International Journal of Advances in Engineering and Management (IJAEM)
Volume 3, Issue 7 July 2021, pp: 2824-2832 www.ijaem.net ISSN: 2395-5252

Design and Static Structural, Study State Thermal Coupled Analysis of Piston Made Of Magnesium Silicon Carbide (Mgsic)

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Submitted: 05-07-2021 Revised: 19-07-2021 Accepted: 22-07-2021

ABSTRACT

Piston is the part of engine which converts heat and pressure energy liberated by fuel combustion into mechanical works. Engine piston is the most complex component among the automotive. The design procedure involves determination of various piston dimensions using analytical method under maximum power condition. The main objective of this work is to investigate the stress distribution, deformations resulting from thermal loads in the cross sections of the piston made of Mg-SiC composite with varying volume fractions (10%, 20% & 30%) of SiC particulates in the base metal Magnesium. The results are compared with the existing Al6061 piston currently in use in Bajaj Pulsar 150cc (4-stroke, 2 valve, Twin spark BSIV Complaint DTS-i Engine). A model of a piston was made using NX 10.0, thermal and static structural coupled analysis was done using ANSYS 18.1. This paper shows the use of AlSic material for the piston for analysis to obtain the deformations and stresses andcompared with the results obtained in the case of Aluminium alloy piston.

Key words: Piston, Composite Material, NX10.0, ANSYS 18.1, Static StructuralAnalysis.

I. INTRODUCTION

Piston

A piston is a component of reciprocating IC-engines. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, purpose of a piston is to transfer force from expanding gas in the cylinder to the crankshaft via a pistonrod. Piston endures the cyclic gas pressure and the inertial forces at work, and this working condition may cause the fatigue damage of piston such as piston side wear, piston head cracks etc.

Functions of a Piston

a) To receive the impulse from the expanding gas & transmit the energy to the crankshaft through the connecting rod.
b) It transmits the force of combustion gases to the crank shaft.
c) It controls the opening & closing of the parts in a 2-strokeengine.
d) It acts as a seal to escape of high pressure gases in to the crank case.

Commonly used Piston Materials

a)Aluminium- Silicon alloy is the most used material. Maximum suitable percentage of Si ranges from 12-19%.
b)Commercial Al4032 : Al- 85%, Si- 12.2%, Mg- 1.0%, Cu- 0.9%, Ni- 0.9%.
c) Zamak: A family of alloys with a base metal of zinc and alloying elements of aluminium, magnesium, and copper.
d) Aluminium Silicon Carbide.

History of Magnesium Piston

1921 seemed to be the year of Mg pistons. There were reports that DOW produced Mg pistons for “Indy 500”. But more importantly, the German Ministry of Transportation (Reichsverkehrsministerium) issued a competition to develop a lightweight piston. Two Mg pistons and two Al pistons were awarded.

In 1925, magnesium pistons were first used in Germany, die cast by Elektron Metall Bad Cannstatt (Mahle) and there were more than 4 million of them in operation by 1937. Magnesium usage grew throughout the 1930‟s and then grew exponentially during World War II. With the introduction of the Volkswagen Beetle, automotive magnesium consumption again accelerated and reached a peak in 1971[1].

The use of water cooling put magnesium at a disadvantage compared with other engine piston materials because of its poor corrosion resistance. By the time more corrosion resistant "high purity" alloys AZ91D and AM60B were developed in the 1980‟s, the cost of magnesium alloys had begun to increase, and the use of magnesium in automotive applications decreased dramatically although a few applications remained[2].

The light- weighing of automobile vehicles is needed to improve the fuel efficiency. Apart from the car door, roof of vehicles, frames, chassis, B-pillar, C-pillar etc., there is a need to reduce the mass of reciprocating engine components like the piston, connecting rod, crankshaft and engine block etc. A light weight piston is proposed as the reduction ofreciprocating mass not only saves fuel but also reduces the vibration of the engine. Typically, for an engine operating at 5300 rpm, there are 2650 power strokes, which cause the significant magnitude of acceleration at either end of the stroke (and hence significant inertia forces proportional to piston head mass) in service. Piston slap, that causes an increase in engine noise as well as liner wear, is also known to be proportional to these inertia forces. This weight reduction can be achieved by low density magnesium (2/3rd of aluminium and 1/4th that of steel But Al pistons are most common.

