Finite Element Methods (MEE 480/580)

Project Report

Group # 3

NIU Spring 2016

Date: May 06. 2016

Structural and Thermal Analysis of an IC Engine Cylinder

Group Members :

Kyamra Marma (25%)

Joseph Kempel (25%)

Arunim Bhattacharya (25%)

Jacob Brinlee (25%)

Submitted To :

Dr. Iman Salehinia

Abstract

The combustion chamber, especially engine cylinder, of internal combustion engine experience continuous thermal and mechanical stresses during its operation. Therefore, the design and the engine development requires comprehensive and thorough assessments of quality, reliability and performance of all systems and engine parts, including piston and engine cylinder. Moreover, engine cylinder is operated under significantly high temperatures, pressures and in chemically active medium. As a result of that, simultaneous impact of thermal and mechanical stresses has high influence on the cylinders durability. The heat flux inside the cylinder varying significantly during the operation through different cycle and reaching the values up to 10^5 W/m^2 and higher. In this project, steady state static and transient thermal and structural analysis of an internal combustion engines cylinder is conducted to analyze the deformation and stress in the cylinder.

Content

List of Figures

Chapter One
Introduction

1.1 **Background**

Heat transfer is an important issue for internal combustion engines because it affects properties such as the in-cylinder pressure and temperature. However, engine heat transfer analysis and modeling is challenging because of the combustion process, the in-cylinder charge turbulence and the rapid motion of the piston within the combustion chamber. All of these factors contribute to the unsteadiness and local variations of the in-cylinder heat transfer. The cooling process is necessary in engines: insufficient cooling can increase the chance of knock occurring and excessive cooling will decreases the overall output work by lowering the average combustion gas pressure and temperature [1]. The conditions within internal combustion engines are fundamentally unsteady and with further development, it may be possible to achieve a more accurate and more widely applicable simulation. The contributions made herein include the steady state static and transient thermal and structural analysis of an internal combustion engines cylinder.

1.2 Summary of the Project

Internal combustion (IC) engine cylinders are important part of the whole engine assembly. Cylinders are of particular engineering importance because of their function. An engine cylinder (rather cylinder block) has to withstand extreme internal pressures and temperatures. At the peak of the combustion the temperature can be as high as 1000°C, and pressures can be as high as 10 MPa. The simulation would specifically try to emulate the pressure and temperature rise during the heat addition process of Otto Cycle, hence the volume of the cylinder will remain constant (corresponding to the top dead Centre). In the structural and thermal analysis of the engine cylinder, the effect of high pressures and temperatures inside cylinders on the deformation of the engine block is studied. This model consists of one cylinder block and corresponding housing with cavities for coolant flow.

1.3 Objectives:

Following objectives is considered in this analysis:

1. To conduct transient thermal-structural analysis of the cylinder block arrangement. For that initially transient thermal analysis of cylinder block was conducted, then exported to transient structural analysis.

2. To conduct a transient thermal analysis for a steady state temperature. This result is used along with maximum cylinder pressure and average heat flux for static structural analysis. After completing all analysis, we will compare the results.

3. To do a convergence study.

Experimental data is taken from a reference paper [1] to source the average heat flux and cyclic pressures with time for conducting both static and transient thermal analysis.

Chapter Two
Geometry and Mesh

2.1 Geometry:

To conduct the analysis, we have designed the simple model of a cylinder block. The following figure shows the dimensions of the engine cylinder and block:

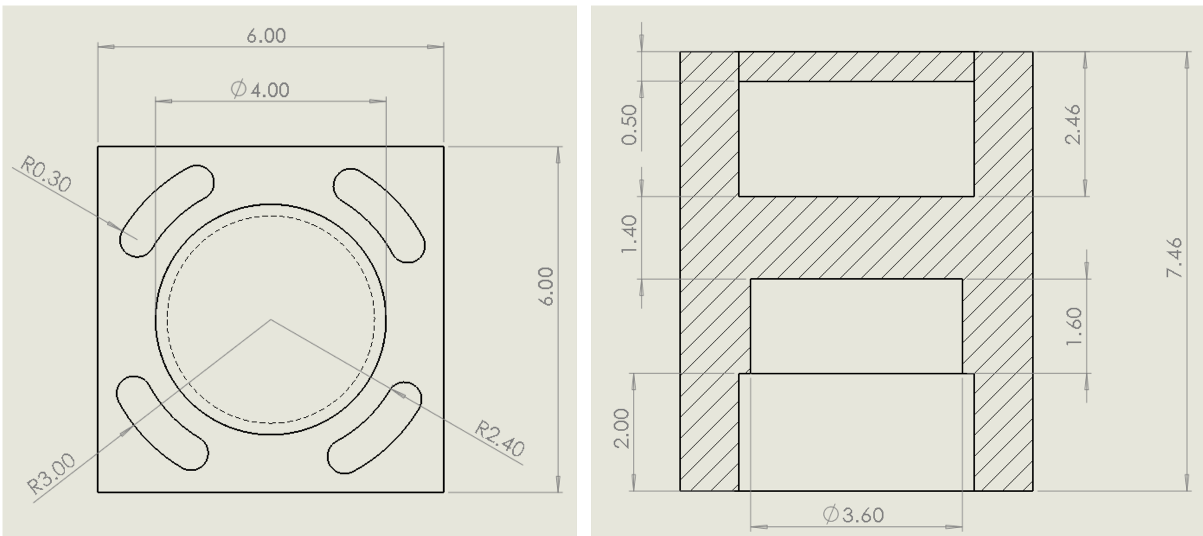


Fig. 1: Dimensions of model (inches)

