© 2017 IJSRSET | Volume 3 | Issue 8 | Print ISSN: 2395-1990 | Online ISSN : 2394-4099
Themed Section : Engineering and Technology

Comparative Analysis of Different Types of Pistons of Hatchback Cars

Mayur Mistry[1], Nayan Mistry[2]
[1]Mechanical Engineering, Parul University, Vadodara, Gujarat, India
[2]Mechanical Design Engineer, Institute for Plasma Research, Bhat, Gandhinagar, Gujarat, India

ABSTRACT
Piston is a reciprocating component of the IC engine, which produces reciprocating motion and converts the reciprocating motion into rotary motion with the help of crankshaft connected with it. There are several types of pistons available in the market. Among them, the three most basic types of pistons are flat type, crown type and disc type. They are designed and used according to their advantages, limitations and applications. The hatchback cars available in the market contains flat type piston. They are used because of their ease of manufacturing and low cost of production. Our aim of the project is to check the compatibility of crown and disc type of piston in hatchback and sedan cars instead of flat type piston by carrying on pressure analysis, thermal analysis and thermo-mechanical analysis using ANYSYS software and compare the results with that of the flat type piston. The modelling of the pistons is carry out in Creo 2.0 parametric software.
Keywords: Design, Analysis, Pistons.

I. INTRODUCTION

A piston is one of the primary components of I.C engines, pumps, compressors and pneumatic cylinders. To prevent the combustion gases from escaping the piston, it is provided with piston rings. It is housed inside a cylinder and it converts the energy of expanding gases into mechanical energy. They are commonly made up of aluminium and cast iron alloys. As it is being considered the heart of the engine, it is most likely to be subjected to forces, internal stresses, piston side wear, piston head cracks and damages like thermal fatigue, mechanical fatigue. Hence, it becomes a necessary part to subject the piston to structural analysis and also scrutinize the piston for thermal stress distribution at real engine conditions. From these results, various aspects to improvise piston life and also improve engine power and efficiency can be known. Aspects such as which piston material to use, which type of piston head to use for better results can be known. Many softwares like ANSYS, SOLIDWORKS, CATIA, PRO/ENGINEER etc are used to carry out the design of piston. Finite Element Analysis can be done to calculate thermal and stress analysis.

II. OBJECTIVE

In hatchback cars, normally flat type pistons are used in the cylinders of the engine. They are easy to manufacture and are least expensive among all the pistons. The main aim of our project is to check the various parameters and forces, the flat piston is subjected to, and compare the data with that of crowned and dished type pistons and also look at the various analyses such as pressure analysis, thermal analysis and thermos-mechanical analysis of all three basic types of piston and also compare them on that basis.

III. TYPES OF PISTON

1) Flat Piston
2) Dome/Crown Piston
3) Bowl Piston

A. Piston parts

- Piston head/Crown
- Piston barrel
- Piston rings
- Piston skirt
- Reinforcing ribs
- Piston (gudgeon) pin
- Connecting rod

B. Piston Materials selection

1. Cast Iron

- **Advantages:** The cast iron has good strength and good wear resistance at high temperatures. It has low coefficient of thermal expansion.
- **Disadvantages:** The cast iron has high weight and low thermal conductivity.
- **Uses:** For moderate power engines with piston speeds below 6 m/s, cast iron pistons are used. the

2. Aluminium alloys

- **Advantages:** The aluminium alloys have light weight and good thermal conductivity. The aluminium is 3 times lighter than cast iron.
- **Disadvantages:** Aluminium alloys exhibit fast reduction in strength at high temperature and high coefficient for thermal expansion.
- **Use:** The strength of forged aluminium pistons is 40% higher than the aluminium pistons made by die casting. Hence, forged aluminium pistons are used for heavy duty, high speed C.I. engines and aircraft engines. For high power engines and piston speeds above 6 m/s, aluminium pistons are used.

3. Alloy cast steel and alloy forged steel

Alloy cast steel pistons are used in some automotive engines while forged steel pistons are used in some aircraft engines.