Reasons for Rare use of Mg Pistons

a) Molten Mg cannot be handled as easy as molten Al. Molten Al always has a protective surface layer in the solid and in the molten state (Pilling-Bedworth ratio > 1). For molten Mg the Pilling-Bedworth ratio is in the range of 0.8. This means that the surface layer of MgO always cracks and allows further oxidation. Additionally the MgO film does notstick to either molten or solid Mg. The result is an ongoing oxidation that could lead to the ignition of molten Mg.

b) The piston head is frequently heated up by the combustion, followed by rapid cooling immediately afterwards. This continued expansion and contraction is also known as thermal fatigue. The more heat resistant the piston material is, the better the performance of a piston in service. In general, it also has to be stated that properties of standard Mg alloys at elevated temperatures often cannot compete with Al alloys. Creep resistance is here of importance.

Possible Solutions to Improve Creep Resistance of Magnesium

Alloying: A combination of alloying elements that form intermetallic phases on grain boundaries and within grains have been state of the art for decades. WE series alloys work like this. According to the ASTM designation system for Mg alloys, W represents Yttrium. E stands for rare earth elements and in this case mostly for Cerium (Ce) and Neodymium(Nd) or a mixture of both. In WE additionally Zirconium is added to achieve a homogeneous grain size. Nevertheless, due to the use of rare earth elements (RE), it is relatively expensive.

Use of Composites: Cast composites designed as based on a magnesium matrix and reinforced with silicon carbide particles constitute a new group of materials that feature the desired set of properties. The use of magnesium for the matrix of composites allows a low weight of the final element to be obtained, while assuring the proper level ofproperties; the introduction of SiC particles, on the other hand, enables the tribological properties, Young's modulus, tensile strength and hardness enhanced.

Use of Composite Materials

Composite materials (also called composition materials or shortened to composites) are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. Typical engineered composite materials include:

a)Composite building materials such as cements, concrete b)Reinforced plastics such as fibre-reinforced polymer c)Metal Composites
d)Ceramic Composites

Metal Matrix Composites

A metal matrix composite (MMC) is composite material with at least two constituent parts, one being a metal necessarily, the other material may be a different metal or another material, such as a ceramic or organic compound.

Metal matrix composites (MMCs) usually consist of a low-density metal, such as aluminium or magnesium, reinforced with particulate or fibres of a ceramic material, such as silicon carbide or graphite. Compared with unreinforced metals MMCs offer higher specific strength and stiffness, higher operating temperature, and greater wear resistance, as well as the opportunity to tailor these properties for a particular application.

Magnesium Silicon Carbide Composite

Cast composites designed as based on a magnesium matrix and reinforced with silicon carbideparticles constitute a new group of materials that feature the desired set of properties.

The use of magnesium for the matrix of composites allows a low weight of the final element to be obtained, while assuring the proper level of properties; the introduction of SiC particles, on the other hand, enables the tribological properties, Young's modulus, tensile strength and hardness of the composite to be enhanced. It should be noted that the Mg-SiC system is characterized by

a) A very good wettability of SiC by molten Mg.
b) A very high stability of SiC in liquid Mg.

Investigations carried out so far have determined the possibility of obtaining adhesive bonding between components and high volumetric fractions of SiC particles with their uniform distribution within the matrix.

Properties	**Mg-SiC (90%-10%)**	**Mg-SiC (80%-20%)**	**Mg-SiC (70%-30%)**	**AL6061**
Density (kg/m3)	1885.2	2032.4	2179.6	2700
Poisson‟s ratio	0.275	0.26	0.245	0.33
Youngs‟ modulus (GPa)	81.5	118	154.5	68
Thermal Conductivity(W/mC)	152.4	148.8	145.2	158

Fabrication of Magnesium Silicon Carbide Composite

- Magnesium alloy (AZ91D) matrix composites can be fabricated by different techniques such as powder metallurgy, squeeze casting, disintegrated melt deposition technique and spray deposition.
- Compared to other manufacturing processes, stir casting is more suited because of the reduction in cost (1/3rd to 1/10th in mass production).
- The required amount of pre heated reinforcement silicon carbide particles (220 mesh)were mixed in the magnesium alloy melt to get uniformly distributed reinforced composite.
- The cast magnesium alloy composites were subjected to solution hardening and artificial aging (T6) heat treatment as per the ASTM standard B661-06.

