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Optimization of Piston Insulation Thickness for Thermal and Static Loading Conditions

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Abstract

In this paper thermal and static loading conditions were analysed for uncoated and coated with insulation on IC Engine piston, which is made of aluminium alloy. The insulation material used was Zirconium. The analysis was carried out by means of a commercial code, ANSYS workbench. The effects of coating on the thermal behaviour of the piston were investigated and thermal, static stresses are plotted. The thickness of Zirconium insulation was varied from 0.2mm, 0.3mm and 0.4mm and compared the theoretical and computational values of mechanical and thermal stresses. The error observed during analysis was 2.06% for mechanical stresses and 8.9% for thermal stresses. The minimum temperature and stresses were found at insulation thickness of 0.4mm.

Keywords: *Ansys, Ceramic coating, IC engine piston, Thermal stress, Mechanical stress*

INTRODUCTION

A piston is the responding part in the IC engine through which mechanical power is transferred and sealed with the piston rings for gas leak. To avoid overheating of the piston and cylinder heads the cooling system is used which will reduce the engine efficiency. The piston is subjected to cyclic heat and pressure and maximum heat is lost through piston head. In order to reduce heat loss, the piston should be provided with proper insulation. The piston insulation increases the performance of the engine and reduces the pollutants emission by proper combustion. Many researchers used the different insulation called thermal barrier coating (TBC) for the piston head. TBC can be applied to high temperature areas or heat transfer surface of internal combustion engine and gas turbine to increase its performance [1]. Performance and thermal analysis was carried out on pistons, which was coated with material made of MgO-ZrO_2 by means of utilizing the marketable code ANSYS and reduction in heat transfer observed for Al Si 48% and for steel 35% [2]. The diesel engine piston surface was insulated with Molybdenum nitride (MON) by utilizing method of arc PVD. Micro hardness, SEM, X-ray and surface roughness analysis were carried out giving the results coated piston hardness was about 2000 ± 400HV while hardness of uncoated piston was 123HV [3]. Both standard and coated case, engine was tested and thermal analysis of results shows that, surface temperature of coated piston part was rises up to 100˚C which leads the temperature of air-fuel mixture increases in the wall quenching and crevice regions.

Considerably decrease of cold start emissions about 43.2%, compared to the standard engine without any degradation in the engine performance [4]. Both content of C-Zro_2 heat insulating property of coating is increases significantly and there is no cracking in the coating surface after 1000 cycles of thermal shock, which is indicates that the plasma electrolyte oxidation coating with Zirconia sol addition possessed a good shock resistance [5]. The break thermal efficiency and specific fuel consumption were enhanced by make use of ceramic coated piston crown, as compared to without coating of piston. By utilization of advanced ceramic metal coating techniques, the level of exhaust emissions like CO, UHC, and NOx Exhaust emission level of CO, UHC and NOx are also greatly diminished [6]. The experimental method of analysis of piston insulation requires much time and expensive. The simulation analysis is the best suited method of testing in this computerized world.

METHODOLOGY

Static analysis

A static structural analysis helps to determination of displacement stresses, displacement strain, and forces in the components or structure which is caused by loads that will not influence the major inertia and damping effects. A strong loading and retort conditions are suspected that is the load and structure’s response are supposed to vary slowly with respect to time. By using ANSYS and SAMCE solver, we can perform the static structural analysis.

METHODOLOGY FOR THE THERMAL ANALYSIS

The ANSYS multi physics, ANSYS mechanical, and ANSYS professional products support the steady state thermal analysis. The effects of steady state thermal loads on systems or components can be calculated by steady state thermal analysis. To determine the temperatures, thermal gradient, heat flow rates and heat fluxes in an object, we can use steady state thermal analysis; those are caused by thermal loads does not change with time.

Coupled analysis to find thermal stress

Here coupled analysis can be used to determine the thermal stresses in the ANSYS workbench. A coupled-field analysis is a combination of analysis from different engineering disciplines (physics fields) that interact to solve global engineering problems hence we often refer to a coupled-field analysis as a multi physics analysis. When the input of one field analysis depends on the results from another analysis, thus analysis are coupled. To find thermal stresses in ANSYS workbench, piston model is imported to ANSYS workbench and is meshed using virtual topology as explained earlier. Results from state thermal analysis are imported to static structure analysis set up. Here loads and boundary conditions are imported from steady state thermal analysis.

