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Design and Analysis of Piston in 4-Stroke CI Engine

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ABSTRACT:

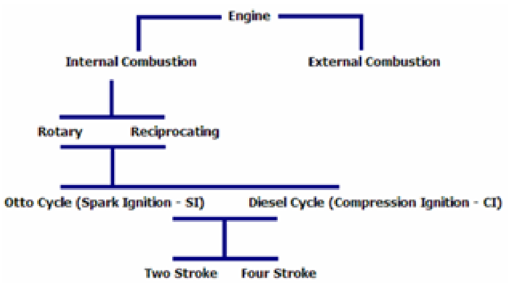
The Aim of this project is to design a piston using CATIA and perform analysis using ANSYS software. The analysis of the piston is done by using different materials. By conducting the above analysis on the combustion chamber stress, deformation and temperature gradient conditions are found and the best material for the combustion chamber is suggested. For this a piston from Tata indica engine is taken and it is modeled with four different types of direct injection combustion chambers namely shallow depth, hemispherical, cylindrical and torroidal combustion chambers. Thermal and Structural analysis is done on this four types of combustion chambers with three different materials i.e cast iron, Aluminum LM6 alloy, Zamak. From analysis it is evident that Torroidal combustion chamber showed better temperature distribution, high amount of heat flux, less deformation, less stress values with aluminium LM6 alloy. So Torroidal combustion chamber is chosen as the best combustion chamber with aluminium LM6 alloy.

INTRODUCTION:

1.1 Internal Combustion Engines:

The Internal Combustion Engine (also known as IC Engine) is an engine in which the combustion of fuel and an oxidizer (typically air) occurs inside a confined space called a combustion chamber. This exothermic reaction creates gases at high temperature and pressure, which are permitted to expand inside that confined chamber. Thrust produced by this expanding gas drives the engine creating useful work.

1.2 Engine Classification:



Spark Ignition (SI) Engine:

Inside the combustion chamber of this type of engine, the mixture of fuel and air is ignited by a spark plug to initiate the exothermic combustion reaction.

Compression Ignition (CI) Engine:

This type of internal combustion engine does not have spark plug. Inside the combustion chamber of this engine, air is compressed to a high enough pressure and temperature that combustion occurs spontaneously when fuel is injected at the end of air compression.

2.COMBUSTION CHAMBER:

A Combustion Chamber is a part in which combustion of fuel or propellant, in particular, is initiated in internal combustion engine The combustion technology increases the inner power of a gas, that translates into a rise in temp, pressure, or volume reliant on the specification in an enclosure. For instance the cylinder of a repayment engine, the volume is manipulated and the combustion creates a rise in pressure and constant flow arrangement, for example a jet-type engine combustor, the compression is initiated & the burning makes an rise in volume. This rise in compression or volume can be utilized to do work, for example, to push a piston on a crank or a engine disc-type in a gas turbine.

2.1 DESCRIPTION OF COMBUSTION CHAMBERS - CI ENGINES:

Primary Considerations in the Design of Combustion Chambers for C.I Engines:

In C.I engines fuel is injected into the combustion chamber at about 15° before T.D.C. during the compression stroke. For the best efficiency the combustion must complete within 15° to 20° of crank rotation after T.D.C. in the working stroke. Thus it is clear that injection and combustion both must complete in the short time. For best combustion mixing should be completed in the short time. In S.I engine mixing takes place in carburetor; however in C.I engines this has to be done in the combustion chamber.

To achieve this requirement in a short period is an extremely difficult job particularly in high speed Cl. engines. From combustion phenomenon of C.I. engines it is evident that fuel-air contact must be limited during the delay period in order to limit, the rate of pressure rise in the second stage of combustion. This result can be obtained by shortening the delay to achieve high efficiency and power the combustion must be completed when piston is nearer to T.D.C., it is necessary to have rapid mixing of fuel and air dun the third stage of combustion.

2.2 TYPES OF COMBUSTION CHAMBERS- CI Engines

The most important function of CI engine combustion chamber is to provide proper mixing of fuel and air in short time. In order to achieve this, an organized air movement called swirl is provided to produce high relative velocity between the fuel droplets and the air.
When the liquid fuel is injected into combustion chamber, the spray cone gets disturbed due to air motion and turbulence inside. The onset of combustion will cause an added turbulence that can be guide d by the shape of the combustion chamber, makes it necessary to study the combustion design in detail.

