Design and Analysis of IC Engine Piston Using Catia and Ansys

A REPORT

SUBMITTED
IN THE PARTIAL FULFILMENT
FOR REQUIREMENT OF
THE AWARD FOR THE DEGREE OF

Master of Technology
In
Machine Design

SUBMITTED BY

KESHAV KUMAR

(University Roll No.-2013111480)

UNDER THE ESTEEMED GUIDANCE OF

Mr. VIVEK KHOKHAR

(H.O.D Mechanical Department)

DEPARTMENT OF MECHANICAL ENGINEETING

GANGA INSTITUTE OF TECHNOLOGY AND MANAGEMENT, KABLANA, JHAJJAR
(June 2022)

CANDIDATE'S DECLARATION

I Keshav Kumar bearing university roll number: 2013111480 a student of M. Tech (MD) Hereby declare that I own the full responsibility for the information, results etc. provided in this dissertation titled "Design and analysis of IC engine piston using Catia and Ansys" submitted to MaharshiDayanand University, Rohtak for award of Master of Technology (Machine Design) degree. I have taken care all respect to honor the intellectual property rights and have acknowledged the contributions of others wherever their findings have been cited. I further declare that in case of any violation of intellectual property right or copyright I as the candidate would be fully responsible for the same.

My supervisor and institute should not be held for full or partial violation of copyright if found at any stage of my degree.

Name of the student- Keshav Kumar
University Roll no.- 2013111480
Branch & Semester. -Mechanical Engineering, 4th semester.

CERTIFICATE

It is certified that thesis report titled "Design and analysis of IC engine piston using Catia and Ansys" submitted by KeshavKumar, Roll No. 2013111480 in the partial fulfillment of requirement for the award of Master of Technology (MD) submitted to MaharshiDayanand University, Rohtak is a record of student's own work carried out under my supervision from February to June. This thesis has not been submitted to any other University or Institute for award of degree. The work contained in this dissertation is at par university standards.

I wish him/her good success in life.

……………………………..

Signature

Name of the Supervisor Mr. VivekKhokhar (H.O.D mechanical department)

Ganga Institute of Technology and Management, Kablana

Date:

ACKNOWLEDGEMENT

This research was supported /partially supported by Ganga Institute of Technology and Management. I am very thankful my HOD Mr. VivekKhokhar who provided insight and expertise that greatly assisted the research. Although they may not agree with all of the interpretations/conclusions of this paper. He took active interest in my progress and inspired me to use this great opportunity to learn about the various aspects of research and not just limit myself to the assigned project.

I would also like to show my gratitude to sharing their pearls of wisdom with me during the course of this research, and I thank 3 "anonymous" reviewers for their so-called insights. I am also immensely grateful to all the professors fo their comments on an earlier version of the manuscript, although any errors are own and should not tarnish the reputations of these esteemed persons.

Name of the student- Keshav Kumar
University Roll no.- 2013111480
Branch & Semester.- Mechanical Engineering, 4th semester.

TABLE OF CONTENTS

1.INTRODUCTION:

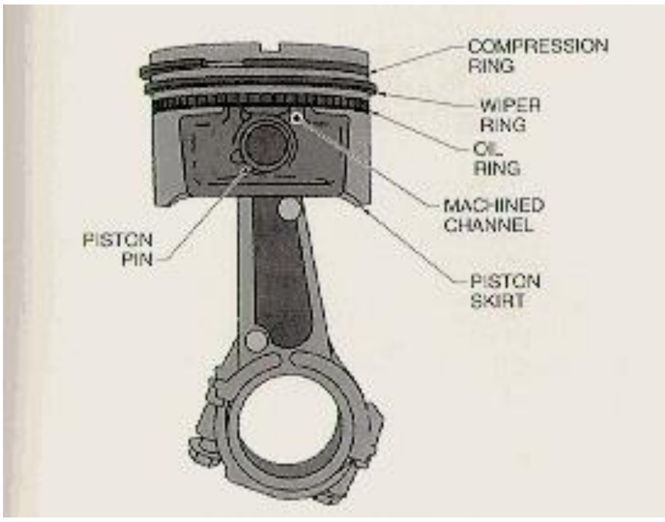
My work is all about the piston. Its work is as important as heart. Piston was invented by renowned German scientist Nicholas August Otto in 1866. The main function of piston is to generate power by expanding of gases and this generated power is further transferred through crankshaft to wheels. Piston is the important components of reciprocating machines like IC engine, reciprocating machines, and where the power is generated by burning of fuel.it is made in such a way that it moves up and down inside a cylinder. There are four rings attached with piston. These rings act as a seal between piston and cylinder walls. These rings help to control excess oil between cylinder and piston. They also help in transferring temperature produced inside the cylinder.in working condition piston experiences high temperature that causes tear and wear of piston, deformation on the surface and may be cracks at certain stages. Therefore it is necessary to examine and further work to enhance the quality of piston. Lots of works are being conducted to enhance the quality of piston so that performance of engine could be increased. In this project the parameters selected are analysis of piston by applying Pressure force acting on the piston and thermal analysis of piston at various temperatures in various stages.

1.1 piston Components:

Some components of piston arrangement are:

1.1.1 **Rings**: rings are inserted to the outer diameter of the piston. The main function of the piston rings are to check the loss of exhaust gases, to transfer temperature generated inside the cylinder, and control excess oil.Rings are small in size but this part has very important role in the engine.

Types of rings:
1. Compressor Rings (top two rings.)
2. Oil Ring.



Compression(Tension Ring): The blower ring is put into the top depressions of the cylinder. The principal capability of the blower ring is to move temperature from the pistonr to the chamber surface. There is likewise aaround pushed over the cylinder, which makes changes the cylinder. The blower ring is utilized to die down it.

The oil regulator ring is embedded beneath the blower ring. The principal capability of this ring is to control the legitimate grease between the piston and the chamber wall. In the state of access grease inside the chamber, then it additionally attempts to scrap it. Here are various kinds of rings gave in a cylinder at different levels. Which perform variousworks.

Thecompression ring is placed at the highest section of thepiston.Its principal capability is to control any sort of spillage inside the ignition chamber during the burning system.

At the point when the air fuel combination is lighted, strain from burning gases is applied to the cylinder head, constraining the piston toward the driving rod.The compressed gases travel through the hole between the chamber wall and the cylinder and into the piston ring groove.During the ignition interaction the power of high tension gases powers the cylinder ring against the chamber liner wall which assists it with shaping a compelling fixing. This strain pushing the cylinder ring is corresponding to the ignition gas pressure.

The other arrangements of rings in the cylinder which are embedded beneath the pressure ring and above the oil rings are called wiper rings.

Wiper rings have a tightened face development and it is utilized to additional seal the ignition chamber. As the name recommends, they help with cleaning the liner wall clean of any overabundance oil and pollutants among chamber and cylinder. Assuming that any of the ignition gases had the option to go through the pressure ring, these gases will be obstructed by the wiper ring.

The last arrangement of rings is oil rings which are set at the base depressions of the cylinder nearest to the crankcase. The fundamental capability of the oil ring is to eliminate any overabundance oil stay on the walls of the chamber liner when the piston is moving.

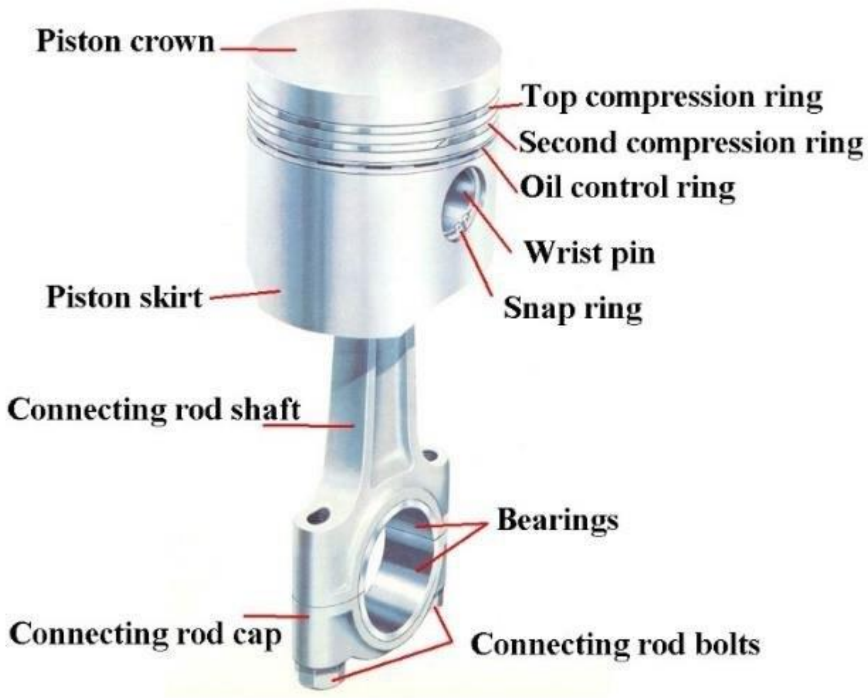
1.1.2 Piston crown or piston Head:
The above portion of the piston is known as crown. Because of its area the cylinder crown faces exceptionally high strain and heat. The cylinder crown that is utilized in the planning of the restriction cycle, the shade which exits from the gas fumes, helps it to out of the IC engine.

1.1.3 Groovesin the Piston ring: Grooves are made on the outer surface of piston. Piston rings are inserted into these grooves.

1.1.4 Skirt:
Cylinder skirt is round and hollow valve in the cylinder. Cylinder skirts are made somewhat unpleasant at the hour of assembling so it can hold oil and furthermore oppose push. Push emerges because of extension stroke. The length of the skirt relies upon the length of the cylinder. It will give a superior smooth surface among cylinder and chamber lastly decrease the motor clamor. Yet, we can't expand the cylinder's length. Generally its mass expands and its latency will likewise increase.

1.1.5 Pin of the piston:
It is likewise called a gudgeon pin. This pin is utilized to interface the cylinder and connecting rod. Hardened steel is utilized for making piston pin.

1.1.6 Connecting rod:
The connecting bar interfaces the cylinder with the driving rod and its fundamental capabilities are like a liver and moves movement from the cylinder to the driving rod. The associating pole is made up of cast aluminum combination. Furthermore, it is so planned that it can endure the powerful burdens of burning and piston movement.



1.1.7 Bolt:
In piston cylinder arrangement we connect clamp with connecting rod. The use of Bolt is to connect these two.

1.1.8 Connecting rod bearing:
Bearing in connecting rod is introduced in two sections and both the parts together make a total circle. Bearings are embedded between the associating bar and the wrench pin.

1.1.9 Cap
In the piston set up below portion is called Cap. The half portion of the connecting rod is cap that gives the space for bearing the interfacing bar.

1.2 Piston design features:

1. They have enough mechanical strength and stiffness.
2. It can effectively stop the heat reached the piston head.
3. It has high temperature corrosion resistance.
4. Dimensions should be as small as possible to lessen the weight of the piston.
5. It has enough rigidity to withstand high pressure.
6. Lighter in weight to keep its inertia forces to the minimum and enable higher engine speeds.
7. It remains silence in both the operations during warming up and normal running.
8. Its material priority great heat conductivity for proficient intensity move. Thus it reduces the risk of detonation and allows a higher compression ratio.
9. Its material should also have low expansion qualities.
10. It Offers resistance to corrosion due to combustion.
11. It should be of the shortest possible in length so that to lessen the overall engine size.

