Design Analysis and Parametric Optimization of Two Aluminium Piston Alloys Using Simulation Tools

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ABSTRACT

Usually the weight and design of the piston influence the engine performance, design analysis and optimization of piston need to be done carefully which ensure the piston is strong in nature, light weight and less cost. In this work explained the distribution of stress in two various aluminum alloys pistons by using simulation tools. In this study, single cylinder four stroke engines of Hero Honda super splendor 125CC motorcycle specifications are used. This study demonstrates the strategy for analytical design of two different aluminum alloy pistons. Piston is modeled by Pro/ENGINEER software and analysis of that model is done by ANSYS workbench. In simulation process, parameters like material properties, temperature and pressure are influenced a lot. Von misses stress, von misses strain, deformation and factor of safety are the parameters influenced a lot in material selection of piston. Thus the piston analysis process ensured the best piston geometry optimization.

KEY WORDS: Design Analysis, Piston, A2618, Al-GHS1300, pro/E, ANSYS.

1. INTRODUCTION

Piston is a moving part of internal combustion engines. Cylinder is surrounding the piston and piston rings are used to gas tightened the piston. Piston is used to transfer power from cylinder to crankshaft through connecting rod. Piston experiences gas pressure and inertia forces during the working condition which leads to the fatigue damage of piston like piston side wear, piston crown cracks. In elaborately told the highest stress appears on the top end of the piston and concentration of stress is the significant reasons for piston fatigue damage.

The following points are important in customer demand point view; a) Piston must have higher strength to resist the high pressure, b) Piston must have less weight to resist the inertia forces, c) Piston must provide enough bearing area to control undue wear, d) Piston should not produce any unwanted noise, e) Piston must be stiff making to resist mechanical distortions.

Engine Specifications: The engine used for this work is a single cylinder four stroke air cooled type Hero Honda super splendor 125CC petrol engine. The engine specifications are given in Table.1.

Table.1. Engine Specifications

Parameters	Values
Engine type	Four stroke petrol engine
Induction	Air cooled type
No. Of cylinders	Single cylinder
Bore	52.4 mm
Stroke	57.8 mm
Displacement volume	124.7 cm^3
Compression ratio	9:1
Maximum power	6.7 kW at 7000rpm
Maximum torque	10.35 Nm at 4000 rpm
No of revolutions/cycle	2

Table.2. Mechanical Properties

Parameters	A2618	Al-GHS 1300
Young's modulus (GPa)	73.7	98
Ultimate tensile strength (MPa)	480	1300
0.2% yield strength (MPa)	420	1220
Poisson's ratio	0.33	0.3
Thermal conductivity (w/mk)	147	120
Coefficient of thermal expansion (1/k)	$25.9\times10^{\wedge-6}$	$18\times10^{\wedge-6}$
Density (kg/m^3)	2767.99	2780

2. METHODOLOGY

a) Analytical design of pistons using piston design formulas.

b) Creation of half sketch portion of piston and converted it into 3D model of piston. Then imported in ANSYS software.

c) Meshing of 3D models using ANSYS software.

d) Analysis of pistons using static stress analysis method in ANSYS software.

e) Under static stress analysis method, two aluminum alloy pistons performances are compared.

f) Select the best suited aluminum alloy.

g) Optimize the best aluminum alloy model for mass reduction.

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); mp = mass of the piston (Kg); V = volume of the piston (mm^3); t_h = thickness of piston head (mm); D = cylinder bore (mm); Pmax = maximum gas pressure or explosion pressure (MPa); σt = allowable tensile strength (MPa); σut = 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 (kJ/kg) = 47000 kJ/kg; BP = brake power of the engine per cylinder (kW); m = mass of fuel used per brake power per second (Kg/kWs); C = ratio of heat absorbed by the piston to the total heat developed in the cylinder = 5% or 0.05; b = radial width of ring (mm); Pw = allowable radial pressure on cylinder wall (N/mm^2) = 0.025 MPa; σp = permissible tensile strength for ring material (N/mm^2) = 1110 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 = BP/IP

