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

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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 conditional and the force or the 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 unbending nature. In present work the Piston is modeled using CATIA V5 modeling and Finite Element analysis (COUPLE 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. T he 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.

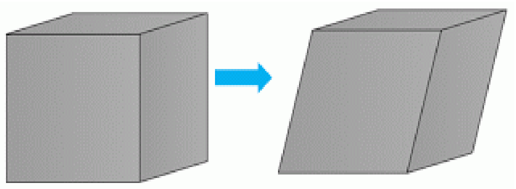
The hybrid metal matrix composite like Al-GHS-1300 and Al/SiC-MMC are the composites which have numerous extraordinary properties over Aluminum alloys and this helps to improve the wear resistant . The change of wear safety because of the upgrade of composite particles and some particles containing aluminum. 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, ud for a general 3 dimensional case is given in terms of principal stress values as:

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

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

$$u_{d,sim} = \frac{1+\nu}{3E}\sigma_y^2$$

Expression for Von Mises stress

The above 2 quantities can be connected using *distortion energy failure theory*, so the condition of failure will be as follows.

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

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

$$\left[\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}\right]^{1/2} = \sigma_v$$

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 1: materials and its properties

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

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

PARAMETERS	**VALUES**
Engine Type	Four stroke, Petrol Engine
Induction	Air cooled type
Number of cylinders	Single cylinder
Bore	51 mm
Stroke	48.8 mm
Length of connecting rod	97.6 mm

Displacement volume	99.27 cm^3
Compression ratio	8.4
Maximum power	6.03 KW at 7500 rpm
Maximum Torque	8.05 Nm at 5500 rpm
Number of revolutions/cycle	2

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 careated 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 = indicated power produced inside the cylinder (W)

η = mechanical efficiency = 0.8

n = number of working stroke per minute = N/2 (for four stroke engine)

N = engine speed (rpm) L = length of stroke (mm)

A = cross-section area of cylinder (mm^2) r = crank radius (mm)
l_c = length of connecting rod (mm)

a = acceleration of the reciprocating part (m/s^2)
m_p = mass of the piston (Kg)

V = volume of the piston (mm^3) t_h = thickness of piston head (mm) D = cylinder bore (mm)

p_{max} = maximum gas pressure or explosion pressure (MPa)

σ_t = allowable tensile strength (MPa) σ_{ut} = ultimate tensile strength (MPa) F.O.S = Factor of Safety = 2.25
K = thermal conductivity (W/m K)

T_c = temperature at the centre of the piston head (K)

T_e = temperature at the edge of the piston head (K)

HCV = Higher Calorific Value of fuel (KJ/Kg) = 47000 KJ/Kg

BP = brake power of the engine per cylinder (KW)

m = mass of fuel used per brake power per second (Kg/KW s)

C = ratio of heat absorbed by the piston to the total heat developed in the cylinder
= 5% or 0.05
b = radial width of ring (mm)

P_w = allowable radial pressure on cylinder wall (N/mm^2) = 0.025 MPa

σ_p = permissible tensile strength for ring material (N/mm^2) = 1110 N/mm^2

h = axial thickness of piston ring (mm) h_1 = width of top lands (mm)
h_2 = width of ring lands (mm)

t_1 = thickness of piston barrel at the top end (mm)

t_2 = thickness of piston barrel at the open end (mm)

ls = length of skirt (mm)

μ = coefficient of friction (0.01)

l_1 = length of piston pin in the bush of the small end of the connecting rod (mm)
d_o = outer diameter of piston pin (mm)

Mechanical efficiency of the engine (η) = 80 %.

η = Brake power (B.P) Indicating power (I.P)

Therefore, I.P = B.P = 6.2 = 7.75 KW

η 0.8

Also, I.P = P x A x L x N

2

I.P = P x πD^2 x L x N 4 2

So, P = 18.66×10^5 N/m^2
Maximum Pressure p_{max} = 10 x P= 10 x 1.866 = 18.66 MPa

V. COUPLED FILED ANALYSIS

A couple- 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 strians generally do not affect the temperature distribution. This there is no need to iterate between the teo fileds. 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 element s that can use to perofrm a coupled field analsis i.e Structural-thermal analysis summarizes them. for detailes description of the elements and their characterstics(DOF's, KEYOPT options, INPUT and OUTPUT etc) see the Element Reference.

