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Optimization of Internal Combustion Engine Piston

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Abstract: In this present work suitable material for design of I.C. engine piston is determined from Aluminium alloy and Aluminium composites. Also optimum dimensions of the Hero Karizma ZMR petrol engine piston are optimized from weight point view. For modelling and analysis CATIA V5R20 & ANSYS 14.5 softwares are used.

Keywords: FEM, Piston, Hero Karizma ZMR petrol engine, Aluminum alloys and composites.

I. 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 main objectives are to determine the best material and optimum design using structural analysis. The paper describes the FEA technique to predict the higher stress and critical region on the component. Using CATIAV5 software the structural model of a piston was developed. Using ANSYS V14.5 software, simulation and stress analysis was performed.

II. OBJECTIVES OF PRESENT STUDY

Finding the most suitable material for given stress conditions from the given list of materials generally used to make the pistons.
Optimizing the dimensions of the piston for achieving the lowest weight.

III. METHODOLOGY

A. Design of piston using CATIA
B. Meshing of designed model using ANSYS 15.
C. Analysis of piston by stress analysis method.
D. Comparing the performance of aluminum alloy and aluminium composite under structural analysis process.
E. Optimization using RSM in order to decrease its weight(volume)

IV. ENGINE SPECIFICATION AND PROPERTIES OF MATERIALS USED:

The engine specifications used for this work is a four stroke single cylinder type Hero Karizma ZMR petrol engine.

Table 1 Specifications of the piston

PARAMETERS	VALUES
Engine type	Four stroke ,petrol engine
Number of cylinders	Single cylinder
Bore	65.5
Stroke	66.2
Maximum power	14.9KW @ 8000rpm
Maximum torque	19.7Nm @ 6500 rpm
Maximum speed	129Kmph
Compression ratio	96.1

Table 2: Properties of materials

S.NO	PARAMETERS	Aluminium alloy	Aluminium Composite (Al-SiC10%-TiB25%)
1.	Density (kg/m3)	2684.95	2850.5
2.	Poisson ratio	0.33	0.314
3.	Coefficient of thermal expansion(1/C)	23×10-6	24×10-6
4.	Elastic modulus(Gpa)	71	106.05
5.	Yield strength(Mpa)	280	250
6.	Ultimate tensile strength (Mpa)	310	285
7.	Thermal conductivity(W/m/0C)	154	217.5

V. PREVIOUS STUDY

Dilip kumar sonar , Madhura Chattopadhyay studied thed design of piston head[1].Tadala akhil et.al have analyzed piston headmade of Aluminum alloys[2].Sundaram.K , Palanikumar.N and Kethavath Vishaldid et.al similar analysis using composites[3,4]. H.C.Anilkumar et.al, B.S.Motgi, R Patil and Arun Kumar M. B. and R. P.Swamy investigated the mechanical properties of Aluminum alloys [5,6,7].Ch.Venkata Rajam et.al ,A.R. Bhagat, Y.M. Jibhakate have done studies on Optimization of I.C. Engine Piston [8,9]

VI. NOMENCLATURE

IP = indicated power produced inside the cylinder (W)
N = engine speed (rpm)
L = length of stroke (mm)
A = cross-section area of cylinder (mm2)
mp = mass of the piston (Kg)
V = volume of the piston (mm3)
tH = thickness of piston head (mm)
D = cylinder bore (mm)
Pmax = maximum gas pressure or explosion pressure (Mpa)
σt = allowable tensile strength (Mpa)
σut = ultimate tensile strength (Mpa)
K = thermal conductivity (W/m K)
Tc = temperature at the centre of the piston head (K)
Te = temperature at the edge of the piston head (K)
HCV = Higher Calorific Value of fuel (KJ/Kg) = 48000 KJ/Kg
BP = brake power of the engine per cylinder (KW)
C = ratio of heat absorbed by the piston to the total heat developed in the cylinder = 5% or 0.05
t1= radial thickness of ring (mm)
Pw = allowable radial pressure on cylinder wall (N/mm2) = 0.025 Mpa
σp = permissible tensile strength for ring material (N/mm2) = 110 N/mm2
t2 = axial thickness of piston ring (mm)
b1 = width of top lands (mm)
b2 = width of ring lands (mm)

t3 = thickness of piston barrel at the open end (mm)
ls = length of skirt (mm)
do = outer diameter of piston pin (mm)
Mechanical efficiency of the engine (η) = 70 %.
H = Brake power (B.P)/ Indicating power
nr = the number of rings

