"DESIGN AND TOPOLOGICAL OPTIMIZATION OF AN INTERNAL COMBUSTION ENGINE PISTON"

Badadhe R. B [1],
Prof. Dr. R. R. Navthar [2]
[1]PG Scholar,Department of Mechanical Engineering,
Dr. V.V.P College of Engineering, Savitribai Phule Pune University, Ahmednagar, Maharashtra, India.
[2]PG Guide, Department of Mechanical Engineering,
Dr. V.V.P College of Engineering Savitribai Phule Pune University, Ahmednagar, Maharashtra, India.

ABSTRACT
This project focuses on the stress distribution of the piston four stroke engines by using FEM. The main objective is to investigate and analyze the stress and maximum or minimum principal stresses distribution on engine piston at the real engine condition during combustion process. In this project, the wok is carried out to measure the stress on the top surface of the piston. In I.C. Engine piston is most complex and important part therefore for smooth running of vehicle piston should be in proper working condition. Pistons fail mainly due to mechanical stresses and thermal stresses. Analysis of piston is done with boundary conditions, which includes pressure on piston head during working condition the stress concentration on the piston head are reduces by optimization with using computer aided design; Solid work software the structural model of a piston will be developed. Furthermore, the FEM analysis is done using ANSYS workbench 21. A piston of 4 wheeler was analyzed and optimized for weight reduction in this study. The project describes the optimization techniques with using finite element analysis technique (FEM) to predict the higher stress and critical region on that component.

Keyword: Piston, FEM, honeycomb structure, Topology optimization.

I. INTRODUCTION
Internal combustion engine is a heat engine in which air & fuel mixture is burned inside the engine, due to which high amount of heat released during combustion process & is the part of thermodynamic cycle of the engine. For example, petrol engine, diesel engine, gas-turbine engine & rocket-propulsion engine etc. The hot pressurized gases that are produced due to combustion process, act on moving surfaces of the ENGINE, such as piston and produce useful work. The piston is the moving disk enclosed in engine cylinder and is main components of IC engine that reciprocate in the engine cylinder. The piston transfers the high-pressure heat energy that produced during combustion process, to the crankshaft through connecting rod, due to which momentum occur in fly-wheel and engine works. A cyclic process is followed by piston for continuous conversion of heat energy into work. As the piston is the heart of an engine, so we must calculate the heat propagation on the piston, so we calculate the deformation & thermal stresses of piston due to periodic load effect. The periodic load effect is often produced due to high-speed reciprocation motion and high pressure of gas the produce during combustion process. Thermal deformation and thermal stresses are produced in piston due to lateral force caused by high pressure gas. The piston cracks due to thermal & mechanical deformation so in orders to decrease the stresses at various load on piston, it is crucial to investigate the stress & temperature distribution, heat transfer and mechanical load on piston. The crucial component of an IC engine that reciprocate in the Engine cylinder is called piston. The piston transfers the energy of expanding gases to the crank shaft with the help of connecting rod.

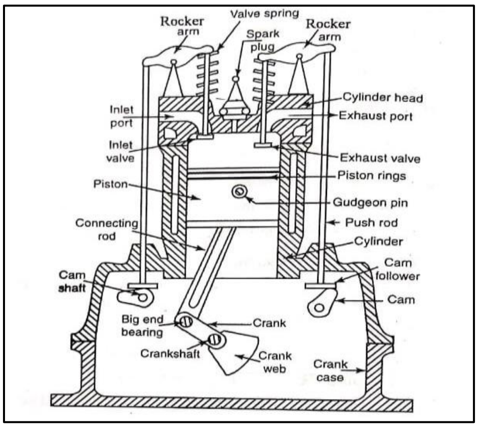


Fig.1 Piston assembly

HONEYCOMB STRUCTURE

Honeycomb structures square measure natural or man-made structures that have the pure mathematics of a honeycomb to permit the reduction of the quantity of used material to reach minimal weight and lowest material price. The geometry of honeycomb structures will vary wide however the common feature of all such structures is an array of hollow cells formed between skinny vertical walls.

