Thermal and Static Structural Analysis on Piston

G.V.N. Kaushik

***Abstract**: In IC engine, Piston is one of the most important and complex part.With increasing power and performance of engine, higher thermal load and the thermal stresses are acting on piston, thereby, decreasing its life time. It is important to maintain Piston in good condition in order to maintain the proper functioning of the engine. Piston mainly fails due to thermal Conditions. In this paper 3D model of piston is developed, structural and thermal analysis is done by ANSYS using 5 different materials to find out the temperature and thermal stress distribution, theoretically finding the total heat flux and compare with the practical values of different Piston Materials used.*

***Index Terms:**IC engine, Piston, ANSYS, Piston Materials.*

I. INTRODUCTION

The piston is an important component of the internal combustion engines. The piston's resistance to the thermal and mechanical loads limits the power of the internal combustion engine. For this reason, during the design stage of the piston, there is a great emphasis on determining the stresses and deformations due to the mechanical and thermal loads.In the engine cylinder, during combustion cycle the energy bounded up in the fuel is rapidly converted into heat and pressure. The heat and pressure values increase slightly within a very short period of time. The piston as the moving part of the combustion chamber has the task of converting this released energy into mechanical work.The basic structure of piston is a hollow cylinder, which is closed on one side, the main purpose of piston in engine cylinder is to transfer force from expanding gas in the cylinder to the crankshaft via piston rod.

The Most important tasks that a piston must fulfill is

- Transmission of force.
- Variable bounding of the working chamber.
- Sealing off the working chamber.
- Heat dissipation.
- Support exchange of charge by drawing and discharging (four-stroke engine)
- Support mixture formation (by means of suitable shape of the piston surface on the combustion chamber side)
- Guiding the sealing elements
- Controlling charge exchange (in two-stroke engine)

In this paper designing the 3D model of piston in solid works, structural and thermal analysis part will be done in ANSYS software by using 4 different materials and finding the best material for piston.

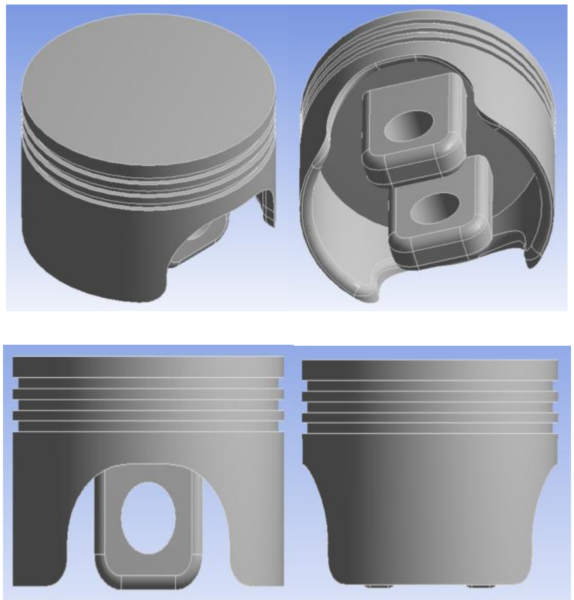

Fig1. Model of Piston

II.MATERIAL PROPERTIES

S. NO	PROPE-RTIES	ALSI	AL-MG-SI	ALSIC-12	42CrMo
1	Young's modulus	2.3×10^5Mpa	0.7×10^5Mpa	1.67×10^5Mpa	2.06×10^5Mpa
2	Poisons ratio	0.24	0.33	0.21	0.28
3	density	2937 kg/m^3	2700 kg/m^3	2890 kg/m^3	7900 kg/m^3
4	Thermal conduct-ivity	197 W/m^{0}c	200 W/m^{0}c	170 W/m^{0}c	40 W/m^{0}c
5	Specific heat	894 J/kg^{0}c	898 J/kg^{0}c	808 J/kg^{0}c	460 J/kg^{0}c

III.THERMAL LOAD AND HEAT TRANSFER COEFFICIENT OF PISTON

The piston top land is the part of piston which comes in contact with the gas, so the temperature of the top land is very high, up to800°C. The heat transfer coefficient of top land is chosen from test data ofrelatedresearch.the heat transfer coefficient of top land is estimated to be equal to 540 W/(m^{2o}C) .The analysis is a steady – state thermal one. The heat transfer between the piston and the oil film between the piston and the cylinder takes place by convection. The Heat transfer coefficients used for different parts of piston is given in Fig.

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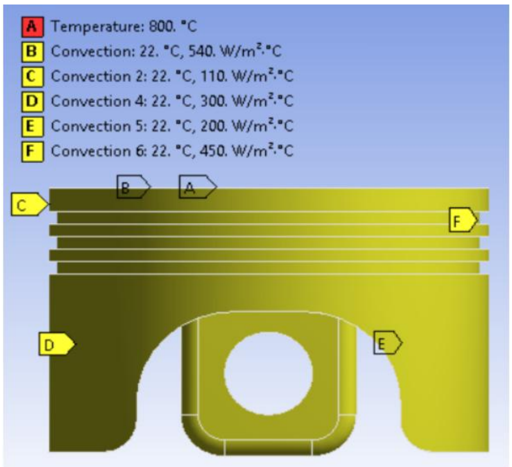

Fig2. Temperature and heat transfer coefficients

IV. MULTILAYER FLAT PLATE

Model can be considered for the heat transfer model on the sides of the piston. In this model, heat is transferred from the piston to the cooling water. The heat passes through different layers as it is transferred from Piston to cooling water. The heat is first transferred from piston to piston rings then to the cylinder sleeve by the oil in the gap and finally reaches the cooling water.The heat transfer coefficients of piston ring and skirt are taken from related test data.

