



STRESS ANALYSIS OF PISTON USING PRESSURE LOAD AND THERMAL LOAD

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ABSTRACT

The main objective of this research work is to investigate and analyze the stress distribution of piston at actual engine condition. In this paper pressure analysis, thermal analysis and thermo-mechanical analysis is done. The parameter used for the analysis is operating gas pressure, temperature and material properties of piston. In I.C. Engine piston is most complex and important part therefore for smooth running of vehicle piston should be in proper working condition. Piston fail mainly due to mechanical stresses and thermal stresses. Analysis of piston is done with boundary conditions, which includes pressure on piston head during working condition and uneven temperature distribution from piston head to skirt. The analysis predicts that due to temperature whether the top surface of the piston may be damaged or broken during the operating conditions, because damaged or broken parts are so expensive to replace and generally are not easily available. The CAD model is created using PRO-E software. CAD model is then imported into ANSYS software for geometry and meshing purpose. The FEA performed by using ANSYS12.

Keywords: Piston, PRO-E, ANSYS12.

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. 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 cracks and so on. So there is a need to optimize the design of piston by considering various parameters in this project the parameters selected are analysis of piston by applying pressure force acting at the top of the piston and thermal analysis of piston at various temperature in various stroke. This analysis could be useful for design engineer for modification of piston at the time of design. In this project we determine the various stress calculation by using pressure analysis, thermal analysis and thermo-mechanical analysis form that we can find out the various zones or region where chances of damage of piston are possible. From analysis it is very easy to optimize the design of piston. The main requirement of piston design is to measure the prediction of temperature distribution on the surface of piston which enables us to optimize the thermal aspects for design of piston at lower cost. Most of the pistons are made of an aluminum alloy which has thermal expansion coefficient, 80% higher than the cylinder bore material made of cast iron. This leads to some differences between running and the design clearances. Therefore, analysis of the piston thermal behavior is extremely crucial in designing more efficient compressor. Good sealing of the piston with the cylinder is the basic criteria to design of the piston. Also to improve the mechanical efficiency and reduce the inertia force in high speed machines the weight of the piston also plays major role. To allow for thermal expansion, the diameter of the piston must be smaller than that of the cylinder. The necessary clearance is calculated by estimating the temperature difference between piston and cylinder and considering the coefficient of thermal expansion of piston.

2.MATERIAL FOR PISTONS

The most commonly used materials for pistons of I.C. engines are cast iron, aluminum alloy (cast aluminum, forged aluminum), cast steel and forged steel.

- a) For a cast iron piston, the temperature at the centre of the piston head (TC) is about 425°C to 450°C under full load conditions and the temperature at the edges of the piston head (TE) is about 200°C to 225°C.
- b) For aluminum alloy pistons, TC is about 260°C to 290°C and TE is about 185°C to 215°C.



3. ANALYTICAL CALCULATION FOR PISTON

Analytical calculations are done for cast iron piston. For doing analytical calculation material properties and dimensional information should be known and so all the parameters consider for design of piston are calculated by using one analytical problem.

Design Considerations for a Piston

In designing a piston for an engine, the following points should be taken into consideration:

- It should have enormous strength to withstand the high pressure.
- It should have minimum weight to withstand the inertia forces.
- It should form effective oil sealing in the cylinder.
- It should provide sufficient bearing area to prevent undue wear.
- It should have high speed reciprocation without noise.
- It should be of sufficient rigid construction to withstand thermal and mechanical distortions.
- It should have sufficient support for the piston pin.

Procedure for Piston Design

The procedure for piston designs consists of the following steps:

- Thickness of piston head (t_H)
- Heat flows through the piston head (H)
- Radial thickness of the ring (t₁)
- Axial thickness of the ring (t₂)
- Width of the top land (b₁)
- Width of other ring lands (b₂)

The above steps are explained as below:

(i). Thickness of Piston Head (t_H):

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

$$t_H = 0.433 \cdot D \cdot \text{square root of } (P_{max}/f_t)$$

Where,

P= maximum pressure in N/mm²

D= cylinder bore/outside diameter of the piston in mm.

f_t = permissible tensile stress for the material of the piston.