Table 2 Chemical composition of AZ91D alloy

Material	%wt
Cu	0.002
Si	0.034
Fe	0.002
Ni	0.001
Mn	0.03
Zn	0.775

Pb	0.001
Sn	0.002
Al	8.40
Mg	Remaining

Piston used for the Experiment

- Bike Variant: Bajaj Pulsar 150 ENGINE
- Type: 4-Stroke, 2-Valve, Twin Spark BSIV Compliant DTS-i Engine Displacement (cc): 149 cc
- Max power (PS @ RPM): 14 @ 8000 Max torque (Nm @ RPM): 13.4 @ 6000 Bore: 57.0 mm
- Stroke: 56.4 mm Fig 1. Bajaj Pulsar 150cc engine piston

II. METHODOLOGY

Step -1 Defining the problem
Step -2 Generation of CAD model of the piston
Step -3 Finding properties of the composites
Step -4 Static and structural analysis using Workbench 18.1 Step -5 Thermal analysis using Workbench 18.1
Step -6 Results and discussion
Step-7 Conclusion

III. RESULTS

Static Structural Analysis
Total Deformation

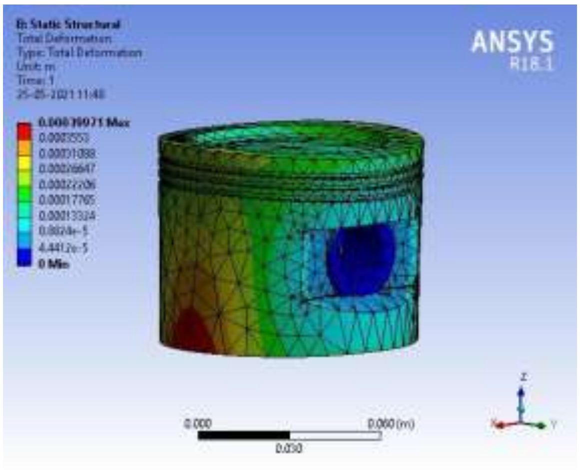


Figure 1. Piston made of Mg-SiC(90%-10%)

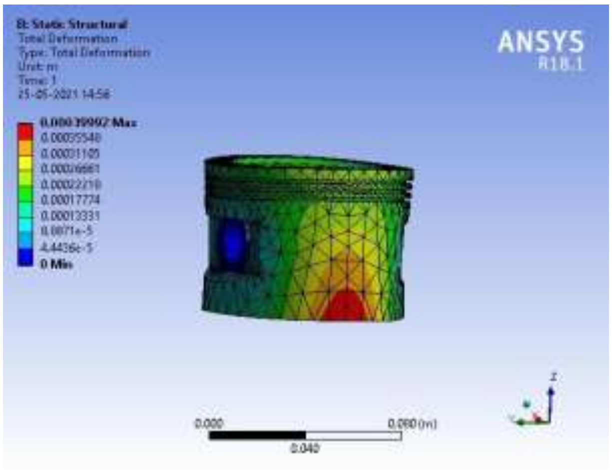


Figure 2. Piston made of Mg-SiC(80%-20%)

