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Design and Static Structural & Steady State Thermal Analysis of Piston Head Using Ansys

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***Abstract:** The piston is an integral component of the engine that transfers the mechanical work from the heat and pressure released during combustion into usable form. Our project uses Ansys 2021R's static-structural and steady-state thermal analysis methods to examine the piston head under varying loads, boundary conditions, and temperature scenarios. We will be comparing and contrasting the outcomes of three distinct materials: aluminum alloy, 316 stainless steel, and Alsi10Mg. The FUSION-360 program is used to build the 2-D and 3-D CAD models of the piston head. The ANSYS software is used to do the FEA study. In order to enhance the structural and thermal performance of the piston, the aforementioned three materials undergo meshing.*
***Keywords:** Piston head, Static-structural & Steady-state thermal analysis, Aluminium alloy, 316 Stainless steel, Alsi10-Mg, Ansys2021R.*

I. INTRODUCTION

The Piston is a heart of an automobile engine. Piston is one of the most important components in I.C. engine which reciprocates within the cylinder. The main function of the piston of an internal combustion engine is to transfer force from expanding gas in the cylinder to the crank shaft through connecting rod [1].

Following are the main parts of piston
1) Piston Head or crown: It is flat, convex or concave depending on design of combustion chamber. It withstands pressure of gas in the cylinder.
2) Piston rings: It is used to seal the cylinder in order to prevent leakage of gas past the piston.
3) Skirt: It acts as bearing for the side thrust of connecting rod on the walls of cylinder
4) Piston pin: It is also called gudgeon pin or wrist pin. It is used to connect the piston to the connecting rod. [2].

A. Functions

The functions which a piston is called to perform in an IC engine are;
1) To form a seal so that the high strain gases within the combustion chamber do not get away into the crankcase.
2) To serve as a consultant and a bearing for small end of the connecting rod. Aside from its ability to perform the above functions efficaciously the pistons need to have some other fascinating characteristics.
3) The design will have to be such that the seizure does now not occur.
4) It must offer adequate resistance to corrosion because of some other products of combustion.
5) It must have the shortest viable length as a way to cut down overall engine measurement.
6) It must be lighter in weight in order that inertia forces created via its reciprocating motion are minimal.
7) Its fabric will have to have a high thermal conductivity for effective warmth switch in order that bigger compression ratios may be used without prevalence of detonation. [1]

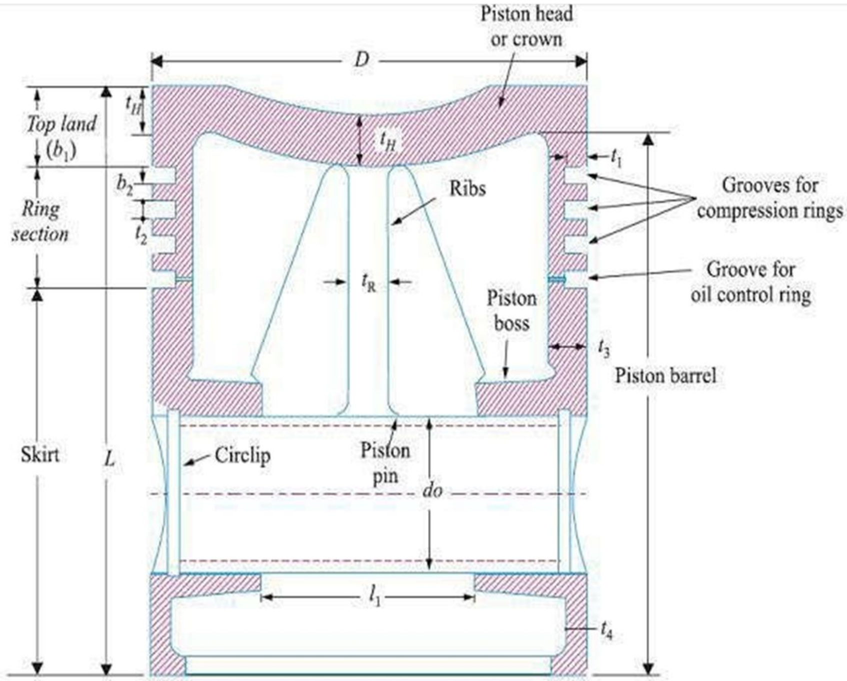

Figure 1: Piston Nomenclature

II. LITERATURE REVIEW

1) Dr. H.C. Thakur et al. [1] conducted a thorough thermal study using ANSYS14.5. They compared pistons with regular geometric length and decreased skirt length, taking into account the surface temperature and heat transfer coefficient as boundary conditions. Finally, as compared to a standard piston, the temperature of the one with the shorter skirt is 10–20 degrees lower. The overall heat flux variation is likewise less in the case of a piston with a shorter skirt than a basic piston.
2) Ekrem Buyukkaya et al. [2] This functionally graded coating research compares the thermal analysis of two distinct materials—AlSi alloy and steel—used in pistons. The comparison was accomplished by comparing the temperature distributions on the surfaces of the uncoated, FGM-coated, Al Si, and steel pistons with those on the uncoated surfaces. The results showed that the functional graded coating raised the maximum surface temperature of the steel pistons by 17% and the AlSi alloy by 28%. As previously observed, the temperature of the AlSi piston surface was 14% lower than that of the steel piston surface
3) The piston is modelled in CATIA V5, according to Manoj Darwai et al. [3]. We transfer the 3D model into ANSYS16.0 for analysis. For the purpose of conducting steady-state thermal and structural analyses using finite element modeling, pistons are constructed from a variety of composite materials, including cast iron, pure aluminum, steel 1008, steel 1020, steel 6061, and Al-SiC-graphite. It can be concluded from the results obtained after applying boundary conditions (Temperature distribution, Heat flux, Stress, Strain) that the Al-Si - Graphite material is best suited for I.C. Engine operations, while the steel 1020 material shows more variation and is thus not suitable.
4) Dadi Kumar Sonar and colleagues [4] Using the design parameters supplied by KIRLOSKAR ENGINE and the CATIA V5R20 software, a piston is developed in this current work. The ANSYS 14.5 software is used to do analysis once the whole design has been imported. In order to conduct structural and thermal analyses on the piston, aluminum alloy was chosen. Presenting and analyzing thermal stress and damages caused by pressure is the focus of this study. We have investigated the factors that impact the piston the most. We have taken notice of your suggestions about the piston's longevity and efficiency.
5) In this study, Xiqun lu et al. [5] use an inverse heat transfer approach to perform thermal numerical analysis on a marine diesel engine's 4-ring articulated piston. The temperature distribution was measured by inserting custom-made metal plugs into the head, skirt, and secondary motion of an articulated piston, as well as the piston ring. The coefficient of heat transfer values was estimated by taking the lubrication oil film into account. In order to measure the temperature of the cylinder, a series of thermal couplings were used. A single ring arrangement was eliminated and the piston head underwent a little redesign. Limitations are imposed.