Table 1. Material Properties

Parameters	Unit	Cast Iron	Aluminium Alloy
Modulus of Elasticity	MPa	110E+03	68.9 E+03
Yield tensile strength	MPa	170	276
Ultimate tensile strength	MPa	240	310
Compressive strength	MPa	860	607
Shear strength	MPa	330	207
Density	Kg/m3	7200	2700
CTE	°C	0.1E-06	25.2 E-06
Thermal conductivity	W/m °C	46.5	167
Poisson's ratio	--	0.26	0.33

C. Design considerations for a piston

- It should have enormous strength to withstand high pressure.
- It should have minimum weight to withstand inertia forces.
- It should form effective oil sealing in the cylinder.
- It should provide sufficient bearing area to prevent undue wear.
- It should 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.

IV. ANALYTICAL APPROACH

Nomenclature

IP = indicated power produced inside the cylinder (W)
η = mechanical efficiency = 0.8
n = number of working stroke per minute
= N/2 (for four stroke engine)
N = engine speed (rpm)
L = length of stroke (mm)
A = cross-section area of cylinder (mm2)
mp = mass of the piston (Kg)
V = volume of the piston (mm3)
th = thickness of piston head (mm)
D = cylinder bore (mm)
pmax = maximum gas pressure or explosion pressure (MPa)
σt = allowable tensile strength (MPa)
σut = ultimate tensile strength (MPa)
F.O.S = Factor of Safety = 2.25
K = thermal conductivity (W/m K)
Tc = temperature at the centre of the piston head (K)
Te = temperature at the edge of the piston head (K)
HCV = Higher Calorific Value of fuel(KJ/Kg)
BP = brake power of the engine per cylinder (KW)
m = mass of fuel used per brake power per second (Kg/KW s)
C = ratio of heat absorbed by the piston to the total heat developed in the cylinder = 5% or 0.05
t1 = thickness of piston barrel at the top end(mm)
t2 = thickness of piston barrel at the open end (mm)
ls = length of skirt (mm)
μ = coefficient of friction (0.01)

l1 = length of piston pin in the bush of the small end of the connecting rod (mm)

A. Design Procedure

1. Thickness of the Piston Head:

According to Grashoff's formula the thickness of the piston head is given by:

$$t_h = D\sqrt{(3p_{max}/16\sigma_t)}$$

Where, $\sigma_t = \underline{\sigma_{ut}}$

$= 2.25$ MPa

$$t_h = 110\sqrt{3(5)/16(35)}$$

$= 18$ mm

Empirical formula:

$$t_h = 0.032\,D + 1.5$$

$= 0.032(110) + 1.5$

$= 5.02$ mm

On the basis of the heat dissipation, the thickness of the piston head is given by:

$$t_h = \frac{[\,C \times HCV \times m \times BP\,] \times 10^6}{12.56 \times K\,(T_c - T_e)}$$

$$= \frac{[0.05 \times 42000 \times 10^{3} \times 4.16 \times 10^{-5} \times 11.4] \times 10^6}{12.56 \times 46.6(220)}$$

$= 8$ mm

Taking larger of the two values, so the thickness of the piston is 18 mm.

2. Piston Barrel Thickness of piston barrel at the top end:

$t_1 = t_h = 18$ mm

3. Length of the skirt:

$l_s = (0.6\,D \text{ to } 1\,D)$

$= 110$ mm

4. Length of piston pin in the connecting rod bushing:

$l_1 = 45\%$ of the piston diameter

$= 0.45 \times 1100$

$= 49.5$ mm

5. Piston pin diameter:

$d_o = (0.28\,D \text{ to } 0.38\,D)$

$= 48$ mm

The centre of the piston pin should be 0.02 D to 0.04D above the centre of the skirt.

B. *Stress calculation*

1. Material-Cast Iron:

a) Stress on piston crown

$$\sigma_b = \frac{3pD^{2}}{16t_h^{2}}$$

b) Thermal stress on piston

$\sigma_t = E \times CTE \times$ Temperature difference

$= E \times \alpha \times (T_c - T_e)$

c) Thermo-mechanical stress

$\sigma_{tm} = \sigma_b + \sigma_t$

Table 2. Analyatical Stress Summary

	Structural stress (N/mm^2)	Thermal stress (N/mm^2)	Thermo-mechanical stress (N/mm^2)
Flat piston	35.011	2.42	37.211
Crown piston	21.44	2.42	23.86
Disc piston	21.44	2.42	23.86

V. DESIGN & ANALYSIS

Following figure 1 shows the dimensions of the piston prepared in Creo software.

