Design and Analysis of Piston on Different Materials using CAE Tools

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Abstract:- Piston plays a main role in energy conversion. Failure of piston happens due to various thermal and mechanical stresses. The working condition of the piston is so worst in comparison of other parts of the internal combustion engine. The main objective of this work is to investigate and analyze the stress distribution of the piston. Design and analysis of a piston using four different materials is carried out in this project. Materials like Ti-6Al-4V, Al alloy 4032, Copper, Al alloy 2024 are used for structural and thermal analysis of the piston. Applied the pressure as 13.6 Mpa and temperature of 1500 degrees on the piston head. Design of the piston is carried out using Solid works software, structural and thermal analysis is performed using Finite Element Analysis. After the analysis on different materials the suitable one for the piston is selected.

1.INTRODUCTION

Piston is one of the mechanical component, invented by German scientist Nicholas August Otto in the year 1866. Piston is considered to be one of the most important parts in a reciprocating Engine, reciprocating pumps, gas compressors and pneumatic cylinders, among the other similar mechanisms in which it helps to convert the chemical energy obtained by the combustion of fuel into useful (work) mechanical power. The purpose of the piston is to provide a means of conveying the expansion of gases to the crankshaft via connecting rod, The piston acts as a movable end of the combustion chamber Piston is essentially a cylindrical plug that moves up & down in the cylinder .It is equipped with piston rings to provide a good seal between the cylinder wall.

1.1 Objectives of the projectare as follows

- To develop structural modeling ofpiston
- To develop structural and thermalanalysis of the piston

1.2 Major Force Acting OverPiston

- Due to explosion of fuel gases
- Due to compression of fuel gases
- Side wall friction and forces
- Thermal load
- Inertia force due to high frequencyof reciprocation of piston
- Friction and forces at crank pinhole

1.3 Functions Of Piston

- To reciprocate in the cylinder as a gas tight plug causing suction, Compression , expansion, and exhauststrokes.
- To receive the thrust generated by the explosion of the gas in the cylinder andtransmit it to the connecting rod.
- To form a guide and bearing to the small end of the connecting rod and to take the side thrust due to obliquity of the rod.

1.4 Factors Considered For Proper Functioning Of Piston

- The piston should have enormous strength and heat resistance properties to withstand gas pressure and inertia forces. They should have minimum weight to minimize the inertia forces.
- The material of the piston should have good and quick dissipation of heat from the crown to the rings and bearing area to the cylinder walls. It should form an effective gas and oil seal.
- Material of the piston must possess good wearing qualities, so that the piston is able to maintain sufficient surface-hardness unto the operating temperatures.
- Piston should have rigid construction to withstand thermal, mechanical distortion and sufficient area to prevent undue wear. It has even expansion under thermal loads so should be free as possible from discontinuities
- The Piston Rings must be in good condition to provide maximum sealing during the stroke of the piston. There must be no Leakage between the piston and the walls of the combustion chamber.
- Intake and Exhaust valves must close tightly so that there is no loss of compression at these points.
- Each piston design must have a provision for returning oil to the oil reservoir and the crankcase. During operation, a significant amount of oil is accumulated in the piston oil ring groove. This oil is returned to the reservoir through piston windows or through a machinedchannel near the piston pin.

LITERATURE REVIEW

- In this paper [1], the coated piston undergone a Von misses test by using ANSYS for load applied on the top. Analysis of the stress distribution was done on various parts of the coated piston for finding the stresses due to the gas pressure and Journal of Engineering and Science Vol. 01, Special Issue 01, July 2016 Copyright @ JES www.jes.ind.in 40 thermal variations. Von misses stress is increased by 16% and deflection is increased after optimization. But all the parameters are well with in design consideration.
- Design, Analysis and optimization of piston [2] which is stronger, lighter with minimum cost and with less time. Since the design and weight of the piston influence the engine performance. Analysis of the stress distribution in the various parts of the piston to know the

stresses due to the gas pressure and thermal variations using with Ansys.

