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Design, Structural and Thermal Analysis of Piston by Using Finite Element Analysis

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Abstract: In this project, it was chosen to investigate a specific piston design and its maximum gas pressure capabilities. The first aim for this project is to create a piston model using the solid modelling software CATIA V5. The geometry will be meshed and analyzed using the ANSYS software. A thorough literature search was conducted for the examination of piston input circumstances and the analytical process. High combustion gas pressures operate as mechanical loads, causing substantial strains in the piston's critical area. For various loading situations, such as maximum gas pressure load, a detailed static structural analysis is carried out. To choose the best material, a comparative research is carried out. Relative examination is never really dominated material. A cylinder is a mechanical part found in an assortment of cycles like pneumatic chambers. Responding siphons, responding motors and gas blowers. It is the upward development inside a chamber that is put away gastight by cylinder .In the auto business, it is found that the cylinder is the most fundamental part of the motor, and that it is presented to serious mechanical and warm loads. Warm burdens are initiated in the cylinder because of the exceptionally high temperature differential between the cylinder crown and the cooling displays. The cylinders are regularly built of aluminum due to its lightweight and heat conductivity. Be that as it may, as a result of its low hot strength and high development coefficient, it isn't suggested for use in high-temperature applications. The reason for a section bar or potentially an associating bar in a motor is to move power from growing gas to the barrel shaped shaft through an interfacing bar and additionally segment pole. To pack or remove the liquid put away in the chamber, the siphons turned around the capacity of the cylinder and communicate power from driving rod to it. In the initial step the primary examination of a common cylinder developed of the aluminum composite is concentrated in this exploration. The subsequent advance is to direct an investigation on a cylinder developed of Aluminum and Cast iron. Lightweight, minimal expense, primarily and thermally safe materials ought to be used in the development of pistons in the third step Validation of investigation result with contrasting the traditional material.

I. INTRODUCTION

When it comes to mechanical engineering, the piston is one of the utmost important components. Piston has a broad range of applications in mechanical systems such as internal combustion engines, pneumatic cylinders, hydraulic cylinders, and so on. A piston is a mechanical component that is present in a range of operations, including reciprocal pumps, gas compressors, pneumatic cylinder and reciprocal engines. It is the moving component within a cylinder that is stored gastight by piston rings, which are utilised with a piston. The task of a piston rod and/or a rod connector in a motor is to transfer the force via the crankshaft from rising gas in the cylinder to the shaft. Because of the shape of the piston and its exposure to structural and thermal loads, a study is required. A piston is a moving part of the cylinders included in reciprocal engines, reciprocal pumps, gas compressors and pneumatic cylinders. The pressure from the expanding combustion gas in the combustion chamber on the piston-connecting rod assembly operates on an internal combustion (IC) motor that transfers the motion to the crankshaft through piston-connecting rod assembly. One approach is to alter the material of a component in the combustion chamber to increase engine performance. This is one of the answers. The shape and size of the engine components are also taken into consideration to improve engine performance. When operating, the piston must withstand cyclic gas pressure as well as inertial forces, and this working situation may result in fatigue damage to the piston, such as piston lateral wear and piston head fractures, among other things. The pistons are often constructed of aluminium because of its lightweight and heat conductivity. However, because of its low hot strength and high expansion coefficient, it is not recommended for use in high-temperature applications.

A. General Information

A piston is a mechanical component found in a variety of processes such as pneumatic cylinders. Reciprocating pumps, reciprocating engines and gas compressors. It is the vertical movement within a cylinder that is stored gastight by piston, which are utilised with a piston. The purpose of a column rod and/or a connecting rod in an engine is to transfer force from expanding gas to the cylindrical shaft through a connecting rod and/or column rod.

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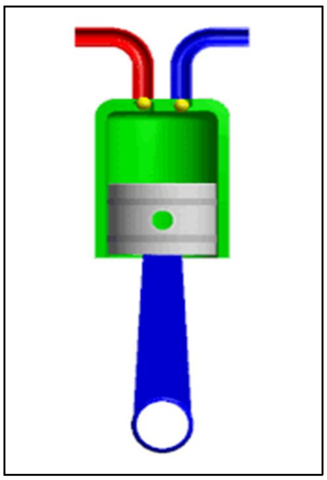
In order to compress or expel the fluid stored in the cylinder, the pumps reversed the function of the piston and transmit force from crankshaft to it. The piston may also play a dual function in the engine by sealing and uncovering openings in the cylinder.

