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Design, analysis and optimization of three aluminum piston alloys using FEA

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ABSTRACT

The presented paper uses the Finite Element Method (FEM) to analyze the thermal stress and distribution of three different aluminum alloys. The simulations are carried out by evaluating the parameters like gas pressure, temperature and material properties of the Piston. The four-stroke engine of Bajaj Pulsar 220CC is used to study the analysis procedure for aluminum alloy piston. The resulting analysis will give the prediction of critical region and maximum stress. It is important to locate the critical area of concentrated stress for appropriate modifications. Static and thermal stress analysis is performed using ANSYS 14.1. The analysis result will help to choose the best aluminum alloy material. The analysis results are used to optimize piston geometry of best aluminum alloy.

Keywords: *Aluminum piston, Gas pressure, Stress, Static, Thermal, FEA*

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. The 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 reached 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 heavy stress concentration at the top of the piston is the main reason for fatigue failure. In the proposed work the piston taken for the study is idle with the rated gas engine. The optimization is required to improve the engines dynamic and economic properties. The analysis results will be helpful to calculate the stress concentration at the top and it will help if further design process. 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. To maintain minimum load the pistons selected must have a low weight. The piston also aids in sealing the cylinder to prevent the escape of combustion gases. It also transmits heat to the cooling oil and some of the heat through the piston rings to the cylinder wall.

The main objective of the research is to analyze the thermal and mechanical stress distribution on the piston at present engine condition during the combustion process. The presented work gives the prediction of higher stress and critical region using FEA. The structural model is developed using solid modeling software. Using FEA software, simulation and stress analysis are performed. 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. The piston transfers the force from expanding gas in the cylinder to the crankshaft via a piston rod.

In an engine, transfer of heat takes place due to the difference in temperature and from higher temperature to lower temperature. During combustion process the heat transfer from the gases to the wall and in the compression stroke and intake stroke heat transfer to the gases. To maintain the pressure and friction between contacting surface piston crown, piston ring and piston skirt should have enough stiffness. The piston is an important part of the engine so it works directly.

1.1 Problem statement

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. The piston transfers the force from expanding gas in the cylinder to the crankshaft via a piston rod. The piston can be damage; can cause wear & tear, cracking due to cyclic gas pressure and internal gas pressure at work. In an engine, transfer of heat takes place due to the difference in temperature and from higher temperature to lower temperature. The heat transfers to the gases during the intake stroke and the first part of the compression stroke. The heat transfer from gases to the wall during combustion and expansion stroke. 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.

1.2 Necessity of work

1. Designing of the piston based on the input parameters and then modeling of the piston in the solid modeling software.
2. FEA software is given model and material input based on the parameters obtained.
3. To determine the Static and Thermal stresses, Total Deformation and to optimize in the existing piston design.
4. To reduce the weight of the piston based on the magnitude of the output of analysis.

1.3 Objective of work

1. Analytical design of pistons using specifications of Bajaj pulsar petrol engine.
2. Creation of 3D models of the piston using solid modeling software.
3. The meshing of 3D models using FEA software.
4. Static stress to analyze piston.
5. Benchmarking of Aluminium alloy pistons by analysis under stress.
6. Analysis of pistons by subjecting to a uniform gas pressure and non-uniform temperature distribution.
7. Aluminum alloy pistons are compared under thermal & mechanical load at uniform gas pressure and nonuniform temperature distribution.
8. Select the best-suited Aluminium alloy.
9. Optimize the model for mass reduction.
10. Analyze the optimized model under static stress.
11. Analyze the optimized model under thermal and mechanical loads.

