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Design and Stress Analysis of an IC Engine Piston Using Different Materials

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1. ABSTRACT

The project titled "Design and Analysis of an IC Engine Piston" focuses on developing an optimized piston design for an internal combustion (IC) engine through advanced modelling and simulation techniques. The piston is a critical component subjected to extreme mechanical and thermal loads during engine operation, making its design and material selection essential for ensuring durability and performance.

The project begins with the conceptual design of the piston using SolidWorks software, incorporating standard design parameters such as bore diameter, stroke length, and compression ratio. Finite Element Analysis (FEA) is then used to evaluate the structural integrity of the piston under thermal and mechanical stresses during the combustion cycle. The analysis includes stress distribution and deformation to identify potential failure zones.

Material selection is also considered, comparing conventional aluminium alloys with advanced materials such as reinforced composites to enhance strength and heat dissipation. Design modifications, including optimization of piston geometry and weight reduction, are implemented to improve engine efficiency and reduce wear.

The results of the analysis provide insights into improving piston durability and performance, contributing to the development of more efficient and reliable IC engines. This study offers a comprehensive approach to enhancing the design lifecycle of engine pistons by integrating simulation, material science, and mechanical analysis

Keywords: stress distribution, deformation, potential failure zones

2. INTRODUCTION

Engine pistons are one of the most complex components among all automotive and other industry field components. The engine can be called the heart of a vehicle, and the piston may be considered the most important part of an engine. There are lots of research works proposing, for engine pistons, new geometries, materials and manufacturing techniques, and this evolution has undergone with a continuous improvement over the last decades and required thorough examination of the smallest details. Notwithstanding all these studies, there are a huge number of damaged pistons. Damage mechanisms have different origins and are mainly wear, temperature, and fatigue related. But more than wear and fatigue, damage of the piston is mainly due to stress development, namely- Thermal stress, Mechanical stress. This paper describes the stress distribution on piston of internal combustion engine by using FEA. The FEA is performed by CAD and CAE software.

2.1. MATERIALS

S.NO	MATERIALS
1.	AL D16T
2.	GRAY CAST IR
3.	AISI 4041
4.	AL 6061

TABLE 2.1 MATERIAL DETAILS

This paper presents a detailed study of the design and analysis of a piston using SolidWorks and ANSYS. The primary objective is to model a piston in SolidWorks, then perform stress and deformation analyses in ANSYS to evaluate the structural integrity and performance of the piston under typical operational loads. The study focuses on understanding the stress distribution across the piston, identifying regions of high stress concentration, and analyzing the deformation behavior to ensure the piston's durability and reliability. By combining SolidWorks for precise geometric modeling and ANSYS for advanced simulation capabilities, this research aims to provide valuable insights into the optimization of piston design for improved engine performance and longevity.

The paper is structured as follows: the design methodology using SolidWorks is presented, followed by the setup of the simulation in ANSYS, including meshing, loading conditions, and analysis types. The results of the stress and deformation analyses are discussed in detail, followed by conclusions on the effectiveness of the design and recommendations for future improvements

1. Design and optimize a piston geometry using SOLIDWORKS.

2. Conduct structural and thermal analyses of the piston using ANSYS.

3. Investigate the effects of design parameters, such as piston shape, material, and cooling channel geometry, on piston performance..

2.2. METHODOLOGY

This study employed a computational approach, utilizing SOLIDWORKS for piston design and ANSYS for structural and thermal analysis. The methodology consisted of the following steps:

STEP 1: Piston Design

1. Geometry creation: A piston geometry was created using SOLIDWORKS, considering typical piston dimensions and features.

2. Parameterization: Key design parameters, such as piston shape, material, and cooling channel geometry, were parameterized for optimization.

channel geometry, were parameterized for optimization.

Step 2: Structural Analysis

1. Mesh generation: A finite element mesh was generated for the piston geometry using ANSYS Meshing.

2. Material properties: Material properties for the piston material (e.g., aluminum alloy) were assigned.

3. Boundary conditions: Boundary conditions, such as loads and constraints, were applied to simulate engine operating conditions.

4. Structural analysis: A static structural analysis was performed using ANSYS Mechanical to evaluate piston deformation, stress, and strain.

