Investigating Piston Design Parameters in Single-Cylinder Four-Stroke Engines

Rajkumar Bhagat[1]; Vedant Awachar[2]; Chetan Bhagat[3]; Prathamesh Bhosale[4]; Bhushan Berlikar[5]; Om Bobade[6]

[1]Professor
[1,2,3,4,5,6]Vishwakarma Institute of Technology, Pune, 411037, Maharashtra, India

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Abstract: In this study, a conventional piston made of the aluminum alloy A2618 is subjected to structural examination. An additional examination is conducted on a piston made of the aluminum alloys GHY1250 and GHS1300. Because of the extraordinarily high pressure and temperature conditions that would occur throughout the combustion process, the material used to create the piston must be lightweight, affordable, and thermally and structurally stable. For this project, it has been decided to look into a specific piston design and its maximum gas pressure capability. Early planning for this project involves creating a piston model using the Solid Modeling application. The decision has been made to mesh the geometry analysis using ANSYS.

The study of piston input conditions and analysis procedure has been the subject of a substantial body of literature research.

Keyword: *Piston Design Parameters, Four-Stroke Engine Dynamics, Thermal Stress Analysis, Mechanical Stress Analysis, Finite Element Analysis (FEA), Piston Material Selection, Heat Transfer Analysis, Combustion Pressure Load, Fatigue Life Estimation, Thermal Expansion, Wear Resistance, Cylinder-Piston Interf.*

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I. INTRODUCTION

The piston, which revolves inside the cylinder of an internal combustion engine, is one of its most important components. The main function of the piston is to transfer force through the connecting rod the gas from the cylinder to the crankshaft. Determining the temperature distribution on the piston is essential for managing thermal loads and deformation during operating conditions. High gas pressure and quick reciprocating inertia forces cause the piston to experience periodic load effects. The piston expands and produces thermal strains and thermal deformation as a result of the lateral force created by the chemical reaction of burning the gas at high pressure. Heat and mechanical deformation are the main causes of piston cracks.

- *Piston*

The most important component of a reciprocating internal combustion engine is the piston, which oscillates inside the cylinder. In addition to being hot, the strain that the high gas pressure causes on the piston inside the cylinder can cause fatigue damage to the piston, which can include side wear or cracks in the piston head, among other things.

The piston in an internal combustion engine needs to be strong enough to withstand high gas pressure and inertia forces.

- It should weigh as little as possible.
- Its structure should be strong to withstand mechanical and thermal distortion; it should be able to reciprocate at high speeds with very little noise.
- To avoid wear, it needs to have enough bearing area.
- It should transfer the heat produced during combustion to the cylinder walls, effectively seal the gas from the top and the oil from the bottom, and be resistant to distortion under high temperatures and forces.

Therefore, the right piston material is chosen to withstand all loads and stresses, improving an IC engine's performance.

II. METHODOLOGY

Using the specifications of the Bajaj Kawasaki motorcycle's four-stroke single-cylinder engine, an analytical piston design was produced.

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- Solidworks was used to create the 3D model of the piston, which was then imported into HyperMesh.
- HyperMesh is used to mesh the 3D model.
- Piston analysis utilizing the stress analysis approach.
- Al alloy piston performance in comparison.
- Pick the best alloy of aluminum.

A. Engine Specifications

The specifications of the engine and materials used for this type of work are shown below.

Table 1: Engine Specifications

Sr no	Parameters	Values
1	Engine Type	Four stroke, Petrol Engine
2	Induction	Air cooled type
3	Number of cylinders	Single cylinder
4	Bore (D)	50 mm
5	Stroke	81.25 mm
8	Compression ratio	8.4
9	Maximum power	6.03 KW at 7500 rpm
10	Maximum Torque	8.05 Nm at 5500 rpm
12	Speed	5000rpm
13	Brake Power	8BHP
14	Maximum pressure	15 N/mm^2

B. Piston Materials

Cast iron and aluminum alloy are the most widely utilized materials for IC engine pistons. However, because Al alloys are lighter than cast iron, they are preferred. Al alloy has four times the heat conductivity of cast iron. In order to provide enough cooling, aluminum pistons are made thicker, which is required for strength.

Table 2: Mechanical Properties of Materials

S.no	Parameters	A2618	Al-GHY 1250	Al-GHS 1300
1	Elastic / Young Modulus (GPa)	70-80	83	98
2	Ultimate tensile strength (MPa)	440	1250	1300
3	Yield Strength (MPa)	370	1190	1220
4	Poisson's Ratio	0.33	0.3	0.3
S5	Thermal Conductivity (W/m°c)	147	135	120
6	Density (kg/m^3)	2767.298	2880	2780

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C. *Properties of Materials*

Conventional Al alloys, such as A2618, Al-GHY1250, and Al-GHS1300, were selected for this project in order to make an IC engine piston. The following table lists the mechanical characteristics of common Al alloys, such as A2618, Al-GHY1250, Al-GHS1300, and Al-GHY1250.

