DESIGN AND ANALYSIS OF FOUR STROKE PISTON FOR DIESEL ENGINE

THERMAL AND STATIC ANALYSIS

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Abstract: In this study, firstly, thermal analysis is investigated on a conventional piston made of Al alloy A2618. Secondly, thermal analysis is performed on piston made of Al-GHS1300, coated with Zirconium material by means of using a commercial code, namely ANSYS. The main objective is to investigate and analyse the thermal stress distribution of piston at the real engine condition during combustion process. In this work, the main emphasis is placed on the study of thermal behaviour of functionally graded coatings obtained by means of using a commercial code, ANSYS on aluminium and zirconium coated aluminium piston surfaces. The analysis is carried out to reduce the stress concentration on the upper end of the piston i.e. (piston head/crown and piston skirt and sleeve). With using computer aided design V5 Catia software the structural model of a piston will be developed. Furthermore, the finite element analysis is done using Computer Aided Simulation software ANSYS. For the analysis of piston input conditions and process of analysis, a lot of literature survey has been done. Comparative study is done to select best material.

Index Terms **- A2618, Al-GHS1300, Zirconium, Thermal analysis, Piston crown, Piston skirt, FEA, ANSYS etc.**

I. INTRODUCTION

Now-a-days the use of automobiles are increased in large amount due to huge population in our world. We are expecting the good performance of automobile cal component like piston within our budget itself. For that purpose the Research and Development and inspection engineers must enhance a varieties of critical components in shortest possible time for new product. Here, we are going to dicuss one of the critical component like piston. Piston is one of the important component in each and every reciprocating I.C engines. Piston is placed inside the cylinder block as a moving component and it is made by gas-tight by piston rings. In an I.C engine, the piston is used for transfer expanding gas force in the cylinder to the crankshaft via a piston rod and conneting rod. During compression, the piston enduces the cyclic gas pressure and the working condition may cause the failure of piston such as piston side wear, piston head or crown cranks and piston over heating-seizure and so on. Therefore, it is very essential to analyses the stress distribution, temperature distribution, heat transfer, mechanical load in order to minimize the stress at different load on piston.

A. HISTORY OF IC ENGINES

1700s - Stream Engines (External Combustion Engines)
1860s - Lenoir Engine (η = 5 %)
1867s - Otto-Langen Engine (η = 11 %, 90 RPM max,)
1876s - Otto Four Stroke Spark Ignition Engine (η = 14 %, 160 RPM max.)
1880s - Two Stroke Engine
1892s - Diesel Four Stroke Compression Ignition Engine
1957s - Wankel Rotary Engine

C. MATERIAL USED FOR PISTON

1. Aluminum alloy A2618
2. Aluminum alloy GHS-1300
3. Zirconium

D. MATERIAL PROPERTIES

Aluminium alloy A2618 & Al-GHS1300

S. No	Parameters	Aluminum alloy A2618	Al- GHS1300
1	Poisson's Ratio (μ)	0.33	0.3
2	Young's Modulus(E) GPa	70-80	98
3	Thermal Conductivity(k) W/m°C	147	120
4	Density(ρ) Kg/m³	2767.9981.25	2780
5	Permissible Bending stress(σ_t)Mpa	370	1220
6	Allowable Bending stress(σ_t)MPa	90	92
7	Ultimate Tensile Strength Mpa	440	1300

Zirconium

PROPERTIES	VALUES WITH UNIT
Atomic number	40
Atomic mass	91.22g/mol
Electro negativity	1.2
Density	6.49 g/cm^3
Melting point	1852◦C
Boiling point	4400◦C
Vander Waals radius	0.160nm
Ionic radius	0.08nm
Isotopes	11
Electronic shell	4d^2
Energy of first ionization	669kj/mol
Energy of second ionization	1346kj/mol
Energy of third ionization	2312kj/mol
Energy of fourth ionization	3256kj/mol
Discovered by	Martin klaproth in 1789

II. PISTON

Piston is one of the mechanical component, piston invented in a **German scientist Nicholas August Otto** in year 1866. Piston is considered to be one of the most important parts in a reciprocating engine, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms in which it helps to convert the chemical energy obtained by the combustion of fuel into useful (work) mechanical power. The purpose of the piston is to provide a means of conveying the expansion of gases to the crankshaft via connecting rod. The piston acts as a movable end of the combustion chamber, Piston is essentially a cylindrical plug that moves up & down in the cylinder It is equipped with piston rings to provide a good seal between the cylinder wall.