1.3 Material selection for piston:
A large area of the cylinders for car applications is made up of aluminium composites. This is on the fact that aluminum is light in weight, has sufficient mechanical opposition and great warm conductivity. For very tough applications, business vehicles, which are utilizing steel cylinders, that gives more impervious to higher tensions and temperatures in the burning chamber. Aluminum cylinders are delivered from cast or forged, high temperature safe aluminum silicon composites. There are three basic sorts of aluminum cylinder composites. The standard piston composite is an eutectic AL-12% Si compound containing likewise approx. 1% every one of Cu, Ni and Mg.

The main composite of aluminium for pistons are: [30]:
Eutectic composite (AlSi12CuMgNi).
Hypereutectic composite (AlSi18CuMgNi).
Unique eutectic combination (AlSi12Cu4Ni2Mg).
Since the composite of aluminum has lower strength than cast iron material, thicker segments must be utilized butt not all the upside of the light weight of this material is understood. Also, due to its higher coefficient of warm development, bigger running clearances must be considered aluminum cylinders. Then again, the warm conductivity of aluminum is about multiple times that of iron. This along with the more prominent thicknesses of the segments utilized, empowers aluminum cylinders to rum attemperatures around 200°C lower than cast iron ones. In certain applications, the strength and wear opposition of aluminum combination cylinders in insufficient to fulfill the heap need, in this manner ferrous materials are utilized. There are a few strategies for involving ferrous metals in cylinder producing.

- As neighborhood support, ferrous metal additions.
- As broaden portions of composite cylinders.
- Pistons developed totally of solid metal or steel.

1.4 properties:
1. High Fatigue Resistance, Bio compatibility, Osseo Conductivity.
2. Light Weight, High Strength and Good Heat Conductor.
3. High Heat Resistance and Increased Thermal Conductivity.
4. High Strength to Weight Ratio, Corrosion Resistance.
5. Load Density, High Thermal Conductivity, High Reliability.

2. LITERATURE REVIEW:

Lei Zhou*et al.* (2014) executed into a variation of the KIVA-3V code to recreate the functioning system of the PM motor. He showed that the attributes of intensity move, outflows and burning of the PM motor are better than the motor without PM, offering important help for the PM motor idea.

AshkanMoosavian*et al.* (2016) showed that piston scuffing fault caused the machine performance to reduce significantly. The vibration signals were analyzed in time domain, frequency domain and time frequency domain. Nonstop wavelet change was utilized to obtain time frequency representations.

Tejuskumarchaudhri*et al.* (2016) compared the tested results for analyzing the tribological characteristics. It can be seen that as speed increaseds, the friction force and friction coefficient also decreased.

Ashkan*et al.* (2017) indicated that piston scratching had significant and detectable effects on the engine vibration. Hence the vibration analysis could be applied as an effective tool for testing of piston scratching fault in IC engine.

M.B Nanda kumar*et al.* (2018) proposed that piston slap noise had reduced by the retained oil film reducing the engine sound by 8 decibels. The motor oil utilization was fundamentally diminished from 65ml/1000 to 25ml/1000.

Parvati Rama Swamy*et al.* (2018) developed the geometric model using Non uniform coatings, leading to non-uniform drop in temperature across the thickness were most likely to affect the lubrication system of the machine and therefore the performance.

ZhiminYao*et al.* (2019) showed that the substrate temperature of Nano PYSZ TBCs pistonwaswidely lower than that of the regular piston, which indicated that TBCs gave warm exhaustion security to pistonand reduced thermal damage to pistons.

S. Prakash*et al.* (2021) recommended that in present day time the universes existing energy sources were centered around petroleum products, which will exhaust soon in the event that we didn't fabricate innovation that could utilize sustainable powers to supply power.

HarshaRajput*et al.* (2021) studied the optimization fortwo different surface textures. The results showed 27% and 21% friction reduction with 100 μm and 120 μm, respectively, for suction and power strokes, compared to an untextured ring.

M. Kalyanakumar*et al.* (2021) observed that the uncoated material has melted around 650°C, whereas the coated specimen was successfully resisted the heat energy up to 1400°C without any physical deformation.

Jami paparao*et al.* (2021) revealed that the thermal efficiency of brake opt. JME20 + HHO ran in dual-fuel operation was found to be greater by about 5.9% compared to that of the baseline data at full load.

Bo Zhao*et al.* (2021) indicated that although a thinner skirt will affect the stability of piston motion and increased the slapping noise and wore, it will benefit hydrodynamic lubrication between skirt and cylinder and reduced friction power loss.

RuiHu*et al.* (2021) illustrated that with the PVBS Nezha III was able to maintain a desired vehicle pitch and heave velocity, besides perform stable saw tooth gliding motion.

VS. Shaisundaram*et al.* (2022) discovered that when cast iron was heated it expanded and covered the clearance level, causing to seize. The mechanical and heat properties of the piston were described in this work when the study was led utilizing five review was directed utilizing five distinct methods.

GuangfuXu*et al.* (2021) suggested that the transfer of heat loss energy fraction can be well decreased with a wider and more open piston bowl.

JialinWang*et al.* (2021) showed that the carburized layer transited from the acicular martensite phase to plate martensite from the surface towards the inside.

XiwenDeng*et al.* (2021) contributed incontrollableheat state design method to controlled the design aim of the one or more feature area of the piston.

F. Millo*et al.* (2021) showed a more intense OH distribution in the radial-bumps region and above the step during the first stage of the burning process.

HaoZhou*et al.* (2021) reduced the compression efficiency caused by leakage and reduced the impact and vibration of piston and increased the stability and controllability of the compressor operation.
PrastowoMurti*et al.* (2021) showed that the designed engine achieved the target output power of 102 W under the heat source and sink temperatures of 130 °C and 23 °C, respectively.

HeshengTang*et al.* (2021) optimized the texture radius and texture depth were chosen to minimize the leakage rate and texture bearing capacity.

3. PROBLEM FORMULATION AND MRTHODOLOGY:

A piston-cylinder is a part of responding machines. It is the moving part inside a chamber and is made gas tight by cylinder rings. Inside an engine its fundamental capability is that to move force from extending gas inside the chamber to the driving rod through a cylinder pole. Cylinder perseveres through the regular gas pressure and the inertial powers while working and this functioning condition might cause the exhaustion harm of cylinder, for example, cylinder head breaks, cylinder side wear. The functioning state of the cylinder of a gas powered motor is so most terrible and the possibilities of disappointment of cylinder because of mileage. So accordingly it is needed to break down the most extreme pressure fixation, strain, distortion and temperature appropriation and intensity motion on cylinder.Themain aim of my work is to design and evaluate of piston made UP of materialA4032, AL6082, AL7075, ALSIC GRAPHITE.

METHODOLOGY:

1. Analytical design of the piston, utilizing detail of 4 stroke single chamber engine of Bajaj (pulsar)motorcycle created.
2. Creation of three dimensional of piston designwith the help of CATIA V5 and then I imported this design in ANSYS software.
3. Analysis of stress and deformation arisen in the piston using FEA method.
4. Check the effective working performance of AL alloy piston.
5. Select the right Material for making piston.
6. Based on the stresses, deformation, shear stress, distribution of temperature and total amount of heat flux.

Engine specifications: [(26), (27)]:

The specification of engine took for my work is: a single cylinder with four stroke and air cooled typed pulsar 220cc engine.support petrol as working fuel. The engine details are mentioned in below table:

PARAMETERS	VALUES
Engine Type	Four stroke engine, petrol
Induction	Air cooling system
No. of Cylinders	Single cylinder
Bore	67mm
Stroke	62.4mm
connecting rod length	124.8mm
Displacement volume	220cm3
Compression Ratio	9.5+/-0.5:1
Maximum Power	15.5100 kw at 85000rpm
Maximum Torque	19.12Nm at rpm of 7000.
Number of revolution/cycle	2

4. MECHANICAL SOFTWARE:

4.1 INTRODUCTION TO CATIA V5R20:

4.1.1 INTRODUCTION:

CATIA means "C-Computer A-Aided T-Three Dimensional I-Interactive A-Application". As another designer of this product bundle, you will find with huge number ofuser of this very good quality computer aided design/CAM/CAE softwareall over the world. Assuming that you are now acquainted with the past deliveries, you can enhance your thought abilities with the numerousimprovements in this latestversion.

CATIA V, developed by DassaultCompany of France, is a completely re-engineered, Next-generation family of CAD/CAM/CAE engineering software solutions for product design management. Althoughits exceptionally easy-to-handle and state-of-the-art user interface, CATIA V5 conveys imaginary idea into innovations for greatest efficiency and innovativeness, from the beginning thought to the end result. CATIA V5 subside the expectation to absorb information, as it allows the versatility of using feature based and parametric plans.CATIA V5 gives three essential stages: P1,P2, and P3. This P1 is for little and medium estimated process-situated organizations that help to develop in the way of the huge scope digitized item definition.

P2 allows for the high level plan designing organizations that require item, cycle, and asset displaying. P3 allows for the top of the line plan utilization and is fundamentally for auto and avionic business, where excellent surfacemodelor class-A surfacing is utilized. The topic of interpretability presented in CATIA V5 incorporates getting heritage information from other CAD (computer aided design) frameworks and, surprisingly, between its own item information the executives modules. The genuine advantage includes the connections stay cooperative. Thus, any alternate made to this outside information gets advised and this model could be refreshed rapidly. CATIA V5 Serves the essential plan undertakings by giving various workbenches. In Catia workbench is described as a predetermined climate including of a bunch of devices that allowed the designer to perform explicit plan undertakings. The essential feature in CATIA V5 are sketcher, part plan, wireframe and surface plan, get together plan, and drafting.

4.1.2 DESIGN PROCEDURE IN CATIA WORK BENCH:

How can CATIA helpdesgning so easy?
It has coordinated a multidisciplinary approach and a cross-discipline improvement stage. With an astounding 3D client experience and nice work processes, and a social plan climate, it makes working simple and straightforward. It depends on a development surface displaying structure and has a solid social plan.

It permits clients to display items as per their genuine ways of behaving. It additionally helps in the planning of electronic, electrical, and circulated frameworks. Besides the graphical UI is easy to use in contrast with other 3D projects. Each device and order in the work area is explicit and effortlessly found.

CATIA has feature of working in many domains.
Most of clients doesn't need all functionalities that anyone could hope to find in CATIA, which affects the client or association, licenses are hence separated to incorporate required usefulness and are pre-characterized. Dependent upon the permit, extra workbenches become accessible and extra apparatuses inside workbenches become accessible. Features in CATIA work a piece like different programming held inside CATIA. They permit the designer to perform various errands. From:

Modeling of part:
Part Designing workbench: The part modeling plan feature empowers designer to plan exact 3D mechanical parts. From gathering portraying to point by point plan, the part modeling plan application obliges the immense larger part of plan prerequisites.

Modeling of Assembly:
Assembly designing workbench: The assembly plan workbench empowers designer to configuration help out part plan and generative drafting applications on adaptable plan projects. Different visual devices consider 3D route through huge assemblies.

Modeling of Surface:
Design workbench for Generative surface: The generative surface plan workbench empowers designer to make wireframe development components and improve existing mechanical part plan with wireframe and surface elements.

FEA (Finite Element Analysis):
Analysis for Generating structural: The Analysis for Generating structural empowers designer to perform first request mechanical investigation for 3D frameworks.