C I engine combustion chambers are classified into two categories:

1. DIRECT INJECTION (DI) TYPE:

This type of combustion chamber is also called an Open combustion chamber. In this type the entire volume of combustion chamber is located in the main cylinder and the fuel is injected into this volume.

2.INDIRECT INJECTION (IDI) TYPE:

In this type of combustion chambers, the combustion space is divided into two parts, one part in the main cylinder and the other part in the cylinder head. The fuel –injection is affected usually into the part of chamber located in the cylinder head.
These chambers are classified further into:
a)Swirl chamber in which compression swirl is generated

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b) Pre combustion chamber in which combustion swirl is induced
c) Air cell in which both compression and combustion swirl are induced.

3. PISTON

INTRODUCTION

In every engine, piston plays an important role in working and producing results. Piston forms a guide and bearing for the small end of connecting rod and also transmits the force of explosion in the cylinder, to the crank shaft through connecting rod. The piston is the single, most active and very critical component of the automotive engine. The Piston is one of the most crucial, but very much behind-the-stage parts of the engine which does the critical work of passing on the energy derived from the combustion within the combustion chamber to the crankshaft. Simply said, it carries the force of explosion of the combustion process to the crankshaft. Apart from the critical job that it does above, there are certain other functions that a piston invariably does .It forms a sort of a seal between the combustion chambers formed within the cylinders and the crankcase. The pistons do not let the high pressure mixture from the combustion chambers over to the crankcase.

3.1 CONSTRUCTION OF PISTON:

Its top known by many names such as crown, head or ceiling and thicker than bottom portion. Bottom portion is known as skirt. There are grooves made to accommodate the compression rings and oil rings. The groove, made for oil ring, is wider and deeper than the grooves made for compression ring. The oil ring scraps the excess oil which flows into the piston interior through the oil return holes and thus avoiding reaching the combustion chamber but helps to lubricate the gudgeon pin to some extent. In some designs the oil ring is provided below the gudgeon pin boss .The space between the grooves are called as lands. The diameter of piston always kept smaller than that of cylinder because the piston reaches a temperature higher than cylinder wall and expands during engine operation. The space between the cylinder wall and piston is known as piston clearance. The diameter of the piston at crown is slightly less than at the skirt due to variation in the operating temperatures. Again the skirt itself is also slightly tapered to allow for unequal expansion due to temperature difference as we move vertically along the skirt the working temperature is not uniform but slightly decrease.

3.2 PISTON DESCRIPTION:

Pistons move up and down in the cylinders which exerts a force on a fluid inside the cylinder. Pistons have rings which serve to keep the oil out of the combustion chamber and the fuel and air out of the oil. Most pistons fitted in a cylinder have piston rings. Usually there are two spring-compression rings that act as a seal between the piston and the cylinder wall, and one or more oil control ring s below the compression rings. The head of the piston can be flat, bulged or otherwise shaped. Pistons can be forged or cast. The shape of the piston is normally rounded but can be different. A special type of cast piston is the hypereutectic piston. The piston is an important component of a piston engine and of hydraulic pneumatic systems. Piston heads form one wall of an expansion chamber inside the cylinder. The opposite wall, called the cylinder head, contains inlet and exhaust valves for gases. As the piston moves inside the cylinder, it transforms the energy from the expansion of a burning gas usually a mixture of petrol or diesel and air into mechanical power in the form of a reciprocating linear motion. From there the power is conveyed through a connecting rod to a crankshaft, which transforms it into a rotary motion, which usually drives a gearbox through a clutch.

4. MODELING

INTRODUCTION TO CAD:

Computer-aided design (CAD), also known as computer-aided design and drafting (CADD), is the use of computer technology for the process of design and design-documentation. Computer Aided Drafting describes the process of drafting with a computer.

CADD software, or environments, provides the user with input-tools for the purpose of streamlining design processes; drafting, documentation, and manufacturing processes. CADD output is often in the form of electronic files for print or machining operations. The development of CADD-based software is in direct correlation with the processes it seeks to economize; industry-based software (construction, manufacturing, etc.) typically uses vector-based (linear) environments whereas graphic-based software utilizes raster-based (pixelated) environments.