When compared to other internal combustion engine components, the piston's functioning state is the worst. The piston is likely to fail as a result of wear and tear. Therefore, an analysis of the piston's maximum stress concentration is required. Designing and analyzing a piston built of A2618, Al-GHY1250, and AlGHS 1300 is the aim of this work. In this study, the piston's material.

A 2618 is replaced by Al-GHY1250 and Al-GHS 1300.

➢ *Piston Design*

A Piston's Design Consideration. The following factors should be taken into account while designing a piston:

- It should be as light as possible.
- It should have noiseless, high-speed reciprocation.
- It must be strong enough to resist the forces of inertia and high gas pressure.
- In order to resist mechanical and thermal distortion, it should be constructed rigidly.
- To avoid wear, it should have enough bearing area.

➢ *Analytical Design*

- η = 80% = 0.8 for mechanical efficiency N = 5000 rpm for engine speed
- η = Indicating power (I.P.) / Brake power (B.P.)
- B.P. / η = 8/0.8 = 10 KW = I.P.
- P=(120*I.P)/ALN = 15.04 * 105 N/m2 P=1.504 MPa I.P. = PALN/120
- Pressure maximum = 10 * P = 15.04 MPa

A2618 alloy piston analytical design

- Thickness of piston head (tH): tH = $\sqrt{3PmaxD}$ 2/16t …………..in mm is the thickness of the piston head as determined by Grashoff's formula.

- Heat flow through the piston head (H) = 4.4 mm tH
- Using the formula H = 12.56 * tH* k * (Tc-Te), the heat flow through the piston head is computed in KJ/sec.
- The thickness of the piston head is determined by heat dissipation and can be expressed as follows: tH = C * HCV * m * B.P. * 106 / 12.56 * k * (TcTe)
- With tH = 3.6 mm, m = 95.45 kg/BP/s

According to the formula above, the maximum thickness is tH = 4.4 mm. Ring (t1) radial thickness $t1 = \sqrt{3Pw}/$t

- t1 = 1.5 mm
- The ring's thickness might be interpreted as t2 = 0.7 t1 to t1

(4)
- t2 = 1 mm
- Number of rings (nr)
- Minimum axial thickness (t2)
- t2 = D/(10 * nr)
- nr = 3rings
- Width of top land and ring lands
- Width of the top land (b1): b1= tH to 1.2 tH = 4.4 mm

(5)
- Width of ring land (b2):
- b2=0.75 t2 to t2= 0.75 mm

(6)
- Maximum thickness of the barrel at the top end
- (t3):
- b= 0.4 + t1
- t3=0.03 D + b + 4.5
- t3=0.03 D + t1 + 4.9 = 7.9 mm

(7)
- Thickness of piston barrel at the open end (t4):
- t4= 0.25 t3 to 0.35t3 = 1.975 mm

(8)
- Length of skirt
- ls= 0.6 D to 0.8 D= 30 mm
- Length of piston pin in the connecting rod
- bushing:
- lp= 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 = ls+ lr + b1= 30 +5.5 + 4.4 = 40.92 mm

- Piston pin diameter (do &di) di = 0.6 do = 8.4 mm do = 0.28 D to 0.38 D = 14 mm
- The piston pin's center should be 0.02 D to 1.5 mm is 0.04 D above the skirt's center.
- Al-GHY1250 alloy piston analytical design
- Piston head thickness (tH) = 3.919644 mm
- Ring's radial thickness (t1) = 1.5 mm
- Ring's axial thickness (t2) = 1.05 mm
- The top land's width (b1) is 3.919644 mm.
- Ring land width (b2) = 0.7875 mm
- The barrel's maximum thickness at the top end (t3) is 7.9 mm.
- The piston barrel's thickness at the open end (t4) is 1.975 mm.
- Skirt length (ls) = 30 mm
- The connecting rod bushing's piston pin length (lp) is 22.5 mm.
- The piston's total length (L) is 40.48214 mm.
- Typically, the piston's length ranges from D to 1.5 D. Diameter of piston pin = di = 8.4 mm, do = 14.

