WEIGHT OPTIMIZATION OF PISTON USING CREO PARAMETRIC AND ANSYS:

Seminar report submitted in partial fulfilment of the requirements for the degree of **Bachelor of Technology in Mechanical Engineering**

Submitted By:

AMARNATH VASISTHA KEERTHI

Sreenidhi Institute of Science and Technology

Because, Life is all about taking the right decisions

Department of Mechanical Engineering SREENIDHI INSTITUTE OF SCIENCE AND TECHNOLOGY (An autonomous institute under JNTUH) Yamnampet, Ghatkesar (M), Hyderabad – 501301

ACKNOWLEDGEMENT:

This project report is the outcome of the efforts of many people, who have driven our passion to explore into Concept and design regarding our project. We have received great guidance, encouragement and support from them and have learned a lot because of their willingness to share their knowledge and experience.

Primarily, we should express our deepest sense of gratitude to our internal guide Dr A. BALA RAJU, Associate Professor, Department of MECHANICAL. His guidance has been of immense help in surmounting various hurdles along the path of our goal.

We also thank our Group Project Coordinator Dr S. VIJAYA BHASKAR SIR, Department of Mechanical.

We are deeply indebted to Prof C.H. SHIVA REDDY, Head, Department of MECHANICAL ENGG, who spared his most valuable time without any hesitation whenever we wanted.

We record with great feeling of gratitude, the contributions of all the faculty members, who encouraged us during this project by rendering their help when needed.

Finally, we thank our parents and adore Almighty God who has made us come in contact with such worthy people at the right time, provided us with all the necessary resources and made us accomplish this task.

ABSTRACT:

Piston is the part of engine which converts heat and pressure energy liberated by fuel combustion into mechanical work. Engine piston is the most complex component among the automotive parts. This project describes the design procedure for a piston for four stroke petrol- engine for hero splendor – pro bike and its analysis on the dimensions of original piston used in bike. The analysis will be done by considering two designs, one being basic and the other optimized one. The design procedure involves determination of varied piston dimensions using analytical method under maximum power condition. In this paper the combined effect of mechanical and thermal is taken into consideration while determining various dimensions. The basic data of the engine are taken from a located engine variety of hero splendor –pro bike. The static structural and transient thermal analysis are done by varying the material used in the two piston designs and the results are plotted. The materials used for the piston design are Grey Cast iron, Cast Aluminium alloy and Aluminium Silicon Carbide. By this project it is observed that the piston made of Aluminium Silicon Carbide is more preferable material as it has lesser deformation, lesser stress and good temperature distribution when compared to Grey Cast iron and Cast Aluminium alloy.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Introduction

Automobile components are in great demand lately due to increased use of automobiles. The increased demand is thanks to improved performance and reduced cost of those components. R&D and testing engineers should develop critical components in shortest possible time to attenuate launch time for brand spanking new products. This necessitates understanding of new technologies and quick absorption in the development of new products.

A piston is a component of reciprocating IC-engines. Piston is the moving component that is contained by a cylinder and is formed gas-tight by piston rings. In an engine, the purpose of piston is to transfer force exerted by expanding gas within the cylinder to the crankshaft via a con-rod / connecting rod. As a crucial part in an engine, piston endures the cyclic pressure and therefore the inertial forces at work, and this working condition may cause the fatigue damage of piston, like piston side wear, piston head/crown cracks then on. The investigations indicate that the maximum stress appears on the upper end of the piston and stress concentration is one among the mainly reason for fatigue failure. On the other hand, overheating-seizure of the piston can only occur when something burns or scrapes away the oil film that exists between the piston and therefore the cylinder wall of the engine.

1.2 Functions of a Piston

1. To reciprocate within the cylinder as a gas tight plug causing Suction, Compression, Expansion, and Exhaust strokes.

2. To receive the thrust generated by the explosion of the gas within the cylinder and transmit it to the connecting rod.

3. To make a guide and bearing to the small end of the con-rod and to require the side thrust because of obliquity of the rod.

1.3 Major forces acting on Piston

1. Due to explosion of fuel gases.
2. Due to compression of fuel gases.
3. Side wall friction and forces.
4. Thermal load.
5. Inertia force because of high frequency of reciprocation of piston.
6. Friction and forces at crank pin hole.

1.4 Factors considering for proper functioning of a Piston

1. The piston should have enormous strength and heat resistance properties to withstand gas pressure and inertia forces. They should have minimum weight to minimize the inertia forces.

2. The material of the piston should have good and quick dissipation of heat from the crown to the rings and bearing area to the cylinder walls. It should form an effective gas and oil seal.

3. Material of the piston must possess good wearing qualities, so that the piston is able to maintain sufficient surface-hardness unto the operating temperatures.

4. Piston should have rigid construction to withstand thermal, mechanical distortion and sufficient area to prevent undue wear. It has even expansion under thermal loads so should be free as possible from discontinuities.

1.5 Model of Piston

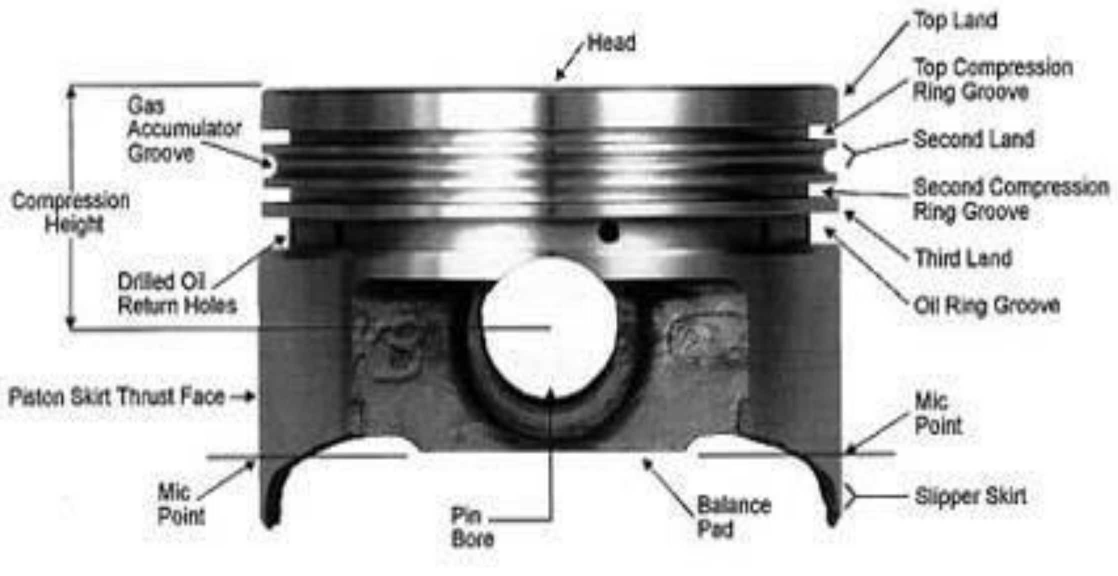


Fig 1.1

2. LITERATURE REVIEW

This topic shows review on design analysis of piston on the basis of improving strength according to the material properties. **Vibhandik** et. al. (2014), studied that Design analysis and optimization of piston and deformation of its thermal stresses using CAE tools, he had selected I.C. engine piston from TATA motors of diesel engine vehicle. He had performed thermal analysis on conventional diesel piston and secondly on optimized piston made of aluminium alloy and titanium alloy material. Conventional diesel piston made of structural steel. The main objective of this analysis is to reduce the stress concentration on the upper end of the piston so as to increase life of piston. After the analysis he conclude that titanium has better thermal property, it also help us to improve piston qualities but it is expensive for large scale applications, due to which it can be used in some special cases.

Ch. Venkata Rajam et. al. (2013), focused on Design analysis and optimization of piston using CATIA and ANSYS. He had optimized with all parameters are within consideration. Target of optimization was to reach a mass reduction of piston. In this analysis a ceramic coating on crown is made. In an optimization of piston, the length is constant because heat flow is not affected the length, diameter is also made constant due to same reason. The volume varied after applying temperature and pressure loads over piston as volume is not only depending on length and diameter but also on thickness which is more affected. The material is removed to reduce the weight of the piston with reduced material. The results obtained by this analysis shows that, by reducing the volume of the piston, thickness of barrel and width of other ring lands, Von mises stress is increased by and Deflection is increased after optimization. But all the parameters are with in design consideration.

V. V. Mukkawar et. al. (2015), describes the stress distribution of two different Al alloys by using CAE tools. The piston used for this analysis belongs to four stroke single cylinder engine of Bajaj Pulsar 220 cc motorcycle. He had concluded that deformation is low in AL-GHY 1250 piston as compare to conventional piston. Mass reduction is possible with this alloy. Factor of safety increased up to 27% at same working condition. He used Al-GHY 1250 and conventional material Al-2618 and results were compared, he found that Al-GHY 1250 is better than conventional alloy piston.

Manjunatha T. R. et. al. (2013), under-look specification for both high pressure and low-pressure stages and analysis is carried out during suction and compression stroke and identify area those are likely to fail due to maximum stress concentration. The material used foe the cylinder is cast-iron and for piston aluminium alloy for both low and high pressure. He concluded that the stress developed during suction and compression stroke is less than the allowable stress. Hence the design is safe.

Swati S. Chougule et. al. (2013), focused on the core objective of this paper is to research and analyse the strain distribution of piston at actual engine condition during combustion process the parameters used for simulation is operating gas pressure and material properties of piston. She concluded that there is a scope for reduction in a scope for reduction in thickness of piston and therefore optimization of piston is done with mass reduction by 24.319% than non-optimized piston. The static and dynamic analysis is carried out which are well below the permissible stress value.

The study of **Lokesh Sing**h et. al. (2015) is related to the material for the piston is aluminium-silicon composites. The high temperature at piston head, due to direct contact with gas, thermal boundary conditions is applied and for maximum pressure mechanical boundary conditions are applied. After all this analysis all values obtained by the analysis is less than permissible value so the design is safe under applied loading condition.

The study of **R. C. Singh** et. al. (2014), discussed about failure of piston in I.C. engines, after all the review, it was found that the function coefficient increases with increasing surface roughness of liner surface and thermal performance of the piston increases. The stress values obtained from FEA during analysis is compared with material properties of the piston like aluminium alloy zirconium material. If those value obtained are less than allowable stress value of material then the design is safe.