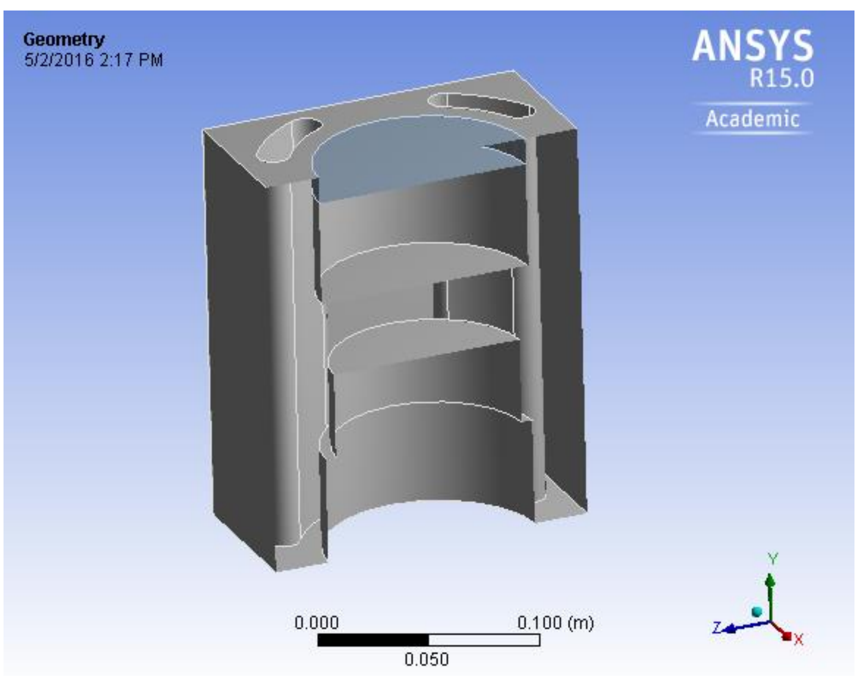
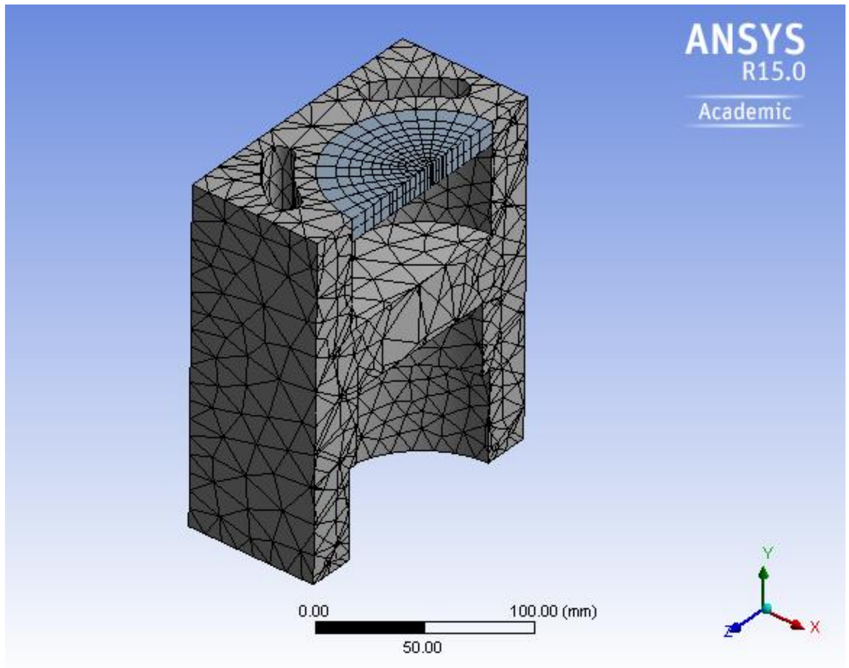


Fig. 2: Geometry of the cylinder and block

2.2 Mesh:

For this work, we used tetrahedral coarse mesh. The following figure shows mesh quality of the cross section of the developed model:



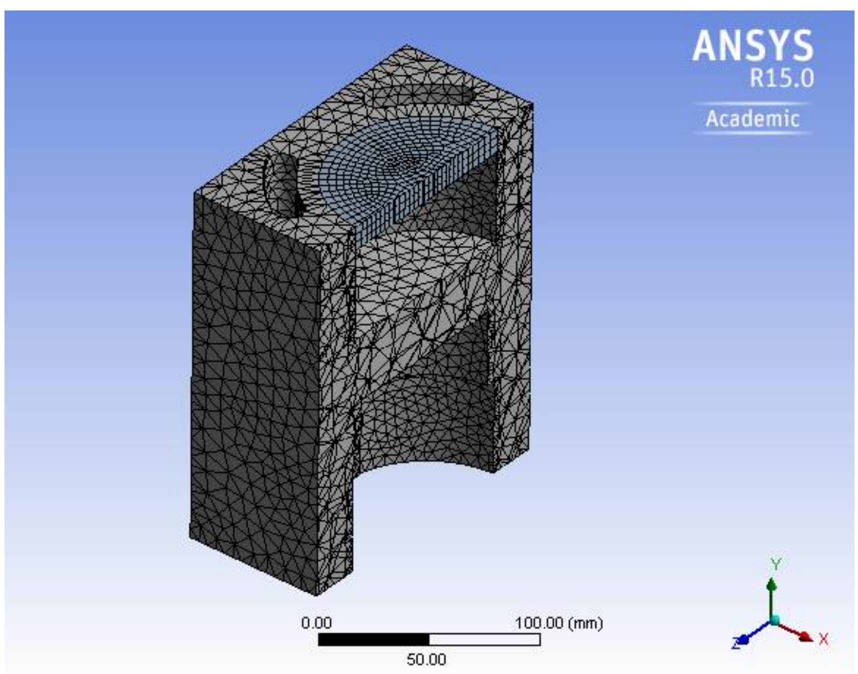


Fig. 3: Mesh (a) Element size: 10 mm (9314 elements) (b) Element size: 05 mm (39941 elements)

Chapter Three
Boundary Conditions and Experimental Setup

3.1: Boundary conditions:

Convection boundary condition 1: The following figure shows the convection boundary condition in coolant cavities:

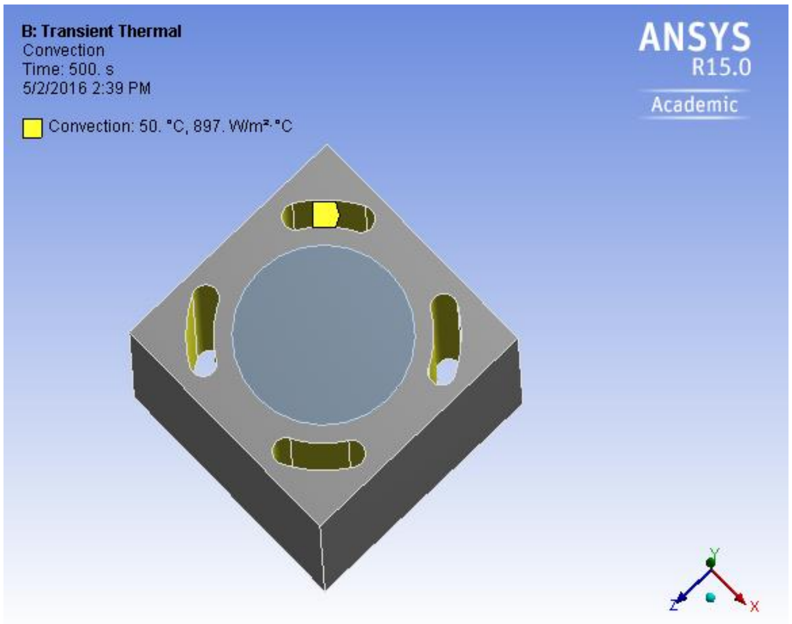


Fig. 4: Coolant cavity boundary condition

Convection boundary condition 2: Convection boundary condition at the outer walls.

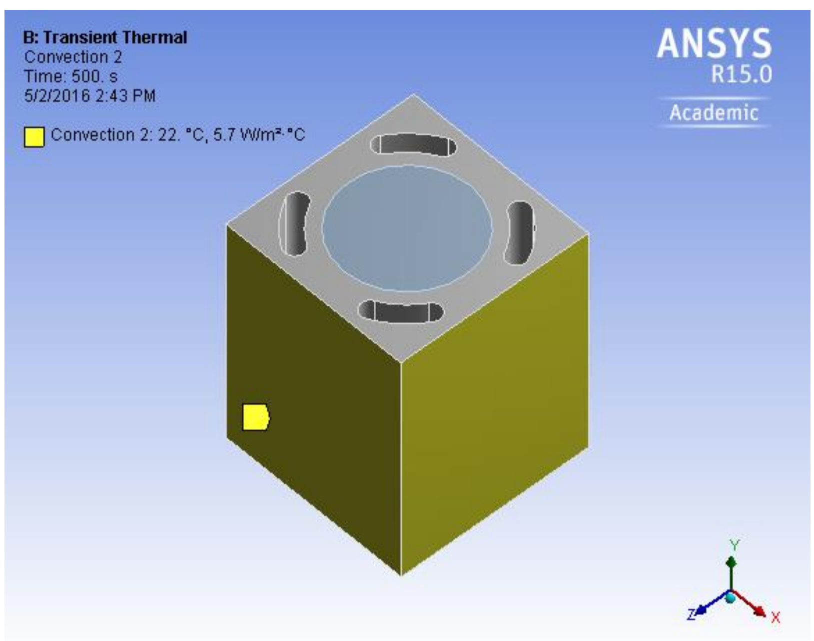


Fig. 5: Outer wall boundary condition

Heat Flux boundary condition: Average heat flux is applied inside the combustion chamber.

