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Experimental and Computational Analysis of Piston Coated With Aluminium Silicon Metal Matrix Composite Material

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Abstract

A piston is a component of reciprocating engines, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings Piston that transfer the combustive gases power to the connecting rod. To improve the efficiency of the engine there is a need to study about the piston. Pistons that are usually made up with alloy steels that show the grate resistant against structural loads. In the project we design a piston by using CatiaV5 design software and we did the structural load analysis by applying various materials such as composites on piston in Ansys workbench software. And performed the chemical and mechanical testing to check the quality and performance of piston, and compare the results of simulation analysis and testing results to make sure design is safe.

Introduction

We almost take our Internal Combustion Engines for granted don't we? All we do is buy our vehicles, hop in and drive around. There is, however, a history of development to know about. The compact, well-toned, powerful and surprisingly quiet engine that seems to be purr under your vehicle's hood just wasn't the tame beast it seems to be now. It was loud, it used to roar and it used to be rather bulky. In fact, one of the very first engines that had been conceived wasn't even like the engine we know so well of today. An internal combustion engine is defined as an engine in which the chemical energy of the fuel is released inside the engine and used directly for mechanical work, as opposed to an external combustion engine in which a separate combustor is used to burn the fuel. The internal combustion engine was conceived and developed in the late 1800s. It has had a significant impact on society, and is considered one of the most significant inventions of the last century. The internal combustion engine has been the foundation for the successful development of many commercial technologies. For example, consider how this type of engine has transformed the transportation industry, allowing the invention and improvement of automobiles, trucks, airplanes and trains.

Internal combustion engines can deliver power in the range from 0.01 kW to 20x103 kW, depending on their displacement. The complete in the market place with electric motors, gas turbines and steam engines. The major applications are in the vehicle (automobile and truck), railroad, marine, aircraft, home use and stationary areas. The vast majority of internal combustion engines are produced for vehicular applications, requiring a power output on the order of 102 kW. Next to that internal combustion engines have become the dominant prime mover technology in several areas. For example, in 1900 most automobiles were steam or electrically powered, but by 1900 most automobiles were powered by gasoline engines. As of year 2000, in the United States alone there are about 200 million motor vehicles powered by internal combustion engines. In 1900, steam engines were used to power ships and railroad locomotives; today two- and four-stoke diesel engines are used. Prior to 1950, aircraft relied almost exclusively on the pistons engines. Today gas turbines are the power plant used in large planes, and piston engines continue to dominate the market in small planes. The adoption and continued use of the internal combustion engine in different application areas has resulted from its relatively low cost, favorable power to weight ratio, high efficiency, and relatively simple and robust operating characteristics.

The components of a reciprocating internal combustion engine, block, piston, valves, crankshaft and connecting rod have remained basically unchanged since the late 1800s. The main differences between a modern day engine and one built 100 years ago are the thermal efficiency and the emission level. For many years, internal combustion engine research was aimed at improving thermal efficiency and reducing noise and vibration. As a consequence, the thermal efficiency has increased from about 10% to values as high as 50%. Since 1970, with recognition of the importance of air quality, there has also been a great deal of work devoted to reducing emissions from engines. Currently, emission control requirements are one of the major factors in the design and operation of internal combustion engines.

A piston is a component of reciprocating engines, Reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod and/or connecting rod. In a pump, the function is reversed and force is transferred from the crankshaft to the piston for the purpose of compressing or ejecting the fluid in the cylinder. In some engines, the piston also acts as a valve by covering and uncovering ports in the cylinder wall.

Automobile components are in great demand these days because of increased use of automobiles. The increased demand is due to improved performance and reduced cost of these components. R&D and testing engineers should develop critical components in shortest possible time to minimize launch time for new products. This necessitates understanding of new technologies and quick absorption in the development of new products .A piston is a moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine its purpose is to transfer from expanding gas in the cylinder to the crank shaft via piston rod and or connecting rod. As an important part in an engine piston endures the cyclic gas pressure and inertia forces at work and this working condition may cause the fatigue damage of the piston. The investigations indicate that greatest stress appears on the upper end of the piston and stress concentration is one of the mainly reason for fatigue failure

Literature survey

Aluminum alloys are ready to cast by all common casting techniques (Budinski 2001).

In order to improve the wear performance, a metal based insert is reinforced with the base alloy. Cast iron and steel inserts normally reinforced with the light weight alloy during the casting process. To achieve the bonding between aluminum and cast iron, special patented processes are used. The presence of dirt and oxide induces trouble to the bonding between insert and alloy. The component was coated with a tin layer by dipping or electro plating and subsequent heat treatments were carried out before casting (Cole and Andrew T 1991).

Gravity die casting and the pressure casting methods are used for the Al-Fin process. A special casting technique derived from the so called Al-Fin process is used in the manufacture of piston by gravity die casting and squeeze casting method. Al-Fin process is also known as Al-Fer process which is achieved by diffusion bond between the insert and aluminum alloy.

