Modeling and Analysis of I.C. Engine Piston

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Abstract

A piston is a reciprocating component of an I.C. engine which converts the chemical energy obtained from combustion of fuel into mechanical power. Failure of piston occurs due the induced thermal stresses and the mechanical stresses. The main objective of this work is to design a piston and analyze the temperature and stress distribution by performing structural analysis and thermal analysis on the piston. The factor of safety is determined for the four materials of piston. Modeling of piston is done in Creo parametric 5.0 software. The structural s and thermal analysis of piston is performed using ANSYS workbench and the factor of safety is determined. By determining the factor of safety of the materials, the material with highest factor of safety is to be used to increase the life of the piston.

Keywords
Piston, Creo parametric, ANSYS, factor of safety, structural analysis, thermal analysis.

1. Introduction
Piston is one of the mechanical components, invented by German scientist Nicholas August Otto in the year 1866. Piston is considered to be one of the most important part in a reciprocating Engine, reciprocating pumps, gas compressors and pneumatic cylinders, among the other similar mechanisms in which it helps to convert the chemical energy obtained by the combustion of fuel into useful mechanical power. A piston is a reciprocating component of an engine which is used to convert the chemical energy obtained by the combustion of fuel into mechanical power. The purpose of the piston is to transfer the energy to crankshaft via connecting rod. In the working condition piston produce the stress and deformation due to periodic load effect which produce from high gas pressure, high speed reciprocating motion of the inertia force and lateral pressure. In an I.C. engine, during the combustion stroke the fuel gets ignited. During the combustion process, high pressure and high temperature are developed in the engine cylinder. By the chemical reaction of burning the gas and high temperature generated make the piston expand and induces thermal stress and results in thermal deformation. The thermal and mechanical stresses cause deformation and also the piston cracks. This thermal deformation and mechanical deformation results in failure of piston. Therefore, it is very essential to analyse the stress distribution, thermal load, mechanical load in order to minimize the mechanical stresses and thermal stresses and increase the efficiency of the piston

1.1 Objectives
The objectives of this research work are to design a piston according to the design standards and perform structural and thermal analysis on the piston for four materials and determine the induced stresses and total deformation in materials of piston and finally determine the factor of safety for each material.

2. Literature Review
Viswanath investigate and analyze the stress distribution of the piston. Design and analysis of a piston using four different materials is carried out in the work. Materials like Ti-6Al-4V, Al alloy 4032, Copper, Al alloy 2024 are used for structural and thermal analysis of the piston. Applied the pressure as 13.6 MPa and temperature of 1500 degree centigrade on the piston head. Kashyap used FEA in research to describe the stress distribution. The mesh optimization is described in this study, which uses a finite element analysis technique to anticipate the component's greater stress and critical region. The piston head, as well as the piston skirt and sleeve, is optimized to reduce stress concentration. Pachpande analysis is carried out on aluminum alloy structural and thermal analysis of piston. In this work the value of displacement, stresses have been found out. Kunal study deals with the various loads which are acting on piston.

The paper study costs and materials optimization with the help of stress analysis by FEA technique. The designation material is steel alloy. Viswabharathy work is carried out to measure the stress and temperature distribution on the top surface of the piston. Pistons 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. Jadhav failure of piston due to various thermal and mechanical stresses is analyzed and the analysis results are used to optimize geometry of piston. The maximum stress intensity is on the bottom surface of the piston crown. Siva piston made of two different materials Al alloy 4032 & AISI 4340 Alloy steel are analyzed. Their structural analysis shows that the maximum stress intensity is on the bottom surface of the piston crown in all the materials. Depending on the thermal conductivity of the materials, heat transfer rate is found maximum in Al alloy piston. Aditya the stress reduction is very important factor which is responsible for the designing of piston crown or piston head. In this work the main consideration is to optimize the piston with reduction of piston weight. The material of the piston becomes reduced. Then the optimized result of the piston obtained. Knowledge gap is identified to found the factor of safety of four materials which are considered

3. Methods

The dimensions of the piston have been taken as input and the design of piston has been carried out in Creo Parametric 5.0 software. The CAD model of the piston designed in Creo has been imported into ANSYS workbench in .iges format. The imported geometry has been subjected to mesh generation and various properties of the materials have been assigned and structural analysis and thermal analysis have been performed on the piston in ANSYS workbench. The induced von mises stresses and the total deformation have been calculated and finally the factor of safety for various materials has been determined.