V. MECHANICAL LOAD AND SUPPORT

The main mechanical stress being applied on the piston is the pressure of the gasses which is considered to be 6.5 Mpa and is applied on the top surface of piston head. The piston is given frictionless supports as shown in the Fig at two places. Static structural analysis is performed on the piston in Ansys.

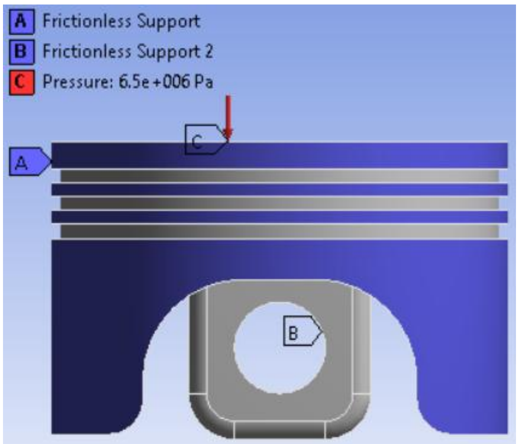

Fig3. Frictionless support to piston

VI. FINITE ELEMENT ANALYSIS OF PISTON

Finite element analysis method is used to perform analysis on the piston when it is subjected to thermal and mechanical loads. To perform the finite element analysis of the piston an analysis software Ansys Workbench is used. Linear static analysis takes place in this experiment, when small changes in rigidityoccur, direction of the loading does not change, the materials remain within linear elastic area and small deformations and stresses are produced.

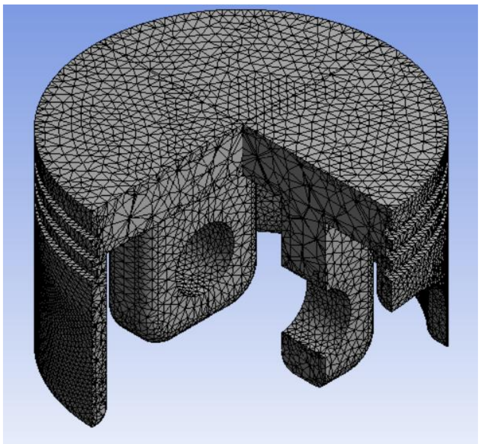

Fig4. Cross-section view of meshed piston

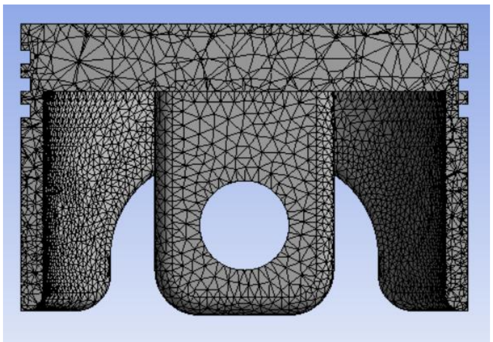

Fig5. Cross-section Side view of meshed piston

VI. THERMAL ANALYSIS ON PISTON

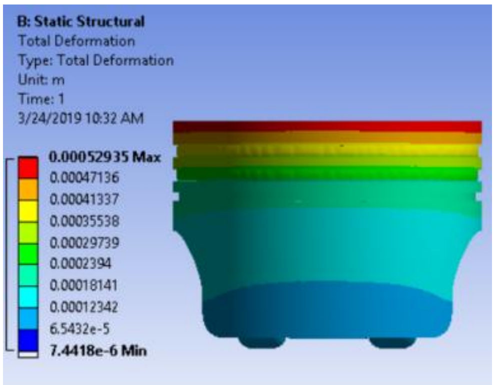

Fig6. Total deformation (42CrMo)

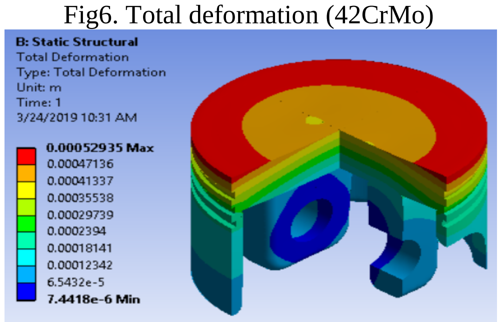

Fig7. Cross-section view Total deformation (42CrMo)

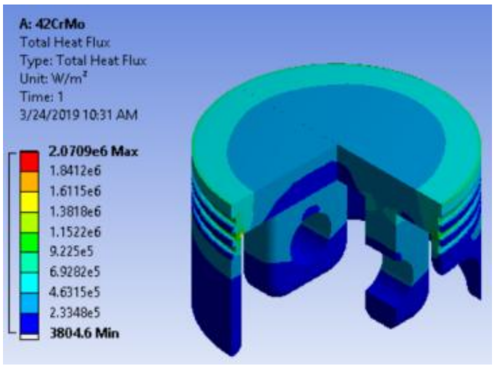

Fig8. Cross-section view Total Heat Flux (42CrMo)

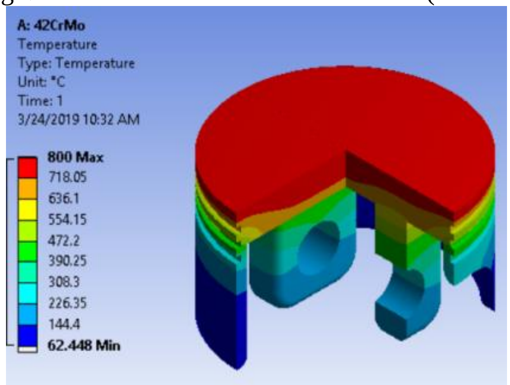

Fig9. Cross-section view Temperature distribution (42CrMo)

