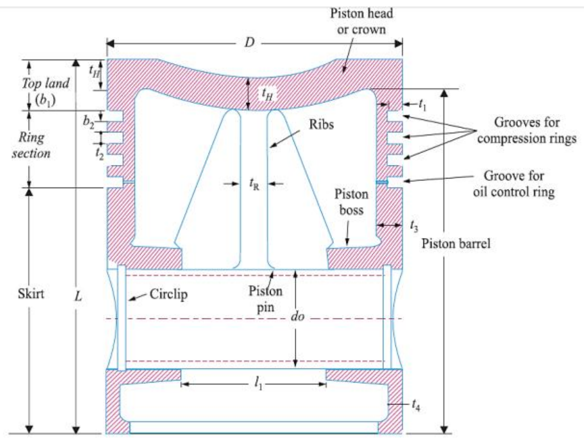

Fig. 1 Piston components for I.C. engine

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2. Literature Review

This topic shows review on design analysis of piston on the basis of improving strength according to the material properties. Vibhandik *et. al* . (2014), studied that Design analysis and optimization of piston and deformation of its thermal stresses using CAE tools, he had selected I.C. engine piston from TATA motors of diesel engine vehicle. He had performed thermal analysis on conventional diesel piston and secondly on optimized piston made of aluminum alloy and titanium alloy material. Conventional diesel piston made of structural steel. The main objective of this analysis is to reduce the stress concentration on the upper end of the piston so as to increase life of piston. After the analysis he conclude that titanium has better thermal property, it also help us to improve piston qualities but it is expensive for large scale applications, due to which it can be used in some special cases. Ch. Venkata Rajam *et. al* . (2013), focused on Design analysis and optimization of piston using CATIA and ANSYS. He had optimized with all parameters are within consideration. Target of optimization was to reach a mass reduction of piston. In this analysis a ceramic coating on crown is made. In an optimization of piston, the length is constant because heat flow is not affected the length, diameter is also made constant due to same reason. The volume varied after applying temperature and pressure loads over piston as volume is not only depending on length and diameter but also on thickness which is more affected. The material is removed to reduce the weight of the piston with reduced material. The results obtained by this analysis shows that, by reducing the volume of the piston, thickness of barrel and width of other ring lands, Von mises stress is increased by and Deflection is increased after optimization. But all the parameters are with in design consideration.V. V. Mukkawar *et. al* . (2015), describes the stress distribution of two different Al alloys by using CAE tools. The piston used for this analysis belongs to four stroke single cylinder engine of Bajaj Pulsar 220 cc motorcycle. He had concluded that deformation is low in AL-GHY 1250 piston as compare to conventional piston. Mass reduction is possible with this alloy. Factor of safety increased up to 27% at same working condition. He used Al-GHY 1250 and conventional material Al-2618 and results were compared, he found that Al-GHY 1250 is better than conventional alloy piston. Manjunatha T. R. *et. al*. (2013), underlook specification for both high pressure and low pressure stages and analysis is carried out during suction and compression stroke and identify area those are likely to fail due to maximum stress concentration. The material used foe the cylinder is cast-iron and for piston aluminum alloy for both low and high pressure. He concluded that the stress developed during suction and compression stroke is less than the allowable stress. So the design is safe. Swati S. chougule *et. al.* (2013), focused on the main objective of this paper is to investigate and analyze the stress distribution of piston at actual engine condition during combustion process the parameters used for simulation is operating gas pressure and material properties of piston. She concluded that there is a scope for reduction in a scope for reduction in thickness of piston and therefore 0ptimization of piston is done with mass reduction by 24.319% than non-optimized piston. The static and dynamic analysis is carried out which are well below the permissible stress value. The study of Lokesh Singh *et. al* . (2015) is related to the material for the piston is aluminum-silicon composites. The high temperature at piston head, due to direct contact with gas, thermal boundary conditions is applied and for maximum pressure mechanical boundary conditions are applied. After all these analysis all values obtained by the analysis is less than permissible value so the design is safe under applied loading condition. The study of R. C. Singh *et. al*. (2014), discussed about failure of piston in I.C. engines, after all the review, it was found that the function coefficient increases with increasing surface roughness of liner surface and thermal performance of the piston increases. The stress values obtained from FEA during analysis is compared with material properties of the piston like aluminum alloy zirconium material. If those value obtained are less than allowable stress value of material then the design is safe.

3. Methodology

Analytical design of piston, using specification of four stroke single cylinder engine of Bajaj Kawasaki motorcycle created.