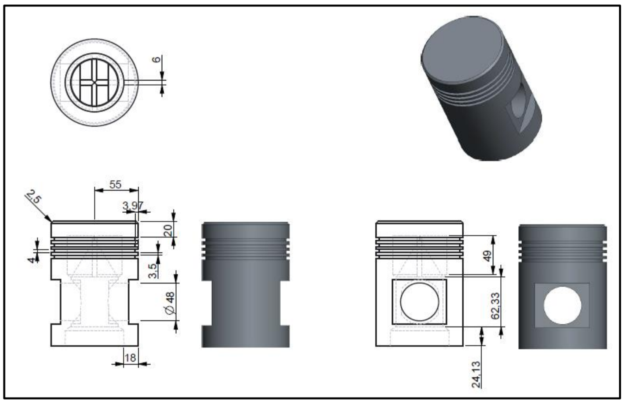


Figure 1. Model of flat piston

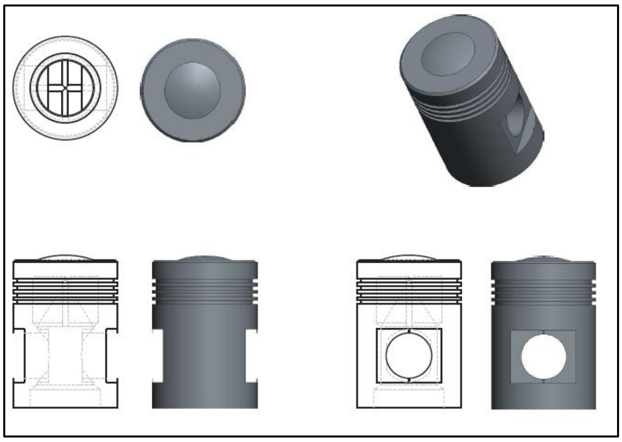


Figure 2. Model of crown piston

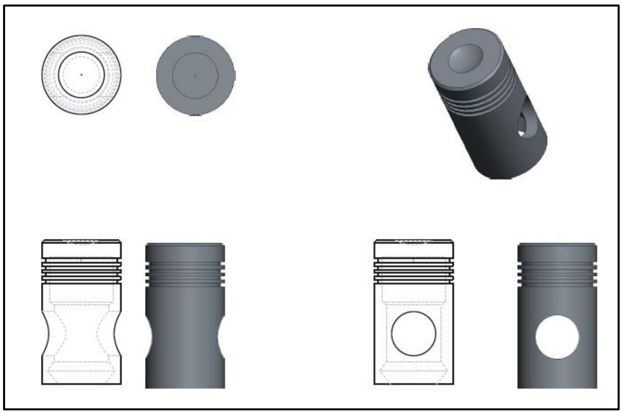
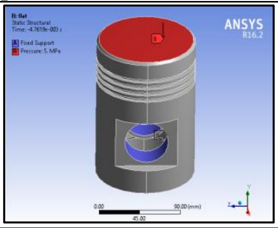
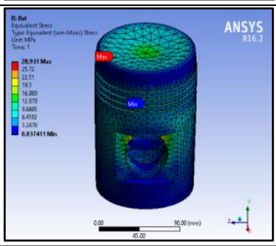
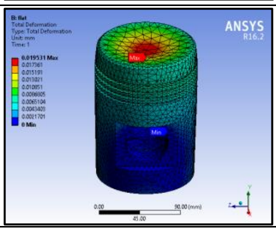