Zone Ching Lin and Din yan chen (1995) studied on Cubic Boron Nitride (CBN) a sintered product, which can be used as a cutting tool material for hard turning and for higher productivity.

Modeling

Piston Design The piston is designed according to the procedure and specification which are given in machine design and data hand books. The dimensions are calculated in terms of SI Units. The pressure applied on piston head, temperatures of various areas of the piston, heat flow, stresses, strains, length, diameter of piston and hole, thicknesses, etc., parameters are taken into consideration Design Considerations for a Piston.

In designing a piston for an engine, the following points should be taken into consideration: It should have enormous strength to withstand the high pressure.

- It should have minimum weight to withstand the inertia forces.
- It should form effective oil sealing in the cylinder.
- It should provide sufficient bearing area to prevent undue wear.
- It should have high speed reciprocation without noise.
- It should be of sufficient rigid construction to withstand thermal and mechanical distortions.
- It should have sufficient support for the piston pin.

Forces

The major forces acting on the piston are as follows:

Inertia force caused by the high frequency of reciprocating motion of piston

Friction between the cylinder walls and the piston rings

Forces due to expansion of gases

Forces acting due to the compression of gases

Friction at gudgeon pin hole

Objective

Designing the piston for 150 cc petrol engine taking reference to the existing piston.

Design is modified to get better results

Creating of 3D model in Solid works and then by using Ansys work bench for analysis

Meshing of 3D model in ansys structural steel module

Material different general and composite materials are selected for the analysis and study.

Chemical Testing will be done on aluminum silicon matrix material.

Mechanical destructive testing will performed to check the material strength of the material to make sure it works on given pressure load.

Types of engines

There are two major cycles used in internal combustion engines: Otto and Diesel. The Otto cycle is named after Nikolas Otto (1832 – 1891) who developed a four-stroke engine in 1876. It is also called a spark ignition (SI) engine, since a spark is needed to ignite the fuel-air

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mixture. The Diesel cycle engine is also called a compression ignition (CI) engine, since the fuel will auto-ignite when injected into the combustion chamber. The Otto and Diesel cycles operate on either a four- or two-stoke cycle.

Since the invention of the internal combustion engine many pistons-cylinder geometries have been designed. The choice of given arrangement depends on a number of factors and constraints, such as engine balancing and available volume:

- In line
- Horizontally opposed
- Radial
- V

Main components of the engine

Piston

Piston is one of the main parts in the engine. Its purpose is to transfer force fromexpanding gas in the cylinder to the crankshaft via a connecting rod.Since the piston is the main reciprocating part of an engine, its movement creates an imbalance. This imbalance generally manifests itself as a vibration, which causes the engine to be perceivably harsh. The friction between the walls of the cylinder and the piston rings eventually results in wear, reducing the effective life of the mechanism. The sound generated by a reciprocating engine can be intolerable and as a result, many reciprocating engines rely on heavy noise suppression equipment to diminish droning and loudness. To transmit the energy of the piston to the crank, the piston is connected to a connecting rod which is in turn connected to the crank. Because the linear movement of the piston must be converted to a rotational movement of the crank, mechanical loss is experienced as a consequence. Overall, this leads to a decrease in the overall efficiency of the combustion process. The motion of the crank shaft is not smooth, since energy supplied by the piston is not continuous and it is impulsive in nature. To address this, manufacturers fit heavy flywheels which supply constant inertia to the crank. Balance shafts are also fitted to some engines, and diminish the instability generated by the pistons movement. To supply the fuel and remove the exhaust fumes from the cylinder there is a need for valves and camshafts. During opening and closing of the valves, mechanical noise and vibrations may be encounteredPistons are commonly made of a cast aluminum alloy for excellent and lightweightthermal conductivity. Thermal conductivity is the ability of a material to conduct and transfer heat. Aluminum expands when heated, and proper clearance must be provided to maintain free piston movement in the cylinder bore. Insufficient clearance can cause the piston to seize in the cylinder. Excessive clearance can cause a loss of compression and an increase in piston noisePiston features include the piston head, piston pin bore, piston pin, skirt, ring grooves, ring lands, and piston rings. The piston head is the top surface (closest to the cylinder head) of the piston which is subjected to tremendous forces and heat during normal engine operation.A piston pin bore is a through hole in the side of the piston perpendicular to piston travel that receives the piston pin. A piston pin is a hollow shaft that connects the small end of the connecting rod to the piston. The skirt of a piston is the portion of the piston closest to the crankshaft that helps align the piston as it moves in the cylinder bore. Some skirts have profiles cut into them to reduce piston mass and to provide clearance for the rotating crankshaft counterweights

Piston Rings

Piston rings commonly used on small engines include the compression ring, wiper ring, and oil ring. A compression ring is the piston ring located in the ring groove closest to the piston head.

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A wiper ring is the piston ring with a tapered face located in the ring groove between the compression ring and the oil ring.