F.S. Silva Fatigue on engine pistons – A compendium of case studies- provided valuable information on the first main conclusion that could be drawn from this work is that although fatigue isn't the liable for biggest slice of damaged pistons, it remains a drag on engine pistons and its solution remains a goal for piston manufacturers. And it'll last a drag for long because efforts on fuel consumption reduction and power increase will push to the limit weight reduction meaning thinner walls and better stresses. To satisfy all the wants with reference to successful application of pistons, especially mechanical and heat mechanical fatigue and thermal/thermal– mechanical fatigue there are several concepts available that can be used to improve its use, such as design, materials, and processing technologies.

G.S. Cole Result of more stringent requirements for improved fuel economy and emissions, there is a growing trend to substitute Al and Mg for conventional steel and cast irons in vehicles. This article describes a number of the technical issues that has got to be considered if the automotive industry is to utilize these lightweight materials in larger volumes. Lightweight metals could also be utilized in the vehicle in both wrought and cast forms. Aluminium, in the form of stamped sheet, has the potential to be used extensively in vehicle structures and closures. However, compared to steel, aluminium is more difficult to stamp and spot weld.
Current research is exploring ways of improving the formability of Al alloys and developing alternate joining methods including adhesive bonding and fasteners. Mg, Al, and metal-matrix composite castings have the potential to be used as replacements for several ferrous castings in powertrain and chassis components. However, due to their different tribology, strength, and ductility, light-metal castings require improved foundry procedures and more sophisticated

design rules before product engineers will use them in larger quantities. A major challenge for lightweight materials is that the ability to supply a functional component at a suitable price. The presentation will conclude with a cost-benefit perspective for typical light-metal applications within the automotive industry.

3. OBJECTIVES AND METHODOLOGY

The main objective of the present work is to find out and suggest optimum material for piston based on quality and economy considering material weight and dimensional issues at the same time. After generating an accurate finite element model, a technique for the optimization workflow was defined. Target of the optimization was to succeed in at minimum thermal stresses within the piston. Also to perform the analysis on different materials and tabulate the results.

The proposed work included following steps:

- Analytical design of piston, using specification of four stroke single cylinder engine of Hero Splendor PRO motorcycle created.
- Create a 3D model of piston for Two stroke Engine using Creo 2.0.
- Analysis of the above geometry for different loading and boundary conditions in ANSYS software.
- Comparison of the results obtained in above step for different materials.
- Choosing the optimum design based on the material and other parameters.

4. DESIGN AND PROPERTIES:

4.1 Nomenclature of Piston

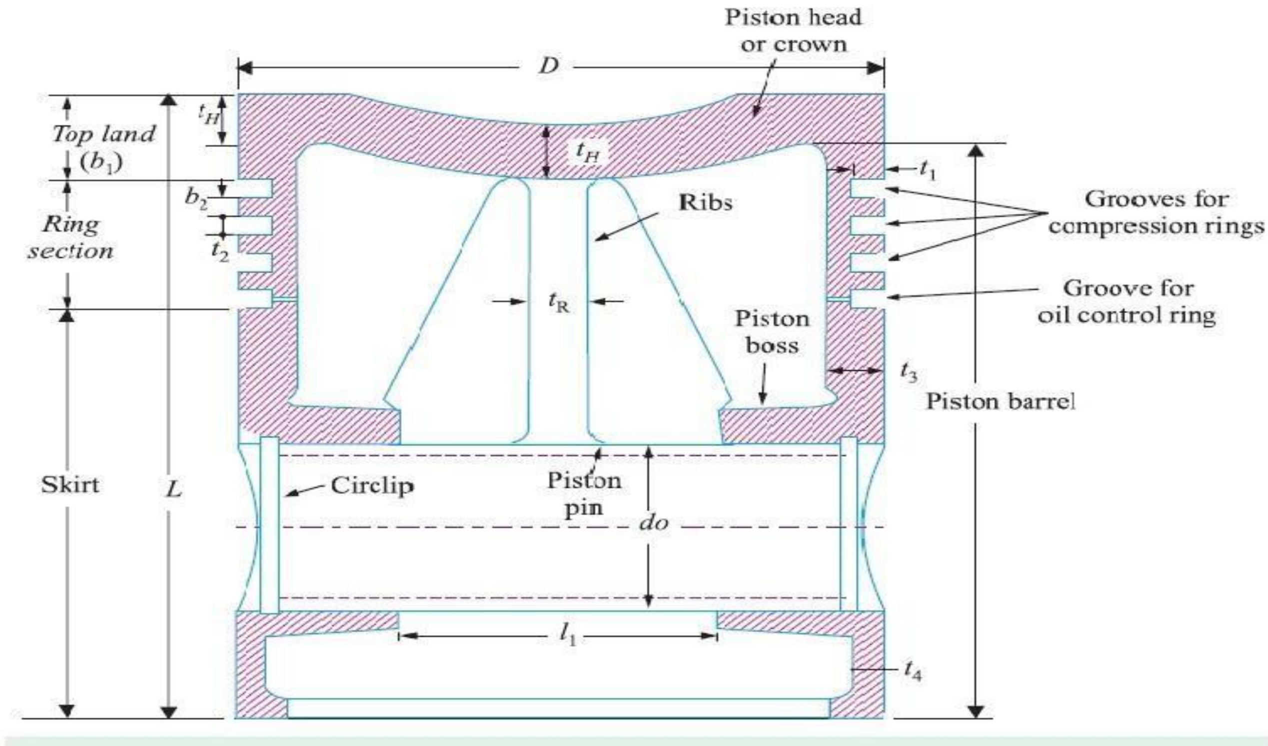


Fig 4.1

4.1.1 Piston Head

The piston head or crown is designed keeping in sight the subsequent two main considerations, i.e.

1. It should have adequate strength to resist the straining action because of pressure of explosion inside the engine cylinder, and

2. It should dissipate the heat of combustion to the cylinder walls as quickly as possible. On the premise of first consideration of straining action, the thickness of the piston head is calculated by treating it as a flat circular plate of uniform thickness, fixed at the outer edges and subjected to a uniformly distributed load because the pressure over the whole Cross-section.

4.1.2 Piston Rings

The piston rings are used to impart the required radial pressure to maintain the seal between the piston and therefore the cylinder bore. These are usually made from grey forged iron or alloy forged iron due to their good wearing properties and also, they keep spring characteristics even at high temperatures.

The piston rings are of the subsequent two types:

1. Compression rings or pressure rings, and

2. Oil control rings or oil scraper.

The compression rings or pressure rings are inserted within the grooves at the highest portion of the piston and should be three to seven in number. These rings also transfer heat from the piston to the cylinder liner and absorb a part of the piston fluctuation because of the side thrust. The oil control rings or oil scrapers are situated below the compression rings. These rings provide proper lubrication to the liner by allowing sufficient oil to maneuver up during upward stroke and at an equivalent time scrap the grease from the surface of the liner so as to attenuate the flow of the oil to the combustion chamber.

The compression rings are usually made from rectangular cross-section and therefore the diameter of the ring is slightly larger than the cylinder bore. A part of the ring is cut- off so as to allow it to travel into the cylinder against the liner wall. The gap between the ends should be sufficiently large when the ring is put cold in order that even at the very best temperature, the ends don't touch one another when the ring expands, otherwise there could be buckling of the ring.

4.1.3 Piston Skirt

The portion of the piston below the ring section is understood as piston skirt. In acts as an impact for the side thrust of the con-rod. The length of the piston skirt should be such the bearing pressure on the piston barrel thanks to the side thrust doesn't exceed 0.25 N/mm2 of the projected area for low speed engines and 0.5 N/mm2 for top speed engines. It may be noted that the maximum thrust are going to be during the expansion stroke. The side thrust (R) on the cylinder liner is typically taken as 1/10 of the maximum gas load on the piston.

4.1.4 Piston Pin

The piston pin (also called wrist pin or wrist pin) is employed to attach the piston and therefore the con-rod. It is usually made hollow and tapered on the within, the littlest inside diameter being at the centre of the pin. The piston pin passes through the bosses provided on the within of the piston skirt and therefore the bush of the tiny end of the con-rod.

The Centre of piston pin should be 0.02 D to 0.04 D above the centre of the skirt, in order to off-set the turning effect of the friction and to obtain uniform distribution of pressure between the piston and therefore the cylinder liner. The material with which the piston pin is made is typically steel alloy containing nickel, chromium, molybdenum or vanadium having tensile strength from 710 MPa to 910 MPa.

4.2 Design Considerations of a Piston

In designing a piston for I.C. engine, the following points should be taken into consideration

1. It should have the necessary strength required to sustain the high gas pressure and inertia forces.
2. Mass of the piston should be minimum to reduce the inertia forces.
3. It should form an effective sealing for the gas and oil inside the cylinder.
4. It should provide bearing area sufficient enough to prevent inappropriate wear.
5. It should disperse the heat of combustion quickly to the cylinder walls.
6. It should reciprocate with high speed inside the cylinder without noise.
7. It should be of sufficient rigid construction in order to bear the thermal and mechanical distortion.
8. It should provide better support required for the piston pin.

4.3 Piston Function Design Requirement

1. Easily slide/move to the reciprocating motion inside of cylinder.
2. Reducing friction between the connecting rod and wrist pin/ gudgeon pin/ piston pin.
3. There strain occurring the piston pin should be negligible.
4. Piston should be able reciprocate even at minimum pressure.

4.4 Piston Structural Design Requirement

1. Piston is designed in cylindrical shape to easily reciprocate in up & down directions.
2. Piston should be compact in size.
3. The geometry of the piston head/crown (curve, flat) should be in correct shape so that in gives maximum efficiency.

4.5 Material for Pistons

Grey Cast Iron

Grey iron, or grey cast iron, is a type of cast iron that has a graphitic microstructure. It is named after the grey colour of the fracture it forms, which is because of the presence of graphite. It is the most common cast iron and therefore the most generally used cast material based on weight.

It is used for housings where the stiffness of the component is more important than its tensile strength, like internal combustion engine cylinder blocks, pump housings, valve bodies, electrical boxes, and decorative castings. Grey cast iron's high thermal conductivity and specific heat capacity are often exploited to form cast iron cookware and disk brake rotors.

A typical chemical composition to get a graphitic microstructure is 2.5 to 4.0% carbon and 1 to three silicon by weight. Graphite may occupy 6 to 10% of the quantity of grey iron. Silicon is vital for creating grey iron as against white cast iron, because silicon may be a graphite stabilizing element in forged iron, which suggests it helps the alloy produce graphite rather than cementite s; at 3% silicon almost no carbon is held in chemical form as iron carbide.
Another important factor affecting graphitization is that the solidification rate; the slower the rate, the greater the time for the carbon to diffuse and accumulate into graphite. A moderate cooling rate forms a more pearlitic matrix, while a quick cooling rate forms a more ferritic matrix. To achieve a totally ferritic matrix the alloy must be annealed. Rapid cooling partly or completely suppresses graphitization and results in the formation of cementite, which is named white iron.