Figure 3. Model of disc piston

A. Analysis of Flat-Piston

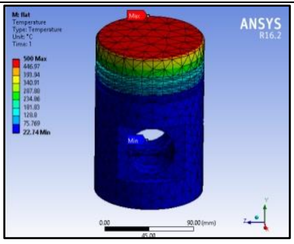
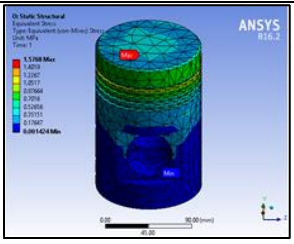
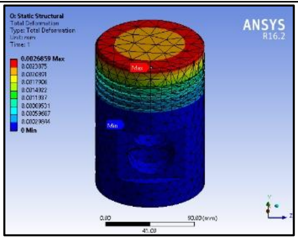
1) Structural Analysis of piston

Combustion of gases in the combustion chamber exerts pressure on the head of the piston during the power stroke. We will take this pressure force as boundary condition in structural analysis using ANSYS16 Workbench. A fixed support is given at the surface of the pin hole because the piston will move from top dead centre (TDC) to bottom dead centre (BDC) with the help of fixed support at the pin hole. So the amount force produced by the explosion of gas will causes the failure of the piston pin (including bending stress). Pressure acting on the piston = 5 N/mm2.

	Fixed boundary condition
	Stress – 28.9 MPa
	Deformation – 0.0195 mm

2) Thermal analysis of piston

The material of the piston is cast iron. For a cast iron piston, the temperature at the centre of the piston head (TC) ranges from 425°C to 450°C under full load conditions and temperature at the edges of the piston head (TE) ranges from 200°C to 225°C. The overall temperature difference between the TC and TE for Grey Cast Iron is 220°C.

	Thermal condition
	Stress – 1.5768 MPa
	Deformation – 0.00268 mm

3) Thermo-mechanical analysis

Pressure and temperature both are applied in the working condition in automobile IC engine. So in this analysis, both pressure and temperature are applied on the piston. Pressure = 5 N/mm2, Temperature = 250°C to 500°C.

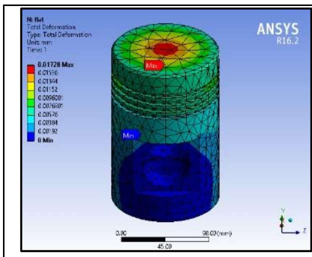
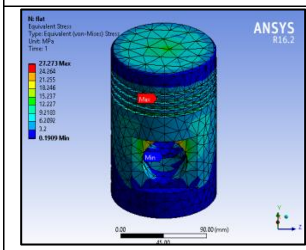
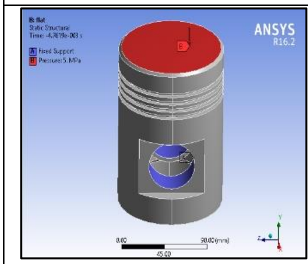
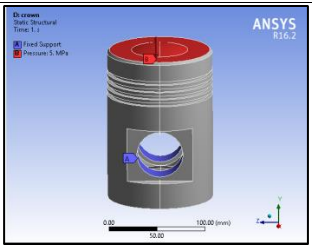
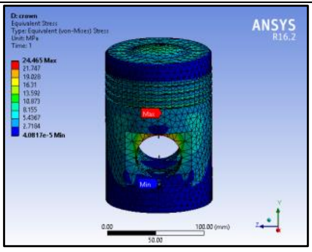
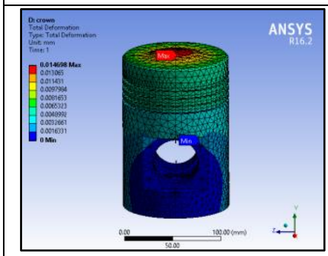
	Boundry condition
	Stress – 27.273 MPa
	Deformation – 0.01728 mm