Fig.1 German Scientist Nicholas August Otto

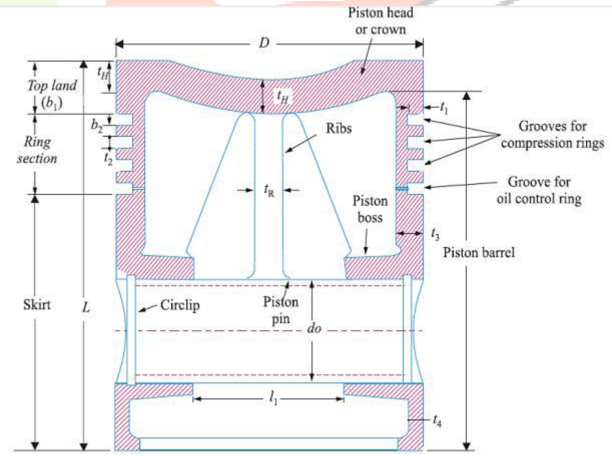

Fig. 2 Piston components for I.C. engine

Following are the main parts of piston

1) Piston Head or crown: It is flat, convex or concave depending on design of combustion chamber. It withstands pressure of gas in the cylinder.
2) Piston rings: It is used to seal the cylinder in order to prevent leakage of gas past the piston.
3) Skirt: It acts as bearing for the side thrust of connecting rod on the walls of cylinder.
4) Piston pin: It is also called gudgeon pin or wrist pin. It is used to connect the piston to the connecting rod.

III. DESIGN

A. DESIGN CALCULATION

Let,

IP = indicated power produced inside the cylinder (W)
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)
a = acceleration of the reciprocating part (m/s^2)
m_p = mass of the piston (Kg)

V = volume of the piston (mm^3)
D = cylinder bore (mm)
Pmax = 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)
Tc = temperature at the centre of the piston head (K)
Te = temperature at the edge of the piston head (K)
BP = brake power of the engine per cylinder (KW)
m = mass of fuel used per brake power per second (Kg/KWs)
b = radial width of ring (mm)
Pw = allowable radial pressure on cylinder wall (N/mm2) = 0.025 MPa
σ_p = permissible tensile strength for ring material (N/mm2) = 1110 N/mm2
h = axial thickness of piston ring (mm)
h1 = width of top lands (mm)
h2 = width of ring lands (mm)
t1 = thickness of piston barrel at the top end (mm)
t2 = thickness of piston barrel at the open end (mm)
l_s = 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)

1) THICKNESS OF PISTON HEAD (t_h)

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

$$t_h = D\sqrt{\frac{3}{16} * \frac{P}{\sigma_t}} \text{ (in mm)}$$

Where
P = 9 MN/m² = 9 N/mm²
D = 140 mm
σt = 469 N/mm²

$$= 140\sqrt{\frac{3}{16} * \frac{9}{469}}$$

$$t_h = 8.397 \text{ mm}$$

2) HEAT FLOW THROUGH THE PISTON HEAD (H)

The heat flow through the piston head is calculated using the formula

$$H = 12.56 * t_h * K * (T_c - T_e) \frac{KJ}{Sec}$$

Where,
K= 174.15W/mk
T_c = 969.75 °C
T_e = 23.366 °C

$$= 12.56 * 8.397 * 174 * 946.384$$

$$H = 17367224.97 \frac{KJ}{Sec}$$

3) RADIAL THICKNESS OF RING (t_1)

$$t_1 = D\sqrt{\frac{3 * P_W}{\sigma_t}} \text{ (in mm)}$$

Where,
D = 140 mm
P_W = 0.03 N/mm²
σt= 90 MN/m² = 90 N/mm²

$$= 140\sqrt{\frac{3 * 0.03}{90}}$$

$$t_1 = 4 \text{ mm}$$

4) AXIAL THICKNESS OF RING (t_2)

The thickness of the rings may be taken as

$$t_2 = 0.7t_1 \text{ to } t_1$$

Let assume t_2 = 4 mm
Minimum axial thickness (t_2)

$$t_2 = \frac{D}{10 * n_r}$$

Where nr = number of rings = 3

$$= \frac{140}{10 * 3}$$

$$t_2 = 4 \text{ mm}$$

5) WIDTH OF THE TOP LAND (b_1)