4. Materials

For the analysis of piston four materials have been selected and structural analysis and thermal analysis have been performed on the piston. The material selection is based on the properties of material which a piston should have. The materials selected for analysis of piston are –

- Aluminium alloy 2024
- Aluminium alloy 4032
- Nickel chromium
- Phosphor bronze

Aluminium alloy 2024 is an Aluminium alloy, with copper as the primary alloying element. It is used in applications requiring high strength to weight ratio, as well as good fatigue resistance. The chemical composition of Aluminium alloy 2024 is shown in Table 1.

Table 1. Composition of Al alloy 2024

Element	**Percentage**
Aluminium	93%
Copper	5%.
Magnesium	2%

The mechanical properties of Aluminium alloy 2024 is shown in Table 2.

Table 2. Properties of Aluminium 2024

Property	**Value**
Young's modulus	73 GPa
Poisons ratio	0.3
Density	2.78 g/cm^3
Thermal conductivity	121 W/mK

Aluminium alloy 4032 also known as silumin is an Aluminium alloy, with silicon as the primary alloying element. It is used in applications requiring high strength to weight ratio, as well as good fatigue resistance. The chemical composition of Aluminium alloy 2024 is shown in Table 3

Table 3. Composition of Al alloy 4032

Element	**Percentage**
Aluminium	85%
Silicon	12%.
Magnesium	3%

The mechanical properties of Aluminium alloy 4032 is shown in Table 4

Table 4. Properties of Aluminium 4032

Property	**Value**
Young's modulus	68 GPa
Poisons ratio	0.34
Density	2.6 g/cm^3
Thermal conductivity	138 W/mK

Nichrome also known as NiCr, nickel-chromium or chromium-nickel is an alloy of nickel and chromium. The chemical composition of Nickel Chromium is shown in Table 5.

Table 5. Composition of Ni-Cr

Element	**Percentage**
Nickel	80%
Chromium	18%
Silicon	2%

The mechanical properties of Nickel Chromium are shown in Table 6.

Table 6. Properties of Nickel Chromium

Property	**Value**
Young's modulus	200 GPa
Poisons ratio	0.32
Density	7.6 g/cm^3
Thermal conductivity	17 W/mK

Phosphor bronze is a copper alloy which is composed of copper that is alloyed with tin and phosphorus. The chemical composition of Phosphor Bronze is shown in Table 7.

Table 7. Composition of Phosphor Bronze

Element	Percentage
Copper	93%
Tin	5%
Phosphorus	2%

The mechanical properties of Phosphor Bronze are shown in Table 8.

Table 8. Properties of Phosphor Bronze

Property	Value
Young's modulus	110 GPa
Poisons ratio	0.34
Density	9 g/cm^3
Thermal conductivity	62 W/mK

5. Results and Discussion

The piston is applied fixed constraints at the piston pin hole and the structural analysis of piston is performed and the total deformation and the factor of safety of each of the selected four materials has been found out.
The structural analysis when performed on Aluminium alloy 2024, is shown in Figure.1