2. DESIGN METHODOLOGY

Table 1: Dimensional details BAJAJ PULSAR 220CC

Parameters	Values
Engine Type	Four stroke ,petrol engine (PTS-I)
Induction	Air-cooled type
Number of cylinders	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	95+/-0.5:1
No. of revolution cycle	2

Table 2: Properties of material

S. No	Parameters	A2618	A4032	AI-GHS
1.	Elastic modulus/young‘s modulus (Gpa)	73.7	79	98
2.	Ultimate tensile strength (mpa)	480	380	1300
3.	Poisson’s ratio	0.33	0.33	0.3
4.	Density (kglm^3	2767.99	2684.95	2780
5.	Thermal conductivity	147	154	120
6.	Coefficient of thermal expansion 1/k)	25.9$\times 10^{-6}$	79.2$\times 10^{-6}$	18$\times 10^{-6}$

2.1 Analytical Design Final calculation:-

Maximum pressure: - 13.65MPA

Table 3: Final calculations

S .No	Prameters	A2618	A4032	AI-GHS
1.	Thickness of the piston head	7.338	8.247mm	4.459mm
2.	The radical width of the ring	1.7494mm	1.7494mm	1.7494mm
3.	Axial Thickness of the piston ring	1.2243mm	1.2243mm	1.7494mm
4.	The width of top land and ring land	0.9182mm	0.9182mm	0.918mm
5.	Piston barrel	8.6594mm	8.6594mm	8.6594mm
6.	At open end	2.164mm	2.164mm	2.164mm
7.	Length of skirt	40.2mm	40.2mm	40.2mm
8.	Length of piston pin in the connecting rod busting	30.15mm	30.15mm	30.15mm
9.	Piston pin diameter	18.76mm	18.76mm	18.76mm