- With the definite-element analysis software, a three-dimensional definite-element analysis [3] has been carried out to the gasoline engine piston. Considering the thermal boundary condition, the stress and the deformation distribution conditions of the piston under the coupling effect of the thermal load and explosion pressure have been calculated, thus providing reference for design improvement. Results show that, the main cause of the piston safety, the piston deformation and the great stress is the temperature, so itis feasible to further decrease the piston temperature with structure optimization.
- This paper [4] involves simulation of a 2-stroke 6S35ME marine diesel engine piston to determine its temperature field, thermal, mechanical and coupled thermal- mechanical stress. The distribution and magnitudes of the afore- mentioned strength parameters are useful in design, failure analysis and optimization of the engine piston. The piston model was developed in solid-works and imported into ANSYS for preprocessing, loading and post processing. Material model chosen was 10-node tetrahedral thermal solid 87. The simulation parameters used in this paper were piston material, combustionpressure, inertial effects andtemperature.
- This work [5] describes the stress distribution of the piston by using finite element method (FEM). FEM is performed by using computer aided engineering (CAE) software. The main objective of this project is to investigate and analyze the stress distribution of piston at the actual engine condition during combustion process. The report describes the mesh optimization by using FEM technique to predict the higher stress and critical region on the component.
- The impact of crown thickness, thickness of barrel and piston top land height on stress distribution and total deformation is monitored during the study [6] of actual four stroke engine piston. The entire optimization is carried out based on statistical analysis. FEA analysis is carried out using ANSYS for optimum geometry. This paper describes the stress distribution and thermal stresses of three different aluminum alloys piston by using finite element method (FEM). The parameters used for the simulation are operating gas pressure, temperature 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.

DESIGN OF PISTON

Pistons are designed with features which perform specific functions during engine operation. The piston head or crown receives the majority of the initial pressure and force caused by the combustion process. The piston pin area is exposed to a significant amount of force due to rapid directional changes. It is also subjected to thermal expansion caused by the transfer of heat from the head to the body of the piston. The piston pin area is subject to more thermal expansion than other areas of the piston. This occurs from the thermal expansion properties of cast aluminum alloy and the mass in the piston pin area.

Some pistons are cast and machined at the factory into a cam ground (elliptical shape). An elliptical shape is an oval shape in which one-half is a mirror image of the other half. These piston shapes provide an advantage in conforming to the ever- changing dimensions of the cylinder bore.

The piston is designed to be an elliptical shape when cold. As the engine reaches operating temperature, the piston pin bore area expands more than other thinner areas of the piston. At operating temperature, the piston shape becomes a circular shape, which matches the cylinder bore for improved sealing and combustion efficiency. Some pistons are designed with a taper, with the smallest diameter of the taper at the piston head. The taper shape compensates for thermal expansion and thermal growth. Thermal growth is the increase in size of a material when heated, with little or no change back to original dimensions. The taper design allows the piston to move freely in the cylinder bore regardless of the heat applied to the piston head. Some Briggs & Stratton engines use a barrel-shaped piston skirt. The barrel shape provides a smoother transition during directional changes of the piston. The piston rolls into the cylinder wall when changing direction at the end of a stroke. This reduces noise, spreads the force of the directional change across a greater surface, and reduces side loading on the piston skirt. Some piston designs have the piston pin offset from centre in the piston. The proper orientation of the piston pin offset is marked by a notch or an arrow on the piston head. The mark on all Briggs & Stratton pistons should be facing or closest to the flywheel on all one- and two-cylinder engines. The offset piston pin design offers a quieter running engine by reducing piston wobble and related noise. This results in truer linear movement of the piston in the cylinder bore.

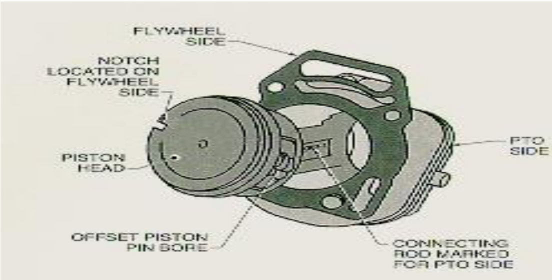


Figure 1 Assembly of Piston

Each piston design must have a provision for returning oil to the oil reservoir and the crankcase. During operation, a significant amount of oil is accumulated in the piston oil ring groove. This oil is returned to the reservoir through piston windows through a machined channel near the piston pin.

Piston windows are a series of small holes machined into the oil ring groove surface of the piston. The oil ring collects excess oil from the cylinder bore. Piston windows allow oil in the oil ring groove to drain into the oil reservoir. Another common method used to return oil to the oil reservoir is through a machined channel near the piston pin. Oil collects in the rear of the oil ring groove and is routed back to the oil reservoir through the channel ending at the piston pin. This provides a path for oil to return to the oil reservoir along the outside surface of the piston when the machined channel is exposed to the oil reservoir at BDC.