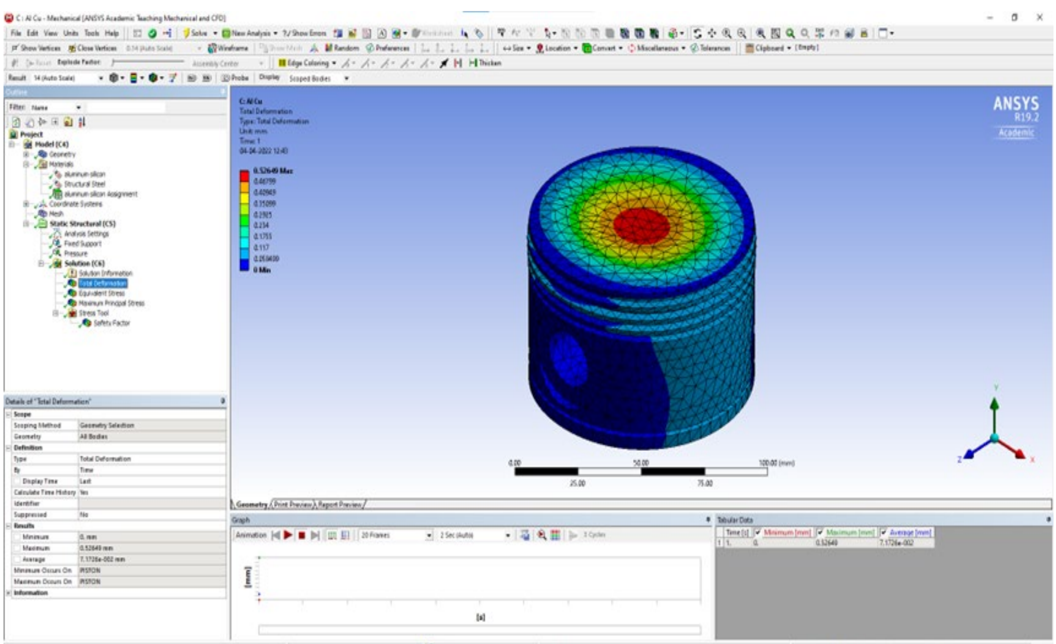

Figure 1. Total deformation of Aluminium alloy 2024 piston

The factor of safety obtained for Aluminium alloy 2024 is 7.2. The analysis is shown in Figure 2