Table 1: Piston design parameters

Sl.No.	Design- 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 (t1)	5.24
4	Axial thickness of the ring (t2)	5
5	Maximum thickness of barrel (t3)	14.34
6	Width of top land (b1)	10.84

7	Width of other ring lands (b2)	4

Geometric modelling

Stress calculations

1. Stress on piston crown

$$\sigma b = \frac{3pD2}{16\times tH2}$$

2. Thermal stress,

$\sigma t = E \times$ Coefficient of thermal expansion × temperature difference

3. Thermo-mechanical stress

$\sigma tm = \sigma b + \sigma t$

Theoretical stress calculation

Stress on piston head = 86.5MPa

Thermal stress = 1.46MPa

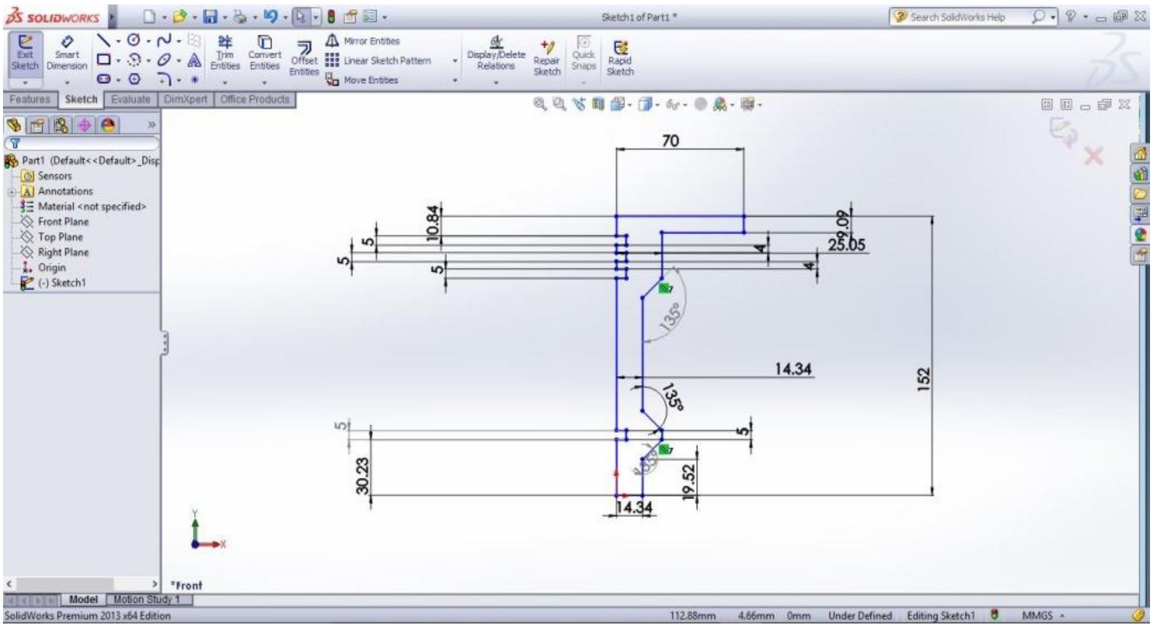

Fig.1 Sketch of piston model by using solid works softeware

RESULTS AND DISCUSSION

Static analysis results

A static structural analysis helps to resolve the displacement stresses, displacements, strain, and forces in the components or structure which is caused by loads that do not influence the major inertia and damping effects.