MATERIAL SELECTION FORPISTON

Pistons are commonly made of a cast aluminum alloy for excellent and light weight thermal 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.
Following section will describe the potential candidate materials those can be used for piston application.
Based on the properties, potential candidate materials for piston are,

- Titanium Ti-6Al-4V
- Al Alloy 4032
- Copper Alloy
- Al Alloy 2024

Properties

- High Fatigue Resistance,BioCompatbility, Osseoconductivity.
- Light Weight, High Strength andGood Heat Conductor.
- High heat Resistance and IncreasedThermal Conductivity.
- High Strength to Weight Ratio,Corrosion Resistance
- Load Density, High Thermal Conductivity, High Reliability
- Easy Machineability and very goodRecycling Characteristics.

MODELLING AND ANALYSISOF 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 APISTON

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 unduewear.
- 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 supportfor the piston pin.

ASSUMPTIONS MADE

It is very difficult to exactly model the piston, in which there are still researches are going on to find out transient thermo elastic behavior of piston during combustion process. There is always a need of some assumptions to model any complex geometry. These assumptions are made, keeping in mind the difficulties involved in the theoretical calculation and the importance of the parameters that are taken and those which are ignored. In modeling we always ignore the things that are of less importance and have little impact on the analysis. The assumptions are always made depending upon the details and accuracy required in modeling.
The assumptions which are made while modeling the process are given below:

- The piston material is considered as homogeneous andisotropic.
- Inertia and body force effects are negligible during the analysis.
- The piston is stress free before the application of analysis.
- The analysis is based on pure thermal loading and thus only stress level due to the above said is done the analysisdoes not determine the life of the piston.
- Only ambient air-cooling is taken into account and no forced Convection is taken.
- The thermal conductivity of the material used for the analysis is uniformthroughout.
- The specific heat of the material used is constant throughout and does notchange with temperature.

THE PISTON MODEL

The following are the sequence of steps in which the piston is modeled,

- Drawing a half portion ofpiston
- Exiting the sketcher
- Developing the model
- Creating a hole .

SOLIDWORKS

Solid Works is mechanical design automation software that takes advantage of the familiar Microsoft Windows graphical user interface. It is an easy-to- learn tool which makes it possible for mechanical designers to quickly sketch ideas, experiment with features and dimensions, and produce models and detailed drawings. A Solid Works model consists of parts, assemblies, anddrawings.

- Typically, we begin with a sketch, create a base feature, and then add more features to the model. (One can also begin with an imported surface or solid geometry).
- We are free to refine our design by adding, changing, or reorderingfeatures.

- Associatively between parts, assemblies, and drawings assures that changes made to one view are automatically made to all other views.
- We can generate drawings or assemblies at any time in the design process.
- The Solid Works software lets us customize functionality to suit our needs.

INTRODUCTIONTO SOLIDWORKS

Solidworks mechanical design automation software is a feature-based, parametric solid modeling design tool which advantage of the easy to learn windows TM graphical user interface. We can create fully associate 3-D solid models with or without while utilizing automatic or user defined relations to capture design intent.

Parameters can be either numeric parameters, such as line lengths or circle diameters, or geometric parameters, such as tangent, parallel, concentric, horizontal or vertical, etc. Numeric parameters can Solidworks mechanical design automation software is a feature-based, parametric solid modeling design tool which advantage of the easy to learn windows TM graphical user interface. We can create fully associate 3-D solid models with or without while utilizing automatic or user defined relations to capture design intent. Parameters refer to constraints whose values determine the shape or geometry of the model be associated with each other through the use of relations, which allow them to capture design intent.

Design intent is how the creator of the part wants it to respond to changes and updates. For example, you would want the hole at the top of a beverage can to stay at the top surface, regardless of the height or size of the can. Solid Works allows you to specify that the hole is a feature on the top surface, and will then honor your design intent no matter what the height you later gave to the can. Several factors contribute to how we capture design intent are Automatic relations, Equations, added relations and dimensioning.

