

# A Study on Design Optimization and Performance Analysis of A Four-Stroke Engine Piston

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*Abstract- The For more than a hundred years, the four-stroke engine has remained a primary power source in automotive and industrial systems due to its dependable operation and effective energy conversion. Among its critical components, the piston plays a central role by moving reciprocally within the cylinder and transferring the force produced by fuel combustion to the crankshaft through the connecting rod. This motion enables the transformation of the fuel's chemical energy into mechanical power required for engine operation. During engine functioning, the piston is exposed to extreme conditions such as high combustion temperatures, intense gas pressure, and continuous cyclic loading. These harsh operating environments make piston design and material selection extremely important for ensuring engine reliability, thermal stability, and long service life. An efficient piston must combine high strength, low weight, and good thermal conductivity while resisting deformation and wear. The present work investigates the design and performance analysis of a four-stroke engine piston using two different materials, namely aluminum alloy and cast iron. To maintain consistency and accuracy in comparison, identical piston dimensions are used for both materials. The geometric modeling of the piston is carried out using CATIA V5, while the numerical simulations are performed with ANSYS Workbench. The analysis covers thermal, structural, and mechanical behavior, including temperature distribution, pressure loading effects, stress development, and strain response under operating conditions. The comparative results obtained from this study highlight the influence of material properties on piston performance and provide a basis for selecting suitable materials to enhance engine efficiency, durability, and overall operational effectiveness.*

*Index Terms- Catia V5, Anasys Workbench 15.0, Temperature, Pressure, Stress*

## I. INTRODUCTION

Any Engines are mechanical systems designed to transfer power from one point to another, and this process is primarily accomplished with the help of a

piston. The piston plays a vital role in converting the energy generated during combustion into mechanical motion. Based on the combustion process, engines are broadly classified into two categories: internal combustion engines and external combustion engines. In an internal combustion engine, fuel combustion takes place inside the engine cylinder, where ignition occurs due to the interaction of air and fuel. In contrast, an external combustion engine operates by generating heat outside the engine cylinder, commonly using steam as the working medium. External combustion engines are generally employed in heavy-duty and large-scale applications. In engine systems, ignition occurs due to fuels such as petrol, diesel, or steam, depending on the engine type. During engine operation, the piston is subjected to high temperatures and pressures, which significantly influence engine performance. Compared to diesel engines, certain engine configurations offer advantages such as lower fuel consumption cost, compact size, reduced space requirement, and overall lower operational expenses. A piston is a fundamental component of reciprocating engines, reciprocating pumps, and gas compressors. It is a moving element housed within a cylinder and is sealed using piston rings to ensure gas-tight operation. In internal combustion engines, the primary function of the piston is to transmit the force generated by expanding gases during combustion to the crankshaft through a connecting rod. In pumping systems, this function is reversed, where mechanical energy from the crankshaft is transferred to the piston to compress or displace fluid within the cylinder.

The piston is connected to the connecting rod through a piston pin, which is typically made of hardened steel. This pin is fixed within the piston but allowed to rotate freely in the connecting rod. Some engine designs employ a fully floating piston pin, allowing relative motion between both the piston and the

connecting rod. During operation, the piston experiences several forces, including friction between the piston and cylinder wall, load acting on the piston head due to combustion pressure, and thermal stresses caused by excessive heat.

The primary objectives of piston design are to withstand high pressure and mechanical loads, minimize the formation of cracks, and enhance heat dissipation to improve cooling efficiency. Achieving these objectives is essential for improving engine reliability, efficiency, and service life.

## II. ENGINE SPECIFICATION PARAMETERS VALUES

PARAMETERS	VALUES
Piston type	Four stroke piston
Diameter of the piston	54mm
Cylinder height	89mm
Number of piston	Single piston
Length of Connecting Rod	120mm
Displacement Volume	145.31 cm <sup>3</sup>
Compression Ratio	9.5+/-0.5:1
Number of Revolutions/Cycle	2
Stroke	9.5cm <sup>3</sup>

## III. PHYSICAL AND MECHANICAL PROPERTIES

PROPERTIES	VALUES
Elastic Modulus	73.5 GPa
Poisson's Ratio	0.33
Shear Modulus	29 GPa
Density	2780 kg/m <sup>3</sup>
Tensile Strength	499 MPa
Yield Strength	396 MPa
Thermal Conductivity	120 W/m-K

### Piston Design Considerations

1. Material Selection: Piston materials play a critical role in ensuring durability and heat dissipation. Common materials include aluminum alloys for

their lightweight properties and efficient heat transfer.