The following are the major components of a piston.

1) Piston head or crown: depending on the architecture of the combustion chamber, piston head or crown form is flat, convex or concave. It can withstand the gas pressure in the cylinder.
2) Piston rings are used to screen the cylinders to prevent gas leakage beyond the piston.
3) It acts as a support for a side push on the cylindrical walls of the connecting rod. The skirt. The skirt.
4) The piston pin is a kind of pin, often known as the gudgeon pin or bracelet. Its function is to connect the piston to the engine connecting rod.



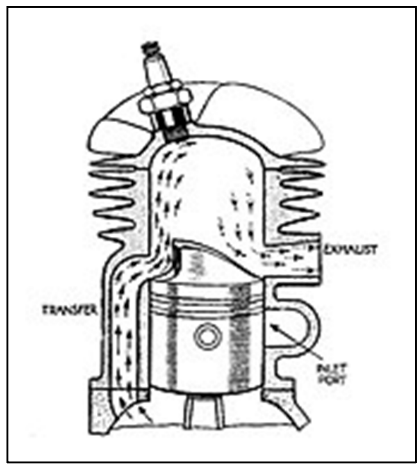


Figure 1. 1 Piston and Connecting rod   Figure 1. 2 Two stroke deflector piston

B. Design Consideration for a Piston

When planning a piston, the following considerations

1) It should be as light as possible in terms of mass.
2) A high-speed reciprocating system with little noise is required.
3) It must have a high strength resist the high gas pressure and inertia forces. iii. It should be lightweight.
4) Construction of the product should be robust in order to resist heat and mechanical deformation.
5) A suitable bearing surface area should be provided in order to avoid wear.
6) The heat generated by combustion should be dissipated as soon as possible to the cylinder walls.
7) It should provide enough support for the piston pin.
8) It should be capable of forming a good oil and gas seal around the cylinder.

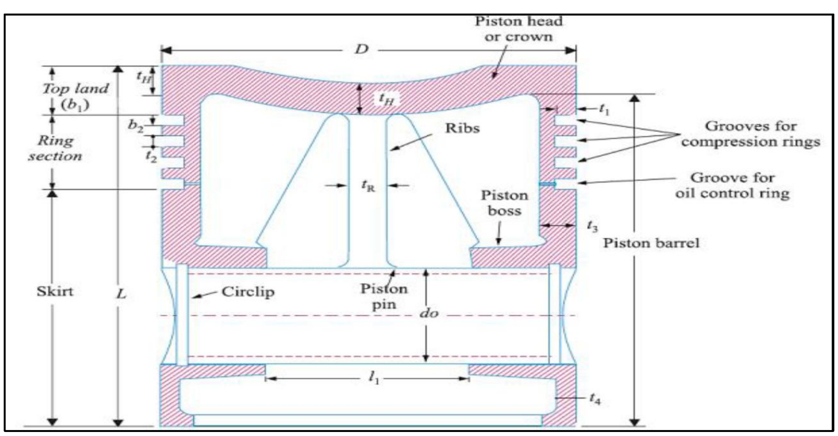


Figure 1. 3 Piston components for I.C. engine

According to the objectives of the current research, the design and analysis of the piston should be done in accordance with the thermal and structural concerns. The use of Computational Fluid Dynamics, as well as the creation of a combustion model are discussed.

C. Petrol Engine Thermal Analysis.

The actual thermodynamic four- or two-way evaluation is not a simple task. However, if information stated assumptions are followed, analysis may be significantly simplified. The resulting cycle, close to the actual operational conditions, is the Otto cycle.
When the combustion of fuel is heated, an electric current is generated to ignite the petrol during the running engine. This occurs at low rpm near TDC (Top Dead Centre). With increasing engine rpm, the spark point is changed before the cycle, and the gas charge may be turned on while compressed. This benefit may be seen in the many designs of Otto engines. The atmospheric engine (non-compression) was 14 percent efficient. The operational efficiency of the compressed charge engine was 32%.
The heat flow from the piston ring to the cylinder is analytically complicated, owing to a huge number of situations occurring during a four-time cycle, all of which influence the thermal flow.