Step 3: Stress and Total deformation Analysis

1. material properties for the piston material were assigned
2. Stress application: the material behaves elastically, meaning that it returns to its original shape after the load is removed.

3. Total Deformation Analysis: This type of analysis is used to evaluate the large deformation behavior of the piston, including plastic deformation and contact between components.

Step 4: Optimization

1. Design of experiments: A design of experiments (DOE) approach was used to evaluate the effects of design parameters on piston performance.

2. Response surface methodology: Response surface methodology (RSM) was used to optimize piston design parameters for improved structural and thermal performance.

Step 5: Results and Discussion

1. Results: The results of the structural and thermal analyses were compared and discussed.

2. Discussion: The effects of design parameters on piston performance were discussed, and recommendations for optimal piston design were provided.

Software Used:

- SOLIDWORKS 2022 (or latest version)
- ANSYS 2022 R1 (or latest version)

3. LITERATURE REVIEW

in this paper [1], the main objective of this research work is to investigate and analyze the stress distribution of piston at actual engine condition. in this paper pressure analysis, thermal analysis and thermo-mechanical analysis are done. the parameter used for the analysis is the coefficient of thermal expansion and material properties of piston. in i.c. engine piston is the most complex and important part therefore for the smooth running of vehicle piston should be in proper working condition. piston fails mainly due to mechanical stresses and thermal stresses. analysis of piston is done with boundary conditions, which includes pressure on piston head during working conditions and uneven temperature distribution from piston head to skirt. the analysis predicts that due to temperature the top surface of the piston may be damaged or broken during the operating conditions, because damaged or broken parts are so expensive to replace and generally are not easily available.

The CAD model was created using SOLIDWORKS software. The CAD model is then imported into ANSYS software for geometry and meshing purposes. The FEA performed by using ANSYS 19. [2] In this present work a piston designed for a single cylinder four stroke petrol engine using SolidWorks software. Complete design is imported to ANSYS 19 software then analysis is performed. Four different materials have been selected for structural and thermal analysis of piston. Results are shown and a comparison is made to find the most suited design [3].

This paper describes the stress distribution and thermal stresses of three different aluminum alloys piston by using finite element method (FEM). The parameters used for the simulation are operating gas pressure, temperature and material properties of piston. The specifications used for the study of these pistons belong to four stroke single cylinder engine of Triumph scrambler 400 X. This paper illustrates the procedure for analytical design of four aluminum alloy pistons using specifications of four stroke single cylinder engine of Triumph scrambler 400 X motorcycle. The results predict the maximum stress and critical region on the different aluminum alloy pistons using FEA.

It is important to locate the critical area of concentrated stress for appropriate modifications. Statistic and thermal stress analysis are performed by using ANSYS 19. The best aluminum alloy material is selected based on stress analysis results. The analysis results are used to optimize piston geometry of best aluminum alloy [4] This paper describes stress distribution and thermal stresses of four different aluminum alloys piston by using finite element method (FEM).

The parameters used for the simulation are coefficient of thermal expansion and material properties of piston. The specifications used for the study of these pistons belong to four stroke single cylinder engine of Triumph scramble 400 X. The results predict the maximum stress and critical region on the different aluminum alloy pistons using FEA. It is important to locate the critical area of concentrated stress for appropriate modifications. Static and thermal stress analysis is performed by using ANSYS 19. The best Aluminum Alloy material is selected based on stress analysis results.

The analysis results are used to optimize piston geometry of best aluminum alloy. [5] In this study, firstly, thermal analyses are investigated on a conventional piston, made of aluminum alloy for design 1 and design 2 parameters. Secondly, thermal analyses are performed on piston material by means of using a commercial code, namely ANSYS. The effects of coating on the thermal behaviors of the pistons are investigated. The finite element analysis is performed by using computer aided design software.

The main objective is to investigate and analyze the thermal stress distribution of pistons at the real engine condition during combustion process. This thesis describes the mesh optimization by using finite element analysis technique to predict the higher stress and critical region on the component. In this work, the main emphasis is placed on the study of thermal behavior of functionally graded coatings obtained by means of using a commercial code, ANSYS, on aluminum piston surfaces. The analysis is carried out to reduce stress concentration on the upper end of the piston i.e. (piston head/crown and piston skirt and sleeve). With computer aided design SolidWorks software, the structural model of a piston will be developed. Furthermore, the finite element analysis is done using Computer Aided Simulation software ANSYS.