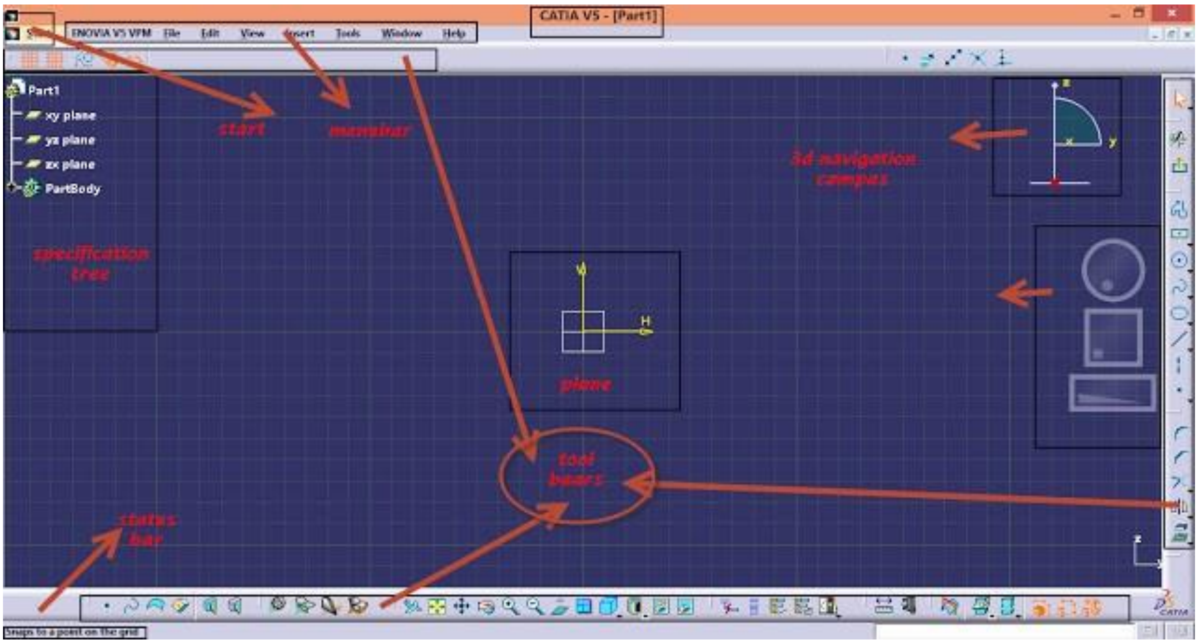
Analysis for Generating structural workbench includes:
- Generative Part Structural Analysis (GPS) togetting mechanical information.
- ELFINI Structural Analysis (EST) todevelopments for mechanical testing.
- Generative Dynamic Analysis (GDY) toresponse for working in a dynamic area.

Part Design for Sheet metal:
Generative sheet metal plan empowers designer to perform cooperative component based designing, making it conceivable to configuration sheet metal parts in simultaneous designing between the unfurled or collapsed part portrayals.

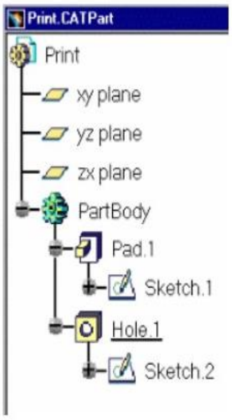
Rendering:
Workbench for Real Time Rendering: The Ongoing Delivering Workbench empowers clients to characterize material determinations that will be shared across the entire item advancement process, while planning materials onto parts and items to create practical renderings.

Engineering Drawing Creation:
Workbench for Generative Drafting: The creating draft feature empowers designer to produce drawings from 3D parts and gathering definitions.

GRAPHICAL USER INTERFACE OF CATIA:



SPACIFICATION TREE:



VIEW TOOLBAR:

<u>4.1.3 Sketcher Module:</u>
The Sketcher feature is a bunch of instruments that provide you make and compel 2D calculations. Highlights (cushions, pockets, shafts, and so forth) could then be made solids or changes to solids utilizing these two dimensional sketch profiles. You can get to the Sketcher feature in numerous ways. Two basic technics are by utilizing the upper draw below menu (Begin Mechanical Plan drawing) or by choosing the Sketcher symbol, when you go the sketcher, CATIA expects that you pick a reference plane to portray on. You could pick a plane as previously or after you select the tool “Sketcher” symbol. To leave the tool “sketcher”, choose the Leave Workbench symbol.

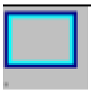
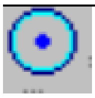
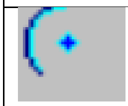
Profile toolbar: The orders situated in this toolbar permit you to make basic calculations (square shape, circle, line, and rectangle) and further more mind boggling calculations (profile, spline, and so forth).

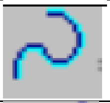
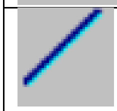
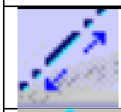
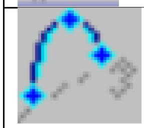
Operation toolbar: When a sketch has been made. Then there are many tools to change this sketch by utilizing orders like trim, mirror, chamfer, and different orders situated in the Activity toolbar.

Constraint toolbar: Profiles might be obliged with layered (distances, points, and so on…) or mathematical (digression, equal, and so forth…) limitations utilizing the orders situated in the Requirement toolbar.

Sketch tools toolbar: The orders in this toolbar permit you to work in various modes which make portraying simpler.
Sketcher application makes it possible for designers to sketch precise and rapid 2D profiles choose the Sketcher icon and then select the desired reference plane it could be the geometry area or specification tree, or select a planar surface. This creates a "non-positioned" sketch (i.e. a sketch for that you do not specify the origin and position of the absolute axis, which are not associative with the 3D geometry). The sketch absolute axis may "slide" on the selected reference plane when the part is updated. Choose one plane of the local axis. H and V are in one line to the main axes of this selected plane. Associativity is kept between both the plane and the sketch.

Sketching simple profiles

	**Create a profile** Use the Sketch tools toolbar or click to define lines and arcs which the profile may be made of
	**Create a rectangle** Use the Sketch tools toolbar or click the rectangle extremity points one after the other.
	**Create a circle** Use the Sketch tools toolbar or click to denote the circle center and then one point on the circle.
	**Create an arc** Use the Sketch tools toolbar or click to denote the arc center and then that of the arc start point and end point.

	**Create a spline** Click the points through which the spline will go.
	**Create a line** Use the Sketch tools toolbar or click the line first and second points.
	**Create an infinite line** Use the Sketch tools toolbar or click the infinite line first and second points.
	**Create a conic** Click the desired points and excentricity for creating an ellipse, a circle, a parabola or a hyperbola, using tangents, if needed.

There are some options those are used in creating solids.

Pad-this feature is used when we need to make a solid or three dimensional profiles. First we select a plane and draw profile then choose Pad tool to make it solid.

Pocket-this command is used when we need to make a cut on solid profile. Means this command is used after pad command.to make any elimination from solid we could use this command.

Shaft- the shaft device is used when we need a round profile. First we select a center lime and make a profile whose shape we want around the center line then choose shaft command.

Fillet-this command is used to make a solid object smooth. First make a solid object by using pad command. Then if we want to make its corner round we use fillet command.

Chamfer-this command is used also used to cut the edge of profile. We can control dimension of both the sides of profile.

Draft-Draft is used on formed object to make them more straightforward to eliminate from molds.

Thickness-Adds or eliminates to the appearances.

Translation-to Move a body.

Mirror- this tool is used to make a similar object. The object will be at same distance from the plane.

Pattern-this tool is used to make or cut the similar type profile around a center line and along the selected line.

Break and trim- Quickly delete elements intersected by other Sketcher elements using breaking and trimming operation.

Create corners- Create a rounded corner (arc tangent to two curves) between two lines using trimming operation.

Reference tool:
Reference command is supported as reference for making a model. This command helps the designer in various works. Without selecting any plane no profile can be created. This plane is the base of any profile.in a complex profile the base may be line or point reference.
1. Reference of plane
2. Reference of line
3. Reference of points

Generative drafting:
Generative Drafting is another command that helps the designer with strong features to createprofile from 3D parts and gathering definitions. This Generative Drafting command gives some idea to draw the profile in correct way.

View:
Front view-A front of a profile is one that shows maximum part of the profile. we can select any view as front view. Front view helps to decide the whole profile.

Projection view-Projection view gives an idea of other sides of the profile. To show the 3D image we need projection view.

Isometric View-The Isometric View used to make a 2D view in any direction, this direction being equivalent to the one of the 3D viewer. Among different outcomes and contingent upon how the 3D viewer is situated when made the view, can get an ordinary X-Y-Z isometric view.

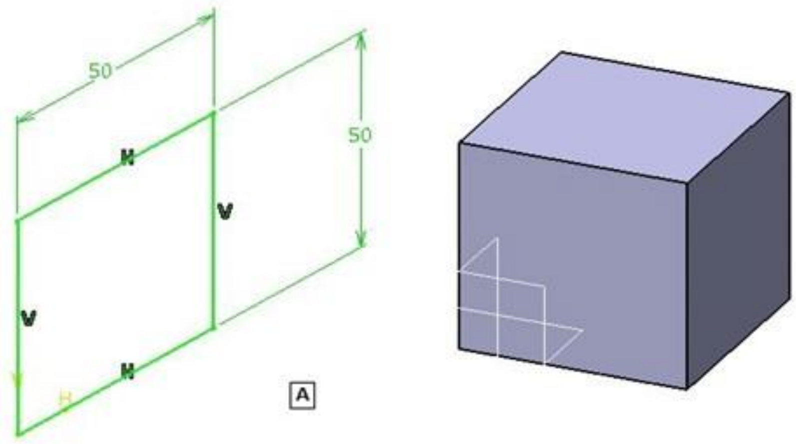
Dimensioning
Generate Dimensions- to produce aspects in a one shot from the imperatives of a 3D part. According to the company needs it can be created: distance, length, range, point and breadth.
Dimensions
Another feature of this software is dimension. This command is very useful to generate dimension all over the profile accurately. There is different method of dimensioning.

Generate Balloons
A balloon is used to reference a reported item.

Text
To produce a text with inside a line wrapping.

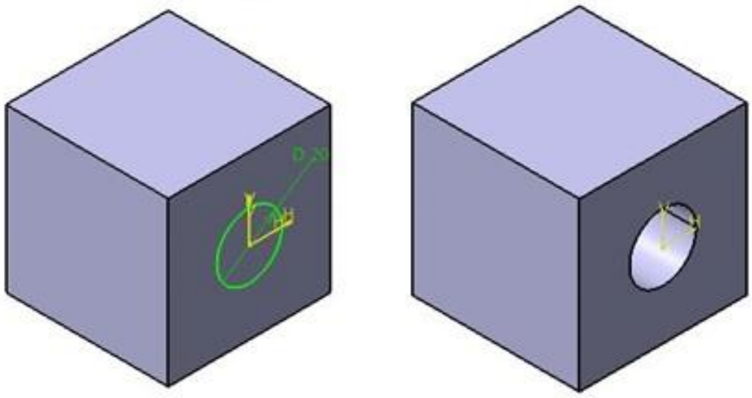
Some commands of workbench are:
PAD command

PAD command is used to create solid part in CATIA software. This command needs a sketch profile. The same profile will be converted in solid. Figure below shows the example of PAD command.