1) A few of such situations are described below.
2) The varying thickness of the oil layer has an impact on the It increases the oil's heat conductivity and establishes surface-to-surface contact between the piston rings and the liner.
3) During a stroke, the rings may twist and change the contact geometry.
4) Tolerances in piston ring manufacturing may vary, affecting the clearance between the ring and the line.
5) In the event of a ring liner contact, surface-to-surface or hydrodynamic friction may occur, resulting in a rise in surface oil and temperature.
6) Piston tilting modifies the amount of piston ring contact.
7) Combustion gases may rise to the top of the ground, enhancing localised heat transfer to the piston top ground.
8) Thermal expansion of the piston and the piston ring changes the piston and piston ring geometry.
9) Combustion gas blow-by affects the heat transmission via the addition of convective heat to both the piston and cylinder line.

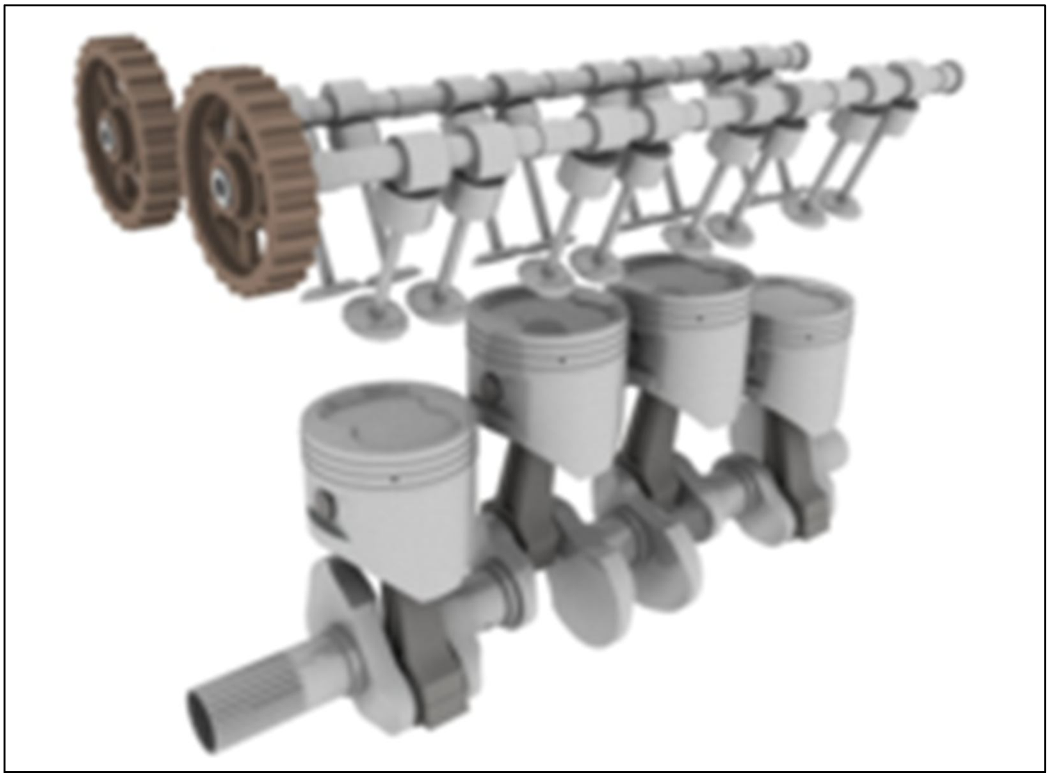


Figure 1. 4 Four Piston Engine moving parts

II. LITERATURE REVIEW

1) Manisha B. Shinde, T. V. Sakore, and V. D. Katkam have collaborated on this project (2016) The structural analysis of a typical piston constructed of the aluminium alloy A2618 is studied in this research. The second step is to conduct an analysis on a piston constructed of Al-GHY1250 and Al-GHS1300. Lightweight, low-cost, structurally and thermally resistant materials should be utilised in the construction of pistons since the conditions that would be encountered throughout the combustion process are very high pressures and temperatures.
2) Using Aluminum Silicon Carbide (AlSiC), an aluminium matrix composite, Abino John, Jenson T Mathew, and colleagues (2015) have developed a lightweight alternative to aluminium in this research. In order to create a 3D model, CATIA v6 was used, and structural and thermal analysis were performed using ANSYS 14. Abrasion resistance and creep resistance are superior in AlSiC compared to aluminium. It also offers extremely excellent stiffness-to-weight and strength-to-weight ratios as well as superior high temperature performance. The fabrication of pistons from AlSiC is also less complicated than the fabrication of pistons from aluminium.
3) Pistons are a crucial component of an internal combustion engine, and their design and analysis take structural and thermal issues into account. A linear static and a linked thermal-structural analysis of a broken piston in an internal combustion engine were carried out effectively by Gudimetal and Gopinath utilising reverse engineering and the finite element technique, which was utilised in conjunction with a damaged IC engine piston.
4) The piston as demonstrated by Rajan et al.According to them, the design parameter may be altered, such as crown thickness, barrel thickness, ring lands thickness and an optimum solution for an existing design.
5) Saigowtham Ponnathi (2016) found that the cylinder liner and piston rings had frictional losses that accounted for 20% of the total amount of mechanical losses. Because the frictional losses in the piston rings and cylinder liners may be minimised, the efficiency of the engine can be increased while the fuel consumption is decreased. It is also possible for the piston, piston rings, and cylinder liners to operate at greater temperatures and pressures, which lowers frictional losses. The design of the piston, piston rings, and cylinder liners are modelled in CATIA V5 for the purposes of this project. The design of engine components is complicated, and the efficiency of the engine is dependent on the kind of material used. It is assumed that the material is an ALUMINUM-FLYASH-ALUMINA combination. The study is carried out in the ANSYS programme, which allows for the determination of the structural and thermal analysis of the piston.