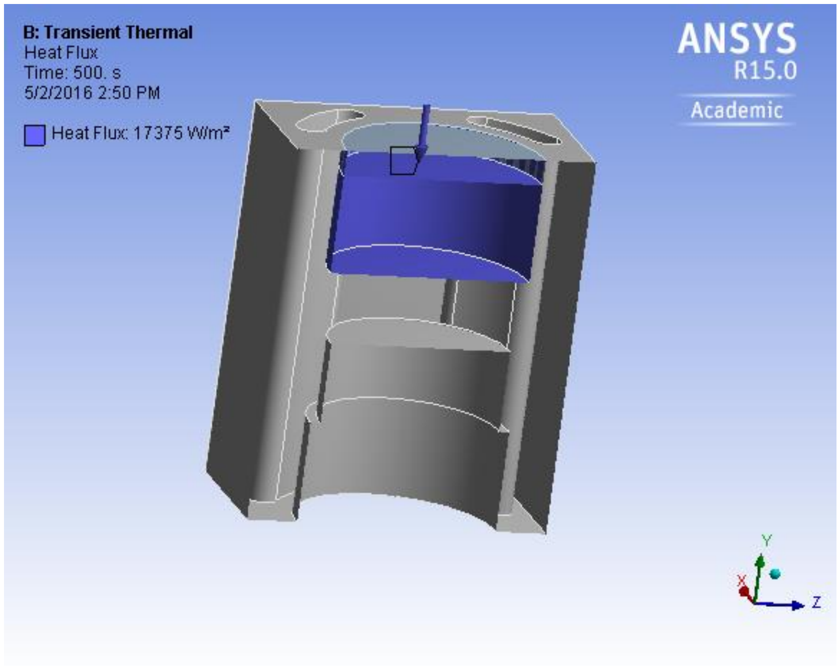


Fig. 6: Heat flux boundary condition

Pressure and fixed boundary conditions:

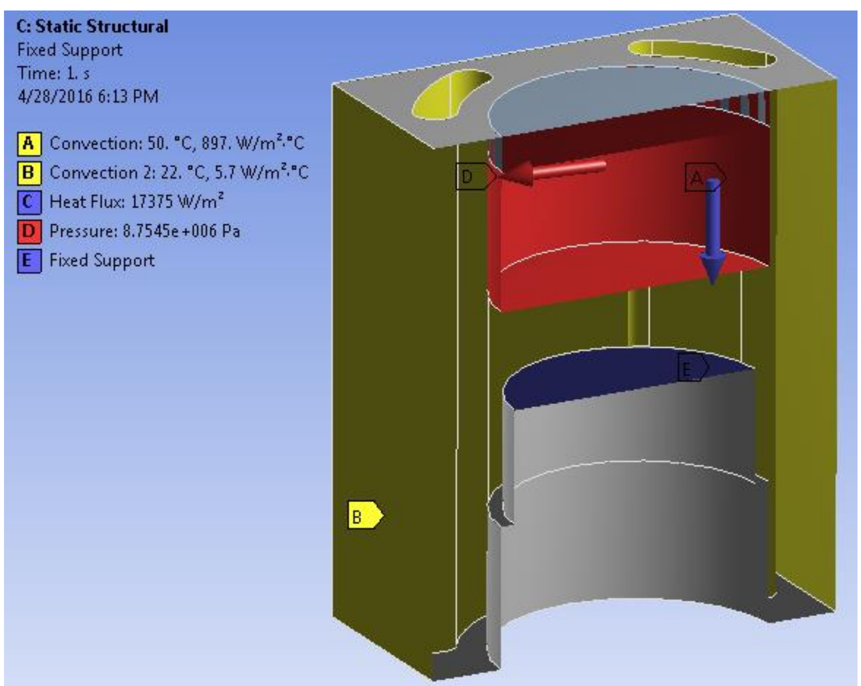


Fig. 7: Pressure and fixed boundary condition

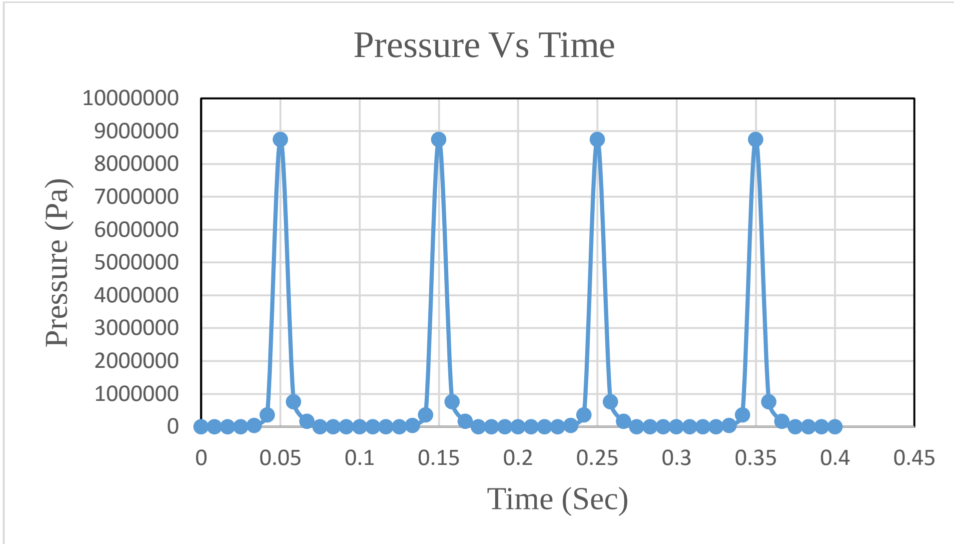


Fig. 8: Cyclic pressure with time

3.2 Experimental Model

Transient thermal-structural analysis model:

In this analysis, maximum deformation, stress, and strain of the system is observed with varying pressures.

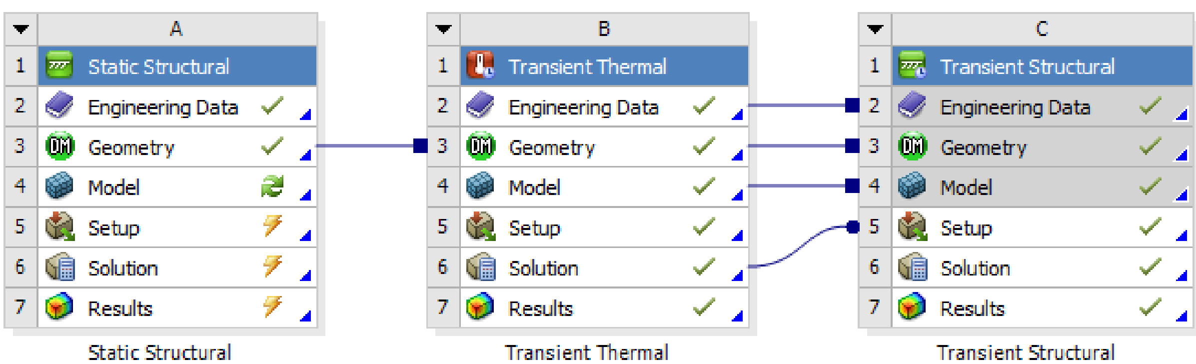


Fig. 9: Transient analysis model

Static thermal-structural analysis model:

Initially a transient thermal analysis is conducted to observe the varying temperature rise in the material until steady state. Then by using result of transient thermal analysis (steady state temperature) a steady state structural analysis is finally executed. A parameter set analysis is conducted to do a convergence study.