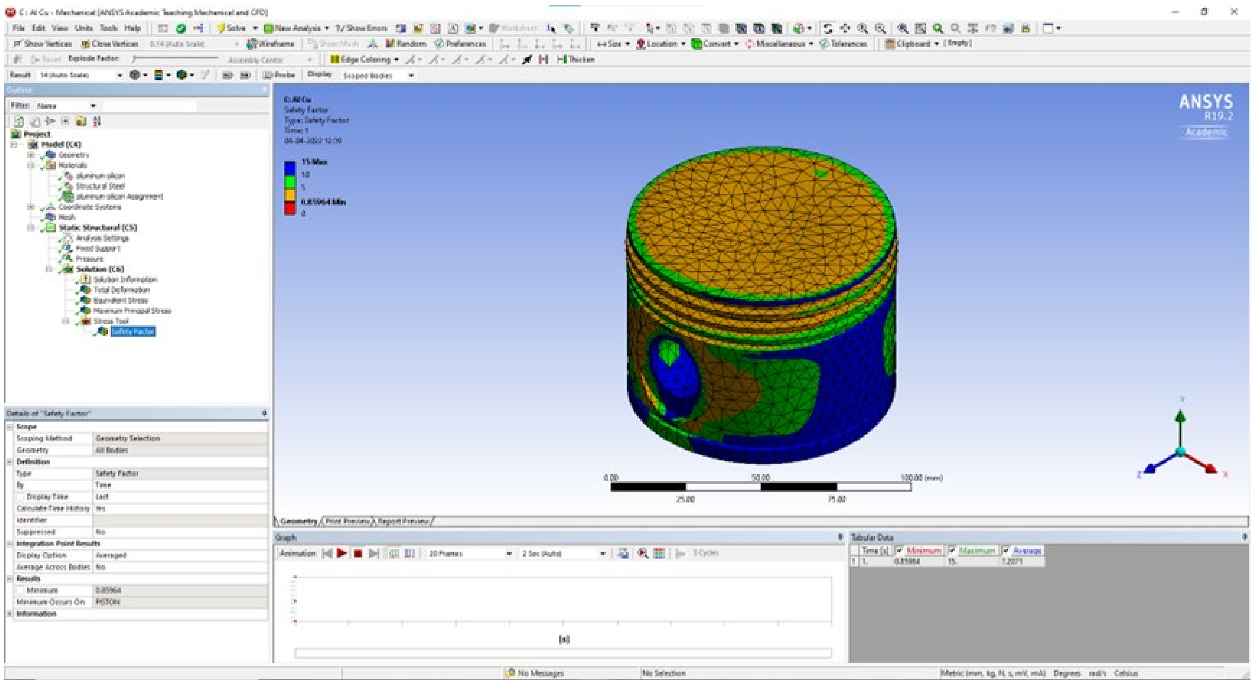

Figure 2. Factor of safety obtained for Aluminium alloy 2024 piston

The total deformation obtained for Aluminium alloy 4032 piston 0.63 mm. The analysis is shown in Figure 3

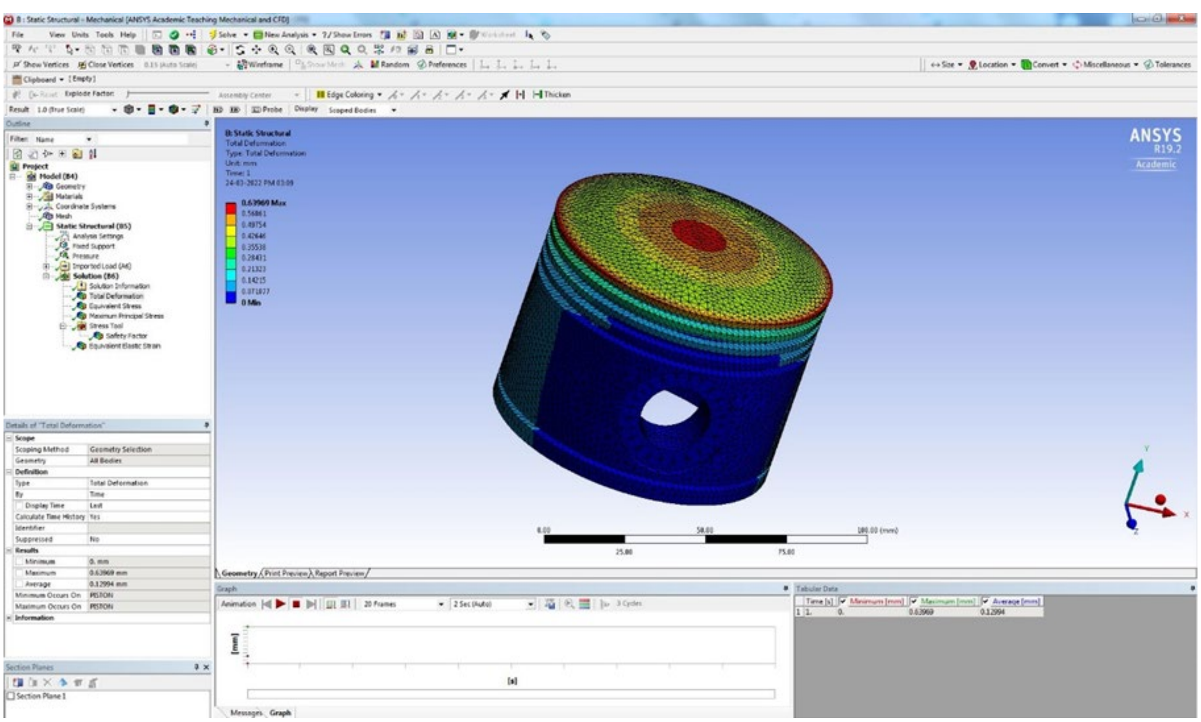

Figure 3. Total deformation of Aluminium alloy 4032 piston

The factor of safety obtained for Aluminium 4032 is 5.21. The analysis is shown in Figure 4

