Design Analysis and Optimization of Piston by using Three Different Aluminium Alloys

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ABSTRACT

This project describes the stress distribution and thermal stresses of three different aluminum alloys piston by using finite element method (FEM). The parameters used for the simulation are operating gas pressure, temperature and material properties of piston. The specifications used for the study of these pistons belong to four stroke single cylinder engine of Bajaj pulsar 220 cc. This project illustrates the procedure for analytical design of three aluminum alloy pistons using specifications of four stroke single cylinder engine of Bajaj pulsar 220 cc motorcycle. The results predict the maximum stress and critical region on the different aluminum alloy pistons using FEA. It is important to locate the critical area of concentrated stress for appropriate modifications. Static and thermal stress analysis is performed by using ANSYS 14.1. The best aluminum alloy material is selected based on stress analysis results. The analysis results are used to optimize piston geometry of best aluminum alloy.

Keyword:-*A2618, A4032, Al-GHS 1300,Piston, CAE software(ANSYS)*

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1. INTRODUCTION

The Piston is a ‘heart’ of an automobile engine. It’s one of the key components of the engine and it’s working the hard condition. The function of the piston is bearing the gas pressure and making the crankshaft rotation through the piston pin. Piston works in high temperature, high pressure, high speed and poor lubrication conditions. Piston contact with high temperature gas directly, the instantaneous temperature can be up to 2500K. Because of the high temperature and the poor cooling condition, the temperature of the top of the piston can be reach 600~700K when the piston working in the engine. And the temperature distribution is uneven. The top of the piston bears the gas pressure, in particular the work pressure. The investigations indicate that greatest stress appears on the upper end of the piston and stress concentration is one of the mainly reason for fatigue failure. In this study, the piston is used in low idle and rated speed gas engine. In order to enhance theenginedynamic and economic, it is necessary for the piston to implement optimization. Based on the analysis of optimal result, the stress concentration on the upper end of piston has become evaluate, which Provides a better reference for redesign of a piston. As one of the major moving parts in the power-transmitting assembly,the piston must be so designed that it can withstand the extreme heat and Pressure of combustion.

1.1 OBJECTIVES

1. To design piston by analytical method based on the input parameters.
2. Create CAD model of piston using CAD software (CATIA).
3. To analyze the model using CAE software (ANSYS) with different material.
4. Comparing the result of obtained from ANSYS.
5. Identification of the suitable aluminum alloy material for manufacturing of the piston under specified conditions.

2. MATERIAL SELECTION

Table 2.1 Mechanical Properties of material

S N	Parameters	A2618	A4032	Al-GHS 1300
1	Elastic Modulus (GPa)	73.7	79	98
2	Ultimate Tensile Strength (MPa)	480	380	1300
3	0.2% Yield Strength (MPa)	420	315	1220
4	Poisson's Ratio	0.33	0.33	0.3
5	Density (Kg/m3)	2767.99	2684.95	2780

3. ENGINE SPECIFICATION

Table 3.1 Engine specification of Bajaj Pulsar 220 cc

PRAMETERS	VALUES
Engine Type	Four stroke, petrol engine (DTS-I)
Induction	Air cooled type
Number of cylinder	Single cylinder
Bore	67mm
Stroke	62.4mm
Length of connecting rod	124.8mm
Displacement torque	220cm^3
Maximum torque	19.12Nm at 7000 rpm
Maximum power	20.8Kw at 8500 rpm
Compression ratio	9.5+/-0.5:1
No. of revolution cycle	2

4. ANALYTICAL DESIGN

Let,

IP = indicated power produced inside the cylinder (W)
η = mechanical efficiency=0.8
n = number of working stroke per minute = N/2 (for four stroke engine)
N = engine speed (rpm)
L = length of stroke (mm)
A = cross-section area of cylinder (mm^2)
r = crank radius (mm)
lc = length of connecting rod (mm)
a = acceleration of the reciprocating part (m/s^2)
m_p = mass of the piston (Kg)
V = volume of the piston (mm^3)
t_h = thickness of piston head (mm)
D = cylinder bore (mm)
p_{max}= maximum gas pressure or explosion pressure (MPa)
σ_t = allowable tensile strength (MPa)
σ_{ut} = ultimate tensile strength (MPa)