- Creation of 3D model of piston using Creo/Pro5.0 and then imported in HyperMesh.
- Mesh of 3D model using HyperMesh.
- Analysis of piston using stress analysis method.
- Comparative performance of Al alloy piston.
- Select the best Al alloy.

4. Material Selection

4.1 Engine specification

Table 1 Engine specification

S. No.	Parameters	Values
1	Engine Type	Four stroke, petrol engine
2	No. of cylinder	single cylinder engine
3	Maximum pressure	15 N/mm^2
4	Bore	50 mm
5	Stroke length	81.25mm
6	Speed	5000rpm
7	Brake power	8BHP
8	Compression Ratio	8.4
9	Maximum Torque	8.05 Nm at 5500
10	Maximum horsepower	6.03 kW at 7500 rpm

4.2 Piston Materials

The most commonly used material for piston of IC engines is Al alloy and cast iron. But Al alloy are more preferable in comparison of cast iron due to its light weight. The heat conductivity of Al alloy is four times that of cast iron. Aluminium pistons are made thicker which is necessary for strength in order to give proper cooling.

4.3 Properties Of Materials

The material chosen for this work are conventional Al alloy i.e. A2618, Al-GHY1250, Al-GHS1300 for an IC engine piston. The Mechanical properties of conventional Al alloy alloy i.e. A2618, Al-GHY1250, Al-GHS1300 are listed in following table.

2. Problem Statement

The working condition of the piston of an internal combustion engine is so worst as compare to other parts of I.C. engine. There are high chances of failure of piston due to wear and tear. So there is necessary to analyze area of maximum stress concentration on piston. The objective of the present work is to design and analysis of piston made of A2618, Al-GHY1250, Al-GHS 1300. In this paper the material of piston A 2618 is replaced by Al-GHY1250 and Al-GHS 1300.

Table 2 Properties of Materials

S. No.	Parameters	Conventional Al alloy A2618	Al-GHY1250	Al-GHS1300
1	Poisson's Ratio (μ)	0.33	0.3	0.3
2	Young's Modulus (E) GPa	70-80	83	98
3	Thermal Conductivity(k) W/m°C	147	135	120
4	Density (ρ) Kg/m³	2767.9981.25	2880	2780
5	Permissible Bending stress(σ_t) Mpa	370	1190	1220
6	Allowable Bending stress(σ_t) Mpa	90	98	92
7	Ultimate Tensile Strength Mpa	440	1250	1300

6. Piston Design

6.1 Design Consideration for a Piston

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

i. It should have minimum mass.
ii. It should have high speed reciprocation without noise.
iii. It should have high strength to withstand the high gas pressure and inertia forces.
iv. It should be rigid in construction to withstand thermal and mechanical distortion.
v. It should have sufficient bearing area to prevent wear.
vi. It should disperse heat of combustion quickly to the cylinder walls.
vii. It should have sufficient support for the piston pin.
viii. It should form effective oil and gas sealing of the cylinder.

6.2 Analytical Design

η= Mechanical efficiency= 80% =0.8
N= Engine speed = 5000 rpm

$$\eta = \frac{\text{Brake power (B.P.)}}{\text{Indicating power (I.P.)}} \quad (1)$$

$$\text{I.P.} = \frac{\text{B.P.}}{\eta} = \frac{8}{0.8} = 10 \text{ Kw}$$

$$\text{Also, I.P.} = \frac{\text{PALN}}{2\text{x}60}$$

$$\text{P} = \frac{2 \text{ x } 60 \text{ x I.P.}}{\text{ALN}} = 15.04 \text{ x } 10^5 \text{ N/m}^2$$

P= 1.504 MPa

Maximum pressure= 10 x P = 15.04 MPa

(a) Analytical design for A2618 alloy piston

Thickness of piston head (t_H):

The thickness of piston head, according to Grashoff's formula is given by,

$t_H = \sqrt{3 p_{max} D^2 / 16\, \sigma_t}$……………….in mm (2)

t_H = 4.4 mm

Heat flow through the piston head (H)

The heat flow through the piston head is calculated using formula

$H = 12.56 * t_H * k * (T_c - T_e)$ ……………….in KJ/sec

On the basis of heat dissipation, the thickness of the piston head is given by,

$t_H = C * HCV * m * B.P. * 10^6 / 12.56 * k * (T_c - T_e)$

t_H = 3.6 mm ……………m=95.45 kg/BP/s

The maximum thickness from the above formula is t_H= 4.4 mm

Radial thickness of ring (t_1)