POCKET command:

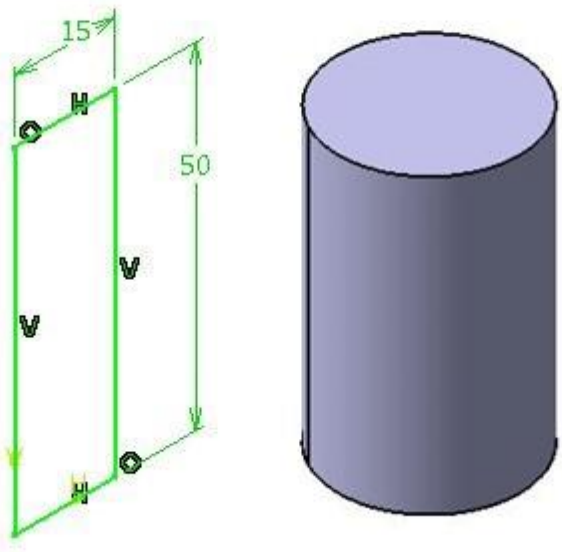
The POCKET orders some way or another something contrary to pad tool. It just aides eliminate calculation having a place with an as of now make part. In the figure below the POCKET tool is assisting with making the chamber opening in the 3D square



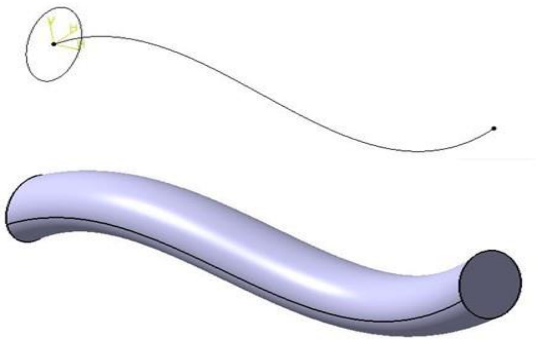
.

SHAFT command:

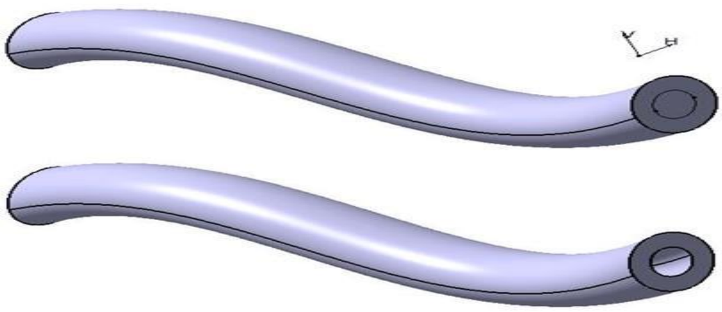
SHAFT command is used to make a solid part around a centre line. It is similar with spin command in other design software. The SHAFT is generally used to create shaft like parts. It needs a centre line around which the solid portion will be rotated.



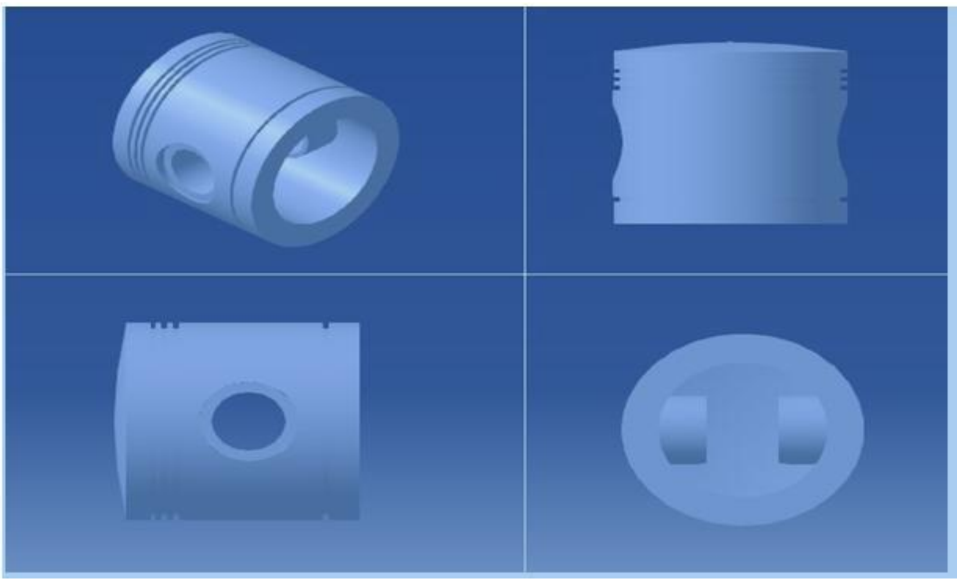
RIB command:
RIB command is used to add material along the pre considered line. In some software this command is generally known as SWEEP. It makes solid along an aide bend. RIB is used to create parts like pipes, springs and so forth.



SLOT command:
slot eliminates the material through an aide bend. Figure shows an illustration of slot . While utilizing slot, It need a similar aide bend that was utilized for RIB. This guarantees that the segment will be similar all through.



Designing of the model:
Create the half piston profile in sketcher workbench next go to exist work bench now go to the sketched based features and go to shaft option apply angle 360 after create the planes offset to xy planes create the circles and apply pocket around the up to surface go to mirror option apply mirror finally as show the figure below:



Different view of piston in CATIA work bench

BOM refers to Bill of Material:
The bill of materials (BOM) provides a listing of all parts and parameters in the current assembly.
BOM is a table to display the number and name of the components belonging to the active component as well as the properties to these components.

Assembly:
CATIA's assembly module allows parts to be grouped into assemblies or subassemblies to model a complete part. Assembly design allows the design of assemblies with an intuitive and flexible user interface.
Start Mechanical design-assembly design.

Assembly procedure:
To assemble the already created components, select product name in specification tree-right click-select components- select existing components.

4.1.4 Benefits of CATIA:
Some major Benefits of CATIA are-
It sets aside time and cash. The product has underlying alteration the board capacities that assistance in programmed refreshes. This strategy lessens the impact of changes in the assembling system. Through these programmed refreshes in the underlying stage, the client saves his experience as well as cash without the need to restart the entire cycle all along.

The mathematical details of composite parts can make the formation of these parts complex, and it expands the gamble of mistakes. However, it assists the client with controlling different part calculations. These incorporate the center hardened parts too.

Anticipate the way of behaving of parts with complex surfaces and permitting changes where required.

4.2 INTRODUCTION TO ANSYS:
ANSYS is an enormous scope multipurpose limited commandssoftwaremade and kept with by ANSYS Inc. to examine a wide range of issues experienced in designing mechanics.

4.2.1 PROGRAM ORGANIZATION:
The program in ANSYS is coordinated into two fundamental levels:
1. Begin level
2. Processor level
The start level goes about as an entryway into and out of the ANSYS program. It is likewise utilized for specific worldwide program controls, for example, changing the work name, cleating the information base, and duplicating parallel records. At the point when you initially enter the program, you are at the start level. At the processor level, a few processors are accessible. Every processor is a bunch of capabilities that play out a particular examination task. For instance the general pre-processor is where you fabricate the model, the arrangement processor is where you apply stacks and get the arrangement, and the general postprocessor in where you assess the consequences of an answer. An extra postprocessor, POST26, empowers you to assess arrangement results at explicit places in the model as a component of time.

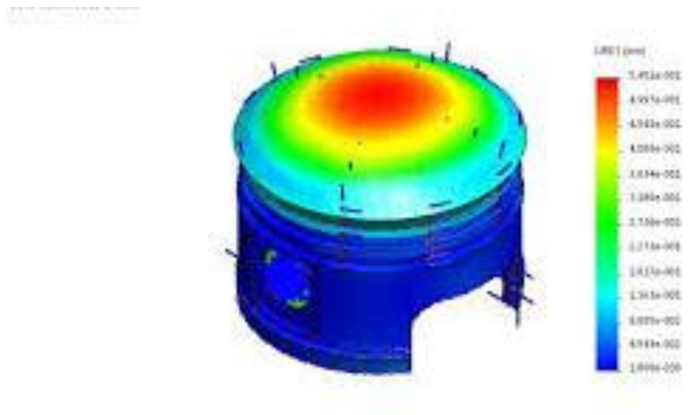
Models of Material:
ANSYS supportsvarious different models of material like:
1. Linear elastic models of material (like isotropic model, anisotropic, orthotropic).
2. Non-linear models of material (like hyper-elastic, multi linear-elastic, and viscoand inelastic elastic)
3. Heat transfer models of material (like orthotropic,isotropic)
4. Temperature dependent models of material features and Creep material.

LOADS:
The word loads in ANSYS phrasing incorporates limit conditions and remotely or inside applied constraining capabilities as shown in loads.

4.2.2 Static structural Analysis in Ansys:
A static structure Analysis decides the stresses ,relocations, strains, and powers in designs or parts brought about by force that don't prompt critical idleness and damping effects. Consistent stacking and reaction situations are accepted, that is the heaps and the design's reactions are considered to fluctuate slowly as for time. A static primary burden can be performed utilizing the ANSYS, or ABAQUS solver. The parts of stacking that can be applied in a static experiment include:

- Remotely applied powers and tensions
- Steady-state inertia forces
- Imposed displacements
- Temperatures

At the complete of the day, these highlights are used more static loading situation which does not fluctuate over the time and location.
For instance, working of piston in tough condition considered one of the finest examples for static structural problems.



Static structure of piston

4.2.3 Difference in Transient Analysis:

Transient Examination can be warm or primary. A transient examination, by definition, includes loads refer to a component of time.You can play out a transient primary examination in such Mechanical application utilizing the transient underlying investigation that explicitly utilizes the ANSYS Mechanical APDL solver. This sort of investigation is useful to make a decisionto unique reaction of a design under the activity of any broad time-subordinate burdens. You could use it to make a decision on the time-differing removals, strains, stresses, and powers inside a construction as it answers any transient burdens.

The time size of the stacking is with the mainaim that the inactivity or damping impacts are viewed as significant. In the state that the lattice and damping impacts are nit significant, you could possibly utilize a static examination all things considered.A transient warm examination follows fundamentally similar systems as a consistent state warm investigation. The fundamental contrast is that most applied loads in a transient examination are elements of time. To determine time-subordinate burdens, you first separation the heap versus-time bend into load steps. Each "corner" on the heap time bend can be one burden step, as displayed in the accompanying sketchers.
Walking on a bridge can be shown a nice example for transient structural analysis. Because the loading conditions change over the time and location.

4.2.4 Key Features of Ansys Mechanical:

- With powerful meshing and post processing capability, along with extensive contact and connection options buit-in, Ansys Mechanical provides a dynamic environment that is depend on a highly refined, Intuitive, and customizable graphical user interface. This empowers users to get answers quickly and accurately to take the project moving forward on time. Other powerful features of Ansys Mechanical include:
- Fast solve: Mechanical includes multiple solver technologies that run in parallel and scale efficiently up to 1000+ cores. GPU technology can also be leveraged for additional parallel computing power.
- Linear Dynamics: Modal, harmonic response, random vibration, and spectrum response can be solved with Mechanical.
- Acoustics: Conduct acoustic simulations to better understand the vibroacoustic behavior of systems, with or without structural pre-loading. Though, pre-loading adds authenticity and allows for the simulation of self-weighted, fastened assembly and even squealing breaks.
- Nonlinearities: In addition to the linear response, users can simulate the behavior of elastic materials as they undergo plastic or even hyper elastic deformation materials like metals and rubber. Viscoelastic response could also be simulated. Nonlinear simulation within Ansys Mechanical also consider contact and large deflection of moving parts relative to each other, with or without friction. These capabilities are robust in static or time-domain transient simulations.
- Thermal and Heat Transfer: Robust steady-state and transient thermal abilities are taken with all levels of Mechanical licenses. Heat transfer through conduction mode, convection and radiation mode are supported. Thermal loading can also be instantly transferred from Ansys'CFD and electromagnetics solvers to Mechanical.

