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# Design and Analysis of Piston for 4 Stroke Engine Using CAE Tools

[1]Mohit Juneja, [2]Dilip Verma, [3]Abhinav Sharma, [4]Rajesh Mishra, [5]Rahul Singh Rajput, [6]Jasveer Singh

[1]Assistant Professor, Department of Automobile Engineering, Hindustan College of Science and Technology, Farah, Mathura, India
[2]Assistant Professor, Department of Automobile Engineering, Hindustan College of Science and Technology, Farah, Mathura, India
[3]Student, Department of Automobile Engineering, Hindustan College of Science and Technology, Farah, Mathura, India
[4]Student, Department of Automobile Engineering, Hindustan College of Science and Technology, Farah, Mathura, India
[5]Student, Department of Automobile Engineering, Hindustan College of Science and Technology, Farah, Mathura, India
[6]Student, Department of Automobile Engineering, Hindustan College of Science and Technology, Farah, Mathura, India

*Abstract:* **Piston is the major part of an internal combustion engine which converts the chemical energy of the fuel into the mechanical energy obtained at the crankshaft through the connecting rod. An internal combustion engine is acted upon by the pressure of the expanding combustion gases in the combustion chamber space at the top of the cylinder. This force then acts downwards through the connecting rod and onto the crankshaft. This paper shows the use of different material from the existing one in the design and analyzed it for better results. A parametric model of piston is modeled using Solidworks 2013 software and analysis is done by using CAE tools of Solidworks. The piston design is for 150cc 4-stroke petrol engine in which the various dimensions of piston is calculated by analytical method considering maximum pressure condition and the materialAluminum alloy 2024-T361 is used in the design is based on the parameters like Vonmises stress, total deformation and factor of safety and the weight reduction from the design.**

*Keywords:* **Solid works 2013, CAE Tools, Aluminium 2024-T361, Maximum pressure, Piston Head.**

## 1. INTRODUCTION

Any machine which derives heat energy from the combustion of fuel and converts part of this energy into mechanical work is known as heat engine. Heat engines are mainly divided into two groups, viz., external combustion engine and internal combustion engine. In the case of external combustion engines, the combustion of fuel takes place outside the cylinder as in the case of steam engines. In internal combustion engines, the combustion of fuel in the presence of air takes place inside the engine cylinder and products of combustion directly act on the piston to develop the power. The internal combustion engines are further classified as petrol engines, diesel engines and gas engines according to the type of fuel used. The internal combustion engines offer some special advantages over external combustion engines in smaller power ranges:

1. The thermal efficiency is high.
2. The horse power developed per unit weight of engine is high.
3. Starting is easy and quick.
4. It offers greater mechanical simplicity.
5. It requires less space.
6. The capital cost is low.

A pistonis a component of reciprocating engines, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms. 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 rod and/or connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder.This pin is mounted within the piston: unlike the steam engine, there is no piston rod or crosshead (except big two stroke engines). The pin itself is of hardened steel and is fixed in the piston, but free to move in the connecting rod. A few designs use a 'fully floating' design that is loose in both components. All pins must be prevented from moving sideways and the ends of the pin digging into the cylinder wall, usually by circlips.

The major forces acting on the piston are as follows:

- Inertia force caused by the high frequency of reciprocating motion of piston
- Friction between the cylinder walls and the piston rings
- Forces due to expansion of gases
- Forces acting due to the compression of gases
- Friction at gudgeon pin hole

**Objective:**

- Designing the piston for 150 cc petrol engine taking reference to the existing piston.
- Design is modified to get better results
- Creating of 3D model in Solidworks and then by using CAE tools Simulation Xpress Study
- Meshing of 3D model in Simulation Xpress Study
- Material Aluminium 2024-T361 is selected for the study

## 2. ENGINE SPECIFICATIONS

The engine parameters used for this design is of 150cc 4 strokes air-cooled petrol engine and the engine specification are as follows:

**TABLE.1: Engine Specification**

| PARAMETERS | VALUES |
|---|---|
| Engine Type | Four stroke, Petrol Engine |
| Induction | Air cooled Type |
| Number of Cylinders | Single Cylinder |
| Bore | 58 mm |
| Stroke | 55 mm |
| Length of Connecting Rod | 110 mm |
| Displacement Volume | 145.31 $cm^3$ |
| Compression Ratio | 9.5+/-0.5:1 |
| Number of Revolutions/Cycle | 2 |