IP = BP/ η = 6.71/0.8 = 8 39 kW

Also, IP = P×A×L×N/2

IP = P×∏D2/4×L×N/2 = 8.39×1000= P×∏/4×0.0524^2×0.0578× (7000/2)

P = 11.54 × 105 N/m2 (or) 1.154 MPa

Maximum pressure, Pmax = 10×P = 10×1.154 = 11.54 MPa

Analytical design for A2618 alloy piston: Analytical design for A2618 alloy piston is as follows:

Thickness of the Piston Head: t_h= 5.28mm ≈ 6mm

σt = σut/2.25 = 480/2.25 =213.33 MPa

Piston Rings: radial width, b= 52.4 1.37mm ≈ 1.3mm; axial thickness, h = 0.7b to b = 0.7×1.3 = 0.91mm ≈ 1mm

Width of Top Land: h_1 = t_h to 1.2 t_h = 1t_h =6 mm

Width of Ring Land: h_2 = 0.75h to h = 0.75h = 0.75 × 1 = 0.75mm

Thickness of piston barrel at the Top end: t_1 = 0.03D+b+4.9 = 0.03(52.4) +1.3+4.9 = 7.7 mm

Thickness of piston barrel at the Open end: t_2 = (0.25t_1 to 0.35t_1) = 0.25×7.7 = 1.925 ≈ 2 mm

Length of the skirt: ls = 0.6D to 0.8D = 0.6D = 0.6×52.4 = 31.44 ≈ 31 mm

Length of piston pin in the connecting rod bushing: l_1 = 45% of the piston diameter=0.45×52.4 = 23.58mm ≈24mm

Piston pin diameter: do = 0.28D to 0.38D = 0.28×52.4 = 14.672 ≈ 14.6 mm

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

Analytical design for AL-GHYS1300 Alloy Piston: Analytical design for Al-GHS1300 alloy piston is as follows:

Thickness of the Piston Head: t_h = 52.4 1 4 mm

σt = σut/2.25 = 1300/2.25 =577.77 MPa

Piston Rings: b = 1.3 mm and h = 1 mm.

Width of Top Land: h_1 = th = 4 mm

Width of the Ring Land: h2 = 0.75 mm

Thickness of piston barrel at the Top end: t1 = 7.7 mm

Thickness of piston barrel at the Open end: t2 = 2 mm.

Length of the skirt: ls = 31 mm

Length of piston pin in the connecting rod bushing: l1 = 24 mm

Piston pin diameter: do = 14.6 mm

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

Modelling and Meshing of Piston: Modelling of the piston is created using pro/E software.