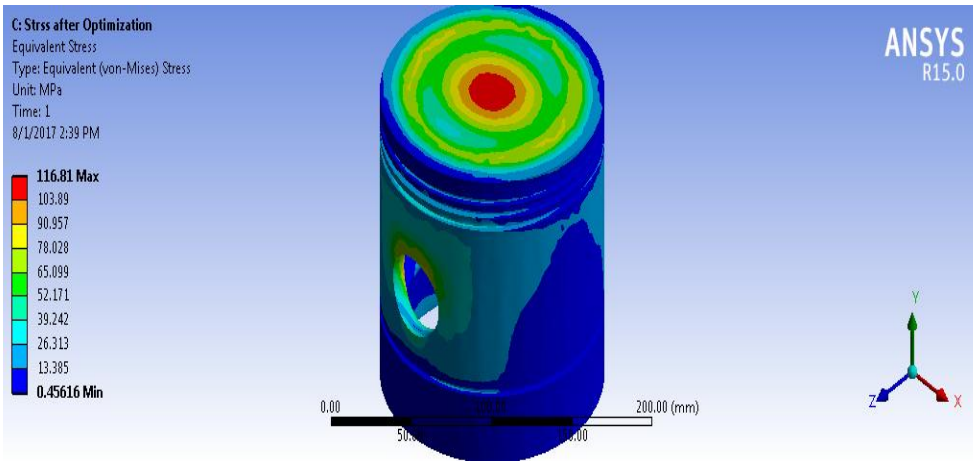

Fig. 2 Von Misses plot of piston after optimization

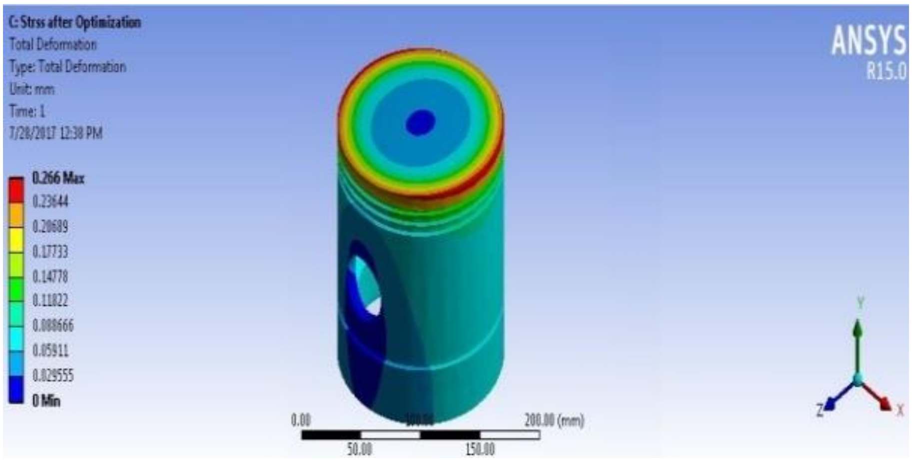

Fig.3 Resultant deformation

Maximum Von Misses stress after optimization is 116MPa, which is within the maximum allowable stress and corresponding deformation was 0.266mm.

THERMAL ANALYSIS RESULTS

In this thermal analysis of piston, we find out the results of piston without coating and with coating. Here Zirconium as a coating material applied on the piston head.

Thermal analysis results of piston without coating

After applying loads and convection boundary condition, steady state thermal analysis was carried out on IC engine piston model considered. Maximum temperature was seen at piston head and minimum at piston base as shown in figure

