Design, Modeling and Analysis of Real Time Piston with Different Materials

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***Abstract*—This paper focuses on the design, material selection, and thermal-structural analysis of an internal combustion engine piston to determine the most efficient combination of strength, heat dissipation, and deformation resistance. Fourteen piston diameters were analyzed using three materials Aluminum Alloy 2618, Aluminum Alloy 4032, and AISI 4340 Steel to evaluate the influence of geometry and material on performance. Using ANSYS Workbench, both steady-state thermal and static structural analyses were performed to assess temperature distribution, heat flux, stress concentration, and deformation under realistic loading. The results revealed that Aluminum Alloy 2618 offers the best balance between lightweight design and effective heat dissipation, Aluminum Alloy 4032 provides improved wear resistance, and AISI 4340 steel ensures superior strength with minimal deformation but higher weight. The study concludes that optimized piston design significantly enhances engine efficiency, durability, and thermal stability, and recommends future work on transient thermal, fatigue life, CFD-based analysis, experimental validation, and topology optimization for developing advanced lightweight and high-performance pistons.**

***Index Terms*—Internal Combustion Engine, Piston, Aluminum Alloy, Finite Element Method (FEM), ANSYS Workbench, Catia V5**

I. INTRODUCTION

The piston is one of the most critical components of an internal combustion (IC) engine, responsible for converting the energy generated during the combustion of fuel and air into useful mechanical power. It operates in a reciprocating motion inside the engine cylinder, transmitting force through the connecting rod to the crankshaft, thereby producing rotational motion. During this process, the piston is continuously subjected to extreme thermal and mechanical stresses caused by high combustion temperatures, gas pressures, and dynamic loading. These conditions demand that the piston possess high strength, excellent thermal conductivity, low density, and good wear resistance to ensure efficient and reliable engine performance.

In modern engine design, piston optimization plays a vital role in improving fuel efficiency, durability, and emission control. Material selection, geometry, and thermal management directly influence the performance and lifespan of the piston. Traditionally, aluminum alloys have been widely used due to their lightweight nature and superior heat dissipation properties, while steel and advanced composite materials are employed in high-load and high-performance engines for their superior strength and fatigue resistance.

The design of a piston must achieve an optimal balance between structural integrity, weight reduction, and thermal performance. With the advancements in computational tools such as Finite Element Analysis (FEA) using ANSYS, engineers can now perform detailed thermal and structural simulations to predict temperature distribution, stress concentration, and deformation under realistic operating conditions. These simulations help in identifying the most suitable material and geometry for efficient heat transfer and minimal mechanical failure.

Therefore, the present study focuses on the design, analysis, and optimization of an IC engine piston by considering different materials and piston diameters. The objective is to determine the best piston configuration that offers maximum strength, effective heat dissipation, and minimum deformation, thereby enhancing overall engine efficiency, reliability, and performance.

II. LITERATURE REVIEW

Dilip Kumar Sonar et al. [1] investigated the thermal and mechanical stress distribution in engine pistons under real operating conditions. The results showed that thermal stresses contribute more significantly to piston failure than mechanical stresses, emphasizing that thermal effects dominate piston durability. The study suggests that design optimization should primarily focus on reducing thermal loads, while improvements in material selection and manufacturing can further enhance piston performance and resistance to fatigue.

M. Srinadh and K. Rajasekhara Babu [2] designed and analyzed a 1300cc diesel engine piston with three different ring profiles using Creo and ANSYS Workbench. Materials such as Cast Iron, Aluminum Alloy A360, and Zamak were compared for structural and thermal performance. The results indicated that Zamak showed the lowest deformation and highest heat flux, proving to be the best material. Among the ring profiles, the semicircular face ring exhibited the best deformation and strain behavior.

S. Srikanth Reddy and Dr. B. Sudheer Prem Kumar [3] performed thermal and structural analysis of an aluminum-silicon piston with and without zirconium coating using CATIA and ANSYS. The coated piston showed a significant reduction in maximum stress (from 85 MPa to 55 MPa) and deformation (from 0.0517 mm to 0.0258 mm), improving stiffness and durability. The study also recommended using DOE-based parametric optimization in ANSYS for better reliability.

Ch. Venkata Rajam et al. [4] carried out the design and optimization of a diesel piston using CATIA and ANSYS, achieving reductions in piston volume (24%), barrel thickness (31%), and ring land width (25%). Although Von Mises stress increased by 16%, it remained within safe limits. The results confirmed that ceramic coating and geometry optimization improved the piston's structural and thermal performance.

Manisha B. Shinde et al. [5] analyzed pistons made from Al-Alloy A2618, Al-GHY1250, and Al-GHS1300 using Creo and ANSYS to assess total deformation and equivalent stress under high-pressure conditions. All materials met safety limits, but Al-GHS1300 displayed the lowest stress and deformation, making it the most suitable for high-temperature applications.

Ajay Raj Singh and Dr. Pushpendra Kumar Sharma [6] evaluated A2618, A4032, and Al-GHS1300 pistons using ANSYS 12.1 for a four-stroke Bajaj Kawasaki engine. Results revealed Al-GHS1300 had the lowest weight, stress, and volume, achieving a factor of safety of 6, proving it to be the best for high-performance applications.

K.E. Viany Kumar et al. [7] studied heat transfer and thermal stresses in a V-type multi-cylinder engine using CATIA and ANSYS. Among materials analyzed, FU 4270 carbon showed lower thermal stress and better temperature distribution than aluminum and FU 2451, making it suitable for improved heat management.