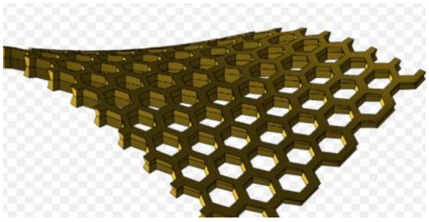


Fig.2. Honeycomb structure

TYPES OF PISTONS

Following are the different types of pistons used in engine:

- Invar Strut Pistons
- Autothermic Pistons
- “Lo-Ex” alloy Pistons
- Specialloid Pistons
- Wellworthy Pistons
- Bi-Metal pistons

II. LITERATURE REVIEW

Aqeel Ahmed et.al [1], this paper is about the mechanical properties and state of the auto cylinder in the motor. At present scaling back of the motor is appealing field for the exploration which helped in the decrease of fuel utilization and outflow toxins from the motor. While on the opposite side different strain sponsors connected with the motor cylinder chamber to keep up with the result power at the bar/more than the bar. These connections cause to create high burdens and removal vectors in the cylinder chamber and the gas powers produced during the ignition cause to deliver warm weights on the substance of the cylinder which at some point may prompts the disappointment of cylinder material. . The fixing material of the Al-Si composite, the projecting strategies and intensity therapy procedures straightforwardly influences the mechanical properties of the cylinder in scaling down motor. An extremely cautious perception is expected during the assembling of auto cylinder to accomplish wanted mechanical properties.

Prashant S. Jadhav et.al [2], This paper focusses on limiting misfortunes of gas powered motor by auxiliary development of fumes gases through 180˚ of wrench insurgency. For this reason, four stroke four unrest system is proposed and this is accomplished by altering current slider wrench component with twofold associating bar course of action. This adjusted motor shows an expansion in the air standard cycle proficiency by 4.10% where as fuel air cycle productivity rise is seen to be 5.25%. There is likewise huge ascent seen in the altered motor over customary motor with regards to net showed warm effectiveness and brake warm proficiency too.

Yang Liu et.al [3] To additionally work on the warm condition of the cylinder for better warm plan, a multi-objective enhancement calculation was utilized in this paper to track down the best blend of plan factors. The outcomes show that warm obstruction covering (TBC) can successfully forestall heat move to the cylinder, and the thicker the ceramic layer, the better the warm protection impact. The enormous temperature angle influences the most extreme warm burdens of the TBC cylinder to happen on a superficial level where the metal holding layer contacts the cylinder framework. Such high warm pressure is the primary driver of covering delamination. The discoveries of this study can give a reference to working on the warm condition of the cylinder and improving the motor execution.

Teng Ren et.al [4], The intensity move and opposition qualities of an isothermal cylinder were inspected through a dimensionless investigation, and the discoveries were contrasted and the exploratory outcomes. Two boundaries, Ka and Xu, were laid out in the dimensionless model. Ka is a record mirroring the intensity move execution, and Xu depicts the temperature variety of permeable media. As the intensity move builds, the liquid opposition increments irreversibly. The boundary Xpor is proposed to show the impact of opposition; explicitly, this boundary relies upon the properties of the permeable media and impacts the hypothetical least all out work. The connection between the hypothetical least absolute work and Xpor is introduced, which can give direction to the ideal plan of isothermal cylinders.

S.Sathishkumar et.al [5] Cylinder is the piece of motor which converts intensity and strain energy freed by fuel ignition into mechanical works. Motor cylinder is the most mind boggling part among the automotives. This paper delineate plan technique for a cylinder for 4 stroke petroleum motor for legend magnificence - genius bicycle and its examination by its correlation with unique cylinder aspects utilized in bicycle. The plan strategy includes assurance of different cylinder aspects utilizing scientific technique under most extreme power condition. In this paper the joined impact of mechanical and load is thought about while deciding different aspects.

G Gopala et.al [6] The paper manages investigation of a get together of the Cylinder, Interfacing bar and Driving rod of a four wheeler petroleum motor. The parts of the gathering must be inflexible and the gathering needs to move as a component. Thus, the investigation ought to include an unbending body examination and adaptable body examination. So the powers in the parts as the motor responds must be determined and these powers are utilized to work out the unique burdens in the part of interest for example the interfacing bar. It is proposed to supplant with two new arrangements of materials for the parts of the gathering and check the boundaries by playing out the static, dynamic and warm examination In this undertaking, the principal parts of the gathering for example motor cylinder, interfacing bar and driving rod are demonstrated and gathered according to the given plan. What's more, the Limited Component Examination is finished in Ansys. The cross section is finished in HyperMesh.

