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Optimization of IC Engine Piston Using FEA

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Abstract:

This paper describes the stress distribution and thermal stresses of three different aluminium 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 Hero Spledor motorcycle. This paper illustrates the procedure for analytical design of pistons using specifications of four stroke single cylinder engine of Hero Spledor motorcycle. The results predict the maximum stress and critical region on the different aluminium 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 HYPER WORKS 13.0. The best aluminium alloy Material is selected based on stress analysis results. The analysis results are used to optimize piston geometry of best aluminium alloy.

Key Words:

A2618, A4032, Al-GHS 1300, HYPER WORKS 13.0, Deformation, Piston, Strain, stress.

I.INTRODUCTION:

An Internal Combustion Engine is that kind of prime mover that converts chemical energy to mechanical energy. The fuel on burning changes into gas which impinges on the piston and pushes it to cause reciprocating motion. The reciprocating motion of the piston is then converted into rotary motion of the crankshaft with the help of connecting rod. IC engines are used in marine, locomotives, aircrafts, automobiles and other industrial applications.

Research Object – Piston:

A piston is a component of reciprocating IC-engines. It is the moving component that is contained by a cylinder and is 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 connecting rod. Piston endures the cyclic gas pressure and the inertial forces at work, and this working condition may cause the fatigue damage of piston, such as piston side wear, piston head cracks and so on.

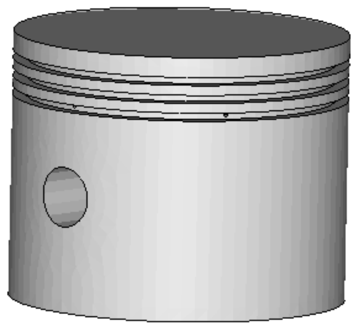

Fig 1: modal of a piston

Piston in an IC engine must possess the following Characteristics:

- Strength to resist gas pressure.
- Must have minimum weight
- Must be able to reciprocate with minimum noise.
- Must have sufficient bearing area to prevent wear.
- Must seal the gas from top and oil from the bottom.
- Must disperse the heat generated during combustion.
- Must have good resistance to distortion under heavy temperature.

In engine, transfer of heat takes place due to difference in temperature and from higher temperature to lower temperature. Thus, there is heat transfer to the gases during intakes stroke and the first part of the compression stroke, but the during combustion and expansion processes the heat transfer take place from the gases to the walls. So the piston crown, piston ring and the piston skirt should have enough stiffness which can endure the pressure and the friction between contacting surfaces. In addition, as an important part in engine, the working condition of piston is directly related to the reliability and durability of engine.

Characterisation of Materials:

The materials chosen for this work are A2618, A4032 and Al-GHS1300 for an internal combustion engine piston. The relevant mechanical and thermal properties of A2618, A4032 and AlGHS1300 aluminium alloys are listed in the following table [2], [6].

S no	Parameters	A4032	A2618	AL GHS-1300
1	Elastic modules (GPa)	79	73.7	98
2	Ultimate tensile strength (MPa)	380	480	1300
3	0.2% Yield Strength (MPa)	315	420	1220
4	Poisson's Ratio	0.33	0.33	0.3
5	Thermal Conductivity (W/m/°C)	154	147	120
6	Coefficient of Thermal Expansion (1/K)	79.2×10^{-6}	25.9×10^{-6}	18×10^{-6}
7	Density (kg/m^3)	2684.9	2767.99	2780

Table 1: Properties of three Aluminium Alloys Engine Specifications

The engine used for this work is a single cylinder four stroke air cooled type Hero Spledor petrol engine. The engine specifications are given in Table 2. [1].

PARAMETERS	VOLUME
Engine Type	Four stroke, Petrol engine
Induction	Air cooled type
Number of cylinders	Single cylinder
Bore X Stroke	50.0 mm x 49.5 mm
DISPLACEMENT VOLUME	97.2 mm
COMPRESSION RATIO	9.9 : 1
MAXIMUM POWER	6.15kW(8.36ps)@8000rpm
MAXIMUM TORQUE	0.82kg-m(8.05NM)@5000rpm
Number of revolutions/cycle	2

Table 2: Engine Specifications

II.PROBLEM FORMULATION:

The objective of the present work is to design and analysis of pistons made of A2618, A4032 and Al-GHS1300. In this paper the materials (A2618 and A4032) of piston are replaced with AlGHS1300. Piston models are created in CREO 3.0. After analysis a Comparison is made between existing A2618 and A4032 pistons viz Al-GHS1300 in terms of volume, weight, factor of safety, deformation, strain and stresses.