- Fatigue and Fracture: Extensive fatigue life and damage calculation capabilities are readily available in Ansys Mechanical, combining fatigue life and fracture mechanic methods allows users to effectively predict the service life of their products and avoid costly warranty issues.
- Fluid-Structure Interaction: Predict fluid-solid interactions accurately using pressure and heat transfer. As the fluid-structure interaction grows and the easy-to-use solutions for both one-way and two-way coupling to Ansys Fluent and Ansys CFX.

4.2.5 The uses of Ansys software:

Antenna Design and Placement. Autonomous Sensor Development. Autonomous software Development. Autonomous System Development. Autonomous System Validation. Avionics & Flight Controls. Battery Cell and Electrode. Battery Management Systems.

4.3 FINITE ELEMENT ANALYSIS:

4.3.1 INTRODUCTION:

The essential work in FEA is that the object or construction could be partitioned into more modest parts of limited aspects called "Limited Components". The first object or the design is viewed like a collection of suchpartsconnected at a certain number of joints known as "Hubs" or "Nodal focuses". Straightforward capabilities are decided to rough the elimination over everycertain part. Such expected capabilities are designated "shape capabilities". This will address the relocation inside the part regarding the dislodging at the hubs of the object.

The certainobjectplan is a numerical instrument for tackling standard and fractional differential conditions. as it is like a mathematical instrument. It can consider of the mind boggling issues that could be addressed in differential situations structure. The uses of FEM are endless as respects the arrangement of functional plan issues.

Simulating reality:

Finite Element Analysis (FEA) is a method for taking care of complicated mechanical issues utilizing the force of current PCs. Picking sound limit conditions and loads, the architect can reenact reality anything that the circumstance or intricacy, the mechanical way of behaving of objects and developments can be dissected and improved without the need of prototyping. Direct outcomes are benefits concerning time and cost in the primary stage, it additionally adds to the unwavering quality of your item.

The use of elements:

The fundamental standard of the certain object plan is the production of a PC model which is developed from a certain number of components. The components all have a numerical characterized connection among power and dislodging. This relationship of every component could be made use to appraise the firmness dispersion of the entire design. By applying a lattice arrangement method, the reaction in the complete construction to the recommended burdens and limit conditions not entirely settled.

Finite element analysis applied on piston.

Basic types of analyses:

The most common FEA type is the linear elastic analysis. This assumes that the structure behaves elastically, the stresses are linearly proportional to forces, the strains are small and the deformation has no effect on the structure. Often it is a good approximation to how the structure behaves in reality, but in few cases these statements don't fit the reality sufficiently. When this occurs the problem changes from a linear to a non-linear problem. Non-linearity can arise due to material behavior and geometric behavior. In practical terms a non-linear analysis is more time consuming and requires more input data.

4.3.2 steps in FEA:

1. Discretization of the domain
2. Application of Boundary conditions
3. Assembling the system equations
4. Solution for system equations
5. Post processing the results.

Discretization of the domain: the task is to separate the continuum under study into pieces of subdivisions called element. Depend on the continuum it could easily be separated into line or area or volume elements.

Application of boundary conditions: from the nature of the problem we have to apply the field conditions i.e. loads and constraints, which will help us in solving for the unknowns.

Assembling the system equations: this involves the formulation of respective characteristic.

Solution for system equations: solving for the equations to get the unknowns. This is basically the system of matrices which are only a bunch of synchronous conditions is tackled.

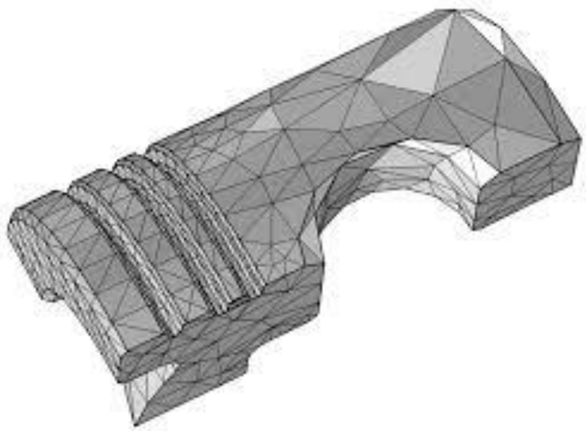
Viewing the results: after the completion of the solution we have to review the required results.

<u>4.3.3 Meshing in FEA:</u>
FEA (Finite element analysis) software is a mathematical portrayalof a physical system comprising a part, material properties and boundary conditions. In several situations, product behavior in the real-world cannot be approximated by simple hand calculations. A general technique like FEA is aeasy method to represent complex behaviors by accurately capturing naturalsteps using partial differential equations. FEA has matured and has been democratized and it is used both by design engineers and specialists.

Meshing is the important steps in performing an accurate simulation using FEA. A mesh is made up of elements which contain nodes that represent the shape of the geometry. An FEA solver cannot easily work with irregular shapes. But it is much happier with common shapes like cubes. Meshing is the steps of turning irregular shapes into more recognizable volumes called "elements."

<u>4.3.3.1 Types of Meshing Methods: Tetrahedral vs. Hexahedral:</u>
It is of two types of meshing methods. For these purpose, we are referring 3D models:
Tetrahedral element meshing or "tet"
Hexahedral element meshing or "hex"
Hex or "brick" elements generally result in more accurate results at lower element counts than tet elements. When it is difficult geometry, tet elements may be the best choice. These default or automatic meshing methods may be enough to calculate any portion you want to; however, there are anothertechnique that provides you more mesh control.

Hybrid Meshing:
In Mechanical you can take a Multi zone method, which is a hybrid of hex and tet elements that allows you to mesh variouscomponents of the geometry with different methods. This allows you to perform less geometry preparation and have more local control meshes.



A piston geometry using Ansys Mechanical's hybrid meshing capabilities

Sweep Meshing:

With sweep meshing the mesh actually sweep the mesh through the volume and faces to help create an efficient mesh with regular sizing.Deciding which mesh method to use usually depends on what type of analysis or physics you are solving for and the accuracy you want to achieve. A few other options are Cartesian meshing and layered teststhose are used for specific analyses like additive manufacturing.

4.3.3.2 Meshing Controls:

Meshing controls enable a more precise mesh. Ansys Mechanical enables you to control local meshes. Instead of a global mesh that meshes the entire CAD with the same method.Some examples of local meshing controls include local sizing, refinement and sphere of influence defeaturing of the geometry.Let's take a connecting rod for example. You may want to apply a general mesh approach across the entire geometry but use a different strategy where the weld and bolted connections are. Using local meshing controls help you to make a more refined mesh at these locations and not mesh the entire part with smaller elements, which would take longer to solve.

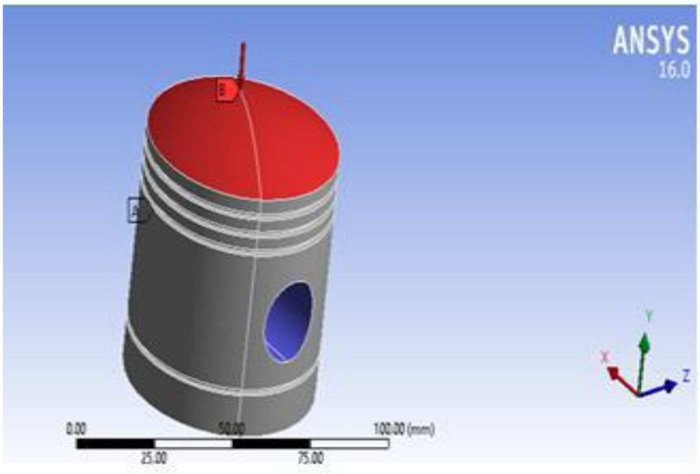
meshed showing Connecting rod geometry

5. RESULT:

BOUNDARY CONDITIONS AT STATIC & THERMAL ANALYSIS:

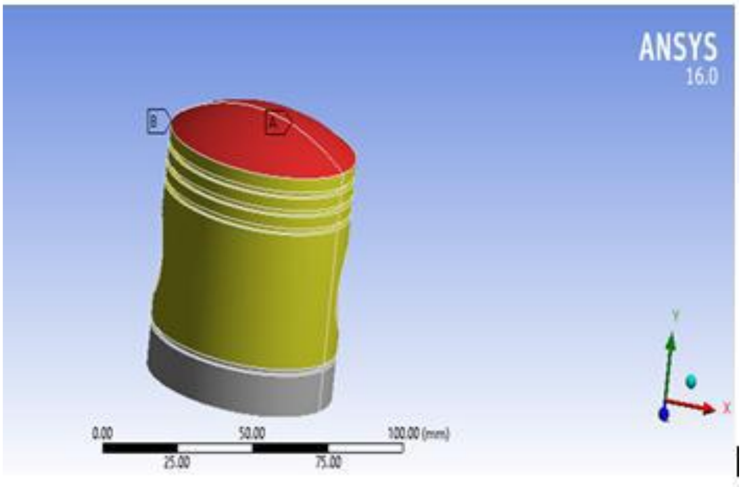
Boundary conditions and loads at static analysis:

1. Maximum pressure load at the upper partof the piston crown surface is 13.65 Mpa
2. Temperature at the piston crown 400 C
3. Piston pin holes are fixed DX=DY=DZ=0



Boundary condition of static analysis

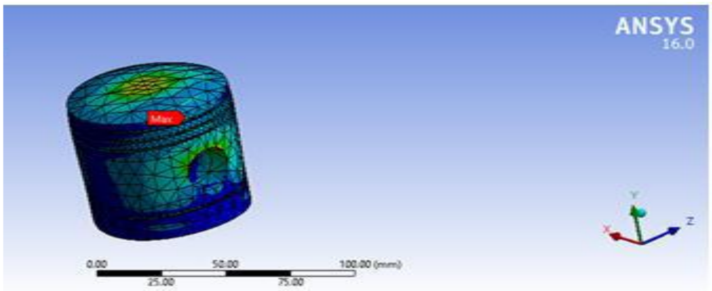
Boundary conditions and loads at thermal analysis:



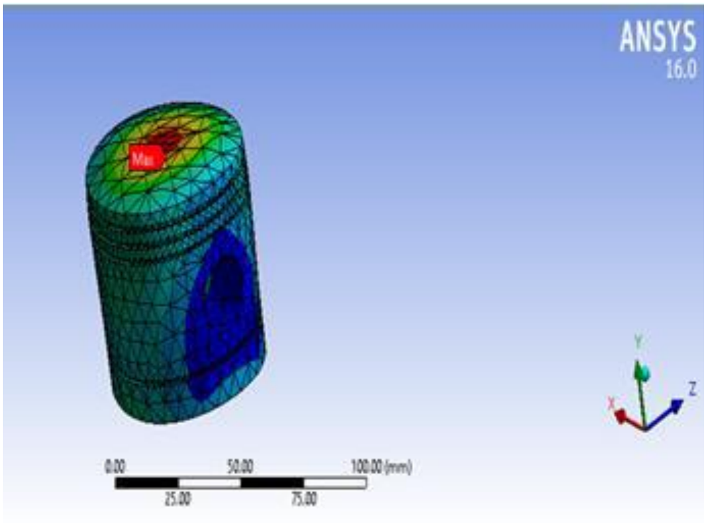
Boundary conditions of thermal analysis

The constructed design of piston in CATIA is analyzed using the ANSYS V16.0 software and the result is depicted below. Burning of gases inside the burning chamber applies strain on the upside of the cylinder during power stir up. Fixed help has provided at surface of pinhole. Since the piston will travel from top on target to base perfectly on target with the assistance of fixed help at pinhole.

