Analysis on Four Stroke Single Cylinder Engine Piston by using Aluminum Alloys (Al-GHS 1300, Al-Sic- Graphite, A6061, Pure Aluminum)

1Tadala akhil, 2K.naresh, 3Abdul khursid, 4Purushotham anil kumar, 1, 3, 4Assistant Professor, 5M.Tech (cad/cam) PG student, Avanthi Engineering College, Tagarapuvalasa

Abstract
This paper describes the thermal and the stress distribution of the piston which is initialized with four different materials by using the COUPLED field analysis by finite element method (FEM). The parameters used for the simulation are the temperature as thermal condition and the force or pressure applying on the piston crown and the material properties of the piston. The specifications used for the piston belong to four stroke single cylinder Hero-Honda motorcycle. Aluminum metal composites are increasing across the broad acknowledgement for vehicles, modern, aviation applications in view of their low thickness, high quality and great structural unbounding nature. In present work the Piston is modeled using CATIA V5 modeling and Finite Element analysis (COUPLED FIELD analysis) by using the modules of both structural and thermal analysis are done for same model utilizing ANSYS software for Aluminum (pure) , Aluminum alloy (A6061), Al-GHS 1300 and Al-SiC-graphite and the results were discussed. The results predict the maximum stress and the critical region on the different aluminum alloys piston using FEA. It is important to locate the critical area of concentrated stress for appropriate modifications.

Keywords: Aluminum (pure), Silicon Carbide, A6061 and Graphite, Al-GHS 1300, Coupled field analysis, Piston, Von-Mises stresses

I. INTRODUCTION
Engine Piston is most important part contrasted with different parts in an automobile division. still part of exploration works have been leading on cylinder with respect to material structure, geometry and manufacturing technique. The purpose of the internal combustion engine piston is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. In this research the piston is made up of hybrid metal matrix, for some analysts term metal matrix composites are maintained with the term light weight metal matrix composites (MMCs). Substantial advance in the development of light metal framework composites has been attained to in late decades, so they could be introduced into the most important applications. In engineering applications, particularly in the automobile industry, MMCs has been utilizes monetarily in fibres reinforcement pistons and crank cases with high strength cylinder surfaces.

The hybrid metal matrix composite like Al-GHS-1300 and Al/SiC-MMC are the composites which have numerous extraordinary properties over Aluminum alloys and this helps to improve the wear resistant. The change of wear safety because of the upgrade of composite particles and some particles containing aluminum. In this research composite particle, for example Graphite(Gr) are basically included as a second fortification material in hybrid metal matrix composite to an increase in hardness, strength and wear resistance.

A piston is a component of reciprocating IC-engines. It is the moving component that is contained by a cylinder and is made of 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. piston endures the cyclic gas pressure and the force to work, and this working condition may cause the fatigue damage of piston, such as piston side wear, piston head cracks and so on.

In engine, transfer of heat takes place due to difference in temperature and from higher temperature to lower temperature. Thus, there is heat transfer to the gases during intakes stroke and the first part of the combustion and expansion processes the heat transfer take place from the gases to the walls. 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. In addition, as an important part in engine, the working condition of piston is directly related to the reliability and durability of engine.

A. Distortion Energy Theory
It is defined that the energy required for the shape deformation of a material. During pure Distortion the shape of the material changes, but the volume does not change.
Distortion energy required per unit volume, \( u_d \) for a general 3 dimensional case is given in terms of principal stress values as:

\[
 u_d = \frac{1 + v}{3E} \left[ \frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2} \right]
\]

Distortion energy for simple tension case at the time of failure is given as:

\[
 u_{d, \text{sim}} = \frac{1 + v}{3E} \sigma_y^2
\]

Expression for Von Mises stress

The left hand side of the above equation is denoted as Von Mises stress.

\[
\left( \frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}{2} \right)^{1/2} \leq \sigma_y
\]

So as a failure criterion, the engineer can check whether Von Mises stress induced in the material exceeds yield strength (for ductile material) of the material. So the failure condition can be simplified as

\[
\sigma_v \geq \sigma_y
\]

Distortion energy theory is the most preferred failure theory used in industry. It is clear from above discussions that whenever an engineer resorts to distortion energy theory he can use Von Mises stress as a failure criterion.

### B. Characterisation of Materials

The materials chosen for this work are A6061, AL-GHS 1300, aluminium (pure), AL-SiC for an internal combustion engine piston. The relevant mechanical and thermal properties of A6061, AL-GHS 1300, aluminium (pure), AL-SiC are listed as below.