Features refer to the building blocks of the part. They are the shapes and operations that construct the part. Shape-based features typically begin with a 2D or 3D sketch of shapes such as bosses, holes, slots, etc. This shape is then extruded or cut to add or remove material from the part. Building a model in Solid Works usually starts with a 2D sketch (although 3D sketches are available for power users). The sketch consists of geometry such as points, lines, arcs, conics (except the hyperbola), and spines. Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity, and concentricity.

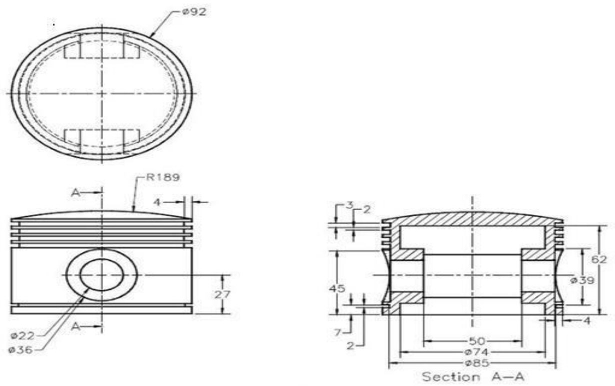
- It contains basic parts or data of standard bolt and nut, gears, cams, bearings etc. These are the product design interface and are capable of 3D solid modeling, Conceptual design, Assembly structure planning, direct model editing, large assembly design, advanced surface design, sheet metal design, weldments, Plastic parts designing, CAD productive tools,

Reverse engineering, Mold designing, Piping&tubing and electrical cable harness&conduit designs.

This can increasing the productivity without lowering the cost, because it gives various data and technical communication, which helps to your design and helps to validate with standards. This can help's the product designers to convert new product ideas into reality. It contains simulation technology, which enables to verify your design.

DESIGN PROCEDURE OFPISTON

- For designing the piston, the following procedure has to be followed.
- Draw the sketch with the given dimensions and then revolve it.
- After the above



step make a through hole inthe piston.

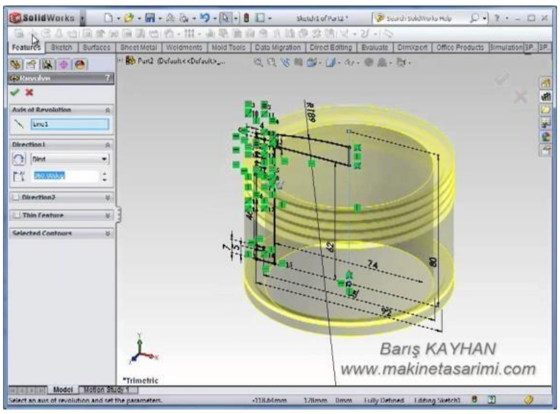


Figure: 2 Piston

FINITE ELEMENTANALYSIS INTRODUCTION

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. It also can be used to analyze either small or large scale deflection under loading or applied displacement. It uses a numerical technique called the finite element method (FEM). In finite element method, the actual continuum is represented by the finite elements. These elements are considered to be joined at specified joints called nodes or nodal points. As the actual variation of the field variable (like displacement, temperature and pressure or velocity) inside the continuum is not known, the variation of the field variable inside a finite element is approximated by a simple function. The approximating functions are also called as interpolation models and are defined in terms of field variable at the nodes. When the equilibrium equations for the whole continuum are known, the unknowns will be the nodal values of the field variable. In the finite element approach, the nodal values of the field variable are treated as unknown constants that are to be determined. The interpolation functions are most often polynomial forms of the independent variables, derived to satisfy certain required conditions at the nodes. The interpolation functions are predetermined, known functions of the independent variables; and these functions describe the variation of the field variable within the finite element. The simulations used in FEA are created using a mesh of millions of smaller elements that combine to create the shape of the structure that is being assessed. Each of these small elements is subjected to calculations, with these mesh refinements combining to produce the final result of the whole structure.