## 3. MATERIAL SPECIFICATION

The chemical composition for the material **Aluminium 2024-T361** is given below:

**TABLE.2: Chemical Composition**

| Element | Content % |
|---|---|
| Aluminium (Al) | 90.8 to 94.7 |
| Copper (Cu) | 3.8 to 4.9 |
| Magnesium (Mg) | 1.2 to 1.8 |
| Manganese (Mn) | 0.3 to0.9 |
| Iron (Fe) | Max 0.5 |
| Silicon (Si) | Max 0.5 |
| Zinc (Zn) | Max 0.25 |
| Titanium (Ti) | Max 0.15 |

The physical and mechanical properties for the material **Aluminium 2024-T361** is given below:

**TABLE.3: Physical and Mechanical Properties**

| PROPERTIES | VALUES |
|---|---|
| Elastic Modulus | 72.4 GPa |
| Poisson's Ratio | 0.33 |
| Shear Modulus | 28 GPa |
| Density | 2780 kg/m$^3$ |
| Tensile Strength | 495 MPa |
| Yield Strength | 395 MPa |
| Thermal Conductivity | 120 W/m-K |

## 4. PISTON DESIGN CALCULATIONS

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

Let,

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

N = Engine speed

H.C.V. = High Calorific value of piston = 47000 kJ/kg

**Density of Petrol:**

$C_8H_{18}$ = 737.22 kg/m$^3$ at 60$^0$F = 0.00073722 kg/cm$^3$ = 0.00000073722 kg/mm$^3$

T = 60$^0$F = 288.855K = 15.55$^0$C

Mass = Density × Volume

m = 0.00000073722 × 145310

m = 0.107 kg

∴ Molecular weight for petrol 144.2285 g/mole

R = Gas constant.

PV = mRT

P = (0.107×8.31430×288.855)/ (0.00002015483)

$P_{max}$= 12.70×10$^6$ N/m$^2$or 12.70MPa

Where, m = mass/molecular weight

R = Gas constant

### 4.1Thickness of Piston head, $t_{h:}$

The piston thickness of piston head calculated using the following Grashoff's formula,

$t_h = \sqrt{(3P_{max}D^2)/(16\sigma_t)}$ in mm

$t_h = \sqrt{(3\times12.70\times58^2)/(16\times220)}$

**$t_h$ = 6.36 mm**

Where, $\sigma_t$ = Allowable tensile strength for piston = 198 MPa

Factor of safety for the design is 2.5

**4.2 Piston Rings:**

Radial Thickness, b

$b = D\sqrt{(3Pw/σp)}$

$P_w$ = Allowable pressure on the cylinder wall = 0.025 MPa

$σ_p$ = Permissible tensile strength for the ring material = 110 $N/mm^2$

**b** = $58\times\sqrt{(3\times0.025/110)}$ **= 1.514 mm**

Axial Thickness, h

$h = 0.7b = 0.7\times1.514$**= 1.06 mm**

Width of Top Land, $h_1 = 1.2t_h$

$h_1 = 1.2\times6.3$ = **7.56 mm**

Width of other ring lands i.e., distance between the ring grooves

$h_2 = 0.75h$ to h

$h_2 = h$ = **1.06 mm**

Number of rings, $n_r = 3$

**4.3 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 mm**

$t_1 = 0.03\times D+d_g+4.5$

$t_1 = 0.03\times58+1.914+4.5$ = **8.154 mm**

**4.4 Thickness of piston barrel at open end, $t_2$:**

$t_2 = 0.25t_1$ to $0.35t_1$

$t_2 = 0.25\times8.154$ = **2.038 mm**

**4.5 Piston Skirt:**

Maximum gas load on the piston

$P_{load} = P_{max}\times\pi D^2/4$

$P_{load} = 12.7\times\pi\times58^2/4 = 33554.4$ N

Diameter of Piston Pin, $d_o$ = 16 mm

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

Maximum side thrust on the cylinder

$R = P_{load}/10 = 3355.44$ N

$σ_b = R/D\times l_s$

$σ_b = 3355.44/58\times34.2 = 1.7$ $N/mm^2$

Where, $σ_b$ = Bearing Pressure

$l_s$ = Length of skirt

Total length of piston, L = Length of skirt+ Length of ring section+ Top land

Length of ring section = $5\times h_2$ = 5.3 mm

**L = 34.2+ 5.3+ 7.56 = 47.06 mm**

## 5. PISTON MODELING

The design of the piston based on the analytical calculations is modelled in the software Solidworks and material assigned for this design is **Aluminium 2024-T361.** Drawing and 3D Modelling of the piston is done using Solidworks software. Modelling of piston is not that difficult but what makes it complicated is that the correct use design calculations and correct material you are using. Design calculations are done mathematically using various formulae for finding the different dimensions of the piston.