For CI f_t may be taken as 37.5N/mm²

Here the material is a particular grade of AL-Si alloy whose permissible stress is 50 Mpa- 90Mpa before calculating thickness of piston head, the diameter of the piston has to be specified. The piston size that has been considered here has an L*D specified as 152*140.

(ii). Heat Flow through the Piston Head (H):

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

$$H = 12.56 \cdot t_H \cdot K \cdot (T_c - T_e) \text{ KJ/Sec}$$

Where,

K=thermal conductivity of material which is W/m⁰k

T_c = temperature at centre of piston head in °C.

T_e = temperature at edges of piston head in °C.

(iii). Radial Thickness of Ring (t₁)

$$t_1 = D \cdot \text{squ.root of } (3p_w/f_t) \quad ()$$

Where,

D = cylinder bore in mm

P_w= pressure of fuel on cylinder wall in N/mm². Its value is limited from 0.0245N/mm² to 0.042N/mm². For present material, σ_t is 90Mpa

(iv). Axial Thickness of Ring (t₂)

The thickness of the rings may be taken as

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

Minimum axial thickness (t₂)

$$t_2 = D/10 \cdot z$$

Where z = number of rings

(v). Width of the top land (b₁)

The width of the top land varies from

$$b_1 = t_H \text{ to } 1.2 \cdot t_H$$



(vi). Width of other lands (b2)

Width of other ring lands varies from

$$b2 = 0.75 * t2 \text{ to } t2$$

(vii). Maximum Thickness of Barrel (t3)

$$t3 = 0.03 * D + b + 4.5\text{mm}$$

Where,

b = Radial depth of piston ring groove

$$b = t1 + 0.4$$

STRESS CALCULATION

1. Stress on Piston Crown

$$6b = \frac{3pD^2}{16 tH^2}$$

2. Thermal Stress,

$$6t = E * \text{Coefficient of thermal Expansion} * \text{Temp. Difference}$$

3. Thermo-mechanical Stress,

$$6tm = 6b + 6t$$

4. Design specification for piston:

S No	Design1 - Dimensions	Size in mm
1	Length of the Piston(L)	130
2	Cylinder bore/outside diameter of the piston(D)	100
3	Radial thickness of the ring (t1)	3.5
4	Axial thickness of the ring (t2)	3.0
5	Maximum thickness of barrel (t3)	11.4
6	Width of the top land (b1)	18
7	Width of other ring lands (b2)	2.5

Allowable stress for Cast Iron (from design data book) = 82.0 to 100 N/mm²

5. Material Properties of Piston material

Parameters	Unit	Cast Iron
Modulus of Elasticity	MPa	100×10 ³
Poisson's Ratio	--	0.27
Tensile Yield Strength	MPa	--
Tensile Ultimate Strength	MPa	140
Density	Kg/m ³	7200
Coefficient of Thermal Expansion	/ ⁰ C	0.1×10 ⁻⁶
Heat Conductivity	W/ m ⁰ C	46.6
Shear Modulus	MPa	45×10 ³

6. Designing of Piston

The piston is designed by giving the dimensions into the modeling software PRO-E. The geometry of the piston is designed in PRO-E is imported to the analysis software in the IGES format. The figure of the designed piston is below-

