Structural Simulation and Optimization of Diesel Engine Piston Material using ANSYS

Rakshith M, Sunil K, Prashant S. Hatti

***Abstract:** During the combustion of fuel in diesel engine, high temperature and pressure will be created as engine runs at high speed and loads. This results in development of high thermal and structural stresses in the piston and if these stresses exceed the design value, failure of piston may take place. To avoid these failures, intensity of stresses should be avoided. In this work an attempt is made to reduce the intensity of stresses by replacing conventional aluminum alloy material of piston with aluminum silicon carbide composite by commercial analysis software package ANSYS.*

***Key Words:** Diesel engine piston, Aluminium alloy, Aluminium silicon carbide composite, Structural analysis, ANSYS14, Material optimization.*

I.INTRODUCTION

A diesel engine being an IC engine uses compression heat to begin the ignition of fuel in the combustion chamber. The diesel engine is based on diesel cycle which consist of induction strokes, compression, strokes, power strokes and exhaust strokes. Piston is an important cylindrical plug which move up and down in reciprocating engine which converts chemical energy into useful mechanical power. The most commonly used material in automotive piston is aluminum due to its low weight, low cost and high strength. A composite material is metallurgically bonding of two or more different materials. The biggest advantage of composite is light and strong. Metal matrix composite has high fracture toughness, stiffness, strength, and can withstand elevated degree at corrosive environment Aluminum silicon carbide (Al-SiC) is the widely used MMC because of their superior properties such has high strength, stiffness, hardness, wear and corrosion resistance and also lightweight.

A. Literature survey

Vinod Junju et. al. (Jun 2012), made an attempt to reduce the intensity of thermo-structural stress by having silicon nitride coating on the top of eutectic aluminium alloy piston crown where ceramic reinforcement was used to reduce the failure of ceramic crown.

Revised Manuscript Received on December 30, 2019.

* Correspondence Author

Rakshith M*, Department of Mechanical Engineering, Cambridge Institute of Technology-North Campus, Bengaluru 562110, India. Email: rakshithm6792@gmail.com

Sunil K, R&D Department, Futuretech Engineering Pvt Ltd, Bengaluru 560079, India. Email: sunilk28@gmail.com

Prashant S. Hatti, Department of Mechanical Engineering, CMR Institute of Technology, Bengaluru 560037, India. Email: prashant.h@cmrit.ac.in

Manisha B Shinde et.al. (Oct 2016), carried out the structural analysis for piston made of Al alloy A2618, Al-GHY1250 and Al-GHS1300. The model is done in Creo and analysis in ANSYS. Comparative study is done to select the best material. Pathipati Vasu et. al. (Mar2018), describes stress distribution of Al-Sic graphite, A7075, A6082, A4032, Al-ghy1250 materials for piston of Bajaj Kawasaki motorcycle using Ansys15.The best material is selected based on results of structural and thermal analysis of these materials. Abino John et. al. (May2015), Aluminium silicon carbide AlSiC, aluminium composite is used as an alternate to aluminium because of their abrasion resistance, creep resistance, strength to weight ratio, stiffness to weight ratio and better high temperature performance.

B. Problem Statement

In an engine, energy of expanding gas in the cylinder may cause wear and tear in piston. So, there is a need to analyze area of maximum stress, strain, deformation, temperature distribution and heat flux on piston. The objective of this work is to model and analysis the piston made of aluminium alloy and aluminium silicon carbide.

II.METHODOLOGY

- Study of literature review
- Creation of 3D model piston using CatiaV5 and imported to ANSYS14.
- Meshing of piston using ANSYS 14.
- Analysis of piston using structural analysis method.
- Comparison between results of piston made of aluminium alloy and aluminium silicon carbide composite.
- Selection of best materials for diesel engine piston.

III. MODELING OF DIESEL ENGINE PISTON

CAD package Catia V5 has been used to model the diesel engine piston using the design and parameter of TATA motor diesel engine piston [5].