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- Al-GHS1300 alloy piston analytical design
- Piston head thickness (tH) = 4.409599 mm
- Ring's radial thickness (t1) = 1.5 mm Ring's axial thickness (t2) = 1.05 mm
- Top land width (b1) = 4.409599 mm
- Ring land width (b2) = 0.7875 mm
- The barrel's maximum thickness at the top end (t3) is 7.9 mm.
- The piston barrel's thickness at the open end (t4) is 1.975 mm.
- Skirt length (ls) = 30 mm
- Length of piston pin in the connecting rod bushing
- (lp) =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 do= 14 mm di= 8.4 mm

Table 3: Output Parameters for Different Materials

Properties	A2618	Al-GHY1 250 alloy piston	Al-GHS 1300 alloy piston
Thickness of piston head (t_H)	4.4mm	3.9196 44 mm	4.40mm.
Radial thickness of ring (t_1)	1.5mm	1.5mm	1.5 mm
Axial thickness of ring (t_2)	1mm	1.05 mm	1.05mm.
Width of the top land (b_1)	4.4mm	3.9196 44 mm	4.40mm
Width of ring land (b_2)	0.75m m	0.7875 mm	0.7875 mm
Maximum thickness of the barrel at the top end (t_3)	7.9mm	7.9mm	7.9 mm
Thickness of piston barrel at the open end (t_4)	1.975m m	1.9475 mm	1.975 mm
Length of skirt (l_s)	30mm	30mm	30mm
Length of piston pin in the connecting rod bushing (l_p)	22.5	22.5m m	22.5mm
Total piston length (L)	40.92m m	40.482 14 mm	40.97214 mm
Piston pin diameter (d_o & d_i)	14&8.4 mm	14&8.4 mm	14&8.4

III. STATIC STRUCTURAL ANALYSIS

A. For A2168 Alloy

The accompanying figure shows the piston's overall distortion. The piston's outside sections were where the largest displacement of 0.10001 mm was noted. On the other hand, the center region of the piston head exhibited the least amount of distortion, measuring 0.011112 mm. This implies that while the edges undergo more structural displacement as a result of mechanical and thermal stresses, the piston crown is comparatively stable under load.

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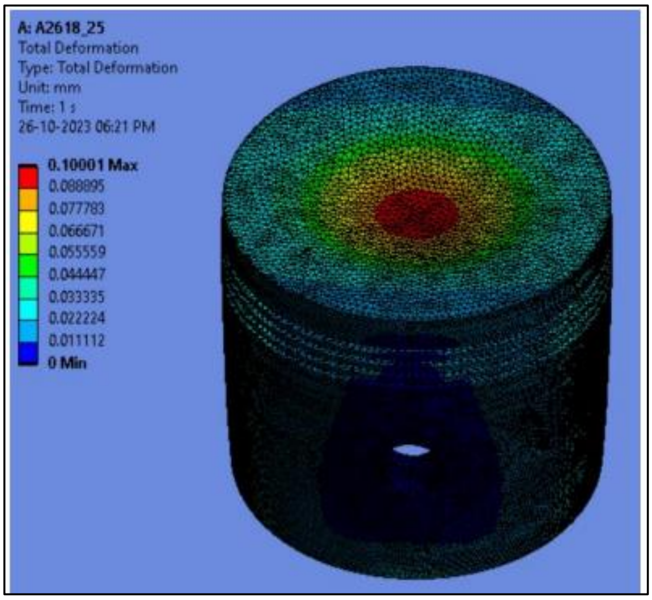

Fig 1: Total Deformation

B. For A2618 Alloy

The change in von Mises strain over the piston is depicted in Figure 2. According to the research, the lowest strain measured was 0.00064387 MPa, while the highest strain measured was 0.00578 MPa. These findings suggest that, under operational loading conditions, the strain distribution is unequal, with specific parts undergoing greater deformation.

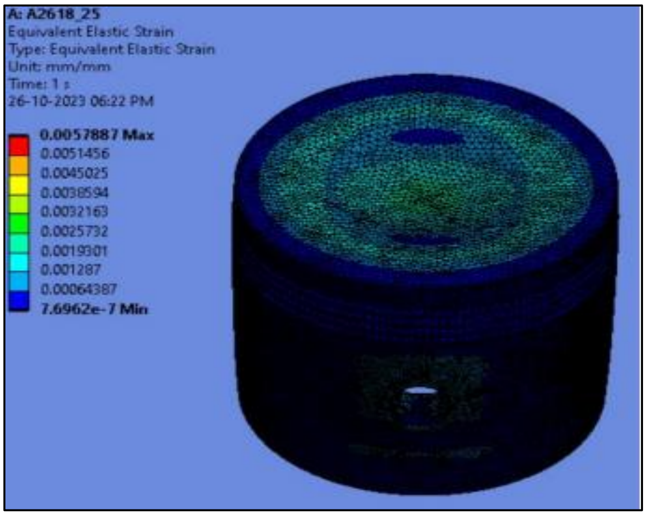

Fig 2: Equivalent Von-Misses Strain

C. For A2618 Alloy

The von Mises stress distribution throughout the piston is shown in Figure 3. According to the modeling results, the piston has encountered a maximum stress of 361 MPa and a minimum stress of 0.042609 MPa. This variance implies that some areas of the piston are subjected to noticeably higher mechanical loads, which the design must take into account to guarantee endurance and structural integrity.