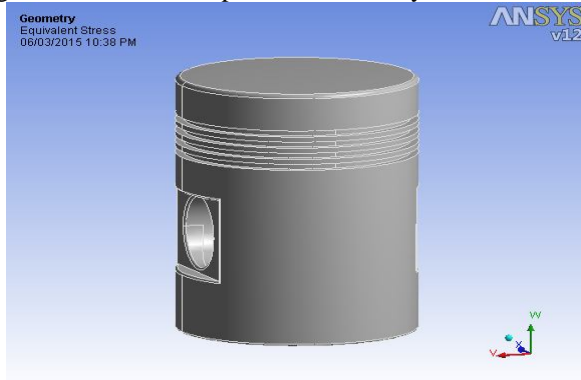


Fig.6.1 Design of Piston

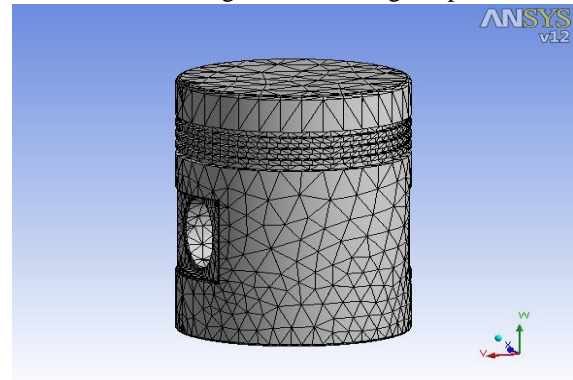


Fig.6.2 Meshed Model of Piston

7. Analysis of Piston

The piston is analyzed by giving the constraints they are

1. Pressure or structural analysis
2. Boundary condition
3. Thermal analysis
4. Thermo-mechanical analysis

7.1 Structural Analysis of Piston

Combustion of gases in the combustion chamber exerts pressure on the head of the piston during power stroke. The pressure force will be taken as boundary condition in structural analysis using ANSYS12 Workbench. Fixed support has given at surface of pin hole. Because the piston will move from TDC to BDC with the help of fixed support at pin hole. So whatever the load is applying on piston due to gas explosion that force causes to failure of piston pin (inducing bending stresses). Pressure acting on piston = 5 N/mm^2 as shown in Fig.7.1.1

