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Design and Analysis of Four Stroke I.C. Engine of TATA Indica Piston using FEA

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Abstract

1. This paper focuses on the optimization of material selection for the TATA INDICA Piston through a comparative analysis of three different materials. The materials investigated include A2618, ALGHY1250, and ALGHY1250 with changed dimensions. The Total Deformation, Equivalent Stress (Von Mises Stress), and mass of each material were measured and analyzed. The results demonstrate that ALGHY1250 with changed dimensions performs better than the other materials. It shows a Total Deformation of 0.23555 mm, Equivalent Stress of 393.04 MPa, and a mass of 0.22263 kg. The obtained Equivalent Stress values for all materials are well below the permissible limit. The reduced mass of ALGHY1250 with changed dimensions, being 5.94% less than A2618 and 9.6% less than ALGHY1250 without dimension modification, further enhances its suitability. Therefore, it is concluded that ALGHY1250 with changed dimensions is the most appropriate material choice for the TATA INDICA Piston.

Keywords: TATA INDICA Piston, material optimization, Total Deformation, Equivalent Stress;

1. Introduction

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 rod and/or connecting rod. As an important part in an engine, 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/crown cracks and so on. The investigations indicate that the greatest stress appears on the upper end of the piston and stress concentration is one of the mainly reason for fatigue failure. On the other hand piston overheating-seizure can only occur when something burns or scrapes away the oil film that exists between the piston and the cylinder wall. The most important factors are heat and the pressure loads on piston which reduces its strength and life also.

Thermal analysis is a branch of materials science where the properties of materials are studied as they change with temperature. FEM method is commonly used for Thermal Analysis and Static Structural Analysis.

- **Major force acting over piston**

1. Due to explosion of fuel gases
2. Due to compression of fuel gases
3. Side wall friction and forces
4. Thermal load
5. Inertia force due to high frequency of reciprocation of piston
6. Friction and forces at crank pin hole.

- **The two main requirements of the piston are as follows**:

1. It should contain all the fluids above and below the piston assembly during the cycle.
2. It should transfer the work done during combustion process to the connecting rod with minimal mechanical and thermodynamic losses.

- **Five main properties of a piston are**:

1. Sufficient thermal conductivity
2. Low thermal expansion
3. High hot strength
4. High strength to weight ratio
5. High resistance to surface abrasion

1.1 Objectives Of Project

The objectives of this project are as follows:

1. Perform analytical calculations of the Tata Indica Piston.
2. Design a 3D model of the piston for a 4-stroke engine.

3. Develop a Finite Element Model for optimizing the mesh of the piston.
4. Investigate and analyze the Total Deformation of the piston.
5. Examine the equivalent (Von-Mises) stresses and total deformation.
6. Optimize the material selection for the piston component.

The main focus of this project is to optimize the material used for the piston by conducting analytical calculations, developing a 3D model, and employing Finite Element Analysis (FEA) techniques. By investigating the Total Deformation and equivalent stresses, the project aims to identify the best material option for enhancing the performance and reliability of the Tata Indica Piston.

1.2 *Scope of Project*

- Existing System:

The pistons are generally made up of Cast iron, Aluminum alloy because of its high heat transfer rate. This expands appreciably on heating so right amount of clearance needs to be provided or else the engine will lead to seize. The pistons are also manufactured using steel. Steel pistons have become attractive for high-stress and motorsport diesel applications because the material is physically so much stronger than aluminum. Because the whole piston is steel, ring-land wear is no concern. And steel pistons can be fit with enormous oil galleys to provide tremendous piston cooling.

- Proposed System:

The piston materials that have been used is the namely aluminum alloy. Lightweight materials have high specific strength, high hardness and wear resistance, low friction coefficient and thermal expansion, high thermal conductivity, high heat-absorbing ability and good ability in abatement. The different materials are analyzed for the manufacturing of piston i.e. aluminum alloy Al-GHy-1250, A-2618 because it is has high shear modulus, less deformation under application of same load and it can withstand heat shocks.