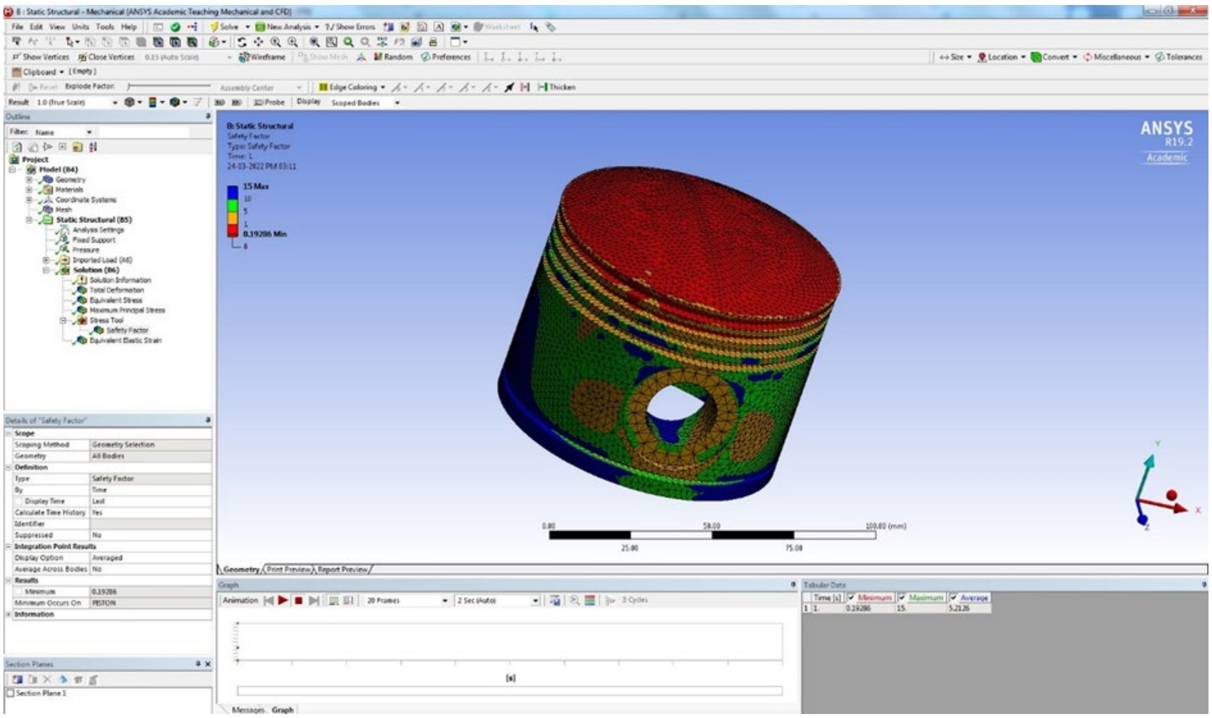

Figure 4. Factor of safety of Aluminium alloy 4032 piston

The total deformation obtained for Phosphor Bronze piston is 0.35. The analysis is shown in Figure 5

