Development and Assessment of Piston by using Al-Si Hybrid Metal Matrix Composites Reinforced with SiC and Cenosphere Particulates

Vinoth M. A.
PG Scholar,
Department of Mechanical Engineering,
The Oxford College of Engineering,
Bangalore, India.

Arun L. R.
Research Scholar,
Department of Mechanical Engineering,
The Oxford College of Engineering,
Bangalore, India.

Vinay Kumar Uppinal
PG Scholar,
Department of Mechanical Engineering,
The Oxford College of Engineering,
Bangalore, India.

***Abstract*— This paper describes the modeling and static structural analysis of piston for various materials by consider loading of gas pressure force at 18 MPa. In this research work piston of an engine was modeled in CATIA and for precision results meshing was carried out in HYPER MESH and then analysis was done by using ANSYS. There are number of variations in piston design which include shape, mass, provision for expansion, skirt design and type of material. Here piston material was replaced by pure aluminium-12.5% silicon based composite material reinforced with 3% silicon carbide and 15% cenosphere particulates and the performance of a piston is compared with the former materials like LM26 and A4032. The parameters like von mises stress, von mises strain and displacements were obtained from ANSYS software. The analysis results clearly shows that the piston with aluminium MMC's has better results than the former materials. When compared to the conventional material the new material found to have less weight and greater strength.**

Keywords—piston, aluminium MMC, static structural analysis, LM26, A4032, CATIA, HYPERMESH, ANSYS

I. INTRODUCTION

A piston is a component of engine and it is a movable part fitted in to the cylinder which can receive and transmit power. In an engine its purpose is to transfer force from expanding gas in the cylinder to the crank shaft via a connecting rod. The piston's primary responsibility is to take thermal energy created by the ignition of fuel and air and transform it into linear motion. Linear motion acts on the crankshaft journal and becomes rotary motion.

Today aluminium alloys are generally used for mass produced pistons. Currently pistons for two-stroke and four-stroke internal combustion engines are exclusively manufactured out of metallic materials mostly aluminium alloys are used. Aluminium alloys pistons are most used in petrol and diesel engines because they are much lighter than existed material. However aluminium metal matrix composites have a smaller rate of expansion than the aluminium and cast iron in which most pistons operate. Because this aluminium metal matrix composite pistons are specially designed to resist high combustion temperature and expansion.

Pistons for internal combustion engines require specialized and highly developed materials. Usually pistons are designed to resist high combustion temperature. Due to their unique properties of aluminium metal matrix composite materials such as greater strength, better stiffness, low density, improved controlled thermal expansion, high thermal conductivity and good wear resistance which have been especially developed for this application offer an alternative to former materials and allow exceptional solutions as well as improved performance in automotive engineering.

Ch.Venkata Rajam [1] analyzed stress distribution in the various parts of the piston is by using ANSYS and they observed that the volume of piston is reduced by 24%, the thickness of barrel is reduced by 31%, width of other ring lands of the piston is reduced by 25% and von-mises stress is increased by 16%. But the deflection is increased after optimization.

Ghodake A. P. [2] developed the piston design by CAE tool and they evaluated the various stresses such as maximum principal stresses, minimum principal stresses, von mises stresses and total deflection occurred during working condition.

Ajay Raj Singh [3] described the stress distribution and thermal stresses of three different aluminium alloys piston by using finite element method and they concluded that Al-GHS 1300 material is superior among the three materials.

S. Srikanth Reddy [4] investigated thermal analyses on a conventional diesel piston made of aluminium silicon alloy and the analyzed results indicated that the maximum stress has changed from 85 MPa to 55 MPa and biggest deformation has been reduced from 0.051762 mm to 0.025884 mm.

A. R. Bhagat [5] describes the stress distribution of the seizure on piston four stroke engine by using finite element analysis and the results analysed indicates that maximum stress has been changed from 228 MPa to 89 MPa and deformation has reduced from 0.419 mm to 0.434 mm.

