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Design, Finite Element Analysis and Optimization of Piston with Different Materials

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ABSTRACT

Piston is made of cast aluminum (Aluminum alloy 4032) because of its high heat transfer rate. One important thing to take care while using it (cast aluminum) is, because it expands appreciably on heating so right amount of clearance needs to be provided or else it will lead the engine to seize. For avoiding above problem in this project, the material is replaced with Aluminum 6061, Aluminum Silicon Carbide Metal Matrix Composite (MMC) and Magnesium Silicon Metal Matrix Composite. And also describes the stress distribution using different materials by using finite element analysis (FEA).

The parameters used for the simulation are operating gas pressure and material properties of piston. The specifications used for the study of these pistons belong to four stroke single cylinder engine of Bajaj Kawasaki motorcycle. The piston is designed and modeled in 3D modeling software Creo 2.0. Static, Dynamic, Modal, Random Vibration and Thermal analyses are performed on the piston by varying materials and compared for better performance. Analysis is done in Ansys 14.5.The analysis results are used to optimize piston material.

INTRODUCTION

The piston transforms the energy of the expanding gasses into mechanical energy. The piston rides in the cylinder liner or sleeve. Pistons are commonly made of aluminum alloys or cast iron. To prevent the combustion gasses from bypassing the piston and to keep friction to a minimum, each piston has several metal rings around it. These rings function as the seal between the piston and the cylinder wall and also act to reduce friction by minimizing the contact usually 2 to 5, with each ring performing a distinct function. The top ring(s) acts primarily as the pressure seal. The intermediate ring(s) acts as a wiper ring to remove and control the amount of oil film on the cylinder walls. The bottom ring(s) is an oiler ring and ensures that a supply of lubricating oil is evenly deposited on the cylinder walls.Area between the piston and the cylinder wall. The rings are usually made of cast iron and coated with chrome or molybdenum. Most diesel engine pistons have several rings.

LITERATURE SURVEY

In the paper by Sheikh Naim Sheikh Yusuf[1] describes the stress distribution of two different aluminum alloys piston by using CAE Tools. The specifications used for the study of these pistons belong to four stroke single cylinder engine of Bajaj Pulsar 150cc motorcycle. This paper illustrates the procedure for analytical design of two different aluminum alloy pistons. The results predict the maximum stress and critical region on the different aluminum alloy pistons using CAE Tools. It is important to locate the critical area of concentrated stress for appropriate modifications. A parametric model of Piston is modeled using PTC Creo Parametric 2.0 software and analysis of that model is carried out by using ANSYS 14.5 Software. The best aluminum alloy material is selected based on parameters like Von misses Stress and strain, Deformation, Factor of safety and weight reduction for two wheeler piston were done in ANSYS14.5software.

In the paper by Manisha B Shinde, Sakore T. V and Katkam V,[2] structural analysis is investigated on conventional piston made of Al alloy A2618. Secondly analysis are performed on piston made of AlGHY1250 and AlGHS1300.The material used for the design of piston should have light weight, low cost, structurally and thermally withstand at very high pressure and temperature condition that will occur in combustion process. In this project, it has been decided to study a particular piston design and its capability for maximum gas pressure. In this work, initial planning is to make piston model using solid modeling software Creo / Pro 5.0. It has been decided to mesh the geometry analyze using ANSYS. For the analysis of piston input conditions and process of analysis, a lot of literature survey has been done. High combustion gas pressures will act as a mechanical loads and causes major stresses in the critical region of the piston. Detailed static structural analysis is carried out for various loading conditions like maximum gas pressure load. Comparative study is done to select best material.

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THEORETICALCALCULATIONS

Analytical Design:

Let IP = indicated power produced inside the cylinder (W)
η = mechanical efficiency = 0.8
n = number of working stroke per minute
= N/2 (for four stroke engine)
N = engine speed (rpm)
L = length of stroke (mm)
A = cross-section area of cylinder (mm2)
r = crank radius (mm)
lc = length of connecting rod (mm)
a = acceleration of the reciprocating part (m/s2)
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)
F.O.S = Factor of Safety = 2.25
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) = 47000 KJ/Kg
BP = brake power of the engine per cylinder (KW)
m = mass of fuel used per brake power per second (Kg/KW s)
C = ratio of heat absorbed by the piston to the total heat developed in the cylinder = 5% or 0.05
b = radial width of ring (mm)
Pw = allowable radial pressure on cylinder wall (N/mm2) = 0.025 MPa
σp = permissible tensile strength for ring material (N/mm2) = 1110 N/mm2
h = axial thickness of piston ring (mm)
h1 = width of top lands (mm)
h2 = width of ring lands (mm)
t1 = thickness of piston barrel at the top end (mm)
t2 = thickness of piston barrel at the open end (mm)
ls = length of skirt (mm)
μ = coefficient of friction (0.01)
I1 = length of piston pin in the bush of the small end of the connecting rod (mm)
do = outer diameter of piston pin (mm)