2. Piston Materials

The functions of the piston and the loads that act on it present a very special set of requirements for the piston material. If low piston weight is the goal, then a low-density material is preferred. Besides its design shape, the strength of the material is the deciding factor for the load capacity of the piston. The change in loads over time requires both good static and dynamic strength. Temperature resistance is likewise important, due to the thermal loads. The thermal conductivity of the material is of significance for the temperature level. As a rule, a high thermal conductivity is advantageous, because it promotes uniform temperature distribution throughout the piston. Low temperatures not only allow greater loading of the material, but also have a beneficial effect on the process parameters at the piston crown, such as the volumetric efficiency and knock limit. Static and dynamic strength values describe material behavior under isothermal conditions. Pistons are exposed to severe changes in temperature at times. The transient heat stresses that arise place cyclical loads on the material that can sometimes exceed the elastic limit.

The materials used for piston is mainly Alluminium alloy. Cast Iron is also used for piston as it possesses excellent wearing qualities, co-efficient of expansion. But due to the reduction of weight, the use of alluminium for piston was essential. To get equal strength a greater thickness of metal is essential. Thus some of the advantage of the light metal is lost. Alluminium is inferior to Cast iron in strength and wearing qualities and hence requires greater clearance in the cylinder to avoid the risk of seizure.

- Aluminum materials

As a light alloy with high thermal conductivity, aluminum is particularly predestined to be used as a piston material. In the unalloyed state, however, its strength and wear resistance are too low. With the discovery of precipitation hardening by Wilm in 1906, aluminum alloys became well suited for technical purposes. Metals have a mutual solubility that varies with temperature, which is very low for certain metals at low temperatures in the solid state.

- Cast iron materials

Cast iron materials generally have a carbon content of > 2%. In these materials, the brittle cementite or graphite can no longer be brought into solution by subsequent heat treatment. They are therefore not suitable for radical hot forming, but their castability can be optimized for the materials used in piston casting, the basic material of the structure is largely perlitic, due to its good strength and wears properties.

- Steels

The iron alloys designated as steels generally have a carbon content of less than 2%. When heated, they transform completely into malleable (suitable for forging) austenite. The iron alloys are therefore excellent for hot forming, such as rolling or forging. Steels used for components generally have a carbon content of less than 0.8%. If they cool slowly after casting or hot forming, then a ferritic-perlitic structure is formed; Both steel grades used for manufacturing pistons today, 42CrMo4 heat-treated steel and 38MnVS6 AFP steel, are suitable for use at temperatures of up to 450°C with regard to strength at elevated temperatures and oxidation resistance. If future engine concepts are going to have similar thermal loads even under normal operating conditions, either antioxidization coating or other heat-resistant and oxidation-resistant steel grades may be used.

3. OBSERVATIONS

- **TATA INDICA**

Engine type air cooled 4 Stroke, 4 Cylinder
Bore X Stroke (mm) = 68.5 X 78
Displacement = 1172 CC
Maximum Power = 52 KW @ 4500 rpm
Maximum Torque = 135Nm @ 2500 rpm
Compression Ratio = 9.5±0.5:1
Density of Petrol C_8 h_{18}=737.22 kg
Temperature T=288.855 K
Molecular Weight of Petrol =0.11422 Kg/mole
No.of revolutions per cycle=2

Table no. 1 Material Information

Sr. No.	Parameter	A2618	ALGhy1250
1	Youngs Modulus(Gpa)	73.7	83
2	Ultimate Tensile Stress (Mpa)	480	1250
3	Poissons Ratio	0.33	0.3
4	Density	2767.99	2880

- Analytical Calculations for Piston when A2618

Mechanical Efficiency=n_{max} = 80 %

BP=$\frac{2\Pi NT}{60}$=$\frac{2X\Pi X2500X135}{60}$=35.342 KW

n = $\frac{BP}{IP}$

IP = $\frac{BP}{n}$=$\frac{35.342}{0.8}$=44.17 KW Equation ……………………….(1)

44.17 KW is for 4 cylinder, so For Single cylinder it is 11.042

IP = p L A N^*

Where N^*=No. of explosions per cycle

N^*=$\frac{N}{2}$

IP = P L A $\frac{N}{2}$

P= $\frac{11.042 X 1000}{\frac{\Pi}{4}X0.068X0.068X0.078X\frac{2500}{2X60}}$ =1.87 Mpa