III.METHODOLOGY:

- Analytical design of pistons using specifications of Hero petrol engine.
- Creation of 3D models of piston using CREO 3.0
- Meshing of 3D models using HYPER WORKS 13.0
- Analysis of pistons using linear static analysis method.
- Comparative performance of three aluminium alloy pistons under linear static analysis method.
- Analyses of pistons under thermal and mechanical loads i.e. the pistons are subjected to Select the best suited aluminium alloy.

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- Optimize the model for mass reduction. By using optimization.
- Analyse the optimized model under static stress.
- Analyse the optimized model under thermal and mechanical loads.

Analytical Design

Let

IP = indicated power 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 (mm2)
m_p = mass of the piston (Kg)
V = volume of the piston (mm3)
δ = thickness of piston head (mm)
D = piston diameter (mm)
p_{max} = maximum gas pressure (MPa)
σ_t = allowable tensile strength (MPa)
σ_{ut} = ultimate tensile strength (MPa)
F.O.S = Factor of Safety = 2
K = thermal conductivity (W/m 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/KW s)

Mechanical Efficiency

(η)=80%

$$\eta = \frac{\text{break power(B.P)}}{\text{Indicated power(I.P)}}$$

$$\text{I.P} = \frac{B.P}{\eta} \quad = 7.6875\text{KW}$$

Piston Diameter D= 50mm
Piston head thickness δ= (0.05-0.10)D = 5 mm
Piston Height H = (0.8-1.3) D = 40mm
Height of piston top part h_1
h_1= (0.45-0.75) D = 22.5
Piston skirt height h_s = (0.31-0.8)D =30 mm
Boss diameter d_o = (0.3-0.5)D =15 mm
Distance b/w boss end faced
b = (0.3-0.5) x D =15 mm
Thickness of piston crown wall S = (0.05-0.2)D
S = (0.05-0.2) x D = 6mm
Distance to the first piston groove
e = (0.06-0.12) x D =3 mm
Thickness of the first piston ring land
h_1 = (0.03-0.05) x D=15mm
Radial thickness of piston ring t
t = (0.04-0.045) x D =2 mm
Piston ring width a = 2-4
Radial clearance of ring Δt
Δt =(0.70-0.95) = 0.7 mm
Piston inner dia. d_i = D-2(s+t+ Δt)=33.6mm
No of oil holes in piston d_0 = (0.3-0.5)a
=0.6 mm
Pin outer diameter Dp = (0.22-0.28) D = 12 mm
Pin inner dia. d_i = (0.65-0.75)d_p = 9 mm

Creation of 3D models of piston using CREO 3.0

Following is the sequence of steps in which the piston is modelled:

Create the profile of a piston in sketcher using revolve tool.

- Extrude tool is used to create the connecting pin mounting land.
- Extrude cut tool is used to create the hole.
- Piston ring cut is given using revolve cut tool.
- Fillets are given at the sharp corners using fillet tool.
- Finally, the hole is created.

Meshing of 3D model of Piston

Cad model is imported in hyper mesh using optistruct profile in .stp or .x_t format files. And create the shell mesh on surface of the piston using tria6 element and capture all features properly. Then create the 3d elements Ctetra. Mesh model is created as shown in below fig.

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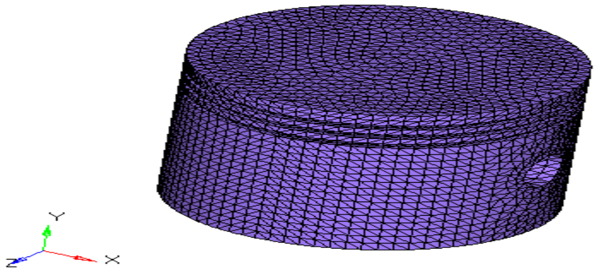
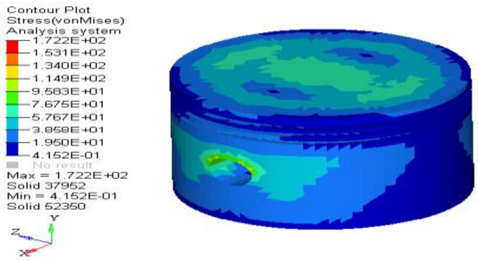


Fig 2: FE model of a piston

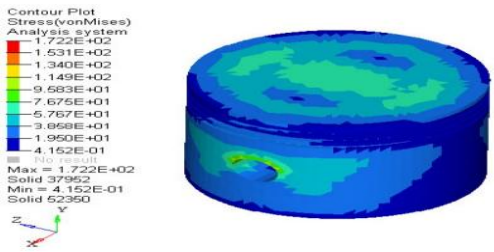
Analysis of piston using linear static analysis method

Frictionless support at pin bore areas and fixed all degree of freedom.