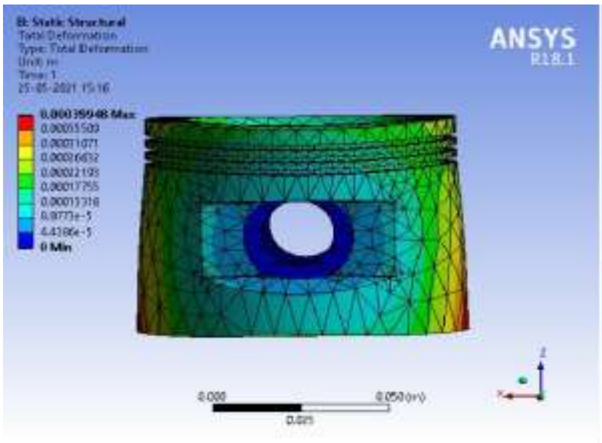


Figure 3. Piston made of Mg-SiC(70%-30%)

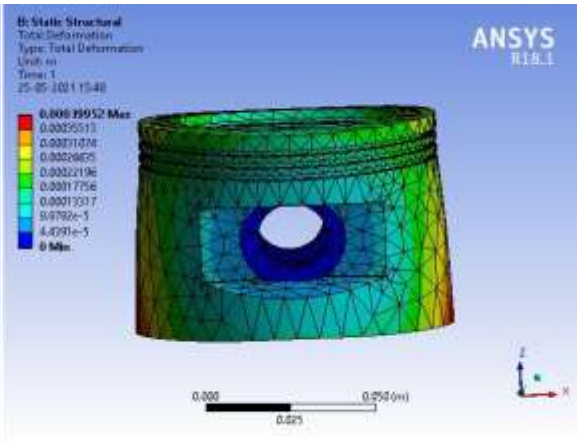
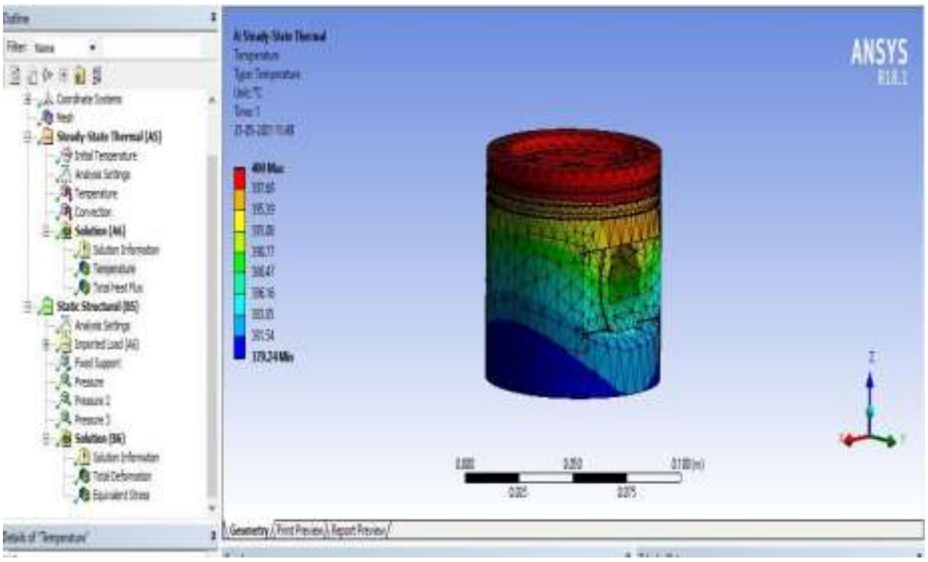


Figure 4. Piston made of AL6061



Coupled analysis of piston

Deformation in piston made of various materials

Material	Maximum deformation (mm)	Minimum deformation (mm)
Mg-SiC (90%-10%)	0.39971	0
Mg-SiC (80%-20%)	0.39992	0
Mg-SiC (70%-30%)	0.39948	0
Al6061	0.39952	0

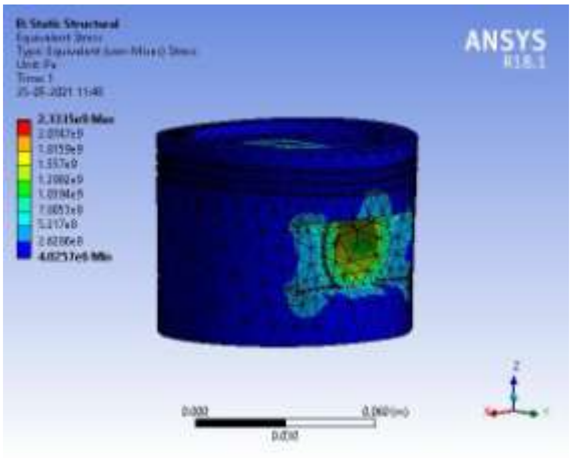


Figure 5. Piston made of Mg-SiC(90%-10%)