Max. Pr.= P_{max}=10 X P

=10 X 1.87

=18.7 Mpa

Analytical Design for Piston

Thickness of Piston (t_h)=$\sqrt{\frac{3PD2}{16\ 6t}}$

As 6t= $\frac{6ut}{FOS}$=$\frac{480}{2.25}$=213.33

(t_h)=$\sqrt{\frac{3X\ 18.7X(0.068)2}{16\ X\ 213.33}}$ = 8.717 mm

Radial Thickness (t_1)= $0.068\ X\sqrt{\frac{3\ X\ Pw}{6t}} = 0.068\ X\sqrt{\frac{3\ X\ 0.025}{213.33}}$

$6t$ = Allowable bending tensile strength for cast iron taking

Pw = Pressure of gas on cylinder , Pw from $0.025\frac{N}{mm2}$ to $0.042\frac{N}{mm2}$

Taking $Pw = 0.025\frac{N}{mm2}$

t_1=0.00127 m =1.27 mm

t_2=0.7 t_1=0.7 X 1.27=0.889 mm

Width of top land b_1=t_h to 1.2 t_h

So that b_1= t_h= 8.717 mm

Width of ring land b_2= 0.75 t_2 to t_2

b_2= 0.75 t_2 = 0.75 X 0.889 = 0.6667 mm

Thickness of Piston barrel at top end

t_3= 0.03 D + b + 4.5 mm

Where b=radial depth of piston ring grooves

b= t_1+ 0.4 mm

So that b= 1.27 + 0.4 = 1.67 mm

t_3=(0.03 X 0.068) + 1.67 + 4.5 = 6.172 mm

(t_4)Piston wall thickness towards open end is decreased and can be taken as

0.25 t_3 to 0.35 t_3

So that t_4 = 0.35 t_3 = 0.35 X 6.172 = 2.16 mm

Length of skirt (l) = 0.6 D = 0.6 X 68.5 = 41.1 mm

Length of piston pin in connecting rod bush in = l_1=45% of Piston Diameter

l_1=0.45 X 68.5 = 30.82 mm

Piston pin diameter (d_0) = 0.28 D to 0.38 D = 0.28 X 68.5 = 19.18 mm.

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

So that center of Pin =0.02 X 0.068=0.0013 m=1.3 mm above center of Skirt.

41.1 mm +1.3 mm=42.4 mm

- Analytical Calculations for Piston when ALGhy1250

IP = 44.17 KW From Equation ……………………….(1)

IP = p L A N^*

Where N^*=No. of explosions per cycle

$N^*=\frac{N}{2}$

IP = P L A $\frac{N}{2}$

$P=\frac{11.042 X 1000}{\frac{\Pi}{4}X0.068X0.068X0.078X\frac{2500}{2X60}}$ =1.87 Mpa

Max.Pr.=P_{max}=10 X P

=10 X 1.87

=18.7 Mpa

Analytical Design for Piston

Thickness of Piston (t_h)=$\sqrt{\frac{3PD2}{16\ 6t}}$

As 6t= $\frac{6ut}{FOS}=\frac{1250}{2.25}$=555.55

$(t_h)=\sqrt{\frac{3X\ 18.7X(0.068)2}{16\ X\ 555.55}}$ = 5.402 mm

Radial Thickness (t_1)= $0.068\ X\sqrt{\frac{3\ X\ Pw}{6t}} = 0.068\ X\sqrt{\frac{3\ X\ 0.025}{555.55}}$

$6t$ = Allowable bending tensile strength for cast iron taking

Pw = Pressure of gas on cylinder , Pw from $0.025\frac{N}{mm2}$ to $0.042\frac{N}{mm2}$

Taking $Pw = 0.025\frac{N}{mm2}$

t_1=0.00079 m =0.790 mm

t_2=0.7 t_1=0.7 X 0.790=0.553 mm

Width of top land b_1=t_h to 1.2 t_h

So that b_1= t_h=5.402 mm

Width of ring land b_2= 0.75 t_2 to t_2

b_2= 0.75 t_2 = 0.75 X 0.553 = 0.414 mm

Thickness of Piston barrel at top end

t_3= 0.03 D + b + 4.5 mm

Where b=radial depth of piston ring grooves

$b= t_1+ 0.4$ mm

So that b= 0.790 + 0.4 = 1.19 mm

t_3=(0.03 X 0.068) + 1.19 + 4.5 = 5.692 mm

(t_4)Piston wall thickness towards open end is decreased and can be taken as

0.25 t_3 to 0.35 t_3

So that t_4 = 0.35 t_3 = 0.35 X 5.692 = 1.992 mm

Length of skirt (l) = 0.6 D = 0.6 X 68.5 = 41.1 mm

Length of piston pin in connecting rod bush in = l_1=45% of Piston Diameter

l_1=0.45 X 68.5 = 30.82 mm

Piston pin diameter (d_0) = 0.28 D to 0.38 D = 0.28 X 68.5 = 19.18 mm.