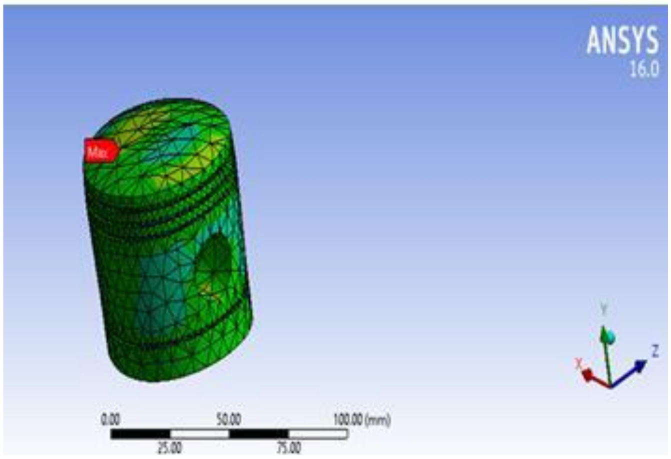
STATIC & THERMAL ANALYSIS:
AL-SIC GRAPHITE:



Stress of AL-SIC graphite material

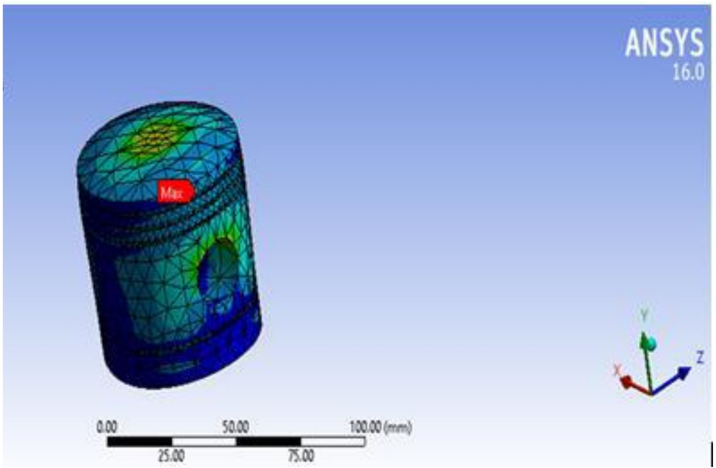


Total developed deformation of AL-SIC graphite material

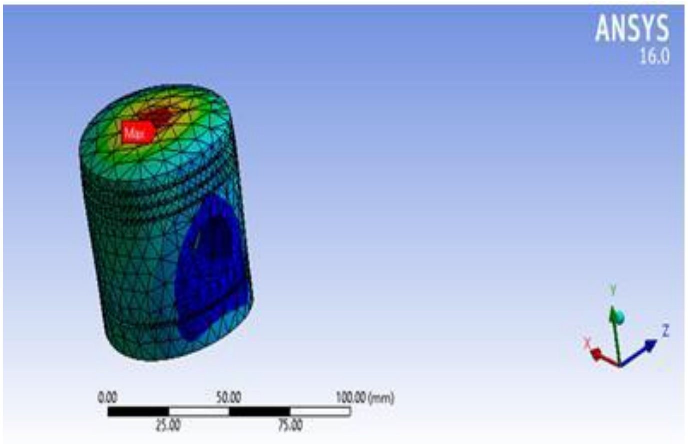


Shear stress of AL-SIC graphite material

AL4032 MATERIAL:

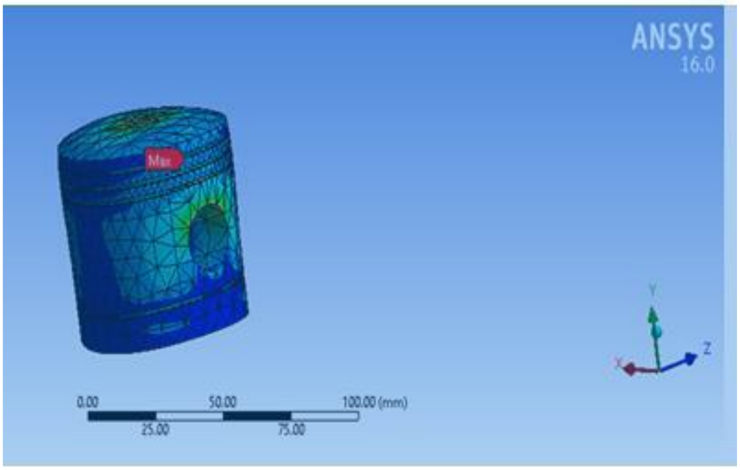


Von mises stress of AL4032 material

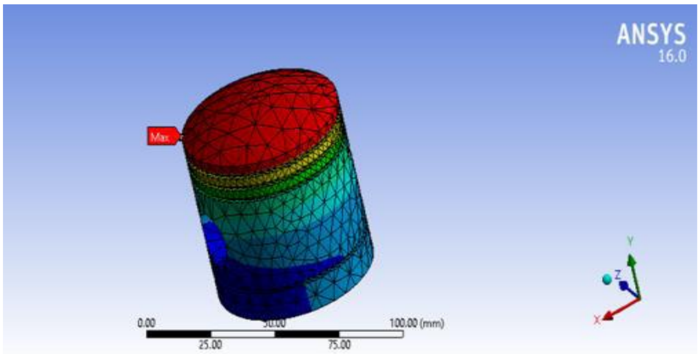


Total developed deformation of AL4032 material

AL6082 MATERIAL:

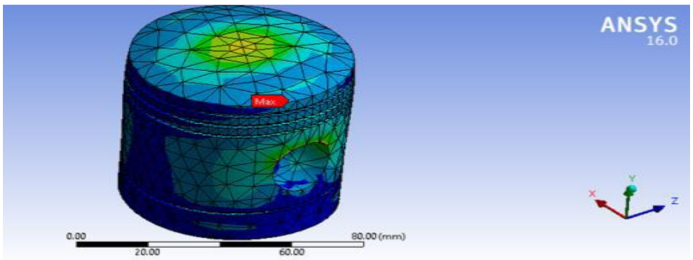


Von mises stress of AL6082 material

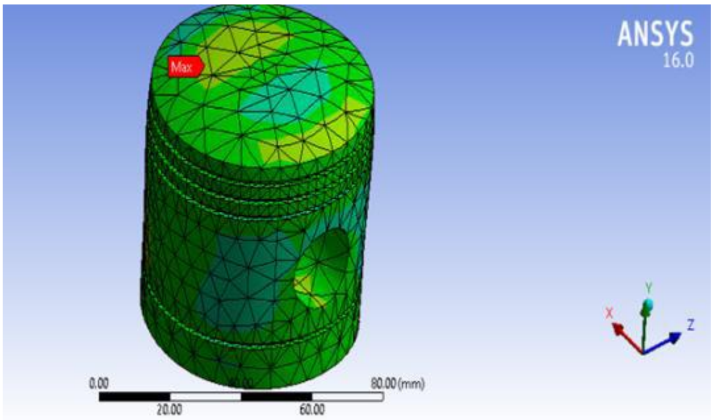


Temperature distribution of AL6082 material

AL7075 MATERIAL:



Von mises stress of AL7075 material

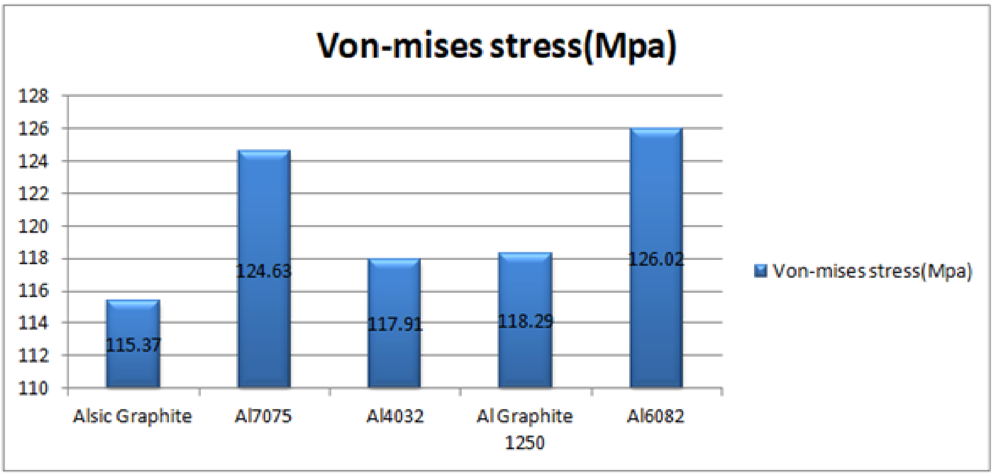


Shear stress of AL7075 material

GRAPHS:
STATIC STRUCTURE ANALYSIS:

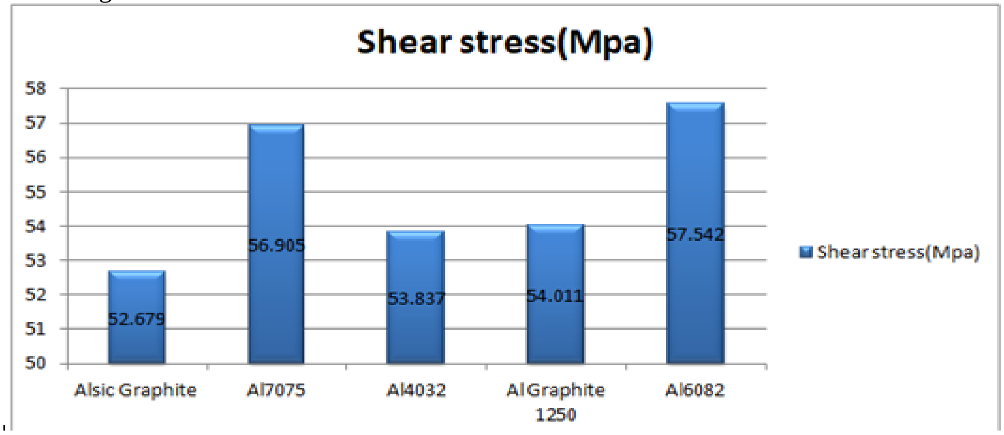
The static structure analysis of AL-sic graphite, A7075, A6082, A4032, AL-ghy 1250 are done and data are taken for Equivalent (von-mises) stress, shear stress, total deformation, heat flux, and temperature. These facts are explained graphically and a comparison is made between these results.

VON-MISES STRESS (Mpa):
We can easily see that for equivalent (von-mises) stress, piston made of AL-sic graphite is found to have least stress of 115.37 Mpa in compare toother tested materials. Highest stress of 126.02 Mpa is observed in AL6082 material.



