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Thermo-Mechanical and Vibration Analysis of the I.C. Engine Piston made of SiC reinforced ZrB2 composite using Finite Element Method (ANSYS)

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ABSTRACT: *The main objective of this research work is to investigate and analyse the stress distribution of piston at actual engine condition. The parameter used for the simulation is operating gas pressure and material properties of piston. To evaluate the material properties of piston the maximum principal stress, minimum principal stress and von mises stresses were calculated. These stresses were calculated for three different materials by comparing we found out that SiC reinforced ZrB2 composite material provides less stress concentration and more stability at higher temperature. For stability checking at higher temperature thermal analysis were carried out. This research work suggests a new type of SiC reinforced ZrB2 composite material that can sustain at higher temperature (1680 K) and pressure (18 MPa). The structure of piston was modeled by using SOLIDEDGE software. Finite element modeling and analysis were performed using ANSYS 14. The natural frequency and Vibration mode of the piston were obtained and its vibration characteristics are analysed. The free vibration analysis show that the natural frequency of vibration varies from 1.28e-5 Hz to 274.44 Hz.*

Keywords: *Composite, CMC, Piston, modal analysis, thermal analysis, ANSYS.*

I. INTRODUCTION

There are significant research works proposing, for engine pistons designs, 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. Engine pistons are one of the complex components and its damage mechanisms have different origins and are mainly wear, temperature, and fatigue related. Among the fatigue damages, thermal fatigue and mechanical fatigue, either at room or at high temperature, play a prominent role [1-2]. For mechanical fatigue analysis we have considered vibration analysis of the piston and used finite element method ANSYS 14.0 to analyse the vibration mode of piston made of ceramics matrix composite (CMC) material.

The engine piston during combustion, exposed to the high temperature and pressure . It is important to calculate the piston temperature distribution in order to reduce the thermal stresses and deformations within acceptable levels. Most of the pistons are made of an aluminium alloy which has thermal expansion coefficient, 80% higher than the cylinder bore material made of cast iron. This leads to some differences between running and the design clearances. The strong periodic fluctuations of temperature in a cylinder cause temperatures to vary in the upper most layer of the piston crown. A large part of the heat absorbed by the piston crown during the expansion stroke is released to the coolant by the piston ring zone and by the cylinder wall [3-4].Thermal analysis using ANSYS 14.0 [7] predict the behaviour of SiC reinforced ZrB2 at a temperature of 1675K.

Piston should be made of a material with good friction properties, of high strength, and capable of producing good casting having good machining properties. Piston aluminium alloys are a special group of industrial aluminium alloys, which have high mechanical properties at elevated temperatures (approximately up to 35000C) [5-6] .The piston is one of the most critical components of an engine. Therefore, it must be designed to withstand from damage that is caused due to extreme heat and pressure of combustion process. The value of stress that caused the damages can be determined by using FEA [9-10].

S.M. Sapuan [1] has suggested a material selection knowledge base model that provides the best suited material for automotive engine components. By his study he suggested SiC reinforced ZrB2 composite material for manufacturing of piston based on its mechanical properties. We have selected this material for our research study. Before this no study have been done on this material. We have done static, modal and thermal analysis to evaluate its properties for piston design and manufacturing.

The objective of this research work is

- To calculate the Maximum principal stress, Minimum principal stress and equivalent (Von-Mises) stresses by considering the gas pressure.
- To optimize the piston model for new composite material SiC reinforced ZrB2.

So the methodology for analyzing the piston is a uniformly distributed gas pressure 18 MPa is applied over top surface of piston (crown) and piston pin hole is considered as frictionless support. Considering the type of fit between piston pin and piston is clearance fit.

II. THE CAD MODEL & LINEAR STATIC ANALYSIS OF ENGINE PISTON

The Cad Model of Piston

ANSYS 14.0 is Finite Element Method based software used for the structural, modal and thermal analysis. For analysis the object geometry is divided into elements. These elements are interconnected to each other at a point known as Node. In present research work we have used FEA for the Thermal, Structural and Modal analysis of 321-Austenitic Stainless steel exhaust manifold. The CAD software SOLIDEDGE [8] is selected to prepare the solid geometry of the Piston. The CAD model with piston pin hole as frictionless support is shown as Fig.1.After the completion the .IGES file is imported from the SOLIDEDGE to ANSYS software for the linear static analysis. The meshed model of piston is shown in Fig. 2. It consists of 14655 nodes and 10800 elements. The analytically calculated pressure force 18 MPa is applied at the top surface of piston (crown) Fig. 3.