III. PROPERTIES OF MATERIALS & DESIGN PARAMETERS

Material Properties: The different materials properties of Al alloy, 316stainlesssteel, Alsi10-Mg are mentioned in below table:

S.No.	Properties of Aluminium alloy	Properties of 316 Stainless steel	Properties of Alsi10Mg
1.	Light Weight	Corrosion resistant.	Low Weight & Low cost
2.	High strength-to- weight ratio	High tensile strength	Good weld-ability
3	Ductile at low temperatures	Easy formability	High Strength
4.	Corrosion resistant	Very durable.	Good Electrical Conductivity
5.	Non-toxic	Temperature resistant	Corrosion Resistant
6.	Heat conducting	Low-maintenance	High Wear Resistance

Table 3.1 Material properties

Mechanical Properties of materials:
Mechanical Properties of Aluminium alloy, Stainless Steel(ss316), Alsi10mg:

S.No.	Materials	Tensile Strength (Mpa)	Modulus of Elasticity (Gpa)	Poisson's Ratio	Shear Strength (Mpa)	Melting Point (°C)	Fatigue Strength (Mpa)
1.	Aluminium alloy	395	70	0.33	235	643	125
2.	Stainless steel(ss316)	550	193	0.29	80.2	1400	270
3.	Alsi10Mg	317	71	0.33	185	596	124

Table 3.2 Mechanical properties

Thermal Properties of materials:
Thermal Properties of Aluminium alloy, Stainless steel(ss316), Alsi10Mg:

S.No.	Materials	Thermal Conductivity (W/ m. K)	Thermal Diffusivity (mm^2/s)	Specific Heat capacity (J/ kg. K)	Density (kg/m^3)
1.	Aluminium alloy	170	71.63	879	2700
2.	Stainless Steel(SS316)	16.3	4.38	500	7750
3.	Alsi10Mg	113	43.78	963	2600

Table 3.3 Thermal properties

Engine specifications:

1.Engine type	4-Stroke single cylinder
2.No.of cylinders	1
3.Bore	50mm
4.Stroke	49.5mm
5.Max power & Torque	@8000rpm & @6000rpm
6.Compression Ratio	9.9:1

Design parameters:

PARAMETERS	VALUES in (mm)
Piston diameter	49.5
Piston hole internal diameter	9
Piston hole external Diameter	14
Piston axial thickness	1.9
Piston length	37
Piston radial thickness	2.0
Depth of ring Groove	2.01
Gap between the rings	2.6
Top land thickness	5.6

Table Design parameters

IV. DESIGN PROCESS

A. *Modelling Of Piston Head*

Software used: Auto desk fusion 360

1) *Process of Modelling*

- First set your metric system in mm
- Select 2d plane x axis, from the center draw a line along y axis with the length of 37mm
- And draw the other line perpendicular to y axis line with a length of 49.5mm
- Draw another line perpendicular to the line with a length of 37 mm
- Give the top land thickness as 5.6mm and radial thickness as 2mm

Revolve the drawing using revolve command so that you will be getting 3d model for the design

2) *Making Grooves*

- Hide the solid model and draw a rectangle on previous drawing with the dimension of 2.01 x 2.01 revolve and extrude it to cut the 3d model.
- Now select the rectangular pattern. And select the direction and make 3 grooves withe the distance between them as 2.6
- Fabricate a ring and align in the grooves as a new body

3) *Making Holes*

- Create sketch, select the centre point and draw the circles of dia14mm and 9mm
- Extrude them to cut the piston so that it is used to accommodate piston pin
- And extrude that again as a new join using offset in extrude so that we will be getting the cylindrical joint with a hole which will be of length 10mm inside of the piston
- And finish sketch
- Edit the names of bodies and components as required
- Save the project
- In our project we had selected the two methods namely;
- Static-structural Analysis
- Steady-State Thermal Analysis

B. *Selection of Engineering Data/Materials*

By clicking on the Engineering data icon , we should choose the Engineering Materials for Analyzing the Piston head Model. We can select the materials and their properties based on our analysis method. In our project we had selected three different materials, namely;

- Aluminium alloy
- 316 Stainless Steel
- Alsi10-Mg

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C. Import the Model

After completion of material selection, next step is to import the geometry 3D model of Piston head into Ansys workbench.

D. Setup of the 3D-model

After completion of importing the 3D model, we can Assign the units and also we can edit the model. Each part of the piston head model gets assigned by the different geometry materials for Analyzing based on the different properties of materials. All of the components in the model must have their materials assigned to them.

E. Meshing

Meshing the model will divide the large component into small elements and nodes, which will make the component easy and convenient to perform the analysis.