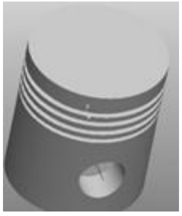

Fig.1. Modelling of A2618 alloy piston

Fig.2. Modelling of Al-GHS1300 alloy piston

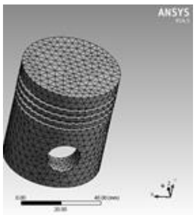

Fig.3. Meshing of A2618 alloy piston

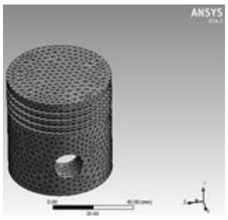

Fig.4. Meshing of Al-GHS1300 alloy piston

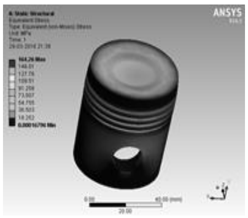

Fig.5. Stress of A2618 alloy piston

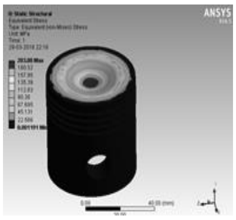

Fig.6. Stress of Al-GHS1300 alloy piston

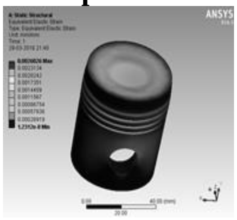

Fig.7. Strain of A2618 alloy piston

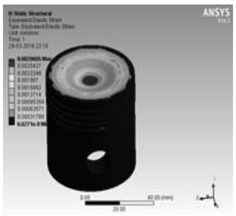

Fig.8. Strain of Al-GHS1300 alloy piston

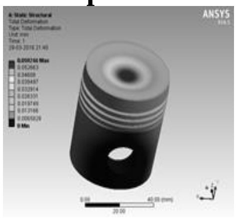

Fig.9. Deformation of A2618 alloy piston

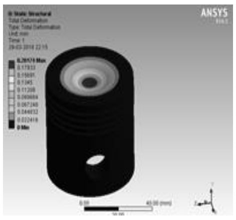

Fig.10. Deformation of Al-GHS1300 alloy piston

Selection of best suited aluminium alloy piston: Depending on the parameters listed in Table below, the best suited Aluminium alloy is selected for the design of piston of Hero Honda super splendor 125cc motorcycle.

Table.3. Parameters for selection of material

Parameters	A2618	Al - GHS 1300
Volume (mm^3)	55095	52613
Mass (kg)	0.152	0.145
Stress (MPa)	164.26	203.08
Strain (mm)	0.0026026	0.0028605
Deformation (mm)	0.059246	0.20174
Factor of safety	2.92	6.40
Inertia force (N)	1491.12	1422.45

Volume of the Al-GHS1300 alloy piston is lesser than A2618 piston. Mass of the Al-GHS1300 alloy piston is lesser than A2618 piston. Also, factor of safety of the Al-GHS1300 is much higher than A2618 piston. So Al-GHS1300 alloy piston is best suitable material for piston of Hero Honda super splendor 125cc motorcycle.

Optimization of model for mass reduction: After selecting the best suited material, we found that factor of safety for Al-GHS1300 is 6.40, so further reduction of mass is possible with this material.

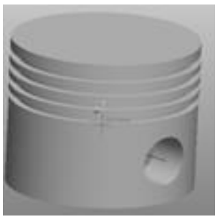

Fig.11. Optimized model of piston

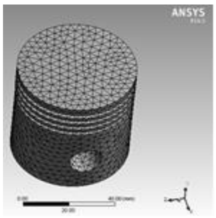

Fig.12. Meshing of optimized model piston

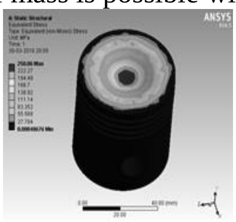

Fig.13. Stress of optimized piston

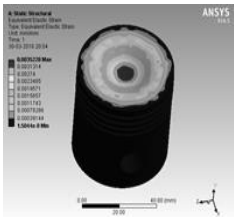

Fig.14. Strain of optimized piston

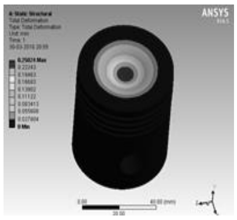

Fig.15. Deformation of optimized piston

4. RESULTS

The results before and after optimization of Al-GHS1300 are recorded below.

Table.4. Parameters of Al-GHS1300 before and after optimization

Parameters	**Before**	**After**
Thickness of piston head (mm)	4	3.2
Width of top land (mm)	4	3.2
Piston barrel (mm)	7.7	5
Skirt length (mm)	31	25
Volume (mm^3)	52613	44398.7

Mass (kg)	0.145	0.123
Stress (MPa)	203.08	250.06
Strain (mm)	0.002865	0.0035228
Deformation (mm)	0.20174	0.25024
Factor of safety	6.40	5.20
Inertia force (N)	1422.45	1206.63

Mass of the piston is 15% reduced after optimization. Inertia force is 15% reduced after optimization; this enhances the performance of the engine. Von misses stress permissible up to 250 MPa.

Deformation after optimization is 0.25024 and this value is taken into consideration for design purpose.

4. CONCLUSION

It is concluded that Al-GHS1300 alloy piston has lesser volume and mass than other alloy piston. And also Al-GHS1300 alloy piston has higher factor of safety than other alloy piston. So Al-GHS1300 alloy is selected for piston design. And this Al-GHS1300 alloy piston is optimized for weight reduction. After optimization, mass of the piston is reduced by 15% and also inertia force is reduced by 15% that enhances the engine performances.

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