Cast Aluminium Alloy

The most common materials used in the manufacturing of pistons of I.C. engines are cast iron, cast aluminium, forged aluminium, cast steel and forged steel. The cast iron pistons are used in engines which are moderately rated with piston speeds less than 6 m / s and aluminium alloy pistons are used for highly rated engines running at higher piston speeds. It may be noted

1. Since the coefficient of thermal expansion for aluminium is about 2.5 times that of cast iron, therefore, the clearance between the piston and cylinder should be greater in order to prevent seizing of the piston when engine is working continuously under heavy loads. But if excessive clearance is provided, then the piston will develop ‘piston slap’ while it is cold and this tendency increases with wear. Seizing of piston will takes place if the clearance between the piston and cylinder wall is less.

2. Since the pistons made of aluminium alloys which have high thermal conductivity (nearly four times that of cast iron), these pistons ensure high heat transfer rate which enables the maximum temperature difference between the centre and edges of the piston head or crown to be less.

3. Since the aluminium alloys are about three times lighter than cast iron, therefore, its mechanical strength is good at low temperatures, but they lose their strength (about 50%) at temperatures above 325°C. Sometimes, aluminium oxide is coated to the aluminium pistons by electrical method.

Aluminium Silicon Carbide

Aluminium-(Silicon Carbide) is a metal-ceramic composite material consisting of silicon carbide particles dispersed in a matrix of aluminium alloy. It has the combined benefits of high thermal conductivity of metal and low CTE (coefficient of thermal expansion) of ceramic. Al-SiC is an advanced packaging material for high technology thermal management because of its composite features. Al-SiC is compatible with a wide range of metallic and ceramic substrate and plating materials used in micro-electronic packaging for aerospace, automotive, microwave applications.

Aluminium combinations are not suitable for high temperature applications due to the fact that elastic and weakness qualities are not as high as coveted in the temperature scope of 500 F to 700 F. The most noteworthy temperature of any point in cylinder must not surpass more than 66% of the liquefying point temperature of the aluminium combination. They are not suitable for high temperature applications based on the fact that the point of confinement temperature for the aluminium combination is of 640K. So we are strengthening silicon carbide in aluminium composite to make the cylinders to withstand high temperatures which has high liquefying temperature when contrasted and aluminium amalgam. Aluminium silicon carbide amalgam demonstrates great improvement of the mechanical properties like extreme rigidity, yield quality, hardness and pliability at raised temperatures.

Properties of materials

Property	**Grey Cast Iron (FG260)**	**Cast Aluminium alloy**	**Aluminium-Silicon Carbide**
Youngs modulus (Gpa)	128	71	83
Density (g/cm^3)	7.2	2.77	2.9
Poisson’s ratio	0.26	0.33	0.3
Tensile strength (Mpa)	260	485	530
Thermal conductivity (W/mK)	50	174.15	216.69

Table 4.5

4.6 FAILURE MODES OF PISTON

There are two types of piston failure

1) Rough out failure
2) Wrong out failure

4.6.1 Rough out failure

4.6.1.1 Damage from Running Unmixed Fuel:

The piston above has severe scouring on the exhaust skirt due to the heaviest damage caused on the clutch side of the piston. All of this damage was caused from running straight fuel. The piston seizes to the cylinder wall due to lack of lubrication. The damage you see was caused within the moments before the piston "stuck," which seized the engine.

This kind of piston damage also can be found on a saw that was run with the carburettor set too lean or one that was run with an air leak. If you didn't know this saw had been run with no oil within the fuel, how would you recognize it wasn't a heat seizure to completely understand the cause of this failure, it's important to seem at the remainder of the piston. The photo below is of the same piston. It shows additional damage that's usually only found on a saw engine that had been run with unmixed.

Fig 4.2

4.6.1.2 Damage from Over-Speeding the Engine:

The piston above has been damaged by over-speeding. Look at the piston material between the ring-lands. You can see an enormous chunk of it's missing and a few has been "squished" thinner, creating a super-wide ring-land. Look at the top ring (bottom of photo). You can see the edge is rounded-over, a sure sign the rings were catching within the exhaust port. When this happens , this triggers a high frequency vibration, eventually breaking the ring-land.

Fig 4.3

4.6.1.3 Damage from Detonation:

The piston above has been damaged by detonation. Notice the damage on the highest and therefore the edges of the piston. The heat caused by detonation made the piston so hot, the rings stuck and therefore the piston seized within the cylinder. You can see the seizure marks on the side of the piston. Both the cylinder and piston are ruined by this damaged. Detonation can be caused by a number of things. In this case, changing to higher octane supreme grade fuel was the solution. See our article on Fuel for more information.

Fig 4.4

4.6.2 **Damage from Heat Seizure:**

The piston above shows the most common severe piston damage we see - the exhaust side has damage caused from excess heat. This damage looks similar to piston damage caused by running straight gas shown in the first image, but with this piston, conditions under the piston looked normal.This kind of damage can be caused by over-revving the saw, running the carburetor adjustment too lean, by ignoring an air leak in the saw's engine, or a combination of factors. The best way to avoid a such a seizure is to use good quality fuel and mix oil, avoid over-revving the engine, and always stop running a saw that shows signs of a potential air leak. This kind of damage can also be caused by a partially plugged fuel filter, which is another reason fuel filters should be replaced regular.

Fig 4.5

Fig 4.6

4.6.2 Wrong out failure

4.6.2.1 Damage from Debris Getting Through the Air Filter:

The damage on this piston skirt is caused by debris getting through the air filtering system. Notice the horizontal machine marks are scrubbed off all across rock bottom indicating extreme decline the lower a part of the skirt. Not shown, but the opposite side of the piston looked perfect. This damage was found only on the intake side of the piston. this is often typical for damage caused by intake debris. the opposite side of the piston isn't exposed to an intake port, so it is not affected at early stages.

What damages the intake skirt is debris from a leaking filter wedging between the piston and cylinder wall causing scuffing on the piston skirt. Since the piston is formed of softer material, the damage is more pronounced on the skirt than on the cylinder bore's pave . This decline the piston increases the clearance, which allows the piston to "rock" within the cylinder's bore. because the skirt becomes thinner and weaker, rocking increases. Eventually the piston will break. When it does, the engine seizes. On a professional saw, the piston skirt performs another important function. Not only does it guide the piston, the skirt is the engine's valve . because the piston travels up and down the cylinder, its base opens and closes the intake port because it passes. For the engine to run its best, it's important for this valve to function well.

Fig 4.7

4.6.2.2 Damage from Bearing Failure:

These fine scratches and "peppering" on the exhaust skirt and lower intake skirt is caused by the failure of the lower rod bearing or main bearings. Small, but hard pieces of the bearings and retention cages are breaking loose, causing this piston damage. If you're lucky enough to catch a piston during this condition, stop running the saw until you discover which bearing is abandoning material. If you retain running the saw, eventually the bearing(s) will completely fail. This usually releases larger pieces of bearing material.

When this happens, sometimes the crank shaft locks up. But if it keeps running, loose pieces within the bottom end will travel up through the transfer ports and into the engine. All the parts won't make the entire trip. Some won't undergo the upper transfer port and when the piston goes by, it'll drive these parts into the cylinder wall, destroying both. To repair this damage, both the crankshaft assembly and therefore the cylinder and piston must get replaced two very expensive components. We typically see this type of injury on saw engines that are over-revved. For more information see our section on Rod Bearing Failure.

Fig 4.8

5. MODELLING OF PISTON

5.1 TECHNICAL SPECIFICATIONS

Engine Type	Air-cooled, 4-stroke single cylinder OHC
Displacement	97.2 cc
Max. Power	5.66 KW, @ 5000 rpm
Max. Torque	7.130 N-m @ 2500 rpm
Compression Ratio	9.9 : 1
Starting	Kick Start / Self Start
Ignition	DC - Digital CDI
Bore	50 mm
Stroke	49 mm

Table 5.1

5.2 THEORETICAL CALCULATION FOR PISTON

1) Torque P = 2πN/60 We know that P = 5.6 kw

5.6×e3=2×3.14×7500×T / 60

T=7.130 N-m.

2) Diameter of piston

πr2h = cc

Cylinder area = displacement

We know that displacement so to find diameter of piston

3.14×r2×0.049=97×E-5 m3

r = radius Diameter D = 2×r

D = 2*0.025 m=0.05m=50mm

D = 50 mm.

3) Cylinder inside pressure Pressure = force/area (F/A)

Force =power/velocity (P/V) We know that power

Velocity =2LN/60=2 0.049*5000/60= 8.16M/S

Force =5.6e3/8.16 = 686.274N P = F/A
Area = $\pi r2$ = 3.14 (0.025)2 = 1.934E-3 M2 P=686.27/1.934E-3 =0.34953Mpa (minimum) Maximum pressure =15 Pmin P max =15 0.34953 =5.24 Mpa.

Max pressure = 5.24 Mpa

5.2.1. Procedure for piston designing :

4) Thickness of piston head

Where
P= maximum pressure in N/mm².
D= cylinder bore/outside diameter of the piston in mm.
σt = permissible tensile stress for the material of the piston.

t_h= 4.01mm

5) Radial thickness of ring (t_1)

Where,
D = cylinder bore in mm

Pw= pressure of fuel on cylinder wall in N/mm². Its value is limited from 0.042N/mm². to 0.0667 N/mm² For present material, σt is 152.2Mpa.

t_1 =1.812mm.

6) Axial thickness of ring (t_2)

The thickness of the rings may be taken as t_2 = 0.7t1 to t1

t_2 = 0.7 × 1.812.

t_2 = 1.26mm.

7) Top land thickness (b_1)

The width of the top land varies from $b_1 = t_h$ to $1.2\ t_h$ $b_1 = 1.2 \times 4.01$

b_1 =4.81mm.

8) Thickness of other land (b_2)

$b_2 = 0.75\ t2$ **to** $t2$

b_2 = **0.75×1.66**

b_2= 1.242mm.

9) Maximum thickness of barrel (t3)

$t_3 = 0.03D + b + 4.5$ mm.

$b = t_1 + 0.4$ b =

1.812+0.4

b = 2.212mm

$t_3 = 0.03\ D + 2.212 + 4.5$mm **$t_3$**

= 8.212mm.