For a Structural-thermal couple field analysis you need to slect 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.

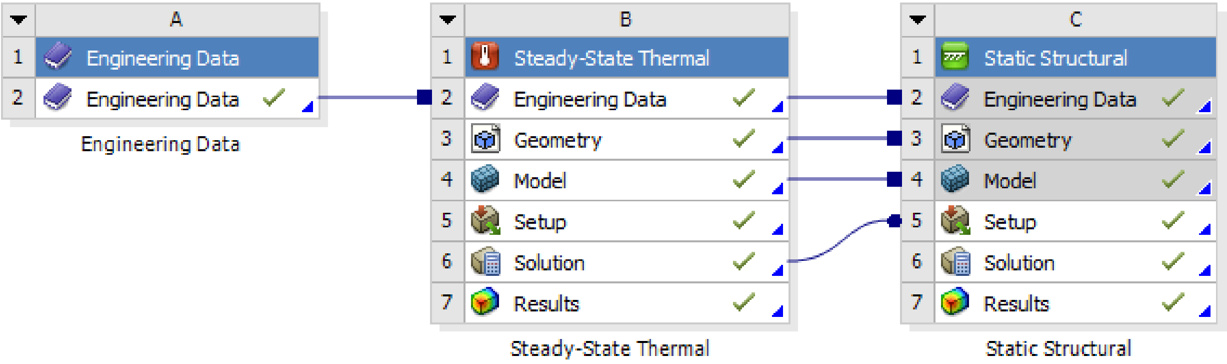


Figure 1: Coupled Field Analysis

The above lineup defines the couple 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 tthe 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.

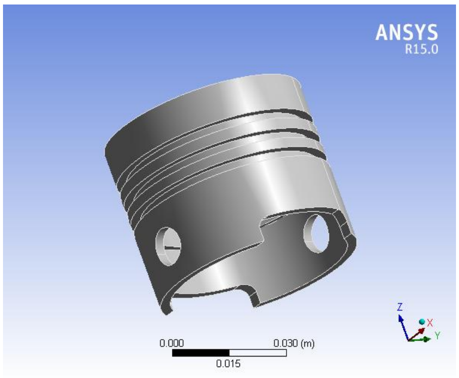


Figure 2 : PISTON 3D Model

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 element s 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.

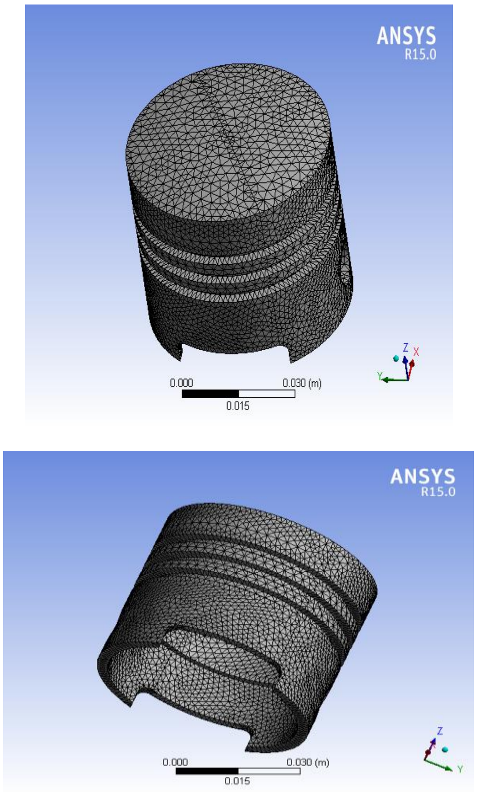
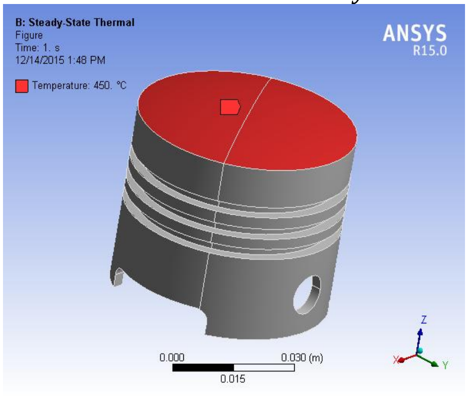