F.O.S = Factor of Safety=2.25
K = thermal conductivity (W/m K)
Tc = temperature at the centre of the piston head (K)
Te = temperature at the edge of the piston head (K)
HCV = Higher Calorific Value of fuel =47000 KJ/Kg
BP = brake power of the engine per cylinder (KW)
m = mass of fuel used per brake power per second (Kg/KW s)
C = ratio of heat absorbed by the piston to the total heat developed in the cylinder=5%=0.05
b = radial width of ring (mm)
Pw = allowable radial pressure on cylinder wall =0.025 N/mm^2
σ_p = permissible tensile strength for ring material 110 N/mm^2
h = axial thickness of piston ring (mm)
h_1 = width of top lands (mm)
h_2 = width of ring lands (mm)
t_1 = thickness of piston barrel at the top end (mm)
t_2 = thickness of piston barrel at the open end (mm)
ls = length of skirt (mm)
μ = coefficient of friction=0.01
l_1 = length of piston pin in the bush of the small end of the connecting rod (mm)
do = outer diameter of piston pin (mm)

Mechanical efficiency of the engine (η) = 80 %.
η = Brake power (B.P) / Indicating power (I.P)
Brake power = $2\ \pi NT/60 = 2\ \pi \times 7000 \times 19.12/60 \times 1000$
BP =14.015 KW
Therefore, I.P = B.P/ η = 14.015/ 0.8 = 17.518 KW
Also, I.P = P x A x L x N/ 2
I.P = P x π/ 4 x D^2 x L x N/ 2
17.518 x1000 = P x π / 4 x $(0.067)^2$ x (0.0624) x (7000)/ 2 x 60
So, P = 13.65 x 10^5 N/m^2 or P = 1.365MPa
Maximum Pressure ($p_{max)}$ = 10 x P
= 10 x 1.365 = 13.65 MPa

4.1 Analytical design for A2618 alloy piston :
Analytical design for A2618 alloy piston is as follows:
Thickness of the Piston Head:
According to Grashoff's formula the thickness of the piston head is given by
Thickness of piston head based on strength:
$t_h = D\sqrt{(3p_{max}/16\sigma_t)}$
where$\sigma_t = \sigma_{ut}$ / 2.25 = 480/ 2.25= 213.33 MPa
Therefore t_h = 67 x $\sqrt{}$(3 x 13.65)/(16 x 213.33)
= 7.338 mm
Empirical formula:
t_h = 0.032 D + 1.5 = 3.644 mm
On the basis of the heat dissipation, the thickness of the piston head is given by:
t_h = [C x HCV x m x BP] x 10^6/ 12.56 x K (Tc – Te)
= [0.05 x 47000 x 28.45 x 10^{-3} x 14.015] x 10^6/ 12.56 x 147 x (350-330) x 3600
= 7.04 mm
The maximum thickness from the above formula ($t_{h)}$ is 7.338 mm.
Piston Rings:
The radial width of the ring is given by:
b = D $\sqrt{(3\ p_w/\sigma_p)}$
= 67 $\sqrt{}$ (3 x 0.025/110)
= 1.7494 mm
Axial thickness of the piston ring is given by:
h = (0.7 b to b) = 0.7 x 1.7494

= 1.2243 mm

Width of Top Land and Ring Lands:

Width of top land:

$h_1 = (t_h \text{ to } 1.2\ t_h)$

$= 7.338$ mm

Width of ring land:

$h_2 = (0.75h \text{ to } h)$

$= 0.75 \times 1.2243$

$= 0.9182$ mm

Piston Barrel:

Thickness of piston barrel at the top end:

$t_1 = 0.03\ D + b + 4.9$

$= 0.03 \times 67 + 1.7494 + 4.9$

$= 8.6594$ mm

Thickness of piston barrel at the open end:

$t_2 = (0.25\ t_1 \text{ to } 0.35\ t_1)$

$= 0.25 \times 8.6594$

$= 2.164$ mm

Length of the skirt:

Ls = (0.6 D to 0.8 D)

= 0.6 x 67

= 40.2 mm

Length of piston pin in the connecting rod bushing:

L_1 = 45% of the piston diameter

= 0.45 x 67

= 30.15 mm

Piston pin diameter:

do = (0.28 D to 0.38 D)

= 0.28 x 67

= 18.76 mm

The centre of the piston pin should be 0.02 D to 0.04D above the centre of the skirt.