10) Open end of the barrel thickness (T open)

At the open end the thickness is taken as

T open = (0.20 to 0.30Tp)

T open = 0.25 (8.212) =2.053

T open = 2.053mm.

11) Gap between the rings (T_L)

$T_L = 0.055 \times D$

$T_L = 2.75$ mm

Second ring = 0.04 D =0.04 (50) = 2.00mm.

12) Depth of ring groove (Dr)

Dr = t1 + 0.4
Dr = 1.812 +0.4

Dr = 2.212 mm.

13) Length of piston

$Lp = h_1 + 2h_2 + 3t_2 + 0.65D = 4.81 + 3(1.66) + 2(1.242) + 0.65\,(50) = 44.77$ mm.
Lp= 44.77 mm.

14) Piston pin diameter

$P_{do} = 0.3D$ to $0.45D$,
$P_{do} = 0.32\,(50)$
$P_{do} = 16$mm
$P_{di} = 12$mm.

PARAMETERS	CALCULATED VALUES
Piston length	**44.77mm**
Piston diameter	**50mm**
Piston pin outer diameter	**16mm**
Piston pin internal diameter	**12mm**
Piston axial thickness	**1.63mm**
Piston radial thickness	**1.812mm**
Depth of ring groove	**2.212mm**
Gap between the rings	**2.75mm**
Top land thickness	**4.01mm**
Piston top end thickness	**4.81mm**
Piston open end thickness	**2.053mm**

Table 5.2

5.3. PISTON MODELLING USING CREO 2.0

5.3.1. CREO 2.0

Creo is a family or suite of Computer-aided design (CAD) apps supporting product design for discrete manufacturers and is developed by PTC. The suite consists of apps, each delivering a distinct set of capabilities for a user role within product development. Creo runs on Microsoft Windows and provides apps for 3D CAD parametric feature solid modeling, 3D direct modeling, 2D orthographic views, Finite Element Analysis and simulation, schematic design, technical illustrations, and viewing and visualization. It is more efficient than the autocad software as the dimensions can be changed after drawing unlike in autocad.

Fig 5.1 shows the basic flat headed piston design with diameter 50mm and volume 48652mm 3 and the fig 5.2 is the developed design where the piston is of 50mm diameter and the volume is 31175 mm^3

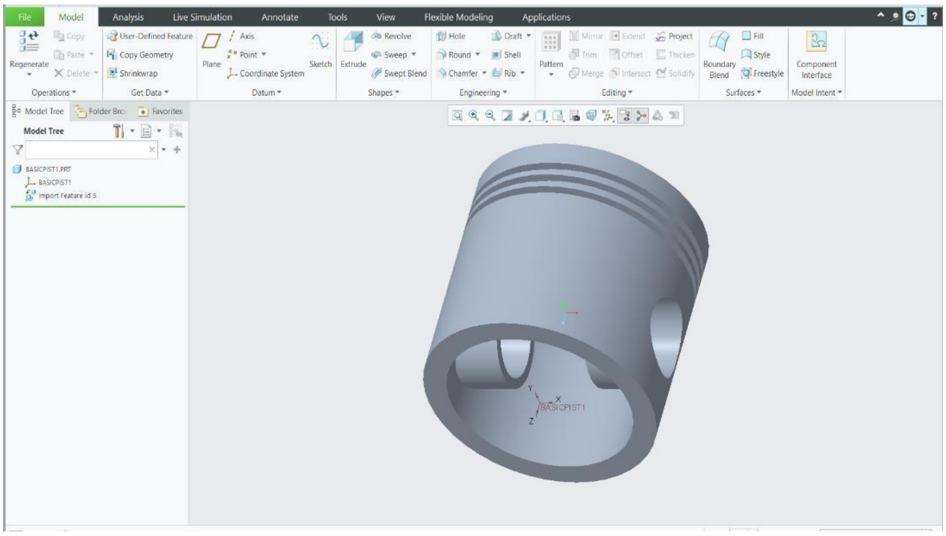


Fig 5.1

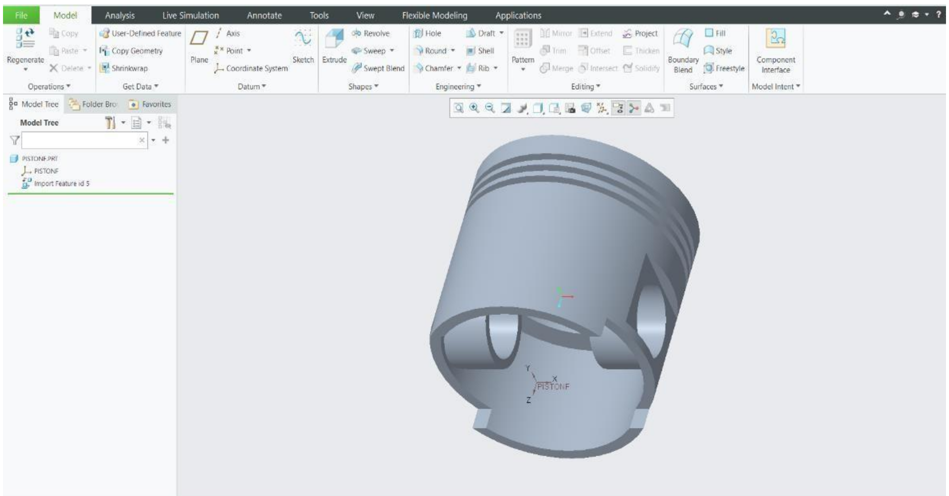


Fig 5.2

6. ANALYSIS ON PISTON USING ANSYS

6.1 INTRODUCTION TO DESIGN ANALYSIS

6.1.1. Design analysis:

Design Validation means whether the component which we are going to manufacture will sustain for various loading conditions or not.
In other words , we can say that Design Validation is a process to find the results like Stresses, Displacement, Strain, Fatigue, Eigen Values, Heat Flux, etc. may or may not come on my model which leads failure.
There are 3 Methods to Validate any Design:
1. Analytical Method
2. Numerical Method 3. Experimental Method.

Analytical method: Analytical Method is classical approach to find results on any design / component which can me manufactured. This is a generic process which involves solution techniques based on formulas / Methods / theorems.
Numerical method: Numerical Method is a mathematical tool designed to solve numerical problems. The implementation of a numerical method with an appropriate convergence check in a programming language is called a numerical algorithm.

FINITE ELEMENT ANALYSIS branch of Numerical Method. The finite element method (FEM) is a numerical technique for finding approximate solutions to boundary value problems for partial differential equations. It is also referred to as finite element analysis (FEA). Finite – Any continuous object has infinite degrees of freedom and it is not possible to solve the problem in this format. The Finite Element Method reduces the degrees of freedom from infinite to finite with the help of discretization or meshing (nodes and elements). Element – All of the calculations are made at a limited number of points known as nodes. The entity joining nodes and forming a specific shape such as quadrilateral or triangular is known as an Element. To get the value of a variable (say displacement) anywhere in between the calculation points, an interpolation function (as per the shape of the element) is used. Method – There are 3 methods to solve any engineering problem. Finite element analysis belongs to numerical method category.

6.1.1.1 Additional information:

Advantages of FEM: It gives a better visualization of our Better Visualization of Failure Location. It Slows down the Design cycle time. The number of prototypes can be decreased. Cuts the Testing cost. The Optimum design can also be achieved faster. Computer-aided engineering (CAE) is the broad usage of computer software to aid in engineering analysis tasks. It includes Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), Multibody dynamics (MBD), Optimization, etc. CAE retrieves description and geometry from a CAD database. It is used in almost every industry such as aerospace, automobile manufacturing. CAE depends on CAD.

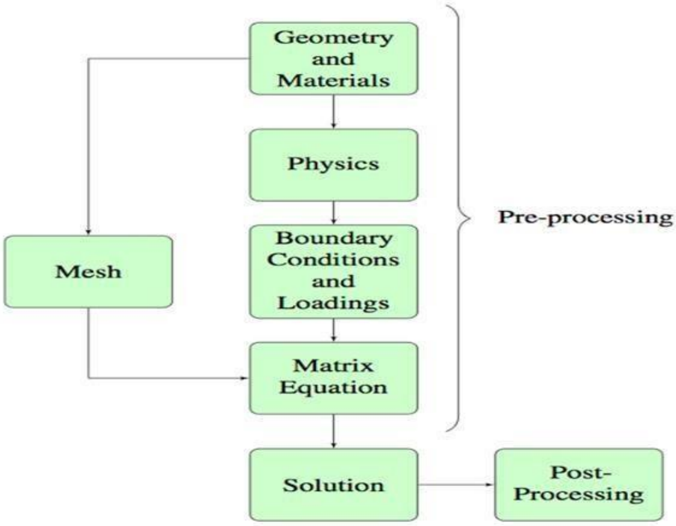


Fig 6.1

6.1.2 Meshing

The basic idea of FEA is to make calculations at only limited (Finite) number of points and then interpolate the results for the entire domain (surface or volume). Any continuous object has infinite degrees of freedom and it's just not possible to solve the problem in this format. Finite Element Method reduces the degrees of freedom from infinite to finite with the help of discretization or meshing (nodesand elements).

HOW NOT TO MESH: Mid nodes should lie exactly on the geometry: For a parabolic tetra meshing task, many CAE engineers prefer to start with linear triangular (instead of parabolic) meshing and then covert it to parabolic. In the conversion process, mid nodes might not get projected automatically on the curved surfaces and fillets. If so, it should be projected on corresponding surfaces before conversion to tetras. When the job is split among several engineers, the element length and over all mesh pattern should be consistent. Minimum 2 elements on the fillets for tetra meshing. For brick meshing, a minimum of 2 elements across the thickness should be used

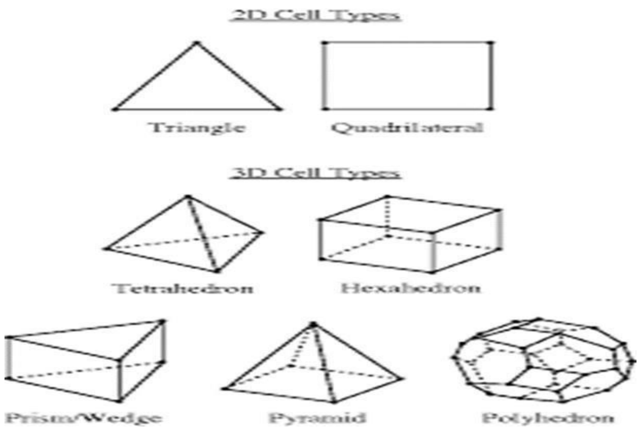


Fig 6.2

6.2. ANALYSIS USING ANSYS SOFTWARE:

6.2.1. Static analysis in ANSYS:

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. The types of loading that can be applied in a static analysis include:

1. Externally applied forces and pressures
2. Steady-state inertial forces (such as gravity or rotational velocity)
3. Imposed (nonzero) displacements

Some of the most common static analyses are:

Linear stress analysis: This analysis allows engineers to validate the quality, performance and the safety of the design in a very efficient and accurate way. In this static analysis, the stress and displacement experienced by the geometry are calculated. In addition, this calculation helps to determine how the part will react to the effect of different forces, temperature and the contact between different components.