Wilfried Wunderlich [6] here the aluminium piston Al 11wt% Si alloys SC100, ACA8, A4032 were tested together with A2618-T6 to studied their mechanical properties and their thermal fatigue behaviour.

Chang-Yeol Jeong [7] studied the effect of alloying elements on mechanical behaviour of Al 12%Si alloys for piston has been conducted. The strength of the matrix was increased by increasing on Ni and Cu content but the elongation was increased in the reverse case.

D.Rudnik [8] illustrated the limitations which result from the material and design of existing composite materials of aluminium alloy matrix for pistons and other engine components to improvement of engine operation features.

Dr. Dietrich Kehr [9] studied the properties, application and advantages of carbon piston here carbon pistons were manufactured by ceramic process and they reduced the piston weight by 30 %, engine performance was increased by 10 %, reduced oil consumption by 50 %, fuel consumption was reduced by up to 5 % and reduced CO emissions by 55 %.

J. Heuer [10] manufactured carbon pistons by turning and milling from the solid with the aid of numerically controlled machines and carbon pistons was accumulated more than 15000 miles without any trouble. Here they evaluated that piston weight is possible to reduce by 10% and another weight reduction of 10 % was realized by the application of ceramic piston pin.

Jonathan A. Lee [11] developed a high performance piston alloys to meet U.S. automotive legislation requiring low exhaust emission and they economically produced Al-Si alloy with silicon content ranging from 6% to 18%. At high silicon levels the alloy exhibits excellent dimensional stability, surface hardness and wear resistant properties.

1.1 *Characterization of materials*

The materials chosen for this work are LM26, A4032 and Al MMC for an internal combustion engine piston. The relevant mechanical properties of LM26, A4032 and Al MMC are illustrated in the below table 1.1.

Table 1.1: Mechanical properties for various samples

S.NO.	Parameters	LM26	A4032	Al MMC
1	Density	2.76	2.69	2.36
2	Young's Modulus	71	79	87
3	Ultimate Tensile Strength	210	380	407.82
4	Poisson's Ratio	0.33	0.3	0.3
5	Yield Strength	210	315	394

II. PISTON DESIGN AND GENERATION OF FINITE ELEMENT MODELING

2.1 Geometric model of piston

The piston model is designed according to the specification and design data which are followed in bajaj discover engine piston. It is a single cylinder four stroke air cooled type petrol engine. Those engine specifications are given in table 2.1 and the geometric model of piston was modeled in CATIA is shown in figure 2.1.

Table 2.1 Bajaj discover engine specifications

Parameters	Significances
Engine Type	Four stroke petrol engine
Induction	Air cooled type
Number of cylinders	Single cylinder
Bore	67mm
Stroke	75mm
Displacement	135 cc
Maximum Power	13.8 bhp at 8500 rpm
Maximum Torque	13.4 N-m at 6000 rpm
Compression ratio	9.35

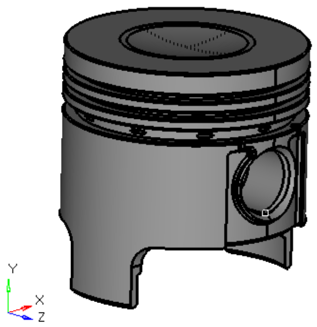

Figure 2.1: Geometric model of piston

2.2 Generation of finite element model

The finite element model is generated by using hypermesh V12 for accuracy. The SOLID 187 tetra hedral element is used for meshing of piston. SOLID187 element is a higher order 3-D, 10-node element. The element is defined by 10 nodes having three degrees of freedom at each node translations in the nodal x, y, and z directions. The mesh count for the finite element model contains 75140 numbers of nodes and 58560 numbers of elements. The FE model of piston is shown in figure 2.2.

