Effect of Changes of Different Materials on Piston used for Automotive Application by the Means of FEA and Reverse Engineering Method

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Abstract— The automobile industry is focusing in the research and development of the automobile vehicles and it's all over design and it's all internal part for improving the efficiency of the internal combustion engine, as per the new modification era of the automobile industry. Automobile vehicles should be lighter, durable and more load capable. Keeping this scenario in mind a comparative study is performed on the piston using various different materials, to find the results of the performance of piston after changing its materials. to developed the structural model of a piston computer – aided design, Solid Works Software are used .The analysis is carried out to reduced the stress concentration on the upper end of the piston (piston head/crown and piston skirt and sleeve) The main objective of this study is to identify the variations in stresses and thermal behaviour of piston and its materials, by the means of using a finite element analysis is done using Computer Aided Simulation software ANSYS and further changes also be done in the designs and material of the piston using the reverse engineering method to determine the reduction in weight with the use of various materials.

Keywords: Piston, Stress, ANSYS, Solid Works Software, Reverse Engineering

I. INTRODUCTION

The aim of the present research is to evaluate the performance of the Piston using Finite Element Analysis (FEA). The design and manufacturing of Internal combustion (IC) Engines are under significant pressure for improvement. The next generation of engine needs to be compact, light, powerful, and flexible, yet produce less pollution and use less fuel. Innovative engine design will be needed to meet these competing requirements. In order to understand the true impact, we would have to go back in time over one hundred years. A time without the simplicity of hopping into a vehicle to take us anywhere we want to go is almost unfathomable. But for the early automotive engineers, the tremendous advancements in automotive technology would be even more surprising.In the thermal analysis the properties of material are studied with the change in temperature where as in static structural analysis stresses are calculated at certain static loading condition. For both the static structural and thermal analysis Finite element method is use.In the last 50 years, cars have learned to think, adjust, and even protect, but this is just tip of the iceberg. High performance is now the catch phrase. The vast majority of people want a vehicle that will get them from point A to point B as easily as possible, but also put a little smile on their faces. Often times, the smile is created by a quick punch of the accelerator and accompanied by a feeling of immense power and control. The automotive manufactures are well aware of this, and to achieve it, they design faster, lighter, and more efficient engine to do the job. But exactly what happens inside an engine and what are the risks involved in designing the strongest on the block.

A. Need of the Project

The Piston is one of the main components of an IC Engine. The piston subjected to a complex state of loading. Therefore, the durability of this component is of critical importance. In the automobile industry damaged or broken parts are generally too expensive to replacer repair especially in case of engine.

B. Scope of the Project

The main aim of this thesis is to design and analysis of piston assembly for an IC Engine and also compares the performance with an existing model.

C. Objective

Finite Element analysis by the means of the Ansys software of the piston under the required load condition.
To optimized various design parameters and to set Specification for implementation.
To develop the geometry of the piston using Solid works software
To investigate maximum stress using stress analysis
To investigate maximum temperature using thermal Analysis.

D. Research Plan

1) Literature Survey regarding piston and various parameters affecting performance
2) design of various parts of piston assembly & selection of suitable lubrication system.
3) Analysis of assembly using Ansys software
4) Reconsideration of various design parameters for getting optimum performance.
5) Comparison of proposed design with existing available component.

E. Problem Statement

In engineering field, the result of failure must be exactly true. Finite element analysis will be able to analysis the created Design as well when all the specification is known, then, that can show the better result. From the review, there are several Problems should be highlighted in this project. These include Failure of piston engine may cause damage to automobile as well as an accident and It is a need to study the failure of Piston to prevent any harm injury to human

II. LITERATURE SURVEY

[1] 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.

[2] 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 misses stress is increased by and Deflection is increased after optimization. But all the parameters are within design consideration.

[3]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.

[4]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. So the design is safe.

[5]Swati S. chougule et. al. (2013), focused on the main objective of this paper is to investigate and analyze the stress 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 0ptimization 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.

[6]The study of Lokesh Singh 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 these analysis all values obtained by the analysis is less than permissible value so the design is safe under applied loading condition.

[7]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.