Deformation analysis: Likewise, this analysis allows designers to verify the quality, performance and the safety of the mechanical part, in this case based on the geometrical changes that can be noticed when specific load conditions are established. Also, it is important to highlight the fact that static analyses help to determine different mechanical properties of the part, such as hardness requirements, traction resistance, compression resistance, shear resistance, sag resistance and torsion resistance. Points to Remember while performing the analysis are that A static structural analysis can be either linear or nonlinear. All types of nonlinearities are allowed – large deformations, plasticity, stress stiffening, contact (gap) elements, hyper elasticity and so on. The Static analysis determines the displacements, stresses, strains and forces in the components caused by the loads. Steady loading and response conditions are assumed to vary slowly with respect to time. The types of loading that can be applied in this are:

Externally applied forces and pressure
Steady state inertial forces (like gravity or rotational velocity)
Imposed (non-zero displacements)
Temperatures (for thermal strains)

6.2.2. Modal analysis in ANSYS:

A modal analysis determines the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a transient dynamic analysis, a harmonic analysis, or a spectrum analysis. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. You can also perform a modal analysis on a pre-stressed structure, such as a spinning turbine blade. If there is damping in the structure or machine component, the system becomes a damped modal analysis. For a damped modal system, the natural frequencies and mode shapes become complex. Points to Remember are

that the Rotational Velocity load is not available in Modal analysis when the analysis is linked to a Static Structural analysis. Pre-stressed Modal analysis requires performing a Static Structural analysis first.
In the modal analysis you can use the Initial Condition object to point to the Static Structural analysis to include pre-stress effects. A modal analysis determines the vibration characteristics (natural frequency and mode shapes) of a structure or a mechanical component. The natural frequency and the mode shaped are the important parameters to design the structure. Modal analysis can also be performed on a pre-stressed structure. In case of damping in the component, the system becomes damped modal analysis. For damped modal analysis the results become complex.

6.2.3. Thermal analysis in ANSYS:

Steady state thermal analysis
You can use a steady-state thermal analysis to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component. Engineers often perform a steady- state analysis before performing a transient thermal analysis, to help establish initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis, performed after all transient effects have diminished.

Transient thermal analysis
Transient thermal analyses determine temperatures and other thermal quantities that vary over time. The variation of temperature distribution over time is of interest in many applications such as with cooling of electronic packages or a quenching analysis for heat treatment. Also of interest are the temperature distribution results in thermal stresses that can cause failure. In such cases the temperatures from a transient thermal analysis are used as inputs to a structural analysis for thermal stress evaluations. Many heat transfer applications such as heat treatment problems, electronic package design, nozzles, engine blocks, pressure vessels, fluid-structure interaction problems, and so on involve transient thermal analyses. The Point to Remember in a transient thermal analysis can be either linear or nonlinear. Temperature dependent material properties (thermal conductivity, specific heat or density), or temperature dependent convection coefficients or radiation effects can result in nonlinear analyses that require an iterative procedure to achieve accurate solutions. The thermal properties of most materials do vary with temperature, so the analysis usually is nonlinear. Thus, the steady state thermal analysis can be used to determine the temperature, thermal gradients, heat flow rates, heat flux in an object that are caused by thermal loads that may or may not vary with respect to time. In order to establish the boundary conditions, the engineers perform the steady state analysis before going to the transient thermal analysis.

6.2.4 Harmonic analysis:
Harmonic analysis is a branch of mathematics concerned with the representation of functions or signals as the superposition of basic waves, and the study of and generalization of the notions

of Fourier series and Fourier transforms (i.e. an extended form of Fourier analysis). A harmonic analysis is used to determine the response of the structure under a steady-state sinusoidal (harmonic) loading at a given frequency.
A harmonic, or frequency-response, analysis considers loading at one frequency only. Loads may be out-of-phase with one another, but the excitation is at a known frequency. This procedure is not used for an arbitrary transient load.

6.3 ANALYSIS AND RESULTS:

6.3.1 Procedure:

In our project we will be performing the static structural and the transient thermal analysis. Thus obtaining the total deformation, equivalent (von-mises) stress,temperature distribution and also the factor of safety of the component. The main idea to perform analysis is to do it on two pistons with different volumes but same radius. In the end, best design will be selected based on whether the values are under the permissible limit.

Step 1- Import the geometries (shown in figures 5.1, 52) into the ANSYS by converting it into IGES format.

Step 2- Add Cast aluminium alloy, Aluminium Silicon Carbide and the Gray cast iron from the library to the engineering materials table.

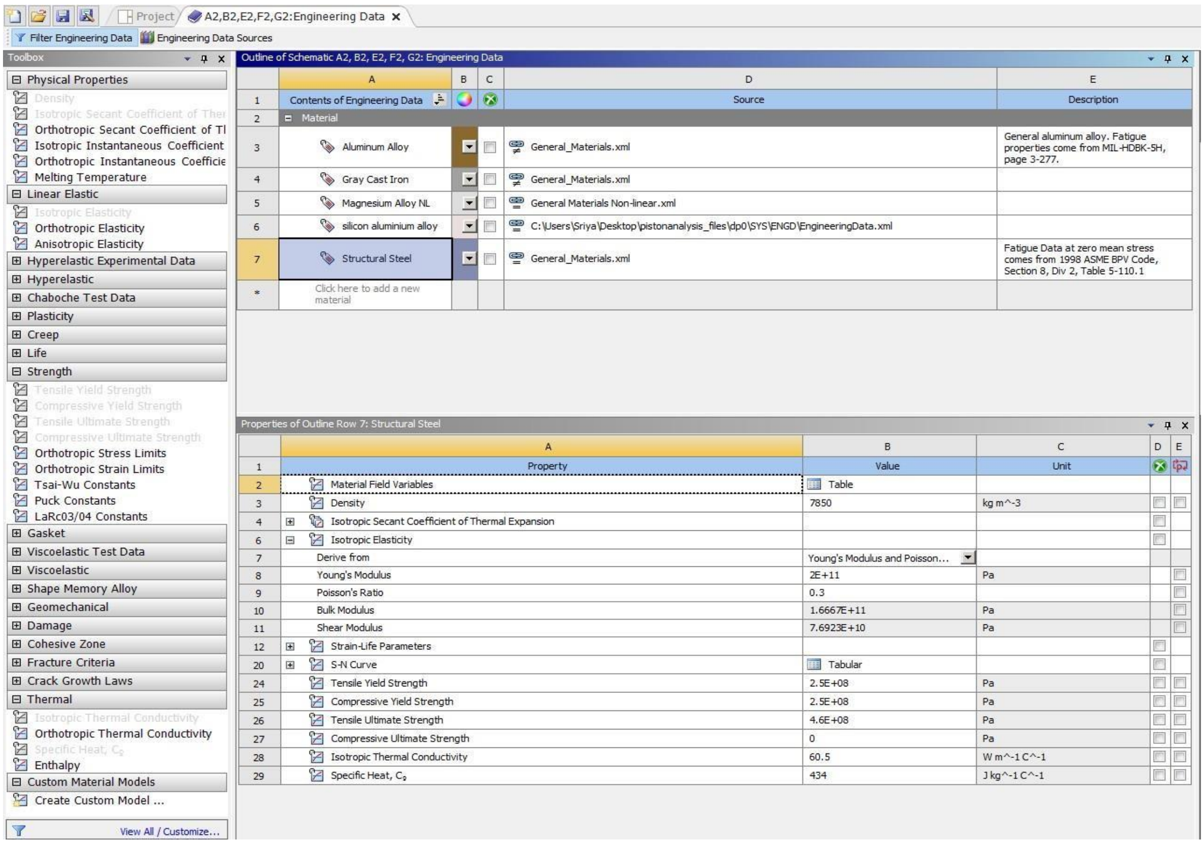


Fig 6.3

Step 3- after importing, open the modelling window and start meshing. Set the properties for meshing depending on the default mesh generated. It should be made sure that all the inner surfaces should also be meshed.