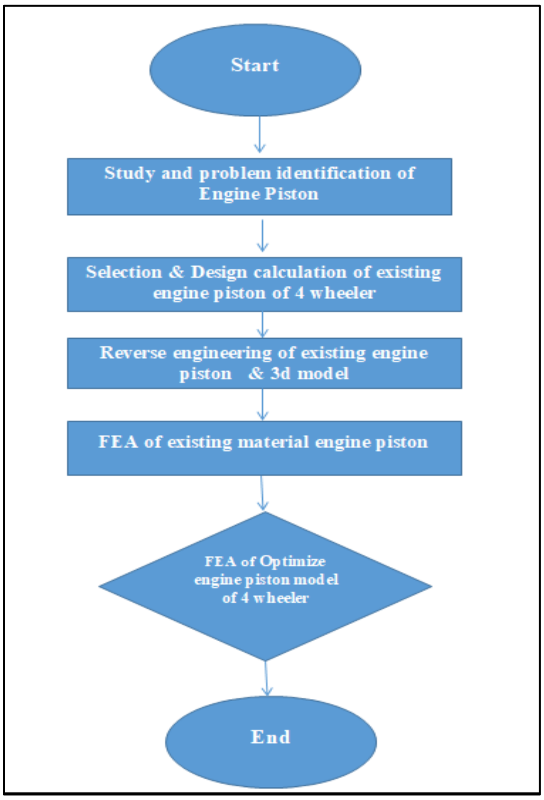
III. PROBLEM STATEMENT

Continuous progress in the automotive field involves the use of new working methods in the calculation and optimization of the internal combustion engine parts. On this occasion, in this project , the impact of a optimization on the piston in the combustion engine of the conventional or hybrid electric car was studied.

IV. OBJECTIVE

- To study engine piston component factors affecting its functionality.
- To develop 3D CAD model using SOLIDWORK and perform FEA analysis using ANSYS Workbench on engine piston of 4 wheeler using static loading.
- Optimization of Piston weight by replacing honeycomb structured plate.
- To analyze the effect of pressure developed inside the combustion chamber on the piston head.

V. METHODOLOGY



SOLIDWORKS MODEL

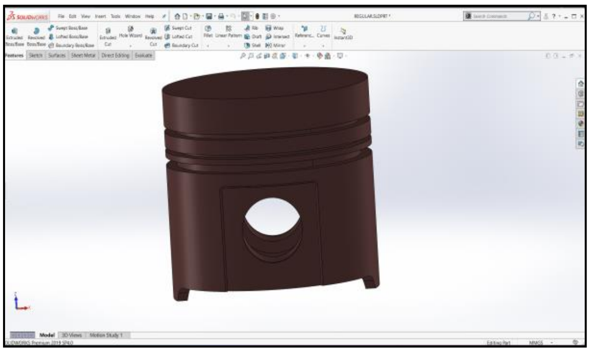


Fig. 1 solid works model for existing piston.

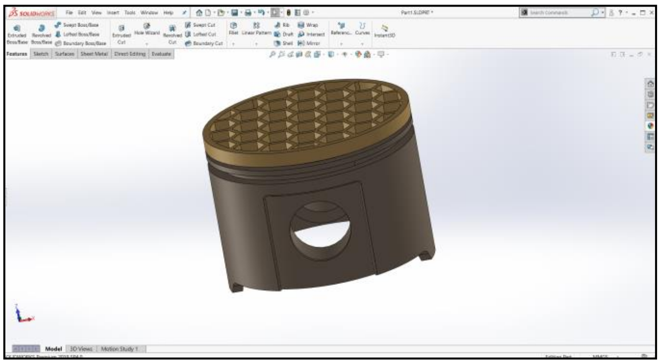


Fig. 2 SOLIDWORKS model for Honeycomb piston.

CALCULATION OF PISTON

Piston nomenclature

In designing a piston for an engine the following points should be taken into consideration:

- It should have enormous strength to withstand the high pressure.
- It should minimize the inertia forces.
- It should form effective oil sealing in the cylinder.
- It should provide sufficient bearing area to prevent under wear.
- It should have high speed reciprocating without noise.
- It should be of sufficient rigid construction to withstand thermal and mechanical distortions.
- It should disperse the heat of combustion.

Most commonly used materials for pistons of I.C. engines are

- Cast iron.
- Cast aluminum.
- Forged aluminum.
- Cast steel.
- Forged steel.

Thickness of piston:

$$th = D\sqrt{\frac{3}{16}\,\frac{Pmax}{\sigma b}}$$

$$\sigma_b = \sigma_t = \frac{s_{ut}}{(fs)}$$

th = Thickness of piston.
D = Cylinder bore.
Pmax = maximum gas pressure or explosion pressure. (Mpa or N/mm2)
σ_b= Permissible bending stress (N/mm2)
When the data is not available, the allowable bending stress (σ_b) for gray cast iron may be taken from 35 to 40 N/mm2
For aluminum alloy, it may be assumed from 50 to 90 N/mm2
Maximum gas pressure (Pmax) may rise upto 8 MPa. The average value of maximum gas pressure may be taken as 4 to 5 MPa.