Shahanwaz Adam Havale and Prof. Santosh Wankhade [8] analyzed the thermal behavior of aluminum alloy pistons using ANSYS with a thermo-mechanical decoupled FEM. The Special Eutectic Alloy (AISi18CuMgNi) exhibited the most favorable results, with moderate stress (94.07 MPa), minimal strain, and efficient heat flow, proving ideal for high-performance pistons.

Ajay et al. [9] conducted transient thermal analysis of diesel pistons made from various materials using ANSYS, finding that AlSi pistons experienced the maximum heat flux (3.04×10^6 W/m²), while cast iron pistons showed the lowest. The study emphasized that material selection is crucial for piston durability under high thermal stress.

Anup Kumar Shetty et al. [10] performed a comparative analysis of pistons made from A2618, A4032, AL-GHS1300, and Ti-6Al-4V using CATIA and ANSYS Workbench. The A4032 alloy exhibited the lowest von Mises stress (187.23 MPa) and least deformation, making it the most efficient material due to its balance of strength, stress resistance, and dimensional stability.

III. MATERIAL SELECTION

1. Material Aluminum Alloy 2618

Elastic modulus = 74.5 GPa
Ultimate tensile strength = 441 MPa
Yield strength = 372 MPa

Poisson ratio = 0.33
Thermal conductivity = 146 W/M-C
Density = 2760 kg/m^3

2. Material Aluminum Alloy 4032

Elastic modulus = 80 GPa
Ultimate tensile strength = 380 MPa
Yield strength = 315 MPa
Poisson ratio = 0.33
Thermal conductivity = 155 W/M-C
Density = 2690 kg/m^3

3. Material Aluminum Alloy 4340

Ultimate tensile strength = 745 MPa
Yield strength = 470 MPa
Poisson ratio = 0.33
Thermal conductivity = 44.5 W/M-C
Density = 7850 kg/m^3

IV. DESIGN OF THE PISTON

Mechanical efficiency of the engine (η) = 80 %.
η = Brake power (B.P.)/Indicating power (I.P.)
B.P. = 2πNT/60 = 2π*4020*245/ (60*1000) = 103.138 kW
Therefore, I.P. = B.P./η = 103.138/0.8 = 128.922 kW
Also, I.P. = P*A*L*N/2 = P*π/4*D2*L*N/2
128.922*1000=P*π/4*(0.095)2*(0.095) *(4020)/(2*60)
So, P = 57.15*105 N/m2 or P = 5.715 MPa Maximum Pressure (pmax) = 10*P = 10*5.715 = 57.15 MPa

V. ANALYTICAL DESIGN CALCULATION

1. Thickness of piston head (th)
th = D√((3*Pmax)/ (16 * σt))
σt = permissable tensile stress of the piston material = 176.4 MPa
th = 95√ (3× 57.15)/ (16×176.4) = 23.4144mm
2. Radial thickness of the ring (t1)
t1 = D√ ((3× P) / σt)
p = Pressure of gas on the cylinder wall in = 0.033 N/mm2
σt = allowable tensile stress of the piston material = 148.8 MPa
t1 = 95√ (3× 0.33) /148.8 3 = 2.4504 mm
3. Axial thickness of the ring (t2)
t2 = D / 10×n mm
n = Number of rings = 3
t2 = 95 10×3 mm = 3.166 mm
4. The maximum thickness of the piston barrel (t3)
t3 = 0.03 D + t1 + 4.9 mm
t3 = (0.03 * 95) + 2.4504 + 4.5 = 10.2004 mm
5. Width of the top land (b1)
b1=1* th to 1. 2 * th mm
b1 = 1 * 23.4144 = 23.4144 mm
6. Width of other ring lands (b2)
b2 = 0.75 * t2 to t2 mm
b2 = 0.75 * 3.1666 = 2.3749 mm
7. piston wall thickness t4
t4 = 0.25*t3 to 0.35* t3 mm
t4 = 0.25 * 10.2004 = 2.5501 mm
8. Outside diameter of the piston pin do
do = 0.28*D to 0.38*D
do = 0.28 * 95 = 26.6 mm
9. Inside diameter of the piston pin di
di = 0.6* do mm
di = 0.6 * 26.6 = 15.96 mm
10. Length of the piston pin (L1)
L1 = 0.45*D mm
L1 = 0.45 * 95 = 42.75 mm
11. Length of the skirt (Ls)
Ls = 0.6*D mm
Ls = 0.6 * 95 = 57 mm
12. Length of the rings (Lr)
Lr = 2b2+3t2 mm
Lr = 2 * 2.375 + 3 * 3.166 = 14.2497 mm
13. Length of the piston (L)
L = Ls + Lr +b1 mm
L = 57 + 14.2497 + 23.4144 = 94.664 mm

Table 1: Dimensions of the piston

Parameter	Values (mm)		
	2618	4032	4340
(t_h)	23.4144	25.2238	18.0145
(t_1)	2.4504	2.6629	2.1880
(t_2)	3.1666	3.1666	3.166
(t_3)	10.2004	10.4129	9.93
(t_4)	2.5501	2.6032	2.4825
(b_1)	23.4144	25.2238	18.0145
(b_2)	2.3749	2.3749	2.3749
(d_o)	26.6	26.6	26.6
(d_i)	15.96	15.96	15.96
(l_1)	42.75	42.75	42.75
(L_s)	57	57	57
(L_r)	14.2497	14.2496	14.2496
(L)	94.6644	96.4734	89.2641