CATIA

SCOPE OF APPLICATION

Commonly referred to as 3D Product Lifecycle Management software suite, CATIA supports multiple stages of product development (CAx), from conceptualization, design (CAD), manufacturing (CAM), and engineering (CAE). CATIA facilitates collaborative engineering across disciplines, including surfacing & shape design, mechanical engineering, equipment and systems engineering.

5. ANALYSIS

5.1 INTRODUCTION TO FEA

Finite Element Analysis (FEA) was first developed in 1943 by R. Courant, who utilized the Ritz method of numerical analysis and minimization of variation calculus to obtain approximate solutions to vibration systems. Shortly thereafter, a paper published in 1956 by M. J. Turner, R. W. Clough, H. C. Martin, and L. J. Topp established a broader definition of numerical analysis. The paper centered on the "stiffness and deflection of complex structures". By the early 70's, FEA was limited to expensive mainframe computers generally owned by the aeronautics, automotive, defense, and nuclear industries. Since the rapid decline in the cost of computers and the phenomenal increase in computing power, FEA has been developed to an incredible precision. Present day supercomputers are now able to produce accurate results for all kinds of parameters.

5.2 TYPES OF ENGINEERING ANALYSIS:

Structural analysis consists of linear and non-linear models. Linear models use simple parameters and assume that the material is not plastically deformed. Non-linear models consist of stressing the material past its elastic capabilities. The stresses in the material then vary with the amount of deformation as in. Vibrational analysis is used to test a material against random vibrations, shock, and impact. Each of these incidences may act on the natural vibrational frequency of the material which, in turn, may cause resonance and subsequent failure. Fatigue analysis helps designers to predict the life of a material or structure by showing the effects of cyclic loading on the specimen. Such analysis can show the areas where crack propagation is most likely to occur. Failure due to fatigue may also show the damage tolerance of the material. Thermal analysis calculates the temperature distribution and related thermal quantities in a system or component.

5.3 FINITE ELEMENT ANALYSIS:

Preprocessing: The user constructs a model of the part to be analyzed in which the geometry is divided into a number of discrete sub regions, or elements," connected at discrete points called nodes." Certain of these nodes will have fixed displacements, and others will have prescribed loads. These models can be extremely time consuming to prepare, and commercial codes with one another to have the most user-friendly graphical “preprocessor" to assist in this rather tedious process. Some of these preprocessors can overlay a mesh on a preexisting CAD file, so that finite element analysis can be done conveniently as part of the computerized drafting-and-design process.

Analysis:

The dataset prepared by the preprocessor is used as input to the finite element code itself, which constructs and solves a system of linear or nonlinear algebraic equations

$$K_{ij}u_j = f_i$$

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where u and f are the displacements and externally applied forces at the nodal points. The formation of the K matrix is dependent on the type of problem being attacked, and this module will outline the approach for truss and linear elastic stress analyses. Commercial codes may have very large element libraries, with elements appropriate to a wide range of problem types. One of FEA's principal advantages is that many problem types can be addressed with the same code, merely by specifying the appropriate element types from the library.

6. RESULTS AND DISCUSSION

THERMAL AND STRUCTURAL ANALYSIS OF PISTON WITH CYLINDRICAL HEAD

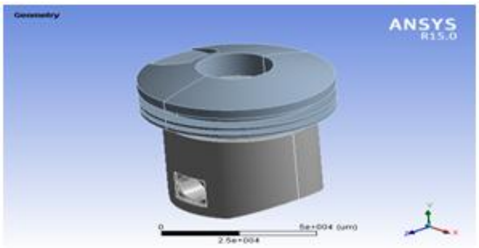

Fig 6.1 cylindrical head combustion chamber model

The Fig 6.1 is the imported model of piston with cylindrical head. Modeling was done in Pro-E and imported with the help of IGES (Initial Graphical Exchanging Specification).