An oil ring is the piston ring located in the ring groove closest to the crankcase. The oil ring is used to wipe excess oil from the cylinder wall during piston movement.

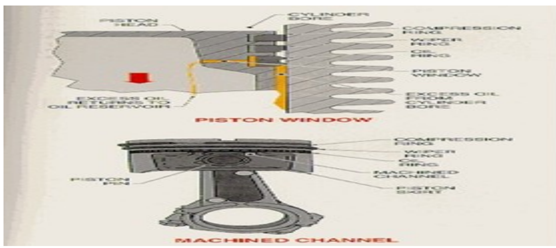

Figure: oil rings

Piston rings seal the combustion chamber, transferring heat to the cylinder wall and controlling oil consumption. A piston ring seals the combustion chamber through inherent and applied pressure. Inherent pressure is the internal spring force that expands a piston ring based on the design and properties of the material used. Inherent pressure requires a significant force needed to compress a piston ring to a smaller diameter. Inherent pressure is determined by the uncompressed or free piston ring gap.

A piston pin bore is a through hole in the side of the piston perpendicular to piston travel that receives the piston pin.

Figure: piston rings

A ring groove is a recessed area located around the perimeter of the piston that is used to retain a piston ring.

Materials

A piston ring material is chosen to meet the demands set by the running conditions. Furthermore, the material should be resistant against damage even in emergency conditions. Elasticity and corrosion resistance of the ring material is required. The ring coating, if applied, needs to work well together with both the ring and the liner materials, as well as with the lubricant.

generally preferable materials are

- cast iron
- aluminum alloys
- grey cast iron
- chromium coatings for rings

Thin, hard coatings produced by PVD or CVD include coating compositions like titanium nitride (TiN), chromium nitride (CrN); however coatings of this type are currently used exclusively for small series production for competition engines and selected production engines (Federal Mogul, 1998, Broszeit et al., 1999). Multilayer TiTiN coatings have been experimentally deposited onto cast-iron piston rings, and the coating is claimed to be more wear resistant than a chromium plated or phosphated surface, particularly when the number of layers is high (Zhuo et al., 2000).

Introduction to composites

Composite materials have been widely used to improve the performance of various types of structures. Compared to conventional materials, the main advantages of composites are their superior stiffness to mass ratio as well as high strength to weight ratio. Because of these advantages, composites have been increasingly incorporated in structural components in various industrial fields.

Basic Concepts of Composite Materials

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Composite materials are basically hybrid materials formed of multiple materials in order to utilize their individual structural advantages in a single structural material. The constituents are combined at a macroscopic level and are not soluble in each other. The key is the macroscopic examination of a material wherein the components can be identified by the naked eye. Different materials can be combined on a microscopic scale, such as in alloying of metals, but the resulting material is, for all practical purposes, macroscopically homogeneous, i.e. the components cannot be distinguished by the naked eye and essentially acts together.

Theoretical Analysis:

By carrying out an analysis and experiments on the piston , and depending on the principle of cooling piston with oil in order to permit the piston to carry more thermal loads without having more damages with increasing the engine speed rate . And there are two types of pistons according to the cooling case , the first type is the piston with the cooling gallery in which the cooling oil is passed , and the second type is the solid piston where the cooling is limited to the under crown surface only.

It has been developed a program for analysis diesel engine piston .This program depends on the Finite Elements method in the procedure of analysis.

HeatTransfer Coefficients Calculations

The heat transfer from the combustion gases is assumed to be similar to the turbulent heat transfer of gases in a cylinder as follows:

$Nu = C\ Re^{m}\ Pr^{n}$

Maximum Thickness of Barrel (t3)

$t_3=0.03*(D+b+4.5mm)$

Where, b = Radial depth of piston ring groove

$b= t_1+0.4$

Stress calculation

Stress on Piston Crown

$6b= \frac{3pD^2}{16tH^2}$

Thermal Stress

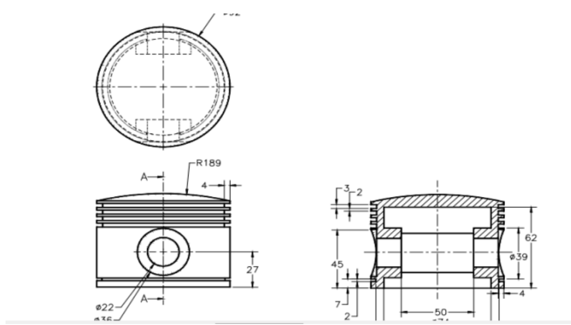
6t=E* Coefficient of thermal Expansion*Temp. Difference

Introduction to CATIA

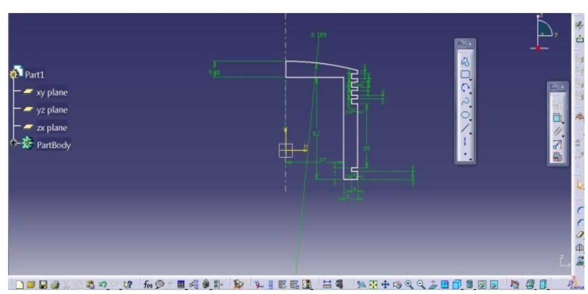
CATIA(computer aided three-dimensional interactive application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company **DASSAULT SYSTEMS.** Written in the C++ programming language, CATIA is the cornerstone of the Dassault systems product lifecycle management software suite.