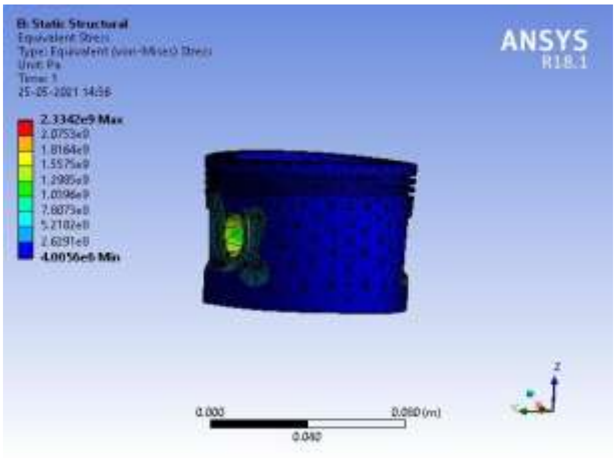


Figure 6. Piston made of Mg-SiC(80%-20%)

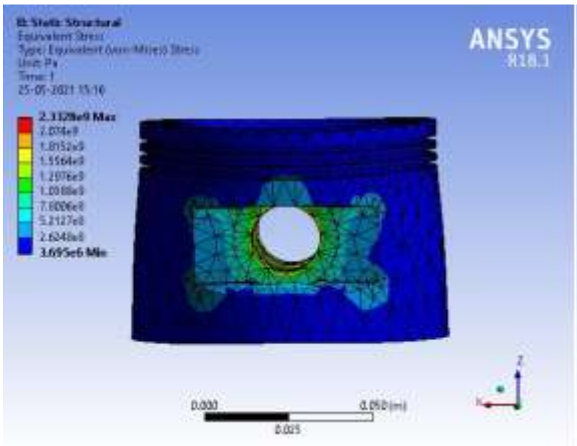


Figure 7. Piston made of Mg-SiC(70%-30%)

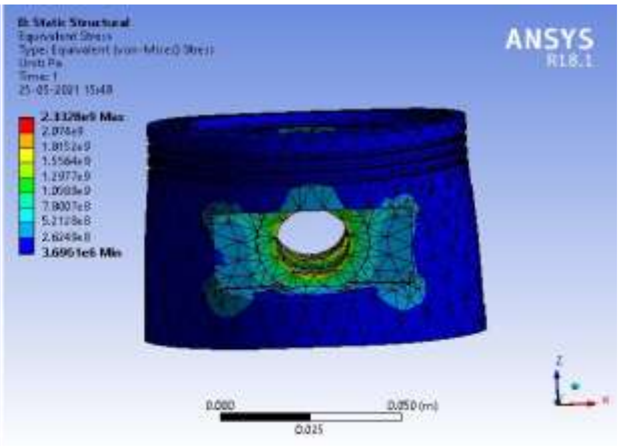


Figure 8. Piston made of AL6061

Equivalent Stress generated in piston made of various materials

Material	Maximum stress(MPa)	Minimum stress (MPa)
Mg-SiC (90%-10%)	2333.5	4.025
Mg-SiC (80%-20%)	2334.2	4.005
Mg-SiC (70%-30%)	2332.8	3.695
Al6061	2332.8	3.696