The width of the top land varies from

$$b_1 = t_h \text{ to } 1.2 * t_h$$
$$= 1.2 * t_h$$
$$= 1.2 * 8.397$$
$$b_1 = 10 \text{ mm}$$

6) WIDTH OF OTHER LANDS (b_2)

Width of other ring lands varies from

$$b_2 = 0.75 * t_2 \text{ to } t_2$$
$$= 0.75 * t_2$$
$$= 0.75 * 4$$
$$b_2 = 3$$

7) MAXIMUM THICKNESS OF BARREL (t_3)

$$t_3 = 0.03 * D + b + 4.5 \text{ mm}$$

Where,

b = Radial depth of piston ring groove

$$b = t_1 + 0.4$$
$$b = 4 + 0.4$$
$$b = 4.4 \text{ mm}$$
$$t_3 = 0.03 * 140 + 4.4 + 4.5 \text{ mm}$$
$$t_3 = 13 \text{ mm}$$

From the above expressions the below tabulated parameters are calculated

S.NO	DIMENSIONS	SIZE in mm
1	Length of the Piston (L)	152
2	Cylinder bore/outside diameter of the piston (D)	140
3	Radial thickness of the ring (t_1)	4
4	Axial thickness of the ring (t_2)	4
5	Maximum thickness of barrel (t_3)	13
6	Width of the top land (b_1)	10
7	Width of other ring lands (b_2)	3

IV.SOLID TYPE PISTON:

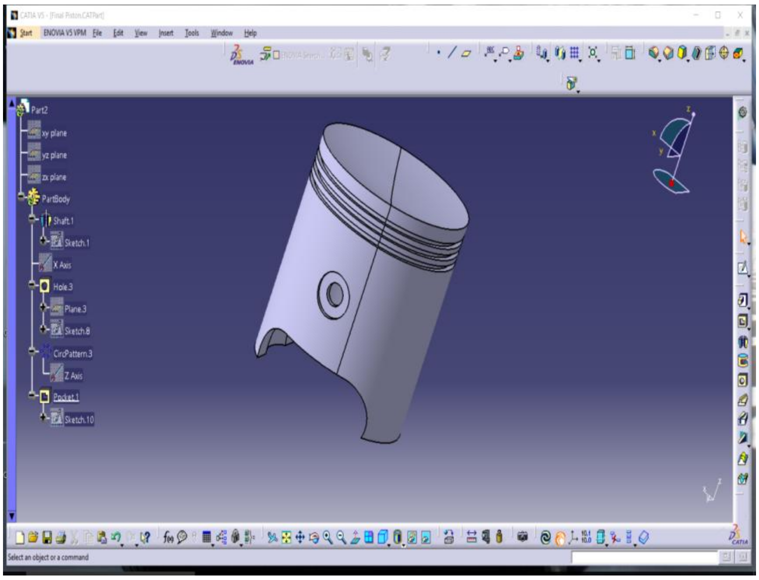

Fig.3 Catia Design without Zirconium Coating

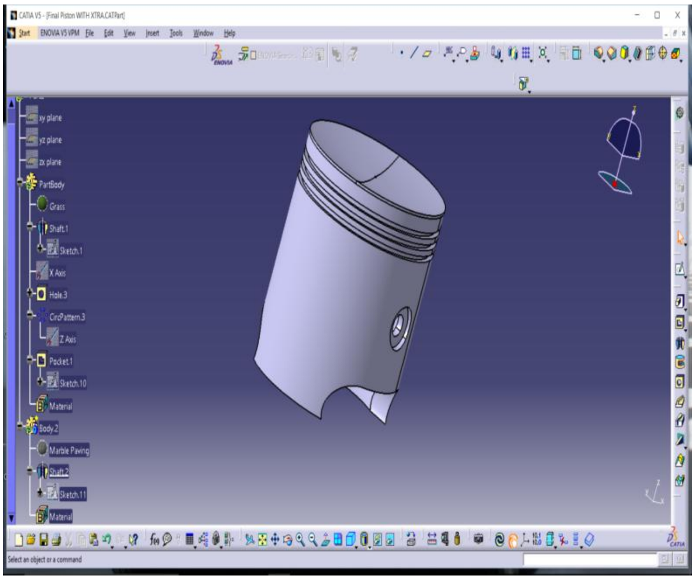

Fig.4 Piston Design With Zirconium Coating

V. ANALYSIS RESULT OF PISTON

A. THERMAL ANALYSIS IN PISTON

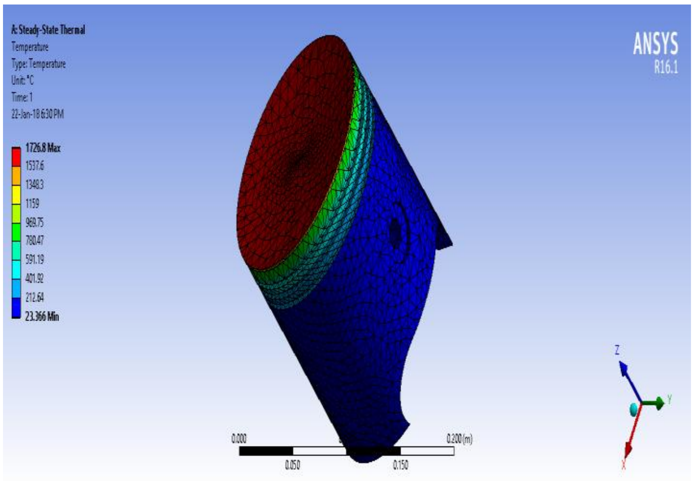

Fig.5 Temperature Al-GHS1300 and Zirconium

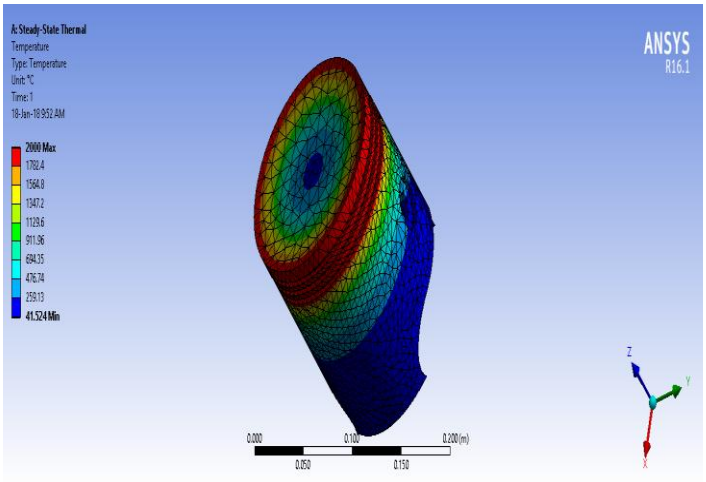

Fig.6 Temperature Al A2618

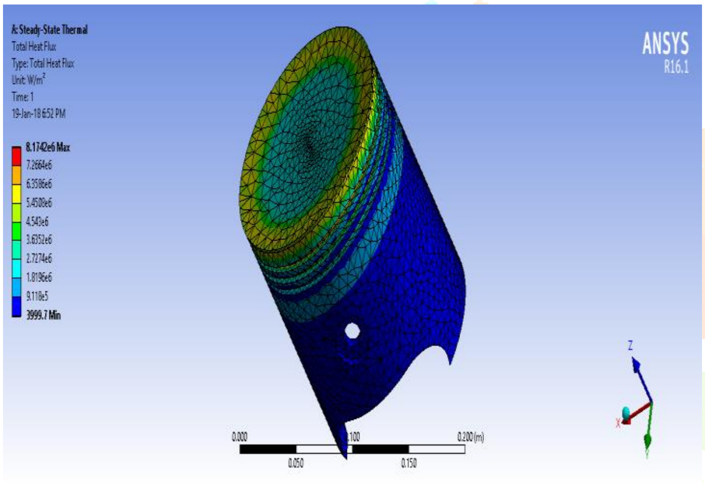

Fig.7 Total Heat Flux Al-GHS1300 and Zirconium

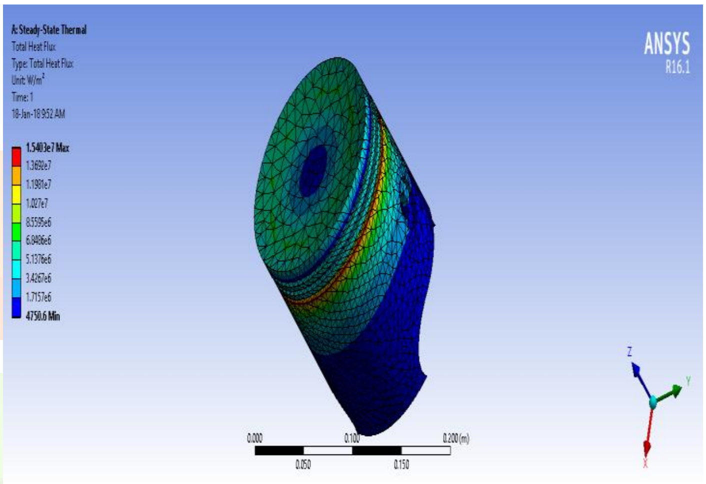

Fig.8 Total Heat Flux AL A2618

B. STATIC ANALYSIS IN PISTON:

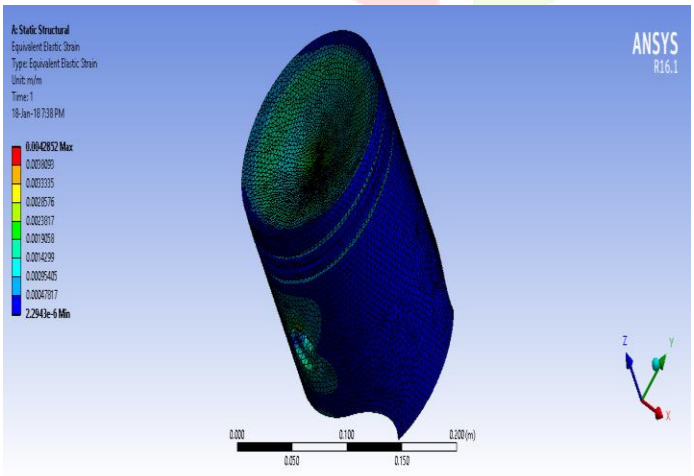

Fig.9 Equivalent Elastic Strain Al-GHS1300 and Zirconium

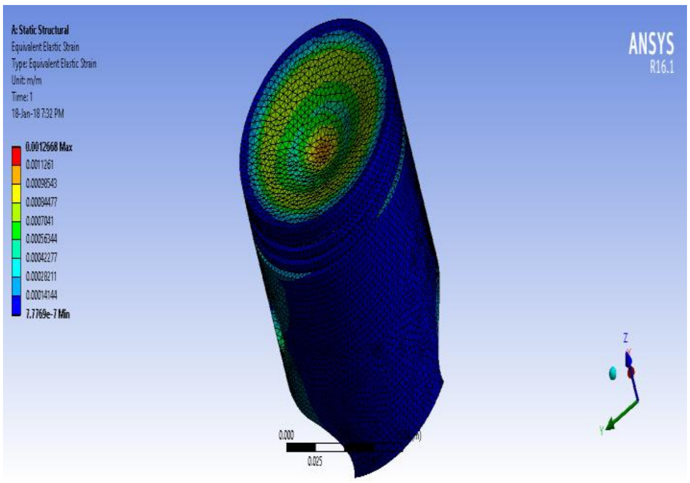

Fig.10 Equivalent Elastic Strain Al A2618

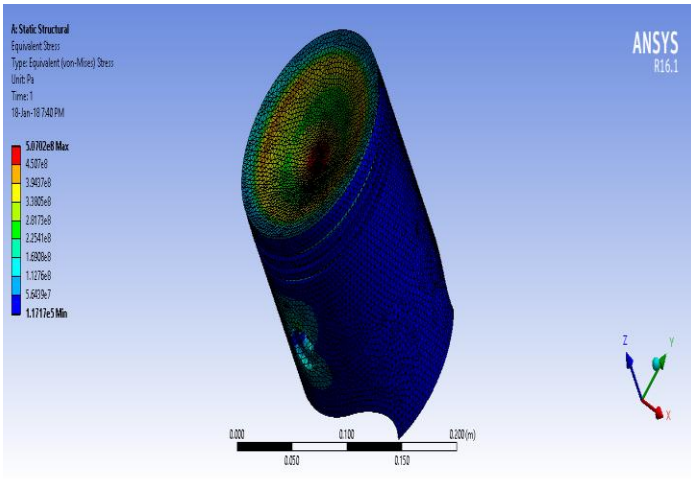

Fig.11 Equivalent Stress Al-GHS1300 and Zirconium

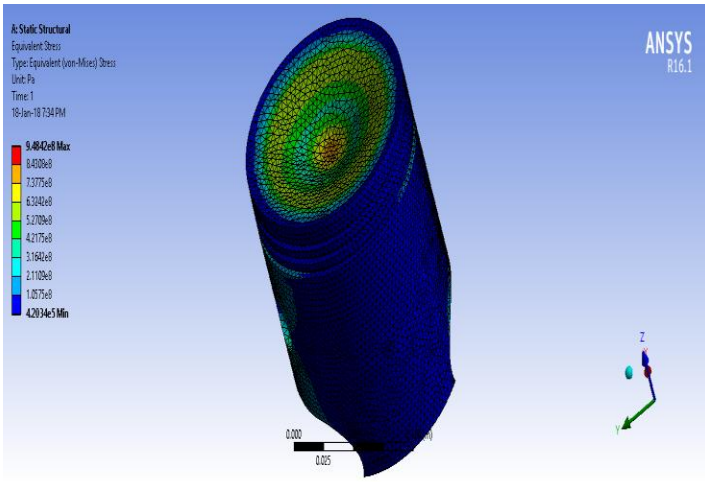

Fig.12 Equivalent Stress Al A2618

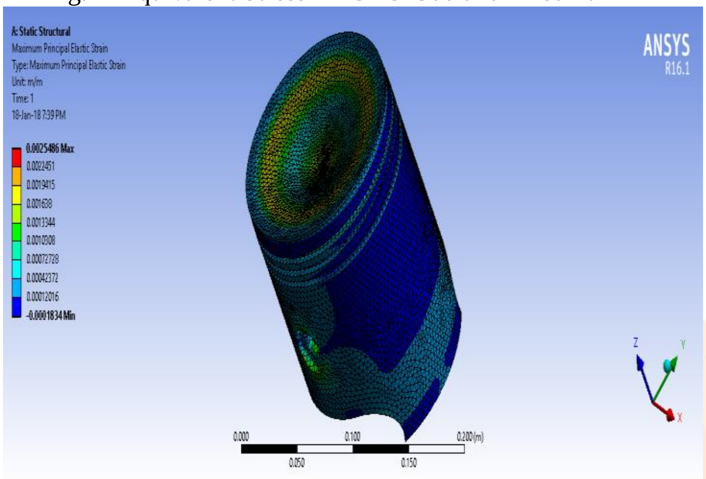