Table 3. Comparison of Analytical and FEA analysis results for piston

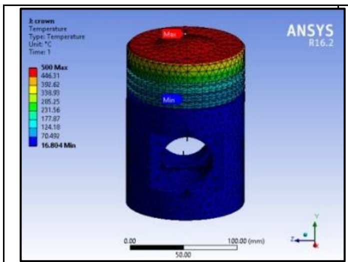
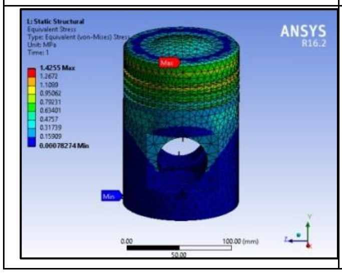
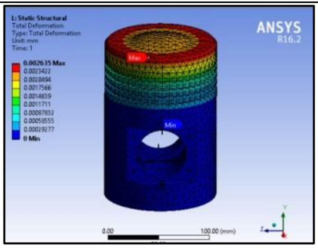
Analysis	Analytic Result	FEA Result	
	Stress (MPa)	Stress (MPa)	Deformation (mm)
Pressure	35.011	28.931	0.01953
Thermal	2.42	1.5768	0.00268
Thermo-mechanical	37.411	27.273	0.01728

B. Analysis of Crown Piston

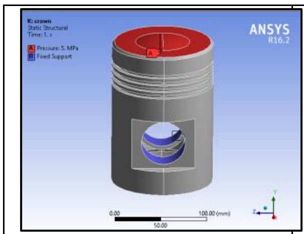
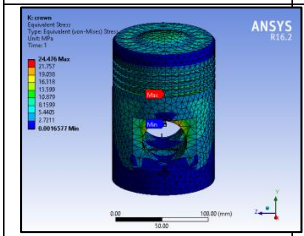
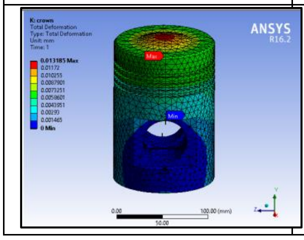
1) Structural Analysis of piston

	Fixed boundry condition
	Stress – 24.465 MPa
	Deformation – 0.0147 mm

2) Thermal analysis of piston

	Thermal condition
	Stress – 1.425 MPa
	Deformation – 0.00263 mm

3) Thermo-mechanical analysis

	Fixed boundry condition
	Stress – 24.476 MPa
	Deformation – 0.01318 mm

✓ **Comparison of results**

Material: Cast iron

Pressure: 5MPa

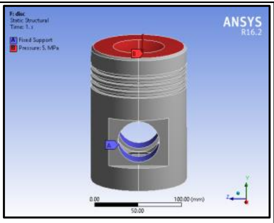
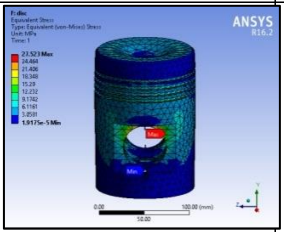
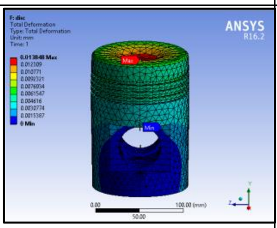
Temperature: 200°C to 450°C

Table 4. Comparison of analytical and FEA analysis results for piston

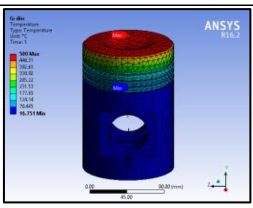
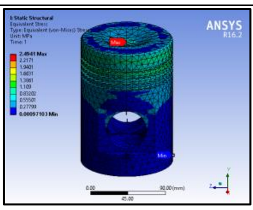
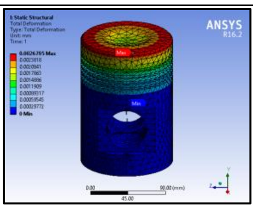
Analysis	Analytic Result	FEA Result	
	Stress (MPa)	Stress (MPa)	Deformation (mm)
Pressure	21.44	24.465	0.014698
Thermal	2.42	1.4255	0.002635
Thermo-mechanical	23.86	24.476	0.013185