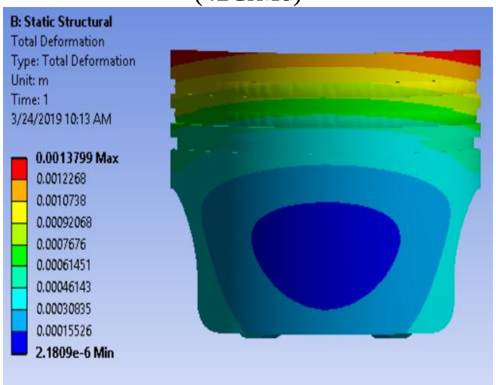

Fig10. Total deformation (Al-Mg-Si)

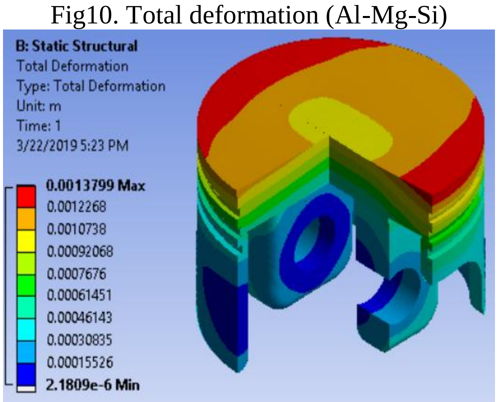

Fig11. Cross-section view Total deformation(Al-Mg-Si)

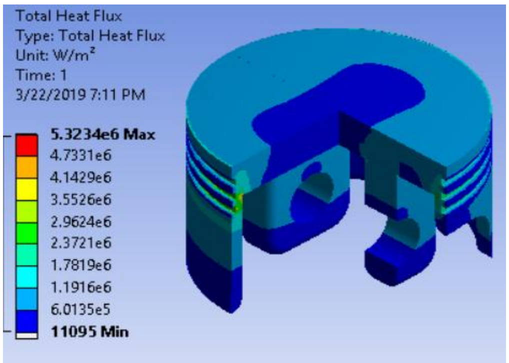

Fig12. Cross-section view Total Heat Flux (Al-Mg-Si)

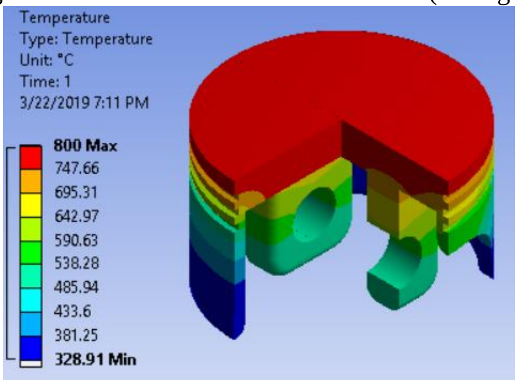

Fig13. Cross-section view Temperature distribution (Al-Mg-Si)

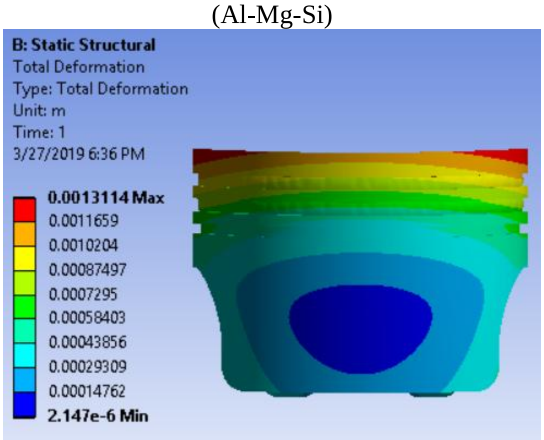

Fig14. Total deformation (Al-Si)

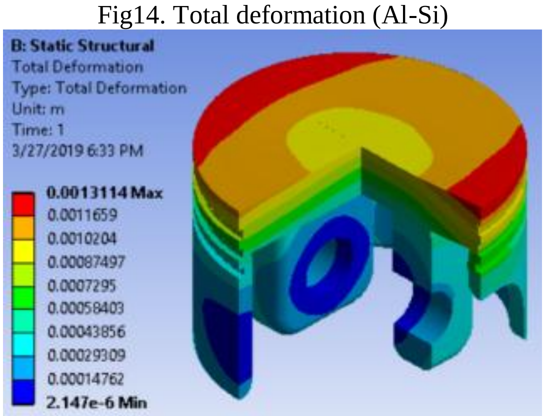

Fig15. Cross-section view Total deformation (Al-Si)

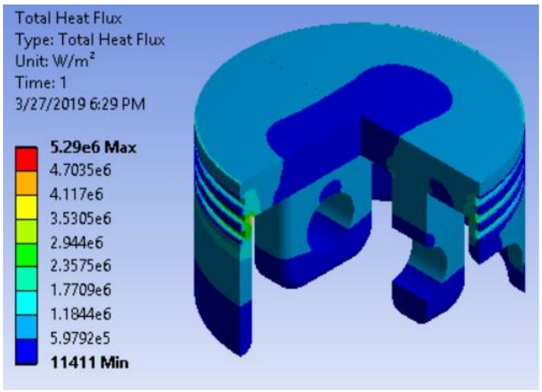

Fig16. Cross-section view Total Heat Flux (Al-Si)