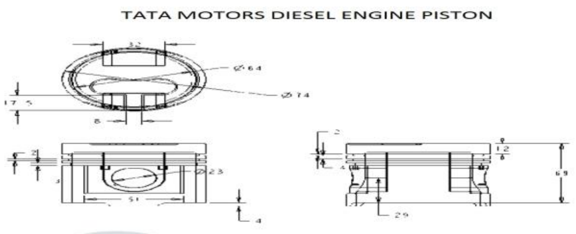

Fig -1: 2D sketch of diesel engine piston

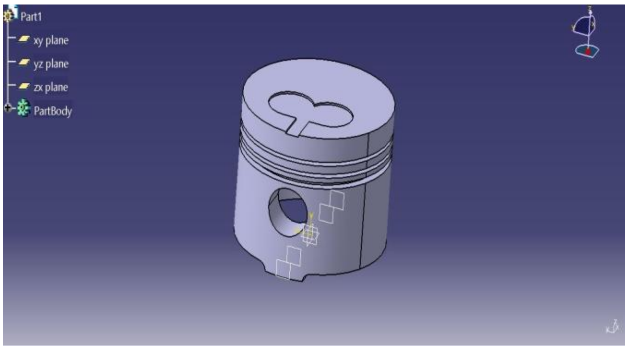

Fig -2: 3D sketch of diesel engine piston

IV. MATERIAL PROPERTIES

The material used for this work are conventional aluminium alloy i.e. Hyper eutectic aluminium alloy(forged) and metal matrix composite i.e. Al-Sic-9(aluminium silicon carbide) for diesel engine piston. The table -I list the properties of mechanical behavior of above two materials.

Table -I: Mechanical properties of aluminum alloy and aluminum silicon carbide composite materials

MATERIAL	Hyper eutectic aluminum alloy (Forged)	Al-Sic -9
YOUNGS MODULAS E (GPa)	84	188
POISSION'S RATIO (μ)	0.33	0.33
DENSITY (Kg/$\mathbf{m}^3$)	2680	3010
COEFFICIENT OF THERMAL EXPANSION(1/k)	$19.5e^{-6}$	$8e^{-6}$
Thermal Conductivity K (W/m k)	155	190
Yield strength (Mpa)	280	488

Initially conventional aluminum alloy piston is analyzed and the results obtained are compared with MMC pistons.

V. STRUCTURAL ANALYSIS

Structural analysis is carried to determine the mechanical loads effects on structures and their components. Focus lies on pressure analysis of piston in this work.

A. Boundary Condition

Pressure will be applied on the top of piston due to explosion of gases in cylinder. The pressure force calculated will be the mechanical load in structural analysis and acts as boundary conditions.

B. Meshing

Auto mesh command is used to mesh the piston in ANSYS14.Mixed mesh type element are used during discretization as main focus of work lies on material optimization.

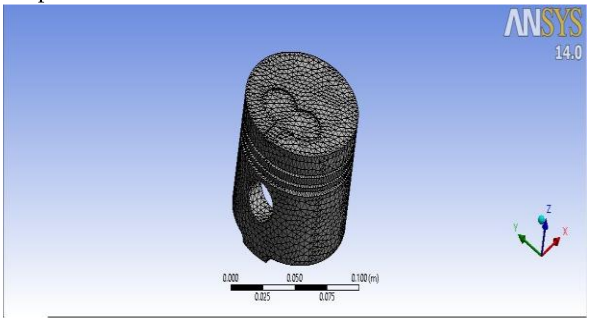

Fig -3: Meshed model

C. Calculation of pressure [5]

Engine Speed N=2700rpm

Piston diameter d=88.90mm

IHP=48.75HP

BHP=39HP

L=110mm

Mechanical Efficiency η=80%

$$\mathrm{IHP} = \frac{\mathrm{PmLA(N/2)}}{60e^3} \qquad (1)$$

P_m=23.67bar

The mean effective pressure 23.67bar will be taken as mechanical load acting on piston head. The surface of pin hole is provided with fixed support as piston will move top to bottom in the cylinder with pin hole fixed.