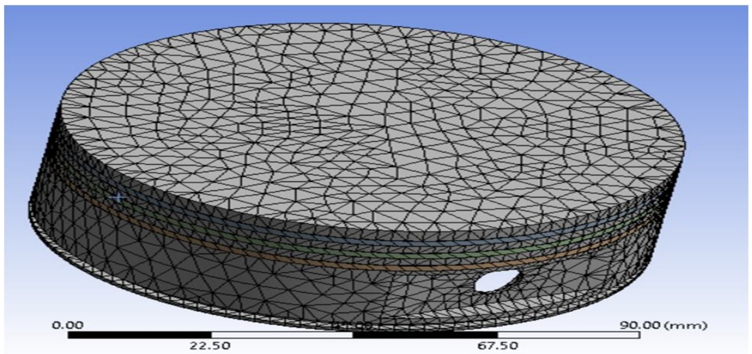

Fig Meshing

1) Display type = Element Quality
2) Physical preferences = Mechanical
3) Element size = 2.35mm
4) Span angle Centre = Fine
5) Smoothing = Medium
6) No. of Nodes = 41063
7) No. of Elements = 20431
8) Element Type = Triangular

F. Applying Boundary Conditions in Structural and Thermal Analysis Methods

Force, pressure, and temperature are the primary loading conditions in finite element analysis. Elements, surfaces, edges, nodes, and points may all benefit from these. In our project of Analysis on Piston head in Structural Method, the boundary parameters are Pressure and Fixed Support.

In case of Steady-state Thermal analysis, the boundary conditions involved for study of heat dissipation and heat flux rate are as follows;

Ambient temperature, Temperature, Convection are applied on the surface of the piston head parts.

G. Solution & Results

After giving the boundary conditions, we solve the model. In solution we should add the parameters or Factors which we want as the Results.

In case of Structural analysis method:

Solution<Insert<Total Deformation<Equivalent Elastic Strain<Equivalent (Von- mises) Stress

In case of Steady-state thermal analysis method:

Solution<Insert<Temperature<Total Heat Flux

Finally, after completing the Input Parameters of solution we click on the Solve to generate the Analytical Results

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V. STATIC-STRUCUTRAL RESULTS WITH DIFFERENT MATERIALS

A. Aluminium alloy

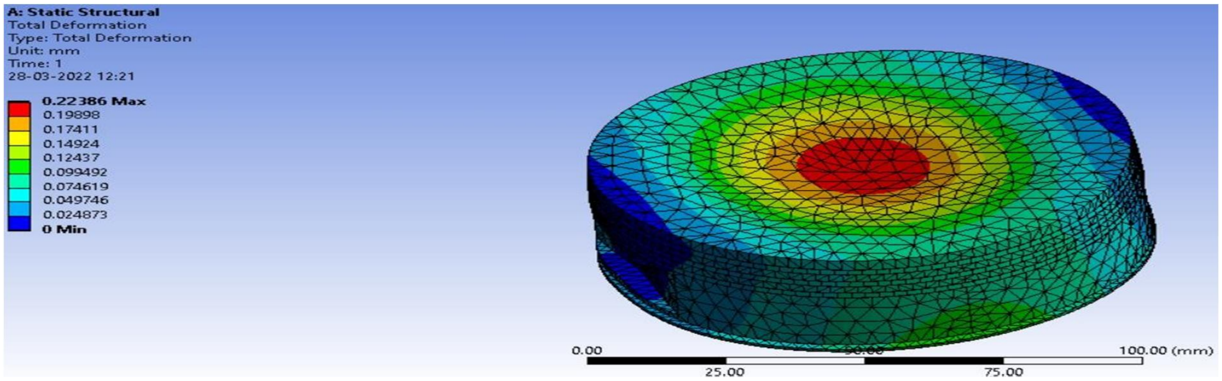

Fig Total deformation of Al alloy

The structural result for Aluminium alloy consists of the Maximum deformation value is 0.22386 mm and minimum value is 0 mm.

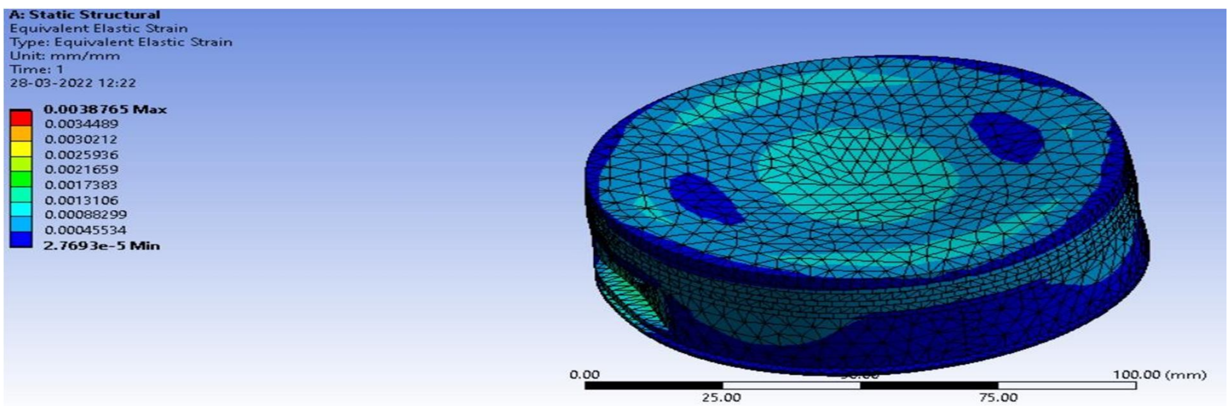

Fig Equivalent Elastic Strain of Al alloy

The structural result for Aluminium alloy consists of the Maximum Equivalent Elastic Strain(e) value is 0.0038765 and minimum value is 2.7693e-5