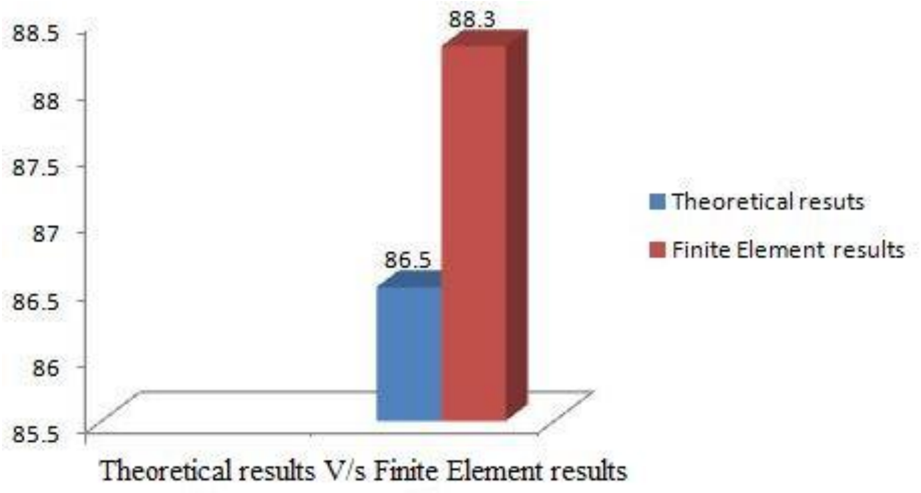

Fig.4 Theoretical results and finite element results

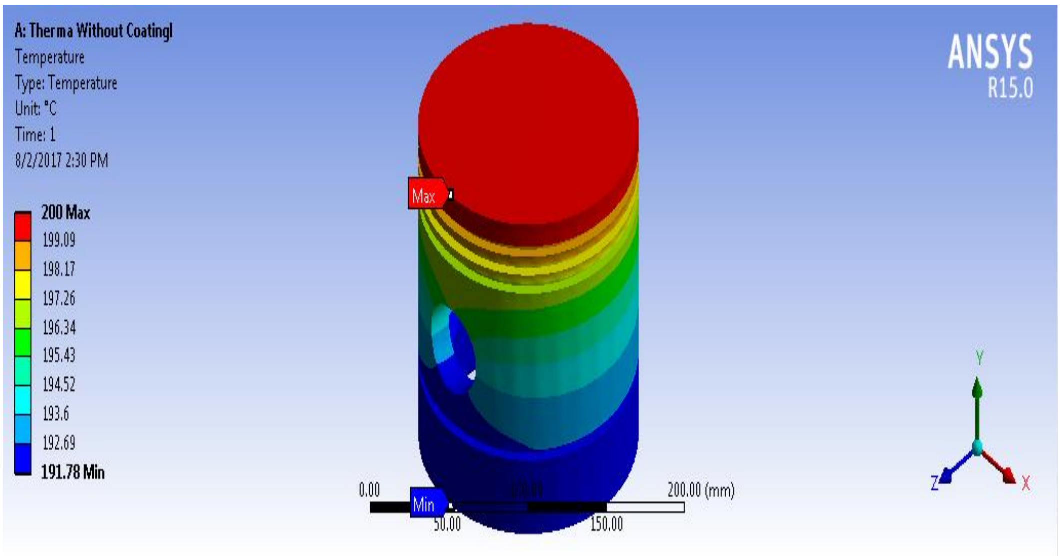

Fig.5 Maximum temperature at piston head and minimum at piston base

Table 2: Comparison of theoretical results and finite element results of mechanical stress

Mechanical stress	**Theoretical value**	**Finite element result**	**Error %**
	86.5MPa	88.3MPa	2.08%

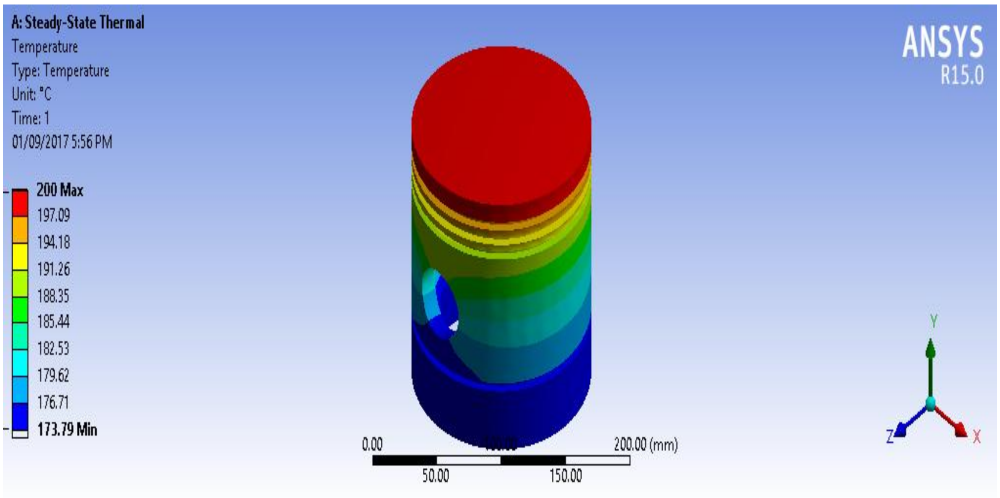

Fig. 6 Steady state thermal analysis of piston without coating

Thermal analysis results of piston with coating

Results shows steady state thermal analysis with various thickness of Zirconium coating