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

So that center of Pin =0.02 X 0.068=0.0013 m=1.3 mm above center of Skirt.

41.1 mm +1.3 mm=42.4 mm

4. OBSERVATION AND RESULT

The analysis is done in ANSYS Workbench for different types of aluminum alloy materials which is suggested best material with different material properties. Following different type of results like Equivalent Stress, Total Deformation is obtained as shown in figure.

Applying the following boundary condition on TATA INDICA piston and execute the structural and thermal analysis using ANSYS workbench.

- Boundary condition: -

  Maximum Pressure is 18.7 Mpa, apply on Piston top head and fixed support has given at surface of pin holes.

- Material:-

  1. A2618
  2. ALGHY1250

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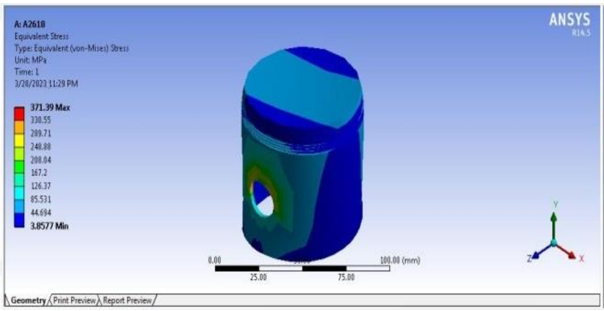
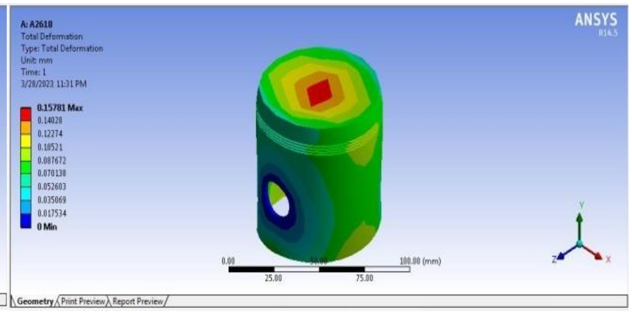
These above materials are apply simultaneously to TATA INDICA two wheeler Piston and analysis of Structural in ANSYS Workbench , these result are shown in following pictures:-

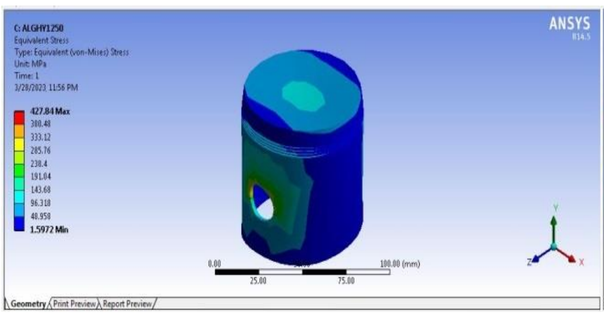
TATA INDICA Four wheeler Piston <u>STRUCTURAL ANALYSIS Result with A2618 material:-</u>