VII. DESIGN DIMENSIONS OF PISTON

A. The parameters tH ,t1, t2, b1, b2, t3, are calculated using the following steps

1) Thickness of Piston Head (tH) :The piston thickness of piston head calculated using the following Grashoff's formula, tH =√ (3pD^2)/ (16σt) in mm
2) Radial Thickness of Ring (t1): $t1 = D \times \sqrt{3Pw/\sigma p}$
3) Axial Thickness of Ring (t2): The axial thickness of the rings may be taken as t2 = 0.7t1 to t1 or $t2 = D/10 \times n$
4) Width of the top land (b1): The width of the top land varies from b1= tH to 1.2 t
5) Width of other lands (b2): Width of other ring lands varies from b2= 0.7t2 to t
6) Maximum Thickness of Barrel at the top end (t3): t3=0.03×D+t1+4.
7) Length of the skirt ls= (0.6D to 0.8
8) Piston pin diameter (do): d0= (0.28D to 0.38D)
9) I.P = B.P /η = 14.9/0.9 = 16.55 KW

Also, I.P = P x A x L x N /2

Substituting the values we have

P = 13.56 Mpa

The dimensions for the piston is calculated and are represented in the table given below. These are used for the modeling of piston in CATIA.In the above procedure the dimensions of the ribs are neglected, so as to make the design for the piston to be simple. The modelled piston is shown in figure 1.

Table 3 Dimensions of the piston

S.NO	DIMENSIONS	SIZE(MM)
1.	Cylinder Bore	65.5
2.	Thickness of piston head(th)	8.03
3.	Radial thickness of ring(t1)	1.71
4.	Axial thickness of the ring(t2)	2.18
5.	Width of the top land(b1)	8.03
6.	Width of the other land(b2)	2.18
7.	Maximum thickness of barrel	8.575
8.	Length of the skirt(Is)	39.3
9.	Piston pin diameter(do)	18.34

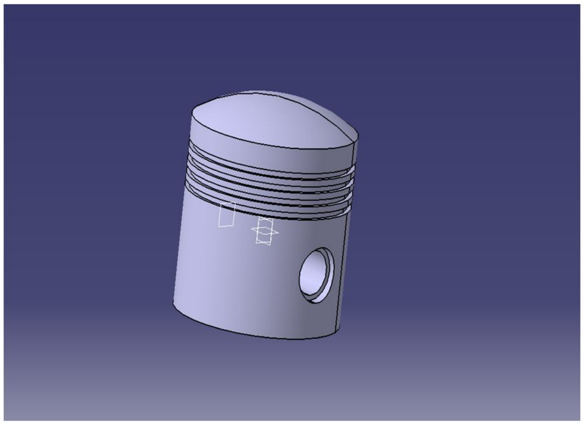

Fig 1 Model of the piston

VIII. ANSYS STIMULATION

A. ALUMINUM ALLOY

Deformation, stress and strain for Al alloy are as shown in figures 2,3,4 respectively