Figure 3: Piston Meshing

2) *Thermal Constraints and Analysis on Piston*



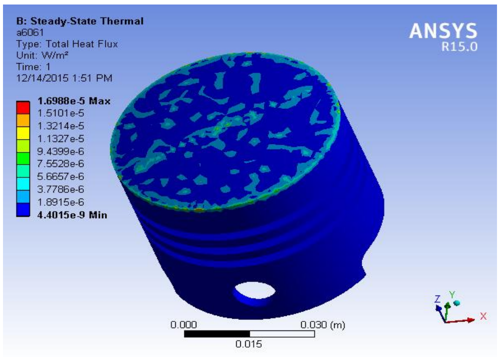


Figure 4: Total Heat Flux A6061

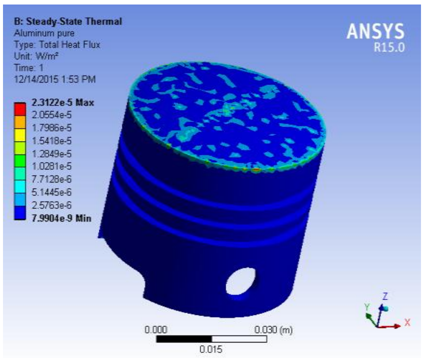


Figure 5: Total Heat Flux Aluminum Pure

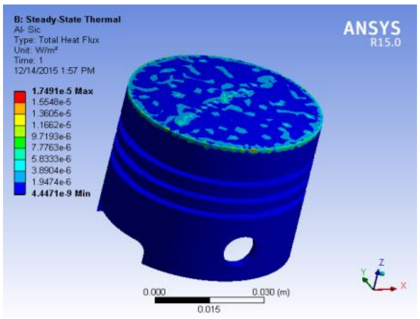


Figure 6: Total Heat Flux Al-Sic

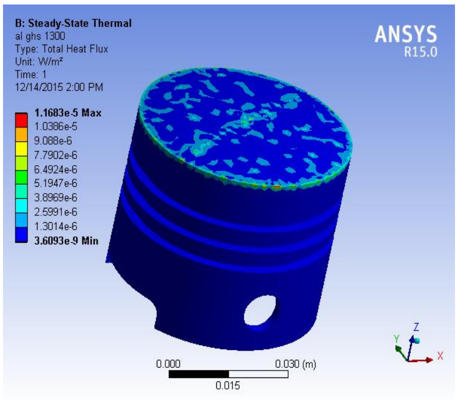


Figure 7: Total Heat Flux Al-GHS 1300

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

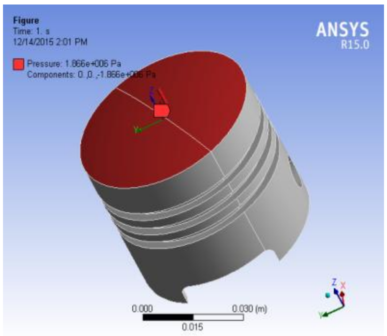


Figure 9 Pressure on Piston Crown

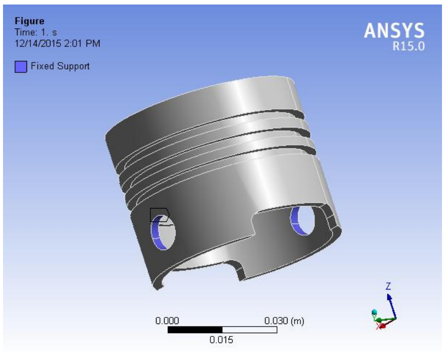


Figure 10: Fixed Supports

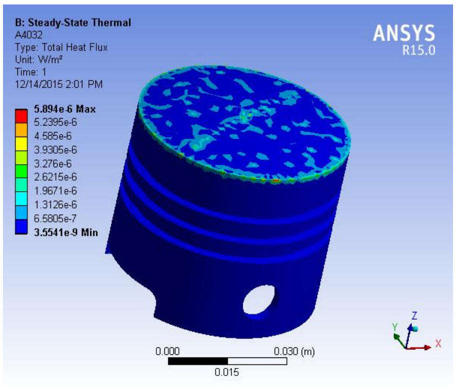


Figure 8: Total Heat Flux A4032

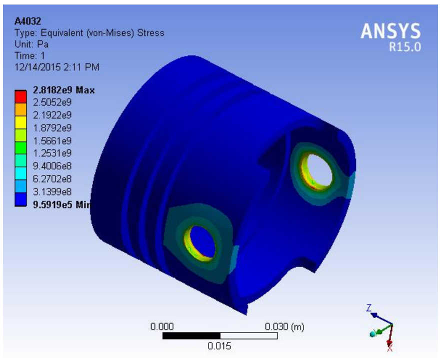


Figure 11: Von-mises Stresses of A4032

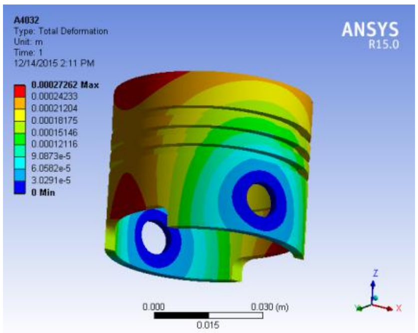


Figure 12: Total Deformation of A4032

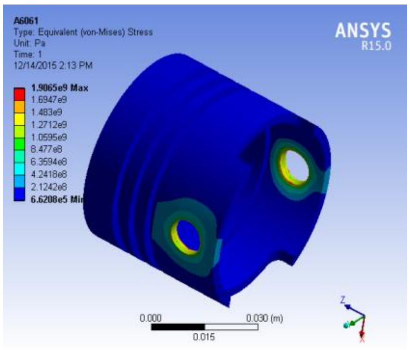


Figure 13: Von-Mises Stresses of A6061

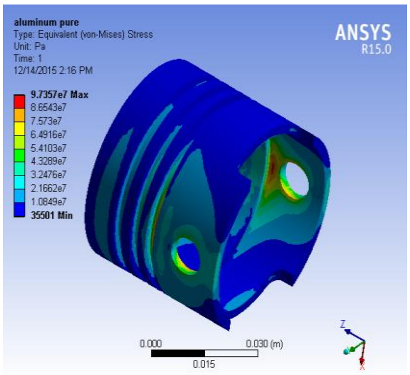


Figure 14: On-Mises Stresses of Aluminum Pure

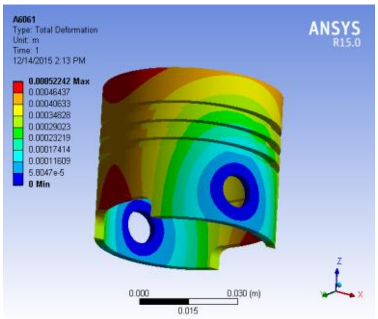


Figure 15: Total Deforamation of A6061

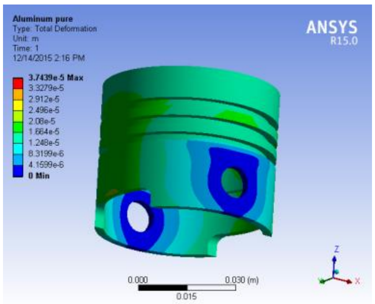


Figure 16: Total Deformation of Aluminum Pure

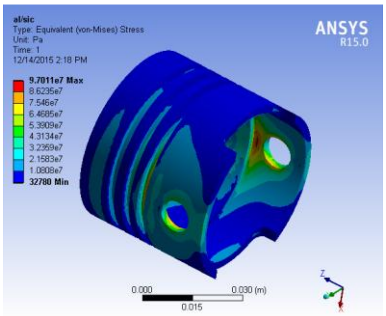


Figure 17: Von-Mises Stresses of Al-Sic

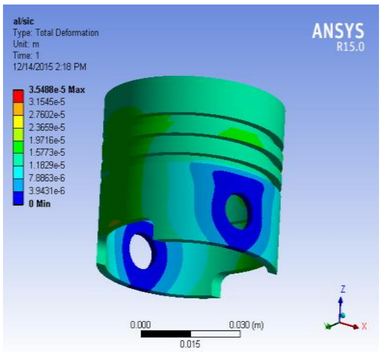


Figure 18: Total Deformation of AL-Sic