$t_1 = D \sqrt{3 P_w / \sigma_t}$ (3)

t_1 = 1.5 mm

The thickness of the ring may be taken as,

$t_2 = 0.7\, t_1$ to t_1 (4)

t_2 = 1 mm

Number of rings (n_r)
Minimum axial thickness (t_2)
$t_2 = D/(10 * n_r)$
n_r = 3rings

Width of top land and ring lands

Width of the top land (b_1):
$b_1 = t_H$ to 1.2 t_H=4.4 mm (5)

Width of ring land (b_2):
b_2=0.75 t_2 to t_2= 0.75 mm (6)

Maximum thickness of the barrel at the top end (t_3):

b= 0.4 + t_1
t_3=0.03 D + b + 4.5

t_3=0.03 D + t_1 + 4.9 = 7.9 mm (7)
Thickness of piston barrel at the open end (t_4):
t_4= 0.25 t_3 to 0.35t_3 = 1.975 mm (8)

Length of skirt

l_s= 0.6 D to 0.8 D= 30 mm
Length of piston pin in the connecting rod bushing:
l_p= 45% of the piston diameter= 22.5 mm

Total length of the piston(L)

Total length of the piston is given by
L=Length of skirt + Length of ring section + Top land = l_s+ l_r + b_1= 30 +5.5 + 4.4 = 40.92 mm

Piston pin diameter (d_o&d_i)

d_o= 0.28 D to 0.38 D = 14 mm
d_i= 0.6 d_o= 8.4 mm
The center of the piston pin should be 0.02 D to 0.04 D above the center of the skirt = 1.5 mm

(b) Analytical design for Al-GHY1250 alloy piston

Thickness of piston head (t_H) =3.919644 mm
Radial thickness of ring (t_1) = 1.5mm
Axial thickness of ring (t_2) = 1.05 mm
Width of the top land (b_1) = 3.919644 mm
Width of ring land (b_2)=0.7875 mm
Maximum thickness of the barrel at the top end (t_3) =7.9mm
Thickness of piston barrel at the open end (t_4) =1.975mm
Length of skirt (l_s) =30mm
Length of piston pin in the connecting rod bushing (l_p) =22.5mm
Total length of the piston (L) = 40.48214 mm
The Length of piston usually varies between D to 1.5 D
Piston pin diameter =d_o= 14, d_i= 8.4 mm

(c) Analytical design for Al-GHS1300 alloy piston

Thickness of piston head (t_H) =4.409599 mm
Radial thickness of ring (t_1) = 1.5mm
Axial thickness of ring (t_2) = 1.05mm
Width of the top land (b_1) = 4.409599mm
Width of ring land (b_2) =0.7875 mm
Maximum thickness of the barrel at the top end (t_3) =7.9 mm
Thickness of piston barrel at the open end (t_4) =1.975mm
Length of skirt (l_s) =30mm
Length of piston pin in the connecting rod bushing (l_p) =22.5mm
Total length of the piston(L) =40.9721mm
The Length of piston usually varies between D to 1.5 D
Piston pin diameter
d_o= 14 mm
d_i= 8.4 mm

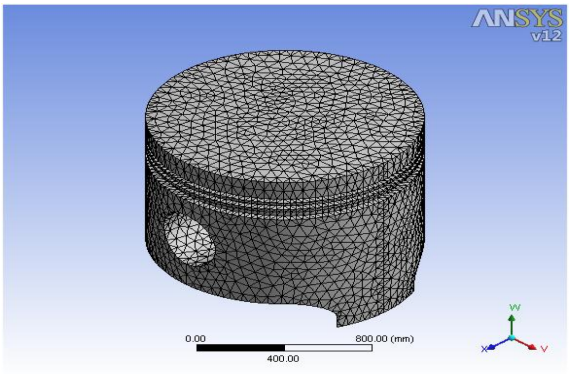

Fig. 3 Meshed piston model

3D model of piston is imported into the ANSYS Workbench for preprocessing. Preprocessing of model consist of meshing, selection of material properties. Meshed piston model is as shown in fig. 3.

7. Result

7.1 For A2618 alloy

The figure illustrates the total deformation of the piston. The value of maximum deformation is 1.4356 mm .The value of minimum deformation 0.0013519 mm, which is occurred at the center of piston head as shown in figure.