Fig.13 Maximum Principal Elastic Stress Al-GHS1300 and Zirconium

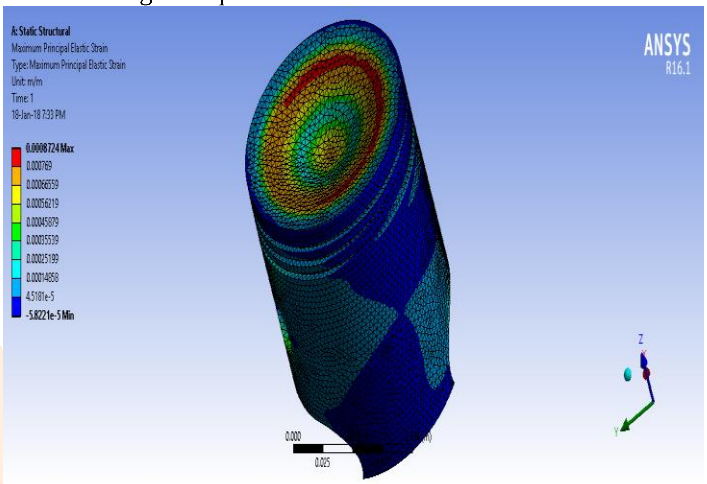

Fig.14 Maximum Principal Elastic Stressal A2618

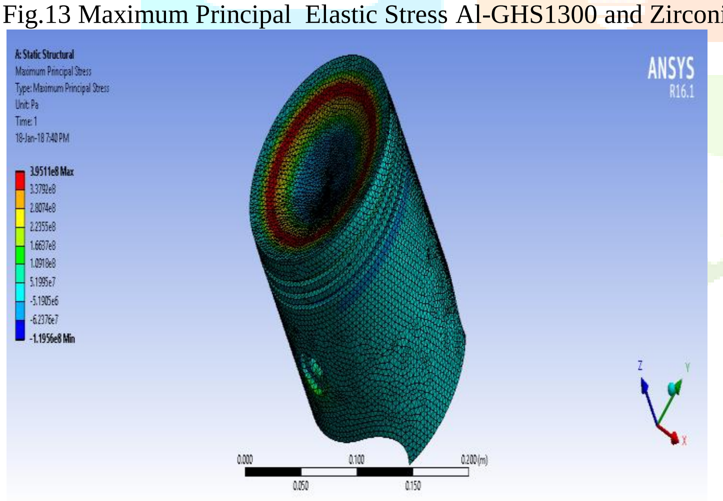

Fig.15 Maximum Principal Stress Al-GHS1300 and Zirconium

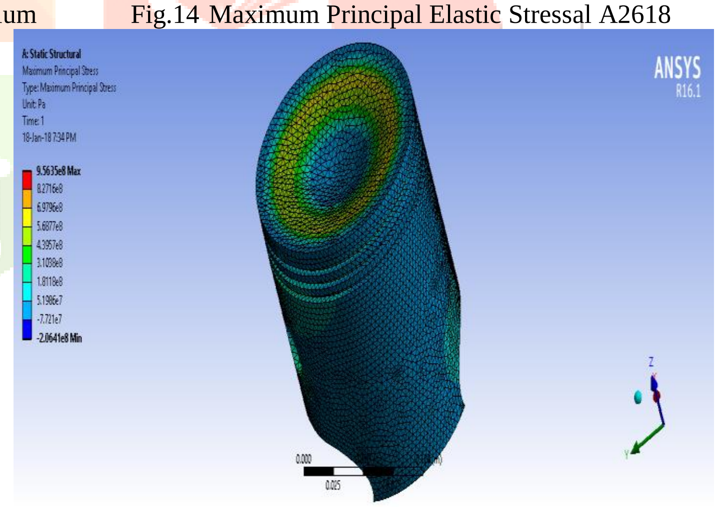

Fig.16 Maximum Principal Stress Al A2618

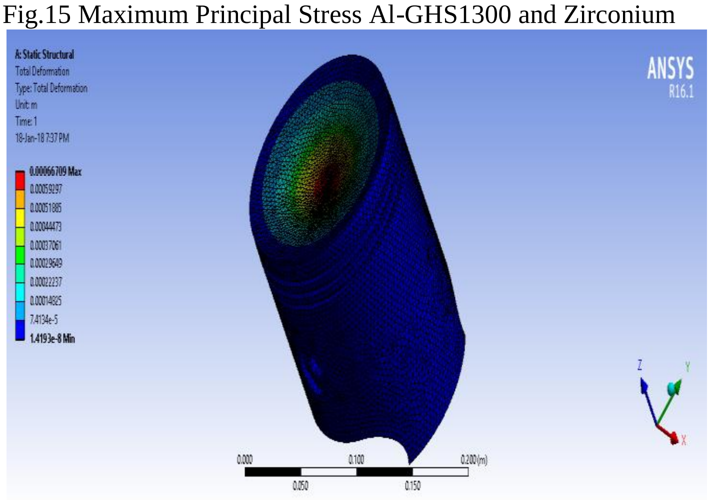

Fig.17 Deformational Al-GHS1300 and Zirconium

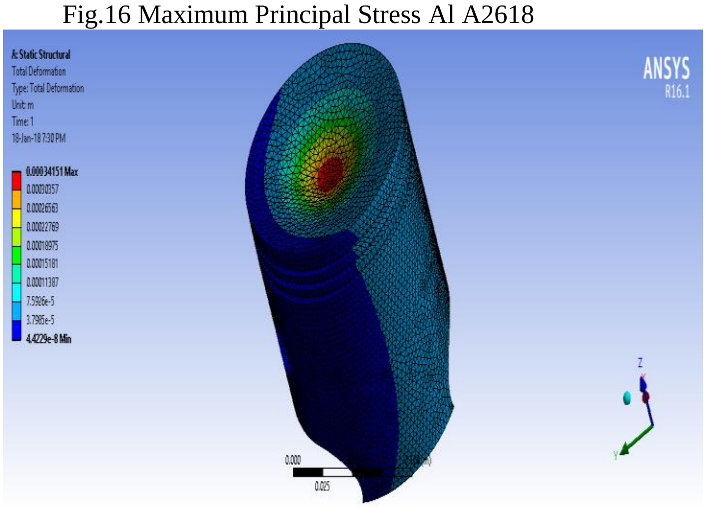

Fig.18 Deformation Al A2618

VI. SIMULATED COMPARATIVE PERFORMANCES OF THREE ALLOYS

A) THERMAL ANALYSIS

S.NO	PARAMETERS	CONVENTIONAL AL ALLOY A2618 MAX MIN	ZIRCONIUM &AL-GHY1250 MAX MIN
1	TEMPERATURE	2000 41.524	1726.8 24.371
2	TOTAL HEAT FLUX	8.1742e6 3999.7	1.5403e7 4750.6

B) STATIC ANALYSIS

S.NO	PARAMETERS	CONVENTIONAL AL ALLOY A2618 MAX MIN	ZIRCONIUM &AL-GHY1250 MAX MIN
1	EQUIVALENT ELASTIC STRAIN	0.0042852 2.2943E-6	0.0012668 7.7769E-7
2	EQUIVALENT (VON-MISES) STRESS	5.0702E8 1.1717E5	9.4842E8 4.2034E5