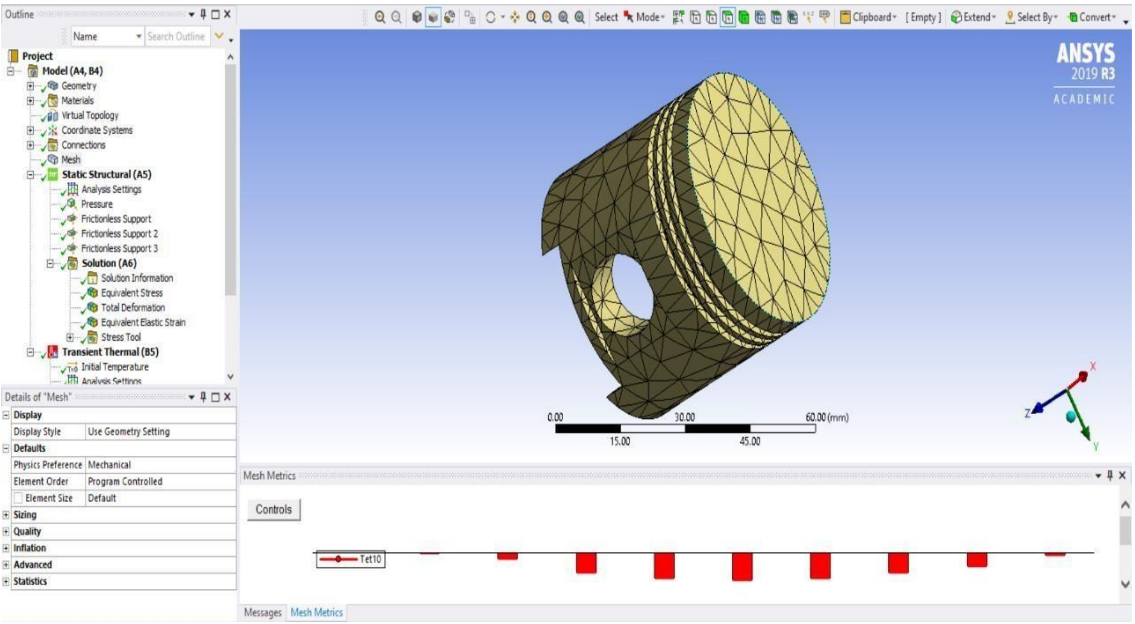


Fig 6.4

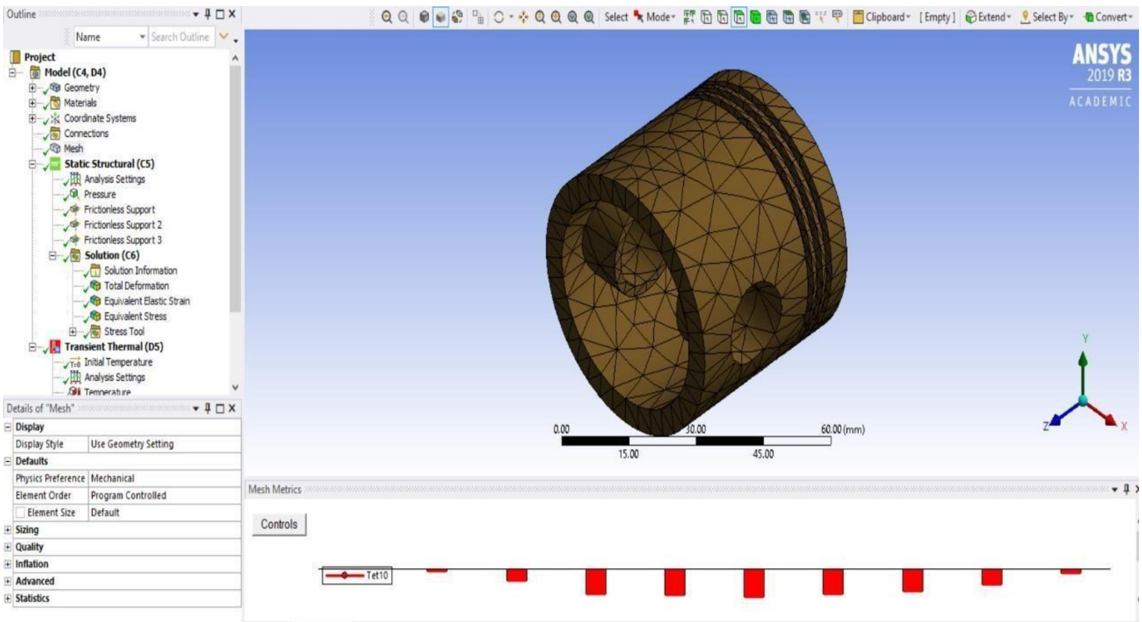


Fig 6.5

Step 4- Starting off with the static structural analysis, the input pressure (5.4MPa) and the frictionless supports have to be entered. Total deformation, equivalent stress, factor of safety and equivalent strain have to be added to the output and solution is proceeded. The frictionless supports are to be given near piston ring slots, outer surface, and the holes where piston pin is placed.

Pressure applied:

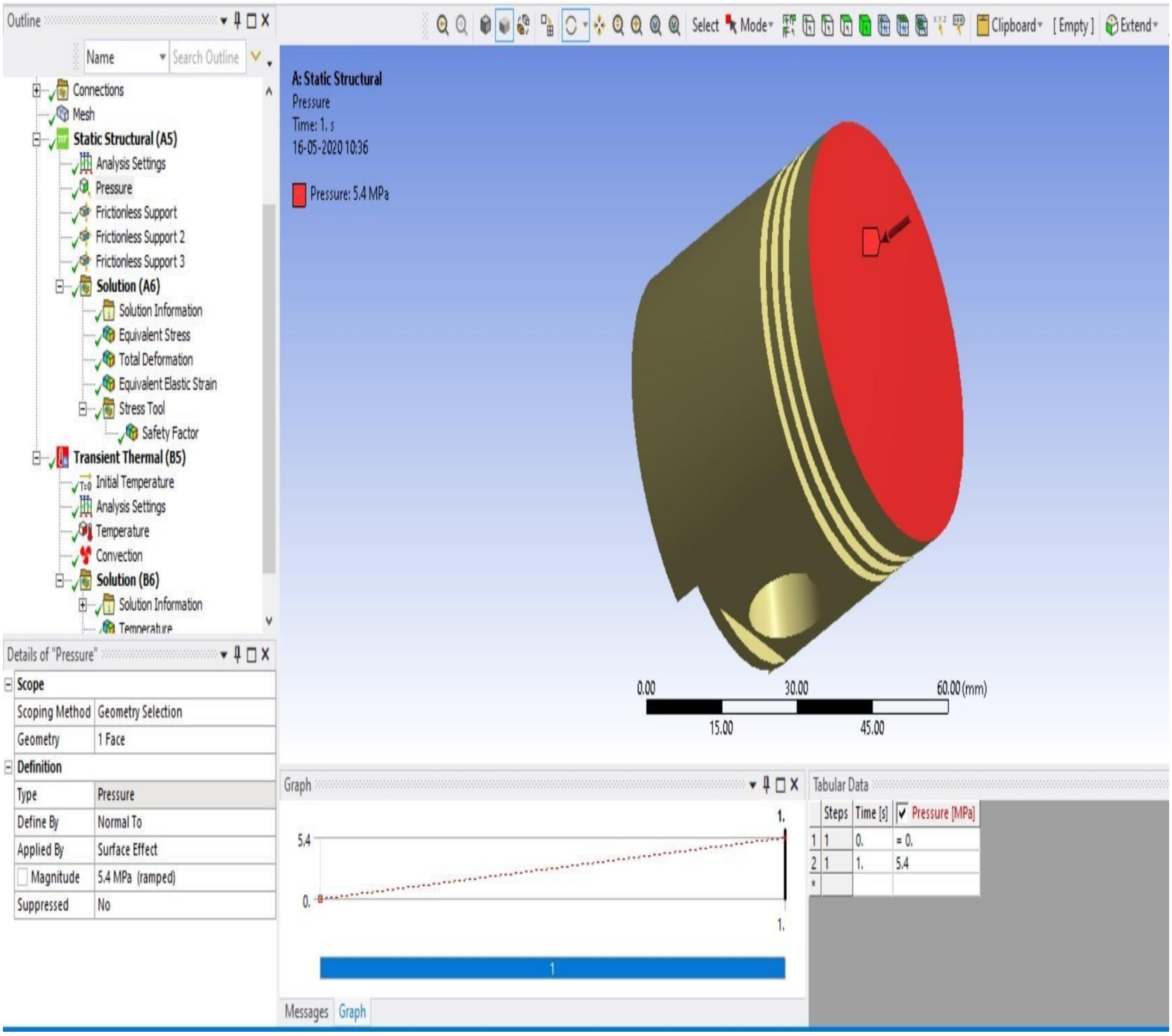


Fig 6.6

Step 5- Then while doing the transient thermal analysis set the initial temperature at 50 degrees and the final temperature at 300 degrees. The number of steps have to be 5. Select the temperature distribution as the output. The convection surface is selected to the outer

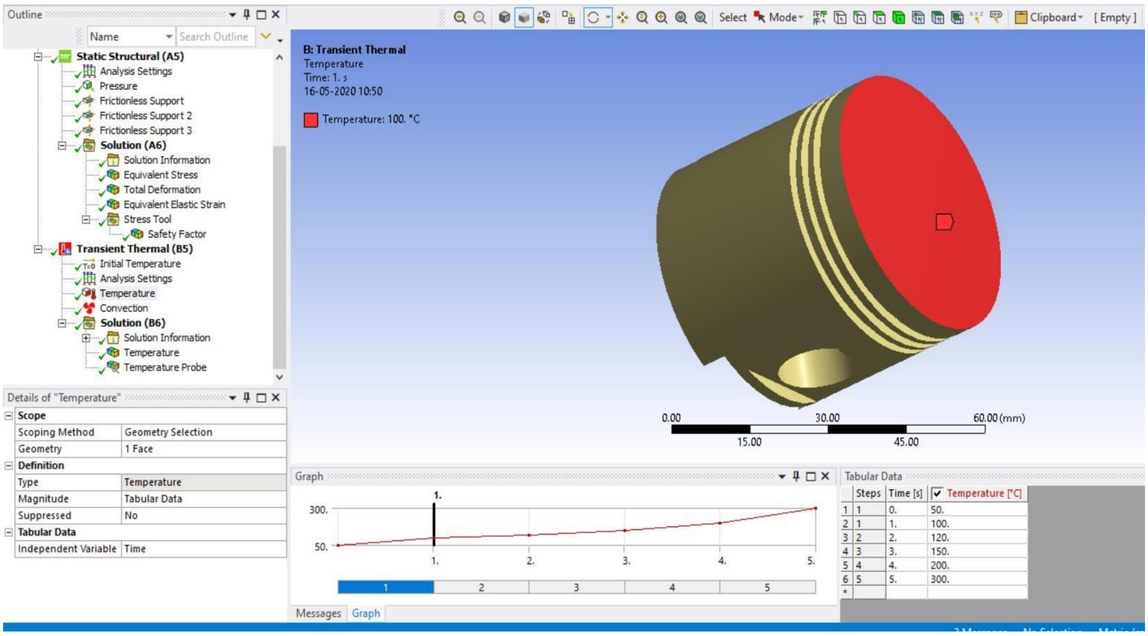


Fig 6.7 (a)

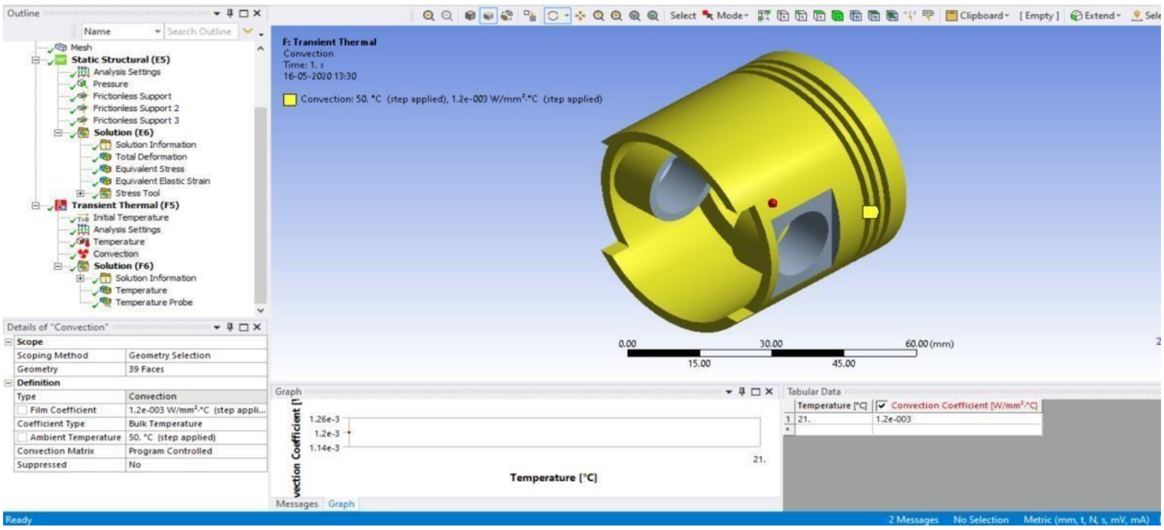


Fig 6.7 (b)