[8]An optimized piston which is lighter and stronger is coated with zirconium for bio-fuel. In this paper [1] The coated piston undergone a Von misses test by using ANSYS for load applied on the top. Analysis of the stress distribution was done on various parts of the coated piston for finding the stresses due to the gas pressure and thermal variations. Vonmisses stress is increased by 16% and deflection is increased after optimization. But all the parameters are well with in design consideration. Design, Analysis and optimization of piston [2] which is stronger, lighter with minimum cost and with less time. Since the design and weight of the piston influence the engine performance. Analysis of the stress distribution in the various parts of the piston to know the stresses due to the gas pressure and thermal variations using with Ansys. With the definite-element analysis software, a three-dimensional definite-element analysis [3] has been carried out to the gasoline engine piston. Considering the thermal boundary condition, the stress and the deformation distribution conditions of the piston under the coupling effect of the thermal load and explosion pressure have been calculated, thus providing reference for design improvement. Results show that, the main cause of the piston safety, the piston deformation and the great stress is the temperature, so it's feasible to further decrease the piston temperature with structure optimization. This paper [4] involves simulation of a 2-stroke 6S35ME marine diesel engine piston to determine its temperature field, thermal, mechanical and coupled thermal-mechanical stress. The distribution and magnitudes of the afore-mentioned strength parameters are useful in design, failure analysis and optimization of the engine piston. The piston model was developed in solid-works and imported into ANSYS for pre-processing, loading and post processing. Material model chosen was 10-node tetrahedral thermal solid 87. The simulation parameters used in this paper were piston material, combustion pressure, inertial effects and temperature.

This work [5] describes the stress distribution of the piston by using finite element method (FEM). FEM is performed by using computer aided engineering (CAE) software. The main Objective of this project is to investigate and analyze the stress distribution of piston at the actual engine condition during combustion process. The report describes the mesh optimization by using FEM technique to predict the higher stress and critical region on the component. The impact of crown thickness, thickness of barrel and piston top land height on stress distribution and total deformation is monitored during the study[6] of actual four stroke engine piston. The entire optimization is carried out based on statistical analysis FEA analysis is carried out using ANSYS for optimum geometry. This paper describes the stresdistribution and thermal stresses of three different aluminium.

Alloys piston by using finite element method (FEM). The parameters used for the simulation are operating gas pressure, temperature and material properties of piston. The specifications used for the study of these pistons belong to four stroke single cylinder engine of Bajaj Kawasaki motorcycle. Many works have already been done on the enhancement of engine efficiency by incorporating thermal barrier coatings with different materials and with different dimensions.

[9]A work on optimization of a piston has been done by Ch.VenkataRajam et al in the year of 2013 [5]. They have considered a piston from a practical example which has been considered in the present work as a base model. Many works has been done on the design optimization with bare pistons as well as pistons with thermal barrier coating in recent years.

[10]Ajay Ray Singh et al. [6] described the stress distribution and thermal stresses of three different aluminium alloy pistons by using finite element method in the year of 2014.

[11]Shuoguo Zhao [7] presented a structural analysis of the piston in 2012. He analyzed the piston by Pro-E software to improve and optimize the structure of the piston.

[12]Aditya Kumar Gupta et al. [8] analyzed the piston, which were consists of two steps. They were Designing and Analysis.

[13]S. Srikanth Reddy et al. [9] in 2013 investigated the thermal analyses on a conventional (uncoated) diesel piston.

[14]In 2012 Yaochen Xu et al.[10] analyzed a piston by ANASYS software to get the deformation, thermal and stress distribution of the piston

[15]S. Bhattacharya et al. [11] worked on a piston of a two stroke spark ignition internal combustion engine which had maximum power of 6.5 kW at 5500 RPM. They were Designing and Analysis. They used Aluminium 4032 alloy as the piston material.

III. THEORETICAL CONSIDERATION

A. Introduction

The Automobile industry is working under the guideline of the government for the design and development of manufacture the Internal Combustion (IC) .the government policy is very strict about pollution free development. The automobile technology is under significant pressure for improvement. The next generation of engines needs to be compact, light, powerful, and flexible, and it must produce less pollution and use less fuel. Innovative engine designs will be needed to meet these competing requirements. In order to understand the true impact, we would have to go back in time over one hundred years. A time without the simplicity of hopping into a vehicle to take us anywhere we want to go is almost unfathomable. But for the early automotive engineers, the tremendous advancements in automotive technology would be even more surprising.