4.2 Analytical design for A4032 alloy piston :

Thickness of the Piston Head: t_h = 8.247mm.
Piston Rings: b = 1.7494 mm and h = 1.2243 mm.
Width of Top Land: h_1 = 8.247 mm
Ring Lands: h_2 = 0.9182 mm
Thickness of piston barrel at the Top end: t_1 = 8.6594 mm
Open end: t_2 = 2.164 mm.
Length of the skirt: L_S = 40.2 mm
Length of piston pin in the connecting rod bushing: L_1 = 30.15 mm
Piston pin diameter: do = 18.76 mm
The centre of piston pin should be 0.02D to 0.04D above the centre of skirt.

4.3 Analytical design for Al-GHS1300 alloy piston:

Thickness of the Piston Head: t_h = 4.459mm.
Piston Rings: b = 1.7494 mm and h = 1.2234mm.
Width of Top Land: h_1 = 4.459 mm
Ring Lands: h_2 = 0.9182 mm
Thickness of piston barrel at the Top end: t_1 = 8.6594 mm
Open end: t_2 = 2.164 mm.
Length of the skirt: L_S = 40.2 mm

Length of piston pin in the connecting rod bushing: L_1 = 30.15 mm
Piston pin diameter: do = 18.76 mm
The centre of piston pin should be 0.02D to 0.04D
above the centre of skirt.