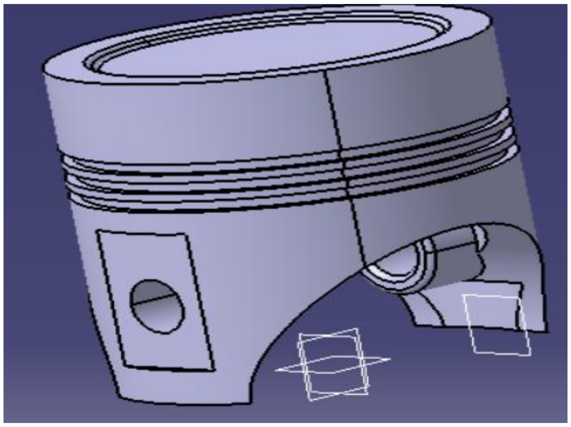

Fig1: Piston

VI. STEADY STATE THERMAL ANALYSIS

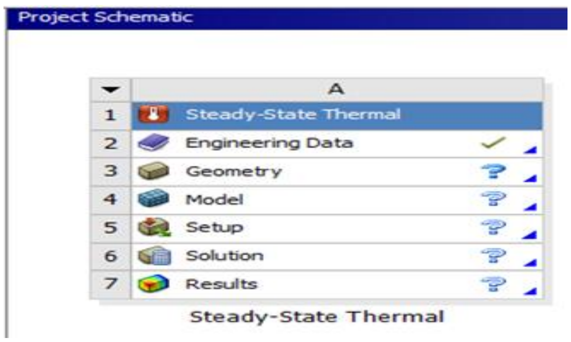

Fig2: Steady state thermal analysis

Now double click on the engineering data in that we add my new material 2618, 4032, 4340 in a library. Now add the new material to the library, Now the all properties of that material are assigned to the material. Now select that material to the piston

a. Thermal Analysis Of 95 Mm Diameter And 95 Mm Stroke Length Of 2168

in earlier I had created a material of the 2618, and now select that material to the piston

And now right click on the geometry click on import and select the design model of the piston that I must draw in the catia v5 software of 95mm diameter and 95mm stroke length piston

Now right click on the model and click on the edit now opened a window of analysis

After that first I must assign the material to the design

Now I am giving mesh element size that 3 mm and click on the generate the mesh

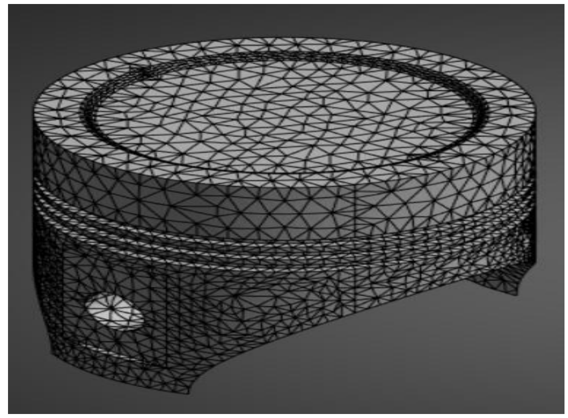

Fig 3: Meshing of the design piston 92mm

Now I can apply the boundary conditions to the design of the piston diameter 95mm and stroke length is 95 and engine cc 2695. The below figure 4says that applying a temperature to top of the piston is 400°C and convection to piston is 183.19w/m$^{2°}$C as shown in the below figure 5.

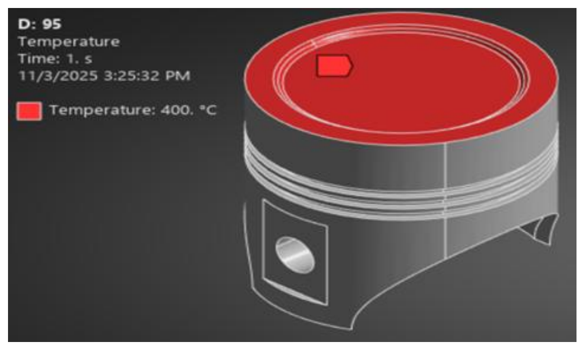

Fig 4: Apply temperature 95 mm

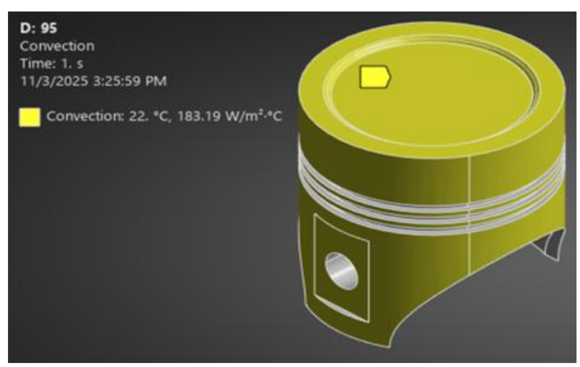

Fig 5: Apply convection 95mm

The below figure are the results of the piston diameter 95mm and stroke length 95mm and engine cc 2695 the first figure 6 is the temperature distribution of the piston and the second figure 7 piston is the total heat flux of the piston.