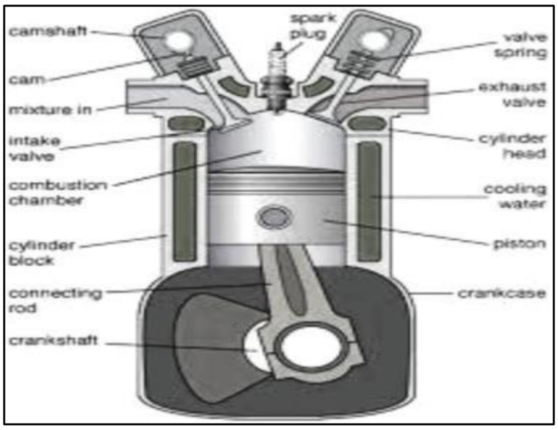


Fig. 1.1: Internal combustion engine parts.

Piston, crank shaft and connecting rods are the main components of internal combustion engines which convert reciprocating displacement of the piston to a rotary motion. A typical automotive crankshaft consist of main journals, connecting rod journals (crank-pins), counter weight, oil hole and a thrust bearing journal. During the service life, combustion and inertia forces acting on the crankshaft cause two types of loading on the crankshaft structure; torsion load and bending load.

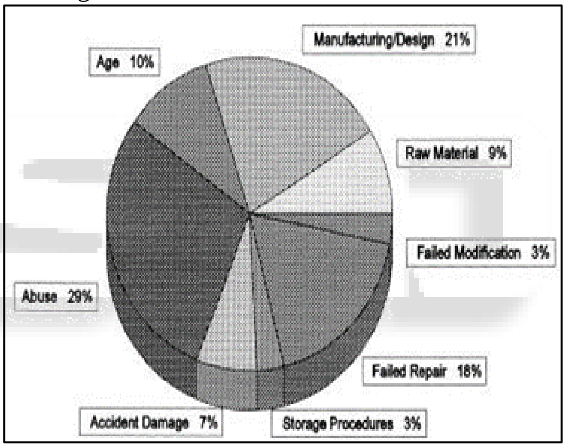
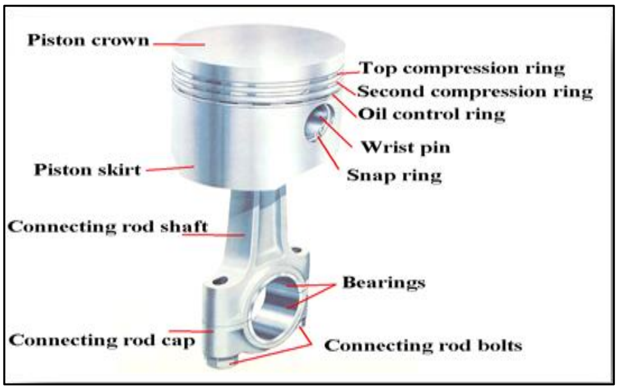


Fig. 1.2: The distribution of causes of failure

B. Function of Piston

Piston is a cylindrical block that moves up and down inside the internal combustion engine. The main function of the piston is to convert the heat energy produced inside engine to convert it into linear motion of the piston movement inside the engine. During the combustion of the fuel high amount of heat and pressure in built up inside the cylinder nowhere else to escape this rising pressure it pushes the piston downwards which in turn pushes the connecting rod and it rotates the crankshaft. The end result as rotation energy at the end of flywheel A piston cylinder arrangement is a kind of thermodynamic system. It consists of a cylinder and a piston that reciprocates inside the cylinder and a working fluid that is trapped in the cavity between cylinder walls and piston. The piston is a tight seal that prevents this working fluid from coming out of the system in spite of it being able to reciprocate. As the piston reciprocates inside the cylinder, the volume of the cavity changes. Since the fluid is trapped in this space, changes in the volume results in changes of other thermodynamic properties such as pressure, temperature etc…

These changes help us to produce some desirable processes that can be used to achieve some external work. Pistons are present not just in IC engines but also in hydraulic systems, pneumatic actuators, pumps, air compressors etc… Either work can be done by the piston cylinder system producing energy from fuel supplied as in the case of an IC engine where increase of pressure due to combustion of fuel forces the piston to rotate the wheels through crank and transmission systems, or, work can be done on the internal fluid as in the case of water or air pumps, air and fluid compressors, where force is applied on the piston to increase pressure of the fluid inside it.