CATIA is mechanical design software. It is a feature based-parametric solid modelling design tool that takes advantage of the easy-to-learn Windows graphical user interface. You can create fully associative 3-D solid models with or without constraints while utilizing automatic or user-defined relations to capture design intent.

Modeling of Piston



Dimensions for piston



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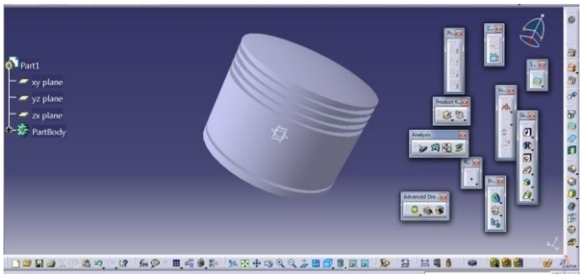
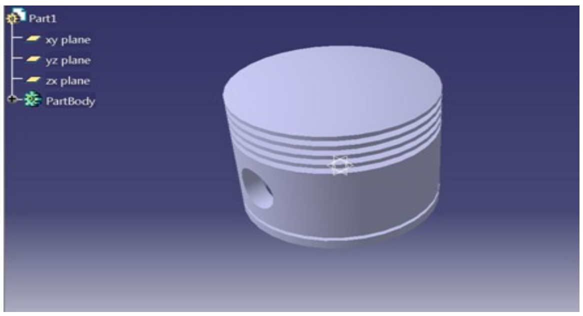
Draw sketch as follows



Now go to features and select revolve option



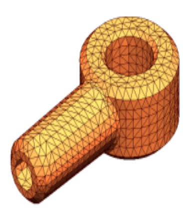
Piston 3d model

Basic Concepts of Analysis

Meshing:

The software uses the Finite Element Method (FEM). FEM is a numerical technique for analyzing engineering designs. FEM is accepted as the standard analysis method due to its generality and suitability for computer implementation. FEM divides the model into many small pieces of simple shapes called elements effectively replacing a complex problem by many simple problems that need to be solved simultaneously.

CAD model of a part



Model subdivided into small pieces (elements)

Finite Element Analysis

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behaviour of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behaviour and many other phenomena. It also can be used to analyze either small or largescale deflection under loading or applied displacement. It uses a numerical technique called the finite element method (FEM).

Introduction to ANSYS

ANSYS 14.5 delivers innovative, dramatic simulation technology advances in every major Physics discipline, along with improvements in computing speed and enhancements to enabling technologies such as geometry handling, meshing and post-processing. These advancements alone represent a major step ahead on the path forward in Simulation Driven Product Development. But ANSYS has reached even further by delivering all this technology in an innovative simulation framework, ANSYS Workbench14.5The ANSYS Workbench environment is the glue that binds the simulation process; this has not changed with version.14.5 In the original ANSYS Workbench, the user interacted with the analysis as a whole using The platform’s project page: launching the various applications and tracking the resulting files employed in the process of creating an analysis. Tight integration between the component applications yielded unprecedented ease of use for setup and solution of even complex multiphysics simulations.

The software offers the following types of studies:

Study type	Study icon		
Static		Modal Time History	
Frequency		Harmonic	
Buckling		Random Vibration	
Thermal		Response Spectrum	
Design Study		Drop Test	
Nonlinear Static		Fatigue	
Nonlinear Dynamic		Pressure Vessel Design	

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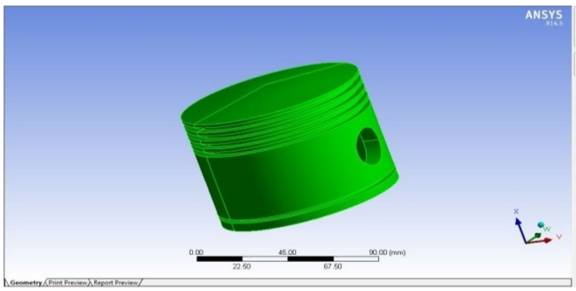
Material Properties

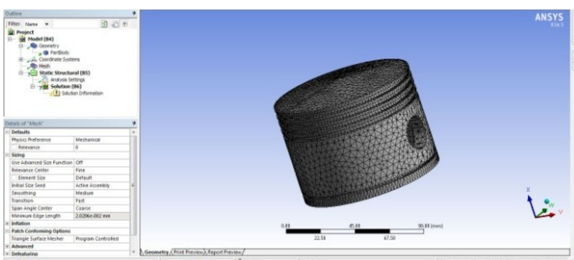
Material	Density Kg/m^3	Young's modulus (Mpa)	Poisson's ratio	Bulk modulus (Mpa)	Shear modulus (Mpa)
magnesium alloy	1800	45000	0.35	50000	16667
silicon carbide	3210	4.4e+005	0.21	2.5287e+005	1.8182e+005
42crmo4	7830	2.1e+005	0.30	1.75e+005	80769
al 6061b4c	2680	1.97 e+005	0.32	1.8241 e+005	74621
Aluminum metal matrix	2700	78000	0.32	72222	29545