- **Steady state analysis for 0.2 mm coating**

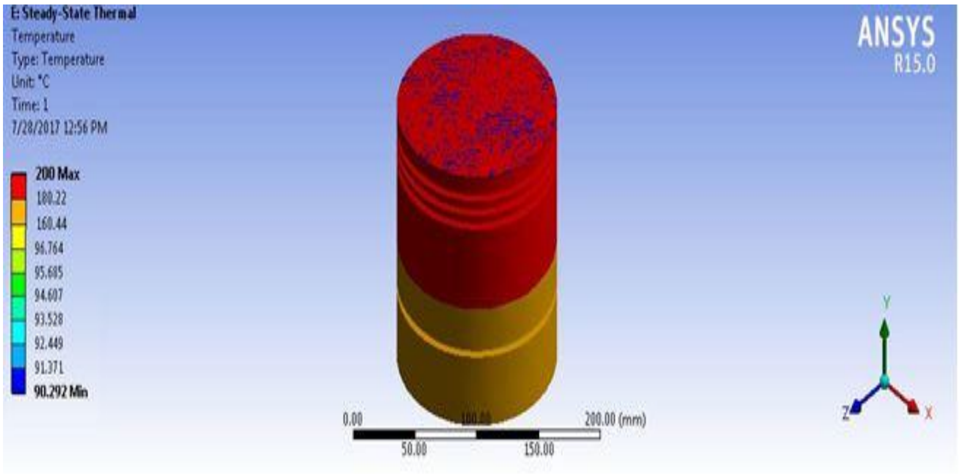

Fig.6.1 (a) Steady state thermal analysis for 0.2mm Zirconium coated piston.

- ***Steady state analysis for 0.3 mm coating***

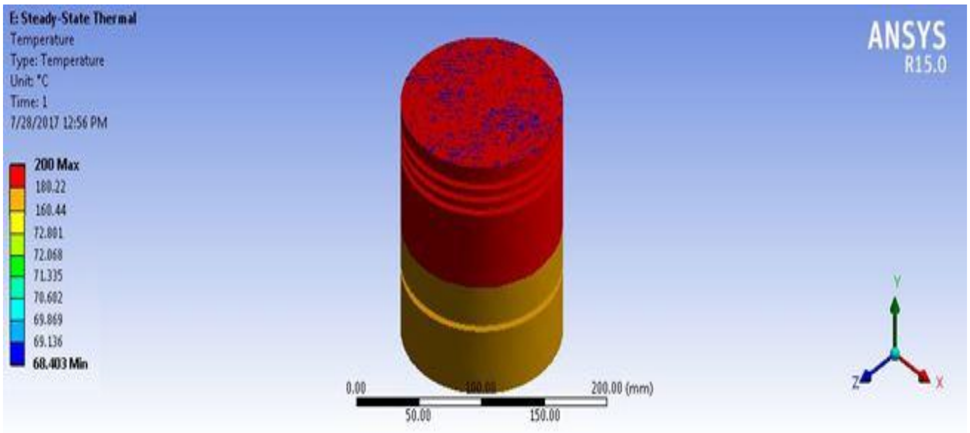

Fig .6.1(b) Steady state thermal analysis for 0.3mm Zirconium coated piston.