C. Failure Analysis of Engine

One cannot correct the cause of premature failure until he first determines what causes the failure. To determine the cause of the failures, the following method was used:

- Appearance – an illustration and brief description of a component that has failed due to a specific cause.
- Damaging Action – what actually damaged the component under the conditions which were present?
- Possible Causes – a listing of those factors capable of creating the particular damaging action.

Corrective Action – the action that should be taken to correct the cause of failure. The major cause producing thermal stresses in engine due to Insufficient engine cooling lack of lubrication or using wrong grade of lubricants The other causes of damaging connecting rod and piston only by hydrostatic lock. Different types of other failure shown in figures.

Fig. 4: Scratches on upper main bearing half in crank

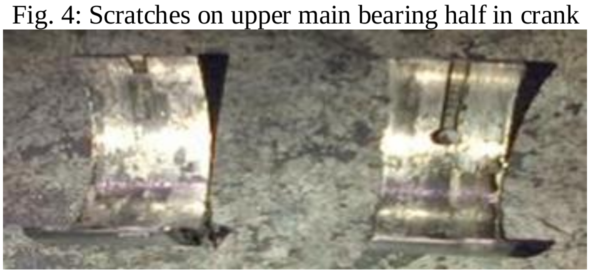


Fig. 5: Scratches on upper main bearing caps

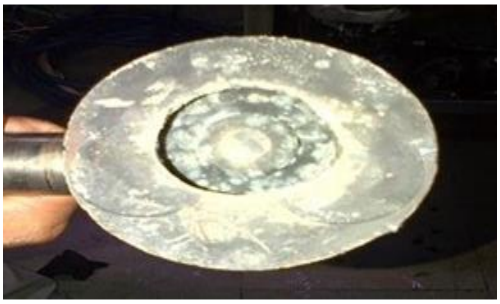


Fig. 6: Worn out piston due to overheating

Fig. 7: Consequent effects of piston can also be Visualized on piston sleeves

Fig. 8: Worn out cylinder surface

Fig. 9:Worn out piston sleeves due to of badly overheat

D. Piston Failure

1) Damage From Running Unmixed Fuel

2) Damage from Debris Getting Through the Air Filter

3) Damage from Bearing Failure

4) Damage from Over-Speeding the Engine

5) Damage from Detonation

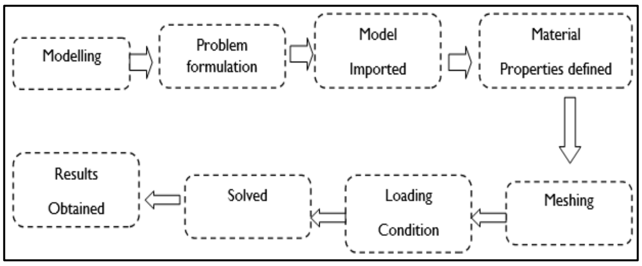
6) Damage from Heat Seizure

IV. METHODOLOGY

A. Finite Element Analysis

Finite Element Method is a computer-based numerical technique for calculating the Strength and behaviour of engineering structures. It can be used to calculate deflection, stress, vibration, Buckling behaviour and many other phenomena. In the finite element method, a structure is broken down into many small simple blocks or elements. The behaviour of an individual element can be described with a relatively simple set of equations. Just as the set of elements would be joined together to build the whole structure, the equation describing the behaviours of the individual elements are joined into an extremely large set of equations that describe the behaviour of the whole structure. The computer can solve this set of simultaneous equations. From the solution, the computer extracts the behaviour of the individual elements. From this, it can get the stress and deflection of all the parts of the structure. The stresses will be compared to allowed values of stress for the materials to be used, to see if the structure is strong enough.

B. Process Chart



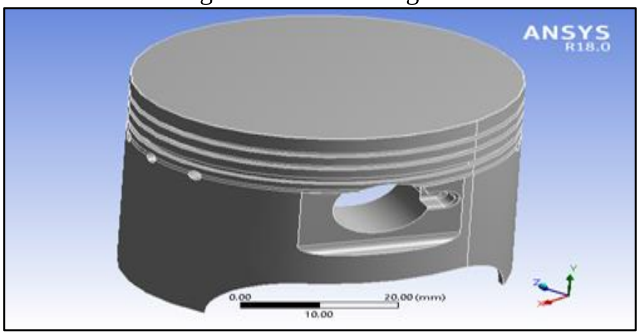
1) Piston Design

The piston is designed by the means of reverse engineering method and all the calculation and measurement are done by the reverse engineering method and also used the data from Machine Design & design data hand book. The entire dimensions are in SI units. The parameters which are taken into consideration are given below in the tables.

