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THERMAL ANALYSIS OF CARBON, BASED PISTON USING FEA

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ABSTRACT

The piston is a critical component of internal combustion engines, and its thermal performance significantly impacts the engine's overall efficiency and durability. This study focuses on the thermal analysis of a piston made from various materials using Finite Element Analysis (FEA). By simulating the thermal behavior under engine operating conditions, the research evaluates the impact of material selection on thermal stress, deformation, and heat dissipation. Graphite and structural steel are considered for comparison, with graphite emerging as the superior material.

Keywords: Thermal analysis, Finite Element Analysis (FEA), piston materials, thermal stress.

1. INTRODUCTION

Finding the normal stresses and thermal stresses using a speculative IC engine piston with various materials is the aim of this investigation. The materials that were taken into consideration for the study were structural steel, cast iron, and aluminum alloys. Although structural steel is the most widely used material in engineering, it has some limits, therefore in order to get around them, we utilized an alternate material from the perspective of design and analysis.

Our research, as covered in the literature review, further demonstrates that traditional materials are unable to keep up with the rapidly evolving automobile viewpoints. Thus, it is critical to find a substitute in order to meet the constantly evolving requirements.

Cast iron, cast aluminum, forged aluminum, cast steel and forged steel . Are the materials that I.C. engines most frequently use for their pistons. Cast iron pistons are utilized for piston speeds less than 6 m/s, and aluminum alloy pistons are used for highly rated engines operating at greater piston speeds.

Aims and Objectives of the present work

The following are the current investigation's goals and objectives:

- Choose the material for the pistons of an internal combustion engine and use numerical computing to confirm the analytical conclusions.
- > Finding the Von-mises stresses on the piston head and examining the stress brought on by gas pressure.
- Assessing the thermal strains on the piston head as a result of temperature variations between the piston's center and edge.
- Using graphite as a novel piston material and experimenting with various piston materials to achieve the best possible result.
- > Validation of CAE software as a useful tool for IC engine piston modeling and thermal analysis.

Using Carbon as material for piston IC Engines:

Pistons for internal combustion engines require highly-developed materials.

Owing to their specific qualities, carbon materials designed for this purpose provide an alternative to conventional materials, enable extraordinary processes, and significantly boost performance in automotive engineering.

Integration of CAE Software

These CAE tools are often used in conjunction with specialized CAE software packages to facilitate problem solving and engineering component design. A difficult issue is the unification of the tools or the data exchange between them. An appropriate systemized database is required in order to properly integrate these systems. The different data is incorporated into and retrieved from CAE tools. Should the CAE software be private and data access difficult, programming transfers may be necessary, but at the expense of functionality and interaction.

The example of CAE design is the landing gear system of an aircraft. The first step in defining the issue is to compile a list of performance requirements. Specialized programs can assist the logical design process at a higher level by estimating the landing gear's size based on predetermined weights and deflections.

Working of Finite Element Analysis

The material and structural characteristics that specify how the structure will behave under specific loading conditions are programmed into Finite Element Analysis (FEA). The material is determined by the expected stress levels in a certain location. The fracture point of previously tested material, intricate details, and the affected high stressed locations are examples of points of interest. The mesh will function in the expanded system similarly to a spider web net, with

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each node having a web of vectors and each neighboring node having a mesh element. Numerous components were created by this network of vectors carrying the objects' material attributes.

A wide range of objective functions (variables within the system) are available for variation:

- ➢ Mass and volume, temperature variation
- Strain energy, stress strain
- Dynamic Force and displacement, velocity and acceleration calculation. Each FEA program comes with the following elements as given below:
- Rod elements, Beam elements
- Plate/Shell/Composite elements
- ➤ Shear panel

Many FEA programs are equipped by multiple materials within the structure such as given below:

- Isotropic, identical throughout
- Orthotropic, identical at 90 degrees
- General anisotropic, different throughout

Modeling of Piston

A complete Finite Element Analysis consists of three stages:

Pre-Processing-

Part module- First of the piston is created in part module.

Property module-CATIA has built-in system of units. Some common systems of consistent units are shown in Table 5

Variable	SI	SI (mm)	US Unit (ft)	US Unit (inch)
Length	М	Mm	ft.	in.
Force	Ν	Ν	Lbf	Lbf
Mass	Kg	tonne (10^3 kg)	Slug	lbf s² /in
Time	Sec	Sec	Sec	Sec
Stress	Pa (N/m ²)	MPa (N/mm ²)	lbf/ft ² psi	(lbf/in ²)
Energy	J	mJ (10 ⁻³ J) in	Ftlbf	Lbf
Density	kg/m ³	tonne/mm ³	slug/ft ³	lbf s ² /in ⁴

Table 1:-Some common systems of units

We are using the SI (mm) system of units for this investigation. The following are the mechanical qualities of the materials used, all of which have an elastic nature.

Post-processing with CATIA/CAE-

When creating graphics, You may use the Visualization module to examine the analysis's results once the process has finished successfully. From the menu that opens, choose Results to open the Visualization module. CATIA/CAE shows a quick visualization of the model and accesses the output database according to the job. To aid in understanding and result analysis, CATIA displays stress zones and maximum to lowest deformation in various colors.

Modeling Procedure:

Figure 2 shows the flow process chart of the IC engine piston regarding the modeling procedure.

In order to solve the problem, a uniform gas pressure is applied after the geometric parameters are determined with reference to the numerical and empirical equations that are stated in a way that allows it to move solely in an axial direction. With the same program, a parabolic octree-tetrahedron element with an element size of two is selected out of the four nodes that were picked. In the CATIA generative workbench, the spring material's properties are finally examined.