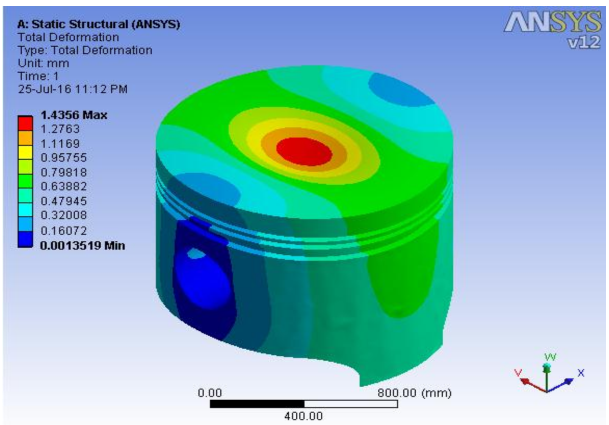

Fig. 4 Total Deformation

The figure 5 illustrates the variation of von-misses stress in the piston. The value of maximum stress found to be 388.39 MPa. The value of minimum stress is found to be 0.55994 MPa.

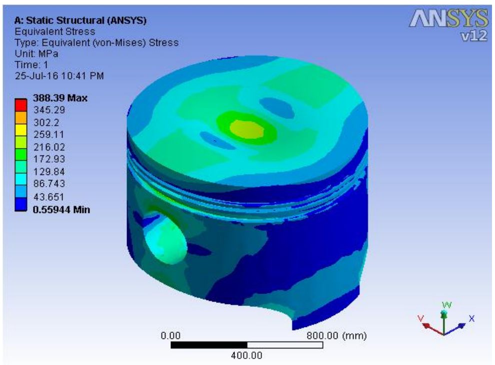

Fig. 5 Equivalent von-misses stress

The figure 6 illustrates the variation of von-misses strain in the piston. The value of maximum strain found to be 0.93174 MPa. The value of minimum strain is found to be 0.0013421 MPa.

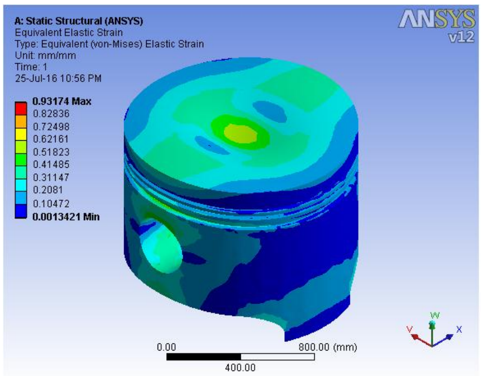

Fig. 6 Equivalent von-misses strain

7.2 For Al-GHY1250 alloy

The figure7 illustrates the total deformation of the piston. The value of maximum deformation is 1.0795 mm .The value of minimum deformation 0.0008463 mm, which is occurred at the center of piston head as shown in figure.

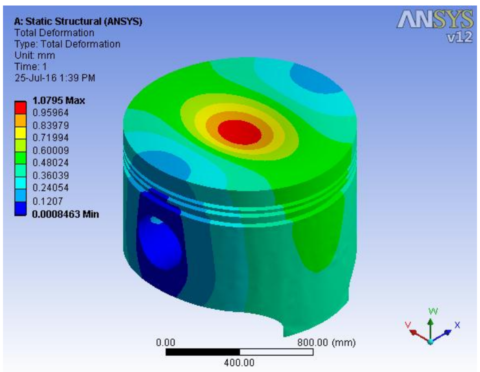

Fig. 7 Total Deformation

The figure 8 illustrates the variation of von-misses stress in the piston. The value of maximum stress found to be 342.1 MPa. The value of minimum stress is found to be 1.1249 MPa.

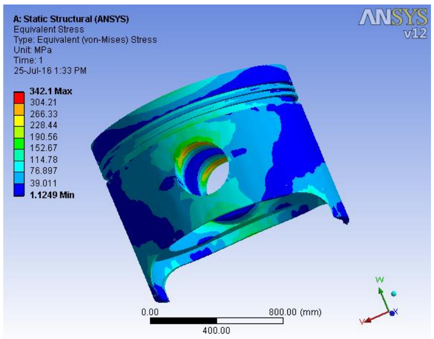

Fig. 8 Equivalent von-misses stress

The figure 9 illustrates the variation of von-misses strain in the piston. The value of maximum strain found to be 1.0171 MPa. The value of minimum strain is found to be 0.0033442 MPa.