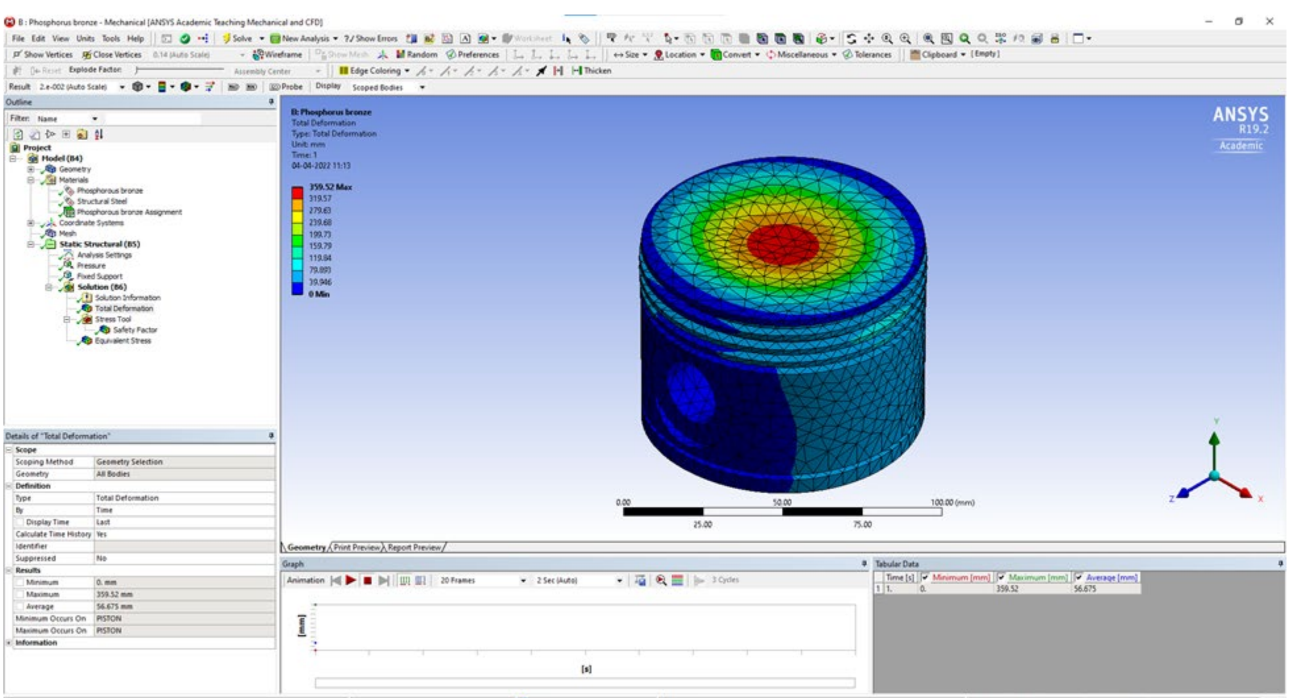

Figure 5. Total deformation of Phosphor Bronze piston

The factor of safety obtained for Phosphor Bronze is 7.28. The analysis is shown in Figure 6