C. Simulation of Disc piston

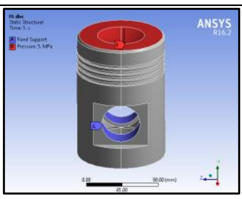
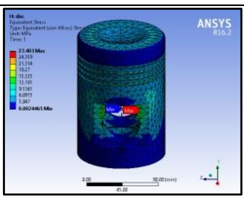
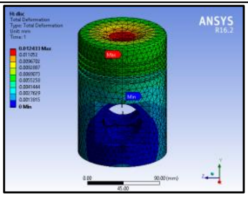
1) Structural Analysis of piston

	Fixed boundry condition
	Stress – 25.523MPa
	Deformation – 0.01384 mm

2) Thermal analysis of piston

	Thermal condition
	Stress – 2.4941 MPa
	Deformation – 0.00267 mm

3) Thermo-mechanical analysis

	Fixed boundry condition
	Stress – 27.403 MPa
	Deformation – 0.01243 mm

✓ **Comparison of results**

Material: Cast iron

Pressure: 5MPa

Temperature: 200°C to 450°C

Table 5. Comparison analytical and FEA analysis results for piston

Analysis	Analytic Result	FEA Result	
	Stress (MPa)	Stress (MPa)	Stress (MPa)
Pressure	21.44	27.523	0.01384
Thermal	2.42	2.4941	0.00267
Thermo-mechanical	23.86	27.403	0.01243

VI. OPTIMIZATION BY CHANGING PISTON MATERIAL

Flat Piston

Material: Aluminium alloy 6061-T6

Pressure: 5MPa

Temperature: 200°C to 450°C

Table 6. Comparison analytical and FEA analysis results for piston

Analysis	Analytic Result	FEA Result	
	Stress (MPa)	Stress (MPa)	Deformation (mm)
Pressure	35.011	25.87	0.029985
Thermal	182.309	183.352	0.75178
Thermo-mechanical	217.320	193.92	0.74431

Crown Piston

Material: Aluminium alloy 6061-T6

Pressure: 5MPa

Temperature: 200°C to 450°C

Table 7. Comparison analytical and FEA analysis results for piston

Analysis	Analytic Result	FEA Result	
	Stress (MPa)	Stress (MPa)	Deformation (mm)
Pressure	21.44	23.128	0.023296
Thermal	182.309	257.32	0.74927
Thermo-mechanical	203.749	271.49	0.74322

Disc Piston

Material: Aluminium alloy 6061-T6

Pressure: 5MPa

Temperature: 200°C to 450°C

Table 7. Comparison analytical and FEA analysis results for piston

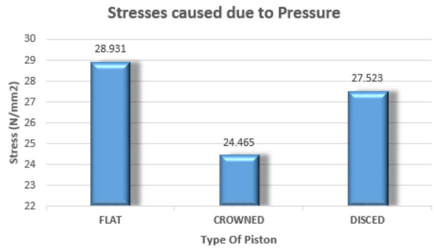
Analysis	Analytic Result	FEA Result	
	Stress (MPa)	Stress (MPa)	Deformation (mm)
Pressure	21.44	26.977	0.02192
Thermal	182.309	243.31	0.75671
Thermo-mechanical	203.749	267.45	0.75025

VII. CONCLUSION

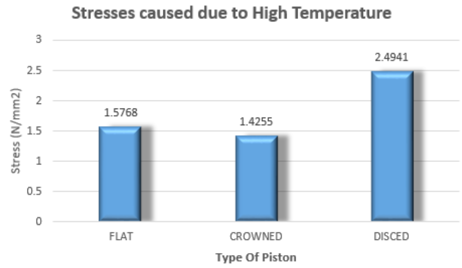
It is concluded from the above analysis and results that pressure and temperature are most important parameters to be considered while accomplishing the analysis. We can conclude that we can use crown piston in place of flat and disc type piston in case of cast-iron in same working environment of hatchback cars. While in the case of aluminium alloy 6061-T6, flat type piston is more reliable than crown and disc piston as it is showing lesser stress than other two types in the same working environment of hatchback cars.