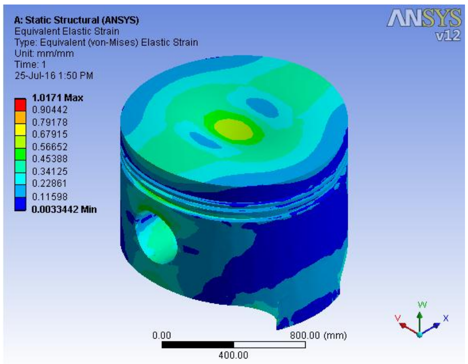

Fig. 9 Equivalent von-misses strain

7.3 For Al-GHS1300 alloy

The figure 10 illustrates the total deformation of the piston. The value of maximum deformation is 0.30634 mm .The value of minimum deformation 0.00024017 mm, which is occurred at the center of piston head as shown in figure.

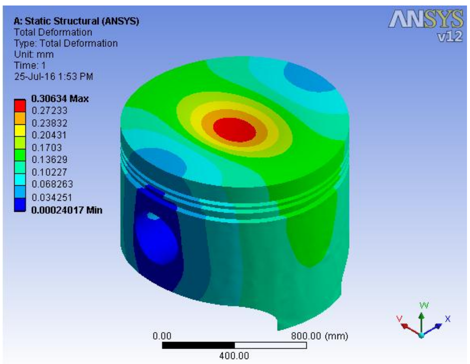

Fig. 10 Total Deformation

The figure illustrates the variation of von-misses stress in the piston. The value of maximum stress found to be

291.25 MPa. The value of minimum stress is found to be 0.95766 MPa.

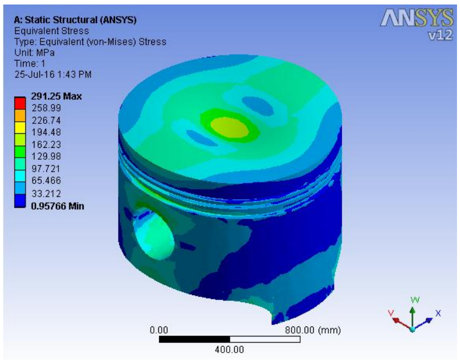

Fig. 11 Equivalent von-misses stress

The figure 11 illustrates the variation of von-misses strain in the piston. The value of maximum strain found to be 1.8492 MPa. The value of minimum strain is found to be 0.0060804 MPa.

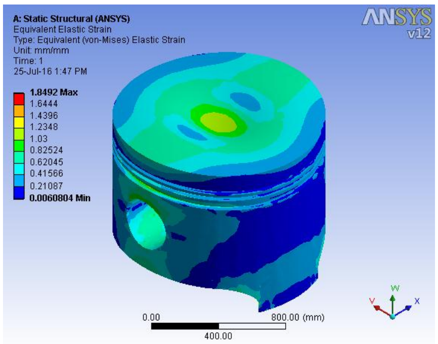

Fig. 12 Equivalent von-misses strain

7.4 Comparative performance

The comparative performance of Simulated result of various parameters like maximum and minimum value of Total Deformation , Equivalent von-misses stress, Equivalent von-misses strain for three different material are as shown in table 3.

Table 3 Simulated Comparative performances of three alloys

S. No	Parameters	Conventional Al alloy A2618 Max Min	Al-GHY1250 Max Min	Al-GHS1300Max Min
1	Total Deformation (mm)	1.4356 0.0013519	1.0795 0.0008463	0.30634 0.00024017
2	Equivalent von-misses stress (MPa)	388.39 0.55994	342.1 1.1249	291.25 0.95766
3	Equivalent von-misses strain (MPa)	0.93174 0.0013421	1.0171 0.0033442	1.8492 0.0060804

Following table 4 shows the comparison between stresses in theoretical result and analytical result for A2618, Al-GHY1250 and Al-GHS1300 alloy used as piston material.

Table 4 Theoretical Result Vs Simulated Result

S. No	Parameters	Stress A2618	Stress Al-GHY1250	Stress Al-HS1300
1	Theoretical Result	388.51	346.97	294.64
2	Simulated Result	388.39	342.1	291.25

Conclusions

After doing comparative analysis of various type of Al alloyi.e.in between A2618,Al-GHY1250 and Al-GHS1300 for total deformation, equivalent von-mises stress and equivalent von-mises strain. From the analyzed result through this work, it is concluded that stress occurred by using this material is lower than the permissible stress value, so that Al-GHS1300 is best material for piston.

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