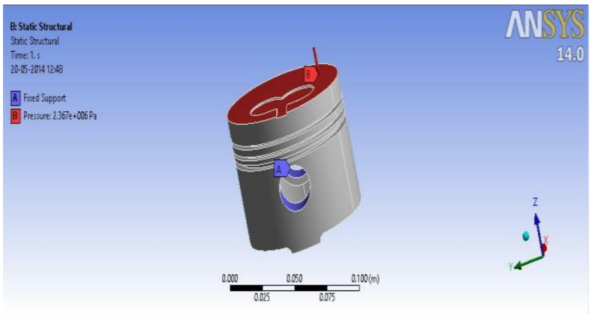

Fig -4: Structural boundary conditions

VI.RESULTS

According to soderberg criterion [6]

$$\frac{\mathbf{1}}{\boldsymbol{FOS}} = \frac{\sigma v}{\sigma e} + \frac{\sigma m}{\sigma y} \qquad (2)$$

Where,

F.O. S=Factor of Safety

σ_v=variable stress=$\frac{\sigma_{max}-\sigma_{min}}{2}$ σ_m=Mean stress=$\frac{\sigma_{max}+\sigma_{min}}{2}$

σ_m=maximum stress σ_e=endurance stress =0.6σ_y

σ_y=yield stress

By the definitions of FOS,

we have

$$F.O.S = \frac{yieldstress}{Workingstress} \quad [6] \qquad (3)$$

A. Hypereutectic aluminium alloy

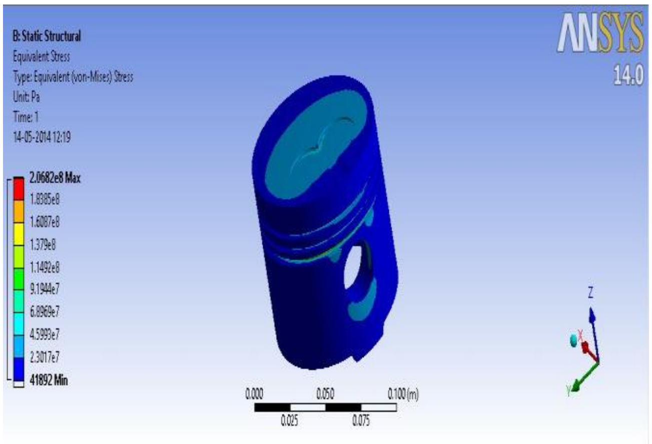

Fig -5.1: Vonmises stress

The maximum and minimum stress obtained through ANSYS14 for hypereutectic aluminium alloy piston are 206.28Mpa and 0. 04182Mpa.Using soderberg criteria, FOS is 1.09 which means design is safe as it is greater than 1. Working stress obtained is 275.06Mpa, which is lesser than the yield strength of 280 Mpa for hypereutectic alloy.

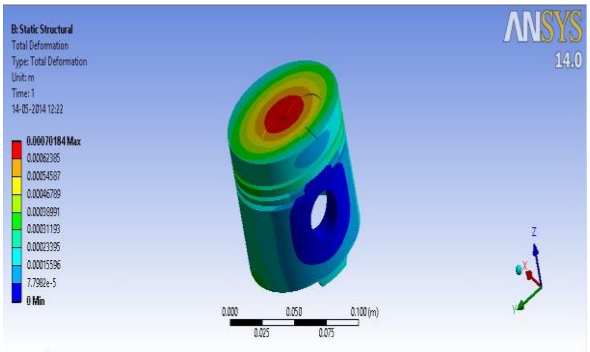

Fig -5.2 Total deformation

Fig -5. Structural analysis results of aluminum alloy piston

Vonmises stress and deformation obtained for aluminum alloy piston are 206.28Mpa and 0.7018mm and are illustrated in fig 5.1 and 5.2 respectively.