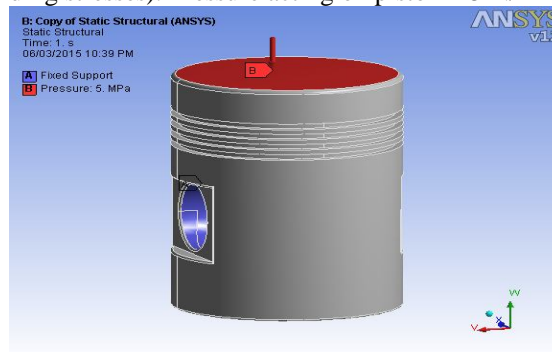


Fig.7.1.1 Applied pressure with fixed support

Results of Structural (Pressure) Analysis of Piston

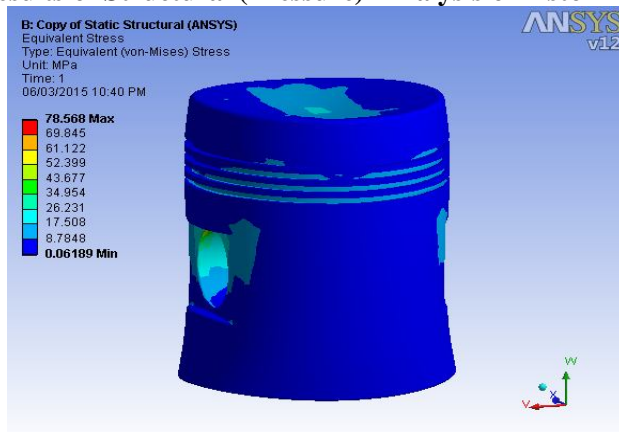


Fig.7.1.2 Equivalent (Von-mises) Stress

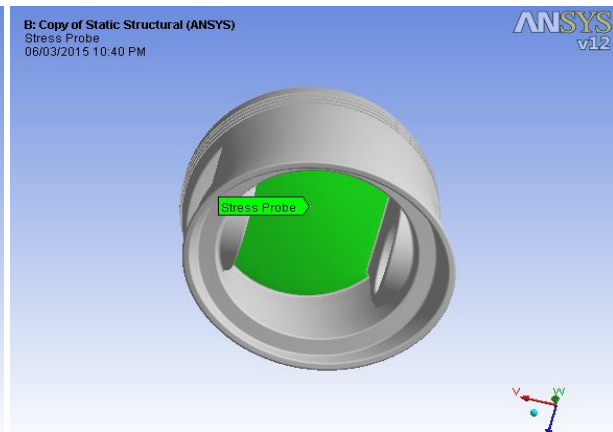


Fig. 7.1.3 Stress probe 1

Maximum Equivalent Stress -78.56 MPa

Bending Stress – 38.25 MPa

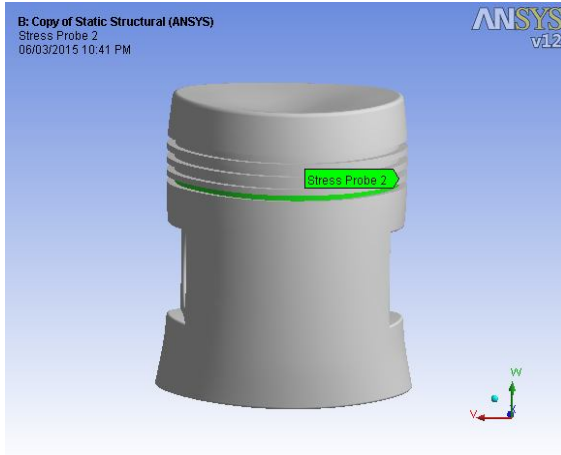


Fig.7.1.4 Stress Probe 2
Compressive Stress – 17.678 MPa

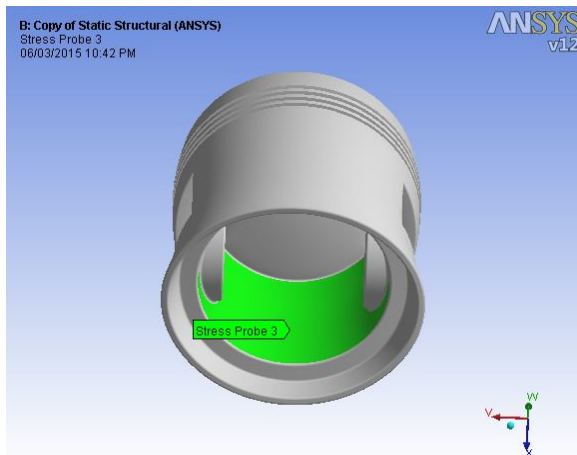


Fig.7.1.5 Stress Probe 3
Tensile Stress – 36.98 MPa

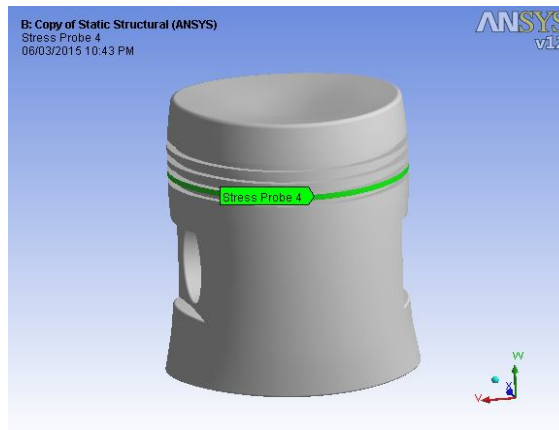


Fig.7.1.6 Stress Probe 4
Shear Stress – 3.45 MPa

7.2 Thermal analysis

As the material used for designing of piston is Cast Iron. For a cast iron piston, the temperature at the centre of the piston head (T_C) is about 425°C to 450°C under full load conditions and the temperature at the edges of the piston head (T_E) is about 200°C to 225°C.