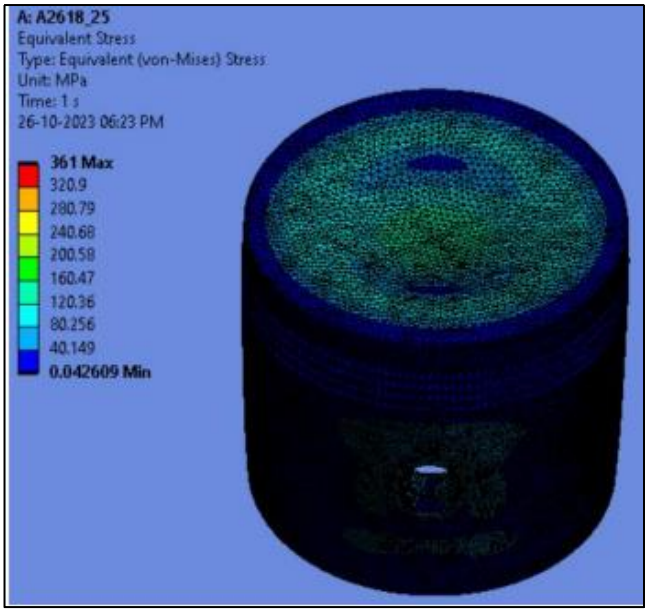

Fig 3: Equivalent Von-Misses Stress

IV. HEAT FLUX ANALYSIS FOR AL-GHS1300

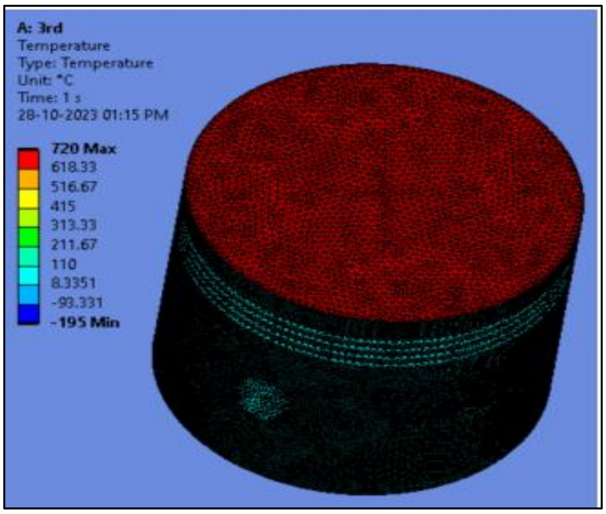

Fig 4: Temperature Distribution

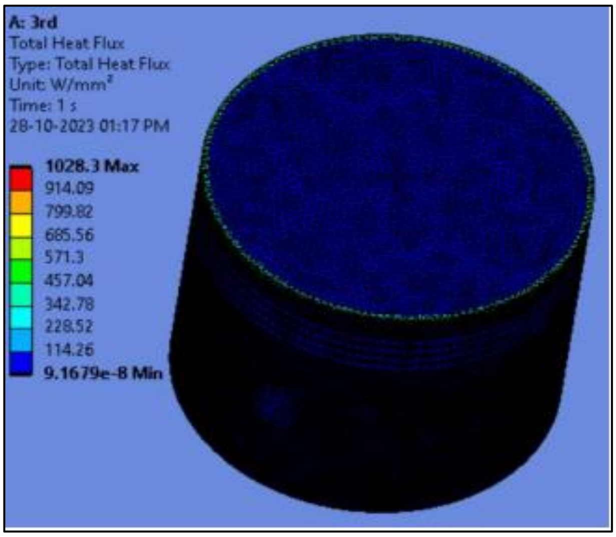

Fig 5: Total Heat Flux

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Table 4: Comparative Analysis

S no	Parameters	Al alloy A2618 Max Min	AlGHY1250 Max Min	AlGHS1300 Max Min
1	Total Deformation (mm)	0.1000 0.011112	0.08549 0.009499	0.072464 0.0080516
2	Equivalent von-misses stress (MPa)	361 0.042609	366.56 0.22049	336.87 0.036998
3	Equivalent von-misses strain (MPa)	0.00578 0.00064387	0.004950 0.0005537	0.0038322 0.00042617

V. CONCLUSION

A comparative analysis was conducted on three aluminum alloys—**A2618**, **AlGHY1250**, and **Al-GHS1300**—by evaluating their **total deformation**, **equivalent von Mises stress**, and **equivalent von Mises strain** under similar loading conditions. Among the materials tested, **Al-GHS1300** demonstrated superior performance. The simulation results showed that the **induced stress in Al-GHS1300 remained below its allowable limit**, indicating its **suitability and reliability** for piston applications. Therefore, Al-GHS1300 emerges as the most **optimal material** choice for enhanced durability and performance in engine components.

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