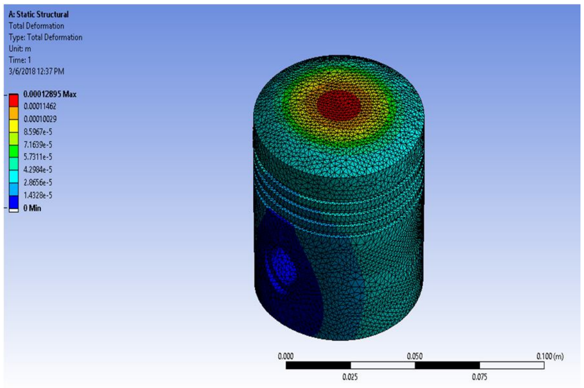

Fig 2 Deformation of Al alloy piston

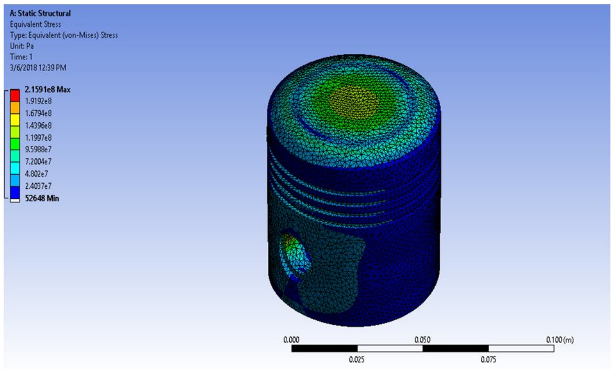

Fig 3 Stress of Al alloy piston

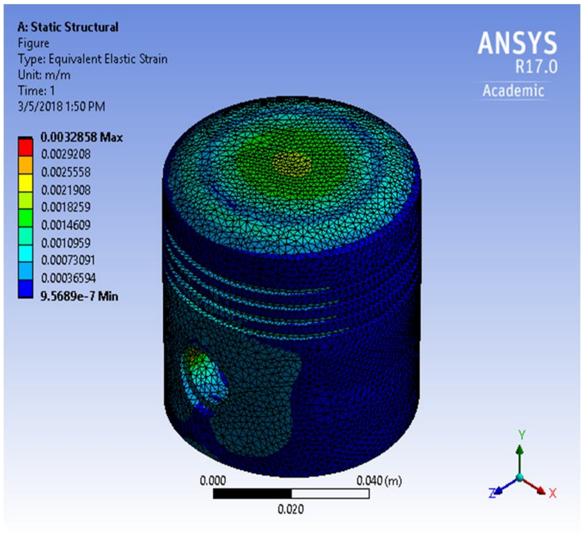

Fig 4 Elastic Strain of Al alloy piston

B. ALUMINUM COMPOSITES

Deformation, stress and strain for Al composites are as shown in figures 5, 6,7 respectively

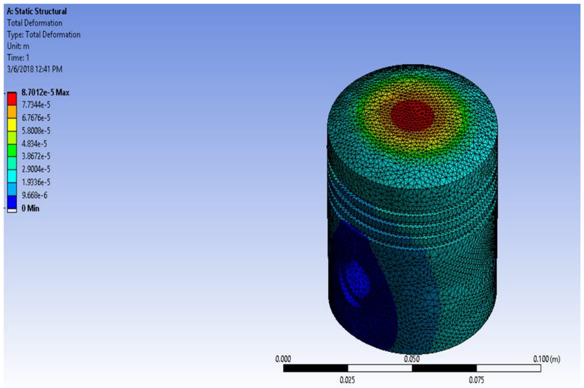

Fig 5 Deformation of Al-SiC10%-TiB$_2$5% composite

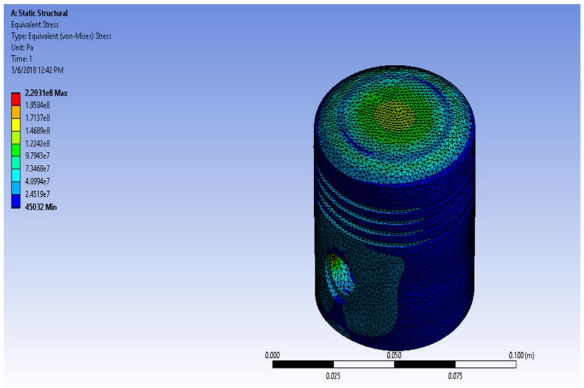

Fig 6 Stresses in Al-SiC10%-TiB$_2$5% composite

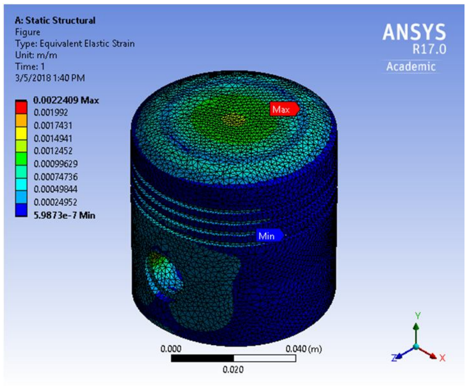

Fig 7 Elastic Strain in Al-SiC10%-TiB25% composite

As can be seen the composite is better than the alloy, because the deformation produced in aluminum composite is 40% less than the deformation produced in aluminum alloy. Although the stresses in composite are 5MPa more than that produced in alloy we can use composite for the design of piston.