2) Calculated parameters and dimensions of piston

S.NO.	Parameter	Size in mm
1	Length of piston	45
2	Cylinder Bore	50
3	Axial thickness of ring	2
4	Radial thickness of ring	2
7	Width of the top land	3.5
8	Length of skirt	34
9	Piston pin Diameter	13

Piston of Passion pro of bike's engine, which is available in market is selected for the present investigation. The dimensions of the selected connecting rod are found using venire calipers, screw gauge and are tabulated in the table. According to the dimensions the model of the connecting rod is developed using Solid Works design software. The modeled connecting rod is shown in figure.



3) Engine Specifications:

The engine used for this work is a single cylinder four stroke air cooled type Bajaj Kawasaki petrol engine. The engine specifications are given in below table

Type	Air Cooled, 4 - stroke single cylinder OHC
Displacement	97.2 cc
Max. Power	6.15kW (8.36 Ps) @8000 Revolutions per minute (rpm)
Max. Torque	0.82kg - m (8.05 N-m) @5000 Revolutions per minute (rpm)
Bore x Stroke	50.0 mm x 49.5 mm

Carburettor	Side Draft, Variable Venturi Type with TCIS
Ignition	DC - Digital CDI

Material selected	Carbon Graphite
Young's Modulus MPa	1.e+005
Poisson's Ratio	0.28
Bulk Modulus MPa	75758
Shear Modulus MPa	39063
Coefficient of Thermal Expansion	1.3e-005 C^-1

Table 1: property of carbon Graphite

Material selected	Gray cast iron
Young's Modulus MPa	1.1e+005
Poisson's Ratio	0.28
Bulk Modulus MPa	83333
Shear Modulus MPa	42969
Tensile Ultimate Strength MPa	240
Coefficient of Thermal Expansion	1.1e-005 C^-1
Specific Heat	4.47e+005 mJ kg^-1 C^-1
Resistivity	9.6e-005 ohm mm

Table 2: property of Gray Cast Iron

Material selected	Aluminum Alloy
Young's Modulus MPa	71000
Poisson's Ratio	0.33
Bulk Modulus MPa	69608
Shear Modulus MPa	26692
Compressive Yield Strength MPa	280
Tensile Yield Strength MPa	280
Tensile Ultimate Strength MPa	310
Coefficient of Thermal Expansion	2.3e-005 C^-1
Specific Heat	8.75e+005 mJ kg^-1 C^-1
Resistivity	3.63e-005

Table 3: property of Aluminium Alloy

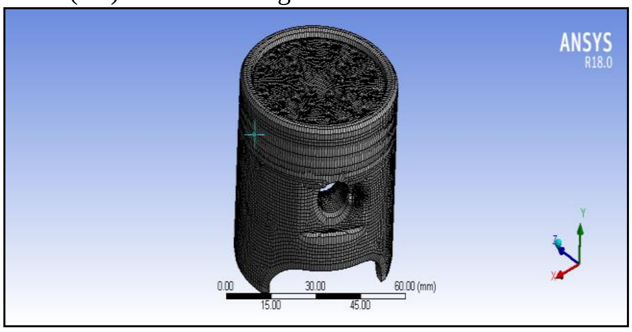
4) Meshing

The next stage of the modeling is to create meshing of the designed model. Parameters used for meshing are given below. The mesh model of connecting rod is shown in figure.