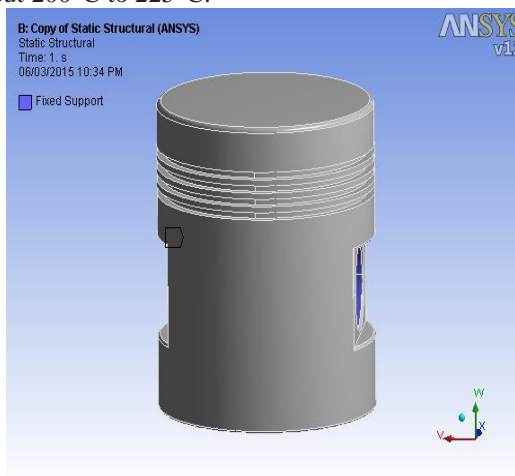


Fig.7.2.1 Fixed Support

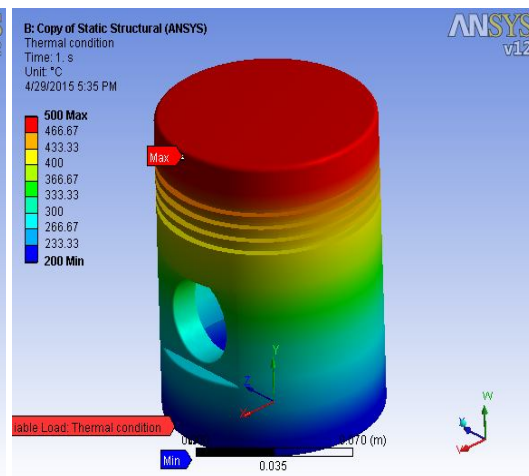


Fig.7.2.2 Thermal Condition

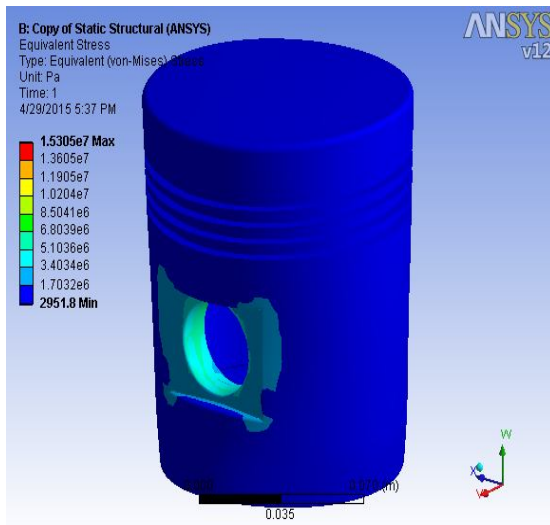


Fig.7.2.3 Equivalent Stress

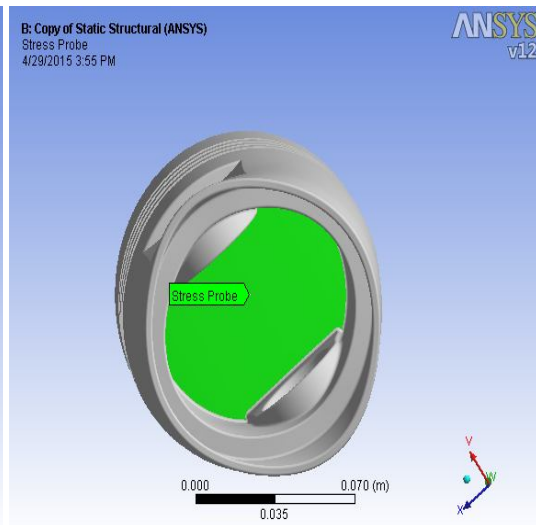


Fig.7.2.4 Bending Stress = 1.72 MPa

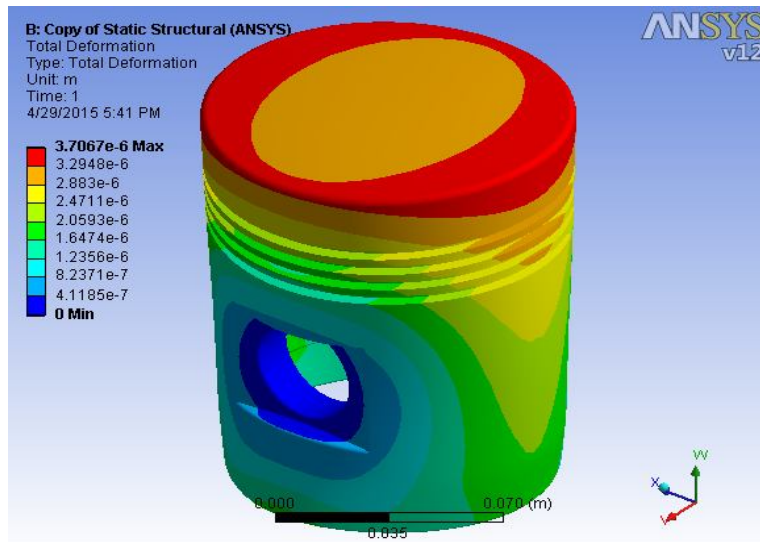


Fig.7.2.5 Total Deformation

7.3 Thermo-mechanical Analysis

In this analysis we apply both pressure and temperature on piston.

Pressure- 5 N/mm²

Temperature – (200⁰C-500⁰C)