2. Shape and Size: The design of the piston must consider its shape and size to optimize combustion efficiency and reduce friction. Combustion chamber shape, valve clearance, and overall dimensions impact the engine's performance.
3. Cooling Features: Effective cooling is essential to prevent overheating. Pistons often incorporate cooling channels or use materials with high thermal conductivity to dissipate heat efficiently.
4. Weight Distribution: Balancing the weight distribution of the piston is crucial for minimizing vibration and wear. Well-designed pistons distribute weight evenly to ensure smooth operation and longevity.

### Piston Analysis Methods

1. Finite Element Analysis (FEA): FEA is widely used for structural analysis of pistons. It helps identify stress concentrations, areas of potential failure, and aids in optimizing the design for strength and reliability.
2. Thermal Analysis: Analyzing the thermal behavior of the piston is essential to prevent overheating. Computational models simulate heat distribution and help design pistons that withstand the rigors of high-temperature environments.
3. Dynamic Analysis: Dynamic analysis assesses the piston's response to forces and accelerations during engine operation. This helps optimize the piston's mass distribution for reduced vibration and increased longevity.
4. Material Fatigue Analysis: Pistons undergo millions of cycles throughout their lifespan. Analyzing material fatigue ensures that the chosen materials can withstand the repeated stress and strain, leading to a longer component life.

## IV. PISTON DESIGN CALCULATIONS

The design calculations for the piston are considered under the maximum pressure condition over the piston are as follows

$D$  = Bore or Diameter of piston  $L$  = Stroke

I.P. = Indicated Power

B.P = Brake power

$\eta_m$  = Mechanical efficiency of the engine = 0.8  
 Engine speed  
 H.C.V. = High Calorific value of piston = 47000 kJ/kg

Density of Petrol:  
 $C_8H_{18} = 737.22 \text{ kg/m}^3$  at  $60^\circ F = 0.00073722 \text{ kg/cm}^3 = 0.00000073722 \text{ kg/mm}^3$   
 $T = 60^\circ F = 288.855 K = 15.55^\circ C$   
 Mass = Density  $\times$  Volume  
 $m = 0.00000073722 \times 145310 m = 0.107 \text{ kg} \dots$   
 Molecular weight for petrol 144.2285 g/mole  
 $R = \text{Gas constant}$   
 $PV = mRT$   
 $P = (0.107 \times 8.31430 \times 288.855) / (0.00002015483)$   
 $P_{max} = 12.70 \times 10^6 \text{ N/m}^2$  or  $12.70 \text{ MPa}$   
 Where,  $m$  = mass/molecular weight  
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Thickness of Piston head,  $th$ :  
 The piston thickness of piston head calculated using the following Grashoff's formula  
 $th = \sqrt{(3P_{max}D^2) / (16\sigma_t)}$  in mm  
 $th = \sqrt{(3 \times 12.70 \times 582) / (10 \times 220)}$   
 $th = 6.76 \text{ mm}$   
 Where,  $\sigma_t$  = Allowable tensile strength for piston = 197 MPa  
 Factor of safety for the design is 2.5

Piston Rings  
 Radial Thickness,  $b = D \sqrt{(3P_w / \sigma_p)}$   
 $P_w$  = Allowable pressure on the cylinder wall = 0.025 MPa  
 $\sigma_p$  = Permissible tensile strength for the ring material = 110 N/mm<sup>2</sup>  
 $b = 58 \times \sqrt{(3 \times 0.025 / 110)} = 1.514 \text{ mm}$   
 Axial Thickness,  
 $h = 0.7b = 0.7 \times 1.514 = 1.06 \text{ mm}$   
 Width of Top Land,  $h_1 = 1.2th$   
 $h_1 = 1.2 \times 6.4 = 7.68 \text{ mm}$

Width of other ring lands i.e., distance between the ring grooves  
 $h_2 = 0.75h$  to  $h$   
 $h_2 = h = 1.06 \text{ mm}$   
 Number of rings,  $n_r = 3$