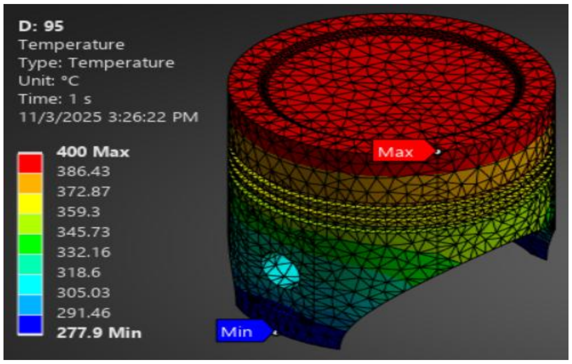

Fig 6: Temperature distribution 95mm

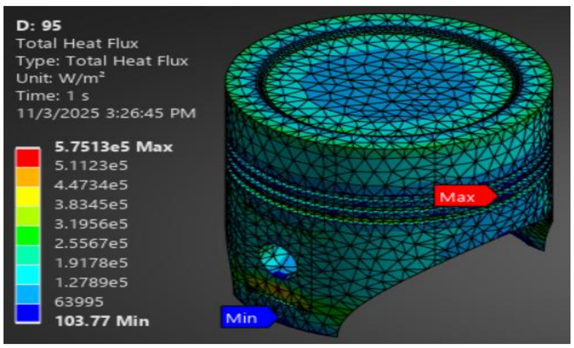

Fig 7: Total heat flux 95mm

b. Thermal Analysis Of 95 Mm Diameter And 95 Mm Stroke Length Of 4032

in earlier I had created a material of the 4032, and now select that material to the piston

And now right click on the geometry click on import and select the design model of the piston that I must draw in the Catia v5 software of 95mm diameter and 95mm stroke length piston

Now right click on the model and click on the edit now opened a window of analysis

After that first I must assign the material to the design

Now I am giving mesh element size that 3 mm and click on the generate the mesh

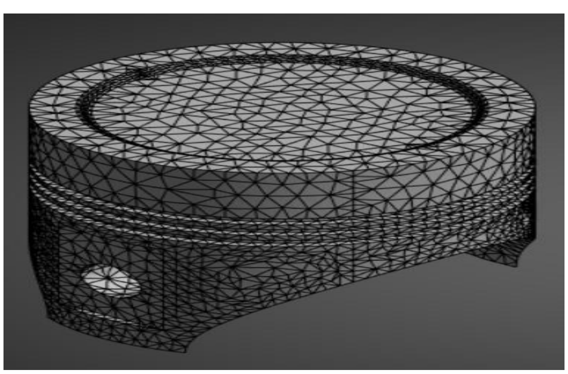

Fig 8: Meshing of the design piston 92mm

Now I can apply the boundary conditions to the design of the piston diameter 95mm and stroke length is 95 and engine cc 2695. The below figure 9 says that applying a temperature to top of the piston is 400°C and convection to piston is 178.63w/m$^{2°}$C as shown in the below figure 10.

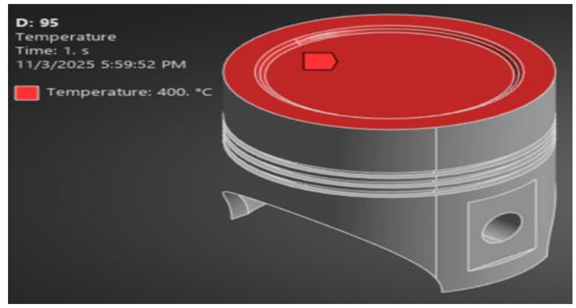

Fig 9: Apply temperature 95mm

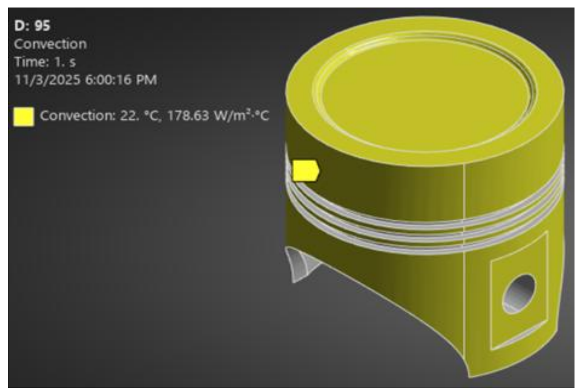

Fig 10: Apply convection 95mm

The below figure are the results of the piston diameter 95mm and stroke length 95mm and engine cc 2695 the first figure 11 is the temperature distribution of the piston and the second figure 12 piston is the total heat flux of the piston.