<table>
<thead>
<tr>
<th>S.No</th>
<th>PARAMETERS</th>
<th>A6061</th>
<th>Aluminum (Pure)</th>
<th>Al-GHS 1300</th>
<th>Al-SiC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Elastic Modulus (GPa)</td>
<td>71</td>
<td>71.5</td>
<td>98</td>
<td>74.50</td>
</tr>
<tr>
<td>2</td>
<td>Ultimate tensile strength (MPa)</td>
<td>320</td>
<td>237</td>
<td>1300</td>
<td>354</td>
</tr>
<tr>
<td>3</td>
<td>Yield Strength (MPa)</td>
<td>280</td>
<td>121</td>
<td>1220</td>
<td>193.38</td>
</tr>
<tr>
<td>4</td>
<td>Poisson’s Ratio</td>
<td>0.33</td>
<td>0.29</td>
<td>0.3</td>
<td>0.30</td>
</tr>
<tr>
<td>5</td>
<td>Thermal Conductivity(W/m°C)</td>
<td>105</td>
<td>229</td>
<td>120</td>
<td>180</td>
</tr>
<tr>
<td>6</td>
<td>Density (kg/m³)</td>
<td>2770</td>
<td>2760</td>
<td>2780</td>
<td>2711.4</td>
</tr>
</tbody>
</table>

### C. Engine Specifications

The engine used for this work is a single cylinder four stroke air cooled type Baja Kawasaki petrol engine. The engine specifications are given in below

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Type</td>
<td>Four stroke, Petrol Engine</td>
</tr>
<tr>
<td>Induction</td>
<td>Air cooled type</td>
</tr>
<tr>
<td>Number of cylinders</td>
<td>Single cylinder</td>
</tr>
<tr>
<td>Bore</td>
<td>51 mm</td>
</tr>
<tr>
<td>Stroke</td>
<td>48.8 mm</td>
</tr>
<tr>
<td>Length of connecting rod</td>
<td>97.6 mm</td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>Displacement volume</td>
<td>99.27 cm³</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>8.4</td>
</tr>
<tr>
<td>Maximum power</td>
<td>6.03 KW at 7500 rpm</td>
</tr>
<tr>
<td>Maximum Torque</td>
<td>8.05 Nm at 5500 rpm</td>
</tr>
<tr>
<td>Number of revolutions/cycle</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 2: Parameters of Considered Engine

II. PROBLEM FORMULATION

The objective of the present work is to design and analysis of pistons made of A6061, AL-GHS 1300, Al-SIC, Aluminum pure. In this the piston actually made of A4032 is replaced by the above materials to know the couple field analysis on them. Piston models are created in CATIA V5 R19 and the model is imported to the ANSYS workbench for the COUPLED FIELD analysis. After the analysis a comparison is made between existing material A4032 and other material pistons in terms of volume, weight, inertia force, deformation, strain and stresses.

III. METHODOLOGY

- Analytical design of piston using specifications of Bajaj Kawasaki petrol engine.
- Creating a 3D model of piston using CATIA V5 R19.
- Importing the model in ANSYS Workbench.
- Meshing the model in ANSYS meshing of Workbench.
- Analysis of piston using thermal properties to the piston by using Steady State Analysis module to know the heat flux.
- Analysis of piston model by linking the thermal properties to the static properties and by using the Static Structural Analysis.
- Analysis of pistons under the uniform pressure and non-uniform distribution of temperature.
- Comparative performance of the four aluminum alloy pistons under the thermal and mechanical loads i.e., pressure and temperature are subjected to a uniform temperature distribution.
- Selected the Best Suited Aluminum alloy.

IV. ANALYTICAL DESIGN

\[ IP = \text{indicated power produced inside the cylinder (W)} \]
\[ \eta = \text{mechanical efficiency} = 0.8 \]
\[ n = \text{number of working stroke per minute} = N/2 \]