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4. MECHANICAL PROPERTIES

TABLE 4.1 MECHANICAL PROPERTIES OF THE MATERIALS

5. MECHANICAL PROPERTY	D16T ALUMINIM ALLOY	GRAY CAST IRON	AISI4041 STEEL	AL6061
Ultimate Tensile strength (MPA)	560-580	200–350	585–655	310-350
Yield strength (MPA)	460-480	150–250	415–515	275-310
Shear Strength (MPA)	300-350	150–200	315–400	200-230
Young's Modulus (E) (GPa)	70-75	100–150	190–210	68.9-70
Density (G/CM³)	2.85	6.9–7.3	7.85	2.70
Coefficient of Thermal Expansion(/°C)	22.6×10^{-6}	$10–12 \times 10^{-6}$	11.7×10^{-6}	23.6×10^{-6}
Thermal conductivity W/m·K	130	50–60	45-50	150–160

1. PROBLEM STATEMENT AND SOLUTION

No. of cylinders	1
Rated Speed	6500 R.P.M
Bore x Stroke	89*64 MM
Max. Power	40 PS @8000 R.P.M
Max. Torque	37.5 NM @6500 R.P.M
Compression Ratio	12: 1

TABLE 5.1 ENGINE SPECIFICATIONS

1.2. DESIGN CALULATATIONS

5.2.1 PISTON DESIGN PARAMETERS

Taking AL Alloy Material

(i) Thickness of Piston Head (th) :

The piston thickness of piston head calculated using the following Grashoff's formula,

th = D√(3pmax/16σt)

Where P= maximum pressure in N/mm² = 8 N/mm²

D= cylinder bore/outside diameter of the piston in mm.

σt = permissible tensile stress for the material of the piston = 124.4MPa

Therefore, th = 89√ (3*8/16*124.4) = 9.77mm

The maximum thickness from the above formula (th) is 9.77 mm.

(ii) Radial Thickness of Ring (t1)

The radial width of the ring is given by:

T1 = D√ (3*pw/ σt)

Where Pw= pressure of fuel on cylinder wall in N/mm². Its value is limited from 0.025N/mm ² to

0.042N/mm².

Therefore, **T1** = 89√(3*0.042/ 124.4) = 2.83mm.

(iii)Axial Thickness of Ring (t2)

The thickness of the rings may be taken as

t2 = 0.7t1 to t2

Therefore, t2 = 0.7 t1 = 0.7*2.83 = 1.98mm.

(iv) Width of the top land (b1)

The width of the top land varies from

b1 = **tH to 1.2 tH**

Therefore, **b1** =1.2*9.77 = 11.724 mm.

(v) Width of other lands (b2)

Width of other ring lands varies from

b2 = **0.75 t2 to t2**

Therefore, **b**2 = 0.75*1.98 = 1.485 mm.

(vi) Thickness of Barrel at the top end (t3)

Radial Depth of Piston ring grooves (b) is about 0.4mm more than radial thickness of piston rings(t1), therefore

b = 0.4+t1 = 3.23mm
t**3** = 0.03*D+b+4.5 = 0.03*89+3.23+4.5
t**3** = 10.4m.

(vii) Thickness of Barrel at the open end (t4)

t4 = 0.25t**3** to 0.35t**3**
t4= 0.25t**3** = 0.25*10.4
t4= 2.6mm

(viii) Piston Pin Diameter (d0)
d0 = 0.3D = 0.3*89
d0 = 26.7mm.

(ix) Number of Rings (nr)
nr = D/(10*t2)
= 89/(10*1.98)

nr = **4** rings.