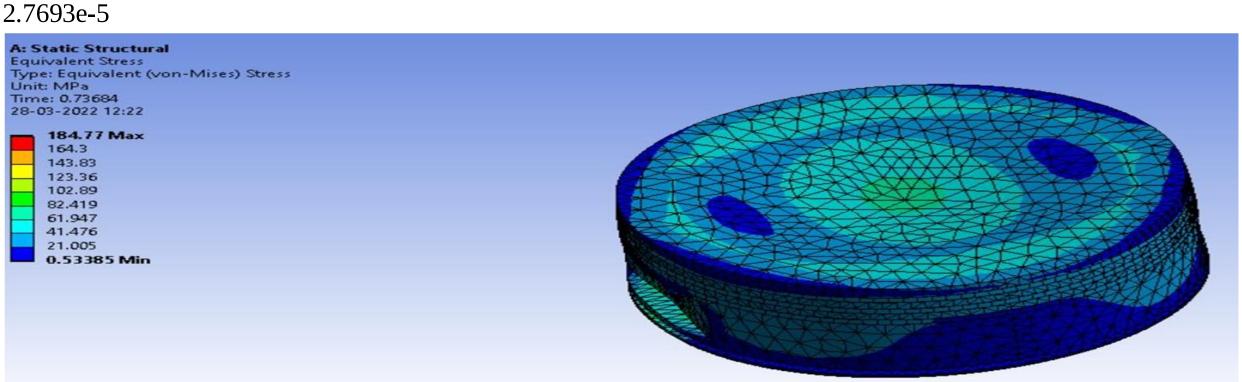

Fig Equivalent Stress of Al alloy

The structural result for Aluminium alloy consists of the Maximum Equivalent Stress value is 184.77 Mpa and minimum value is 0.533 Mpa.

B. 316 Stainless Steel

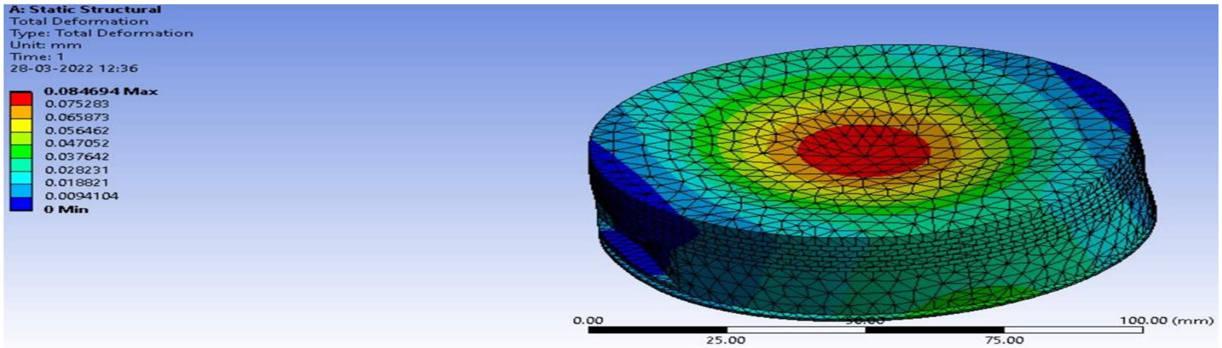

Fig Total deformation of 316Stainless steel

The structural result for 316 Stainless steel consists of the Maximum deformation value is 0.084694 mm and minimum value is 0 mm.

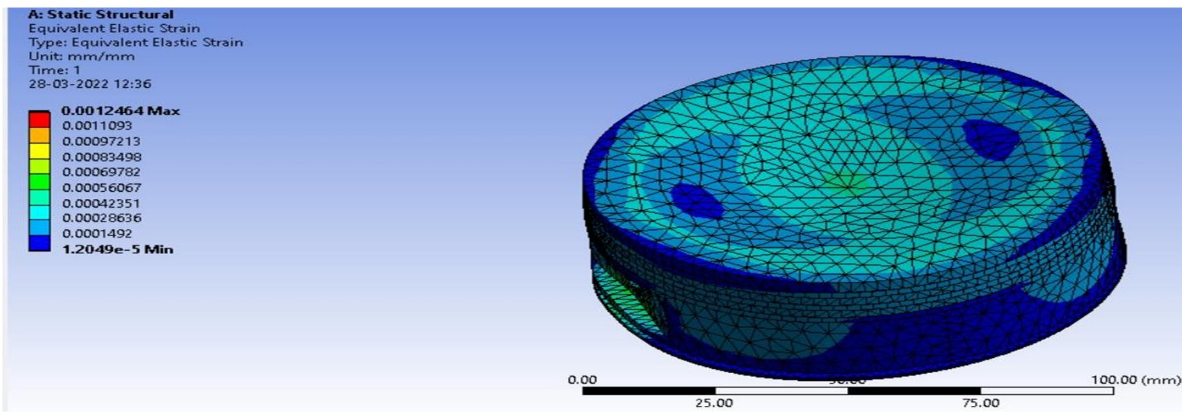

Fig Equivalent Elastic Strain of 316Stainless steel

The structural result for 316 Stainless steel consists of the Maximum Equivalent Elastic Strain(e) value 0.0012464 and minimum value is 1.2049e-5.