5. ANALYSIS

5.1 SOLID MODEL

Fig 5.1 Solid Modelling of Piston

5.2 MESHING

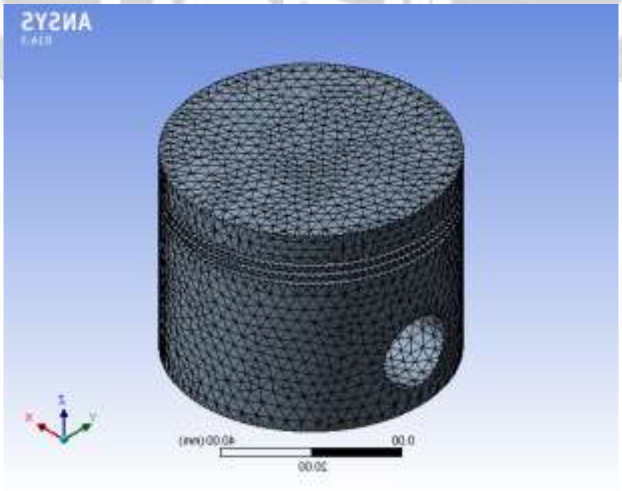

Fig 5.2 Mesh model

5.3 LOADING & BOUNDARY CONDITIONS

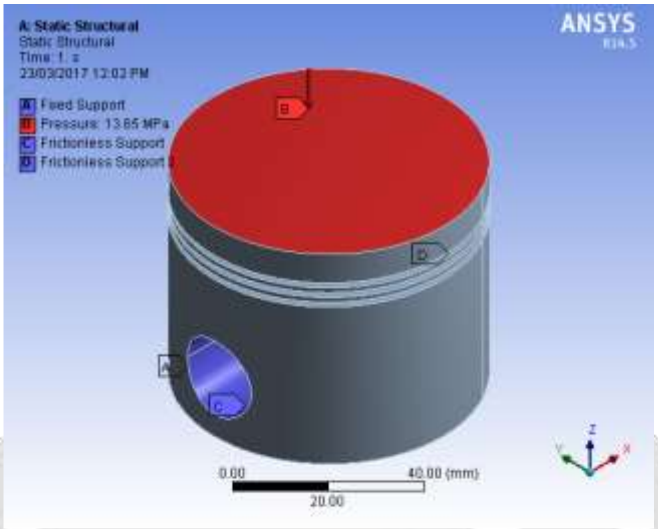

Fig 5.3 Loading & Boundary Condition

5.4 STRUCTURAL ANLYSIS OF PISTON:

5.4.1 Total Deflection of A2618 Alloy piston (100%)

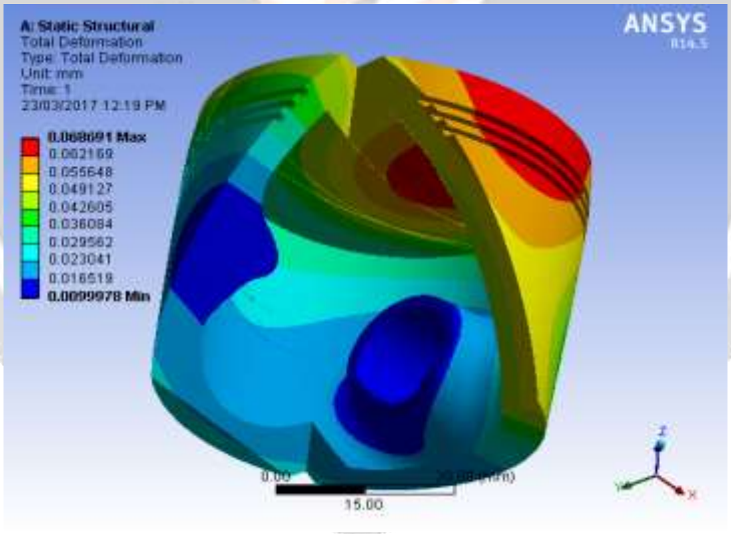

Fig 5.4.1 Total Deflection of A2618 Alloy piston

5.4.2 Stress ofA2618 alloy piston (100%)

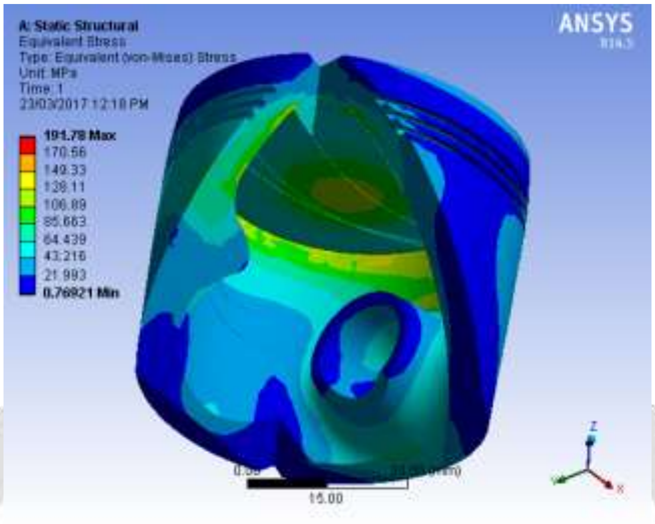

Fig. 5.4.2 Stress of A2618 alloy piston

5.4.3 Strain of A2618 alloy piston (100%)

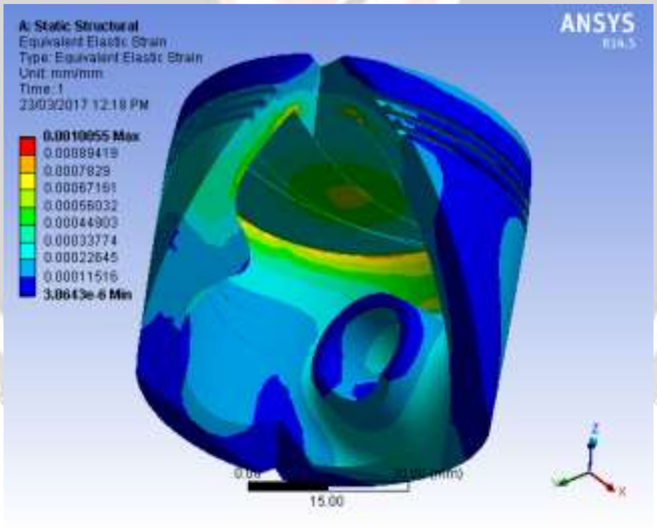

Fig. 5.4.3 Strain of A2618 alloy piston

5.4.4 Total Deflection of A2618 Alloy piston (250%)

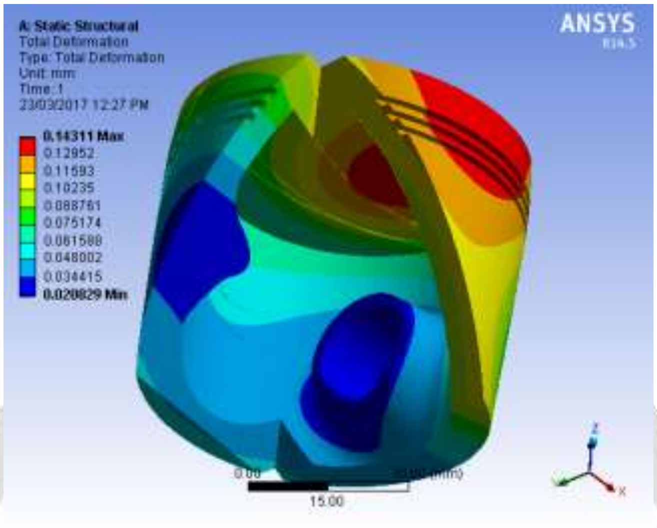

Fig. 5.4.4 Total Deflection of A2618 Alloy piston

5.4.5 Stress ofA2618 alloy piston (250%)

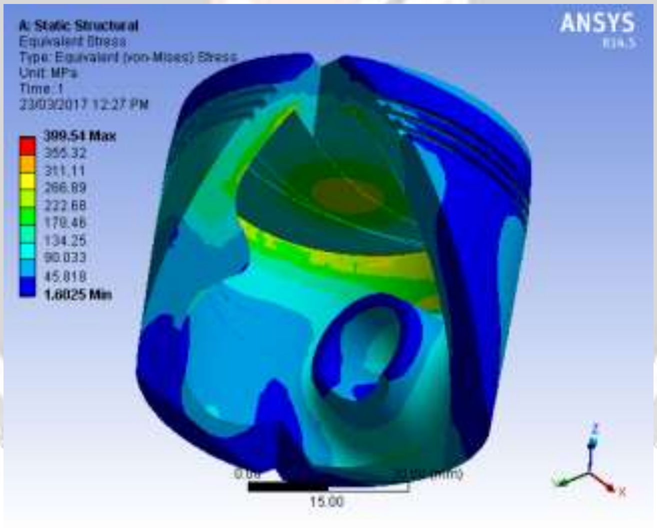

Fig. 5.4.5 Stress of A2618 alloy piston

5.4.6 Strain of A2618 alloy piston (250%)

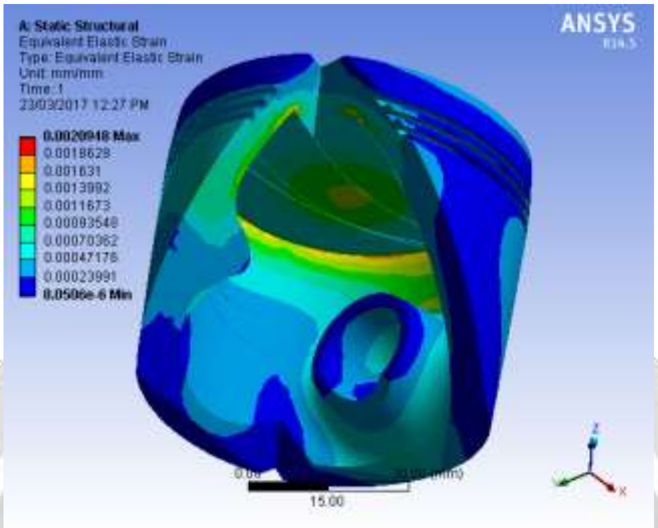

Fig. 5.4.6 Strain of A2618 alloy piston

6. RESULTS

The values of deformation, stress and strain at 100% and 250% load conditions.