5.2.2THEORETICAL STRESS CALCULATIONS

σb = **Pzmax** *(ri/δ) ²

Pzmax = Max. Gas Pressure (5 MPa)

ri = Crown Inner Radius = [D/2 – (s+t1+dt)]

s = 0.05*D = 4.45mm

dt = 0.0008m

ri = 37.2192 mm

δ = Thickness of Piston Crown

δ = 0.08D to 0.1D = 0.1*89 = 8.9mm

σb = 5*(37.2192/8.9)²

σb = 87.45 MPa

Hence required theoretical stress obtained from calculation is 87.45 MPa

5.3 THE MODEL OF THE PISTON

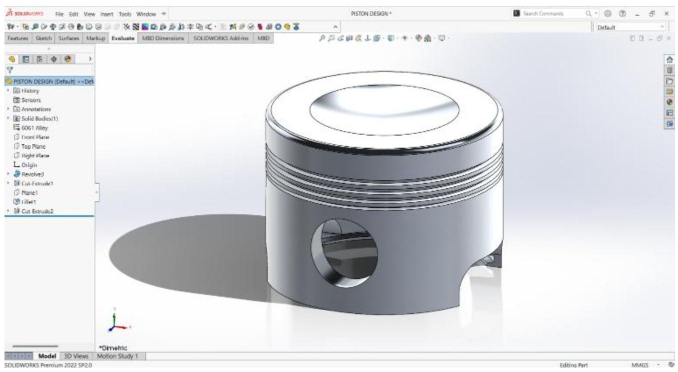
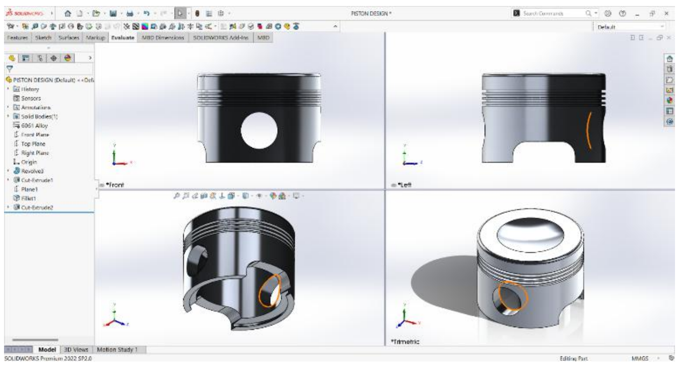