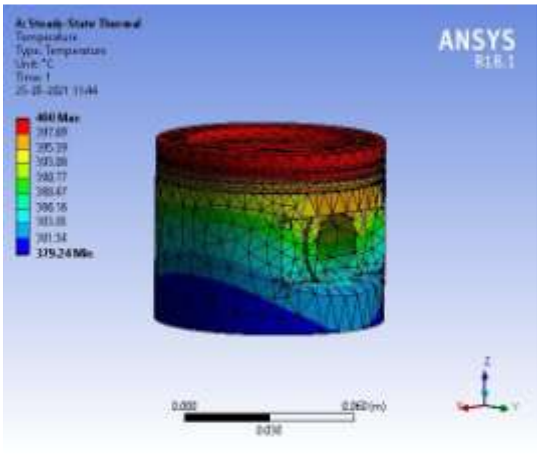


Figure 9. Piston made of Mg-SiC(90%-10%)

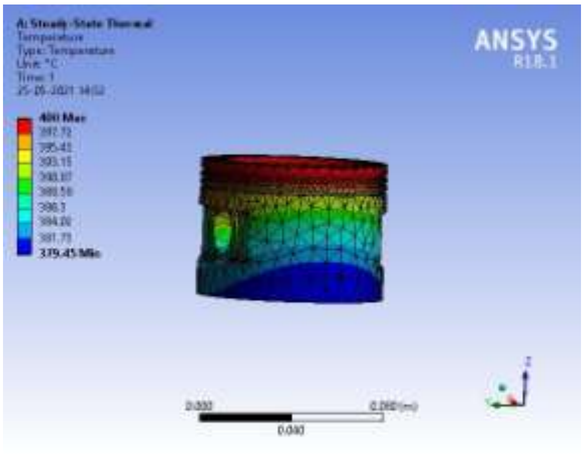


Figure 10. Piston made of Mg-SiC(80%-20%)

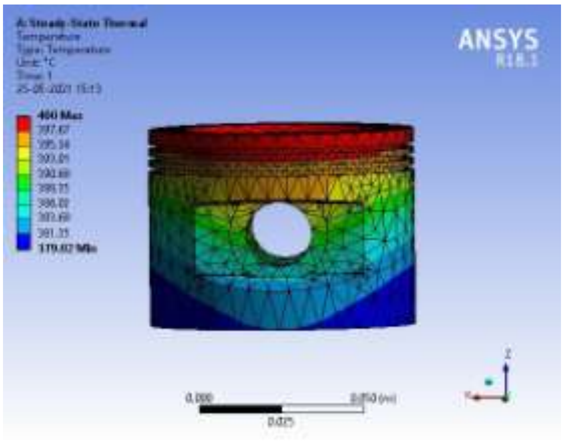


Figure 11. Piston made of Mg-SiC(70%-30%)

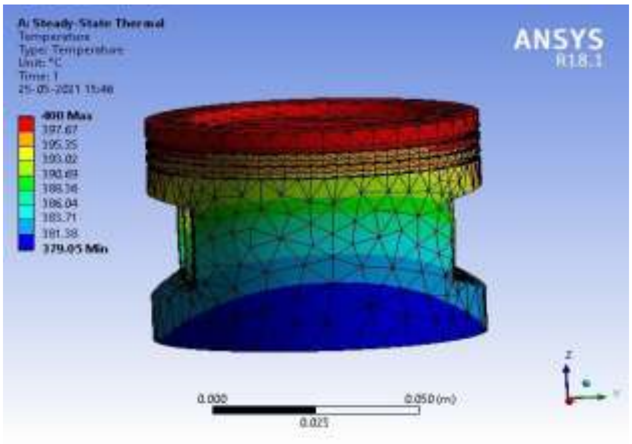


Figure 12. Piston made of AL6061

Steady state Thermal Analysis

Material	**Minimum temperature (ºC)**
Mg-SiC (90%-10%)	379.24
Mg-SiC (80%-20%)	379.45
Mg-SiC (70%-30%)	379.02
Al6061	379.05