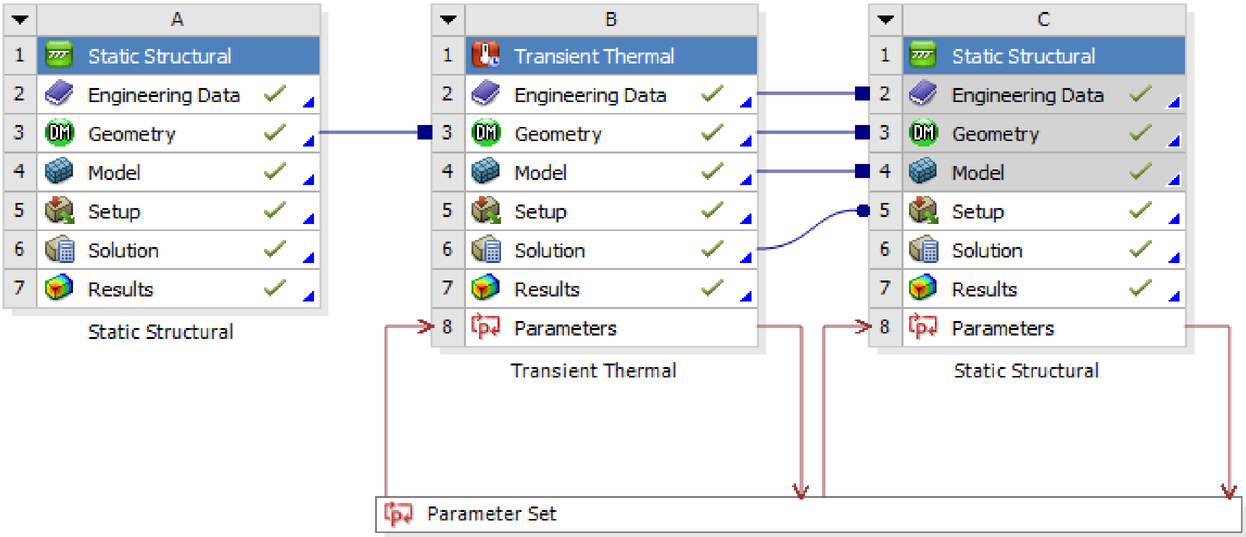


Fig. 10: Static analysis model

3.2 Materials

- Cylinder Body
  - ASTM Grade 40 Gray cast iron
  - Properties:
    - Density- 7200 kg/m^3
    - Young's modulus- 110 GPa
    - Poisson's ratio- 0.28
    - Thermal conductivity- 46 W/m °C
    - Thermal expansion- 11.0E-6 °C^{-1}
    - Displacement – 450cc (approx.)
    - Engine Speed-1200 rpm
- Coolant Properties:
  - 50/50 Glycol Water
  - Convection heat transfer coefficient: 897 W/m^2 °C
  - Coolant Temperature: 50°C
  - Most automobiles have a cooling system designed to reject sufficient heat under normal operating conditions using a 50/50 glycol solution in water.
  - Advantages of Glycol-Water coolant: Doubles the wetting ability of water. - Improves heat transfer. - Reduces cylinder head temperatures. - Reduces rust, corrosion and electrolysis. -Provides long term corrosion protection. - Cleans and lubricates water pump seals. - Complexes with hard water to reduce scale.
- Ambient Conditions: Temperature: 22°C

Chapter Four
Results and Discussion

4.1 Results:

The following results is obtained from the following analysis:

4.1.1 Transient Analysis

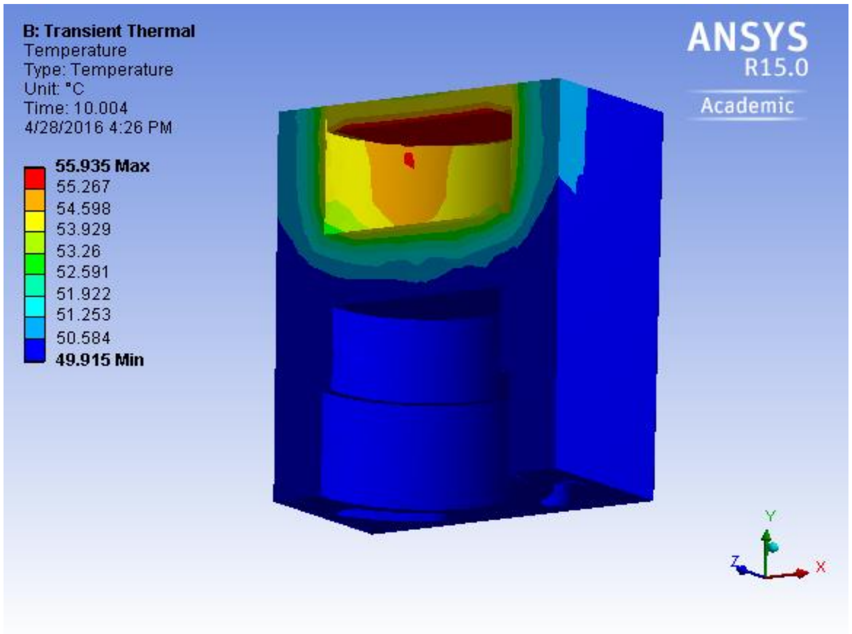


Fig.11: Temperature distribution at 10 s

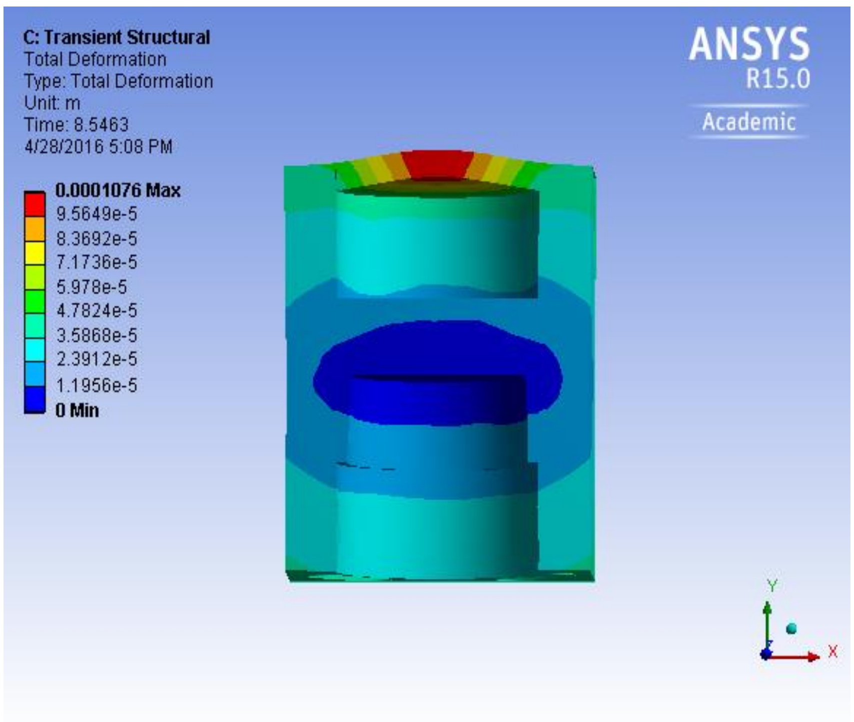


Fig. 12: Total deformation at 8.5 s

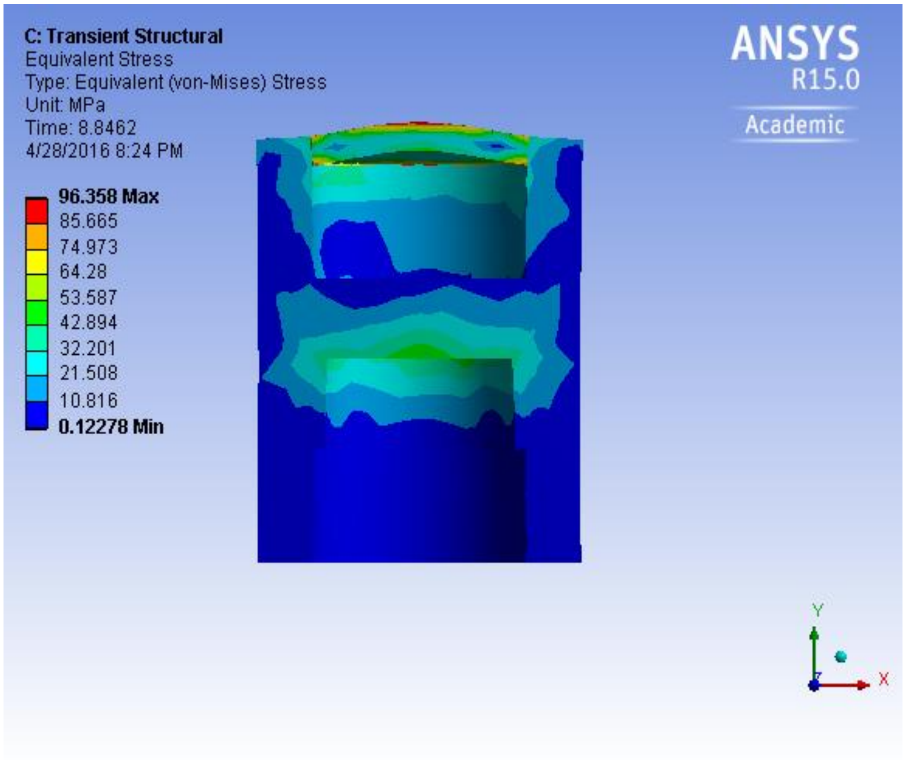


Fig. 13: Equivalent stress at 8.8 s

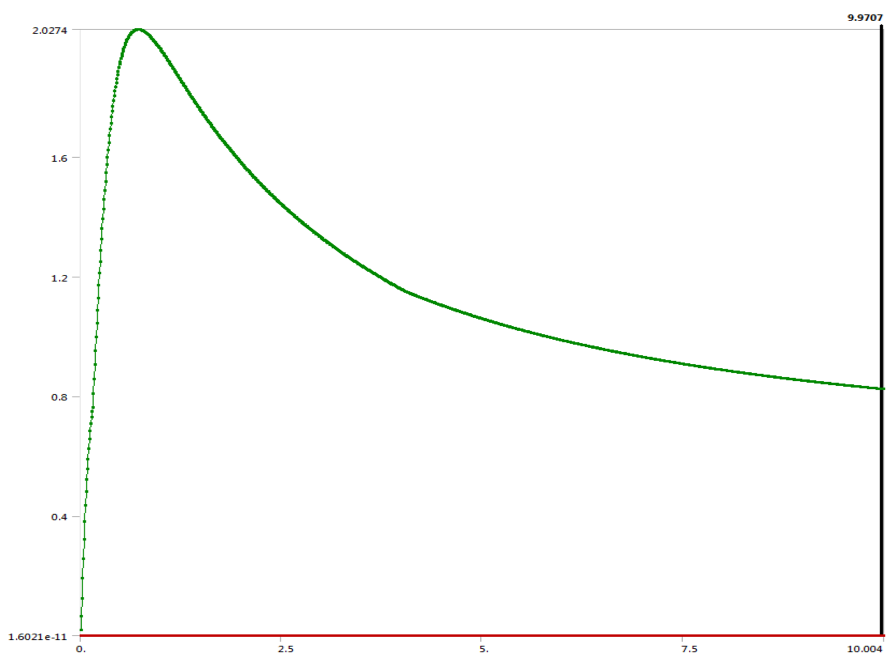


Fig. 14: Thermal error vs time