Analysis on Piston

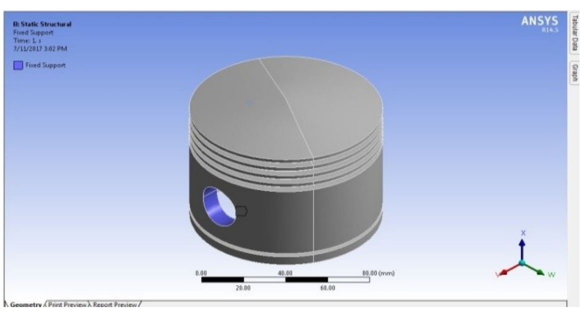
Model



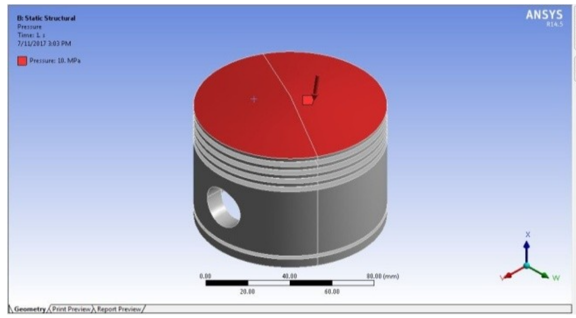
Mesh



Fixed support

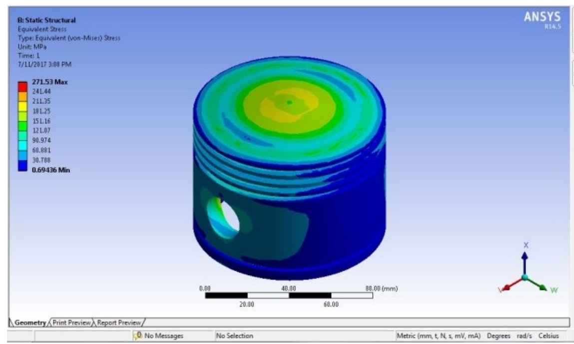


Load condition

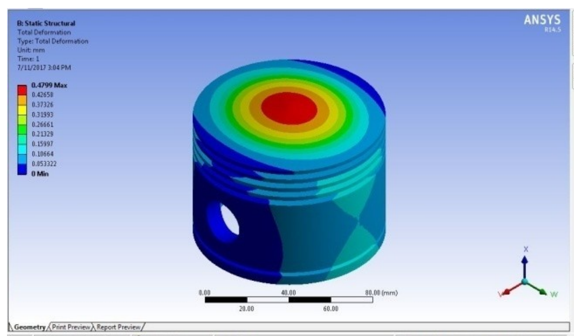


Magnesium alloy

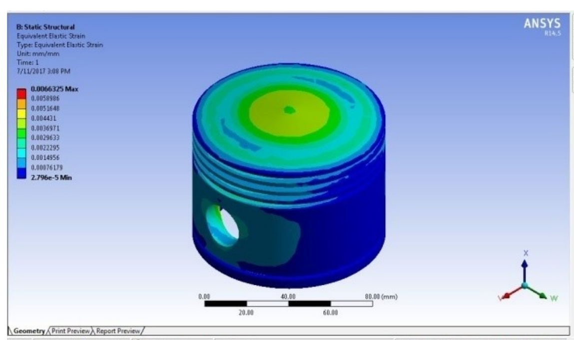
Stress



Deformation



Strain



Silicon carbide

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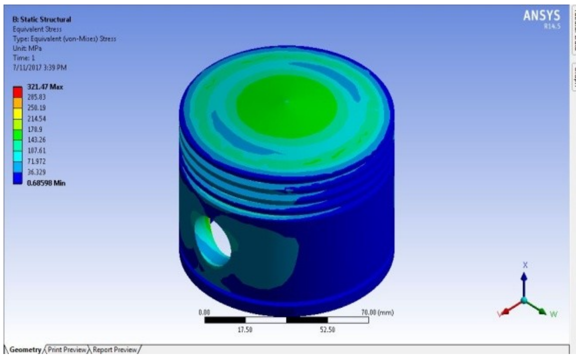
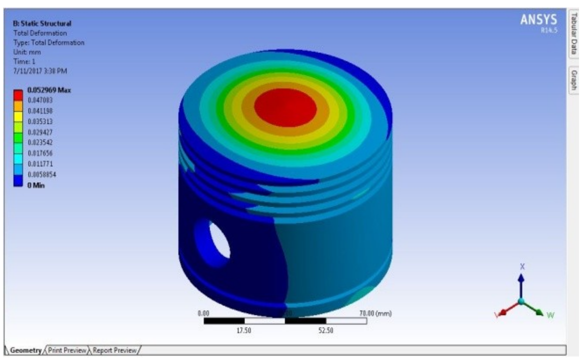
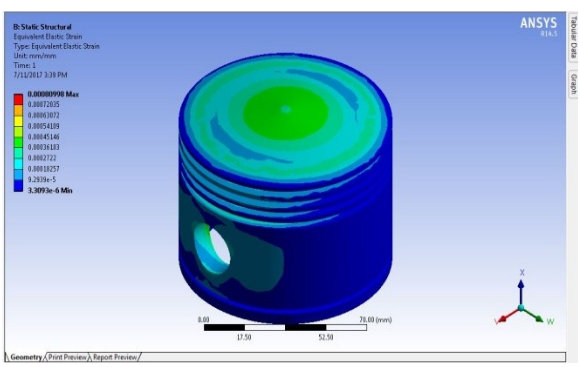