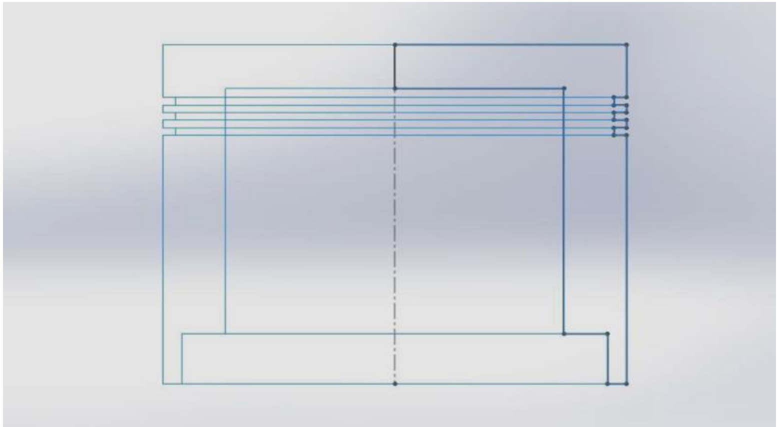

**Fig 1: Piston after using revolving command**

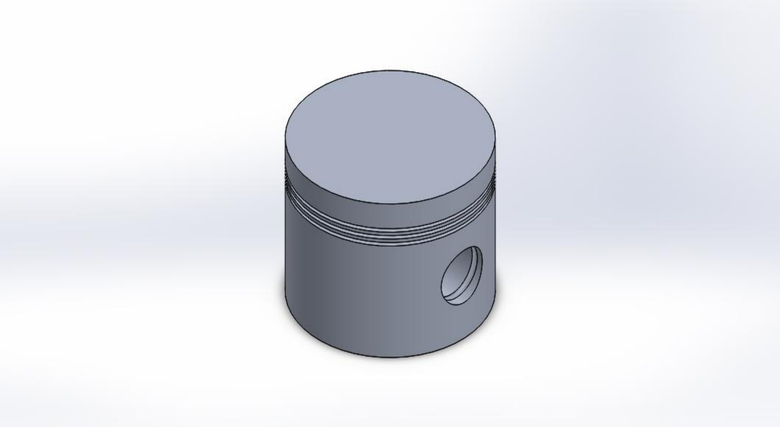

**Fig 2: 3D Model of Piston**

## 6. RESULTS AND DISCUSSION

Analysis of the design is done by using CAE tools of the Solidworks Simulation Xpress Study in which the static structural analysis is carried out on the piston. The maximum pressure 12.70 MPa is applied at the top of the piston head.

### 6.1 Mesh Information:

**TABLE 4: Mesh Information**

| | |
|---|---|
| **Mesh type** | Solid Mesh |
| **Mesher Used** | Standard mesh |
| **Automatic Transition:** | Off |
| **Include Mesh Auto Loops:** | Off |
| **Jacobian points** | 4 Points |
| **Element Size** | 2.56536 mm |
| **Tolerance** | 0.128268 mm |
| **Mesh Quality** | High |
| **Total Nodes** | 49029 |
| **Total Elements** | 30466 |