III. PROBLEM STATEMENT

A. *Materials and Methodology*

1) *Aluminum:* Chemical element (symbol Al), 13 atomic, 26.98 atomic and one, stable isotope: 27. A relatively dense aluminium is a soft, silver metal: 2,70 to 2,90 kg/dm3 and a melting point: 660°C. On contact with the air, a thin, waterproof film of aluminium oxide is produced. In conjunction with other metals, aluminium is a highly significant building element. Oxide, hydroxide, chloride, sulphate, silicate and acetate are the main compounds of aluminium.
2) *Grey Cast Iron:* It is a kind of cast iron that has a graphitic microstructure and is used in the production of steel. It was given this name because of the grey hue of the fracture it produces, which is caused by the presence of graphite in the iron. It is the most common cast iron and the most frequently used cast material in terms of volumetric usage. Internal combustion engine cylinder blocks, pump housings, valve bodies, electrical boxes, and ornamental cast iron are examples of applications where the stiffness of the component is more essential than the tensile strength of the component. The excellent thermal conductivity and specific heat capacity of grey cast iron are often used in the production of cast iron cookware and disc brake rotors.

Table 1. 1 Mechanical properties of the Material

SI No	Properties	Aluminium	Grey Cast Iron
1	Density (Kg/m^3)	2880	7200
2	Young's Modulus (GPa)	115	124
3	Poisson's ratio	0.3	0.3
4	Bulk Modulus (MPa)	95.8	103.3
5	Shear Modulus (MPa)	44.23	47.69
6	Tensile Yield Strength (MPa)	480	240
7	Compressive Yield Strength (MPa)	480	600
8	Ultimate tensile strength (MPa)	650	276
9	Specific Heat (J/Kg C)	875	447

The motor piston model is created by CATIAV5 and the piston performance is examined using ANSYS simulation software. A pressure on the top of the piston is applied to analyse stress in a static structural analysis. The transient column is analysed thermally to detect the temperature effects on the column.

B. Thermal Analysis

a set of methods is a thermal analysis in which the change of a substance's physical properties is assessed by temperature. The most frequently utilised methods are those that measure changes in mass or energy in a substance's sample. Shows entire aluminium piston heat flux statistic overall heat flux in aluminium piston. Temperature fluctuation between the different piston heights of the piston in a stable state shown in figure and the limited circumstances indicated in figure. Top maximum temperature.

C. Structural Static Analysis:

A static structural analysis detects motions, tensions, pressures and stresses in cargo structures or components that do not cause significant inertia and damping. Stable loading and response conditions are assumed; structural loads and reactions are thought to slowly change over time. The ANSYS can conduct a static structural load.

The load types that may be used in a static analysis include:

1) Forces and pressures exerted externally.
2) Inertial steady-state strengths (such as gravity or rotational velocity).
3) 3Displacement (non-zero) imposed.
4) Temperatures (for thermal strain).

In order to advance the efficiency of the engine, the behaviour of the piston has to be studied. The pistons usually consist of alloy steels which demonstrate the high resistance to thermal and structural stresses. In the structural and thermal study, we determine if our selection of materials for the piston is safe under applied load circumstances or not. The findings are compared at the conclusion. This study will assist those working in the area of continuous thermal piston analysis.