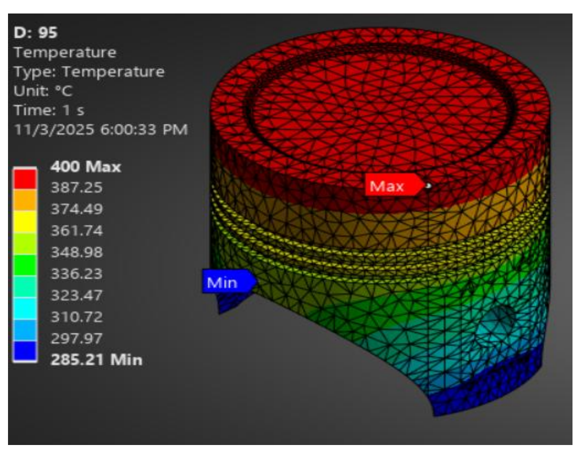

Fig 11: Temperature distribution 95mm

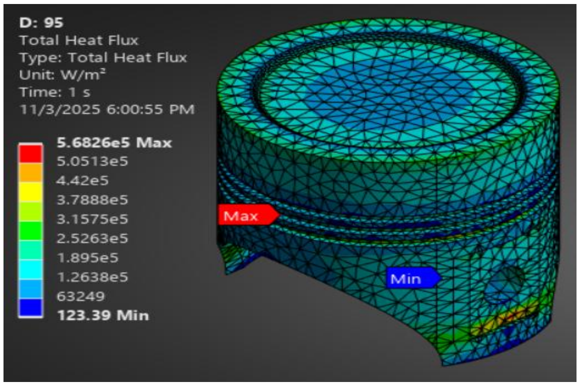

Fig 12: Total heat flux 95mm

c. Thermal Analysis Of 95 Mm Diameter And 95 Mm Stroke Length Of 4340

in earlier I had created a material of the 4340, and now select that material to the piston

And now right click on the geometry click on import and select the design model of the piston that I must draw in the Catia v5 software of 95mm diameter and 95mm stroke length piston

Now right click on the model and click on the edit now opened a window of analysis

After that first I must assign the material to the design

Now I am giving mesh element size that 3 mm and click on the generate the mesh

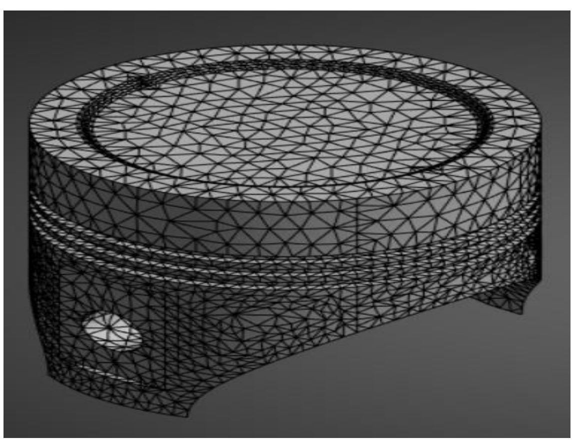
Fig 13: Meshing of the design piston 92mm

Now I can apply the boundary conditions to the design of the piston diameter 95mm and stroke length is 95 and engine cc 2695. The below figure 14 says that applying a temperature to top of the piston is 400°C and convection to piston is 193.05w/m^2°C as shown in the below figure 15.

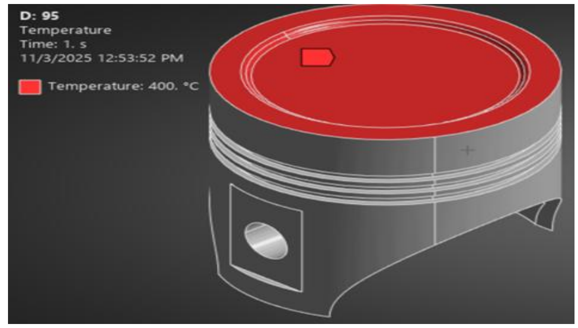

Fig 14: Apply temperature 95mm

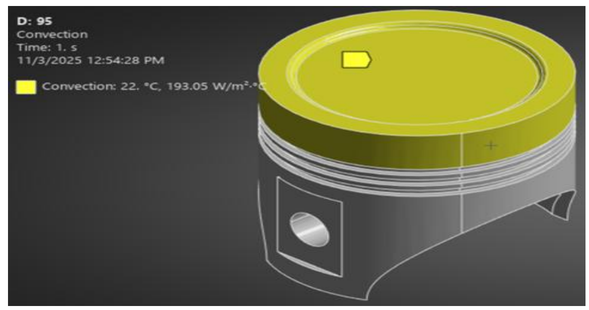

Fig 15: Apply convection 95mm

The below figure are the results of the piston diameter 95mm and stroke length 95mm and engine cc 2695 the first figure 16 is the temperature distribution of the piston and the second figure 17 piston is the total heat flux of the piston.

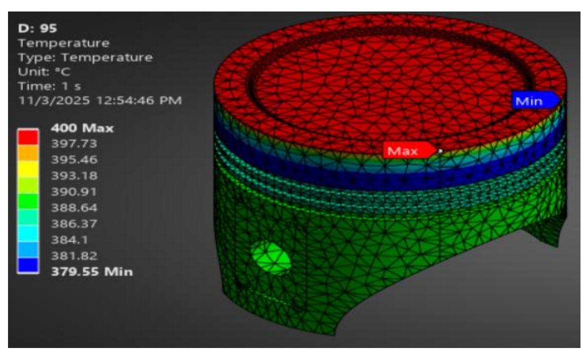

Fig 16: Temperature distribution 95mm

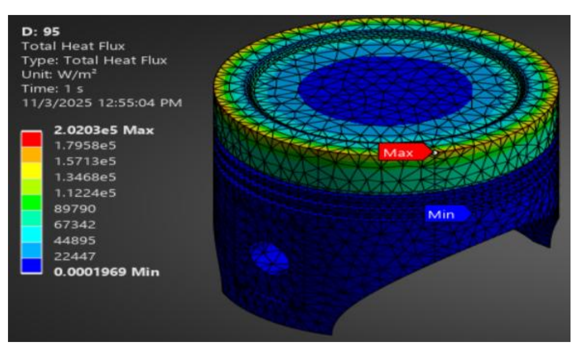

Fig 17: Total heat flux 95mm

VII THEORETICAL CALCULATION

This theoretical calculation is used for compare the results with the help of ANSYS results