Fig 5.3.1 The model of the piston



5.3.2 The model of the Piston

5.4 ANALYSIS OF PISTON IN ANSYS:

5.4.1 MESHING

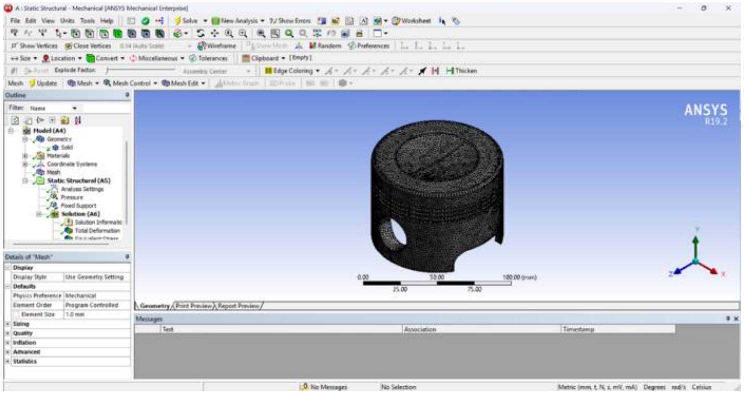


FIG 5.4.1. MESHING OF PISTON

5.4.2 BOUNDARY CONDITIONS

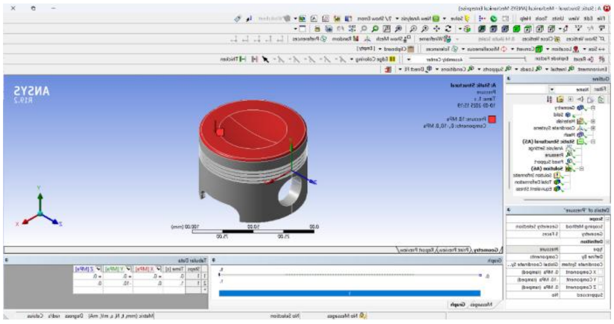


FIG 5.4.2 PRESSURE APPLIED ON PISTON

5.4.3 FIXED SUPPORTS

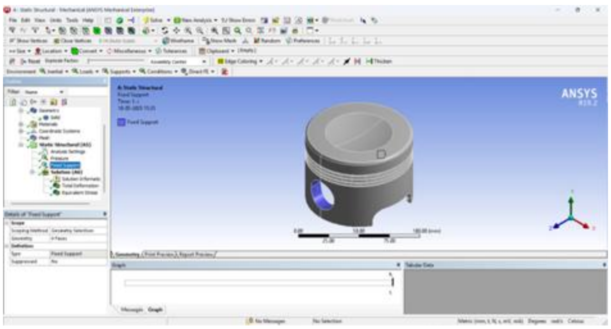
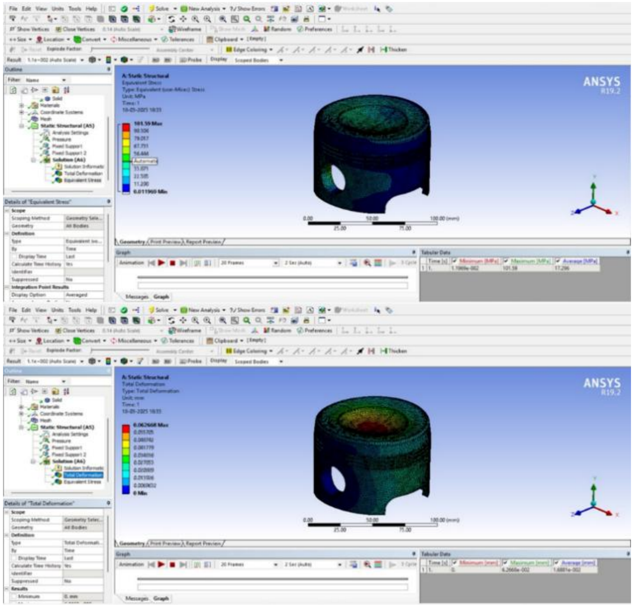


FIG 5.4.3 FIXED SUPPORTS APPLIED ON PISTON

6. EQUIVALENT STRESS AND TOTAL DEFORMATION OF AL



D16T

FIG 6.1 EQUIVALENT STRESS AND TOTAL DEFORMATION OF AL D16T AT 5MPA

7.RESULTS

7.1 Materials Used for Piston:

- AL D16T
- GRAY CAST IRON
- AISI 4041
- AL 6061
- The structural static analysis is conducted on piston by using these different materials. First the analysis is carried out by AL D16T and then the Parameters like von-mises stresses and deformation is found. Later the analysis is performed on piston by GRAY CAST IRON, AISI 4041 and AL 6061 and above parameters are calculated.

MATERIALS	MAXIMUM EQUIVALENT STRESS(MPA)				
	AT 5MPA	AT 10MPA	AT 15MPA	AT 20 MPA	AT 25 MPA
AL D16T	101.59	203.18	304.77	406.36	507.95
GRAY CAST IRON	102.95	205.9	308.85	411.8	514.75
AISI 4041	102.41	204.82	307.23	409.64	512.05
AL 6061	101.81	203.62	305.43	407.24	509.04

7.2 The obtained results are tabulated in the below table:

7.2.1 Maximum Equivalent Stresses Obtained For 4 Different Materials

TABLE7.2.1MAXIMUM EQUIVALENT STRESSES OBTAINED FOR 4 DIFFERENT MATERIALS

7.2.2 Maximum Deformation Obtained For 4

MATERIALS	MAXIMUM DEFORMATION (mm)				
	AT 5MPA	AT 10MPA	AT 15MPA	AT 20MPA	AT 25MPA
AL D16T	0.062688	0.12534	0.18801	0.25067	0.31334
GRAY CAST IRON	0.040634	0.081267	0.1219	0.16253	0.20317
AISI 4041	0.021134	0.042267	0.063401	0.084534	0.10567
AL 6061	0.06198	0.12396	0.18594	0.24792	0.3099