(for four stroke engine)

\[ N = \text{engine speed (rpm)} \]
\[ L = \text{length of stroke (mm)} \]
\[ A = \text{cross-section area of cylinder (mm}^2\) \]
\[ r = \text{crank radius (mm)} \]
\[ l_c = \text{length of connecting rod (mm)} \]
\[ a = \text{acceleration of the reciprocating part (m/s}^2\) \]
\[ m_p = \text{mass of the piston (Kg)} \]
\[ V = \text{volume of the piston (mm}^3\) \]
\[ t_h = \text{thickness of piston head (mm)} \]
\[ D = \text{cylinder bore (mm)} \]
\[ p_{max} = \text{maximum gas pressure or explosion pressure (MPa)} \]
\[ \sigma_l = \text{allowable tensile strength (MPa)} \]
\[ \sigma_{ut} = \text{ultimate tensile strength (MPa)} \]
\[ \text{F.O.S} = \text{Factor of Safety} = 2.25 \]
\[ K = \text{thermal conductivity (W/m K)} \]
\[ T_c = \text{temperature at the centre of the piston head (K)} \]
\[ T_e = \text{temperature at the edge of the piston head (K)} \]
\[ \text{HCV} = \text{Higher Calorific Value of fuel (KJ/Kg)} = 47000 \text{ KJ/Kg} \]
\[ \text{BP} = \text{brake power of the engine per cylinder (KW)} \]
\[ m = \text{mass of fuel used per brake power per second (Kg/KW s)} \]
\[ C = \text{ratio of heat absorbed by the piston to the total heat developed in the cylinder} \]
\[ = 5\% \text{ or } 0.05 \]
\[ b = \text{radial width of ring (mm)} \]
\[ P_w = \text{allowable radial pressure on cylinder wall (N/mm}^2\) = 0.025 MPa \]
\[ \sigma_p = \text{permissible tensile strength for ring material (N/mm}^2\) = 1110 N/mm² \]

h = axial thickness of piston ring (mm) 
h₁ = width of top lands (mm) 
h₂ = width of ring lands (mm) 

\[ t₁ = \text{thickness of piston barrel at the top end (mm)} \]
\[ t₂ = \text{thickness of piston barrel at the open end (mm)} \]
\[ lₛ = \text{length of skirt (mm)} \]
\[ µ = \text{coefficient of friction (0.01)} \]

\[ l₁ = \text{length of piston pin in the bush of the small end of the connecting rod (mm)} \]
\[ dₒ = \text{outer diameter of piston pin (mm)} \]

Mechanical efficiency of the engine (\( \eta \)) = 80 %.

\[ \eta = \frac{\text{Brake power (B.P)}}{\text{Indicating power (I.P)}} \]

Therefore, \( I.P = B.P = 6.2 = 7.75 \text{ KW} \)

\[ \eta = 0.8 \]

Also, \( I.P = P \times A \times L \times N² = 2 \)

\[ I.P = P \times \pi D² \times L \times N² \]

So, \( P = 18.66 \times 10⁵ \text{ N/m}² \)

Maximum Pressure \( p_{\text{max}} = 10 \times P = 10 \times 1.866 = 18.66 \text{ MPa} \)

V. COUPLED FIELD ANALYSIS

A coupled-field analysis is a combination of analyses from different engineering disciplines that interact to solve a global engineering problem, hence, we often refer to a coupled-field analysis as a multiphysics analysis. When the input of one field analysis depends on the results from another analysis, the analysis are coupled. Some analysis can have one-way coupling; for example, in a thermal stress problem, the temperature field introduces thermal strains in the structural field, but the structural strains generally do not affect the temperature distribution. This there is no need to iterate between the two fields. More complicated cases involve two way coupling.

5.1 STRUCTURAL- THERMAL Analysis

This capability, available in the ANSYS Multiphysics product, provides you with the ability to perform Thermal-Stress analyses. In dynamic analyses, you can also piezo caloric effect. Applications of the latter include thermo elastic damping in metals and MEMS devices such as resonator beams.

The Ansys program includes a variety of elements that can use to perform a coupled field analysis i.e Structural-thermal analysis summarizes them. For details description of the elements and their characteristics (DOF’s, KEAYOPT options, INPUT and OUTPUT etc) see the Element Reference.

For a Structural-thermal couple field analysis you need to select the UX, UY, UZ and TEMP elements DOFs for set of KEYOPTS. The structural-thermal KEYOPT settings also make large deflection, stress stiffness effects, and pre-stress effects available using the NLGEOM SSTIF and PSTRES commands.

The above lineup defines the coupled field analysis i.e structural-thermal coupled field analysis. In this analysis the 3D model is defined in the CATIA modeling software and the model is first imported in the Steady-state Thermal module and then applying the thermal loads on the piston and the constraints has been defined and then the thermally defined constraints are linked up with the geometry of thermal to geometry of the structural and model of thermal to model of structural and the solution has been bonded with the thermal and structural setup therefore it form the imported loads in the statical
analysis section on the piston while applying the loads on the piston and pressure is uniformly applied on the piston crown.