D. Analysis of Heat Transport using the Finite Element Method

The Finite Element Method may be used to conduct a multidimensional heat transport study. This kind of solution technique is based on the usage of components representing the object's body. The physical, geometric and material characteristics of the building are expressed in each constituent. The elements are nodes in which the node value changes along the elements are described by a shape function. The number of nodes of the element may vary, although three or four node elements are often employed in a 2D analysis, while four or eight node elements are usually used for 3D analysis. Each node has a number of degrees of freedom depending on the kind of analysis. Finite element analyses comprise of a material or design computer model that is strained and analysed for certain outcomes. It is frequently utilised either for the refining or for any new design of the current product. The alteration of the current design or product or structure is used to qualify the product for a new condition of service. In structural failure, FEA may sometimes assist to determine design changes to satisfy the new circumstances. In the manufacturing sector, two kinds of analyses are often used: 2D modelling and 3D modelling. In case 2D modelling is performed on a regular computer, the results are less accurate. 3D modelling instead provides more precise results while losing the ability to operate efficiently on all but the fastest machines. Compared to non-linear systems, the complicated nature of linear systems is smaller. Nonlinear systems cause plastic deformation, and many may also test a material all the way to a material fracture

IV. PROBLEM SOLVING

A. Geometric Model

This piston model is created in CATIA V5 and then imported for standard load analysis to ANSYS Workbench 18.1. A comparison of current conventional steel piston structural steel, aluminium and grey cast iron was carried out after the research. The final results are produced after meshing the model, the boundary conditions are implemented correctly. The following graphic displays the final findings of structural analysis of various materials such as aluminium and cast iron.

Finite element mesh is formed using parabola elements of tetrahedral (elements). The stress of vonmises is controlled for convergence. In the current work, an automated technique is utilised to create the mesh. The piston mesh is illustrated in picture. In the thermal analyse of the ANSYS model, the convection limit is affected by the surface load on the outside surface. The top of the piston is extremely high due to direct contact with the gas. The top surface of the piston is thus supplied with a temperature of 360 degrees. Figure shows the thermal limit conditions of the piston.

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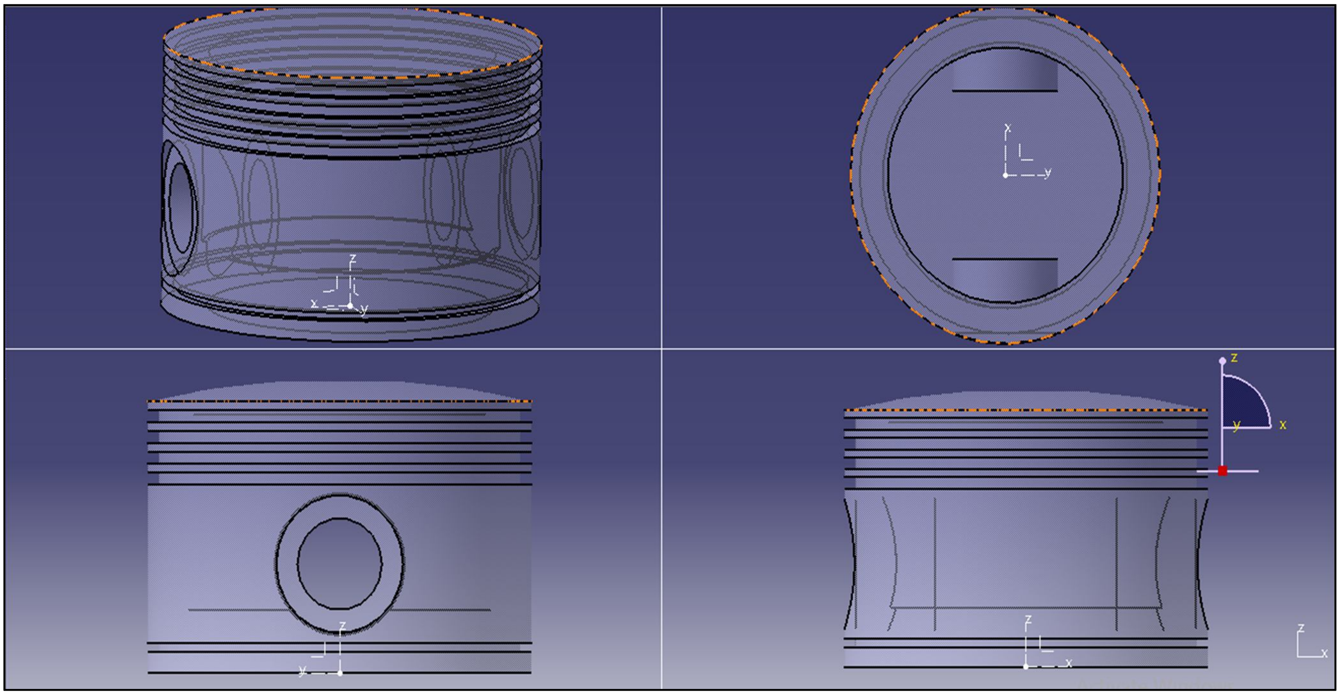