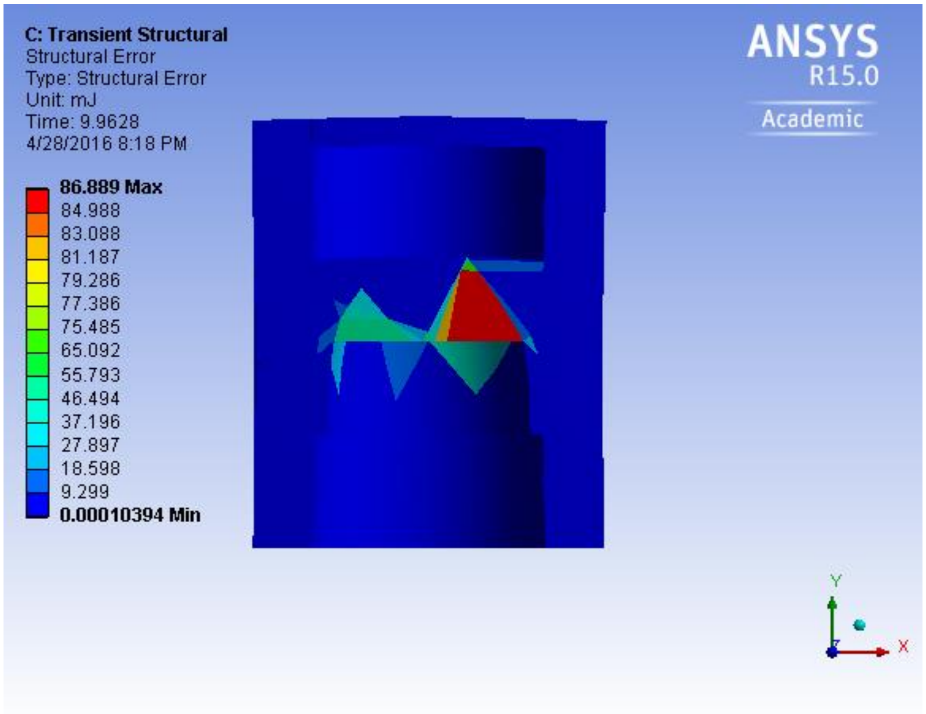


Fig. 15: Structural error

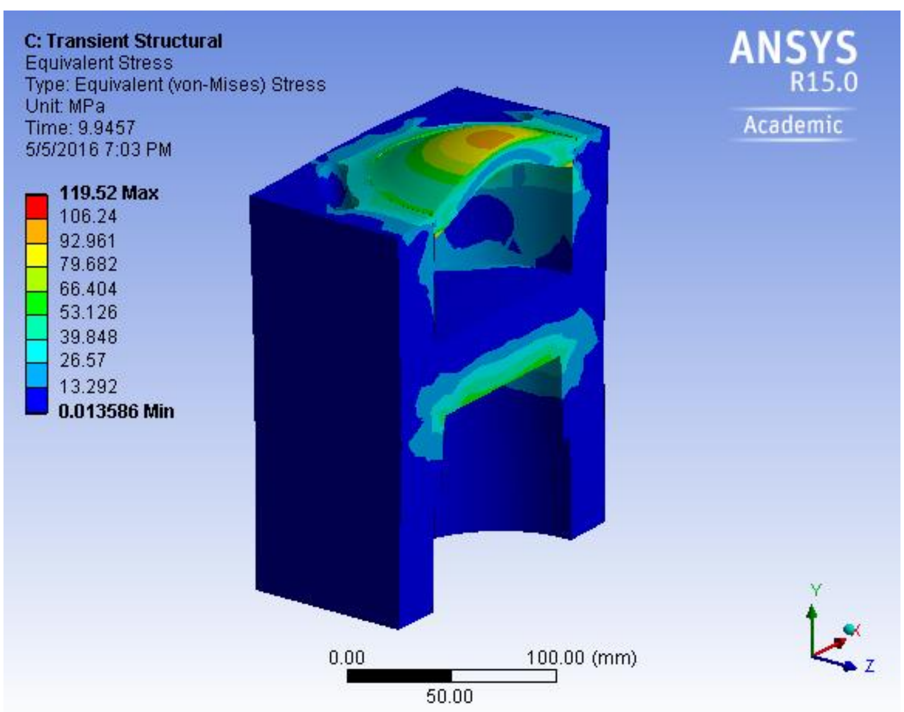


Fig. 16: Equivalent stress (Analysis by mid-side node on)

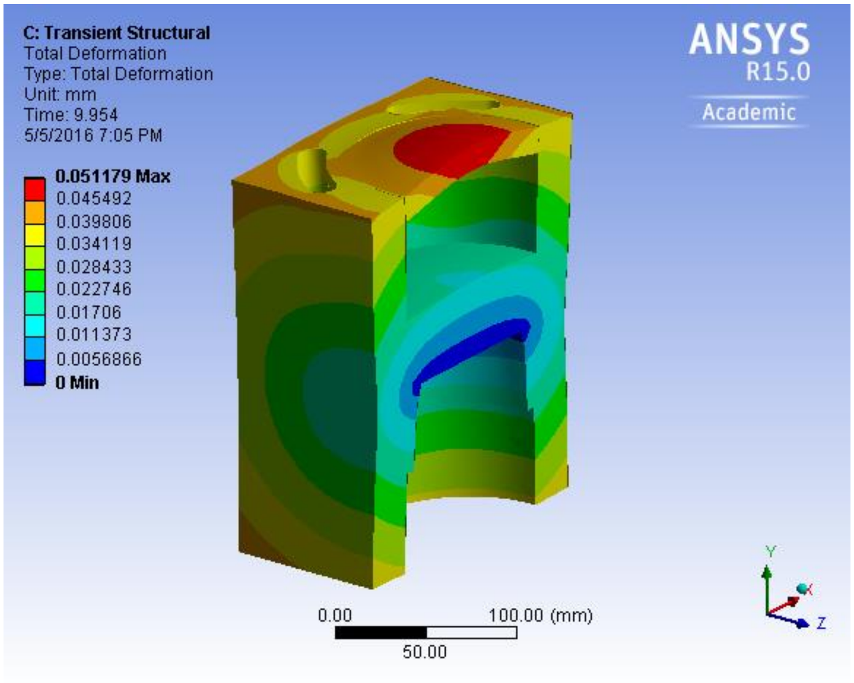


Fig. 17: Total deformation (Analysis by mid-side node on)

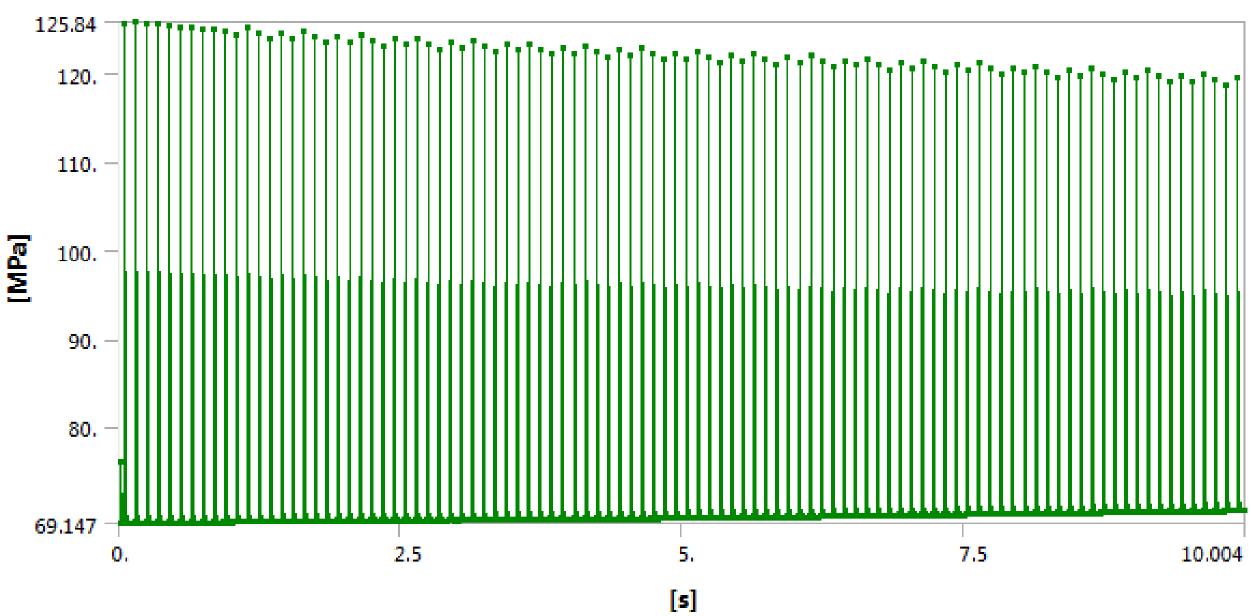


Fig. 18: Max. Equivalent stress (Analysis by mid-side node on)