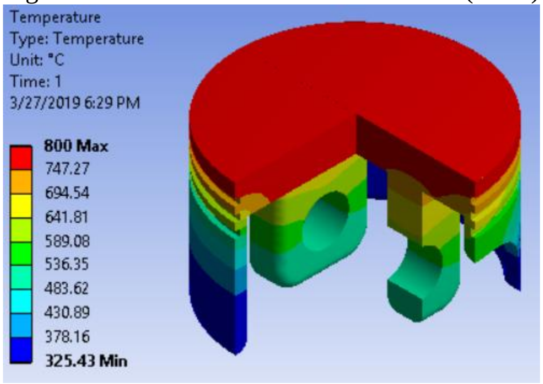

Fig17. Cross-section view Temperature distribution (Al-Si)

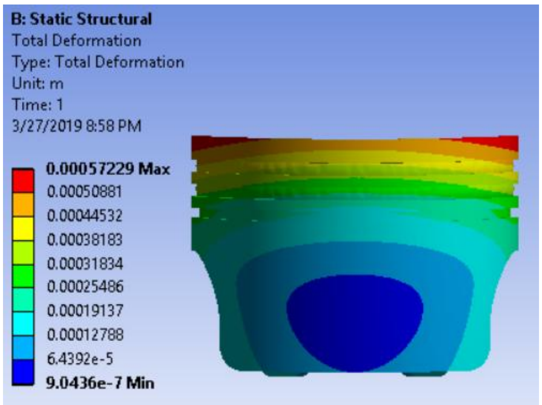

Fig18. Total deformation (Al-Si-C-12)

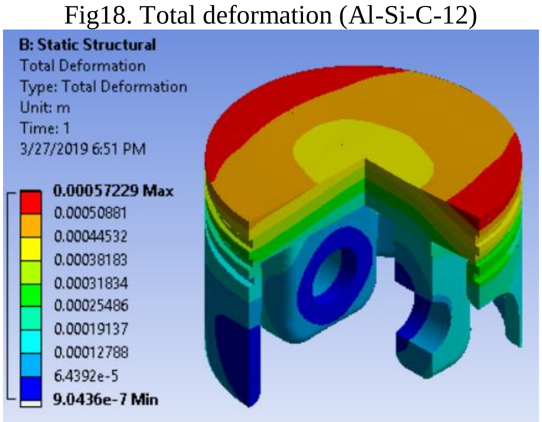

Fig19. Cross-section view Total deformation(Al-Si-C-12)

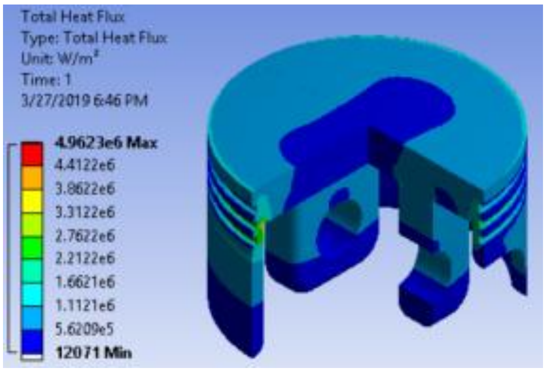

Fig20. Cross-section view Total Heat Flux (Al-Si-C-12)

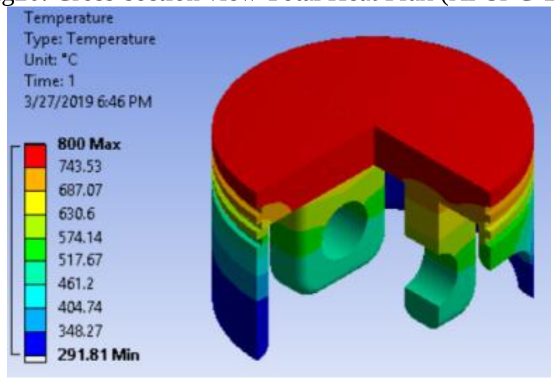

Fig21. Cross-section view Temperature distribution (Al-Si-C-12)

VIII.MINIMUM AND MAXIMUM DEFORMATION OF PISTON DUE TO THERMAL LOADS

Material	Min Deformation	Max Deformation
42CrMo	$7.4418e^{-6}$m	0.00052935m
Al-Mg-Si	$2.1809e^{-6}$m	0.13799m
Al-Si	$2.147e^{-6}$m	0.0013114m
Al-Si-C-12	$9.0436e^{-7}$m	0.00057229m

IX. MINIMUM AND MAXIMUM HEAT FLUX OF PISTON DUE TO THERMAL LOADS

Material	Min Heat Flux	Max Heat Flux
42CrMo	3804.6 W/m^2	$2.0709e^5$ W/m^2
Al-Mg-Si	11095 W/m^2	$5.3234e^5$ W/m^2
Al-Si	11411 W/m^2	$5.29e^5$ W/m^2
Al-Si-C-12	12071 W/m^2	$4.9623e^5$ W/m^2

X. MINIMUM AND MAXIMUM TEMPERATURE OF PISTON DUE TO THERMAL LOADS

Material	Min Temperature	Max Temperature
42CrMo	62.448 ^{0}C	800 ^{0}C
Al-Mg-Si	328.91^{0}C	800 ^{0}C
Al-Si	325.43 ^{0}C	800 ^{0}C
Al-Si-C-12	291.81 ^{0}C	800 ^{0}C

From the obtained results, it is observed that 42CrMo has the best thermal properties compared to Al-Mg-Si,Al-Si,Al-Si-C-12. 42CrMo displays high thermal conductivity and least deformation. It can withstand high temperatures and the lowest temperature on piston when thermal load is applied is just 62^{0}C, which is very low compared to other three materials.Al-Si-C-12 is the second best material after 42CrMo.