We are taking cylinder bore of 4 inch. i.e 101.6 ~~ 102

Therefore, $th = 102\sqrt{\frac{3}{16}\,\frac{8}{90}} = 13.18$ mm

Radial thickness of the Ring (t1)

$t1 = D\sqrt{\frac{3pw}{\sigma t}}$ = 3.45 mm

Pw = Pressure of gas on cylinder wall in N/mm2. Its value is limited from 0.025 N/mm2 to 0.042 N/mm2

σ_t = Allowable bending (tensile) stress in MPa. It's value is taken from 85 MPa to 110 MPa.

Axial thickness of Ring (t2)

t2 = 0.7 t1

t2 = 0.7 * 3.45 = 2.415mm

Width of the top land,(i.e. the distance from the top of the piston to the first ring groove)

b1= 1.2 th

b1 = 1.2 * 13.18 = 15.816mm

Width of the other ring land, (i.e the distance between the ring grooves)

b2 = 0.75 * 2.415 = 1.81125mm

Maximum thickness of the Barrel (t3)

t3 = 0.03* D + b + 4.5

b = Radial depth of the piston ring

b = t1 + 0.4 = 3.45 + 0.4 = 3.85mm

This is we can design piston without considering the external factors affecting the dimension concern.

We are modifying the piston from rigid structure to hexagonal sub-elemental structure
(composed of hexagonal internal structure)

STATIC ANALYSIS OF EXISTING PISTON

ANSYS Workbench 21.0 platform to perform modal analysis of thrust coupling. ANSYS Workbench 21.0, as the most advanced CAE software, provides users with simulation modules including: structure, fluid, electromagnetic, heat transfer, and other fields. It is the industry's most advanced engineering simulation technology integration platform, with intuitive and friendly interface, convenient pre-processing and post-processing functions, and its extensive solution functions.

1. MATERIAL PROPERTIES

Table 1 Material properties

Details of "Aluminum Alloy"

Common Material Properties	
Density	2.77e-06 kg/mm³
Young's Modulus	71000 MPa
Thermal Conductivity	table(T) = 0.14862 W/mm·°C
Specific Heat	8.75e+05 mJ/kg·°C
Tensile Yield Strength	280 MPa
Tensile Ultimate Strength	310 MPa

2. Finite Element Analysis:

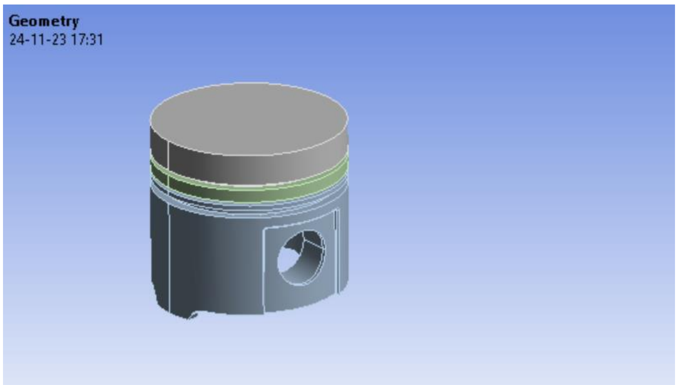
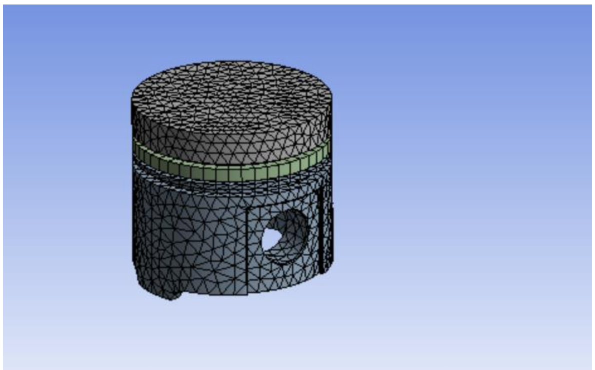


Figure1. Geometry of existing piston

Properties	
Volume	1.4259e+005 mm³
Mass	0.39498 kg

3. Mesh

ANSYS Meshing is a general-purpose, intelligent, automated high-performance product. It produces the most appropriate mesh for accurate, efficient Multiphysics solutions. A mesh well suited for a specific analysis can be generated with a single mouse click for all parts in a model. Full controls over the options used to generate the mesh are available for the expert user who wants to fine-tune it.