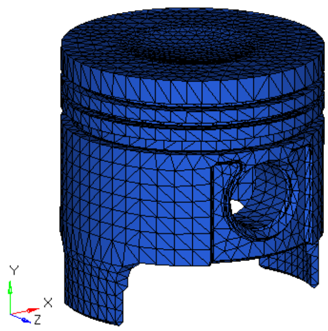

Figure 2.2: Finite element model of piston

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 7, July - 2014

III. METHODOLOGY OF PISTON ANALYSIS

During the working condition piston exposed to the high gas pressure because of combustion. So the methodology for analyze the piston is to consider the gas pressure as applied uniformly over the piston crown. The pressure force generated by the burning of fuel is calculated using gas equation and it is assumed that side thrust force and inertia force is negligible but in reality this may have some influence on stress and deformation of piston. Also the temperature effect is neglected and assumed that temperature is uniform.

3.1 Pressure calculations for piston

From the gas equation:

$$\mathbf{P\,V = M\,R_{specific}\,T}$$

Mass = density x volume

= 737.22e-9 * 135e3

$$\mathbf{M = 0.1\ Kg}$$

$$R_{specific} = R/M$$

= 8.3543/0.1

$$\mathbf{R_{specific} = 83.54}$$

$$P = (M * R_{specific} * T) / V$$

P= (0.1*83.54*288)/135e3

$$\mathbf{P = 18\ MPa}$$

Where

P= Pressure in MPa

V= Volume in m^3

M= mass of the fuel in Kg

$R_{Specific}$= Specific gas constant

T= Temperature

The pressure force of 18 MPa is applied on highlighted red colour surface of the piston crown in vertically downward direction and it's shown in figure 3.1.

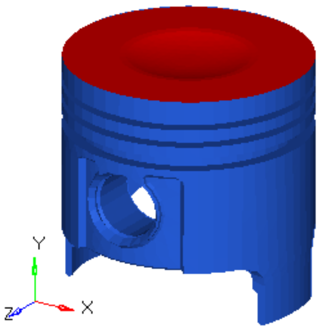

Figure 3.1: Pressure force on piston

IV. STATIC STRUCTURAL ANALYSIS RESULTS AND DISCUSSIONS

4.1 Static analysis of piston using LM26 material

In LM26 alloy has maximum von mises stress induced in the piston is 320 MPa at the inner boss fillet area which is due to stress concentration effect and pressure application on top face of the piston. The stress at piston ring grooves is approximately 140 MPa. The stress distribution is shown in the figure 4.1.

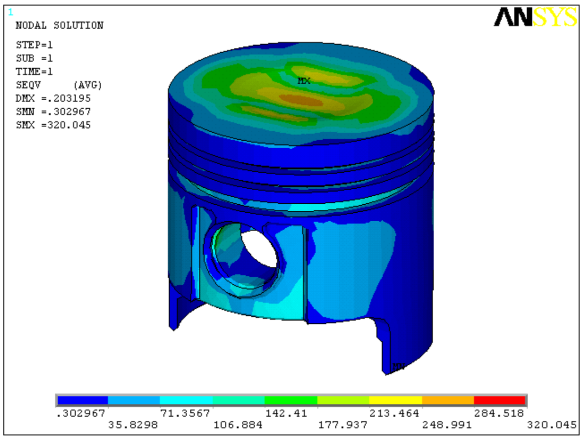

Figure 4.1: Von misses stress plot on piston for LM26

The maximum displacement is 0.203 mm is observed at the center of the piston due to applied pressure force and the deformation pattern of the piston is shown in figure 4.2.

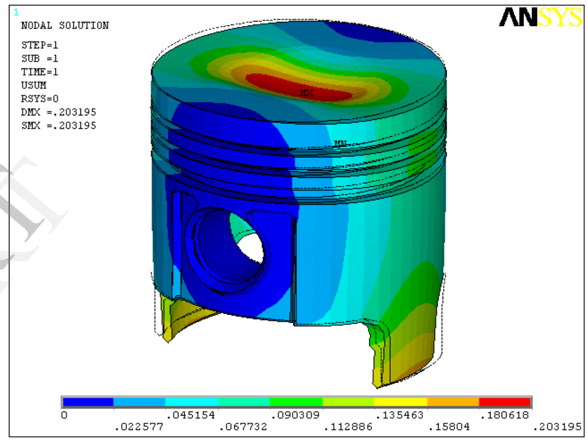

Figure 4.2: Total deformation on piston for LM26

4.2 Static analysis of piston using A4032 alloy

In A4032 alloy has maximum von mises stress induced in the piston is 314 MPa and the stress at piston ring grooves is approximately 120 MPa. The stress distribution is shown in the figure 4.3.