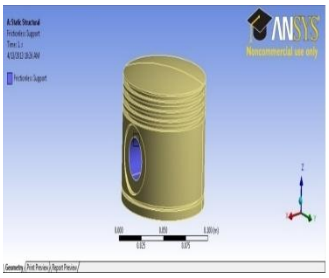


Fig.1. CAD model of piston

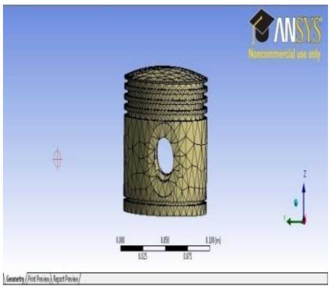


Fig. 2. Meshed model of piston

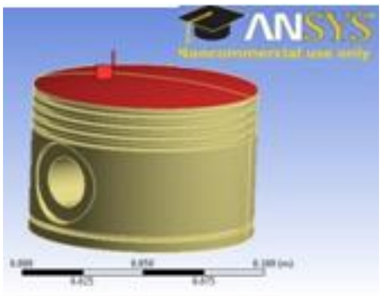


Fig. 3. Application of pressure

Materials and Parameters Variation

The material is changed for the same loading condition (18 MPa at top surface of piston crown and piston pin hole frictionless supported) , a table (1) is obtained.

Table 1. Different Materials and parameter variation

S.N.	Properties (Max Value)	Al Alloy (2024-T6)	Grey Cast Iron	SiC reinforced ZrB2 Composite
1	Max. Principal Stress (Pa)	2.8494e8	2.8333e8	2.8262e8
2	Min. Principal Stress (Pa)	-8.345e7	-8.568e7	-7.9908e7
3	Equivalent(Von-Mises)Stress (Pa)	3.7587e8	3.6807e8	3.7433e8

From the table it is concluded that SiC reinforced ZrB2 Composite provides the better strength and rigidity in comparison to Al alloy and grey cast iron. Silicon carbide reinforced Zirconium diboride is a ceramic matrix composite (CMC) material. It provides good strength and rigidity at high temperature and pressure. By using SiC reinforced ZrB2 composite material the overall performance of the engine increases.

Linear Static Analysis of Heavy Duty Engine Piston

A static structural analysis is used to determines the strains, stresses, displacements, and forces in structures and it do not include inertia and damping effects. The piston static analysis is done by ANSYS 14.0. For the static analysis the combustion pressure of 18MPa is applied at the crown. From the figure 4 the results shows that during sudden impact the maximum principal stress occurs at the crown and the chances of piston failure is from the crown (red colour coding). Figure 5 shows that for the given condition of loading the

Equivalent Von-Mises stress are maximum at the crown of engine piston . Higher temperature and pressure provides higher displacement and it is found that the Von Mises stress affects the lateral displacement.

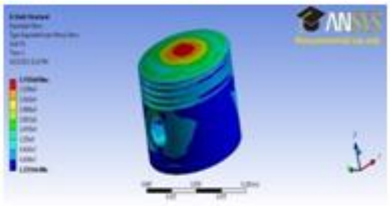


Fig.4. Principal stress variation

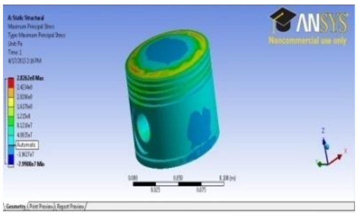
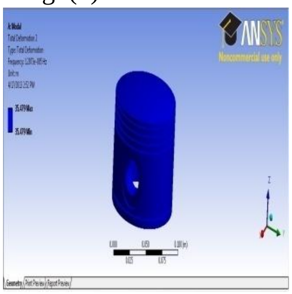