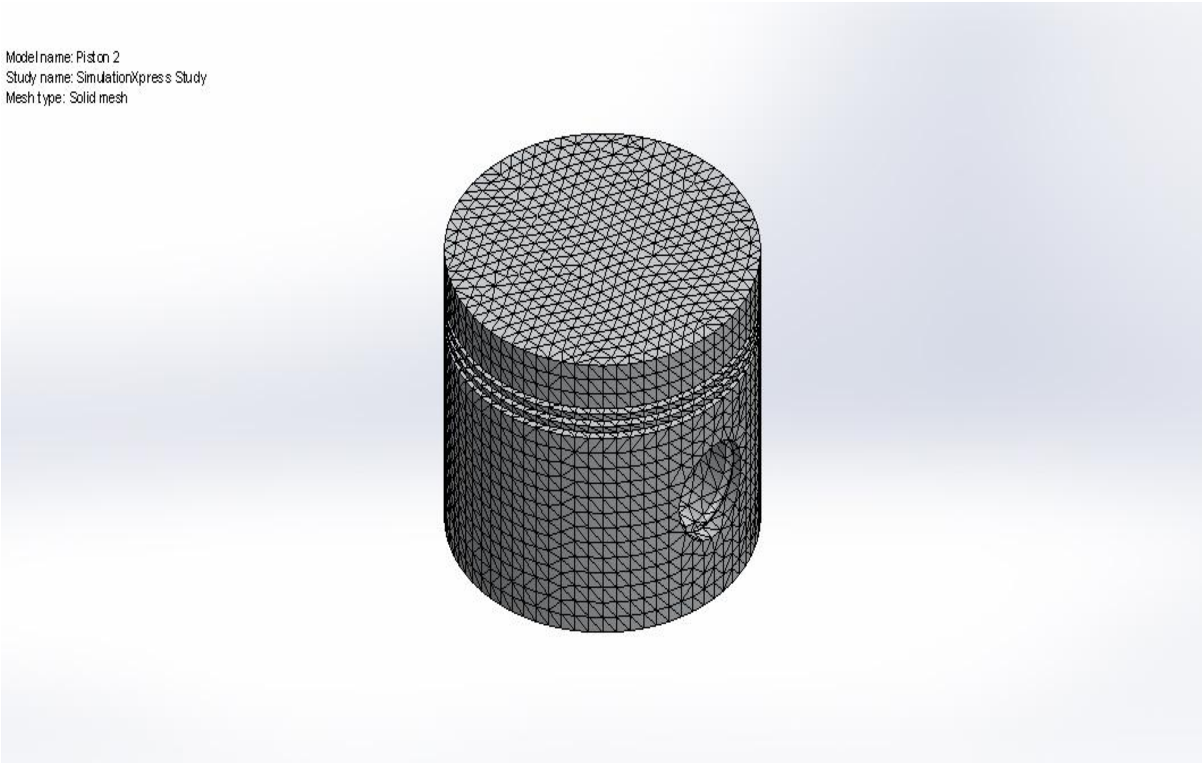


**Fig.3: Meshing of Piston**

### 6.2 Study Results:

The maximum Vonmises stress concentration is at the top of piston head due to the maximum stress concentration after combustion.