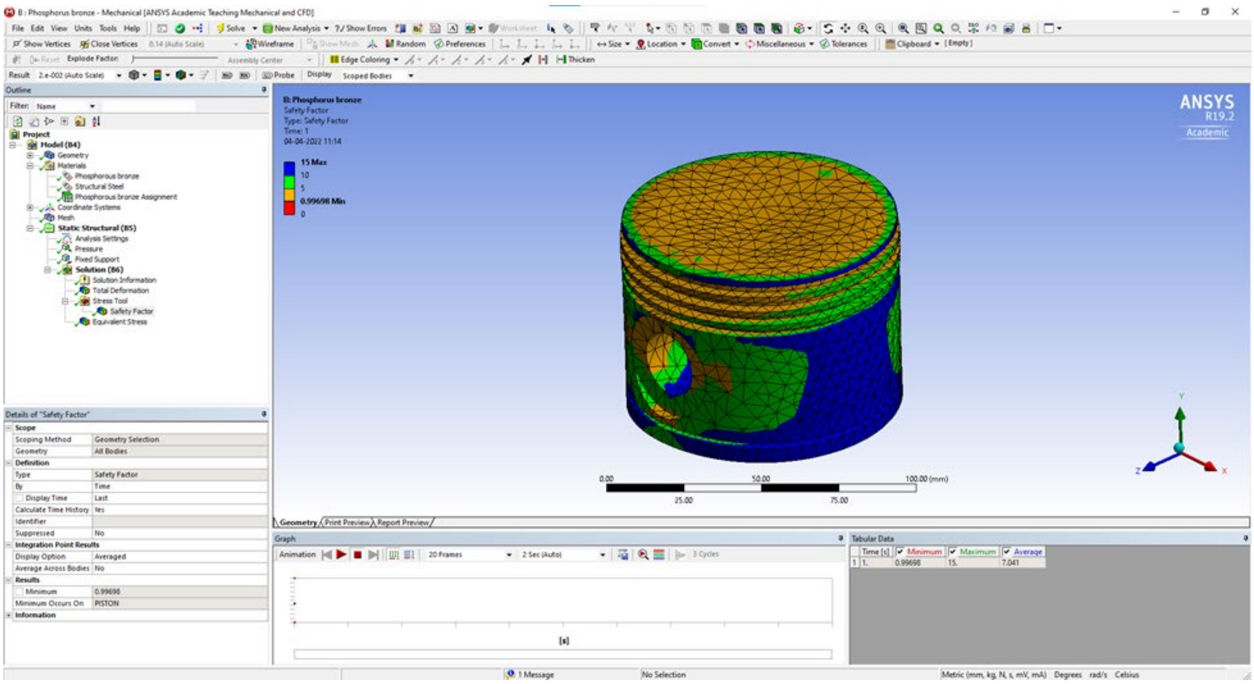

Figure 6. Factor of safety of Phosphor Bronze piston

The total deformation obtained for a Nickel Chromium piston is 0.26. The analysis is shown in Figure 7.

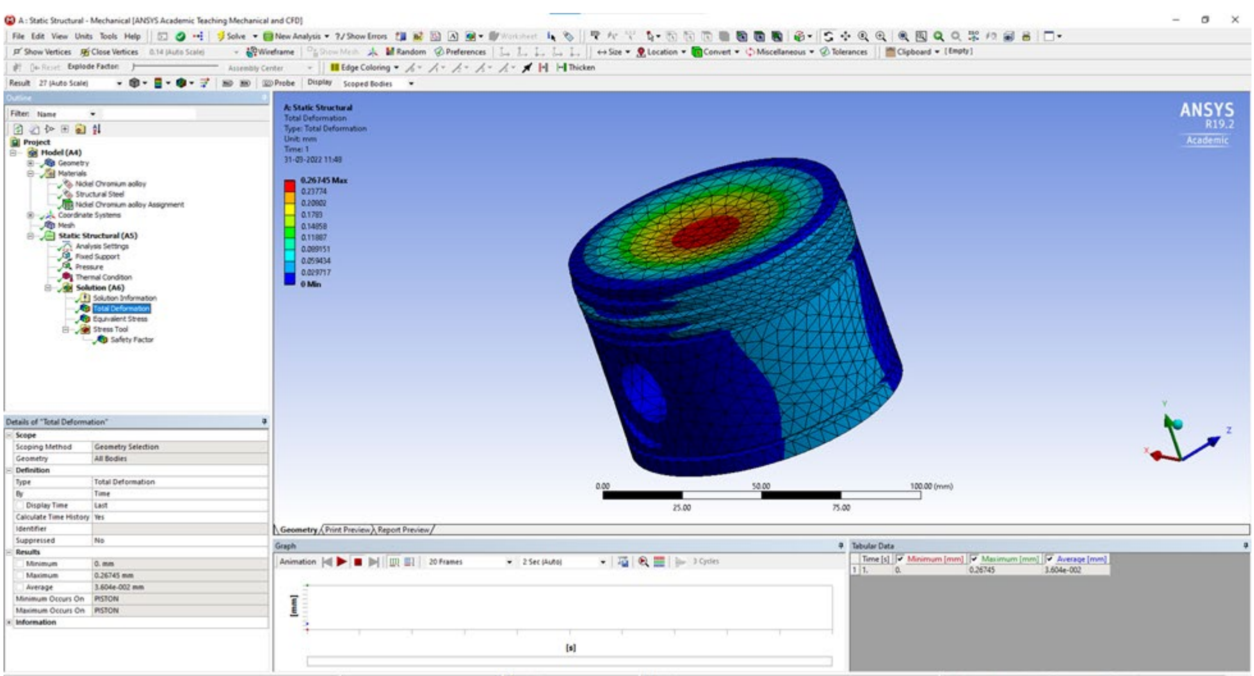

Figure 7. Total deformation obtained for Nickel Chromium piston

The factor of safety obtained for the Nickel Chromium piston is 6.83. The analysis is shown in Figure 8