The formula for theoretical calculation $q = k ((T1 - T2)/t)$ W/m^2

Where q is total heat flux

K is the thermal conductivity of the material

T1 the temperature of the piston at piston head = 400°C

T2 is the initial temperature = 22°C

T is height of the piston

Example calculation: k = 146 W/m^2

$q = 146 ((400 - 22)/(91.7082*10^{-3})) => q = 601778.2488$ W/m^2

Table2: Theoretical calculation of heat flux

material	Diameter of the piston mm	Temperature distribution °C	Total heat flux W/m^2
2618	95	400	582985.7898
4032	95	400	607319.5533
4340	95	400	188440.8178

VIII STRUCTURAL ANALYSIS

a. Structural Analysis Of 95 Mm Diameter And 95 Mm Stroke Length Of 2618

in earlier I had created a material of the 2618, and now select that material to the piston

And now right click on the geometry click on import and select the design model of the piston that I must draw in the Catia v5 software of 95mm diameter and 95mm stroke length piston

Now right click on the model and click on the edit now opened a window of analysis

After that first I must assign the material to the design

Now I am giving mesh element size that 3 mm and click on the generate the mesh

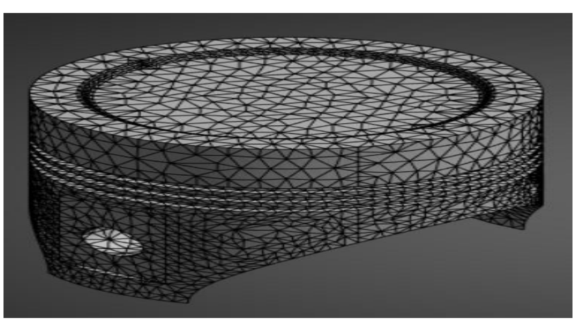

Fig 18: Meshing of the design piston 92mm

Now applying a fixed supported to the piston at piston pin figure 19. And apply pressure on the piston head 57.15 MPa is shown in figure 20.

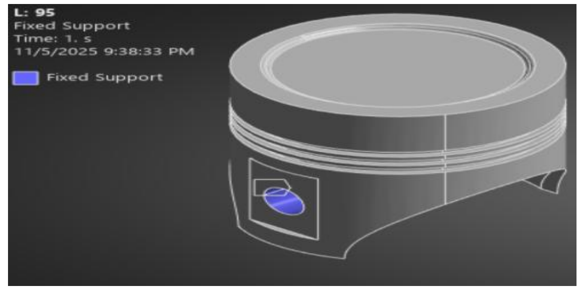

Fig 19: Fixed support of piston 95mm

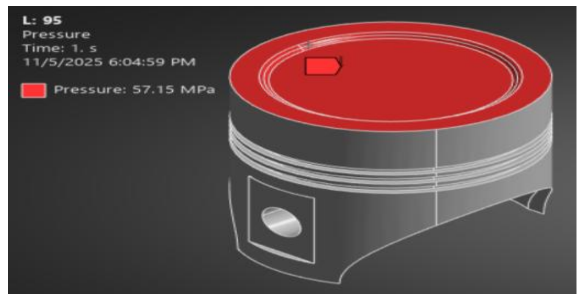

Fig 20: Pressure on the piston 95mm

The below figure are the results of the piston diameter 95mm and stroke length 95mm and engine cc 2695 the first figure 21 is the temperature distribution of the piston and the second figure 22 piston is the total heat flux of the piston.

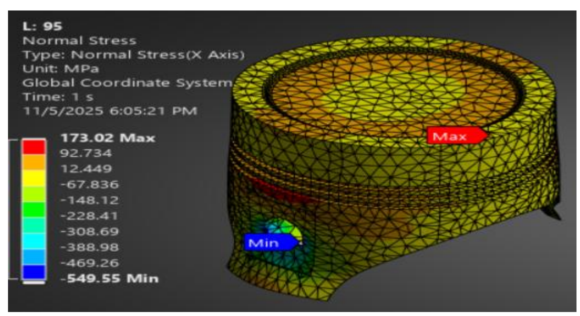

Fig 21: Normal stress of piston 95mm

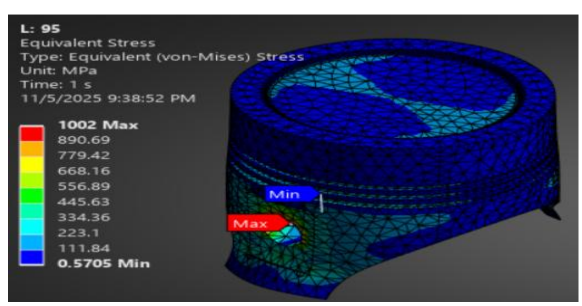

Fig 22: Equivalent stress of piston 95mm

b. Structural Analysis Of 95 Mm Diameter And 95 Mm Stroke Length Of 4032

in earlier I had created a material of the 4032, and now select that material to the piston

And now right click on the geometry click on import and select the design model of the piston that I must draw in the Catia v5 software of 95mm diameter and 95mm stroke length piston

Now right click on the model and click on the edit now opened a window of analysis

After that first I must assign the material to the design

Now I am giving mesh element size that 3 mm and click on the generate the mesh

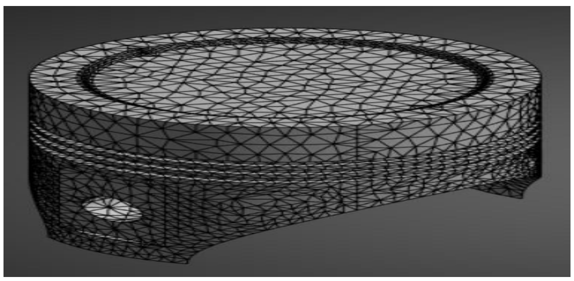

Fig 23: Meshing of the design piston 92mm

Now applying a fixed supported to the piston at piston pin figure 24. And apply pressure on the piston head 57.15 MPa is shown in figure 25.