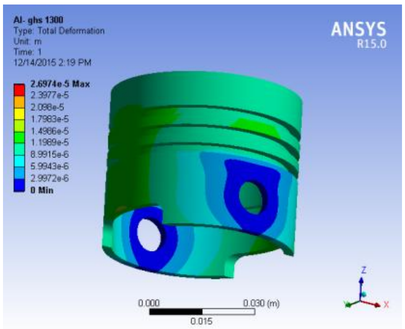


Figure 19: Von-Mises of Al-GHS 1300

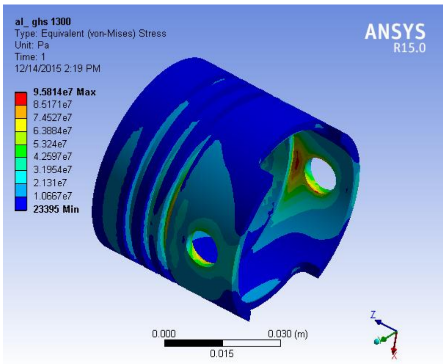


Figure 20: Von-Mises Stresses of Al-GHS 1300

VI. RESULTS & DISCUSSSION

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

S.no	Material	Total deformation (m)	Von-mises stresses (MPa)	Total heat flux(W/m^2)
1	Aluminum (pure)	3.7439 x 10^{-5}	9.7357x10^7	2.3122x 10^{-5}
2	A4032	0.000272	2.8182x 10^9	5.894x10^{-6}

3	A6061	0.00052242	1.9065x 10^9	1.6988x10^{-5}
4	Al/SiC	0.000003588	9.7011x 10^7	1.789x10^{-5}
5	Al-GHS 1300	0.00000269	9.58x 10^7	1.1683x10^{-5}

Table 3: Results Obtained For Materials

s.no	**Material**	**Von-mises stresses (Mpa)**	**Ulimate yield srength (MPa)**
1	Aluminum (pure)	9.7357x10^1	237
2	A4032	2.8182x10^3	380
3	A6061	1.9065x10^3	320
4	Al/SiC	9.7011x10^1	354
5	Al-GHS 1300	9.58x10^1	1300

Table 4: Comparing The Von_Mises Or Equivalent Stresses With The Ulimate Yield

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

[1] E. Ramjee and K. Vijaya Kumar Reddy, “Performance analysis of a 4-stroke SI engine using CNG as an alternative fuel”, Indian Journal of Science and Technology, Vol. 4, No. 7, July 2011.

[2] Wilfried Wunderlich and Morihito Hayashi, “Thermal cyclic fatigue analysis of three aluminium piston alloys”, International Journal of Material and Mechanical Engineering, June 2012.