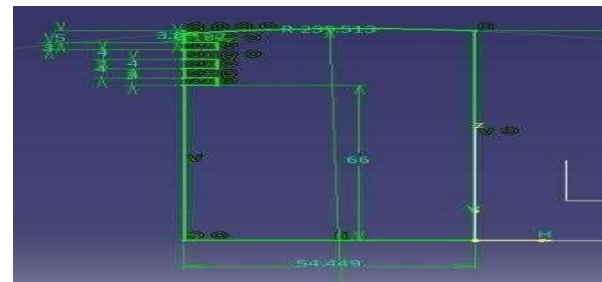
Maximum thickness of piston barrel at the top end,  $t_1$ :  
 Radial depth of the piston grooves,  
 $d_g = 0.4 + b$   $d_g = 0.4 + 1.514 = 1.914$   $t_1 = 0.03 \times D + d_g + 4.5$   
 $t_1 = 0.03 \times 58 + 1.914 + 4.5 = 8.154 \text{ mm}$

Thickness of piston barrel at open end,  
 $t_2: t_2 = 0.25t_1$  to  $0.35t_1$   $t_2 = 0.25 \times 8.154 = 2.038 \text{ mm}$

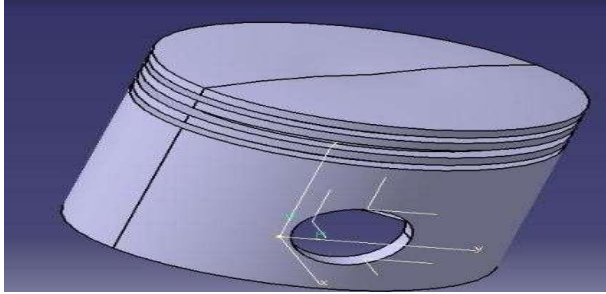
Piston Skirt:

Maximum gas load on the piston  $P_{load} = P_{max} \times \pi D^2 / 4$   
 $P_{load} = 12.7 \times \pi \times 58^2 / 4 = 33554.4 \text{ N}$   
 Diameter of Piston Pin,  $d_o = 16 \text{ mm}$   
 The centre of piston pin should be 0.02D to 0.04D above the centre of skirt.  
 Maximum side thrust on the cylinder  $R = P_{load} / 10 = 3355.44 \text{ N}$   
 $\sigma_b = R / D \times l_s$   
 $\sigma_b = 3355.44 / 58 \times 34.2 = 1.7 \text{ N/mm}^2$  Where  
 $\sigma_b$  = Bearing Pressure  
 $l_s$  = Length of skirt  
 Total length of piston,  
 $L = \text{Length of skirt} + \text{Length of ring section} + \text{Top land}$   
 Length of ring section =  $5 \times h_2 = 5.3 \text{ mm}$   
 $L = 34.2 + 5.3 + 7.56 = 47.06 \text{ mm}$

V. PISTON MEDELLING



VI. 3D MODEL OF THE PISTON



### VII. MESH INFORMATION

Mesh type	Solid Mesh
Mesher Used	Standard mesh
Proximity	On
Include Mesh Auto Loops:	On
Jacobian points	2
Element Size	3.466
Tolerance	0.128268 mm
Mesh Quality	High
Total Nodes	49129
Total Elements	31466

### VIII. CONCLUSION

In the present study, a piston was designed and analyzed for a four-stroke petrol engine used in a motorcycle with an approximate displacement of 220 cc. The design and simulation results confirm that the piston is structurally safe and suitable for the intended operating conditions. The maximum shear stress obtained from the analysis was found to be lower than the allowable design shear stress of the selected material, indicating that the piston can safely withstand the applied mechanical loads.

The factor of safety obtained from the simulation results closely matches standard design practice for engine pistons. Since an acceptable factor of safety for piston design generally lies between 2.0 and 3.0, a value of 2.5 was considered appropriate in this study, ensuring a balanced combination of strength, reliability, and material efficiency.

Material optimization was achieved by removing excess material from the lower region of the piston skirt and selectively reducing material around the piston pin area. These modifications help in reducing overall piston weight without compromising structural integrity. The geometric modeling of the piston was carried out using CATIA V5, while detailed thermal and structural analyses—including temperature, pressure, stress, and strain—were performed using ANSYS Workbench 15.0.

Based on the obtained results, it is concluded that further improvements in piston performance are possible through design optimization focused on stress and strain concentration zones. Additionally, proper material selection and constraint conditions for the piston pin play a crucial role in enhancing durability and operational efficiency. This study provides a foundation for future advancements in piston design aimed at improving performance, reducing weight, and increasing service life.

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