4.1.2 Static Analysis

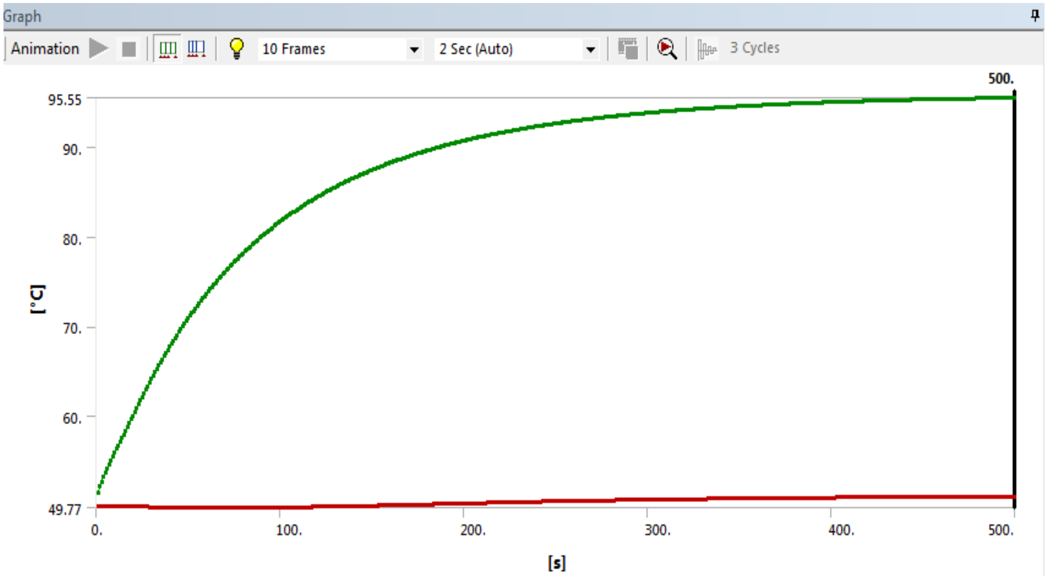


Fig. 19: Maximum temperature vs time

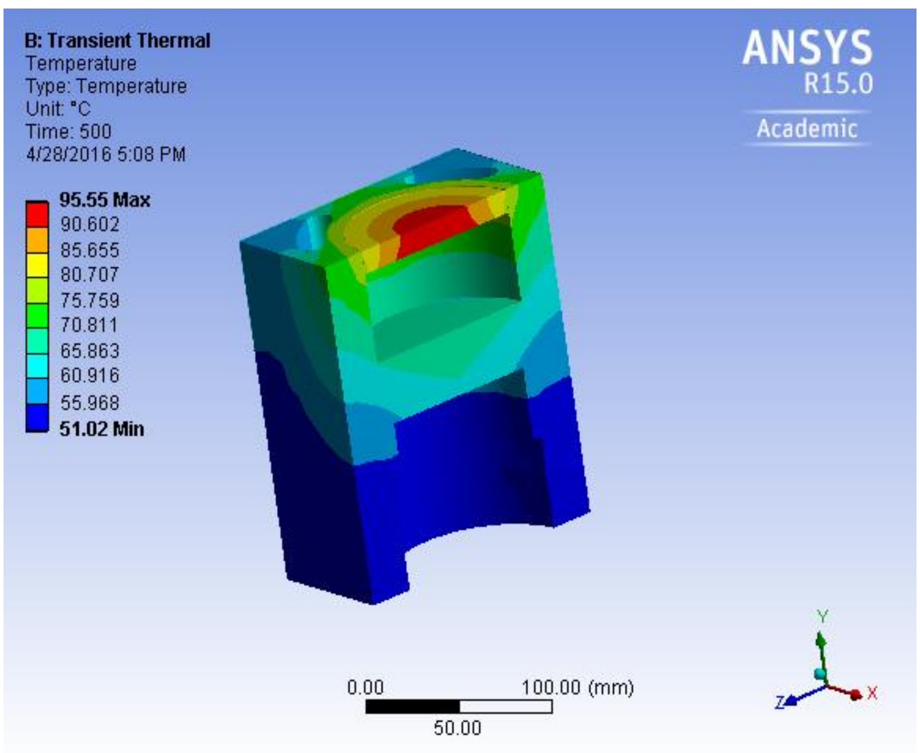


Fig. 20: Temperature distribution

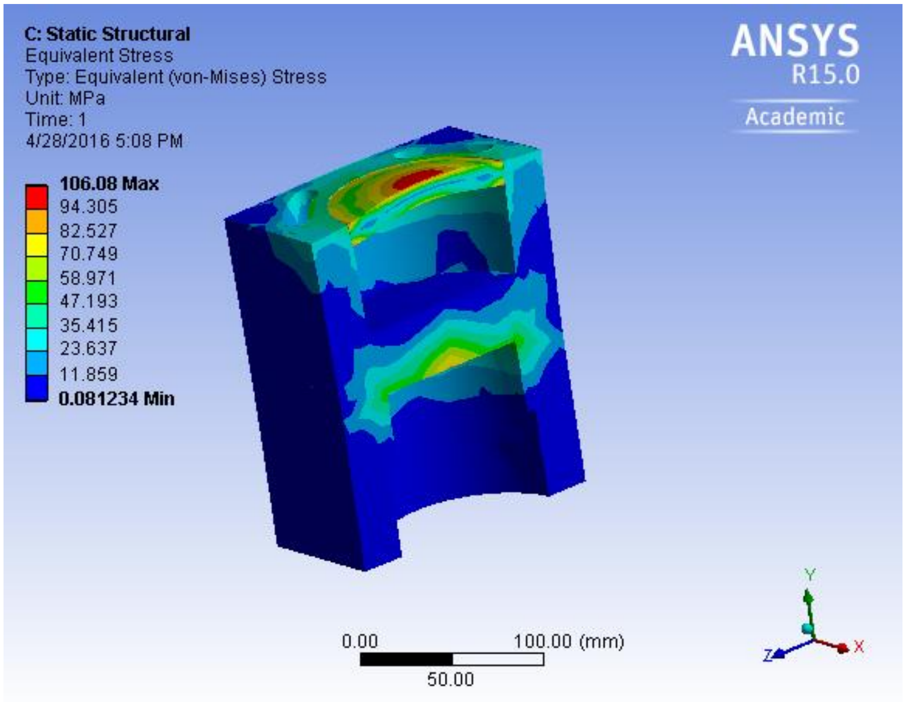


Fig. 21: Equivalent (Von-Misses) stress

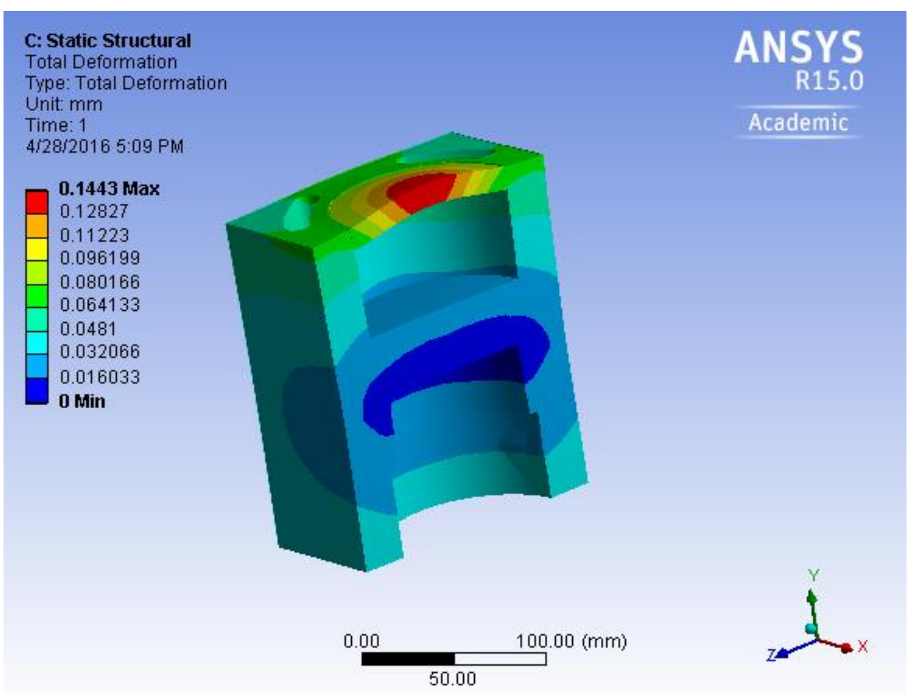


Fig. 22: Total deformation

4.1.3 Convergence Study

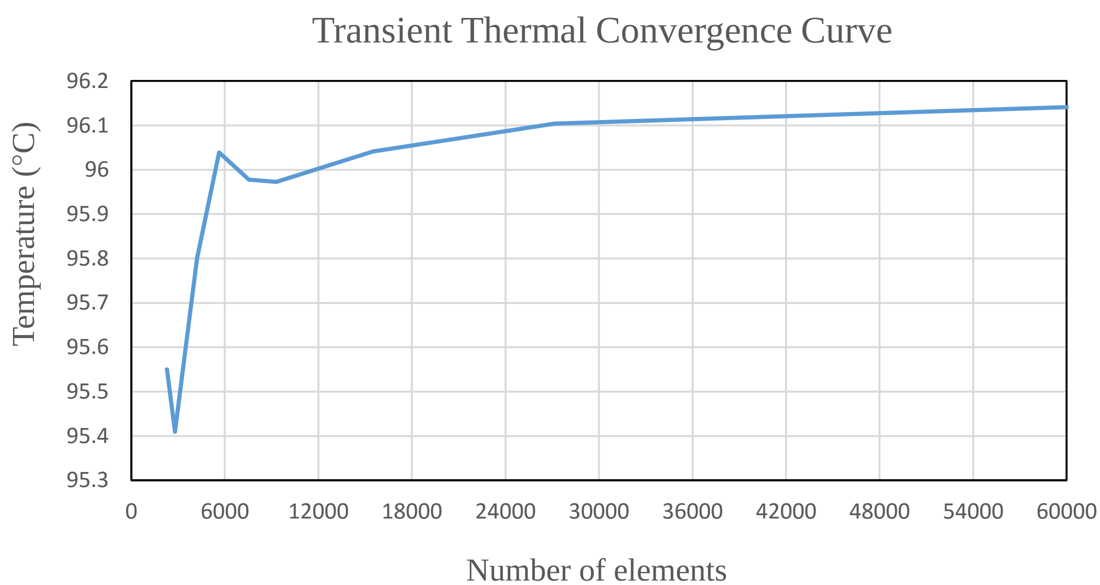


Fig. 23: Transient thermal convergence study

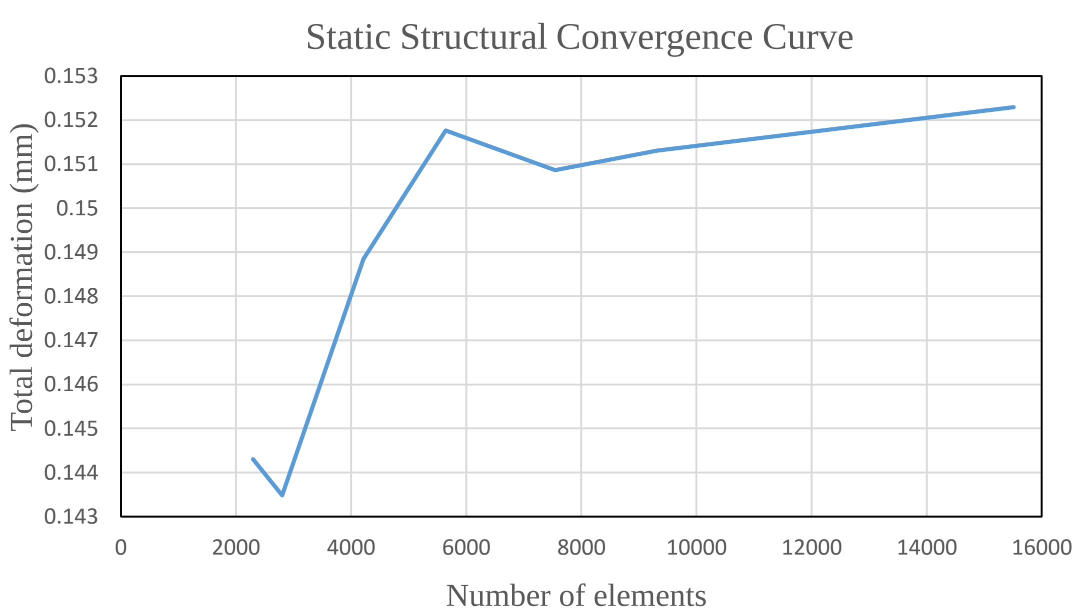


Fig. 24: Static structural convergence study

4.2 Discussions

For transient analysis, average heat flux is calculated form the reference paper and inserted to ANSYS-transient thermal module. The solution of transient-thermal module is then exported to transient-structural to solve for deformation and stresses in the cylinder and housing. Due to limited hard-drive space and extended time required to achieve a solution, the simulation time is limited to 10 seconds. For initial simulation a coarse mesh is used with element size of 25 mm. The maximum deformation is 0.1076 mm (Fig. 12) and the thermal error reduces with time (Fig. 14). However, the structural error (Fig. 15) for this coarse mesh is high. It could be because of using bottom surface of piston as a fixed support. For second run of simulation the element size is reduced to 10 mm with mid-side node kept on, amount of structural error is reduced than previous case. For all purposes, tetrahedral element is used. With the increase of temperature, the value of maximum equivalent stress is gradually decreases (Fig. 18).

In static analysis, initially a transient thermal analysis is conducted for 500 seconds to observe the varying temperature rise in the material until steady state. The temperature is found 95.55°C (Fig. 19 & 20). Then by using result of transient thermal analysis (steady state temperature) a steady state structural analysis is finally executed. In this analysis, in addition to other boundary conditions, average heat flux is 17375 W/m^2 