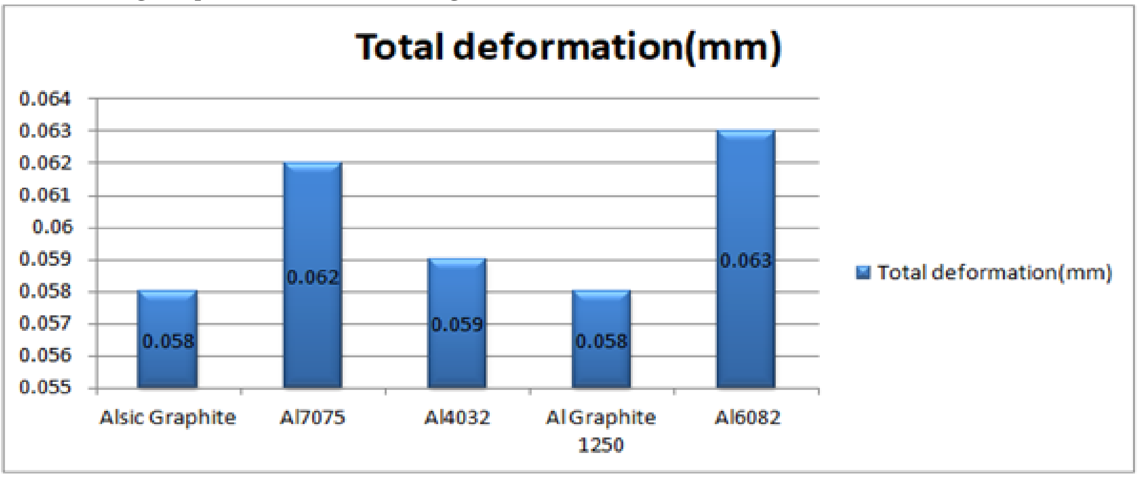
Von-mises stress graph

SHEAT STRESS GRAPH:
We can see that for equivalent shear stress, piston made of AL-sic graphite ishaving least shear stress of 52.679Mpa in compare toother tested materials. Highest shear stress is observed in AL6082 material.



Equivalent shear stress graph

TOTAL DEFORMATION:
We can easily compare that the piston made of AL-sic graphite received least total deformation is 0.058mm in compare toother tested materials including the present material. The highest total deformation is observed in AL6082 and the value is 0.063mm



Total deformation graph

Modeling and analysis of piston is done. Modeling of piston is completed in CATIA design software by using various commands. The CATIA part file is then converted into IGS file format and imported to Ansysworkbenchfor further analysis. First static structural analysis is performed on piston at 13.65 Mpa pressure on three different materials, such as grey cast iron, aluminium alloy and AL-sic graphite in Ansys workbench. Piston made of different aluminium alloys like AL-sic graphite, A7075, A6082, A4032, AL-GHY 1250 have designed and analyzed successfully. In static analysis, and in thermal analysis the pistons have analyzed to get the equivalent stress, equivalent elastic strain, total deformation and temperature distribution in all conditions AL-sic material is performed better thanthat of the remaining materials.From above results we can conclude that AL-sic alloy piston is better than conventional alloy piston.

Consider titanium alloy:I have chosen Titanium alloy as a piston’s material, its properties such as constants, thermal conductivity and elasticity are shown.

Constants of titanium alloy:

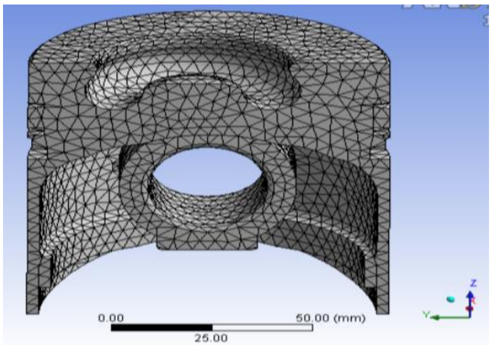
Density	4.62e-009 tonne mm^-3
Coefficient of thermal expansion	9.4e-006 c^-1
Specific heat	5.22e+008 mjtonne^-1 c^-1
Thermal conductivity	2.19e-002w mm^-1 c^-1
resistivity	1.7e-003 ohm mm

Elasticity of Titanium alloy

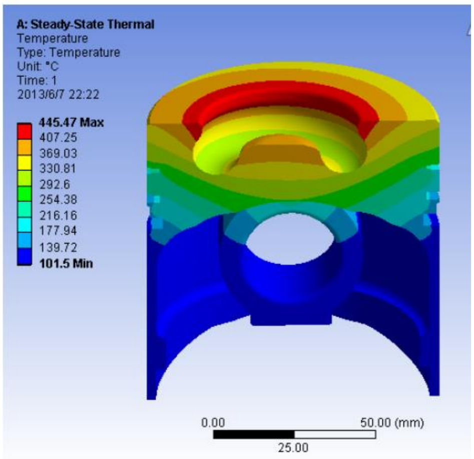
Temperature C	Young’s modulus Mpa	Poisson’s ratio	Bulk modulus Mpa	Shear modulus Mpa
	96000	0.36	1.1429e+005	35294

Meshing

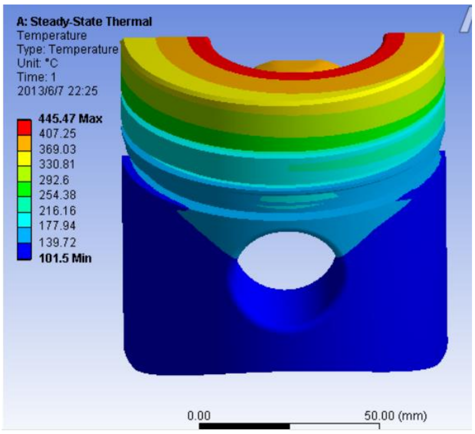
Due to symmetry in construction of piston, the half portion of the model is sufficient to do the analysis. The piston shape is irregular, especially in the presence of various curved surfaces. Firstly, automatic meshing method is taken to mesh the model. The mesh grid is depicted in the figure. The model has a total of 37471 nodes and 23128 elements.



Result of temperature distribution



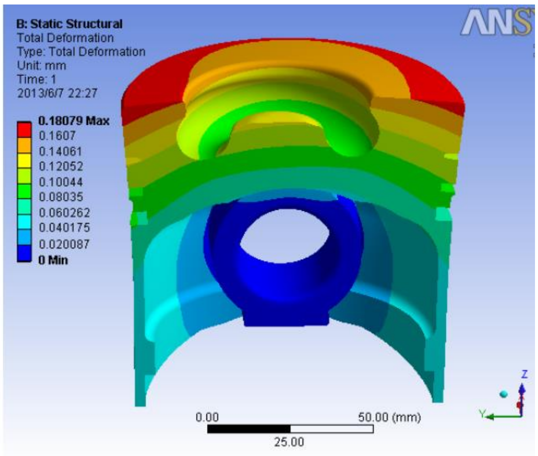
The temperature field of piston in the thermal load acts (internal)



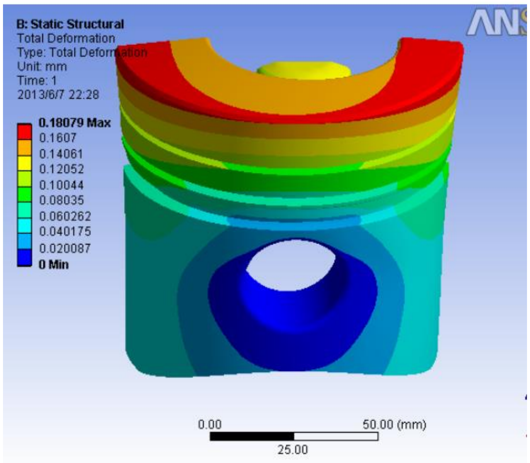
The temperature field of piston in the thermal load acts (external)

The temperature distribution of the piston is uneven all over the piston, with the maximum value of 345.5 ℃ And the minimum value of 101.5 ℃. There is a spread of temperature distribution on the upper face of the piston area. The calculated temperature is maximum at the burningcylinder side from the center of the piston. The maximum temperature recorded in the exit of the exhaust part of the burning chamber, the temperature recorded 345.5 ℃.

Result of deformation distribution:



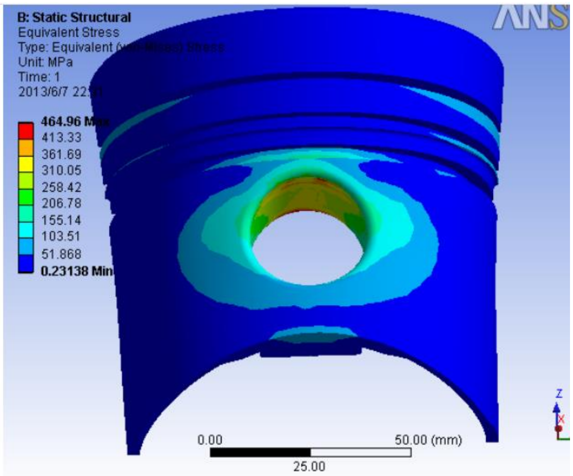
Temperature distribution in the thermal and force coupling (internal)



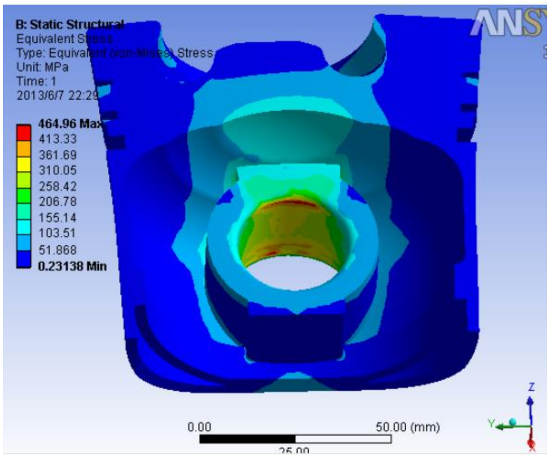
Temperature distribution in the thermal and force coupling (external)

The figures showed the deformation in the piston under the mechanical and thermal loads. It'sobserved that the edge of the upper portion of the piston and fire shore have the highest deformation. The found value is between 0.016-0.018mm. For overall calculation of the piston, from top to bottom of the piston cylindrical, deformation decrease gradually and then gradually increase.