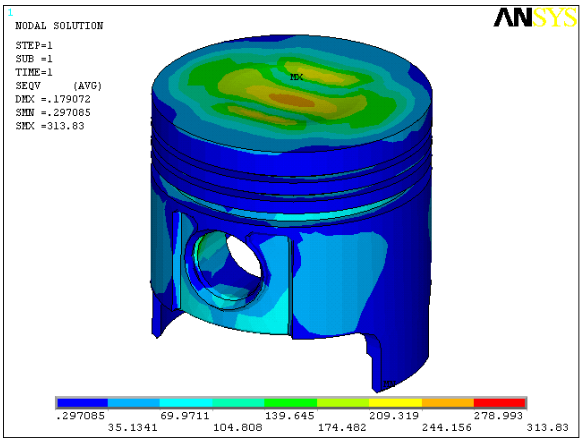

Figure 4.3: Von mises stress plot on piston for A4032

The maximum displacement is 0.179 mm is observed at the center of the piston due to applied pressure force and the deformation pattern of the piston is shown in figure 4.4.

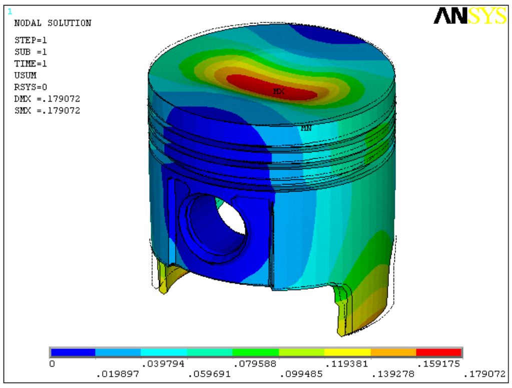

Figure 4.4: Total deformation on piston for A4032

4.3 Static analysis of piston using aluminium MMC

The analysis is carried out by using aluminium metal matrix composite material properties. The maximum von mises stress induced in the piston is 305 MPa at the inner boss fillet area which due to stress concentration effect and pressure application on top face of the piston. The stress at piston ring grooves is approximately 110 MPa. The stress distribution is shown in the figure 4.5.

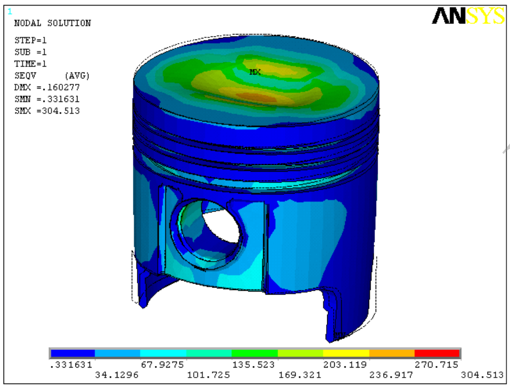

Figure 4.5: Von mises stress plot on piston for aluminium MMC

The maximum displacement is 0.160 mm is observed at the centre of the piston due to applied pressure force and the deformation pattern of the piston is shown in figure 4.6.