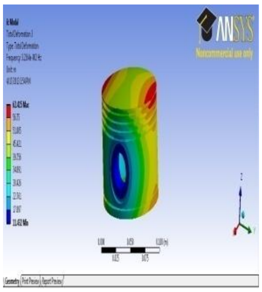
Fig. 5. Equivalent (Von-Mises) stress

Vibration Character Analysis

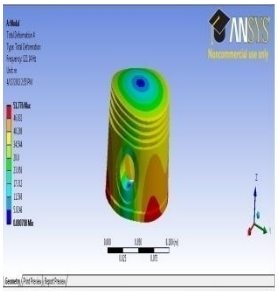
To determine the dynamic response, modal analysis using FEA is performed using implicit FE code-ANSYS 14.0. ANSYS 14.0 Workbench is selected as calculation platform, for free vibration analysis load freedom is selected by program automatically. The first 10 order vibration mode of piston is calculated as shows in Fig. (6).



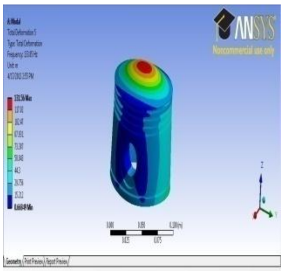
(a) First order Vibration Mode



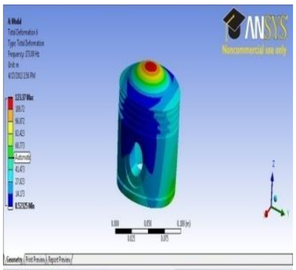
(b) Second order Vibration Mode



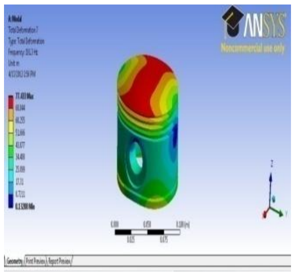
(c) Third order Vibration Mode



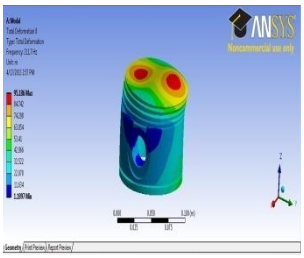
(d) Fourth order Vibration Mode



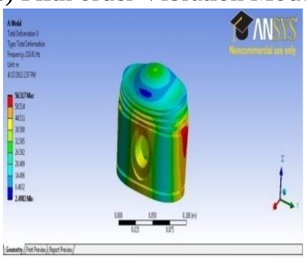
(e) Fifth order Vibration Mode



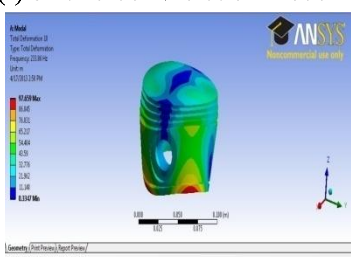
(f) Sixth order Vibration Mode



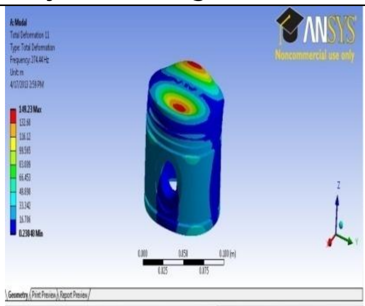
(g) Seventh order Vibration Mode



(h) Eight order Vibration Mode



(i) Nine order Vibration Mode



(j) Tenth order Vibration Mode

Fig.6. The first tenth orders vibration mode of the piston

III. THERMAL ANALYSIS

ANSYS 14.0 Workbench is selected for thermal analysis of Sic reinforced ZrB2 composite material engine piston to check the suitability at higher temperature. Fig. 7 shows high temperature of 1675 K is applied throughout the body for thermal analysis. Fig. 8 shows the heat flux generation. The heat flux generation in piston is under safe condition. It is mention by blue colour region .The red colour region is not available which shows that localization of thermal stresses is not available and design and material is safe. Fig. 9 shows the nodal triads. The orientation of nodes from its original position is very less which shows that the deformation is less.