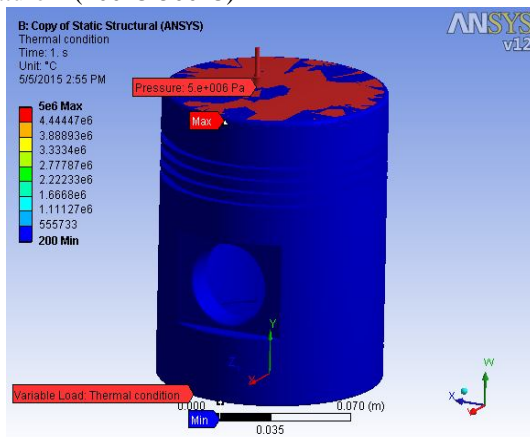


Fig. 7.3.1 Thermo-mechanical condition

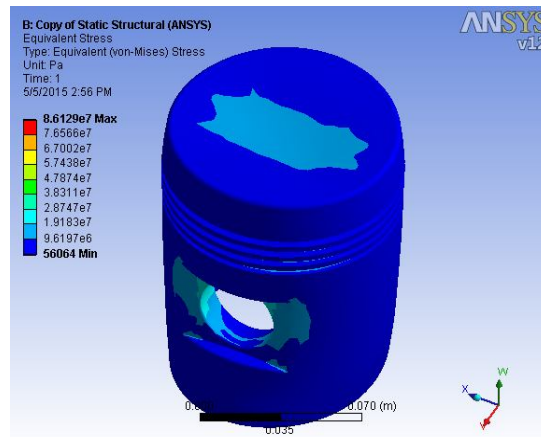


Fig.7.3.2 Equivalent Stress

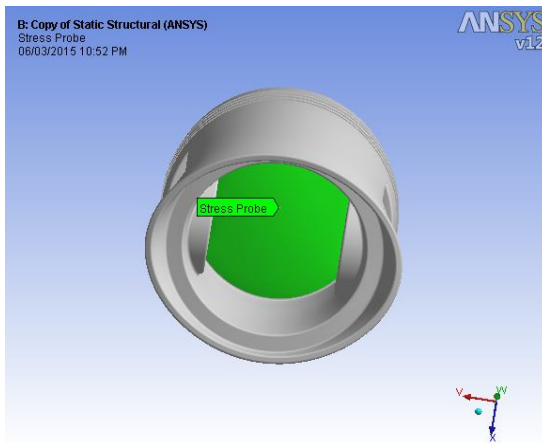


Fig.7.3.3 Bending Stress=39.45Mpa

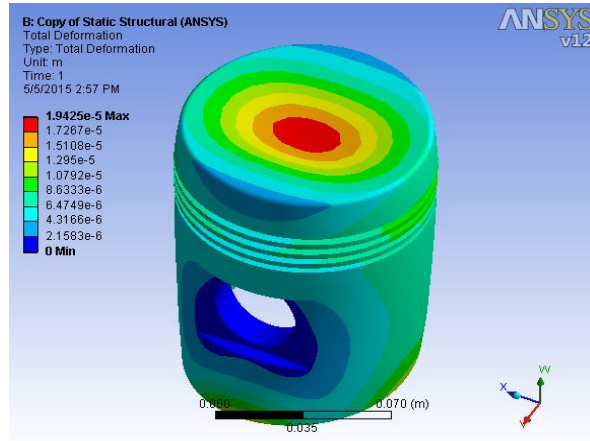


Fig.7.3.4 Total Deformation

8.COMPARISON OF RESULT

Material – Cast Iron

Pressure – 5 MPa

Temperature – 280⁰C-500⁰C

Comparison of Analytical and FE Analysis results for piston

Analysis	Analytically Calculated Stress(MPa)	Stress by Fem Analysis (MPa)	%Error
Pressure	36.62	38.24	4.23
Thermal	2.4	1.72	28.33
Thermo-mechanical	39.18	39.45	0.68

9.CONCLUSION

It is concluded from the above study that using PRO-E software design and modeling become easier. Here material used for Piston is Cast Iron because Cast Iron sustain more temperature than other material. The temperature distribution of piston is very important to check the effect of temperature is maximum on which part of piston. After the analysis of temperature distribution the result comes out that the maximum temperature is on the piston head and the minimum temperature is on the piston skirt.

The equivalent stress values obtained are well below the permissible value of 86MPa-100MPa.

From the above result of comparison we conclude that analytical and FE analysis results for mechanical, thermal & thermo-mechanical loading are approximately similar . The percentile difference between analytical results & analysis results of piston are very small. Hence the design of piston is safe.

REFERENCES

- [1] RS Khurmi and JK Gupta “Machine Design” Eurasia publishing house (pvt.) ltd. Ram Nagar, New Delhi - 110055, <http://www.simpopdf.com>, 2005