[3] Dallwoo Kim, Akemi Ito et.al., “Friction characteristics of steel pistons for diesel engines”, Journal of Materials Research and Technology, June 2012.

[4] Piotr Szurgott and Tadeusz Niezgoda, “Thermo mechanical FE analysis of the engine piston made of composite material with low hysteresis” Journal of KONES Powertrain and Transport, Vol. 18, No. 1, 2011.

[5] V. B. Bhandari, “Design of Machine Elements”, 3rd Edition, McGraw Hill.

[6] Technical Data, Advanced Materials Technology, Bickenbach, Germany, DB- AMT@web.de.

[7] F. S. Silva, “ Fatigue on engine pistons – A Compendium of case studies”, Department of Mechanical Engineering, University of Minho, Portugal, Engineering Failure Analysis 13 (2006) 480– 492.

[8] Shigley, Mechanical Engineering Design, 9th edition, McGraw-Hill.

[9] P. S. Shenoy and A. Fatemi, “ Dynamic Analysis of Loads and Stresses in Connecting Rods”, Journal of Mechanical Engineering Science, 2006, Vol. 220, No. 5.

[10] P. S. Shenoy and A. Fatemi, “ Connecting Rod Optimization for Weight and Cost Reduction”, SAE Paper No. 2005-01-0987, SAE 2005 Transactions: Journal of Materials and Manufacturing .

[11] P. Gudimetal P. and C. V. Gopinath, “ Finite Element Analysis of Reverse Engineered Internal Combustion Engine Piston”,© King Mongkut’s University of Technology,Bangkok, Thailand, AIJSTPME, 2009.