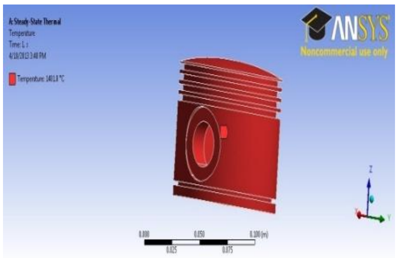


Fig.7. Temperature Distribution

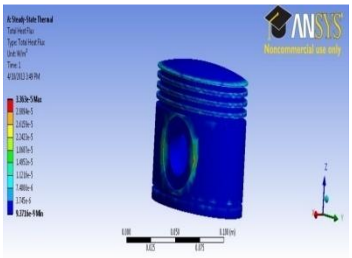


Fig.8. Heat flux generation

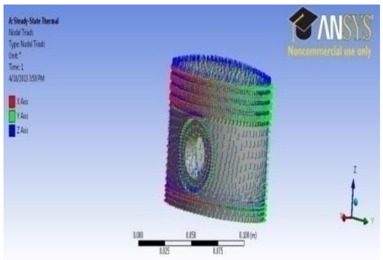


Fig. 9 Nodal Triads

IV. CONCLUSION

It is observed that vibration and the stresses induced are the two major factors for piston failure. The results of this study show that the stresses which are produced during the operations for SiC reinforced ZrB2 material are less than the design stress. Also the distribution of the temperature is in prescribed limit. The SiC reinforced ZrB2 composite piston can maintain its properties at higher temperature (1675 K) and pressure (18 MPa) fig (8 & 9). The total heat flux generation is very low and thermal deformation is within prescribed limit. These results show that SiC reinforced composite is more suitable for piston manufacturing. SOLIDEDGE software has a powerful function of solid modeling and ANSYS software has powerful analysis capabilities. They are suited for FEA analysis for parts with complex shape. The 3D solid model of a piston is prepared by applying SOLIDEDGE software and is transferred to ANSYS software through the interface in this paper. The first 10 order natural frequency of the piston and its vibration mode are obtained corresponding vivid images.

REFERENCES

[1] S.M. Sapuan, M.S..D. Jacob, F. Mustapha and N. Ismail , "A prototype knowledge-based system for material selection of ceramic matrix composites of automotive engine components" *Materials and Design Vol 23,* 2002 page 701-708.

[2] Sufang Tang, Jingyi Deng, Shijun Wang and Wenchuan Liu, "Comparison of thermal and ablation behaviors of C/SiC composites and C/ZrB 2 –SiC composites" *Corrosion science Volume 51,* 2004 page 54-61.

[3] Hongyuan Zhang,Xingguo Ma and Shuangliang Ge, "Modeling and transient dynamics analysis to a new type of engine piston" *Journal of Theoretical and Applied Information Technology ,Vol. 48 No.2, 2013.*

[4] Amin Almasi, "Reciprocating Equipment Piston Rod Dynamic Elastic-Plastic Deformation Analysis" World Academy of Science, Engineering and Technology, 2009.

[5] Piotr Szurgott, Tadeusz Niezgoda, "Thermo-mechanical fe analysis of the engine piston made of composite material with low histeresis" *Journal of KONES Powertrain and Transport, Vol. 18, No. 1* 2011.

[6] Dr.Najim A.Saad; Dr. Haitham R. Abed Ali ; Dr. Hayder Shakir Abudalla, "Numerical analysis of the thermal –stresses of a petrol engine piston with different materials" *The Iraqi Journal For Mechanical And Material Engineering, Vol.8, No.3,* 2008
[7] ANSYS, Structural analysis Guide, release 14.0(2011).
[8] SOLIDEDGE, Version 19,release 19.0 (2006).
[9] Antoine Rios, Bruce Davis and Paul Gramann "Computer Aided Engineering in Compression Molding" ,The Madison Group: Polymer Processing Research Corporation 505 S. Rosa Rd. Madison, WI 53719.
[10] Srecko Manasijevic, Radomir Radisa, Srdjan Markovic, Zagorka Acimovic-Pavlovic , Karlo Raic, "Thermal analysis and microscopic characterization of the piston alloy AlSi13Cu4Ni2Mg", *Intermetallics,Vol. 19* ,pp. 486 – 492, 2011.