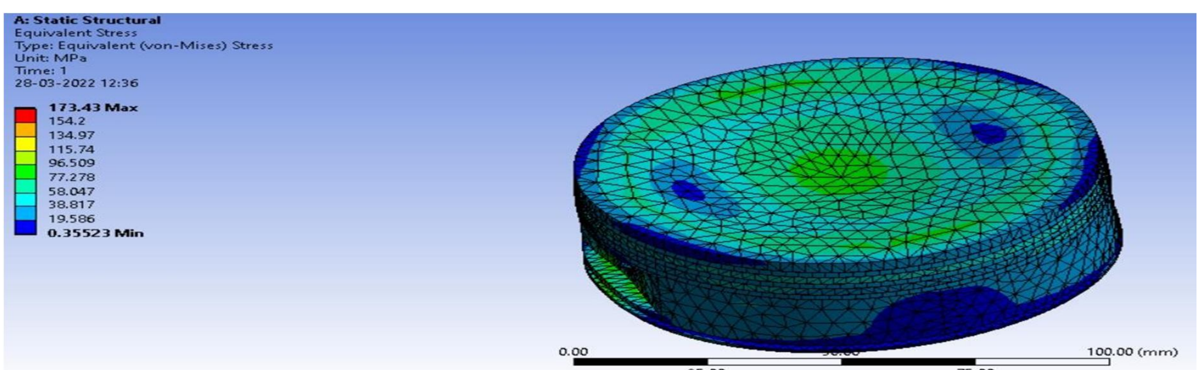

Fig Equivalent Stress of 316Stainless Steel

The structural results for 316 Stainless steel consists of maximum Equivalent Stress value of 173.43 Mpa and Minimum value of 0.35523 Mpa

C. Alsi10-Mg

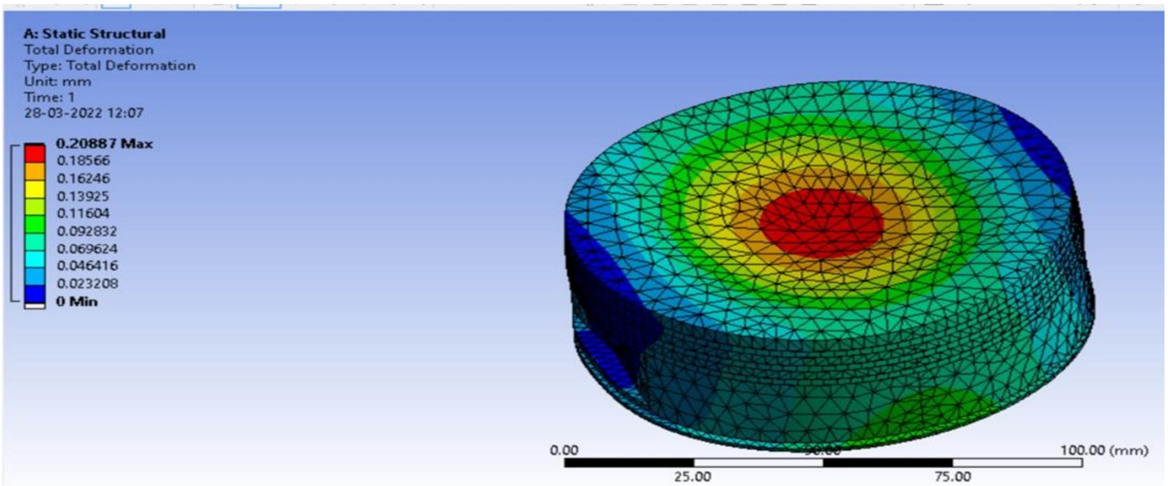

Fig Total deformation of Alsi-10Mg

The structural result for Alsi10-Mg consists of the Maximum deformation value is 0.20887 mm and minimum value is 0 mm

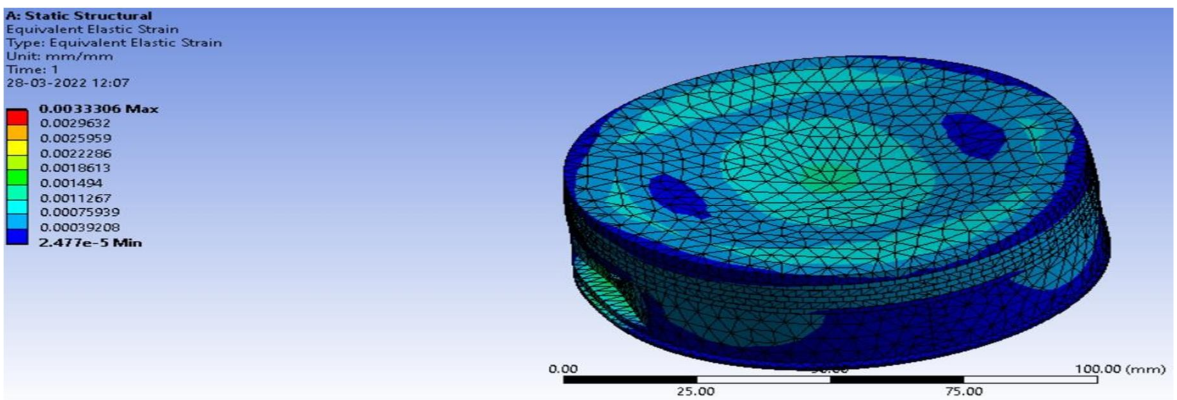

Fig Equivalent Elastic Strain of Alsi10-Mg

The structural result for Alsi10-Mg consists of the Maximum Equivalent elastic Strain(e) value 0.0033306 and minimum value is 2.477e-5.