Different Materials

7.2.2 MAXIMUM DEFORMATION OBTAINED FOR 4 DIFFERENT MATERIALS

7.3 GRAPHS:

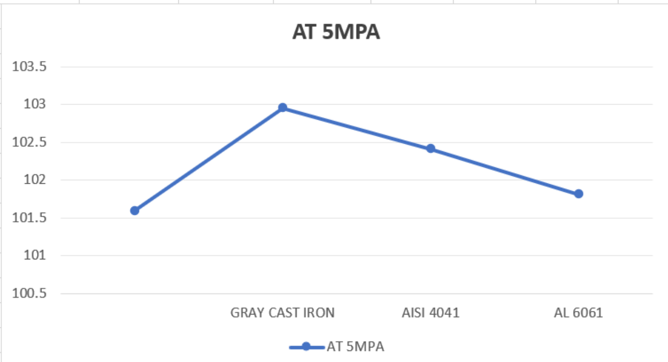


fig 7.3.1 Graphical representation of Stress at 5MPA

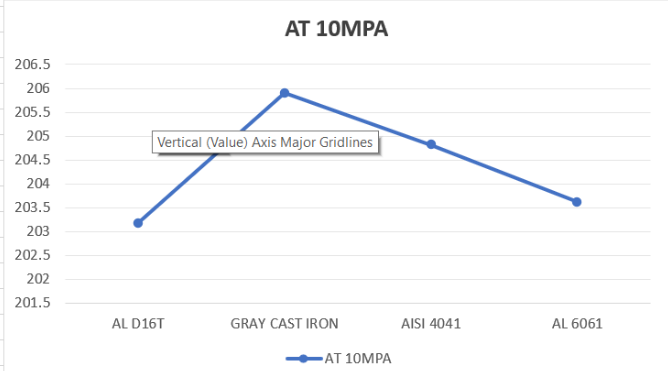


Fig 7.2.2 Graphical Representation of stress at 10 MPA

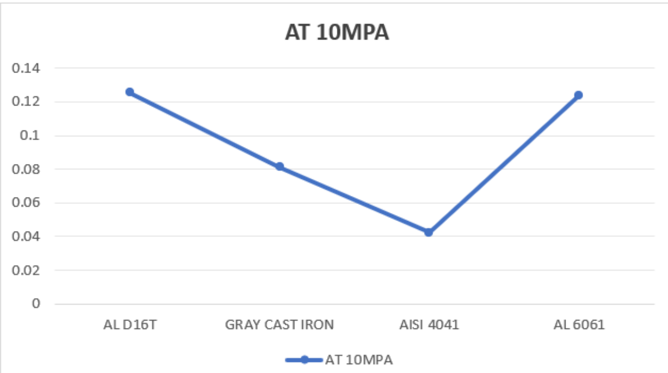


Fig 7.3.3 Graphical representation of Total deformation at 10 MPA

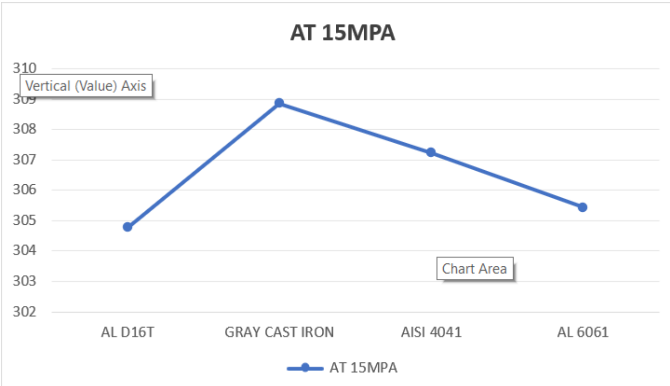


Fig 7.3.4 Graphical Representation of Stress at 15MPA

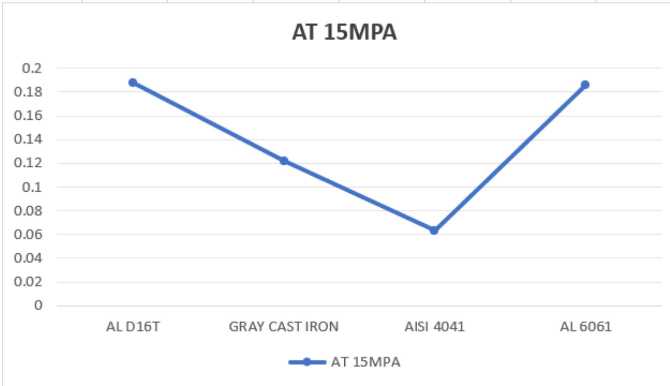


Fig 7.3.5 Graphical representation of Total deformation at 15MPA

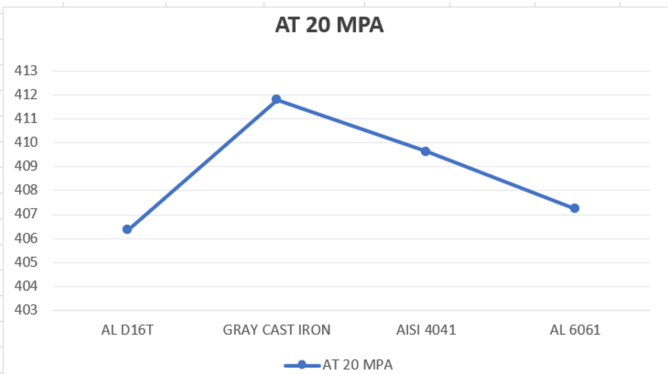


Fig 7.3.6 Graphical Representation of Stress at 20 MPA

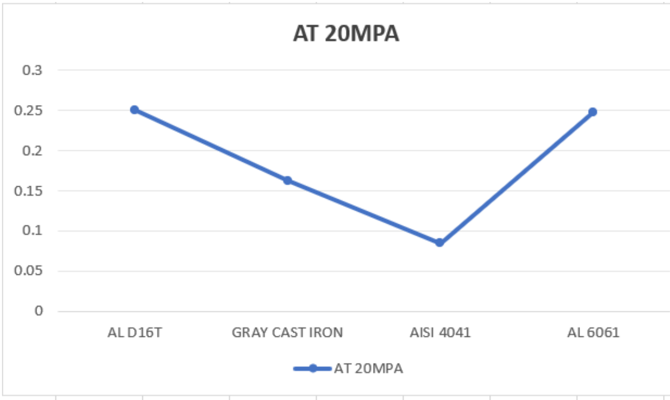


Fig 7.3.7 Graphical representation of Total Deformation at 20MPA

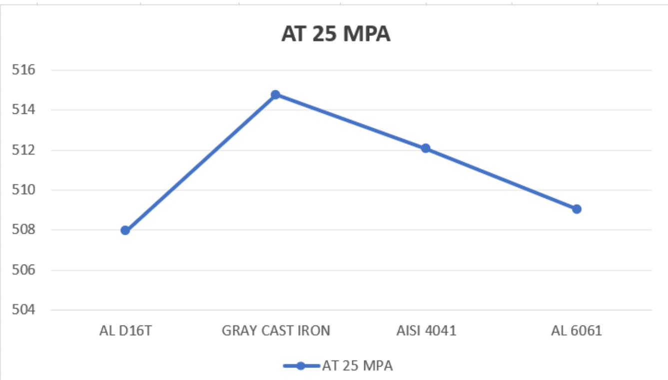


Fig 7.3.8 Graphical representation of Stress at 25 MPA

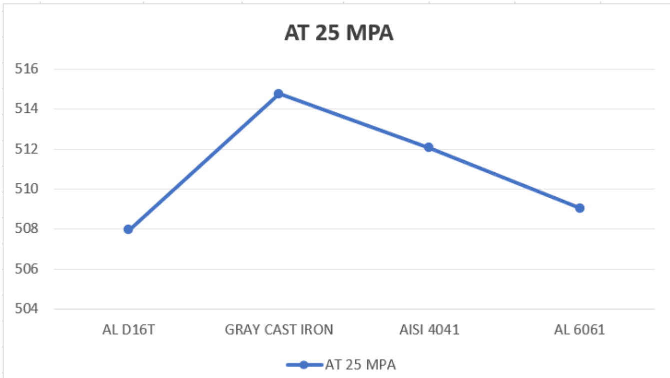


Fig 7.3.9 Graphical representation of Total Deformation at 25 MPA

CONCLUSION

This research outlines a numerical method for determining the optimal piston design. the initial stage involves performing manual calculations to establish the design parameters. developing a well-structured piston design is crucial to minimize stress concentration and prevent potential failures

in this study, the piston model was created using solidwork and subsequently imported into ansys software in step format. the piston was analyzed under the influence of pressure, necessitating a thorough evaluation of stress distribution and total deformation by incorporating appropriate constraints and loads in the analysis.
the results obtained from the finite element analysis (fea) provide essential insights for determining whether the piston design is structurally sound. these observations play a key role in ensuring the design's safety and reliability.