MESHING

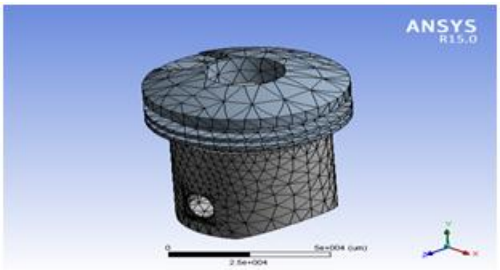

Fig 6.2 Meshed model of cylindrical head combustion chamber

Fig 6.2 shows the meshed modal. Default solid Brick element was used to mesh the components. The shown mesh method was called Tetra Hydral Mesh

MATERIAL: CAST IRON

TEMPERATURE:

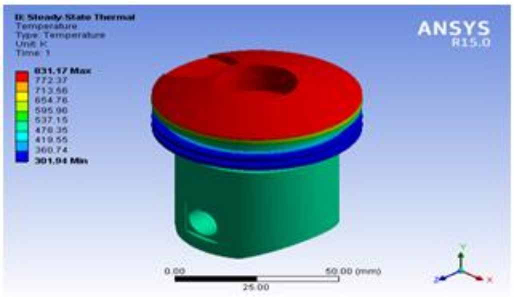

Fig 6.3 Temperature distribution with cast iron

Fig 6.3 shows the temperature distribution of cast iron material of cylindrical head combustion chamber is determined. The maximum value occurs on the head and it is found to be 831 K.

TOTAL HEAT FLUX:

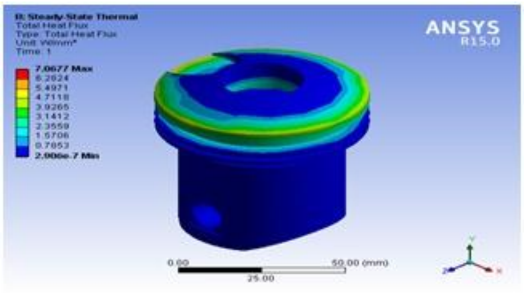

Fig 6.4 Total heat flux distribution

From Fig 6.4 the total heat flux of the model can be determined. It can be observed that the maximum heat flux is 7.06 W/mm2 and minimum value is 0.7853 W/mm2.

THERMAL ERROR

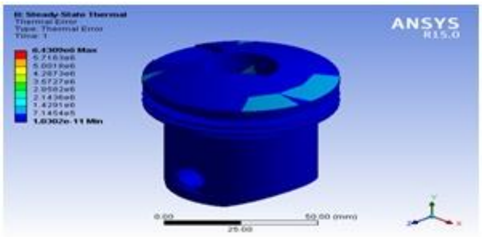

Fig 6.5 Thermal error with cast iron

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From Fig 6.5 the values of thermal errors can be determined. It can be observed that the maximum and minimum thermal values are MAX:7.1454 e5 and MIN:1.032e-11.

TOTAL DEFORMATION

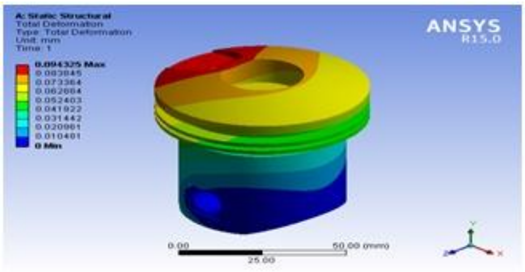


Fig 6.6 Deformation with cast iron

From Fig 6.6 the total deformation of the model can be determined. The maximum and minimum values are found to be MAX:0.094325 mm and MIN:0.010481 mm

VON-MISES STRESS

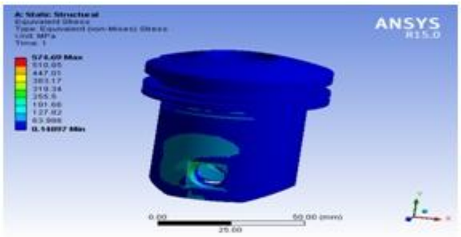


Fig 6.7 Distribution of von-mises stress

From fig 6.7 the stress values of cast iron can be determined. It can be observed that the maximum and minimum values of stress are MAX: 383 MPa and MIN:0.1489MPa