Downward pressure (11.86 MPa) due to gas load acting on piston head.



(a)



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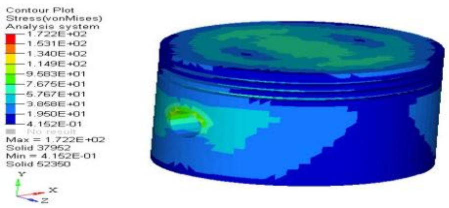
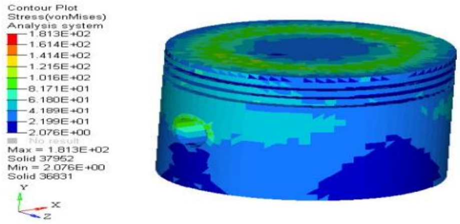


(c)

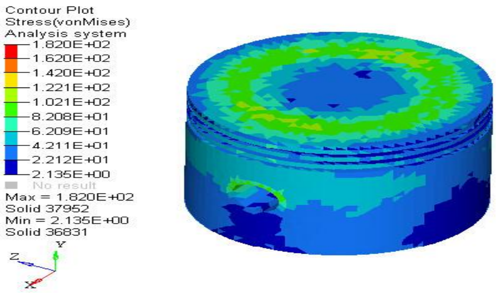
Fig 3: Stress analysis of (a) A4032 (b) A2168 (c) Al-GHS1300 alloy pistons

Analysis of piston using coupled stress analysis method

- Frictionless support at pin bore areas and fixed all degree of freedom.
- Downward pressure (11.86 MPa) due to gas load acting on piston head.
- Thermal loads at piston head350°C, top piston land 330°C, piston ring area 250°C, and skirt 140°C applied on the piston as a temperature.
- Analysis done in hyperwors optistruct solver.



(a)



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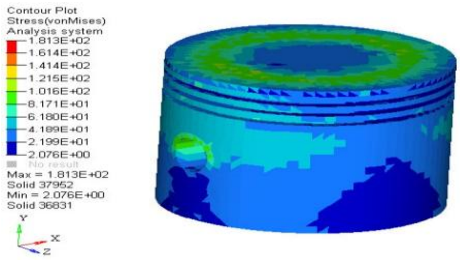

(c)

Figure 4: coupled Stress analysis of (a) A2168 (b) A4032 (c) Al-GHS1300 alloy

Optimization of Piston Model:

After selecting the best suited material, we found that the FOS for Al-GHS1300 is 7.1, so further reduction of mass is possible with this material. While in the other materials, the FOS is 2.08 (A2618) and 1.52(A4032), so mass reduction is impossible with these materials.

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Optistruct procedure:

- ➢ Topology optimization method is used for the optimization.
- ➢ Same loads & boundary conditions are used as above.

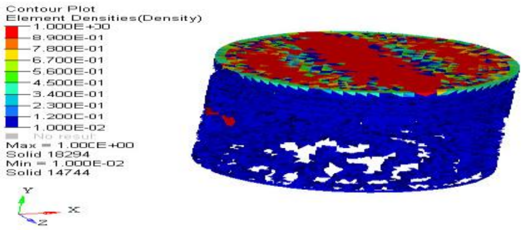

Figure 5: optimization analysis of Al-GHS1300 alloy

Analysis of optimized piston using coupled stress analysis method

- ➢ Frictionless support at pin bore areas and fixed all degree of freedom.
- ➢ Downward pressure (11.86MPa) due to gas load acting on piston head.
- ➢ Thermal load applied on the piston as a temperature.