XI. STATIC STRUCTURAL ANALYSIS ON PISTON

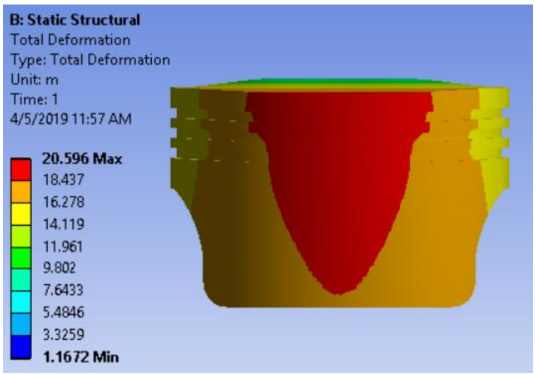

Fig22. Total deformation (42CrMo)

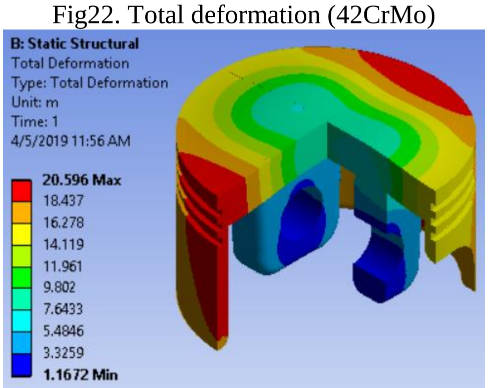

Fig23. Cross-section view Total deformation (42CrMo)

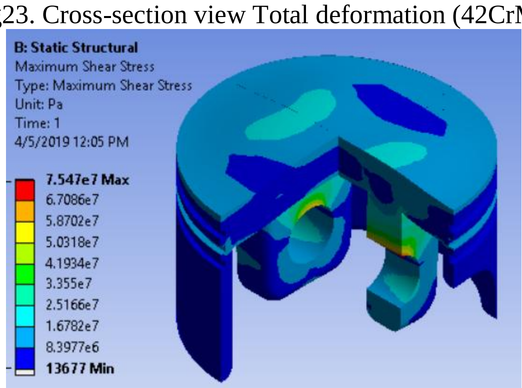

Fig24. Cross-section view Max. Shear stress (42CrMo)

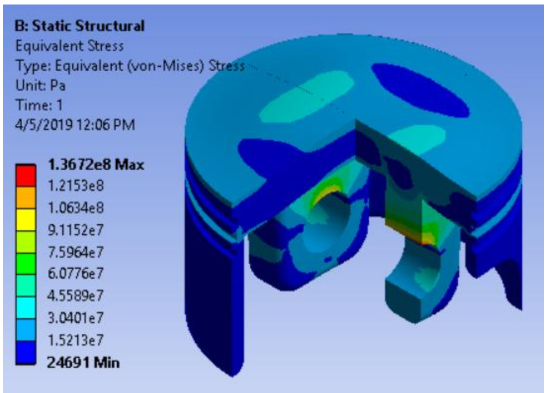

Fig25. Cross-section view Von-Mises stress (42CrMo)

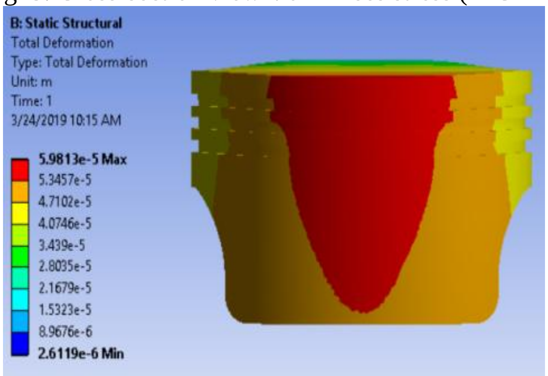

Fig26. Total deformation (Al-Mg-Si)

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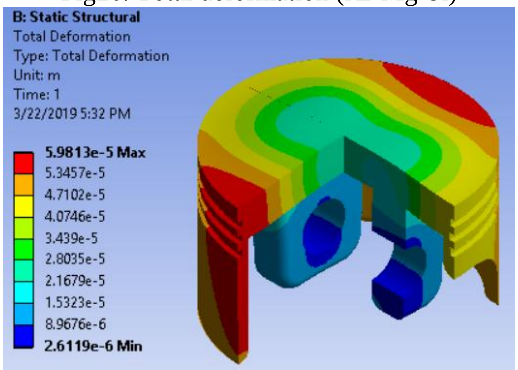

Fig27. Cross-section view Total deformation(Al-Mg-Si)

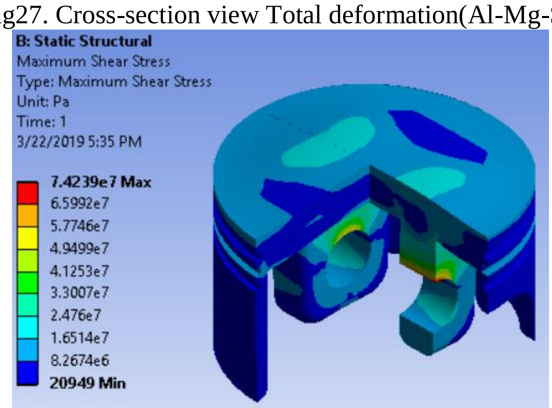

Fig28. Cross-section view Max. Shear stress (Al-Mg-Si)