Thickness of the Piston Head - th = D√(3pmax/16σt)

Piston Rings: The radial width of the ring is given by:
b = D √(3 pw/σp)
Axial thickness of the piston ring is given by: h = (0.7b to b)

Width of Top Land and Ring Lands

Width of top land:
h1 = (th to 1.2 th)
Width of ring land:
h2 = (0.75h to h)

Piston Barrel Thickness of piston barrel at the top end: t1 = 0.03 D + b + 4.9
Thickness of piston barrel at the open end: t2 = (0.25 t1 to 0.35 t1)

Length of the skirt: ls = (0.6 D to 0.8 D)
Length of piston pin in the connecting rod bushing lI = 45% of the piston diameter

Piston pin diameter do = (0.28 D to 0.38 D)
= 0.28 x 51 = 14.28 mm

3D MODEL OF PISTON

Fig: Final 3D model of Piston

ANALYSIS OF PISTON

MATERIAL – ALUMINUM – SILICON COMPOSITE

STATIC ANALYSIS

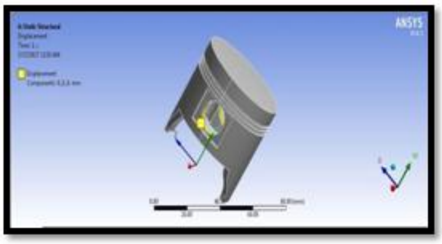

Fig: Displacement

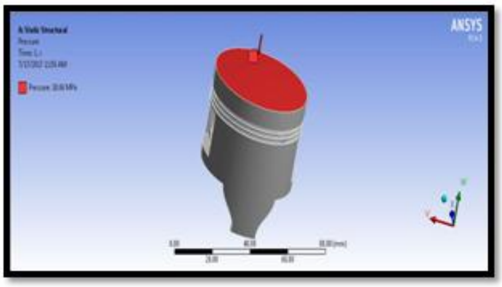

Fig - Pressure

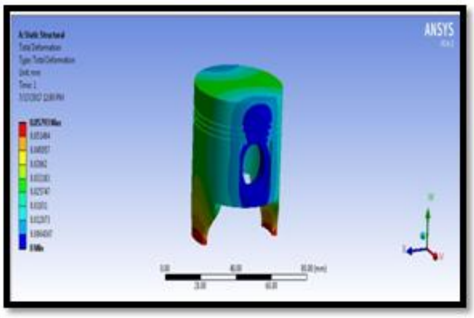

Fig: Total Deformation For al-si

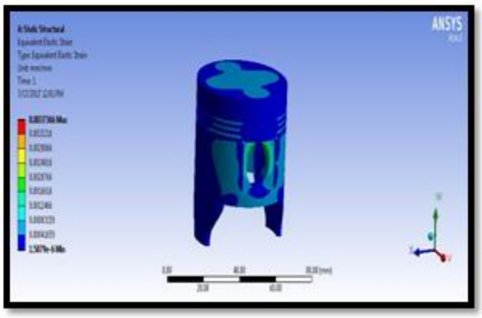

Fig: Strain For al-si

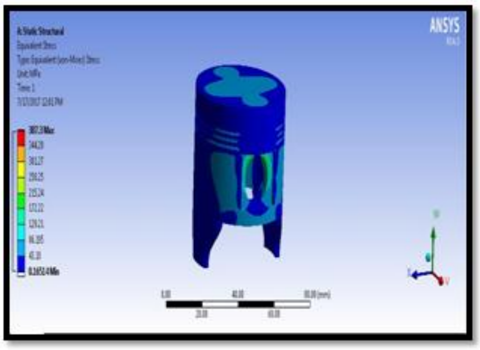

Fig: Stress for al-si

MODAL ANALYSIS

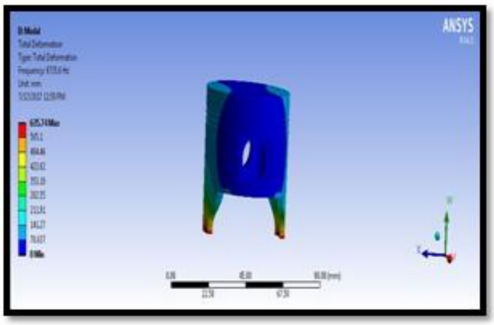

Fig: Deformation-1 for al-si

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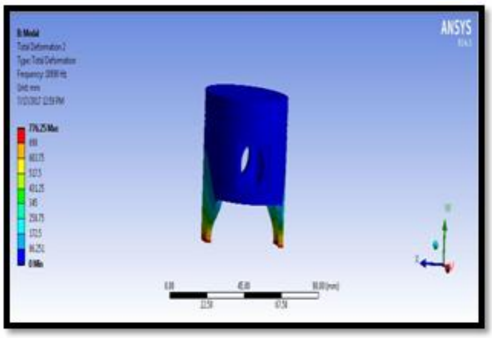