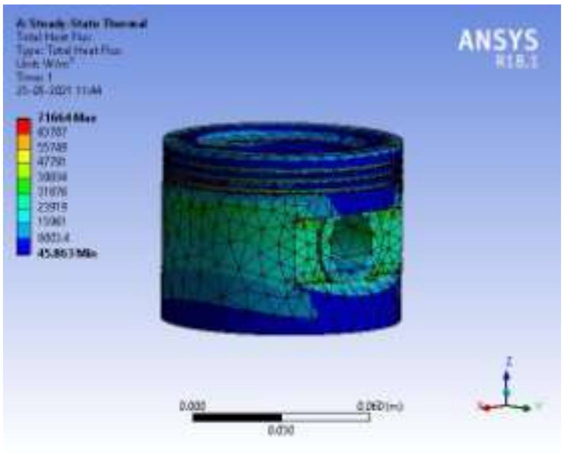


Figure 13. Piston made of Mg-SiC(90%-10%)

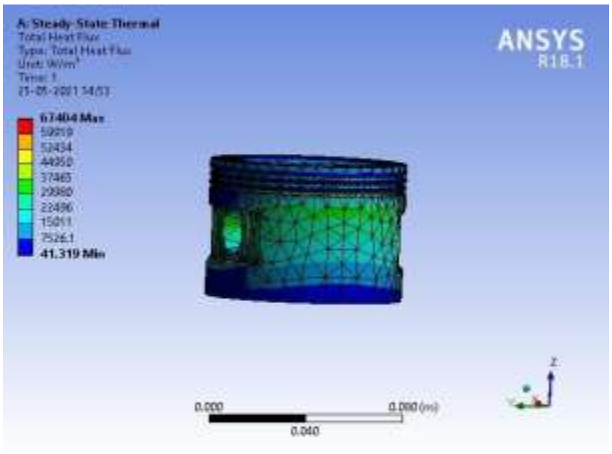


Figure 14. Piston made of Mg-SiC(80%-20%)

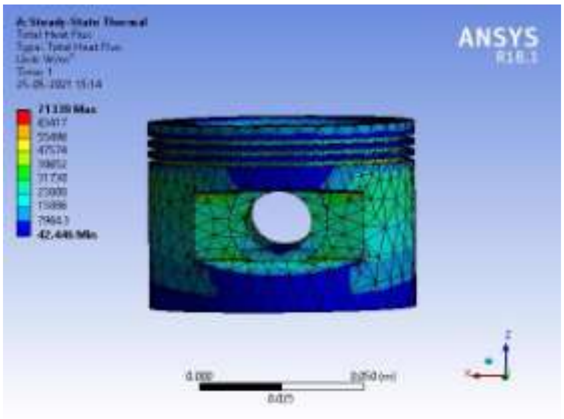


Figure 15. Piston made of Mg-SiC(70%-30%)

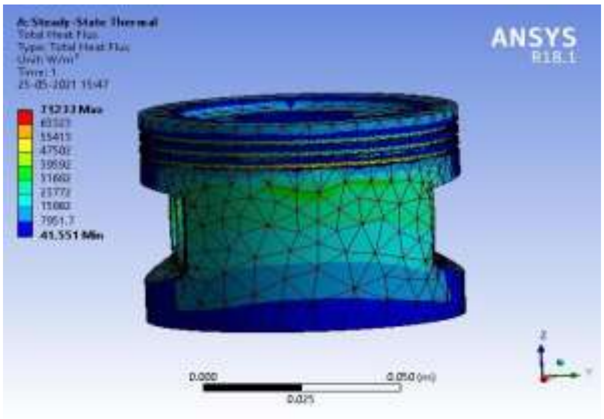


Figure 12. Piston made of AL6061

Total Heat Flux in piston made of various materials

Material	**Maximum heat flux** **(W/m2)**	**Minimum heat flux** **(W/m2)**
Mg-SiC (90%-10%)	71664	45.863
Mg-SiC (80%-20%)	67404	41.319
Mg-SiC (70%-30%)	71339	42.446
Al6061	71233	41.551

Overall results tabulated

Material	**Al6061**	**Mg-SiC (90%-10%)**	**Mg-SiC (80%-20%)**	**Mg-SiC (70%-30%)**
Maximum Deformation (mm)	0.39952	0.39971	0.39992	0.39948
Maximum Stress (MPa)	2332.8	2333.5	2334.2	2332.8
Steady State Thermal Analysis				
Minimum Temperature(°C)	379.5	379.24	379.45	379.02
Maximum HeatFlux (W/ m2)	71233	71664	67404	71339

IV. CONCLUSION:

An effort has been made to propose Magnesium as a piston material by overcoming the challenges of Mg alloy with the help of composites.