Numerical Analysis: Calculated Parameters for Piston:

Table 2: Calculated Parameters for Piston

S. NO.	Parameter	Size in mm
1	Length of piston	42
2	Cylinder Bore	53
3	Axial thickness of ring	1.181



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4	Radial thickness of ring	1.688
5	Maximum thickness of barrel	8.178
6	Width of the outer ring land	1.266
7	Width of the top land	8.018
8	Length of skirt	31.8
9	Piston pin Diameter	15.9



Fig.2:- Modeling Process of IC engine piston

Piston Calculation:

BP $\eta_{mech} =$ IP $IP = \frac{BP}{0.8} = \frac{5.5}{0.8} = 6.875 \text{ KW}$ Where: η = Mechanical efficiency IP = Indicated Power BP= Break power $IP = \frac{P \times L \times A \times n}{P}$ 60 $P_{me} = 1.244 \text{ MPa}$ $P_{max} = 10 x P = 12.44 MPa$ Where: P= pressure in MPa L= Length of piston in mm A= Area of piston in mm^2 Thickness of piston head 3 Ртах $t_{\rm H}=D$ 16σt $t_{\rm H} = 9.28$ empirical formula $t_n = 0.032D + 1.5 = 3.19 \text{ mm}$

 $[M_f = 45.493 \text{ kg/kws}]$



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$$tn = \frac{10 \times 100 \times 100 \times 100}{12.56 \times 150 \times 75 \times 3600}$$

Piston rings:-Radial thickness

Г

 $t_1 = D \sqrt{\frac{3 Pw}{\sigma t}}$ $P_w = 0.025 - 0.042 \text{ N/mm}^2$ $\sigma t = 85-110$ MPa for cast iron rings $t_1 = 1.688 mm$ Axial Thickness $t_2 = 0.7 t_1$ to $t_2 = (0.7 \times 1.688) = 1.181$ mm Where: D = Diameter of Bore in mm Width of top land and Ring land Width of top land $b_1 = t_H$ to 1.2 $t_H = 8.018mm$ Width of ring land $b_2 = 0.75 t_1$ to $t_2 = 1.266mm$ Piston Barrel Thickness of piston Barrel at top end $t_3 = 0.03 D + b + 4.5 mm$ $t_{3\,=}\,0.03\!\times 53+2.088+4.5=8.178mm$ Thickness of piston Barrel at open end $t_4 = (0.25 t_3 \text{ to } 0.35 t_3) = 2.022 \text{ mm}$ Length of skirt $L_S = (0.6 D \text{ to } 0.8 D) = 31.8 \text{mm}$ Length of piston pin in on rod bushing $l_1 = 45\%$ of piston dia. = 23.85 Piston pin dia. $d_p = (0.28 D + 0.038 D)$ = 14.9mm Centre of pin should be 0.02 D to 0.04 D above piston skirt Heat flow through piston head $H = 12.56 \times t_H \times (T_c - T_E) \text{ KJ/sec}$ H = 744.368 KJ/secWhere: Tc = temperature at the center of piston head in °C T_E = temperature at the edges of the piston head in °C **FEA Analysis**

FEA analysis is integrated into FEA software like CATIA, ANSYS, and ABAQUS. Modeling may be used to regularize personal verification. Verification of linear analysis is typically less complicated than verification of non-linear analysis through the use of classical equations to determine the solutions



Fig 3 CATIA V5 Section of piston

Fig 4 CATIA V5 3D Model of piston



Figure 6: Total Displacement in Graphite Piston

2. RESULTS

In order to determine the impact of a material change on the piston's performance, this study examines one of the engine's components, the piston, using two distinct production materials. The maximal equivalent stress for graphite is 24.389 MPa and for structural steel is 24.428 MPa, according to research. The thermal analysis yields a maximum heat flow of 1.9288 W/mm for structural steel and 1.462 W/mm for graphite.. The following results were found by applying the calculations:

	1	e	
S. No	Piston Material	Structural Steel	Graphite
1.	Maximum Thermal Range (°C)	22.012-280 °C	22.019-280 °C
2.	Maximum Heat Flux (W/mm)	1.9288 W/mm	1.462 W/mm
3.	Maximum Equivalent Stress (N/m ²)	24.428 MPa	24.389 MPa
4.	Maximum Deformation (mm)	0.00074929 mm	0.0053919 mm

Table 2: Effect of Thermal Stresses and Equivalent Stress on Piston Performance using Different Piston Materials

As the table and results shows that when utilizing graphite as the piston material, the maximum heat flux, maximum deformation, and equivalent stress are all at their lowest, and that when using structural steel as the piston material, the maximum values of all variables are greater than when using graphite.

Thus, based on the data, we can conclude that the piston's maximum thermal stress and maximum deformation may be expressed as

Structural Steel > Graphite



editor@ijprems.com 3. CONCLUSION

- To enhance comprehension and analysis of the outcome, the CATIA program offers distinct deformation and stress zones. CATIA has produced better results and required less work to solve the complicated computation..
- > The performance of the piston is enhanced by the use of graphite as the piston material.
- The meshing element comprising triangular and quadrilateral nodes with least mesh size works better and delivers desired output.
- Since graphite has demonstrated less thermal stress and deformation and better thermal behavior than structural steel, it should be utilized to construct the piston.
- > The weight has been reduced and high mechanical strength may be obtained at low temperatures by substituting graphite for the piston material.

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