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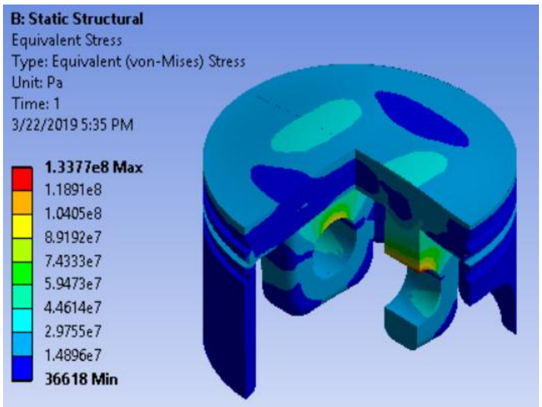

Fig29. Cross-section view Von-Mises stress (Al-Mg-Si)

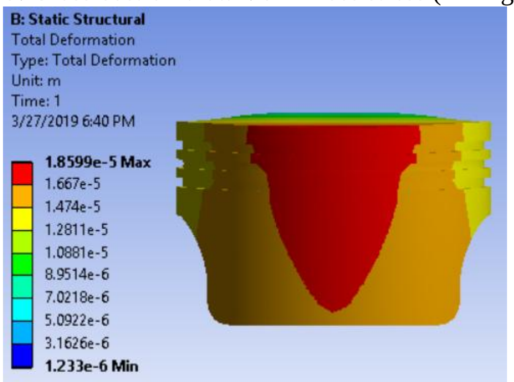

Fig30. Total deformation (Al-Si)

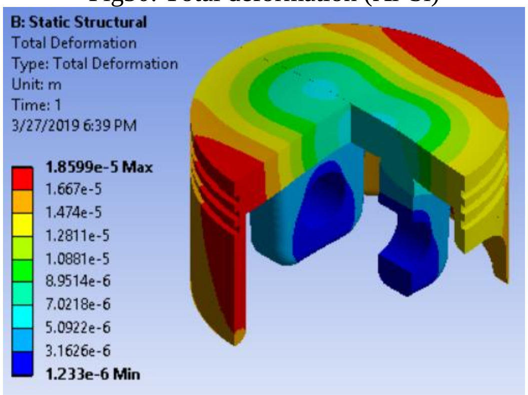

Fig31. Cross-section view Total deformation (Al-Si)

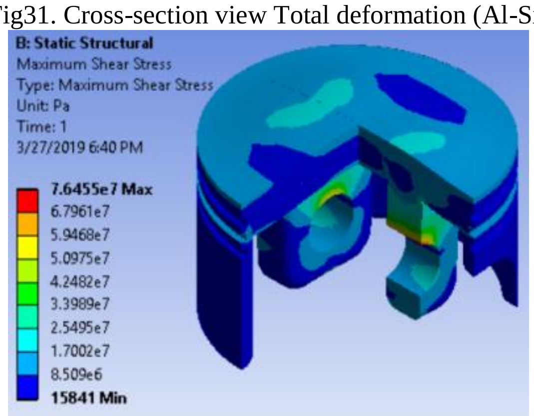

Fig32. Cross-section view Max. Shear stress (Al-Si)

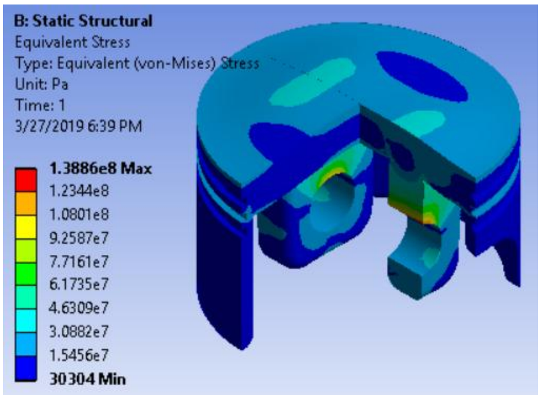

Fig33. Cross-section view Von-Mises stress (Al-Si)

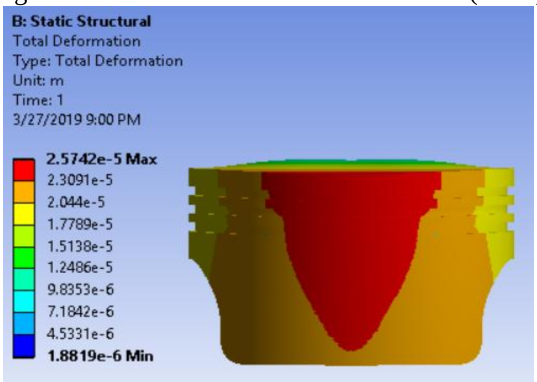

Fig34. Total deformation (Al-Si-C-12)

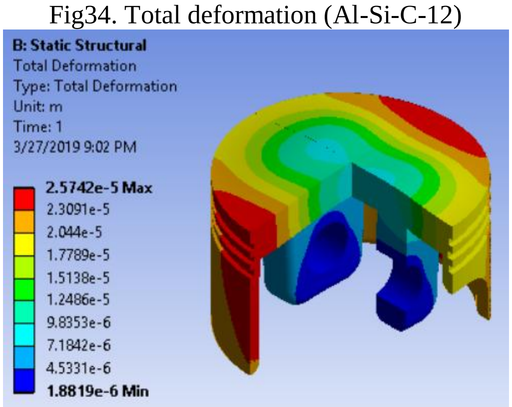

Fig35. Cross-section view Total deformation (Al-Si-C-12)