3. FINITE ELEMENT ANALYSIS OF ALLOY PISTON A2618

3.1 Loading & Boundary Conditions

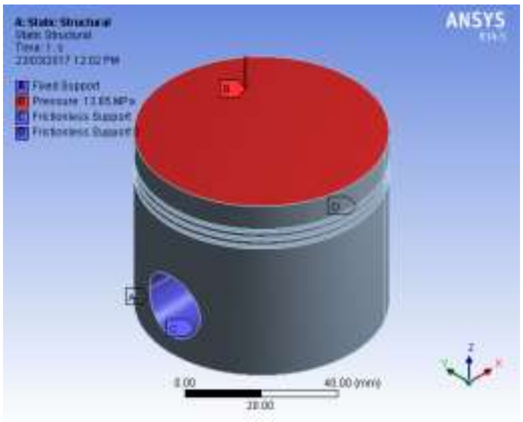

Fig. 1: Force Model of alloy piston

3.2 Total Deflection of alloy piston

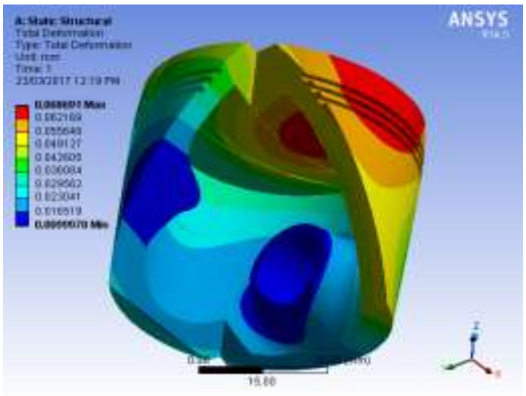

Fig. 2: Total Deflection of Alloy piston

3.3 The stress of alloy piston

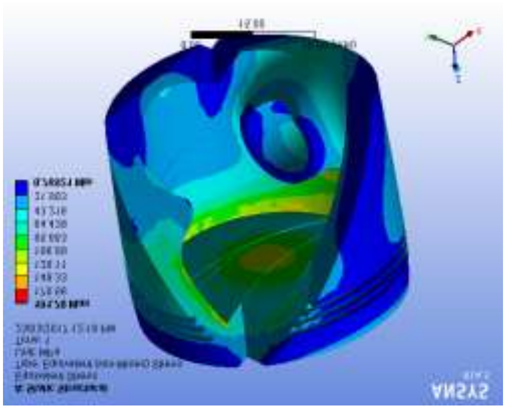

Fig. 3: The stress of Alloy piston

3.4 The strain of alloy piston

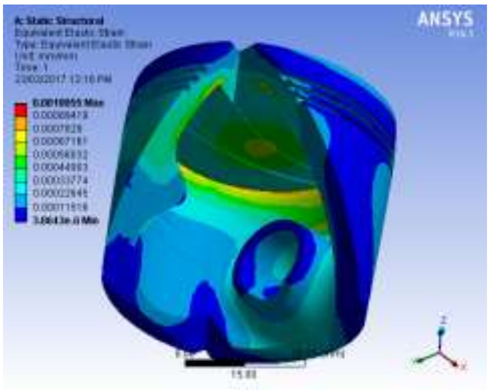

Fig. 4: Strain of Alloy piston

4. FINITE ELEMENT ANALYSIS OF ALLOY PISTON A4032

4.1 Total Deflection of alloy piston

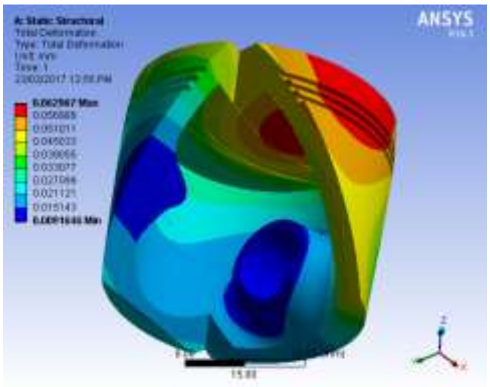

Fig. 5: Total Deflection of Alloy piston

4.2 Stress of alloy piston

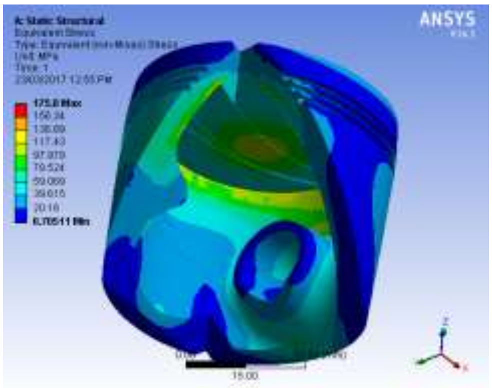

Fig. 6: Stress of Alloy piston

4.3 Strain of alloy piston

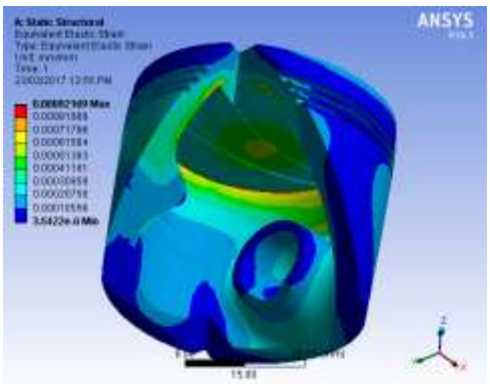

Fig. 7: Strain of Alloy piston

5. FINITE ELEMENT ANALYSIS OF ALLOY PISTON AI-GHS

5.1 Total Deflection of alloy piston

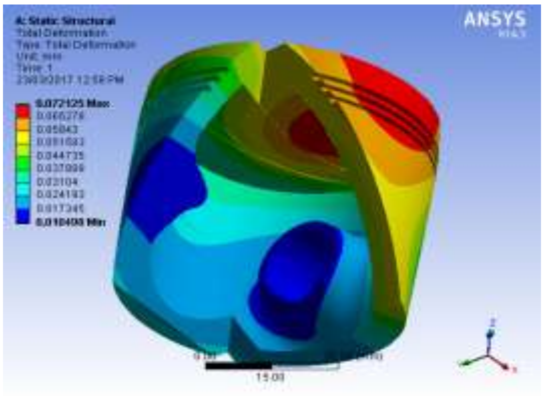

Fig. 8: Total Deflection of Alloy piston

5.2 Stress of alloy piston

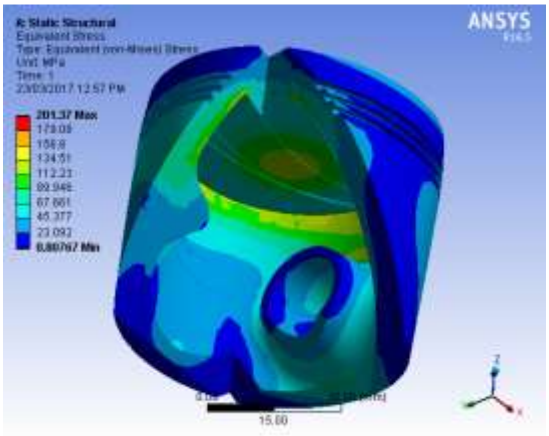

Fig. 9: Stress of Alloy piston

5.3 Strain of alloy piston

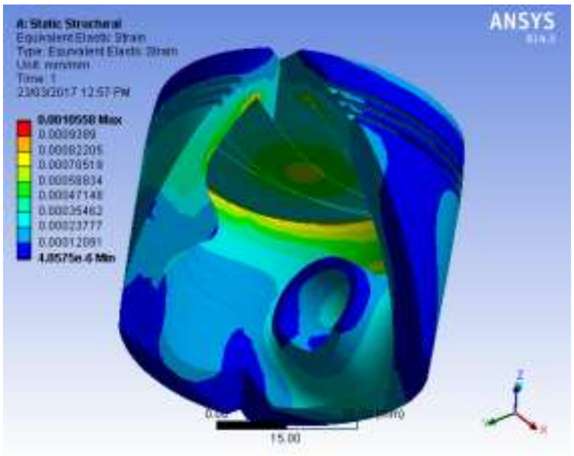

Fig. 10:Strain of Alloy piston

6. RESULT

Comparative Analysis of three Aluminum alloys under static stress analysis method:

The load variation analysis is performed for the three different piston alloys. The load is varied from 125% to 250% of the calculated pressure of the Bajaj Pulsar four stroke petrol engine.

S No.	Pressure Load (Mpa)	Material	Ansys Result		
			Deformation (MM)	Stress (Mpa)	Strain
1	13.65 = 100%	A2186	0.0010055	191.78	0.068691