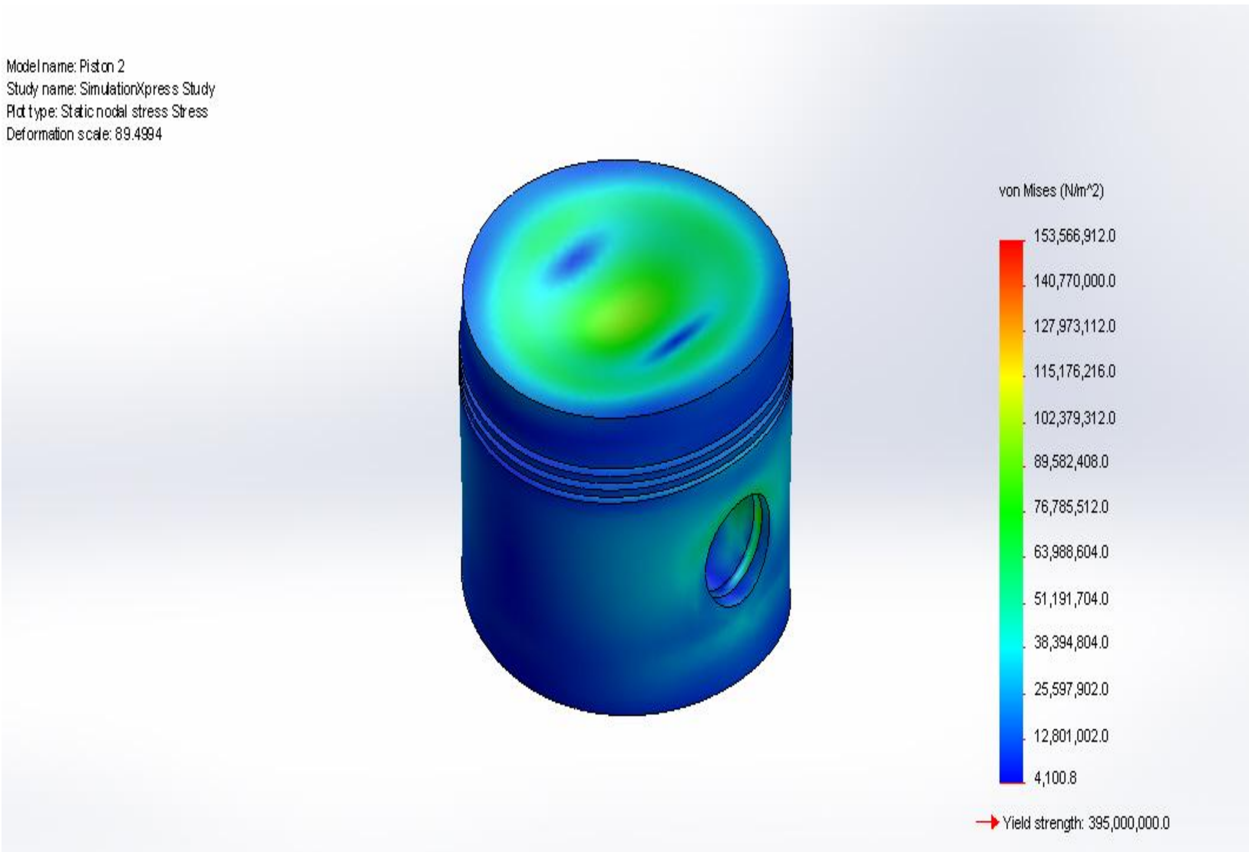


**Fig.4: Von mises stress**

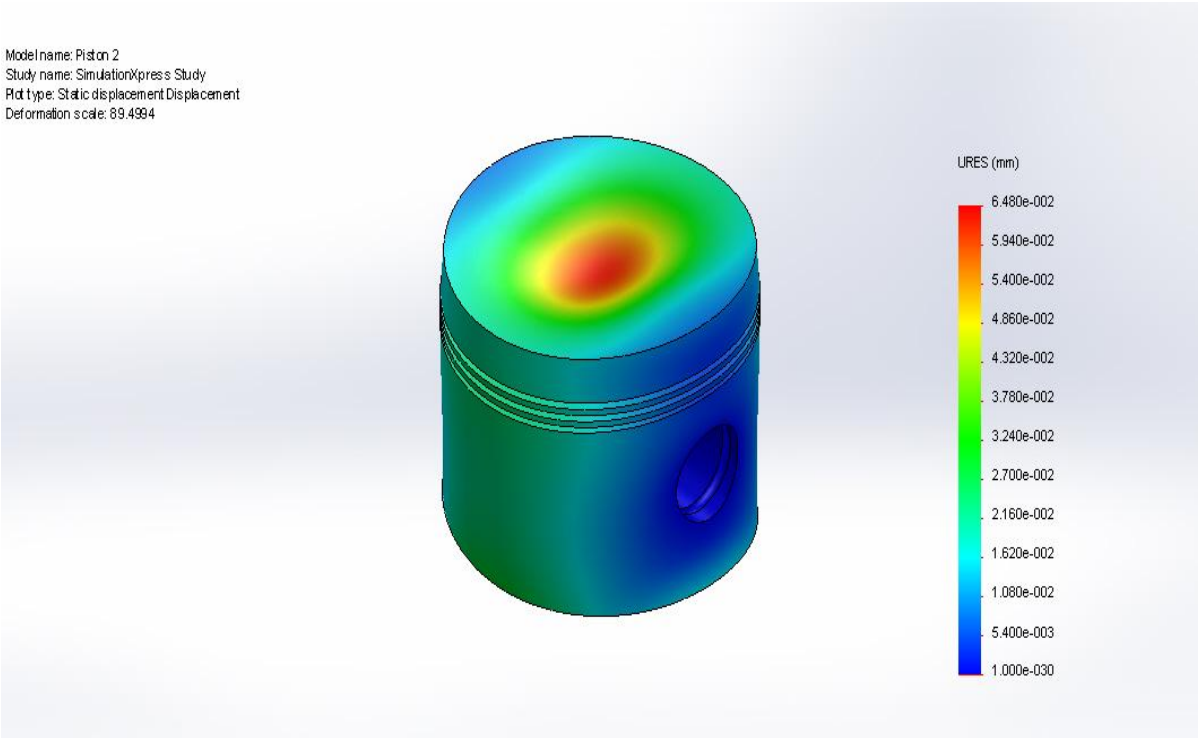


**Fig.5: Total Deformation**

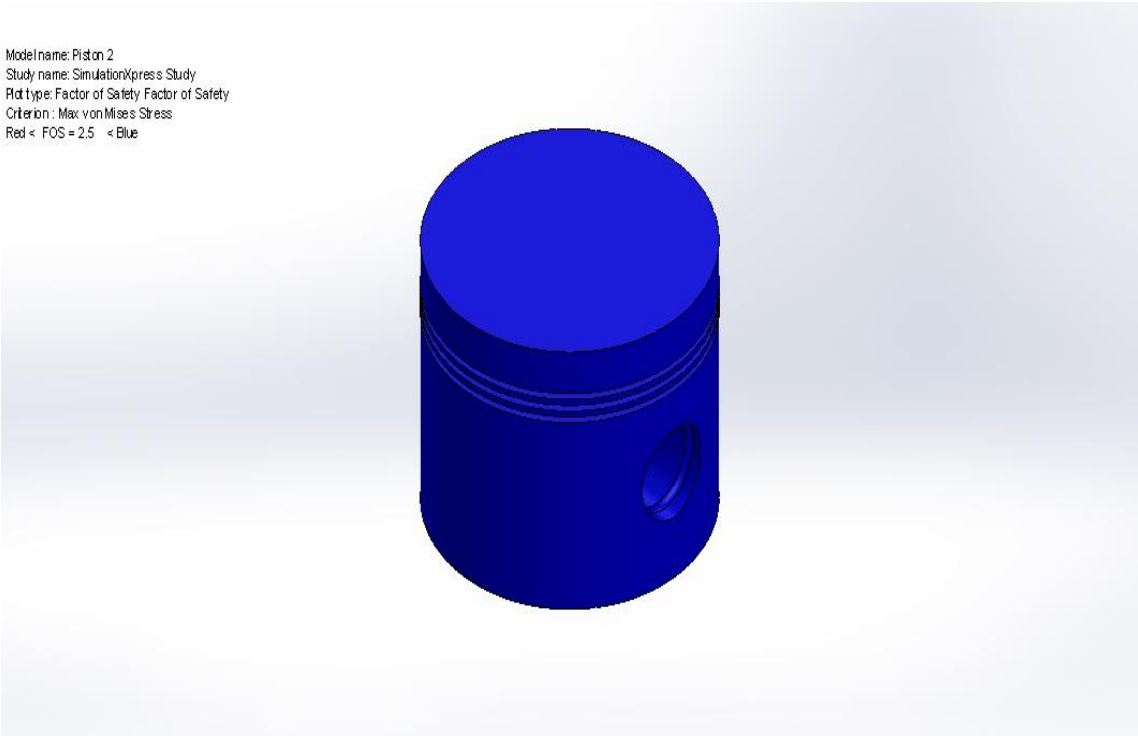


**Fig.6: Factor of Safety**

**TABLE.5: Results after Analysis**

| Sr. No. | PARAMETERS | Aluminium 2024-T361 |
|---|---|---|
| 1. | Maximum Vonmises stress | 102.379 MPa |
| 2. | Total Deformation | 0.0648 mm |
| 3. | Factor of Safety | 2.5 |
| 4. | Mass | 0.171 kg |
| 5. | Volume | 6.1746e-005 $m^3$ |

## 7. CONCLUSION

- The piston is designed for the 4 stroke petrol engine for bike of displacement approximately 150cc.
- The results shows that the max vonmises stress is smaller than the allowable design stress for the material 2024-T361. Max Vonmises stress < Allowable design stress
- According to the software the factor of safety is around 2.5 which is almost similar to the design consideration of the piston which lies between 2.0 to 3.0 so, factor of safety of 2.5 is taken into consideration.
- There is possibility of the material removal from the bottom side of piston skirt and some material from the piston pin side without much affecting the stress-strain concentration of the piston.
- The maximum deformation is at the centre of the piston head because it is the area where the maximum pressure is applied when combustible gases pushes the piston downwards.
- Therefore it is visible that there is scope of future advancements in the design by examine the stress concentration on the piston pin taking its bearing constraint with proper material selection.

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