- von mises equivalent stress obtain in practically more than the theoretically observed by the materials
- maximum deformation occurs at the center of the piston head
- piston with above mentioned materials is safe for 87145 mpa peak cylinder pressure operation without any failure

I. REFERENCES

- [1] BB.A. Devan1, G. Ravinder "Thermal analysis of aluminum alloy piston "International Journal of Emerging Trends in Engineering Research (IJETER), vol. 3 no6, PP: 511 -515 (2015).
- [2] Ajay Raj Singh, Dr. Pushpendra Kumar Sharma, "Design, Analysis and Optimization of Three Aluminum Piston Alloys Using FEA" Int. Journal of Engineering Research and Applications, Vol. 4, Issue 1 Version 3, January 2014, PP.94-102.
- [3] Hitesh Pandey, Avin Chandrakar, PM Bhagwat, "Thermal Stress Analysis of a Speculative IC Engine piston using CAE Tools" int. journal of Engineering Research and Applications (IJERA), vol.4, issue 11(version5), November 2014, PP.60-64.
- [4] S. Srikanth Reddy, Dr.B. Sudheer Premkumar" Thermal Analysis and Optimization of I.C. Engine Piston Using Finite Element Method "International Journal of Innovative Research in Science Engineering and Technology., Vol.2, Issue12, December2013.
- [5] A. R. Bhagat1, Y.M. Jibhakate "Thermal Analysis and Optimization of I.C. Engine Piston Using Finite Element Method" International Journal of Modern Engineering Research (IJMER), Vol.2, Issue.4, July-Aug 2012, PP-2919-2921.
- [6] Aditya Kumar Gupta1, Vinay Kumar Tripathi2, "Design Analysis and Optimization of Internal Combustion Engine Piston Using CAE tools ANSYS" IJERA.vol.4, Issue 11(version - 5), November 2014.
- [7] Jadhav Rajendra B, G. J. Vikhe Patil "Computer Aided Design and Analysis of Piston Mechanism of Four Stroke S.I. Engine" IEEE 2010, Frontiers in automobile and mechanical engineering conference, PP.97-103.
- [8] Vaishali R. Nimbarte and Prof. S.D. Khamankar, "Stress Analysis of Piston using Pressure Load and Thermal Load", IPASJ International Journal of Mechanical Engineering (IIJME), August 2015.
- [9] Lokesh Singh, Suneer Singh Rawat, Taufeeque Hasan and Upendra Kumar, "Finite Element Analysis of Piston in ANSYS", International Journal of Modern Trends in Engineering and Research.
- [10] Gadde Anil Kumar and Chandolu Nehemya Raj, "Design and Analysis of an I.C. Engine Piston and Piston Rings by using Three Different Materials", International Journal of Advances in Mechanical and Civil Engineering, April 2017.
- [11] Dilip Kumar Sonar and Madhura Chattopadhyay, "Theoretical Analysis of Stress and Design of Piston Head using CATIA & ANSYS", International Journal of Engineering Science Invention, June 2015.
- [12] Vaibhav V. Mukkawar, Abhishek D. Bangale, Nitin D. Bhusale and Ganesh M. Surve, "Design Analysis and Optimization of Piston

Using CAE Tools", International Journal of Advances in Mechanical and Civil Engineering, April 2015.

- [13] Ajay Raj Singh and Dr. Pushpendra Kumar Sharma, "Design, Analysis and Optimization of Three Aluminum Piston Alloys Using FEA", Int. Journal of Engineering Research and Applications, Issue 1 (Version 3, January 2014).
- [14] Dipayan Sinha, Susenjit Sarkar and Samar Chandra Mandal, "Thermo-Mechanical Analysis of a Piston with Different Thermal Barrier Coating Configuration", International Journal of Engineering Trends and Technology (IJETT) – Volume 48 Number 6, June 2017.
- [15] V B Bhandari, "Design of Machine Elements", Third Edition