6.3.2 Results

1. FOR CAST ALUMINIUM ALLOY

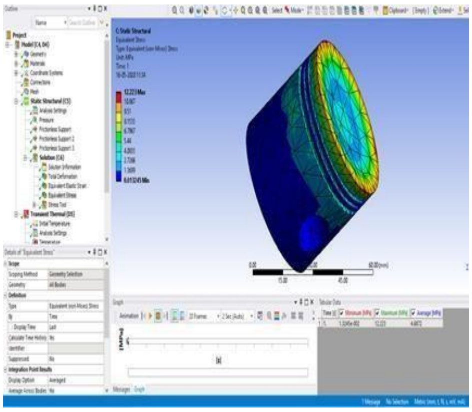
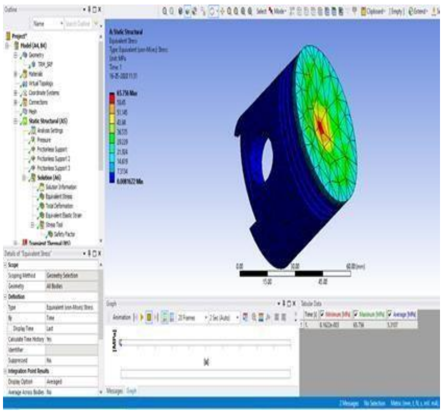
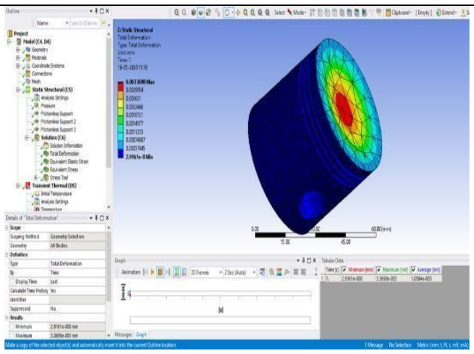
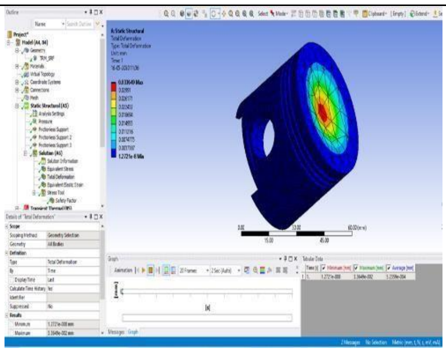
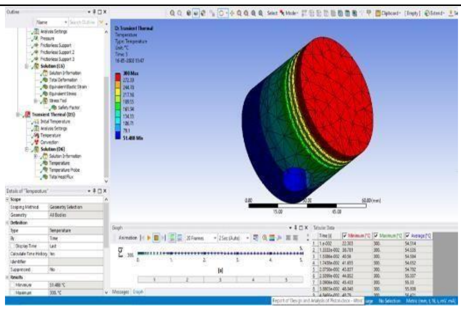
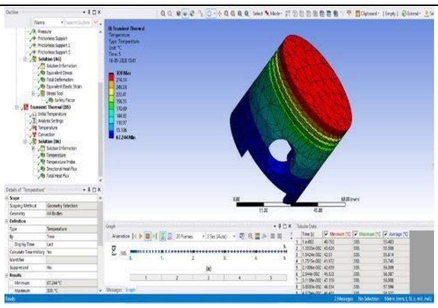
S.NO	NAME OF THE SOLUTION	PISTON 1	PISTON 2
1.	Equivalent stress		
2.	Total deformation		
3.	Transient thermal Temperature distribution		

Table 6.1

Static structural

Results	Minimum	Maximum	Units	Time (s)
Total Deformation	2.9161e-008	3.3698e-003	mm	1.
Equivalent Elastic Strain	3.3645e-007	1.7778e-004	mm/mm	1.
Equivalent Stress	1.3245e-002	12.223	MPa	1.
Safety Factor	15.	15.	Units Unavailable	1.

Transient thermal

Results	Minimum	Maximum	Units	Time (s)
Temperature	51.488	300.	°C	5.
Total Heat Flux	5.3269e-003	3.5578	W/mm²	5.

Probe: Reactions	X Magnitude	Y Magnitude	Z Magnitude	Total	Units	Time (s)
Temperature Probe				181.84	°C	5.

Piston 2

Static structural

Results	Minimum	Maximum	Units	Time (s)
Equivalent Stress	8.1622e-003	65.756	MPa	1.
Total Deformation	1.2721e-008	3.3649e-002	mm	1.
Equivalent Elastic Strain	1.2175e-007	9.3444e-004	mm/mm	1.
Safety Factor	4.2183	15.	Units Unavailable	1.

Transient thermal analysis

Results	Minimum	Maximum	Units	Time (s)
Temperature	67.244	300.	°C	5.
Directional Heat Flux	-1.1687	1.2438	W/mm²	5.
Total Heat Flux	1.2191e-002	3.1733	W/mm²	5.

Probe: Reactions	X Magnitude	Y Magnitude	Z Magnitude	Total	Units	Time (s)
Temperature Probe				175.39	°C	5.

Result analysis:

Though the equivalent stresses in piston 2 are more than that in piston 1, piston 2 is the ideal design because stress values are under permissible limit of the material. Also, the temperature difference in the piston 2 is slightly better than the piston 1. The design of pistons is such that the piston 2 deformation is under the limit. Observing all the cases opting for piston 2 is better as its weight is much lesser than the first one.

2. FOR ALUMINIUM SILICON CARBIDE

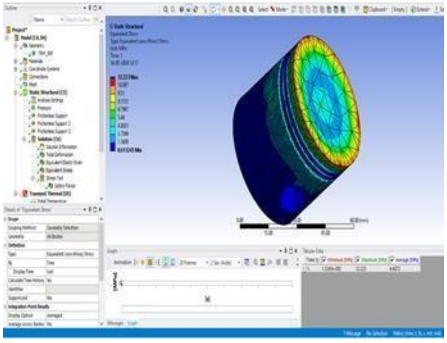
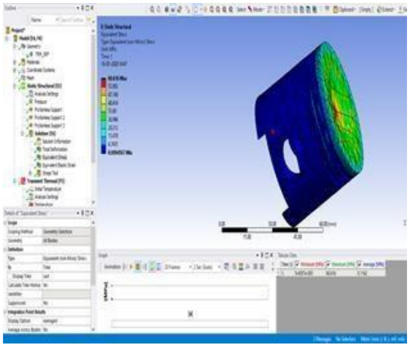
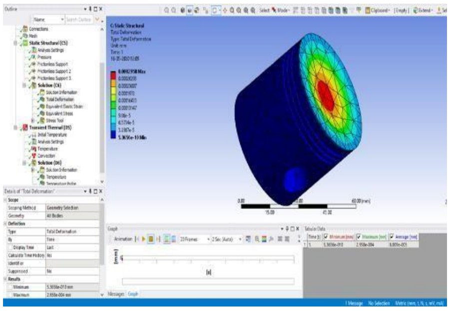
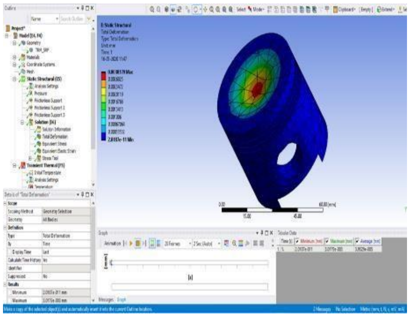
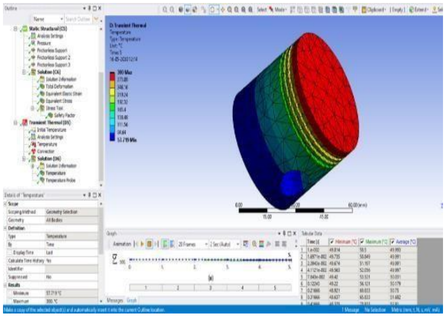
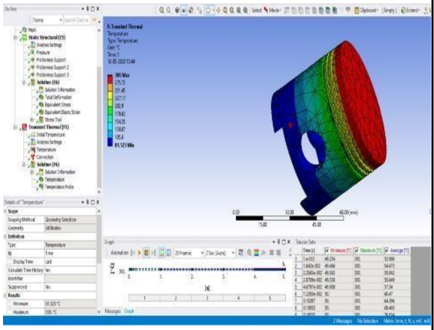
SNO	NAME OF THE SOLUTION	PISTON 1	PISTON 2
1.	Equivalent stress		
2.	Total deformation		
3.	Transient thermal Temperature distribution		

Table 6.2

Static structural

Results	Minimum	Maximum	Units	Time (s)
Total Deformation	5.3656e-010	2.958e-004	mm	1.
Equivalent Elastic Strain	1.9732e-008	1.7022e-005	mm/mm	1.
Equivalent Stress	1.4147e-002	12.9	MPa	1.
Safety Factor	6.3337	15.	Units Unavailable	1.

Transient thermal

Results	Minimum	Maximum	Units	Time (s)
Temperature	72.241	300.	°C	5.
Total Heat Flux	7.062e-003	3.9696	W/mm²	5.

Probe: Reactions	X Magnitude	Y Magnitude	Z Magnitude	Total	Units	Time (s)
Temperature Probe				196.45	°C	5.

Piston 2

Static structural

Results	Minimum	Maximum	Units	Time (s)
Total Deformation	2.0187e-011	3.0179e-003	mm	1.
Equivalent Stress	9.4507e-003	60.616	MPa	1.
Equivalent Elastic Strain	1.2258e-008	7.3907e-005	mm/mm	1.
Safety Factor	1.5332	15.	Units Unavailable	1.