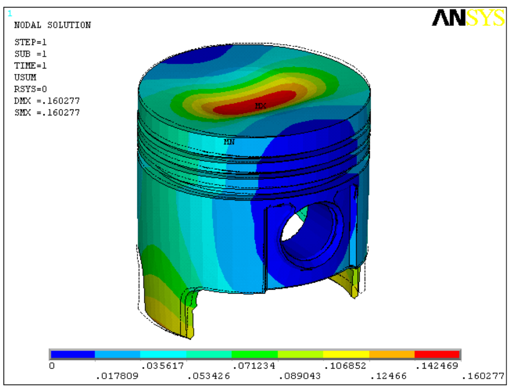

Figure 4.6: Total deformation on piston for aluminium MMC

V. CONCLUSIONS

In this research static structural analysis of piston were performed on various materials like LM26, A4032 and aluminium MMC by consider loading of gas pressure force at 18 MPa. The obtained results are as following:

- The static structural analysis results for LM26 material are Von-mises stress=320 MPa, Von-mises strain=0.00476 and Displacement=0.203mm.
- For A4032 material obtained results are Von-mises stress=313 MPa, Von-mises strain=0.00419 and Displacement=0.179mm.
- The static analysis results for Al MMC are Von-mises stress=304 MPa, Von-mises strain=0.00374 and Displacement=0.160mm.
- It is observed that the analysis results clearly shows that the piston with aluminium MMC material has better results than the former materials LM26 and A4032. It also indicated that have minimum displacement than conventional materials.
- When compared to the conventional material the new material found to have less weight and more strength.

SCOPE OF THE FUTURE WORK

- In the present research pressure force of 18 bars and uniform temperature on piston is used for static structural analysis. So the work can be carried out by applying different pressure and temperature.
- And also the study can be extended by analyzing thermal and vibration characteristics.

REFERENCES

[1] Ch.Venkata Rajam, P.V.K.Murthy, M.V.S.Murali Krishna and G.M.Prasada Rao "Design Analysis and Optimization of Piston using CATIA and ANSYS" International Journal of Innovative Research in Engineering & Science ISSN: 2319-5665. (January 2013, issue 2 volume 1)

[2] Ghodake A. P. and Patil K.N. "Piston Design and Analysis by CAE Tools" IOSR Journal of Engineering (IOSRJEN) ISSN: 2250-3021 ISBN: 2878-8719 PP 33-36 National Symposium on engineering and Research

[3] Ajay Raj Singh and Dr. Pushpendra Kumar Sharma "Design, Analysis and Optimization of Three Aluminium Piston Alloys Using FEA" Ajay Raj Singh et al International Journal of Engineering Research and Applications. ISSN: 2248-9622, Vol. 4, Issue 1(version 3, January 2014, pp.94-102)

[4] S. Srikanth Reddy and Dr. B. Sudheer Prem Kumar "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, Issue 12, December 2013 ISSN: 2319-8753

[5] A.R. Bhagat and 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 ISSN: 2249-6645

[6] Wilfried Wunderlich and Morihito Hayashi "Thermal Cyclic Fatigue Analysis of Three Aluminum Piston Alloys" International Journal of Material and Mechanical Engineering, 2012, pg: 57-60, Published Online June 2012

[7] Chang-Yeol Jeong "Effect of Alloying Elements on High Temperature Mechanical Properties for Piston Alloy" The Japan Institute of Metals Materials Transactions, Vol. 53, No. 1 (2012) pp. 234 to 239

[8] D.Rudnik, J.Sobczak and A.Wojciechowski, K.Pietrzak "New Material Solutions in Combustion Engines", Journal of KONES Internal Combustion Engines 2003, vol.10, pg: 3-4

[9] Dr. Dietrich Kehr, Dr. Joachim Metz and Hans-Joachim Wagner "Carbon pistons for internal combustion engines" Schunk Kohlenstofftechnik, Heuchelheim, Germany

[10] J. Heuer "Development and Testing of Carbon Pistons" Research, Structural Materials Daimier-Benz Akitiengesell schaft, Stuttgart, Germany

[11] Jonathan A. Lee "Cast Aluminium Alloy for High Temperature Applications" The Minerals, Metals & Materials Society, NASA-Marshall Space Flight Center, Mail Code ED33, Huntsville, AL 35812, USA.