- ***Steady state analysis for 0.4 mm coating***

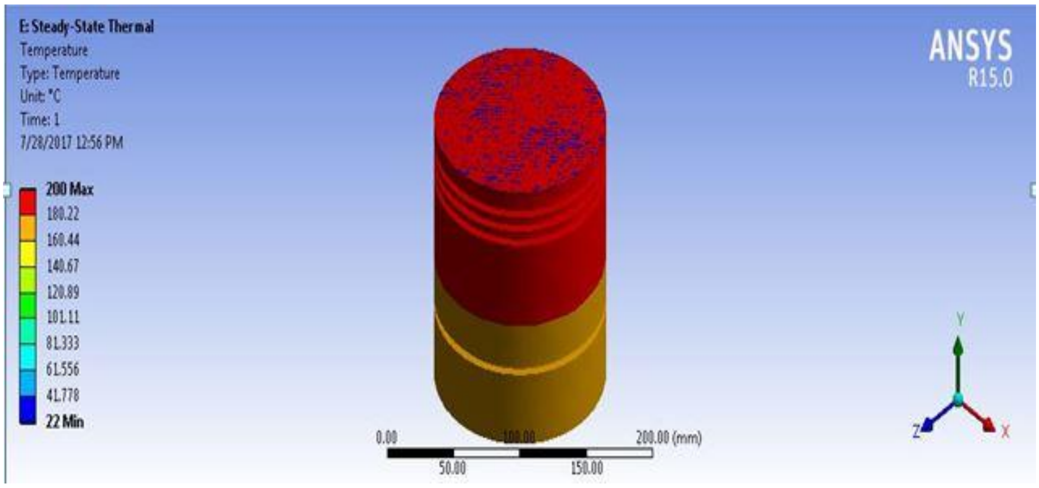

Fig. 6.1(c) Steady state thermal analysis for 0.4 mm Zirconium coated piston

Fig 6.1(a) shows steady state thermal analysis of IC engine piston coated with 0.2mm of Zirconium alloy. Here the maximum temperature applied on the piston head 200˚C and Zirconium alloy absorbs heat finally results in decrease in temperature about 90.29˚C.

Fig. 6.1(b) shows steady state thermal analysis of IC engine piston coated with

0.3mm of Zirconium alloy. Here the maximum temperature applied on the piston head was 200˚C and Zirconium alloy absorbs heat, finally results in decrease in temperature about 68.433˚C. Fig. 6.1(c) shows steady state thermal analysis of IC engine piston coated with 0.4mm of Zirconium alloy. Here the maximum temperature applied on the pi ston head is 200˚C and zirconium alloy absorbs heat, finally results in decrease in temperature about 22˚C.

From the above results of steady state thermal analysis with various coating thickness it was observed that increase in coating thickness, increases piston performance by reducing thermal stresses and hence increase piston life.

Coating usually costs more, considering coating cost and performance of piston, suitable coating thickness can be used. Among these three cases of coating 0.4mm of Zirconium coating gives better performance since it gives more barrier.

Table 3 Coating thickness and temperature

Sl. No.	*Coating thickness*	*Minimum temperature*
1	0.2 mm	90.29˚C
2	0.3 mm	68.43˚C
3	0.4 mm	22˚C

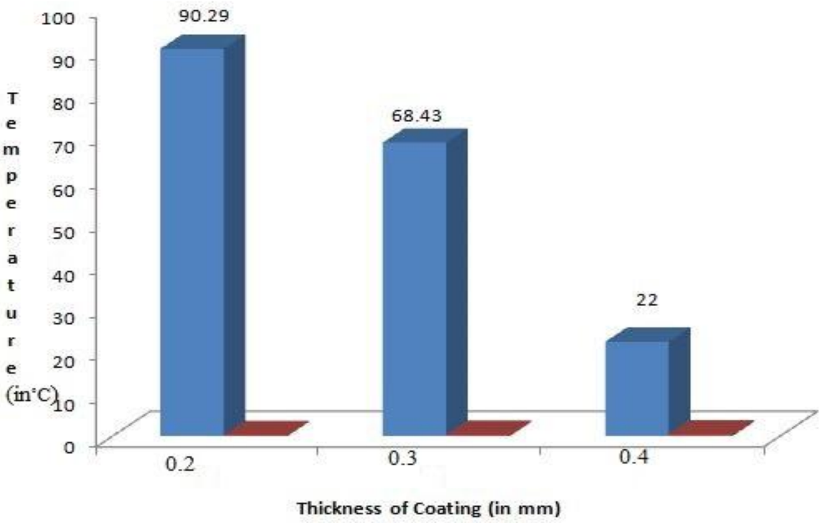

Fig.7 Temperature V/s coating thickness

Table 3 shows the parameter study for the steady state thermal analysis with various thickness of coating along with minimum temperature.