Number of nodes: 33505

Number of element: 33852

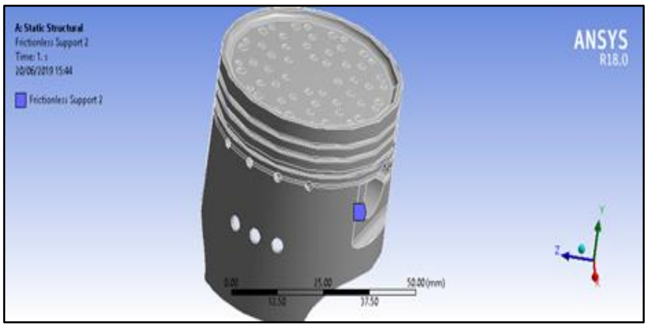
Model (A4) > Mesh > Image

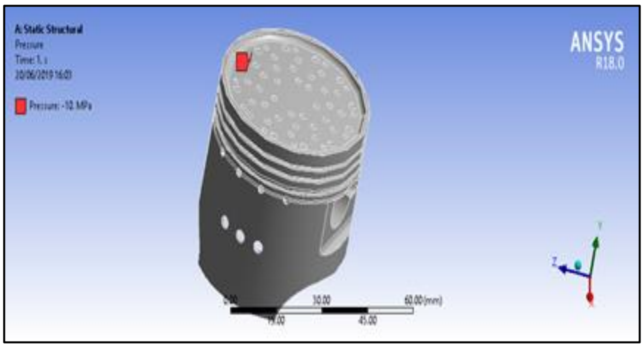


V. Result and Analysis

A. Load Analysis of the Piston

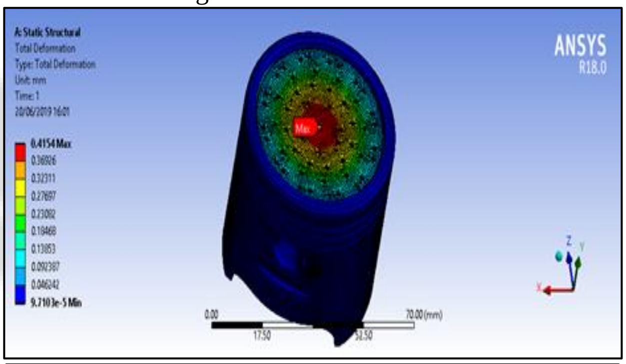
A Model of piston is used for analysis in ANSYS Workbench. Analysis is done with the pressure of 10MPa load applied at the piston and fixed support and frictional support . It is shown in fig

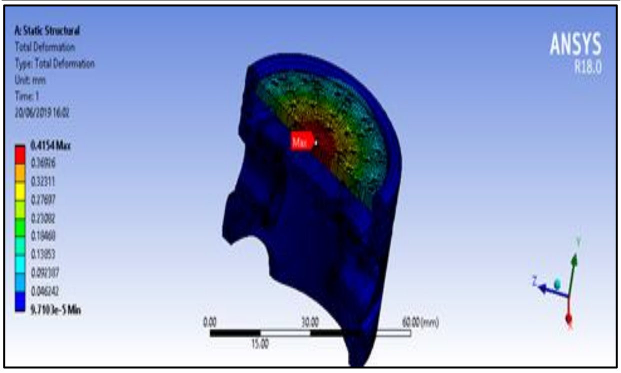




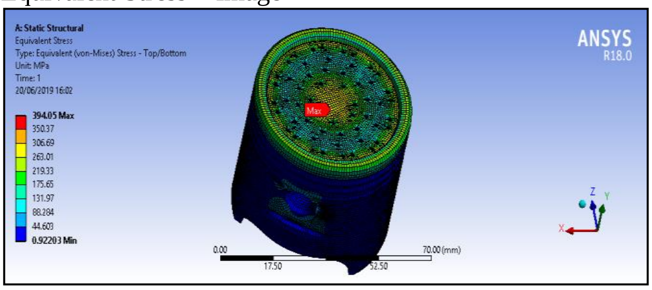
B. Result Analysis and Discussion Aluminum Alloy

Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation > Image



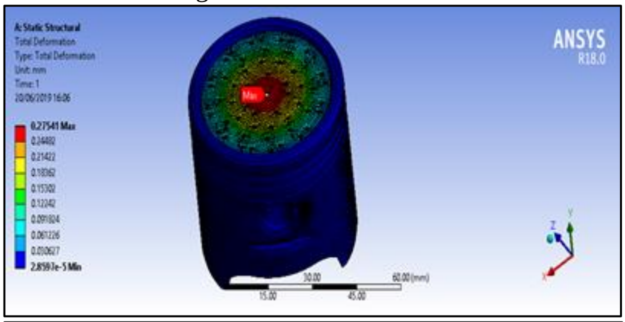


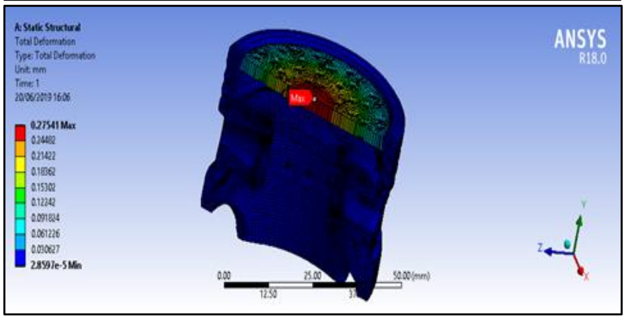
Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress > Image



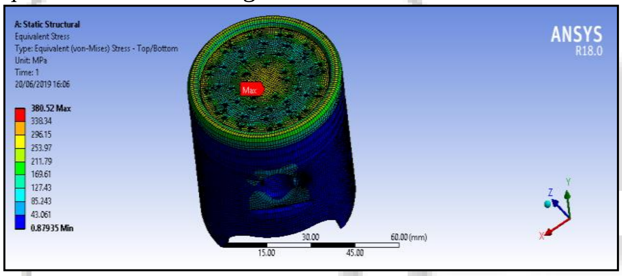
C. Cast Iron

Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation > Image



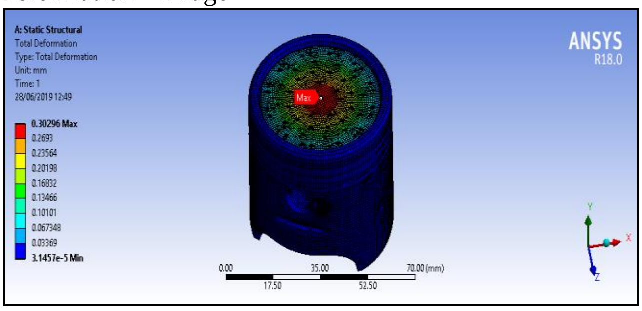


Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress > Image

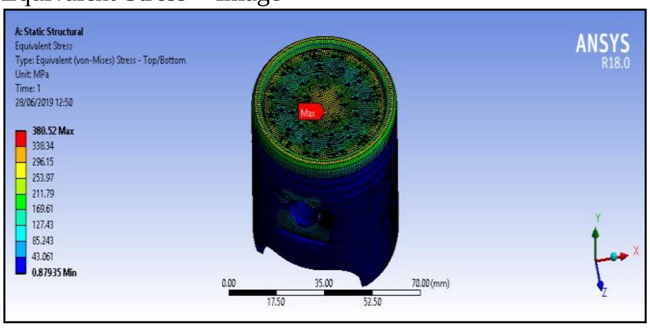


D. Carbon Graphite

Model (A4) > Static Structural (A5) > Solution (A6) > Total Deformation > Image



Model (A4) > Static Structural (A5) > Solution (A6) > Equivalent Stress > Image



E. Table compression of materials

Material Data	Pressure	Equivalent Stress (Von - Misses)	Total Deformation	Mass	Density
Aluminium Alloy	10Mpa	Max-394.05 Min-0.92203	Max-0.4154 Min-9.7103e-5	0.1316 kg	2.77e-006kg mm^-3
Gray Cast Iron	10Mpa	Max-380.52 Min-0.87935	Max-0.27541 Min-2.8597e-5	0.34207kg	7.2e-006kg mm^-3
Carbon Graphite	10Mpa	Max-380.52 Min-0.87935	Max-0.30296 Min-3.1457e-5	0.10642kg	2.24e-006kg mm^-3

VI. CONCLUSION

It has been found that most of the internal combustion engine piston is made Alunimium Alloy and Cast iron. But on comparison of different materials for similar boundary Conditions & loading conditions it's been observed that out of the three materials Carbon Graphite is the most suitable material on the basis of Stress, Total deformation, Thermal Resistivity, fatigue & damage. By using Carbon graphite we could reduce the weight of the Piston. From the Above Result of Static Structural and Steady State thermal Analysis it is Concluded that the carbon graphite piston shows outstanding results in both the analysis Procedures with the additional weight Reduction of 68.88% and is a good indication to Replace the alunimium and gray cast iron or other materials which are used in the production of the materials in the automobile industry.

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