STRAIN

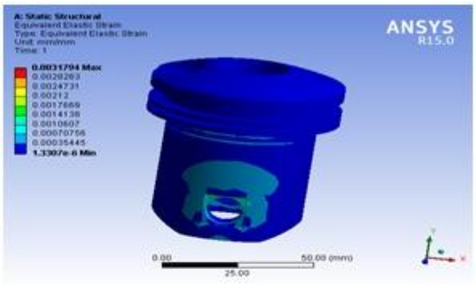
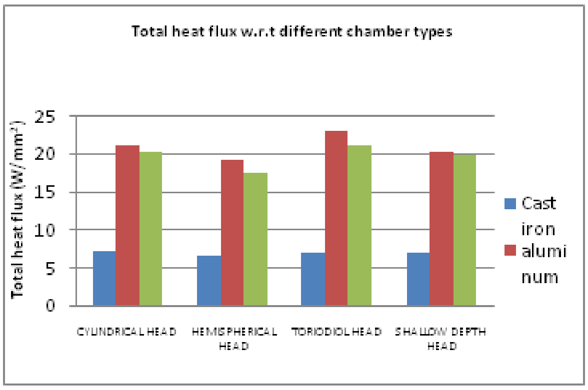


Fig 6.8 Strain with cast iron

From fig 6.8 the strain values for cast iron model can be determined. It can be observed that the maximum and minimum values are MAX:0.00212 and MIN:1.3307e-6.

6.1 RESULT TABLES AND GRAPHS

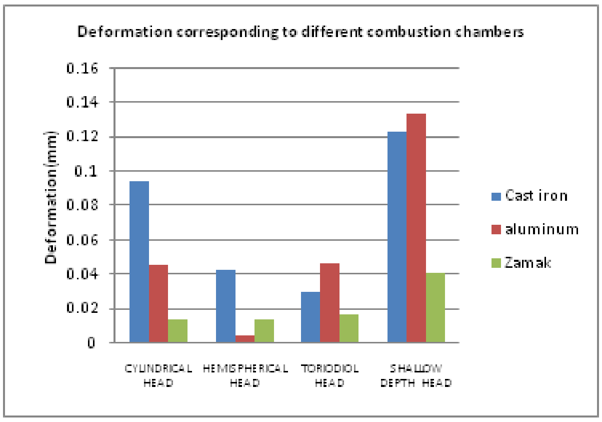
TOTAL HEAT FLUX:



Graph no. 6.11 Total heat flux vs different combustion chambers

Graph 6.11 illustrates that Torroidal type combustion chamber with aluminium LM6 alloy accounted for maximum heat flux of 22.972W/mm2

TOTAL DEFORMATION:



Graph no. 6.12 Deformation vs different types of combustion chamber

Graph 6.12 illustrates that deformation is less for Hemispherical head combustion chamber with aluminium LM6 alloy of 0.004603mm.

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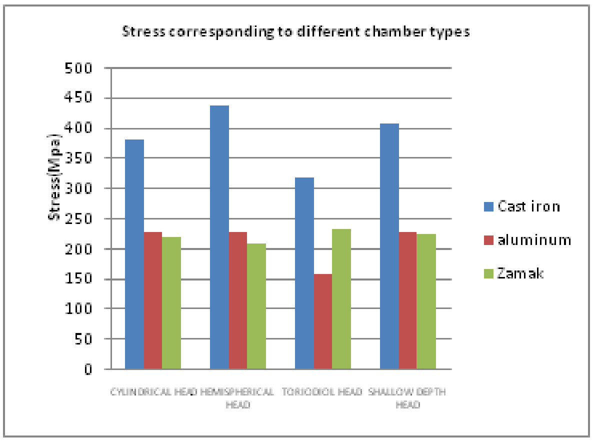
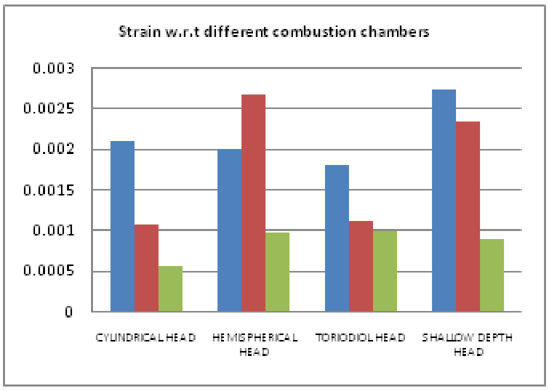
STRESS:



Graph no. 6.13 Stress vs different combustion chambers

Graph 6.13 illustrates that low stress of 160MPa accounted for Torroidal type combustion chamber with aluminum LM6 alloy.

STRAIN:



Graph no. 6.14 Strain vs different types of combustion chambers

Graph 6.14 illustrates that minimum strain of 0.00012597 accounted for Cylndrical combustion chamber with zamak.