2) Thermal Constraints and Analysis on Piston

For coupled field analysis first the piston is imported to ansys workbench for meshing in the static thermal module and the piston is meshed with the tetrahedron or quadrilateral meshing is done on the whole 3D model to define and refinement is done on the piston and the meshing style is free or Default meshing. the statics denied after meshing the model is divided into 39167 elements and the number of nodes formed are 69788. the minimum edge length size is 0.00002694 metres. relevance is high and smooth curving is high to get the results accurately.

1) Meshing of the Piston

For coupled field analysis first the piston is imported to ansys workbench for meshing in the static thermal module and the piston is meshed with the tetrahedron or quadrilateral meshing is done on the whole 3D model to define and refinement is done on the piston and the meshing style is free or Default meshing. the statics denied after meshing the model is divided into 39167 elements and the number of nodes formed are 69788. the minimum edge length size is 0.00002694 metres. relevance is high and smooth curving is high to get the results accurately.

Figure 2: PISTON 3D Model

Figure 3: Piston Meshing

Figure 4: Total Heat Flux A6061

Figure 5: Total Heat Flux Aluminum Pure

Figure 6: Total Heat Flux Al-Sic
the above figures the total heat flux values varying from the maximum and minimum and different cross sections and the crown temperature is more and even in distributed and the edges of the crown is having the possibility of highest heat transfer and highest heat flux is preset in AL-GHS 1300.

THERMAL - STRUCTURAL ANALYSIS OR COUPLED FIELD ANALYSIS.

the thermal loads are incorporated in structural defining by the IMPORTED BODY TEMPERATURE defined by the IMPORTED LOADS under Static Structural analysis settings

Figure 7: Total Heat Flux Al-GHS 1300

Figure 8: Total Heat Flux A4032

Figure 9 Pressure on Piston Crown

Figure 10: Fixed Supports

Figure 11: Von-mises Stresses of A4032

Figure 12: Total Deformation of A4032

Figure 13: Von-Mises Stresses of A6061
VI. RESULTS & DISCUSSION

The values of Deformation, Total Heat Flux and the Equivalent stresses are recorded in the table below.

<table>
<thead>
<tr>
<th>S.no</th>
<th>Material</th>
<th>Total deformation (m)</th>
<th>Von-mises stresses (MPa)</th>
<th>Total heat flux(W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aluminum (pure)</td>
<td>3.7439 x 10⁻⁵</td>
<td>9.7357 x 10⁷</td>
<td>2.3122 x 10⁻⁵</td>
</tr>
<tr>
<td>2</td>
<td>A4032</td>
<td>0.000272</td>
<td>2.8182 x 10⁶</td>
<td>5.894 x 10⁻⁶</td>
</tr>
</tbody>
</table>
### Table 3: Results Obtained For Materials

<table>
<thead>
<tr>
<th>s.no</th>
<th>Material</th>
<th>Von-mises stresses (Mpa)</th>
<th>Ultimate yield strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Aluminum (pure)</td>
<td>9.7357x10^7</td>
<td>237</td>
</tr>
<tr>
<td>2</td>
<td>A4032</td>
<td>2.8182x10^3</td>
<td>380</td>
</tr>
<tr>
<td>3</td>
<td>A6061</td>
<td>1.9065x10^7</td>
<td>320</td>
</tr>
<tr>
<td>4</td>
<td>Al/SiC</td>
<td>9.7011x10^4</td>
<td>354</td>
</tr>
<tr>
<td>5</td>
<td>Al-GHS 1300</td>
<td>9.58x10^1</td>
<td>1300</td>
</tr>
</tbody>
</table>

### Table 4: Comparing The Von_Mises Or Equivalent Stresses With The Ultimate Yield

<table>
<thead>
<tr>
<th>s.no</th>
<th>Material</th>
<th>Von-Mises stresses (Mpa)</th>
<th>Ultimate yield strength (MPa)</th>
</tr>
</thead>
</table>

### Strength

AL-GHS has the less deformation and high total heat flux then coming to the distortion energy theory comparison it has the least VON-MISES stresses under the thermal - Structural loading condition.

### VII. CONCLUSION

It is concluded from the results that the inertia forces are less, which enables the performance of engine. The FOS of AL-GHS 1300 is higher than other materials because of the highest ultimate yield strength and used for higher distribution of pressure and temperature, so further development of power engines using this material is possible. Further research may be done to select a material with less weight and higher strength, so as to reduce inertia forces

### REFERENCES