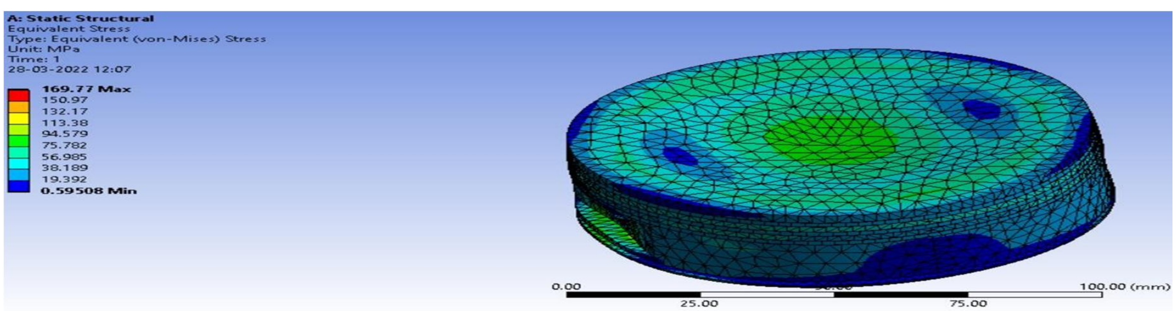

Fig Equivalent Stress of Alsi10-Mg

The structural results for Alsi10-Mg consists of maximum Equivalent Stress value of 169.77 Mpa and Minimum value of 0.59508 Mpa

D. Steady-State Thermal Results With Different Materials

1) Aluminium alloy

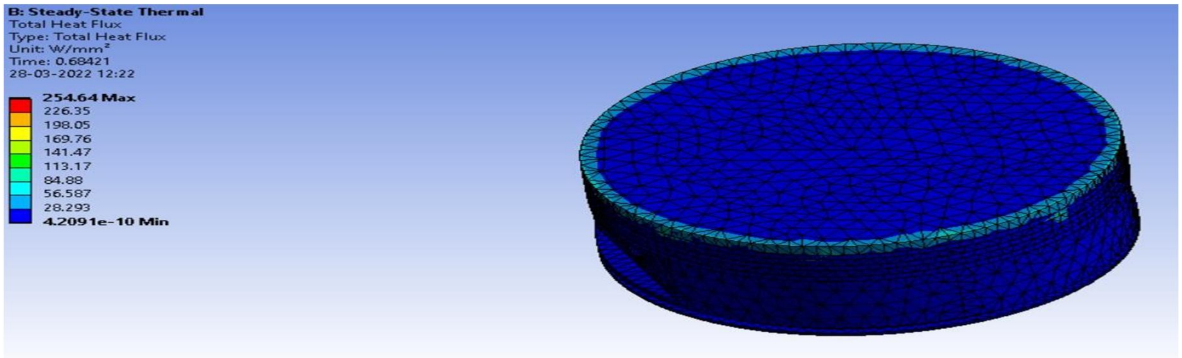

Fig Total Heat Flux of Al alloy

The maximum total heat flux value for aluminium alloy is 254.64 W/mm^2 and minimum value is 4.2091e-10 W/mm^2.

2) 316Stainless Steel

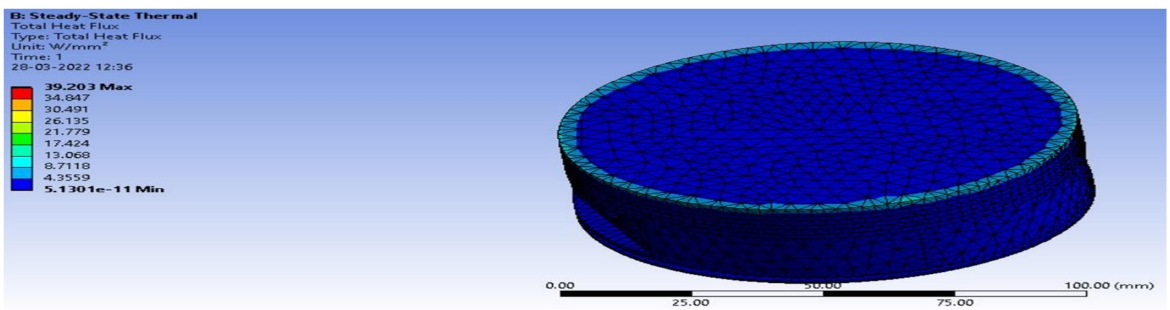

Fig Total heat Flux of 316 Stainless Steel

The maximum total heat flux value for 316 Stainless steel is 39.203 W/mm^2 and minimum value is 5.1301e-11 W/mm^2.

***3)* Alsi-10Mg**

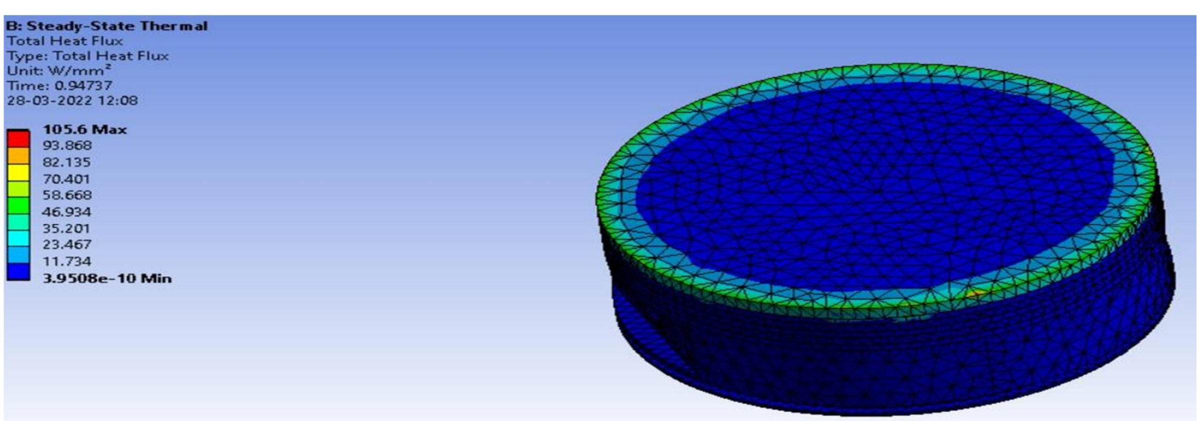

Fig Total Heat Flux of Alsi10-Mg

The maximum total heat flux value for Alsi10-Mg is 105.6 W/mm^2 and minimum value is 3.9508e-10 W/mm^2.