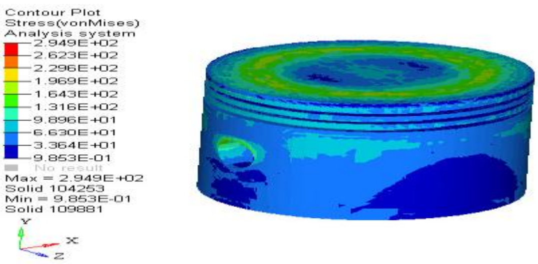

Figure 6: coupled Stress analysis of Al-GHS1300 alloy

S.NO	PARAMETER	BEFORE	AFTER
1	Thickness Of Piston Head(mm)	5	4
2	Piston Barrel(mm)	4	3
3	Piston Top Land(mm)	8	6
4	volume (mm^3)	53467.63	38079.14
5	Weight(Kg)	148.64	105.86

Table 3: Optimized parameters of a pistons

IV.RESULTS ANALYSIS

The liner static analysis values of deformation, stress and strain at different load conditions are recorded in table-4.

S. No	Pressure/ Load (MPa)	Material	Analysis Results		
			Deformation (mm)	Stress (MPa)	strain
1	100% (11.86)	A4032	0.05984	172.2	0.001932
		A2618	0.06414	172.2	0.002071
		AL-GHS 1300	0.04824	172.2	0.001558
2	150% (17.79)	A4032	0.08976	258.2	0.00289
		A2618	0.09621	258.2	0.003107
		AL-GHS 1300	0.07236	258.2	0.002337
3	200% (23.72)	A4032	0.197	344.3	0.00386
		A2618	0.1283	344.3	0.004143
		AL-GHS 1300	0.19648	344.3	0.003115
4	250% (29.65)	A4032	0.1496	430.4	0.00483
		A2618	0.1604	430.4	0.00517
		AL-GHS 1300	0.1206	430.4	0.003894

Table 4: deformation, stress and strain results linear static analysis

The values of deformation, stress and strain under coupled field at different load conditions are recorded in table-5.

S. No	Pressure/ Load (MPa)	Material	Analysis Results		
			Deformation (mm)	Stress (MPa)	strain
1	100% (11.86)	A4032	0.0831	315.2	0.003538
		A2618	0.0710	182	0.00219
		AL-GHS 1300	0.05304	181.3	0.00164
2	150% (17.79)	A4032	0.1125	330.6	0.003711
		A2618	0.1031	268.1	0.003225
		AL-GHS 1300	0.07716	267.3	0.005419
3	200% (23.72)	A4032	0.1418	376.6	0.004227
		A2618	0.1352	354.4	0.004261
		AL-GHS 1300	0.1013	353.4	0.003198
4	250% (29.65)	A4032	0.1711	462.7	0.005193
		A2618	0.1673	440.2	0.005296
		AL-GHS 1300	0.1254	439.5	0.003976

Table 5: deformation, stress and strain results under coupled field analysis

After optimization the liner static analysis values of deformation, stress and strain at different load conditions are recorded in table-6.

S. No	MATERIAL	PRESSURE/ LOAD (MPa)	Analysis results		
			Deformation(mm)	Stress (N/mm^2)	strain
1	Al-GHS 1300	100% (11.86)	0.08269	284.2	0.001773
		150% (17.79)	0.124	426.2	0.002659
		200% (23.72)	0.1654	568.3	0.003545
		250% (29.65)	0.5067	710.4	0.004432

Table 6: Deformation, stress and strain results linear static analysis after optimization

After optimization the values of deformation, stress and strain under coupled field at different load conditions are recorded in table-7.

S. No	MATERIAL	PRESSURE/ LOAD (MPa)	Analysis results		
			Deformation(mm)	Stress (N/mm^2)	strain
1	Al-GHS 1300	100% (11.86)	0.8762	294.9	0.001847
		150% (17.79)	0.1290	437	0.002734
		200% (23.72)	0.1703	579.1	0.003620
		250% (29.65)	0.2117	721.2	0.004507

Table-7: Deformation, stress and strain results under coupled field analysis after optimization

Reserve factor values after optimization under coupled field analysis recorded in table-8.

MATERIAL	PRESSURE/LOAD(MPa)	OBTAINED STRESS (MPa)	UTS (MPa)	RF
ALGHS -1300	100%	294.9	1300	4.40
	250%	721.2	1300	1.8

Table-8: Reserve factor after optimization

V.CONCLUSION:

It is concluded from the results that the weight and volume of Al-GHS 1300 is least among the three materials. This enhances the performance of the engine. The RF of Al-GHS 1300 is 1.8 for max loading condition, much higher than the other materials, so further development of high power engine using this material is possible. Further research may be done to select a material with less weight and higher strength, so as to reduce the inertia forces.

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