Transient thermal

Results	Minimum	Maximum	Units	Time (s)
Temperature	81.523	300.	°C	5.
Total Heat Flux	2.3194e-003	3.9136	W/mm²	5.

Probe: Reactions	X Magnitude	Y Magnitude	Z Magnitude	Total	Units	Time (s)
Temperature Probe				187.78	°C	5.

Result analysis:

Both the equivalent stresses obtained in the analysis are lesser than the permissible stress which is between 50-90MPa. So, considering the piston 2 would not be any disadvantage in functioning. Also, the temperature difference in the piston 2 is slightly better than the piston 1. The piston with given dimensions can accommodate more deformation than the obtained two. Observing all the cases opting for piston 2 is better as its weight is much lesser than the first one and all the resultant values are way under the permissible limit.

3. FOR GREY CAST IRON

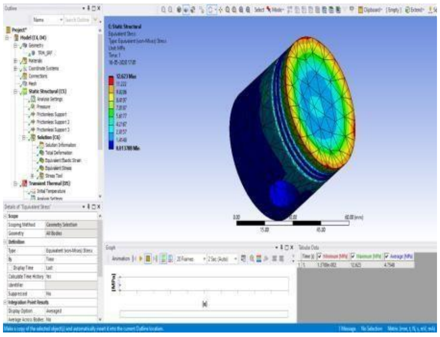
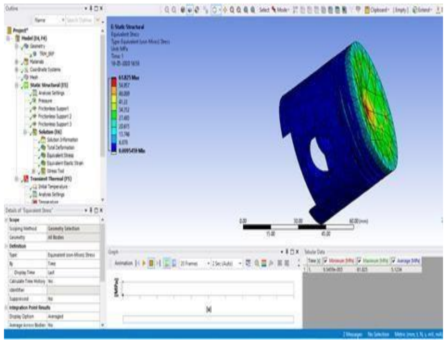
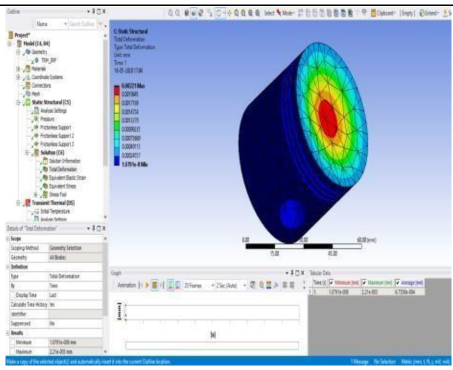
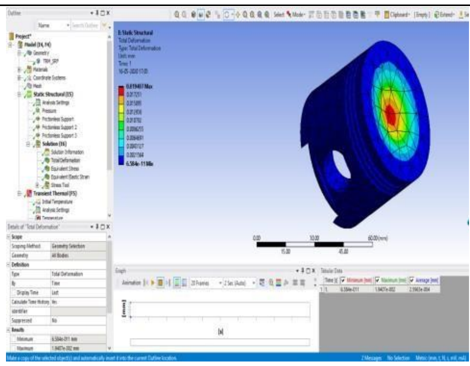
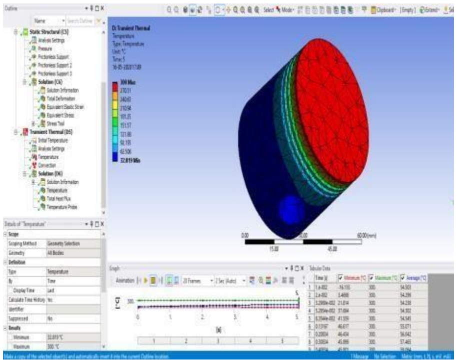
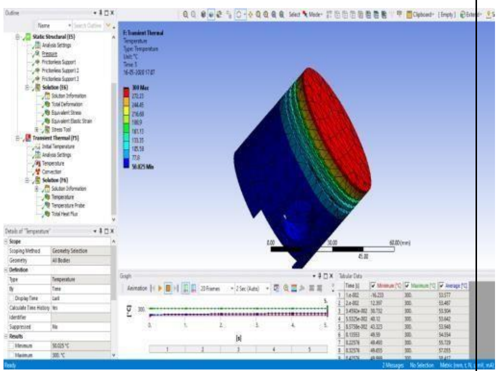
SNO	NAME OF THE PROPERTY	PISTON 1	PISTON 2
1.	Equivalent stress		
2.	Total deformation		
3.	Transient thermal (temperature distribution)		

Table 6.3

Static structural analysis

Results	Minimum	Maximum	Units	Time (s)
Total Deformation	1.0791e-008	2.21e-003	mm	1.
Equivalent Elastic Strain	1.5647e-007	1.2281e-004	mm/mm	1.
Equivalent Stress	1.3788e-002	12.623	MPa	1.
Safety Factor	0.	0.	Units Unavailable	1.

Transient thermal analysis

Results	Minimum	Maximum	Units	Time (s)
Temperature	32.819	300.	°C	5.
Total Heat Flux	1.7948e-004	1.2999	W/mm²	5.

Probe: Reactions	X Magnitude	Y Magnitude	Z Magnitude	Total	Units	Time (s)
Temperature Probe				87.197	°C	5.

Piston 2

Static structural analysis

Results	Minimum	Maximum	Units	Time (s)
Total Deformation	6.584e-011	1.9407e-002	mm	1.
Equivalent Stress	9.5459e-003	61.825	MPa	1.
Equivalent Elastic Strain	7.8783e-008	4.8842e-004	mm/mm	1.
Safety Factor	0.	0.	Units Unavailable	1.

Transient thermal analysis

Results	Minimum	Maximum	Units	Time (s)
Temperature	50.025	300.	°C	5.
Total Heat Flux	5.6623e-006	1.306	W/mm²	5.

Probe: Reactions	X Magnitude	Y Magnitude	Z Magnitude	Total	Units	Time (s)
Temperature Probe				86.365	°C	5.

Result analysis:

Both the equivalent stresses obtained in the analysis are lesser than the limit under which they are supposed to be. Also, the temperature difference in the piston 2 is slightly better than the piston 1. The piston with given dimensions can accommodate more deformation than the obtained two. Observing all the cases opting for piston 2 is better as its weight is much lesser than the first one and all the resultant values are way under the permissible limit.

6.4 DISCUSSIONS AND RESULTS

- Compared to the piston 1, piston 2 has less mass, volume. The change in volume percentage is nearly 35.9%. Evidently it is better to use piston 2. The criteria for its design is to keep its funcionality same and just reduce the material.

- All the deformation, equivalent stress, temperature distribution and heat flux values obtained for both the pistons are below the permissible level and a slight rise of those in piston 2 can be neglected.

- Among all the three materials considered, mostly the Aluminium cast alloy is the most used in manufacturing the pistons. But the analysis done in this project has given better results for Aluminium Silicon Carbide. All the results for it have turned out to be better than the Aluminium Cast alloy.

- Another material considered is the Grey Cast iron which gives the results that have a small deviation from the AlSiC. But the Grey Cast iron is a brittle material and its reliabitlity is lesser than a ductile material.

The results tabulated earlier for piston 2 are listed in the below table

SNO	Results	Aluminium cast alloy	Aluminium silicon carbide	Gray cast iron
1.	Equivalent stress (MPa)	65.75	60.6	63.037
2.	Total deformation(mm)	0.03361	0.003	0.0223
3.	Heat flux (W/mm^2)	3.17	3.91	1.3125
4.	Temperature distribution (^oC)	300 - 67.12	300 – 81.52	300 – 50.073

Table 6.4

- When any of the two materials is compared to AlSiC, it can be observed that all the values are better for AlSiC.

- The heat flux of AlSiC is more and it implies higher heat exchange which in turn will avoid detonation, knocking of IC engine and faster heat transfer.

- Similarly, the low deformation and low equivalent stress values also work in favor of the material.
- Hence, it can be concluded that AlSiC is the better one among the three materials considered that can be used in manufacturing.

7.CONCLUSION:

- Desiging and Analysis of piston is completed sucessfully.
- The piston is optimized under the concept of weight reduction.
- The analysis of both the pistons (before and after optimization) with three different materials(Grey cast iron, Cast Aluminium alloy, Aluminium Silicon Carbide) has been done and the results are tabulated.
- By the end of this project it is observed that piston made of Aliminium Silicon Carbide has lesser deformation, lesser stress and good temperature distribution when compared to Grey Cast iron and Cast Aluminium alloy.
- By this project it can be concluded that the properties of AlSiC are better compared to Grey Cast iron and Cast Aluminium alloy and it is more preferable material for making the piston more effective.

8. REFERENCES

- Computer Aided Design and Analysis of Piston Mechanism of Four Stroke S.I. Engine.
- Mathur M.L., Sharma, A Course in Internal Combustion Engine R.P. Dhanpat Rai Publication 1997 (i, ii, iii).
- V. B. Bhandari, Design of Machine Elements, Fourth edition, Tata McGraw Hill, New York, 2016.
- Amitabha Ghosh, Ashok Kumar Malik, Theory of Mechanism and Machines, third edition, Affiliated press pvt limited New De 1998.
- Shigley, Joseph Edward, Theory of Machines and Mechanisms, Tata McGraw Hill, New York, 2003.
- Khurmi, R.S. and Gupta, J.K., A Textbook of Theory of Machine,4th Edition, Eurasia Publishing House (Pvt.), Ltd, New Delhi, 2003.
- Dr. P.C. Sharma, Aggarwal, R.D.K, A Text Book of Machine Design, S. K. Kataraia and sons, New Delhi. 2004.
- Thermal Analysis and Optimization of I.C. Engine Piston using Finite Element Method.
- Sathishkumar. S, Design and Analysis of I.C engine piston using Catia and Ansys software, https://researchgate.net/, May 2015.
- R. Prabou, C. Jagadeesh Vikram, P. Naveenchandran & E. Raja, Structural and Thermal Analysis of Piston using Composite material, International Journal of Pure and Applied Mathematics, Volume 119, No. 12, 2018.
- Vinod Yadav, Dr. N. D. Mittal, Design and Analysis of Piston Design for 4 Stroke Hero Bike Engine, International Journal of Engineering Innovation & Research, Volume 2, Issue 2.
- Shahanwaz Adam Havale, Prof. Santosh Wankhade, design, Thermal Analysis of Piston using Ansys, International Research Journal of Engineering and Technology, Volume 04, Issue: 12, Dec-2017.

- Abino John, Jenson T Mathew, Vasdev Malhotra, Nitin Dixit, Design and Analysis of Piston by SiC Composite Material, International Journal for Innovative Research in Science & Technology| Volume 1 | Issue 12 | May 2015.