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VI. RESULTS

A. *Comparision Of Theoritical And Analytical Results Of Piston Head*

1) *Theoretical Results*

S.No.	Materials	Deformation (mm)	Strain	Stress (Mpa)
1	Aluminium alloy	0.09802	0.002649	185.44
2	316 Stainless steel	0.03326	0.000898	173.50
3	Alsi19Mg	0.08881	0.00243	170.4

Table Theoretical results

2) *Analytical Results*

S.No.	Materials	Deformation (mm)	Strain	Stress (Mpa)
1	Aluminium alloy	0.22386	0.00387	184.77
2	316 Stainless steel	0.08469	0.00124	173.43
3	Alsi19Mg	0.20887	0.00333	169.72

Table Analytical results

B. *Analytical Results Of Structural And Thermal Analysis Of Piston Head*

S.No.	Materials	Deformation (mm)	Strain	Stress (M pa)	Total Heat Flux(W/mm^2)
1.	Aluminium alloy	0.22386	0.00387	184.77	254.64
2.	316 Stainless Steel	0.08469	0.00124	173.43	39.203
3.	Alsi10Mg	0.20887	0.00333	169.72	102.60

Table 7.3 Analytical results of Structural and Thermal results

C. *Graphical Results Of Structural And Thermal Analysis Of Piston Head*

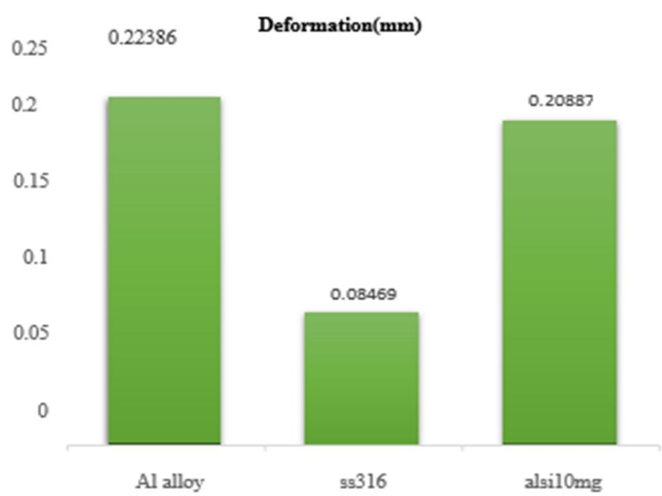

Fig Graphical result of Deformation

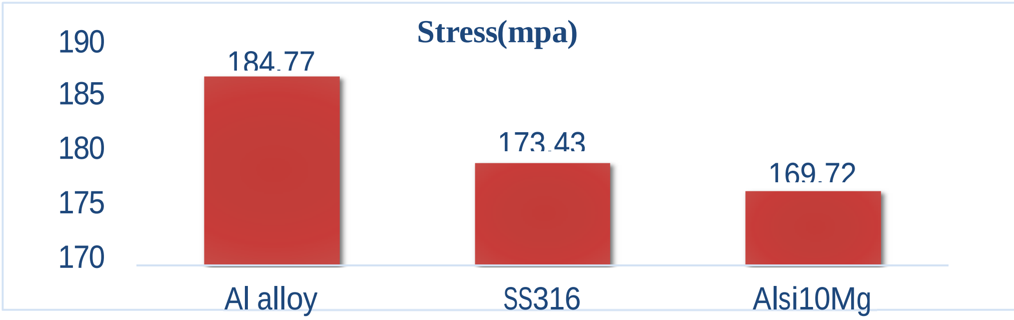

Fig Graphical result of Stress

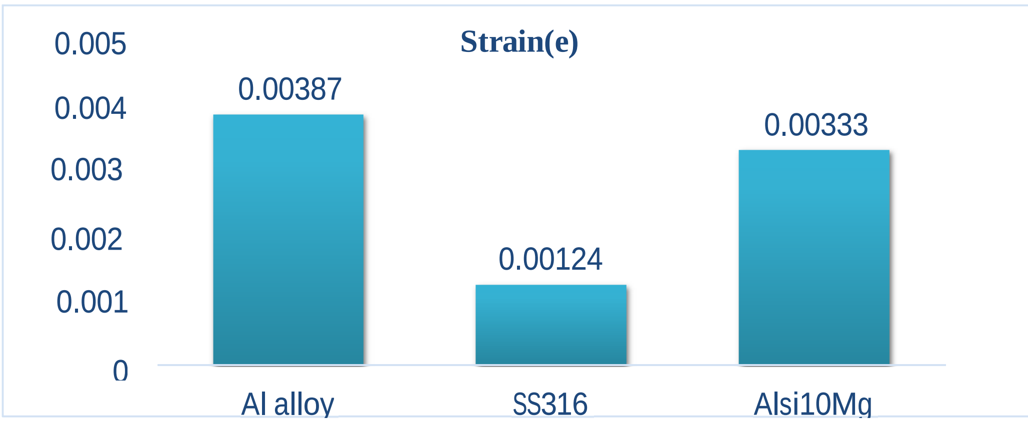

Fig Graphical result of Strain

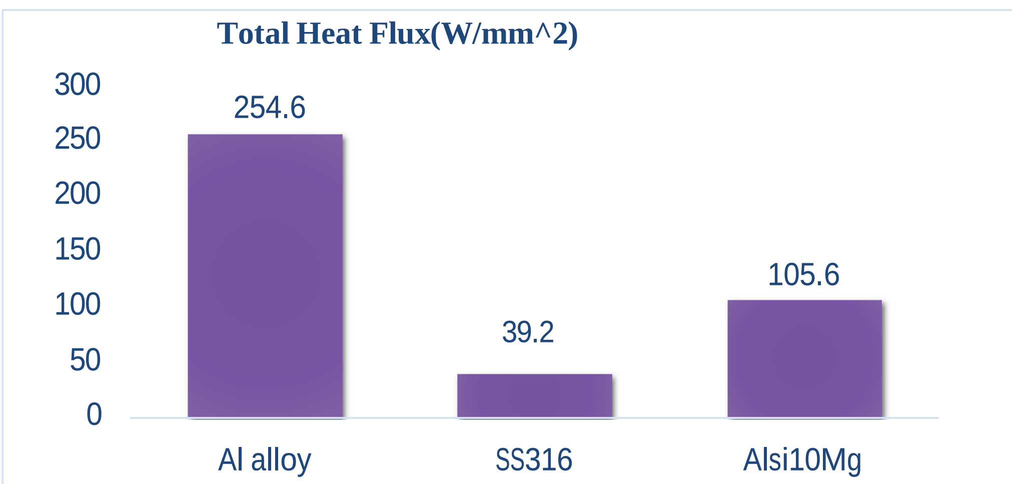

Fig Graphical result of total heat flux

VII. CONCLUSION