Fig: Deformation-2 for al-si

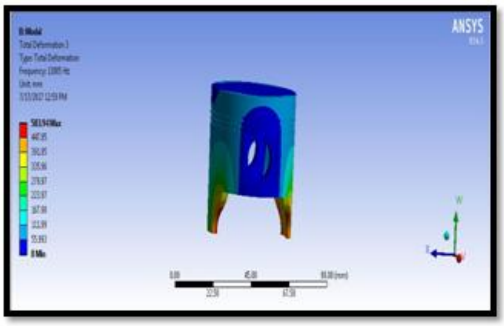

Fig: Deformation-3 for al-si

RANDOM VIBRATION ANALYSIS

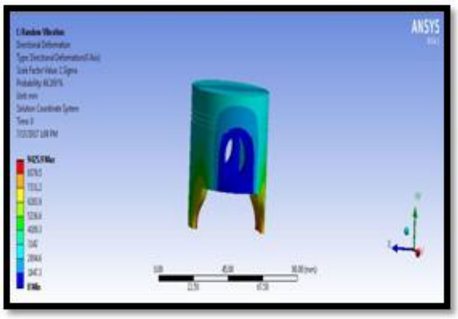

Fig: Directional deformation for al-si

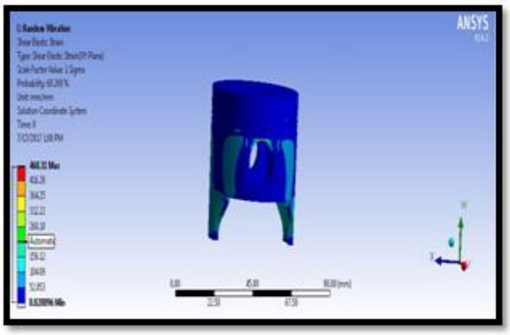

Fig: shear elastic strain for al-sic

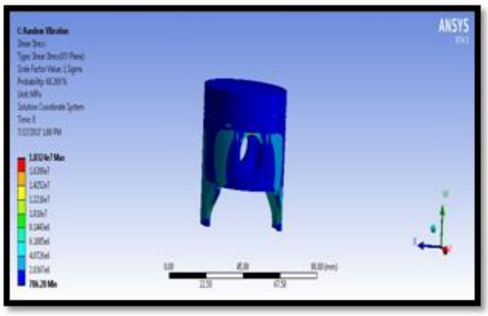

Fig: shear stress for al-sic

TRANSIENT STRUCTURAL ANALYSIS

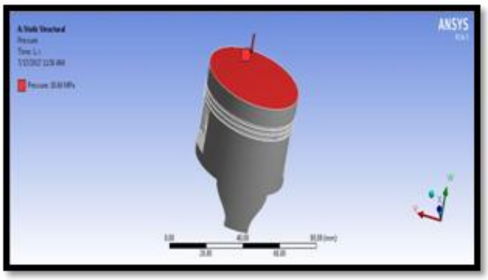

Fig: Pressure

Analysis settings→time→10sec

Pressure - 37.32MPa

Fig: Pressure

5Secs

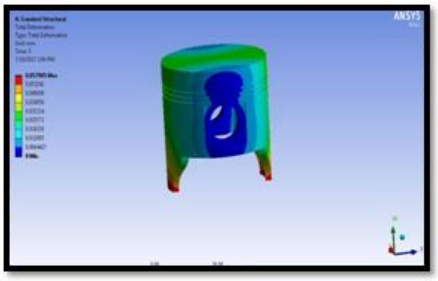

Fig: Total deformation for al-silicon at 5secs

Fig: Strain For al-silicon at 5secs

Fig: Stress For al-silicon at 5secs

THERMAL ANALYSIS

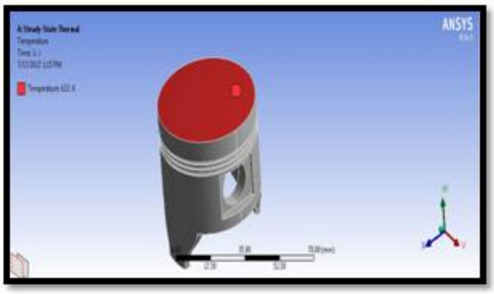

Fig: Temperature

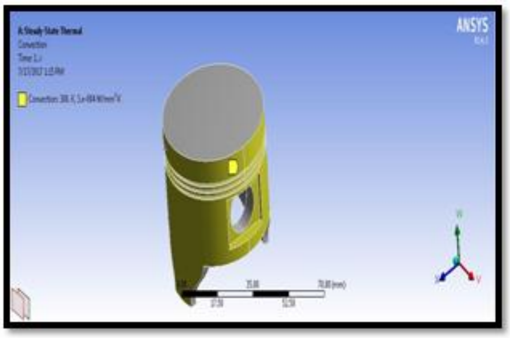

Fig: Convection

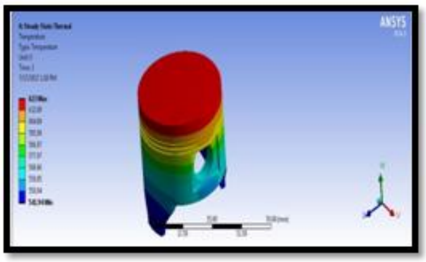

Fig: Temperaturefor Aluminum-si

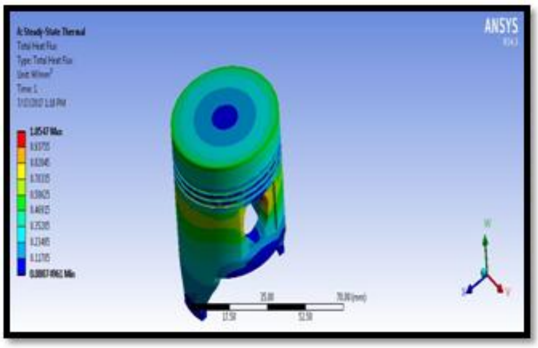

Fig: Total Heat Flux For al-si

RESULTS TABLES

STATIC STRUCTURAL ANALYSIS

MATERIALS	DEFORMATION (mm)	STRESS (MPa)	STRAIN
AL 6061	0.075314	387.39	0.0048587
AL 4032	0.076268	387.39	0.0049202
AL-SI Composite	0.05793	387.3	0.0037366
MG-SI Composite	0.073562	383.59	0.0047919

MODAL ANALYSIS

MATERIALS	DEFORMATION-1 (mm)	DEFORMATION-2 (mm)	DEFORMATION-3 (mm)	FREQUENCY3 (Hz)
AL 6061	641.6	783.63	508.69	11511
AL 4032	643.39	785.83	510.71	11471
AL-SI Composite	635.74	776.25	503.94	13005
MG-SI Composite	773.31	934.19	600.64	13999

RANDOM VIBRATION ANALYSIS

MATERIALS	DIRECTIONAL DEFORMATION (mm)	SHEAR ELASTIC STRAIN	SHEAR STRESS (MPa)
AL 6061	8915	443.58	1.3341E7
AL 4032	8906.2	443.17	1.3162E7