- [2] S.S. Feng et al., An experimental and numerical study of finned metal foam heat sinks under impinging air jet cooling, International Journal of Heat and Mass Transfer 77 (2014) 1063–1074.
- [3] M.M. Haque et al., “Effect of superheating temperatures on microstructure and properties of strontium modified aluminium–silicon eutectic alloy” Journal of Materials Processing Technology 162–163 (2005) 312–316



- [4] Ajay Raj Singh et al., Dr. Pushpendra Kumar Sharma, “Design, Analysis and Optimization of Three Aluminum Piston Alloys Using FEA” *Int. Journal of Engineering Research and Applications*, ISSN : 2248-9622, Vol. 4, Issue 1 Version 3, January 2014, pp.94-102.
- [5] M.X. Calbureanu et al., “The finite element analysis of the thermal stress distribution of a piston head” *International Journal OF Mechanics*, Issue 4, Volume 7, 2013, pp- 467-474.
- [6] S. Srikanth Reddy et al., Thermal Analysis and Optimization of I.C. Engine Piston Using Finite Element Method, *International Journal of Innovative Research in Science, Engineering and Technology*, Vol. 2, Issue 12, December 2013, pp 7834-7843.
- [7] A. R. Bhagat et al., Thermal Analysis And Optimization Of I.C. Engine Piston Using finite Element Method, *International Journal of Modern Engineering Research (IJMER)* www.ijmer.com Vol.2, Issue.4, July-Aug 2012 pp- 2919-2921.
- [8] Vinay V. Kuppast et al., “Thermal Analysis of Piston for the Influence on Secondary motion”, *International Journal of Engineering Research and Applications (IJERA)* ISSN: 2248-9622, Vol. 3, Issue 3, May-Jun 2013, pp.1402-1407
- [9] Bhaumik Patel, Ashwin Bhabhor (2012) “thermal analysis of a piston of reciprocating air compressor” *IJAERS*, ISSN: 2249–8974, PP. 73-75..