Statistics	
Nodes	23153
Elements	11360

Type	Element Size
Element Size	5.0 mm

Figure2. Finite element mesh model of existing piston

Final existing piston mesh model, it contains 23153 nodes and 11360 elements. Element size was 5 mm

Boundary condition

After the material and piston geometry have been set, the boundary conditions of piston need to be applied in ANSYS Mechanical to simulate its operating conditions. Under Static Structural analysis, 5 MPa of pressure is applied on top surface of piston head .This pressure is due to combustion of gases in cylinder.

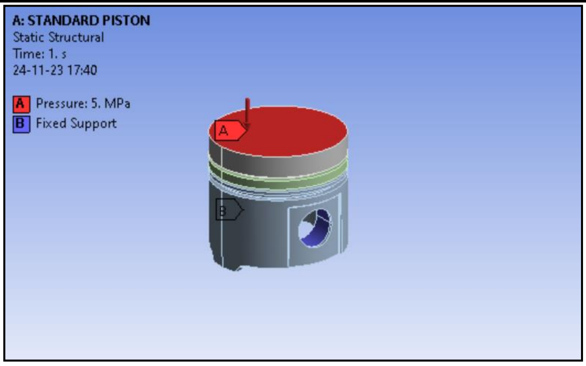


Figure 3. Boundary condition of existing piston

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Results:

Total Deformation

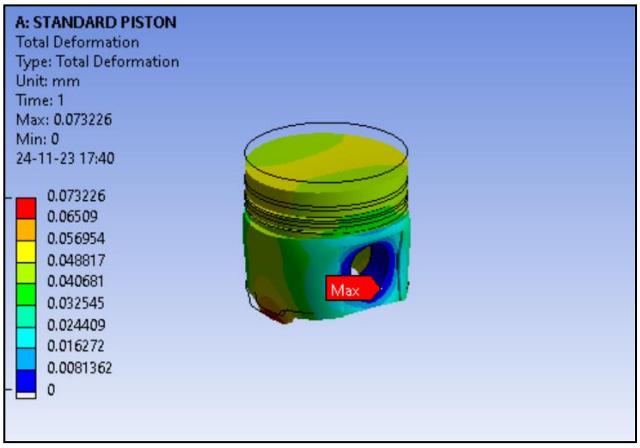


Figure 4. Total deformation of existing piston

Equivalent Stress

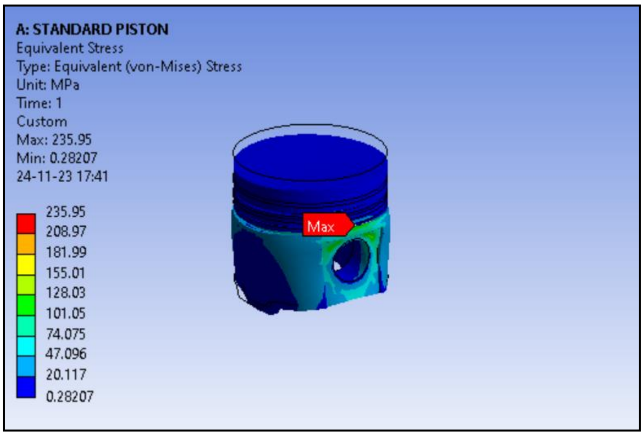


Figure 5. Equivalent Stress of existing piston

Equivalent Strain

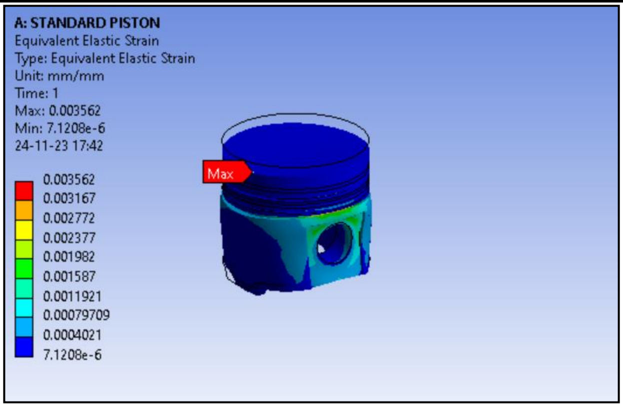


Figure 6. Equivalent Strain of existing piston

TOPOLOGY OPTIMIZATION

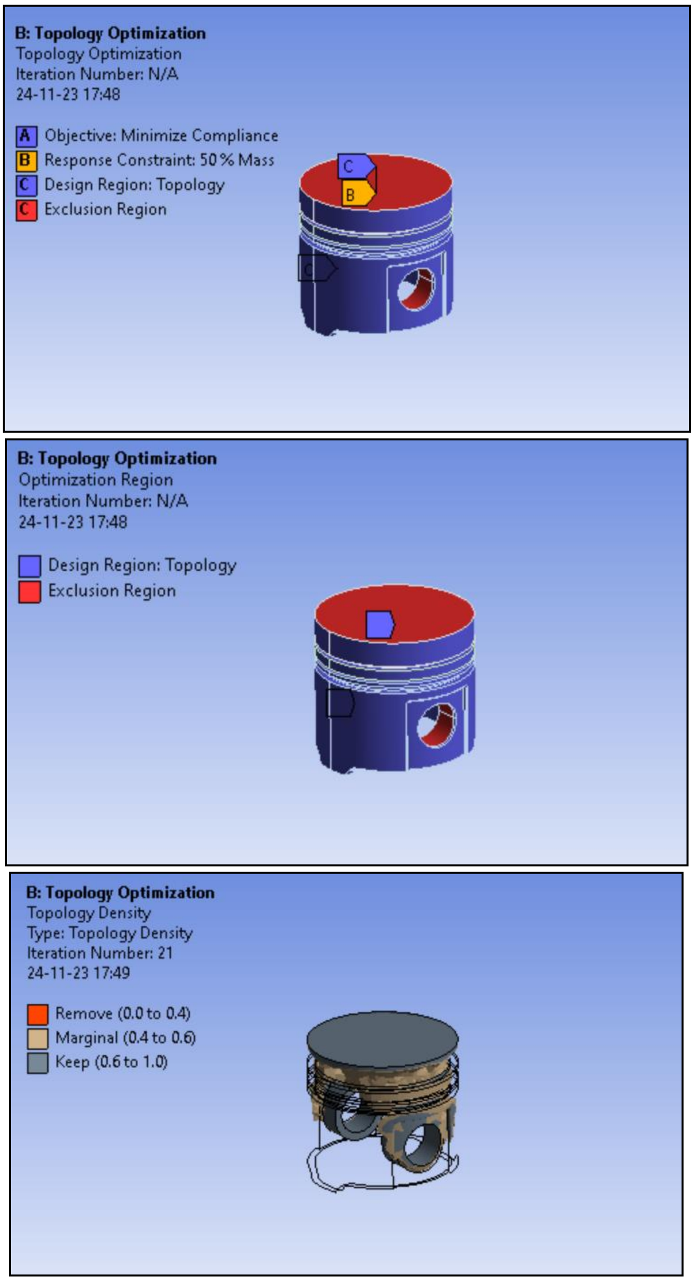


Figure 8 Results of Topology Optimization

The goal of the mathematically described optimization issue is to reduce the compliance of the structure under a given set of constraints, such as volume or stress limitations.

The compliance is a measurement of the deformation or strain energy caused by loads or forces outside the structure.

Then the response constraint is added like how much mass we need to retain. The convergence accuracy of the analysis was set to 0.1%.

The amount of mass to be retained was set to 50%. After feeding all the parameters we performed the topology optimization.

The solution converged after 21 iterations.