The commercial piston used in Bajaj Pulsar 150cc motorbike, was modelled using UG-NX 10.0,Static structural, and steady state thermal coupled analyses were done using ANSYS WORKBENCH 18.1and the total deformation, equivalent stress, temperature distribution and total heat flux in the piston made of commercial Al6061, Mg-SiC (90%- 10%), Mg-SiC (80%-20%) and Mg-SiC (70%-30%) were found and compared.

In static structural analysis with a pressure of 14 MPa,12Mpa acting on the compression rings and 10 Mpa acting on the oil ring, it was found that the stresses induced were least in Mg- SiC(70%-30%)pistonfollowed by Al6061, Mg-SiC (90%-10%) Mg-Sic (80%-20%) pistons. Thus Magnesium Silicon Carbide piston performed exceedingly well in reducing the stress induced. Also, as the percentage of SiC particles increased in Mg base metal the results got better.The total deformation was induced was least in Mg-SiC (70%- 30%)piston followed by Al6061,Mg-SiC (90%-10%) and Mg-SiC (80%-20%) pistons.

In steady state thermal analysis wit temperature of 400 ^{c} applied on the piston crown and heat transfer mode considered as convective with convection coefficient of 1.24 w/m $^{2\,0}$c . The minimum temperature was found in Mg-SiC (70%- 30%) piston followed by Mg-SiC (90%-10%), Mg-SiC (80%-20%) and Al6061 pistons. The maximum heat flux was found in Mg-SiC (90%-10%) piston followed by Mg-SiC (70%-30%),Al6061 and Mg-SiC (80%-20%)pistons.

REFERENCES

[1] DeovratVibhandik, Ameya Pradhan, SampadaMhaskar, Nikita Sukthankar, AtulDhale, (2014) , Design Analysis and Optimization of Piston and Determination of its Thermal Stresses Using CAE Tools, 3(5), pp.273-277.

[2] Ch. VenkataRajam, P. V. K. Murthy, M. V. S. Murali Krishna, G. M. Prasada Rao, (2013), Design analysis and optimization of piston using CATIA and ANSYS, International Journal of Innovative Research in Engineering & Science, 1(2), pp. 41-51.

[3] Vaibhav V. Mukkawar, Abhishek D. Bangale, Nititn D. Bhusale, Ganesh M. Surve, (2015), Design analysis and optimization of piston using CAE tools, International Conference, Pune, India.

[4] Manjunatha.T. R, Dr. Byre Gowda. H. V, Prabhunandan. G. S, (2013), Design and Static Structural Analysis of Cylinder and Piston of Two Stage Reciprocating Compressors Using ANSYS, International Journal of Innovative Research in Science, Engineering andTechnology , 2 (12), pp. 7590-7596.

[5] Swati S. Chougule, Vinayak H. Khatawate, (2013), Piston Strength Analysis Using FEM,International Journal of Engineering Research and Applications, 3, pp.124-126

[6] Lokesh Singh, Suneer Singh Rawat, Taufeeque Hasan, Upendra Kumar, (2015), Finite element analysis of piston in ansys, 02, pp. 239-241.

[7] R. C. Singh, Roop. Lal, Ranganath M. S., Rajiv Chaudhary, (2014), Failure of Piston inIC Engines: A Review, IJMER, 4.

[8] Jan Filipczyk, ZbigniewStanik, (2012), Piston damages-case studies and possibilities of early detection, Journal of KONES Powertrain and Transport, 19(4), pp. 179-184.

[9] GantlaShashidhar Reddy and N. Amara NageswaraRao, (2013), Modeling and analysis of diesel engine piston, International journal of Mathematics and Engineering, 2, pp. 199 – 202.

[10] VivekZolekar, Dr. L. N. Wankhade, (2013), Finite Element Analysis and Optimization of I.C. Engine Piston Using RADIOSS and Optistruct, Altair technology conference.