Fig.7 it shows as decrease in the thickness of coating increases the temperature of the piston. Larger coating thickness having less temperature hence increase coating thickness, increases performance of piston.

Thermal stress

After importing loads, coupled static analysis was run to find thermal stresses in piston model. Fig.8 shows thermal stress on piston model subjected to thermal loads, maximum thermal stress was 1.59MPa.

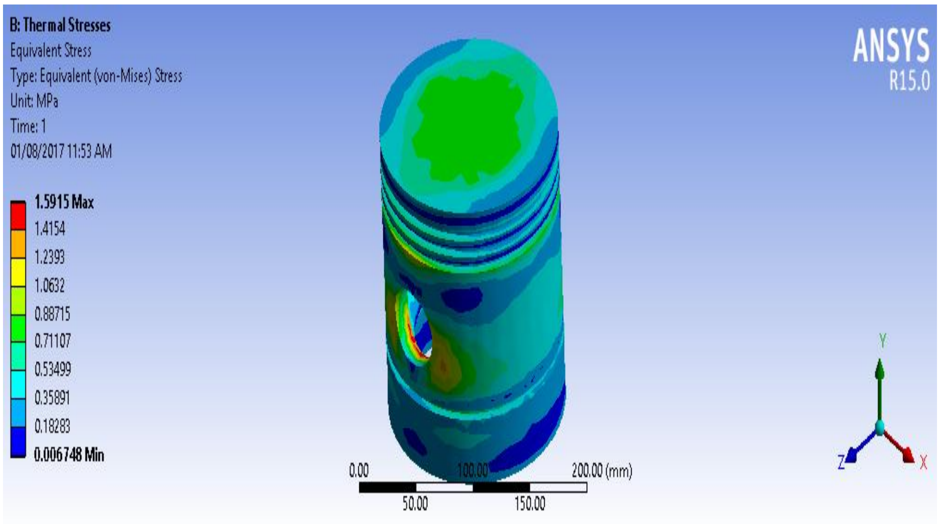

Fig. 8: Thermal stresses in IC engine piston

Table 4: comparison of theoretical results and finite element results

Thermal stress	*Theoretical value*	*Finite element result*	*% of error*
	1.46Mpa	1.59MPa	8.9%

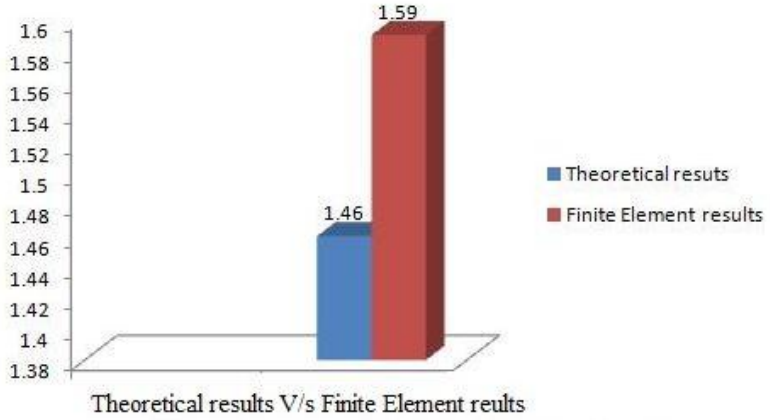

Fig.9: Theoretical V/s finite element results

CONCLUSIONS

1. Finite element analysis was carried out for standard piston model used in IC engine and the result analysis indicate that the maximum stress was 88Mpa. Maximum stress concentration was found on upper end of the piston.
2. Since the maximum stress value was well within allowable stress and maximum stress optimized value was 116MPa.
3. Piston was optimized based on permissible stress limit in order to save piston manufacturing cost without compromising its performance.
4. The % error of analytical results and FEA results was less. Hence the design of piston is safe

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