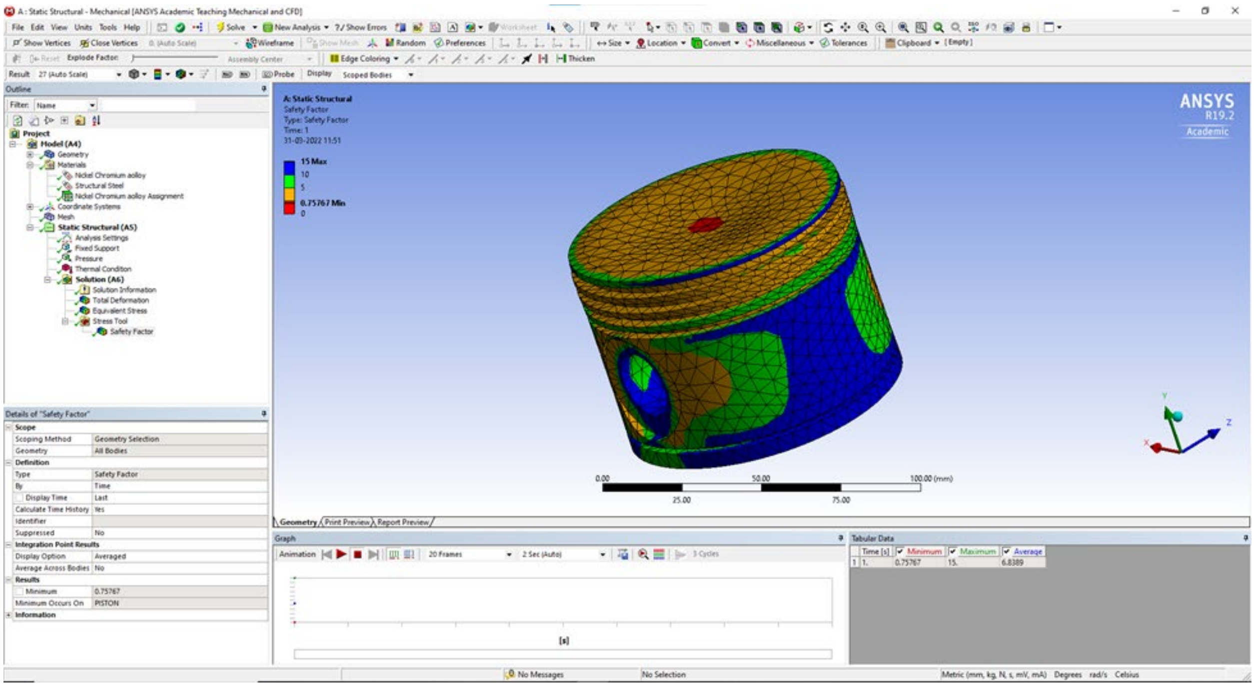

Figure 8. Factor of safety of Nickel Chromium piston

The results obtained in the analysis of piston for the four materials have been tabulated in Table 9.

Table 9. Analysis of piston

S. No.	**Material**	**Von-mises Stress (MPa)**	**Total Deformation (mm)**	**Factor of Safety**
1.	Aluminium alloy 2024	77.57	0.52	7.20
2.	Aluminium alloy 4032	139.49	0.63	5.21
3.	Nickel Chromium	80.40	0.26	6.83
4.	Phosphor Bronze	82.91	0.35	7.28

6. Conclusion

From the experiments it has been concluded that the piston made of Aluminium Alloy 2024 and Phosphor Bronze have better factor of safety and thus can be more efficient during the working. So, by choosing Aluminium Alloy 2024 and Phosphor Bronze as material for the manufacturing of piston the life span and efficiency of piston can be improved. The total deformation occurred for a phosphor bronze piston is very less i.e., 0.35mm and the deformation for Aluminium Alloy 2024 is 0.52mm. The factor of safety of Phosphor Bronze piston obtained is 7.28 and the factor of safety of Aluminium Alloy 2024 is 7.20. Hence by using Phosphor Bronze or Aluminium Alloy 2024 the efficiency of piston can be improved.

Future scope of work

The same work is extended with above materials under fatigue loading conditions.

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Biography

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