AL-SI Composite	9425.9	468.31	1.8324E7
MG-SI Composite	10994	485.83	1.5527E7

TRANSIENT STRUCTURAL ANALYSIS

Time: 5secs, Pressure: 18.66MPa

MATERIALS	DEFORMATION (mm)	STRAIN	STRESS (MPa)
Al6061	0.075406	0.0048641	387.81
Al4032	0.076362	0.0049258	387.82
Al-sic	0.057985	0.0037398	387.63
Mg-sic	0.073649	0.0047925	384.08

Time: 10sec, Pressure: 37.32MPa

MATERIALS	DEFORMATION (mm)	STRAIN	STRESS (MPa)
Al6061	0.151	0.0097391	776.48
Al4032	0.15291	0.0098626	776.5
Al-sic	0.11608	0.007486	775.91
Mg-sic	0.14747	0.0095863	769.15

THERMAL ANALYSIS

MATERIALS	TEMPERATURE (K)	TOTAL HEAT FLUX (W/mm^2)
Al6061	623	0.99771
Al4032	623	0.96968
Al-sic	623	1.0547
Mg-sic	623	0.96708

CONCLUSION

By observing static analysis results, the deformations and stresses are less when Al – Si composite is used. By observing Modal analysis results, the frequencies are less when Aluminum alloy 4032 is used, so the vibrations will decrease for this material. Due to lesser frequencies, the directional deformation and shear stress are less when Aluminum alloy 4032 is used in Random vibration analysis. By observing dynamic analysis or transient structural analysis, the stresses are less than their respective yield stress values for Al – Si and Mg – Si composites even for the doubled pressures. By observing thermal analysis results, the heat flux values are more when Al – Si composite is used. So heat transfer rate is more when this material is used. So it can be concluded that using Al – Si composite is better due to lesser stresses and high heat transfer rates.

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