Figure 4. 1 Different view of Piston

B. Static Structural Analysis

The force is transferred via the piston during the combustion phase. The piston also suffers from a burden of stress owing ignition. The piston is intended to resist the shock load and would not suffer fatigue failure with frequent cycles or transient stuffing. In traditional internal combustion engines the gudgeon pin (connecting the piston with the connecting rod) is subjected to a mixture of shearing and bending stresses. When combustion takes place, the column is distorted and the energy deposited inside the piston is a deciding factor in determining the piston's output and failure conditions if static stress is applied. The yield criteria of Mises may be stated in terms of von Mises stress or tensile stress.

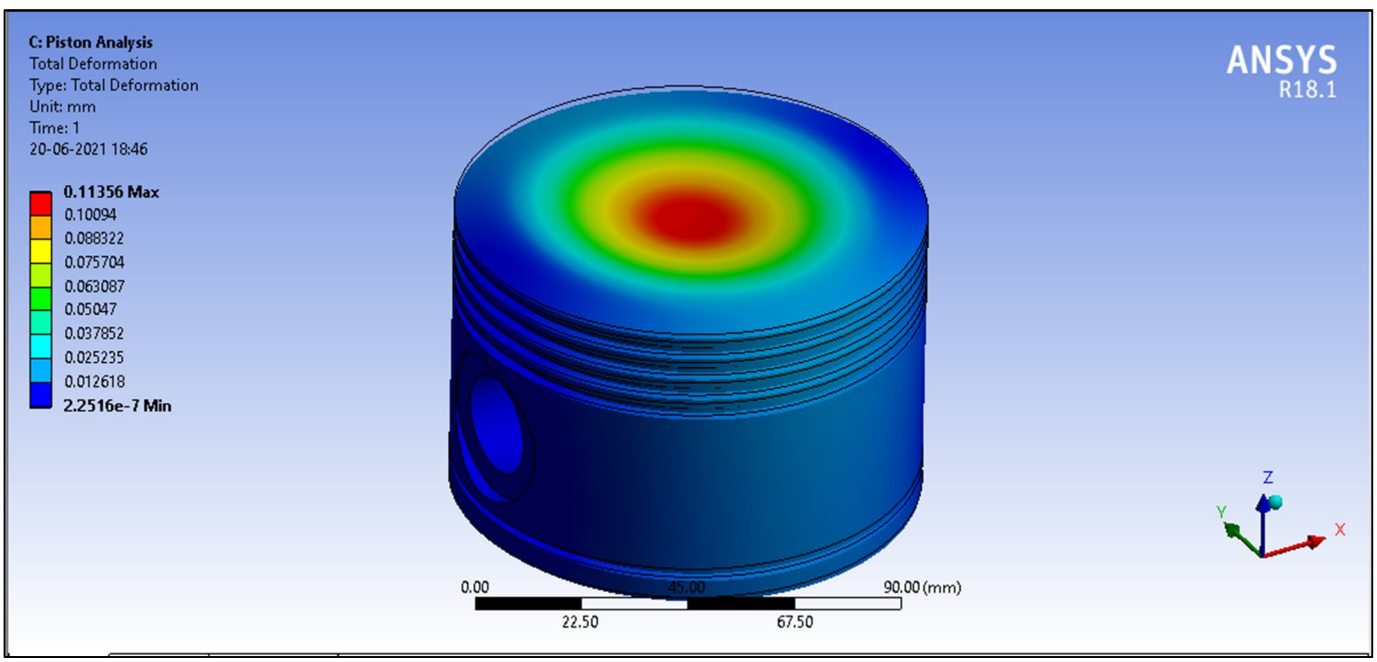

Figure 4. 2 total deformation of cast iron

C. Thermal Analysis

Most of the IC pistons are built from aluminium alloy, 80% more than the borer liner material produced of cast iron. This leads to some differences in operating and design clarifications. Since design, the maximum temperature should never be and over 60% of the melting point heat of the alloy in the piston, since the alloy exposed to the highest temperature alters the crystalline structure which significantly impedes the piston's working for longer term. Equations of heat transmission for various piston surfaces were determined.