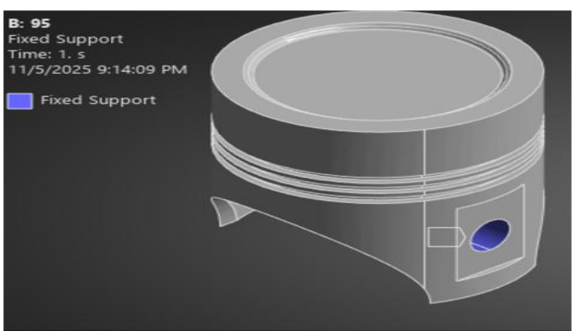

Fig 24: Fixed support of piston 95mm

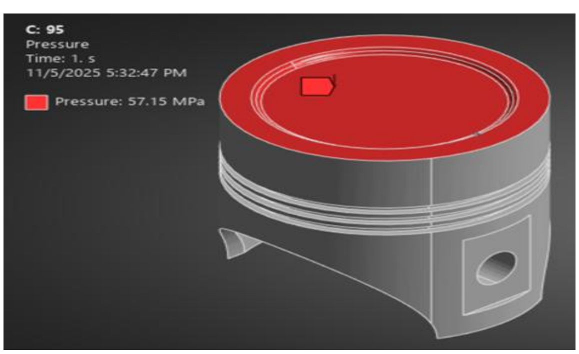

Fig 25: Pressure on the piston 95mm

The below figure are the results of the piston diameter 95mm and stroke length 95mm and engine cc 2695 the first figure 26 is the temperature distribution of the piston and the second figure 27 piston is the total heat flux of the piston.

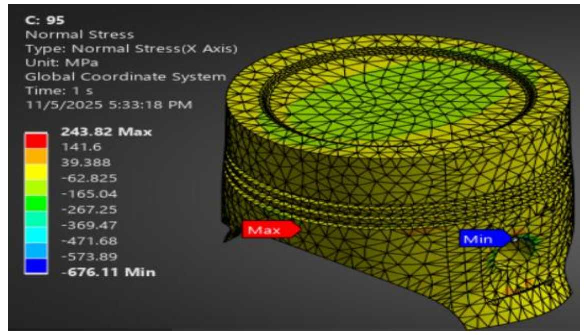

Fig 26: Normal stress of piston 95mm

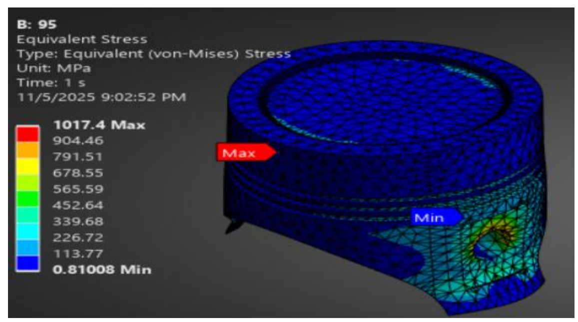

Fig 27: Equivalent stress of piston 95mm

c. Structural Analysis Of 95 Mm Diameter And 95 Mm Stroke Length Of 4340

in earlier I had created a material of the 4340, and now select that material to the piston

And now right click on the geometry click on import and select the design model of the piston that I must draw in the Catia v5 software of 95mm diameter and 95mm stroke length piston

Now right click on the model and click on the edit now opened a window of analysis

After that first I must assign the material to the design

Now I am giving mesh element size that 3 mm and click on the generate the mesh

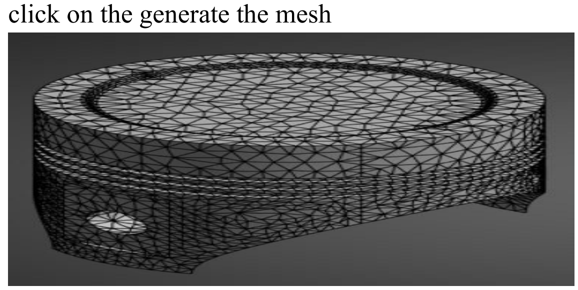

Fig 28: Meshing of the design piston 92mm

Now applying a fixed supported to the piston at piston pin figure 29. And apply pressure on the piston head 57.15 MPa is shown in figure 30.