1) The piston head undergoes on different load, boundary conditions, thermal conditions analysis by three different materials.
2) Meshing is done on piston material for improving the element quality and to analyze the finite particles of material.
3) Static-Structural and Steady-state thermal analysis is done and the results are plotted in above table.
4) By evaluating and comparing the deformation, stress, total heat flux parameters results on three materials, it is concluded that 316Stainless steel is having low deformation value and low heat flux value. Aluminium alloy and Alsi10mg are having high deformation, stress and heat flux compare to SS316 material.

5) Low deformation indicates the longer life span for a material and low heat flux materials increases chances of reducing heat losses during combustion in IC engines.
6) Reduced heat transfer causes the exhaust gas temperature to rise, which in turn boosts the engine's work output and thermal efficiency.
7) Finally, we can conclude that 316Stainless steel material can also be suggested for piston manufacturing. which helps in reducing heat losses and increase in thermal efficiency. In point of Perspective of having good thermal conditions and properties SS316 material can also be suitable for piston production.

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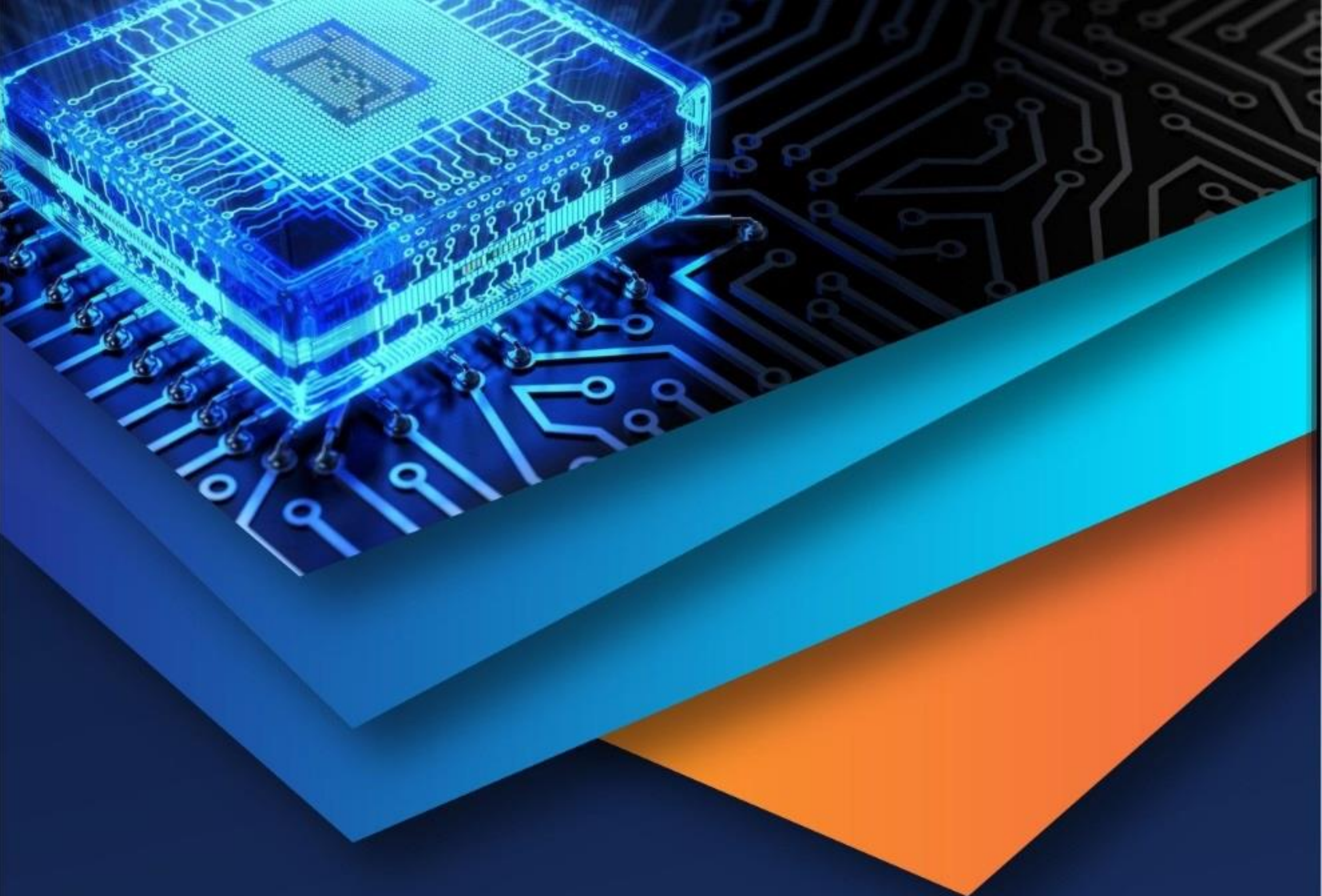

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