Stress



Deformation

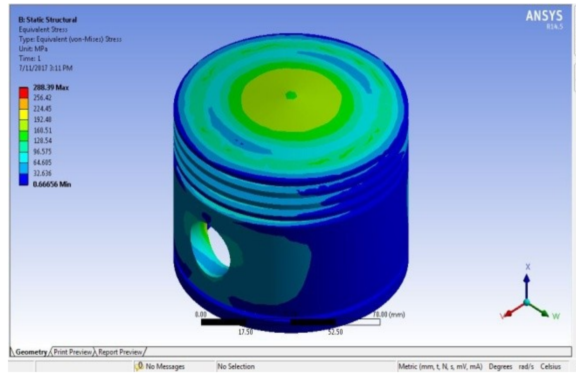


Strain



42crmo4

Stress



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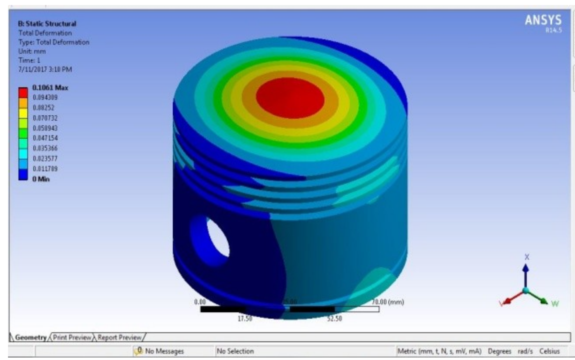

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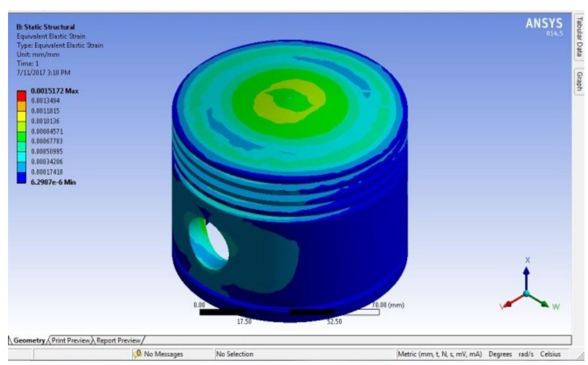

Al 6061+b4c

Stress

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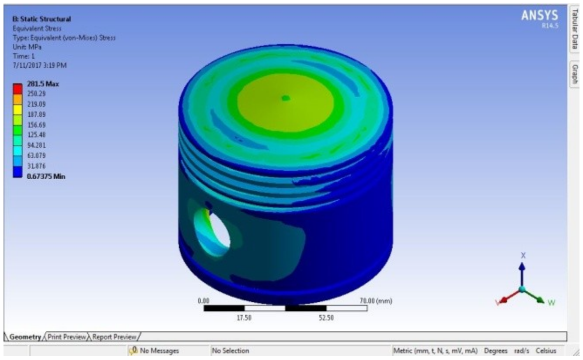

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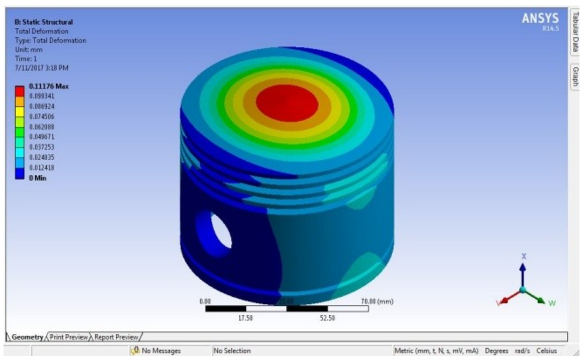