3	MAXIMUM PRINCIPAL ELASTIC STRAIN	-4.223E-7 -0.0041101	-1.6433E-7 -0.00092604
4	MINIMUM PRINCIPAL STRESS	3.0783E7 -5.3262E8	7.2253E7 -8.3613E8
5	TOTAL DEFORMATION	0.00066709 1.4193E-8	0.00034151 4.4229E-8

VII. CONCLUSION

It is concluded from the above study the piston is designed using Catia software and analyzing the piston using the ANSYS software, only few steps are needed to make drawing in three dimensions. The piston model is imported to ANSYS for analysis. Piston made of two different materials Al alloy A2618 & Al Alloy GHS1300 and Zirconium are analyzed. Their Thermal and Static analysis shows that the maximum stress intensity is obtained in Al alloy A2618, when compared to Al Alloy GHS1300 and Zirconium alloy piston. Maximum temperature is found at the centre of the top surface of the piston crown in Al alloy A2618. Depending on the thermal conductivity of the materials, heat transfer rate is found maximum in Al alloy piston. For the given loading conditions, Al Alloy GHS1300 and Zirconium alloy piston is found most suitable. But when the loading pattern changes, other materials may be considered. With the advancement in material science, very light weight materials with good thermal and mechanical properties can be used for fail safe design of the I.C Engine. This will reduce the fuel consumption and protect the environment. Finally, we concluded that Al Alloy GHS1300 and Zirconium alloy material is best one when compared to Al alloy A2618.

VIII. REFERENCES

- A.AtishGawale, A. Shaikh and VinayPatil, “Nonlinear Static Finite Element Analysis and Optimization of connecting rod World
- Journal of Science and Technology, Vol. 2(4), pp .01-04, 2012.
- R. Bhagat, Y. M. Jibhakate, Thermal Analysis and Optimization of I.C. Engine Piston Using Finite Element Method, International
- Journal of Modern Engineering Research (IJMER), Vol.2, Issue.4, pp.2919-2921, 2012.
- Kamo R., Assanis D.N., Bryzik W.: Thin thermal barrier coatings for engines. SAE Transactions 1989, No 980143.
- EkremBuyukkaya, “Thermal Analysis of functionally graded coating AlSi alloy and steel pistons”, Surface and coatings technology (2007)
- P. Carvalheira1, and P. Gonçalves, FEA of Two Engine Pistons Made of Aluminium Cast Alloy A390 and Ductile Iron 65-45-12 Under
- Service Conditions, 5th International Conference on Mechanics and Materials in Design Porto-Portugal, 24- 26, pp .1-21, 2006.
- C.H. Li, Piston thermal deformation and friction considerations, SAE Paper, vol. 820086, 1982.
- Properties And Selection: Irons, steels and high performance alloy, ASM Handbook, vol. 1, ASM International, 1990.
- A.C. Alkidas, Performance and emissions achievements with an uncooled heavy duty, single cylinder diesel engine, SAE, vol. 890141,
- 1989.
- A.C. Alkidas, Experiments with an uncooled single cylinder open chamber diesel, SAE Paper, vol. 870020, 1987.