THERMAL AND STRUCTURAL ANALYSIS RESULTS

PISTO IN CYLINDRICAL COMBUSTION CHAMBER

	Cast iron	Aluminium LM6	Zamak
Temperature (K)	831	830	853
Total heat flux (W/mm^2)	7.06	21	20.15
Thermal error	7.1454e5	5.2623e6	1.2887e7
Total deformation (mm)	0.094325	0.046089	0.014059
Stress (MPa)	383	229	220
Strain	0.00011066	0.00016573	0.00012597

Table no. 6.15 Cylindrical head combustion chamber results

PISTO IN HEMISPERICAL COMBUSTION CHAMBER

	Cast iron	Aluminium LM6	Zamak
Temperature (K)	831	830	851
Total heat flux (W/mm^2)	6.49	19.21	17.39
Thermal error	1.284e6	4.7499e6	1.131e7
Total deformation(mm)	0.042601	0.004603	0.014043
Stress (MPa)	440	228	210
Strain	0.002012	0.0026892	0.00099188

Table no. 6.16 Hemispherical head combustion chamber results

PISTO IN SHALLOW DEPTH COMBUSTION CHAMBER

	Cast iron	Aluminium LM6	Zamak
Temperature (K)	831	831	838
Total heat flux (W/mm^2)	6.89	20.12	19.69
Thermal error	1.9302e6	5.3075e8	1.602e7
Total deformation (mm)	0.12344	0.13371	0.040744
Stress (MPa)	410	230	225
Strain	0.0027369	0.0023494	0.0008987

Table no. 6.17 Shallow depth combustion chamber results

PISTO IN TORROIDAL COMBUSTION CHAMBER

	Cast iron	Aluminium LM6	Zamak
Temperature (K)	831	830	838
Total heat flux (W/mm^2)	7.0046	22.972	21
Thermal error	2.0783e6	5.1367e6	1.4383e7
Total deformation (mm)	0.030381	0.04701	0.016708
Stress (MPa)	318	160	235
Strain	0.00182184	0.0011187	0.00099817

Table no. 6.18 Torroidal head combustion chamber results

7. CONCLUSIONS:

- Pistons in Combustion chambers plays a vital role in internal combustion engine. The amount of heat that is produced depends upon the shape and size of combustion chamber.

- For improving engine efficiency and performance, combustion chambers of different shapes and sizes are being developed by Vehicle manufacturers to have a lead in the competition.

- In this project four different types of direct injection type combustion chambers are modelled for Tata Indica engine piston.

- Thermal and Structural analysis is being performed on this four types of Pistons in combustion chambers viz. hemispherical , cylindrical , shallow depth and torroidal type combustion chambers with three types of materials i.e. cast iron, aluminium alloy and zamak.

- In Thermal analysis highest temperature of around 830K is found on the top of the piston. Temperature distribution is uniform throughout the piston. Torroidal type combustion chamber with aluminium LM6 alloy gave better temperature distribution compared to other three types of Pistons in combustion chambers.

- Total heat flux gradient is maximum near the piston crown and piston ring areas for all types of combustion chambers. Maximum rate of change of heat energy per unit area accounted for torroidal type chamber for aluminium LM6 alloy.

- Thermal errors are quite low for shallow depth Combustion chamber type for aluminium LM6 alloy.

- In structural analysis pressure of 3.5 MPa is applied on the piston head and fixed supports are attached at the piston pin areas. Total deformation, Elastic strain, Von-mises stress are determined.

- Hemispherical type combustion chamber along with aluminium silicon alloy as material recorded the lowest deformation of 0.004603mm.
- Lowest stress values are recorded for aluminium alloy material with Torroidal type combustion chamber with 160MPa.

- Also the strain values are less for cylindrical combustion chamber for zamak material and it is found to be 0.000581.

- By analyzing the above results aluminium silicon alloy showed better results compared to cast iron and zamak. And also since aluminium has the lowest density and the main consideration is to reduce weight, aluminium LM6 alloy is chosen as the best material.

- By verifying the above results Torroidal type combustion chamber attained better Temperature distribution, high amount of Total heat flux, less Thermal Errors, less stress and strain results compared to the other three types with aluminium LM6 as the material.

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