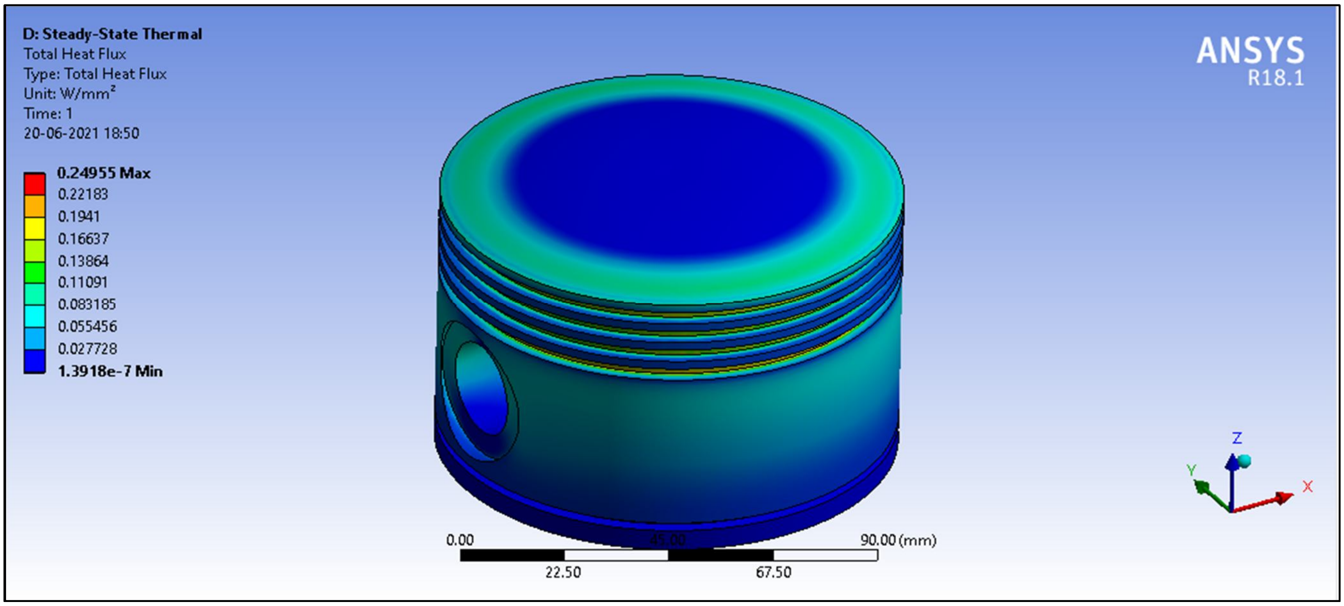

Figure 4. 3 heat flux

V. RESULT AND CONCLUSION

A composite material (aluminium) piston is successfully developed and analysed. Aluminum piston provides great strength even in harsh conditions for ageing. Aluminum has a lower deformation, reduced stress and a superior temperature distribution compared to Grey cast iron. Aluminum piston overcomes some of the limitations of cast iron piston. We gain a good understanding of the Al material and its characteristics through this research.

The greatest heat transmission occurs over a smaller area owing to the curved surface of the piston crown, where the compression ratio of the gases is maximal. Even in this area, it has a modest thickness and maximal heat. Although the piston is comparatively less stressful, the deflection measured is very considerable as shown . Fig 19 to 27 illustrates stress distribution, deformation, fatigue life and piston temperature. When the bottom part of the piston is observed, stress, deflection and temperature readings are below and improvement may thus be achieved.

The design parameter of the piston with change was determined to be adequate

1) Improvement in current outcomes.
2) The highest stress was determined to be 264 MPa, which is less than the maximum tensile stress (650 MPa) and the material's yield strength (480 MPa).
3) The maximum thermal stress at 360^0 has been determined.
4) The minimal safety factor is 15 that is higher than unit, so that our piston design is safe under the circumstances of applied load.

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