IX. OPTIMIZATION

Optimization is done in order to achieve the objective of Minimization of the volume (weight) without crossing the stress and deflection limits. Following input parameters taken for optimization

P1= width of the top land (b1)
P2= radial thickness of the ring (t1)
P3= axial thickness of the ring (t2)
P4= length of the skirt (Is)
P5= maximum thickness of the barrel

P6= width of the other land (b2)

The Design of Experiments is used to find the optimum points the bounds of the input parameters are taken as follows.

Table 4 Lower and Upper limits of parameters

ID	Name	Classification	Lower Bound	Upper Bound
P1	XYPlane.L13	Continuous	7.227 [mm]	8.833 [mm]
P2	XYPlane.L14	Continuous	1.539 [mm]	1.881 [mm]
P3	XYPlane.L15	Continuous	1.962 [mm]	2.398 [mm]
P4	XYPlane.L18	Continuous	35.37 [mm]	43.23 [mm]
P5	XYPlane.L19	Continuous	7.7175 [mm]	9.4325 [mm]
P6	XYPlane.L22	Continuous	1.962 [mm]	2.398 [mm]

The Response Surface chart is drawn in ANSYS and is as shown in figure 8

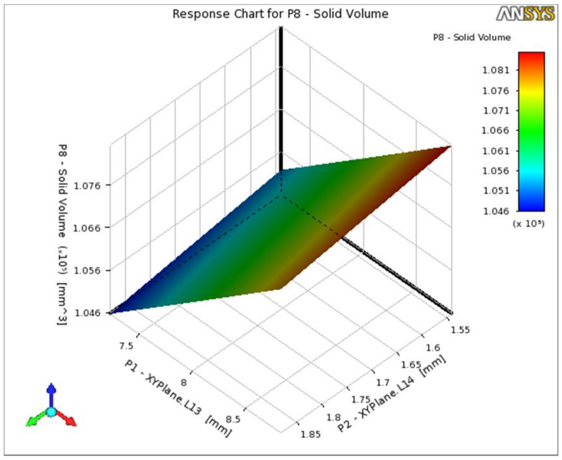

Fig 8 Response surface of Solid Volume

Best candidates of the optimization study using Response Surface Optimization are as shown in table 4. Table 5 shows the ratings used.

Table 5 Candidate points of Solid Volume

	P1 – XYPlane.L13 (mm)	P2 - XYPlane.L14 (mm)	P3 - XYPlane.L15 (mm)	P4 - XYPlane.L18 (mm)	P5 - XYPlane.L19 (mm)	P6 - XYPlane.L22 (mm)	P8 - Solid Volume (mm^3)
Candidate Point 1	7.227	1.881	1.962	35.37	7.7175	1.962	★★★ 87875
Candidate Point 2	7.7899	1.7028	2.3845	35.651	7.7541	2.352	★★ 91733
Candidate Point 3	7.3177	1.5766	2.2637	37.386	7.7584	2.0199	★★ 93757

Table 6 Rating Values (Response Surface Optimization system)

	P8 - Solid Volume (mm^3)
Objective	Range
★★★	[87875 ; 91006]
★★	[91006 ; 97267]
★	[97267 ; 1.0353E+05]
−	[1.0353E+05 ; 1.0979E+05]
×	[1.0979E+05 ; 1.1605E+05]
××	[1.1605E+05 ; 1.2231E+05]
×××	[1.2231E+05 ; 1.2544E+05]

X. RESULT ANALYSIS OF OPTIMIZATION

From minimization of surface volume it can be seen that candidate point 1 has got three stars, so for design of the piston the dimensions of the candidate point 1 must be taken into consideration.

XI. CONCLUSION

A comparison is made between piston made of Al alloy and Al composite. It is found that Al composite performs better than Al alloy. Optimization is done with an objective decreasing volume. It is observed for the objective of having minimum volume is met by choosing candidate point 1 as shown in table 5.

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