B. Aluminium silicon carbide composite

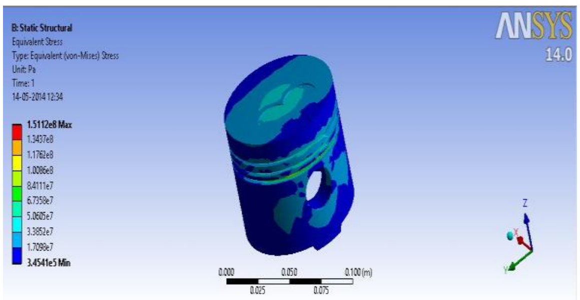

Fig -6.1: Vonmises stress

The maximum and minimum stress obtained through ANSYS14 for aluminium composite piston are 151.28Mpa and 0. 03454Mpa.Using soderberg criteria, FOS is 2.23 which means design is safe as it is greater than 1. Working stress obtained is 201.47Mpa, which is lesser than the yield strength of 450Mpa for aluminium silicon carbide.

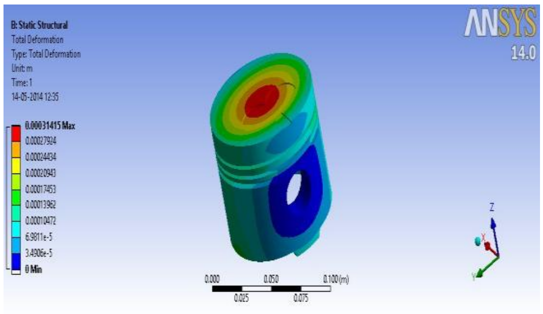

Fig -6.2 Total deformation

Fig -6. Structural analysis results of aluminum silicon carbide mmc piston

Vonmises stress and deformation obtained for aluminum silicon carbide piston are 151.28Mpa and 0.3141mm and are illustrated in fig 6.1 and 6.2 respectively.

C. Comparative performance

The comparative performance of simulated results of various parameters like maximum and minimum value of total deformation and equivalent Vonmises stress for two different material are listed in table-II.

Table -II: Structural analysis results

Materials	Deformation(mm)	Stress (Mpa)
Hyper eutectic alloy	0.7018	206.28
Al-Sic-9	0.3141	151.28

VII. CONCLUSIONS

The CATIAV5 modeled piston when analyzed in ANSYS14 commercial package, The Vonmises stress obtained in aluminum silicon carbide composite piston is 151.28Mpa. whereas Vonmises stress obtained in aluminum alloy piston is 206.28Mpa.

Deformation obtained in aluminum alloy piston is 0.7018mm but in aluminum MMC piston it is 0. 3141mm.

The stress intensity along with deformation has been reduced in AlSiC composite piston because of the reinforcement particle present in composite material which enhances the structural properties of piston made of composite. Thereby performance and efficiency of engine improves by using AlSiC piston.

ACKNOWLEDGEMENT

The authors would like to acknowledge the support of Cambridge Institute of Technology-North Campus, Bengaluru 562110, Futuretech Engineering Pvt Ltd, Bengaluru 560079 and CMR institute of Technology, Bengaluru 560037 for carrying out this work.

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AUTHORS PROFILE

Rakshith M, Rakshith M, Assistant Professor in Department of Mechanical Engineering, Cambridge Institute of Technology-North Campus Bengaluru, India. Completed M.Tech. in Machine Design from CMR Institute of Technology, Bengaluru. Has 3 years of experience in teaching. Area of expertise includes Dynamics of Machines, Design of machine elements. Has published many papers in international journals and has attended international conferences. Area of research includes finite element analysis, fatigue, nanocomposites.

Sunil K, Senior Quality Engineer, in Department of R&D, Futuretech Engineering Pvt Ltd, Bengaluru, India. Completed B.E in Mechanical Engineering in Rajarajeswari College of Engineering, Bengaluru. Has 5 years of industrial experience.

Prashant S Hatti, Assistant Professor in Department of Mechanical Engineering, CMR Institute of Technology, Bengaluru, India. Completed M.Tech. in Design Engineering from Dayananda Sagar College of Engineering, Bengaluru and presently pursuing Ph.D from VTU, Belgaum, Karnataka. Has 9 years of experience in teaching. Has presented and published many papers in international conferences and journal. Area of research includes nonmaterials, purification of exhaust gases.