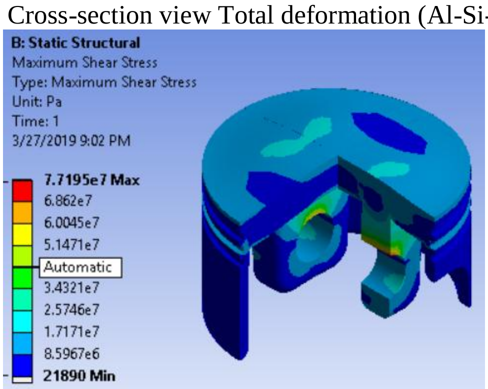

Fig36. Cross-section view Max. Shear stress (Al-Si-C-12)

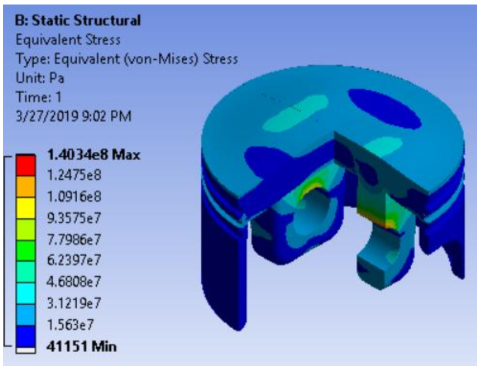

Fig37. Cross-section view Von-Mises (Al-Si-C-12)

XII.MINIMUM AND MAXIMUM DEFORMATION OF PISTON DUE TO MECHANICAL LOADS

Material	Min Deformation	Max Deformation
42CrMo	1.672 m	20.596 m
Al-Mg-Si	$2.6119e^{-6}$ m	$5.9813e^{-5}$ m
Al-Si	$1.233e^{-6}$ m	$1.8599e^{-5}$ m
Al-Si-C-12	$1.8819e^{-6}$ m	$2.5742e^{-5}$ m

XIII. MINIMUM AND MAXIMUM SHEAR STRESS ACTING ON PISTON DUE TO MECHANICAL LOADS

Material	Min Shear Stress	Max Shear Stress
42CrMo	13677 Pa	$7.547e^{7}$ Pa
Al-Mg-Si	20949 Pa	$7.4239e^{7}$ Pa
Al-Si	15841 Pa	$7.6455e^{7}$ Pa
Al-Si-C-12	21890 Pa	$7.7195e^{7}$ Pa

XIV. MINIMUM AND MAXIMUM VON-MISES STRESS ACTING ON PISTON DUE TO MECHANICAL LOADS

Material	Min Von-Mises Stress	Max Von-Mises Stress
42CrMo	24691 Pa	$1.3672e^{8}$ Pa
Al-Mg-Si	36618 Pa	$1.3377e^{8}$ Pa
Al-Si	30304 Pa	$1.3886e^{8}$ Pa
Al-Si-C-12	41151 Pa	$1.4034e^{8}$ Pa

From the results,It is observed that Al-Si undergoes least deformation compared to other metals and 42CrMo has lowest minimum Shear and Von-Mises stress developed. Al-Mg-Si has lowest Maximum Shear and Von-Mises stresses developed compared to all the other materials.

XV. TOTAL DEFORMATION WHEN BOTH MECHANICAL AND THERMAL LOADS ARE APPLIED

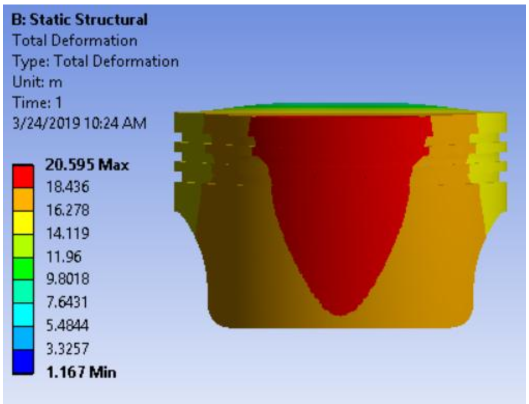

Fig38. Side view Total deformation (42CrMo)

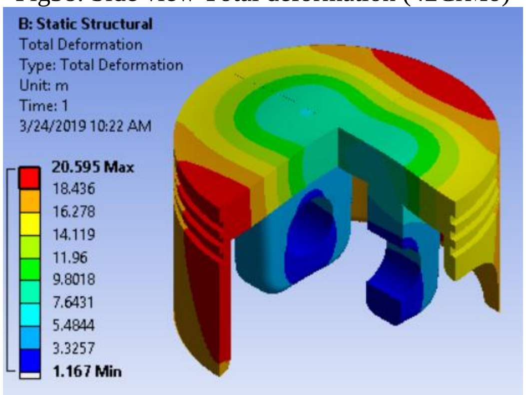

Fig39. Cross-section view Total deformation (42CrMo)

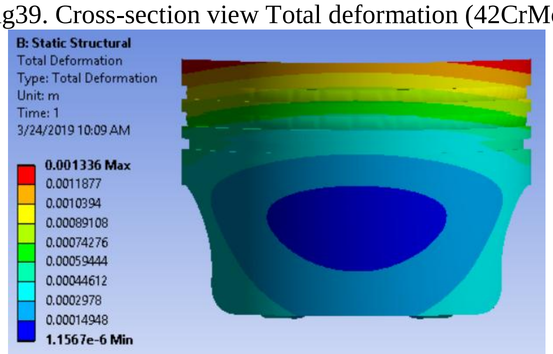

Fig40. Side view Total deformation (Al-Mg-Si)