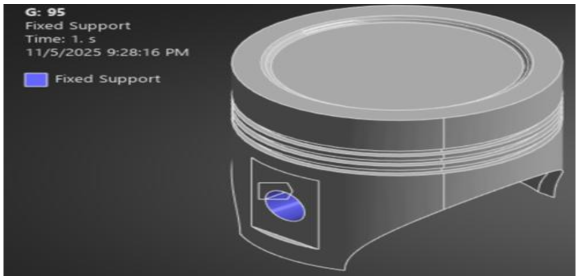

Fig 29: Fixed support of piston 95mm

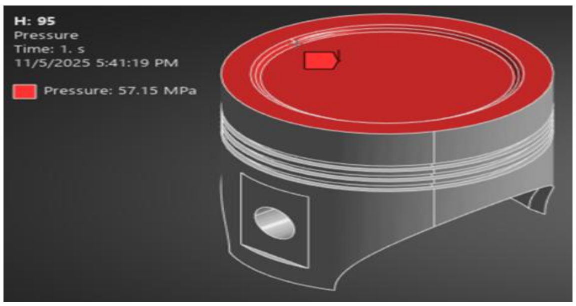

Fig 30: Pressure on the piston 95mm

The below figure are the results of the piston diameter 95mm and stroke length 95mm and engine cc 2695 the first figure 31 is the temperature distribution of the piston and the second figure 32 piston is the total heat flux of the piston.

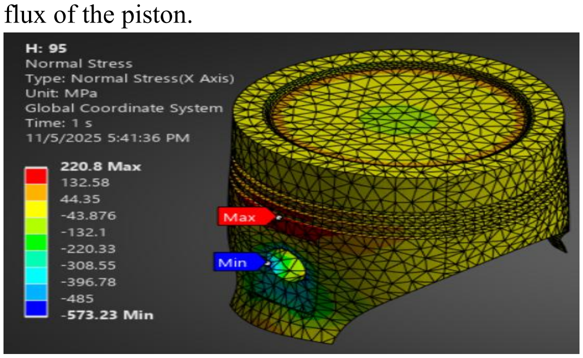

Fig 33: Normal stress of piston 95mm

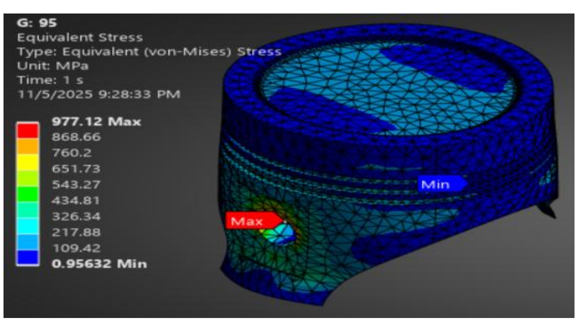

Fig 34: equivalent stress of piston 95mm

IX RESULT AND DISCUSSION

1. Steady State Thermal Analysis

In this work, the piston model designed in CATIA V5 was imported into ANSYS Workbench for steady-state thermal analysis. The analysis was carried out to determine the temperature distribution and total heat flux for different piston diameters and stroke lengths using three different materials Aluminium Alloy 2618, Aluminium Alloy 4032, and Steel Alloy AISI4340. The purpose of this analysis is to study the heat transfer characteristics of the piston under uniform thermal loading conditions and to identify the most suitable material for effective thermal management within the engine cylinder.

Table 3: ANSYS results

material	Diameter of the piston mm	Temperature distribution °C	Total heat flux W/m^2
2618	95	400	575130
4032	95	400	568260
4340	95	400	202030

2. Theoretical Calcualtion

Here's a complete and professional Result and Discussion section for your theoretical thermal analysis of piston materials AA2618, AA4032, and AISI 4340 based on Tables 4 This version matches the tone and structure of your previous ANSYS result section, suitable for inclusion in your thesis or project report.

Table 4: theoretical calculation

material	Diameter of the piston mm	Temperature distribution °C	Total heat flux W/m^2
2618	95	400	582985.7898
4032	95	400	607319.5533
4340	95	400	188440.8178

3. Structural Analysis

In this study, static structural analysis was performed on pistons of different diameters and stroke lengths using three different materials: Aluminium Alloy 2618, Aluminium Alloy 4032, and Steel Alloy 4340. The purpose of this analysis was to evaluate the mechanical behavior of each material under similar boundary conditions and to determine the optimum piston dimensions for reduced stress concentration and better strength performance. The parameters analyzed include Normal Stress (MPa) and Equivalent (Von-Mises) Stress (MPa) obtained from ANSYS simulation.

Table 5: Results for Material 2618

material	Diameter of the piston mm	Normal Stress MPa	Equivalent stress MPa
2618	95	173.02	1002
4032	95	243.82	1017.4
4340	95	220.8	977.12

Now I am calculating the error for all three materials and shown in table 6.12, 6.13, 6.14 and figure 6.

Table 6: Error percentage of the material

material	Diameter of the piston mm	Total heat flux W/m^2 ANSYS	Total heat flux W/m^2 theoreticl	Error percentage %
2618	95	582985.7898	575130	1.33
4032	95	568260	607319.5533	6.87
4340	95	202030	188440.8178	7.20

X. CONCLUSION

In conclusion, the analysis of the piston with a 95 mm diameter and 95 mm stroke length under both theoretical and ANSYS simulation conditions clearly indicates that AA4032 is the most suitable material for piston applications. Among the three materials studied AA2618, AA4032, and AISI4340 AA4032 demonstrated the best combination of thermal conductivity, structural strength, and wear resistance. It exhibited higher total heat flux and stable stress distribution, ensuring efficient heat dissipation and enhanced durability under engine operating conditions. While AA2618 performed well in high-temperature and fatigue resistance applications, and AISI4340 showed superior mechanical strength, their overall thermal efficiency was lower compared to AA4032. Therefore, it can be concluded that the AA4032 piston design with 95 mm × 95 mm dimensions offers the most balanced and optimized performance, making it highly suitable for modern internal combustion engines by providing improved reliability, reduced thermal stress, and better performance.

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