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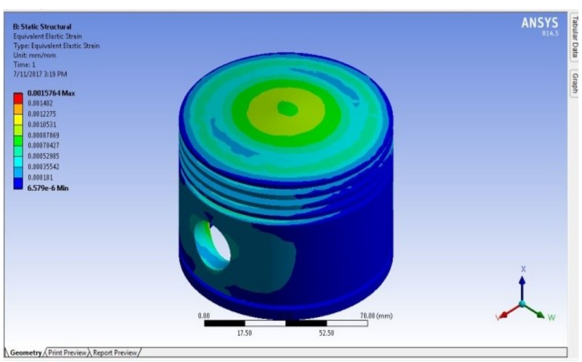
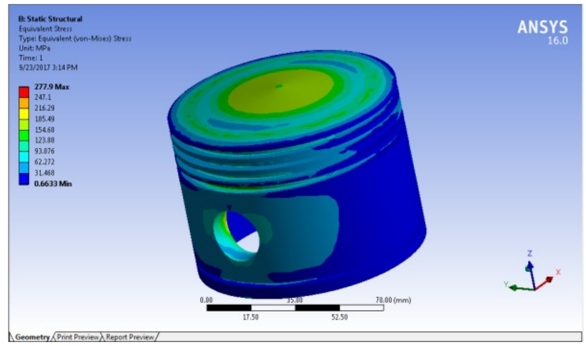


Aluminum metal matrix

Stress



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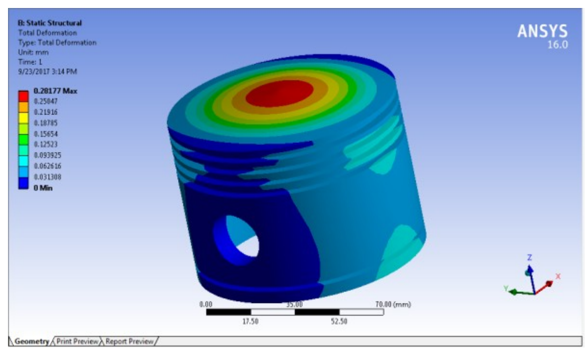
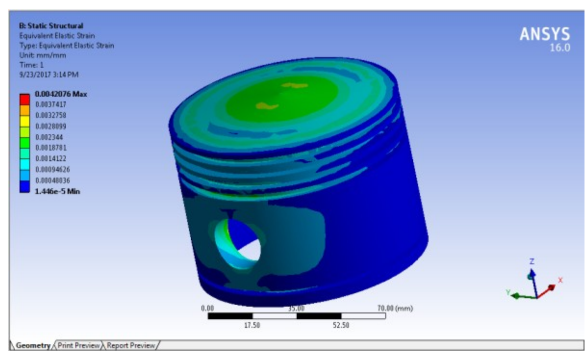


Strain



Analysis result table

Maximum values after analysis are noted in table.

Material	Maximum stress (Mpa)	Total deformation (mm)	Maximum strain
magnesium alloy	271.53	0.4799	0.0066325
silicon carbide	321.47	0.052969	0.00080998
42CrMo4	288.39	0.1061	0.0015172
Al 6061+B4C	281.5	0.11176	0.0015764
Aluminum metal matrix	277.90	0.28177	0.0042076

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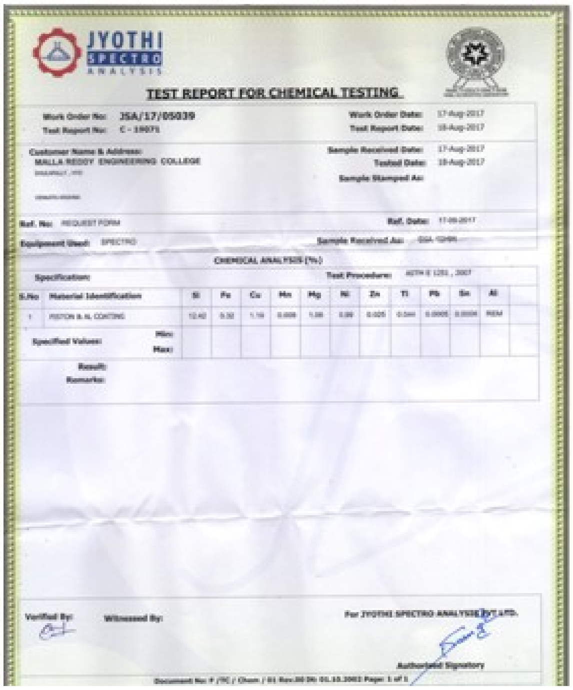
Chemical testing results


JYOTHI SPECTRO ANALYSIS

TEST REPORT FOR CHEMICAL TESTING

Work Order No: JSA/17/05039
Test Report No: C - 19071
Work Order Date: 17-Aug-2017
Test Report Date: 18-Aug-2017
Customer Name & Address: MALLA REDDY ENGINEERING COLLEGE
Sample Received Date: 17-Aug-2017
Tested Date: 18-Aug-2017
Sample Stamped As:
Ref. No: REQUEST FORM
Ref. Date: 17-08-2017
Equipment Used: SPECTRO
Sample Received As:

CHEMICAL ANALYSIS (%)

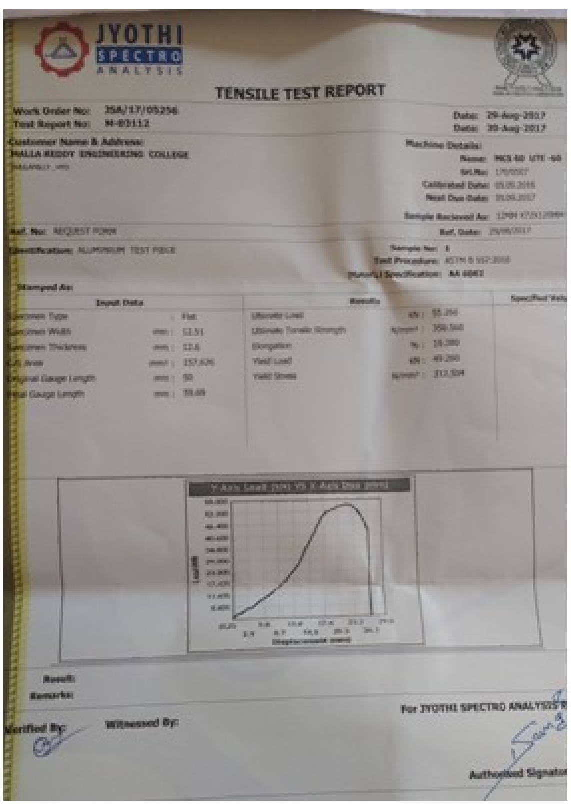
Specification:
Test Procedure: ASTM E 1251 , 2007

S.No	Material Identification	Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Pb	Sn	Al
1	PISTON & AL COATING	12.42	0.32	1.16	0.008	1.08	0.89	0.025	0.044	0.0005	0.0006	REM
Specified Values: Min:												
Max:												

Result:
Remarks:

Verified By:
Witnessed By:
For JYOTHI SPECTRO ANALYSIS PVT LTD.
Authorised Signatory

Mechanical testing results


JYOTHI SPECTRO ANALYSIS

TENSILE TEST REPORT

Work Order No: JSA/17/05256
Test Report No: M-03112
Date: 29-Aug-2017
Date: 30-Aug-2017
Customer Name & Address: MALLA REDDY ENGINEERING COLLEGE
Machine Details:
Name: MCS 60 UTE -60
Ref. No: REQUEST FORM
Identification: ALUMINIUM TEST PIECE
Sample No: 1
Material Specification: AA 6082
Stamped As:

Input Data			Results		
Specimen Type		Flat	Ultimate Load	kN	55.290
Specimen Width	mm	12.51	Ultimate Tensile Strength	N/mm²	[illegible]
Specimen Thickness	mm	12.6	Elongation	%	19.380
C/S Area	mm²	157.626	Yield Load	kN	49.290
Original Gauge Length	mm	50	Yield Stress	N/mm²	[illegible]
Final Gauge Length	mm	59.69			

Y-Axis Load (kN) VS X-Axis Disp (mm)

Result:
Remarks:
Verified By:
Witnessed By:
For JYOTHI SPECTRO ANALYSIS
Authorised Signatory

Conclusion

- Testing, Modeling and analysis of piston is done.
- Brief study about pistons, designs, applications, and different composite materials is done in this project.
- On the same dimension of existing piston physical model, one CAD model is generated in CATIA V5 software.
- Modeling of piston is done in CATIA V5 design software by using various commands and tools.
- The CATIA file is converted into IGS file and imported to ansys workbench software for analysis.
- First Static structural analysis is carried out on piston at 10mpa pressure load conditions, on same material properties of aluminum silicon metal matrix.
- First Static structural analysis is carried out on piston at 10MPa pressure with five different materials, such as magnesium alloy, silicon carbide, 42CrMo4 (special steel alloy), Aluminum alloy (6061) +5% Boron carbide (B4C) and aluminum metal matrix in ansys workbench
- Maximum stress, deformation, maximum strain and maximum shear stress are noted and tabulated.
- Magnesium alloy and aluminum metal matrix having the nearly same least stress value but aluminum metal matrix shows less deformation compare to magnesium alloy.
- Piston made up of aluminum silicon metal matrix is selected for testing and analysis purpose.
- Chemical testing is performed on aluminum silicon matrix composite material to make sure quality and quantity of alloy material i: e percentage is according required specification.

- Mechanical testing (destructive) is performed by universal mechanical testing machine, to find out its yield strength and other mechanical properties.
- On the working load condition for piston i.e 10 mpa , after analysis on ansys workbench software we get the maximum stress value is 277.90 mpa.
- After destructive mechanical testing of same material value of max yield stress is 312.504.
- As the CAD design model of material aluminum silicon metal matrix works under 277.90 MPa which is less than yield stress value of material, hence we can conclude that design is safe.

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