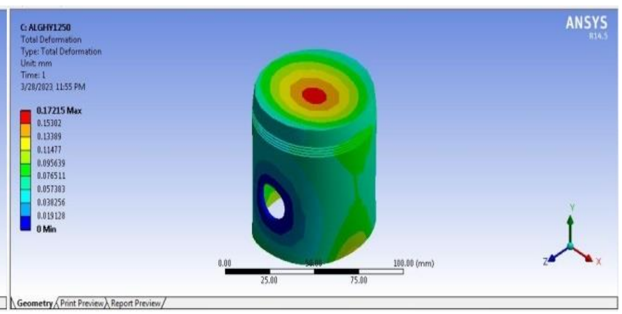




Equivalent Stress **Total Deformation**

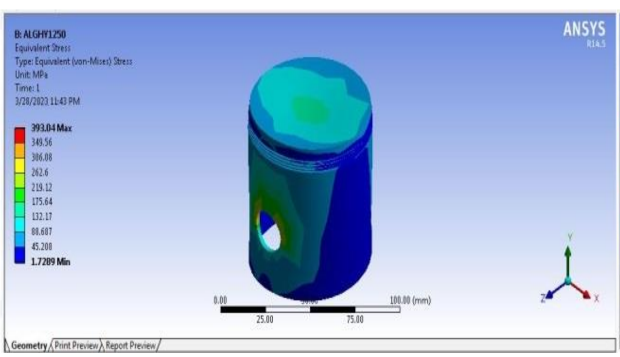
TATA INDICA Four wheeler Piston <u>STRUCTURAL ANALYSIS Result with ALGHY1250 material:-</u>

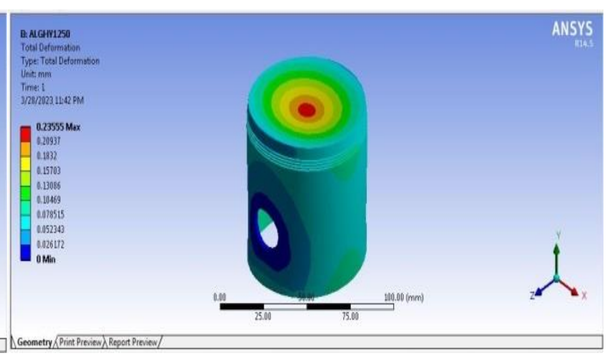




Equivalent Stress **Total Deformation**

TATA INDICA Four wheeler Piston <u>STRUCTURAL ANALYSIS Result with ALGHY1250 material with Changed dimension :-</u>





Equivalent Stress **Total Deformation**

5. Discussions Result And Discussion

Table no. 2 TATA INDICA analysis

Sr. No.	**Test**	**A2618**	**ALGHY1250**	**ALGHY1250 with Changed dimension**
1	Total Deformation	0.15781 mm	0.17215 mm	0.23555 mm
2	Equivalent stress	371.39 Mpa	427.84 Mpa	393.04 Mpa
3	Mass	0.2367 kg	0.24628 kg	0.22263 kg

The table above presents a comparison of A2618 and ALGHY1250 with same dimension and ALGHY1250 with changed dimension materials for the TATA INDICA Piston. Based on the final results, it is concluded that ALGHY1250 with changed dimensions outperforms A2618 and ALGHY1250 materials for the TATA INDICA Piston**.**

For A2618 material, the Total Deformation is measured at 0.15781 mm, the Equivalent Stress or Von Mises Stress is 371.39 MPa, and the Mass is 0.2367 kg.

For ALGHY1250 material, the Total Deformation is measured at 0.17215 mm, the Equivalent Stress or Von Mises Stress is 427.84 MPa, and the Mass is 0.24628 kg.

In comparison, ALGHY1250 with changed dimensions shows a Total Deformation of 0.23555 mm, an Equivalent Stress or Von Mises Stress of 393.04 MPa, and a Mass of 0.22263 kg.

It is worth noting that the values of the Equivalent Stress obtained for all materials are well below the permissible limit. Furthermore, ALGHY1250 with changed dimensions shows an improvement in performance. Therefore, the design of the piston using ALGHY1250 with changed dimensions is deemed safe and preferable for the TATA INDICA Piston.

6. CONCLUSIONS

Based on the discussion above, it has been determined that when ALGHY1250 is used with changed dimensions, it exhibits superior performance compared to the other two materials. The Total Deformation is measured at 0.02279mm, and the Equivalent Stress/Von Mises Stress is recorded at 310.82 MPa, both of which are favorable. Additionally, the mass of the ALGHY1250 with changed dimension is 0.22263 kg, which is 5.94% less than the A2618 material and 9.6% less than the ALGHY1250 without dimension modification. Therefore, based on these results, the most suitable material choice for the TATA INDICA Piston is ALGHY1250 with the changed dimensions.

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