Table 6.1 Comparative analysis of three aluminium alloys

S. N.	**Pressure Load (Mpa)**	**Material**	**Ansys Result**		
			Strain	**Stress (Mpa)**	**Deformation (mm)**
1.	13.65 = 100%	A2618	0.0010055	191.78	0.068691
		A4032	0.00092169	175.8	0.062967
		AL GHS 1300	0.0010558	201.37	0.072125
2.	250% = 13.65 × 2.50 = 34.125	A2618	0.0020948	399.54	0.14311
		A4032	0.002011	383.56	0.13738
		AL GHS 1300	0.0022623	431.5	0.15455

7. CONCLUSIONS

It is concluded from the results that the weight and volume of Al-GHS 1300 is least among the three materials. Hence the inertia forces are less, which enhances the performance of the engine. The FOS of Al-GHS 1300 is 6, much higher than the other materials, so further development of high power engine using this material is possible.

Table 7.1 Parameters for selection of material

S. N.	Parameter	A2618	A4032	Al-GHS 1300
1.	Volume (mm^3)	97904.97	101379.91	67625.39
2.	Weight (gm)	271	272.2	188
3.	Inertia Force (N)	1229.217	1238.93	1132.328
4.	FOS	2.25	1.80	6.09
5.	Strain	0.0010055	0.00092169	0.0010558
6.	Stress (MPa)	191.78	175.8	201.37
7.	Deformation (mm)	0.068691	0.062967	0.072125

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