FEA OF HONEYCOMB STRUCTURE PISTON

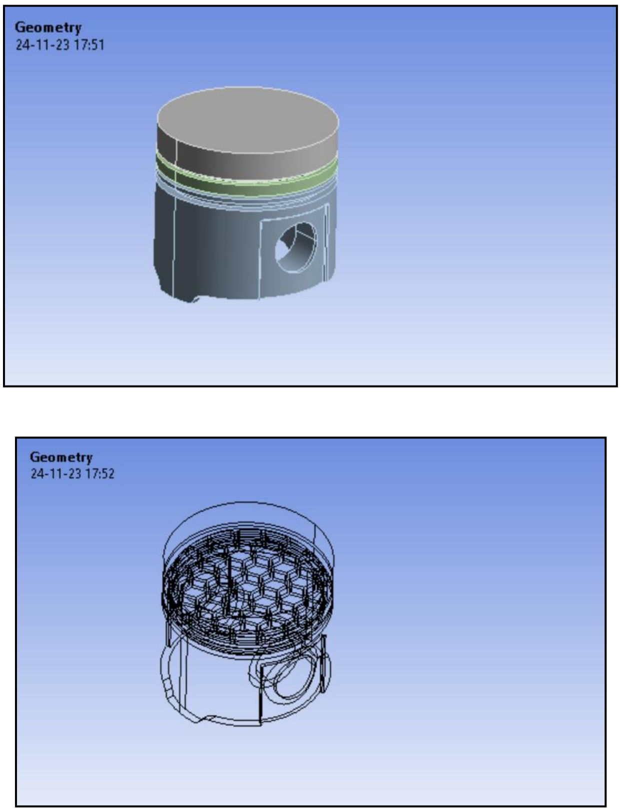


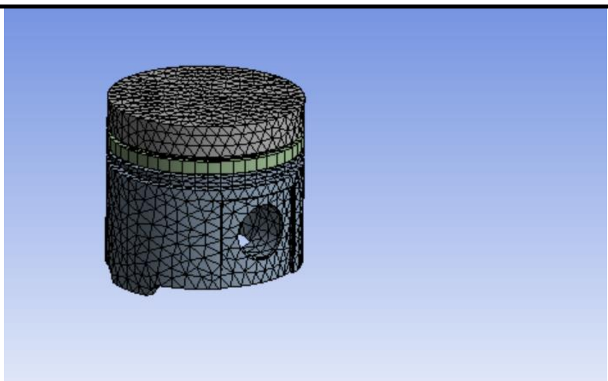
Figure 9. Geometry of honeycomb structure piston

Properties

Volume	1.2796e+005 mm^3
Mass	0.35445 kg

Meshing

As the main link of finite element analysis, grid division can best reflect the idea of finite element. The quality of the web site not only affects the efficiency of model analysis, but also directly affects the accuracy of analysis results. Therefore, according to the existing hardware, without affecting the accuracy of the calculation results, the method of dividing the mesh can be appropriately selected to save calculation time.



Statistics		Type	Element Size
Nodes	23153	Element Size	5.0 mm
Elements	11360		

Figure 10. Finite element mesh model of honeycomb structure piston

Final existing piston mesh model, it contains 23153 nodes and 11360 elements. Element size was 5 mm
Element Types

Boundary condition

After the material and piston geometry have been set, the boundary conditions of piston need to be applied in ANSYS Mechanical to simulate its operating conditions. Under Static Structural analysis, 5 MPa of pressure is applied on top surface of piston head. This pressure is due to combustion of gases in cylinder.

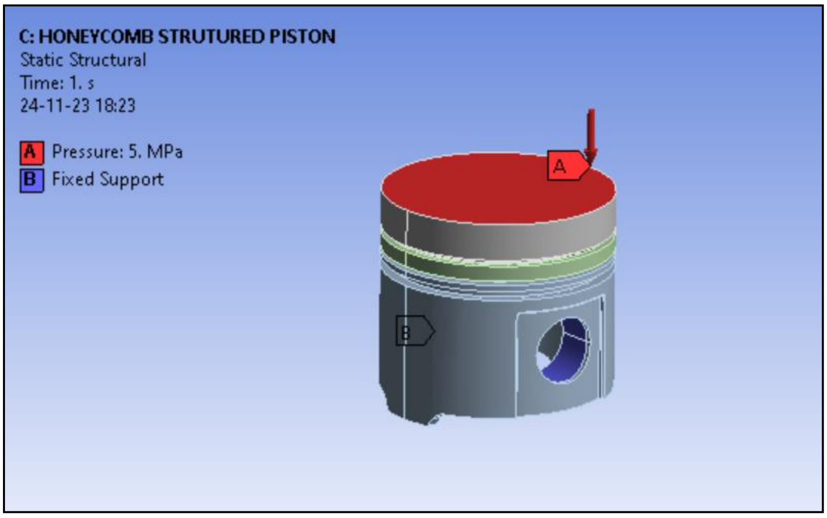


Figure 11. Boundary condition of honeycomb structure piston

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Results:

Total Deformation

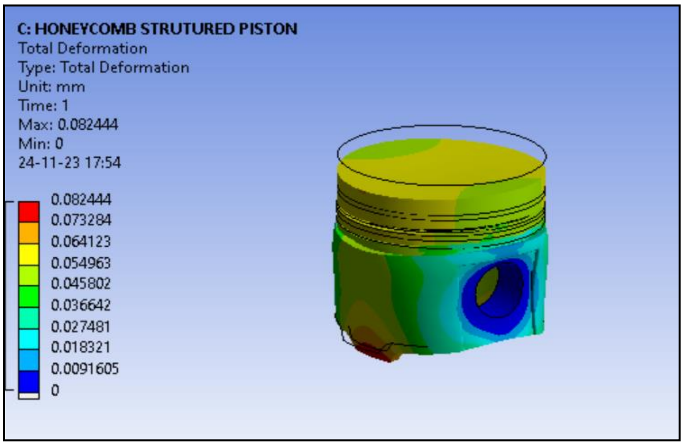


Figure 12. Total deformation of honeycomb structure piston

Equivalent Stress

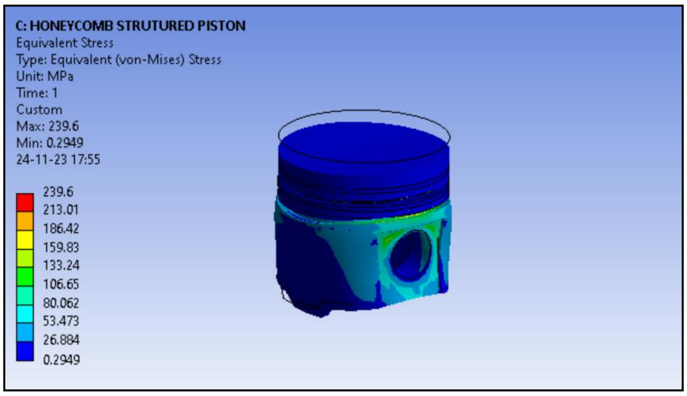


Figure 13. Equivalent Stress of honeycomb structure piston

Equivalent Strain

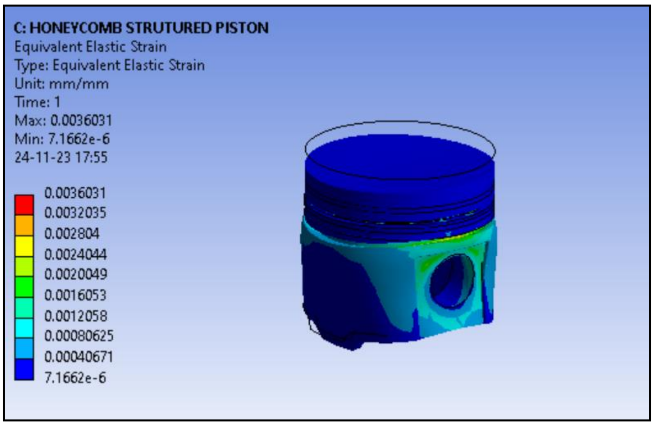
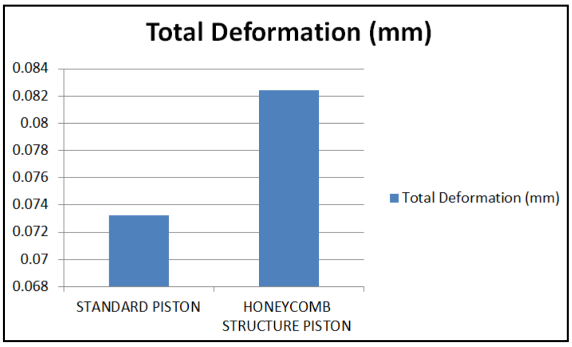
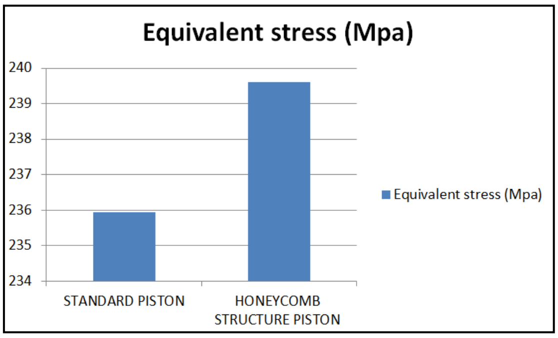


Figure 14. Equivalent Strain of honeycomb structure piston

Parameter	STANDARD PISTON	HONEYCOMB STRUCTURE PISTON
weight	0.39498 kg	0.35445 kg
Total Deformation (mm)	0.073226	0.082444
Equivalent stress (Mpa)	235.95	239.6
Equivalent strain	0.003562	0.0036031

FEA Results





VI. CONCLUSION

- The design and static structural analysis of existing piston and honeycomb structure piston has been carried out. Comparison has been made between honeycomb structure piston with existing piston having same design and same load carrying capacity.
- The stress and displacements have been calculated using ANSYS 21 for existing piston and honeycomb structure piston. From the static analysis results it is found that there is a maximum displacement of 0.073226 mm in the existing piston and 0.082444 mm honeycomb structure piston. By analyzing the design, it was found that all the stresses in the existing piston were well within the allowable limits and with good factor of safety.
- The stresses in the honeycomb structure piston of design are much lower than that of the allowable stress.
- Thus a total weight reduction of 40gms was achieved. Initial weight was 394.98 g whereas final weight was 354.45 g.
- So we have successfully reduced the weight of existing piston by 10 % using honeycomb structure.

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