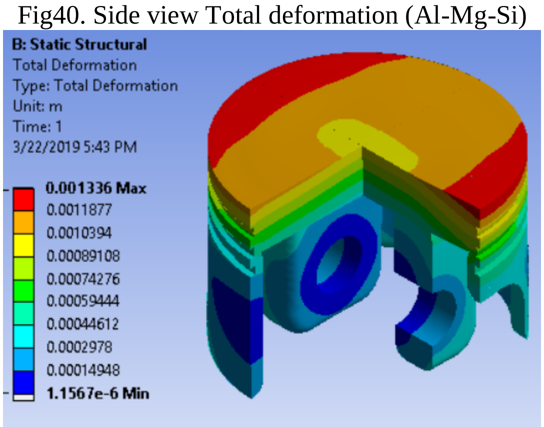

Fig41. Cross-section view Total deformation (Al-Mg-Si)

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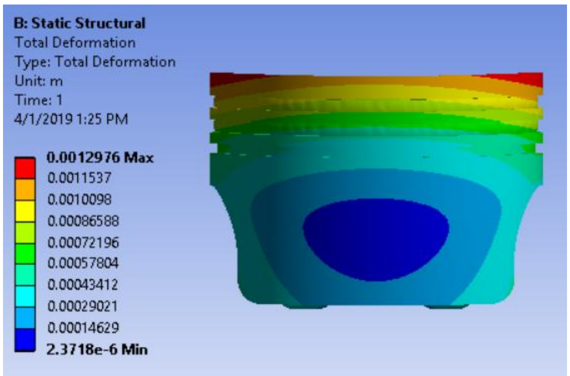

Fig42. Side view Total deformation (Al-Si)

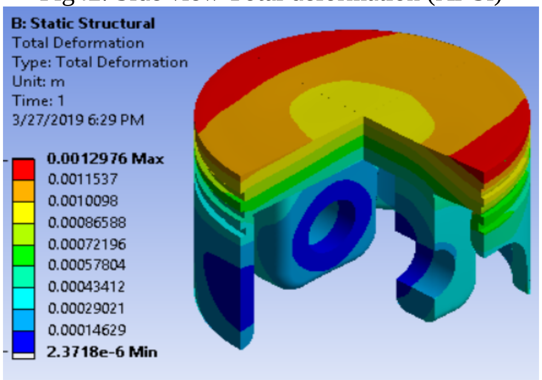

Fig43. Cross-section view Total deformation (Al-Si)

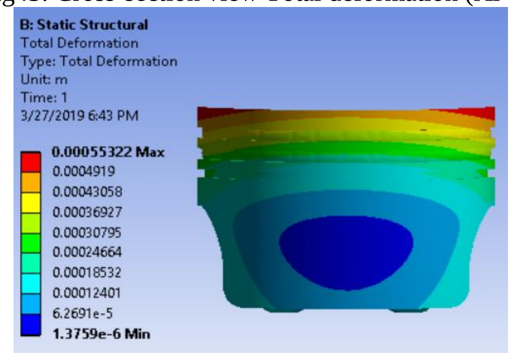

Fig44. Side view Total deformation (Al-Si-C-12)

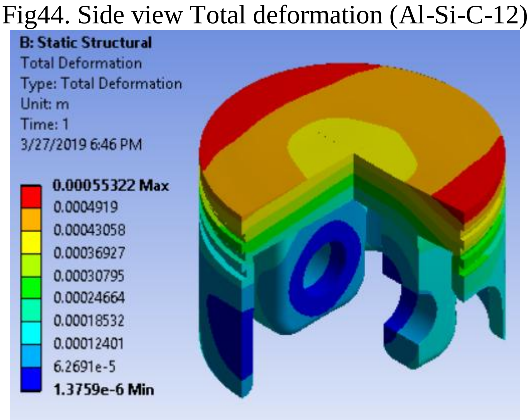

Fig45. Cross-section view Total deformation (Al-Si-C-12)

XVI.MINIMUM AND MAXIMUM DEFORMATION OF PISTON WHEN BOTH THERMAL AND MECHANICAL LOADS ARE APPLIED

Material	Min Deformation	Max Deformation
42CrMo	1.167m	20.595m
Al-Mg-Si	$1.1567e^{-6}$m	0.001336 m
Al-Si	$2.3718e^{-6}$m	0.0012976 m
Al-Si-C-12	$1.3759e^{-6}$m	0.00055322 m

When both Mechanical and Thermal loads are applied on the materials, Al-Si-C-12 is the material that undergoes least deformation while 42CrMo undergoes maximum deformation.

XVII.RESULTS

After performing analysis on 4 different alloys namely 42CrMo,Al-Mg-Si,Al-Si,Al-Si-C-12 and under three different load conditions (Mechanical loads, Thermal loads, Both Mechanical and Thermal loads), we can conclude that 42CrMo, Al-Si-C-12 undergo least deformation under thermal loads and under mechanical loads Al-Si, Al-Si-C-12 undergo least deformation. In case of Both Mechanical and Thermal loads Al-Si-C-12 undergoes the least deformation. This is mainly because while 42CrMo can withstand high temperatures but cannot withstand high mechanical loads and in case of Al-Si, it can withstand mechanical loads but cannot withstand high temperatures like 42CrMo. In case of Al-Si-C-12, it can withstand both mechanical and thermal loads. Hence Al-SI-C-12 undergoes least deformation when both mechanical and thermal loads are applied. In conclusion while designing a piston 42CrMo must be used to make the piston top land because it is the surface of piston that directly comes in contact with combustion of fuel and high temperatures and Al-Si-C-12 must be used for piston skirt and rest of the piston.

XVIII. FUTURE SCOPE

In this work simulation is carried out for four types of material 42CrMo, Al-Si, AlSic-12, Al-Mg-Si.This work can be extended to study for various materials and for different compositions. Different kinds of materials can be applied on various parts of piston depending on the type of loads that are applied on them and analysis can be performed. Simulation and flow analysis can be carries out.

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