and the maximum pressure loading is considered and the value is 8.754 MPa. The maximum deformation is 0.1443 mm (Fig. 22) and the maximum equivalent stress is found 106.08 MPa (Fig. 21), located at the cylinder head. A convergence study of transient thermal and static structural in respect of total deformation is conducted by a parameter set analysis. The coarse mesh elements size is varied from 25 mm to 8 mm. With the increase of number of the elements, both the temperature and total deformation is converged (Fig. 23 & 24).

4.3 Future Scope

- To repeat the above transient thermal-structural analysis by replacing averaged flux with a cyclic flux.
- To conduct the testing of engine cylinders made with different materials.
- To increase the simulation time for transient analysis.
- To model the whole engine block with moving parts.

4.4 Conclusion

The FEM analysis of internal combustion engine cylinder is conducted to analyze the effect of cyclic pressure variations, averaged heat flux and consequent buildup of temperature in the cylinder block. In transient analysis, with the increase of temperature, the reduction is maximum equivalent stress is observed, while no such pattern is observed in case of maximum deformation. The static analysis is conducted at steady state temperature distribution (imported from transient thermal analysis) and maximum pressure. The resultant maximum equivalent stress is lower than the transient analysis (10 seconds). The FEM analysis of internal combustion engine cylinder can be improved by using cyclic heat flux loading and increasing simulation time.

References:

1. Agrira A., Buttsworth D. R., and Said M. A. (2014), Instantaneous Heat Flux Simulation of a Motored Reciprocating Engine: Unsteady Thermal Boundary Layer With Variable Turbulent Thermal Conductivity", *Journal of Heat Transfer (ASME)*, Vol. 136 / 031703-7.

2. Waterwetter Supercoolant with Rust & Corrosion Inhibitor Technical Information (1999), Red Line Synthetic Oil Corp, Benicia, CA, USA.