		A4032	0.00092169	175.8	0.062967
		AL GHS 13000	0.0010558	201.37	0.072125
2	125% = 13.65×1.25 = 17.0625	A2186	0.0010893	207.76	0.074415
		A4032	0.0010474	199.77	0.071553
		AL GHS 13000	0.0011731	223.74	0.080139
3	150% = 13.65 × 1.50 = 20.475	A2186	0.083001	231.73	0.001215
		A4032	0.0011312	215.75	0.077277
		AL GHS 13000	0.0013406	255.71	0.091588
4	175% = 13.65 ×	A2186	0.0013406	255.71	0.091588

	1.75 = 23.885	A4032	0.0012569	239.72	0.085864
		AL GHS 13000	0.001525	290.87	0.10418
5	200% = 13.65 × 2.00 = 27.30	A2186	0.0016758	319.63	0.11448
		A4032	0.0016339	311.64	0.11162
		AL GHS 13000	0.0017596	335.61	0.12021
6	225% = 13.65 × 2.25 = 30.7125	A2186	0.0018434	351.6	0.12593
		A4032	0.0018015	343.6	0.12307
		AL GHS 13000	0.0020948	399.54	0.14311
7	250% = 13.65 × 2.50 = 34.125	A2186	0.0020948	399.54	0.14311
		A4032	0.002011	383.56	0.13738
		AL GHS 13000	0.0022623	431.5	0.15455

7. CONCLUSION

The piston plays a major role in the performance of the engine performance, materials of the piston is made up of impacts the strength of the piston. As expected the maximum stress intensity observed on the bottom surface of the piston crown in both the materials. The maximum displacement is absorbed in the top of the piston of 4032 and A2618. The highest value of maximum temperature found in the piston is due to the thermal conductivity of the materials and the total maximum heat flux is absorbed in both the piston materials. Results comparison between two alloys is found approximately same. Thus further research can be carried with the advanced materials and different designing, analysis.

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