Results of the stress distribution



Stress distribution in the thermal and force coupling (external)

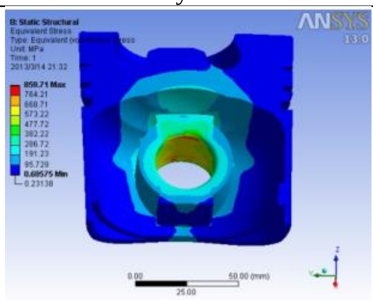
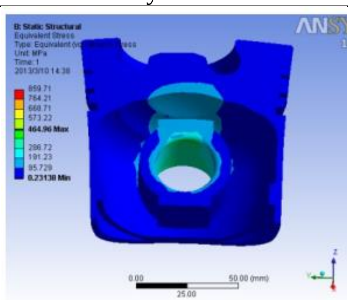


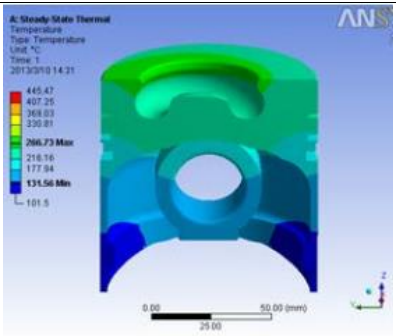
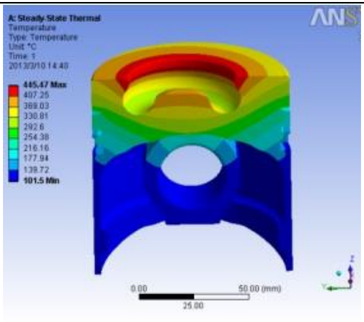
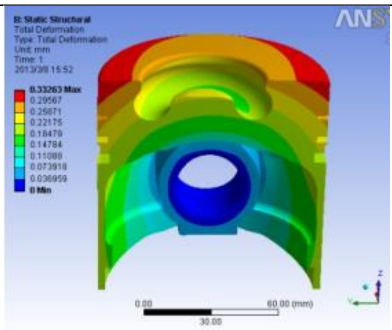
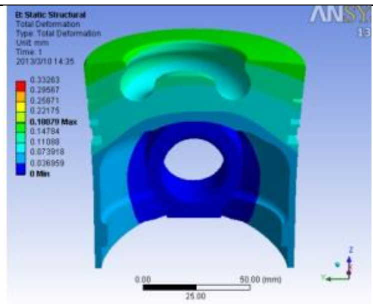
Stress distribution in the thermal and force coupling (internal)

Figure show the stress distribution when the piston is under the action of both temperature and the side thrust. The largest stress produces on the upper portion of the piston pin boss; the value recorded is 116 Mpa. The result shows that the temperature contributed a great deal on the piston stress. The stress values on the most sections of the piston are under 100 Mpa.

COMPARISION:

The aluminum alloy piston was chosen to compare with titanium alloy piston. Thefinal results of stress distribution, temperature distribution and deformation of these two pistons are shown as:

Type	Aluminium alloy	Titanium alloy
Stress	 The highest stress occurs on the upperside of the piston pin, the calculated value is 126 Mpa.	 The highest stress occurs on the upperside of the piston pin, the calculated value is 116 Mpa.

Temperature	 The maximum temperature occurs on the junction of the upper face of the piston and combustion chamber. The value is 267 °C.	 The maximum temperature occurs on the junction of the upper side of the piston and combustion chamber, the value is 345 °C.
Deformation	 The maximum stress occurs on the pistonskirt, the found value is 0.063mm.	 The highest stress occurs on the pin boss of the piston, the found value is 0.018mm.

6. CONCLUSION:

The result showed that titanium alloy piston has a better performance in stress and deformation in comparison with aluminum alloy piston. Considering that the malting point of aluminum is 660°C and for titanium is 1668°C, regarding to its melting point, we improved it by 25%. We can saythat titanium material has better thermal property than aluminum.

7. FUTURE SCOPE:

It can be easily observed that titanium material can help us to enhance piston performance and qualities. Although titanium is expensive material for piston manufacturing and may be it is uneconomical for large-scale applications, it could be consider in some certain cases.

8. REFERENCES:

[1] **Achten***et al.* 1994 "*A Review of Free Piston Engine Concepts*", SAE Paper 941776.
[2] **Ajay Raj Singh***et al.* "*Design Analysis and Optimization of Three Aluminium Piston Alloys Using FEA*" Int. Journal of Engineering Research and Applications, Vol. 4, Issue 1 version 2014, pp.94-102
[3] **Alperstein,** *et al.* "*Fumigation Kills Smoke Improves Diesel Performance,"* SAE Transactions, vol. 66, pp.574-558
[4] **Ashkan Moosavian**-2016 *"Piston scuffing fault and its identification in an IC engine by vibration analysis"*
[5] **Ashkan Moosavian**-2017 *"the effect of piston scratching fault on the vibration behavior of an IC engine"*
[6] **Aziz Hairuddin***et al. "Effect of different heat transfer models on a diesel homogeneous charge compression ignition engine"*.International Journal of Automotive and Mechanical Engineering.2013, 8:1292-304.
[7] **B. Bhandari***et al. "Design of Machine Elements"* 3rd Edition, McGraw Hill.
[8] **Baruah P.C.***et al.* 1988 *" A Free Piston Engine Hydraulic Pump for an Automotive Propulsion System"* SAE paper 880658.
[9] **Bates B***et al. "Climate change and water: Intergovernmental Panel on Climate Change"*,2008.
[10] **Bodansky D.***et al."The Copenhagen climate change conference: a postmortem."*American Journal of Internal Law.2010, 104:230-40.
[11] **Braun A. T***et al.* 1973 *" The Braun Linear Engine"* SAE Paper 730185.
[12] **Caris***et al.* 1959 *"A New Look at High Compression Engines"* SAE Transactions, vol. 67, pp. 112-124.
[13] Chan C. et al. "The state of the art of electric and hybrid vehicles" Proceedings of the IEEE. 2002, 90:247-75

[14] **Cho HM***etal.* *"Spark ignition natural gas engines- A review"*.Energy Conversion and Management. 2007, 48:608-18
[15] **Ch. VenkataRajam***etal.* *"International Journal of Innovative Research in Engineering & Science"* issue 2 volume 2013.
[16] **Christensen***et al.* 1997 *"Homogeneous Charge Compression Ignition Using Isooctane, Ethanol and Natural Gas"* A Comparison with spark Ignition operation SAE paper 972874.
[17] **Christensen***et al.* 1998 *"Supercharged Homogeneous Charge Compression Ignition"* SAE paper 980787.
[18] **Das***et al.* 1990 *"Hydrogen Engines: A view of the past and a look into the future"*. International Journal of Hydrogen Energy, vol. 15,no.6, pp. 425-443.
[19] **Edson, M.H.***et al.*1964 *"The Influence of Compression Ratio and Dissociation on Ideal Otto Cycle Engine Thermal Efficiency, Digital Calculations of Engine Cycles"* SAE prog. In Technology, vol. 7,pp. 49-64.
[20] **Graham RL,***etal.* *"How increasing CO2 and climate change affect forests"*. Bio Science.1990, 575-87.
[21] **Harsh Rajput***et al.* 2020 *"Optimization of the surface texture on piston ring in four stroke IC engine".*
[22] **Hidehiko Kajiwara***et al*. "*An analysis approach for prediction of piston temperature distribution in diesel engines".*
[23] **Houghton JT***etal.* *"Climate change 2001: the scientific basis 2001".*
[24] https://grabcad.com/tutorials/catia-v5-basic-tutorial---1
[25]https://premjis.com/phpppages/moddets.php?Model=pulsar+220&/DetMode=techspecs
[26] https://themechanicalengineering.com/piston/
[27] https://www.bikewale.com/bajaj-bikes/pulsar-220/specifications-features/
[28] https://www.technia.com/blog/what-is-catia/
[29] https://x-engineer.org/engine-piston/
[30] **IsamJasimjabber***et al.* 2014 *"Design and analysis of IC engine piston and piston ring using CATIA and ansys software"* International Journal of Mechanical Engineering and Technology, volume 5, Issue 2,
[31] **Jonathan P***et al.* 2006 *"Responses to questions on the design elements of a mandatory market based greenhouse gas regulatory system."* World resources institute, Washington.
[32] **Karim***et al.* 1971 *"Experimental and Computational Considerations of the Compression Ignition of Homogeneous Fuel Oxidant Mixtures"* SAE paper 710133.
[33] **Kamil M**. *et al.* *"An integrated model for predicting engine friction losses in internal combustion engines."* International Journal of Automotive and Mechanical Engineering.2014, 9:1695-708.
[34] **Kamil M***et al.* *"Modeling of common rail fuel injection system of four cylinder hydrogen fueled engine*."Journal of Engineering and Technology. 2010,1:42-52.
[35] **Klotsch***et al.* 1959. *"Ford Free Piston Engine Development"* SAE paper 590045.
[36] **Kong S-C***etal.* *"A study of natural gas/DME combustion in HCCI engines using CFD with detailed chemical kinetics."* Fuel 2007, 86:1483-9.
[37] **Lee. W**. *et al.* 1983. *"Analysis of Local pressures, surface Temperatures and Engine Damages under Knock Conditions."* SAE Transactions, Vol. 92, section 2, pp. 511-523.
[38] **Maly***et al.* 1990. *"Theoretical and Experimental Investigation of Knock Induced surface Destruction."* SAE Transactions, vol. 99, section 3, pp. 99-137.
[39] **M. B. Nanda kumar***et al.2018 "Experimental investigation of the effect of laser texturing on the used IC engine piston skirt"*
[40] **Muranaka***et al.* 1987 *" Factors Limiting the Improvement in Thermal Efficiency of S.I. Engine at Higher Compression Ration"* SAE Transactions, vol. 96, section 4, pp. 526-536.
[41] **Najt***et al.* 1983 *"Compression Ignited Homogeneous Charge Combustion,"* SAE paper 830264.
[42] **Ogden JM***et al*. "*A comparison of hydrogen, methanol and gasoline as fuels for fuel cell vehicles."*Implications for vehicle design and infrastructure development.Journal of power sources. 1999,79:143-68.
[43] **Onishi***et al.* 1979, *"Active thermo atmospheric combustion a new combustion process for internal combustion engines."* SAE paper 790501.
[44] **Overington***et al.* 1981 *"Gasoline Engine Combustion and Turbulence and the Combustion Chamber,"* SAE paper 810017.
[45] **ParvatiRamaswamy***et al.* 2018 *"A Model to Predict the Influence of Inconsistencies in Thermal Barrier Coating Thicknesses in Pistons of IC Engines."*
[46] **Rob G**. *et al.* *"Watching Earth's Climate change in the Classroom."* 2005
[47] **S.srikanthReddy***etal.* *"Thermal Analysis and Optimization of IC Engine Piston Using Finite Element Method"* International Journal of Innovative Research in Science, Engineering and Technology, vol. 2, Issue 12, 2013.
[48] **S. Prakash***et al.* 2020*, "Thermal barrier coating on IC engine piston to improve efficiency using dual fuel."*
[49] **Szwaja S***et al.* "*Hydrogen combustion in a compression ignition diesel engine. International Journal of Hydrogen Energy."* 2009,34:4413-21.
[50] **Taylor AM**. *etal.* *"Science review of internal combustion engines. Energy Policy."* 2008,36:4657-67.
[51] **Tejaskumarchaudhari***et al*. 2016*. "Investigation of friction characteristics in segmented piston ring liner assembly of IC engine."*
[52] **Thring***et al.* 1989. *"Homogeneous charge compression Ignition engines."* SAE paper 892068.
[53] **TrimmDL***et al.* "*Onboard fuel conversion for hydrogen fuel cell driven vehicles."* Catalysis Reviews. 2001,43:31-84.
[54] **Underwood***et al.* 1957. *"The GMR 4-4 Hyprex Engine A concept of the free piston engine for automotive use."* SAE paper 570032.
[55] **Vaishali R.***et al.* *"stress analysis of piston using pressure load and thermal load IPASJ."*

[56] **Van Blarigan***et al.* 1995.*"NOx emission data verified in a hydrogen fueled engine,"* combustion research facility news, vol. 17, no. 4.
[57] **V. Esfahanian***etal.**"thermal analysis of an SI engine piston using different combustion boundary condition treatments."*
[58] **VinodYadav***etal*.*"design and analysis of piston design for 4 stroke hero bike engine."*International journal of engineering innovation & research vol. 2, issue 2,2013.
[59] **Williams***et al*. 1996, *"fuel decarbonization for fuel cell applications and sequestration of the separated CO2. PU/CEES."* Report no. 295.