Comparative graphs of Cast iron pistons

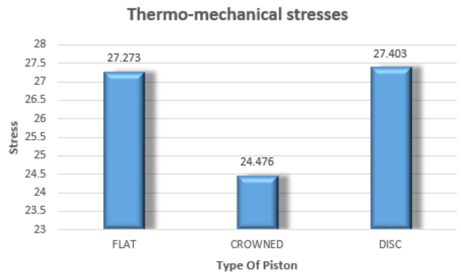
1) Graph of stresses caused due to pressure



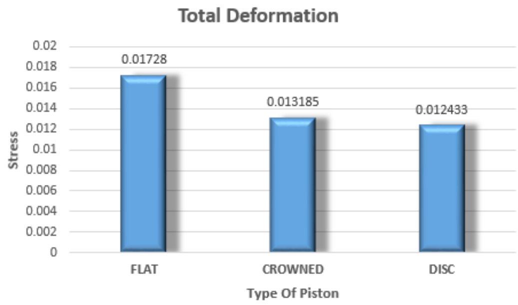
2) **Graph of stresses caused due to high temperature**



3) Graph of thermo-mechanical stresses

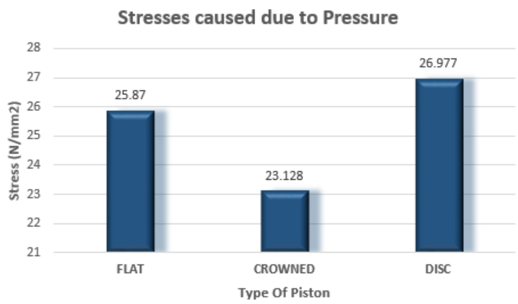


4) Graph of total deformation of pistons

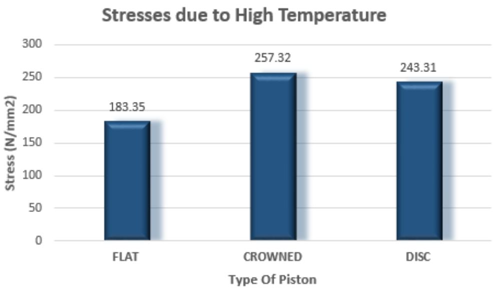


Comparative graphs of Aluminium alloy pistons

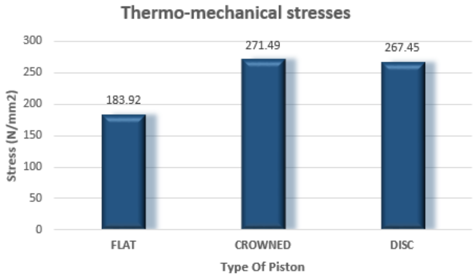
1) Graph of stresses caused due to pressure



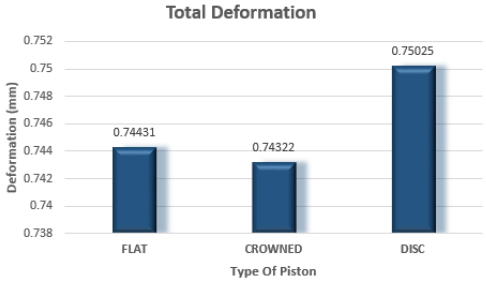
2) Graph of stresses caused due to high temperature



3) Graph of thermo-mechanical stresses



4) Graph of total deformation of pistons



VIII. REFERENCES

[1]. "Thermal Analysis and Optimization of I.C.Engine Piston using Finite Element method"-by Dr B.SudheerPrem Kumar and S.Srikanth Reddy

[2]. "Thermal Analysis of Stress and Design of Piston Head using CATIA and ANSYS"-by Dilip Kumar Sonar and MadhuraChattopadhyay

[3]. "Design the Piston of Internal Combustion Engine by Pro\ENGEER"-by Shuoguo Zhao.

[4]. "Static and Thermal Analysis of Piston and Piston Rings"-by M.Srinadh and K.RajasekaraBabu.

[5]. "Design, analysis and optimization of three aluminium pistons alloys using FEA"-by Ajay Raj Singh, Dr Pushpendra Kumar Sharma.

[6]. "A textbook of Machine Desgin"-by R.S.Khurmi and J.K.Gupta

[7]. "Design of Machine elements"-by V B Bhandari (4th edition)