INTRODUCTION TOSIMULATION

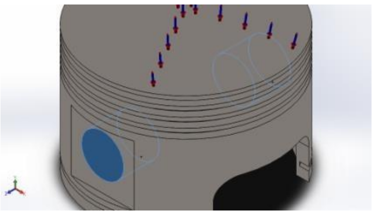
Simulation is a design analysis system. Simulation provides simulation solutions for linear and nonlinear static, frequency, buckling, thermal, fatigue, pressure vessel, drop test, linear and nonlinear dynamic, and optimization analyses. Powered by fast and accurate solvers, Simulation enables you to solve large problems intuitively while you design. Simulation comes in two bundles: Simulation Professional and Simulation Premium to satisfy your analysis needs. Simulation shortens time to market by saving time and effort in searching for the optimum design. After building your model, you need to make sure that it performs efficiently in the field. In the absence of analysis tools, this task can only be answered by performing expensive and time-consuming product development cycles. A product development cycle typically includes thefollowing steps:

- Building your model.
- Building a prototype of the design.
- Testing the prototype in the field.
- Evaluating the results of the fieldtests.

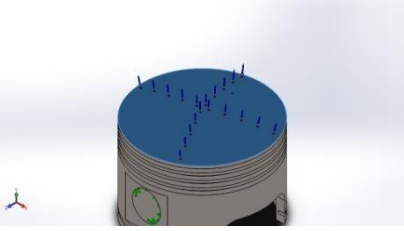
Modifying the design based on the field test results. Analysis can help you accomplish the following tasks:

- Reduce cost by simulating the testing of your model on the computer instead of expensive field test.
- Reduce time to market by reducing the number of product developmentcycles.

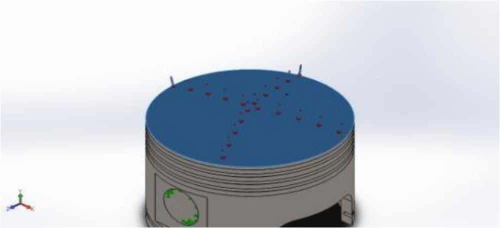
Fixture



Pressure

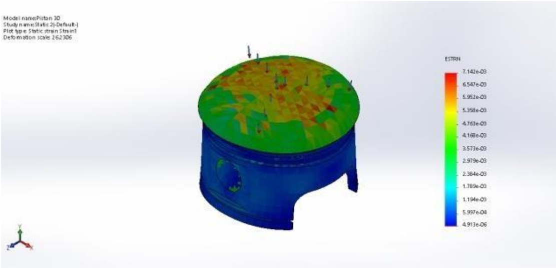


Temperature

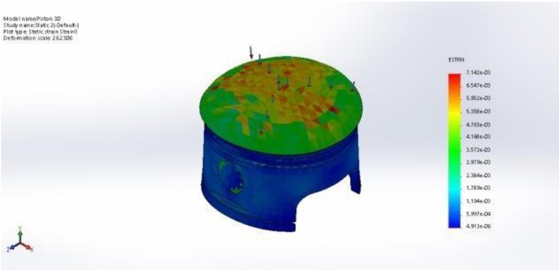


Mesh

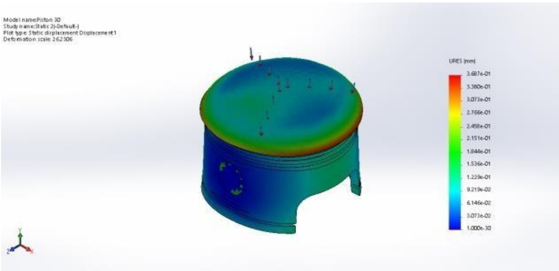
Ti-6Al-4V
Stress



Strain

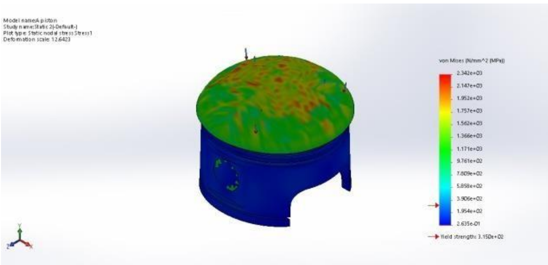


Displacement



Al Alloy 4032

Stress



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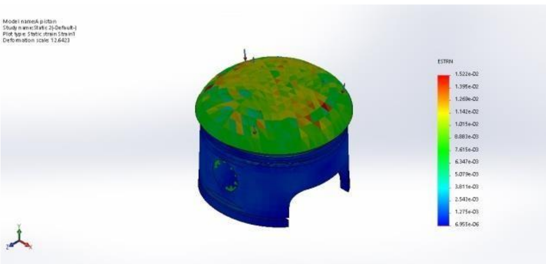

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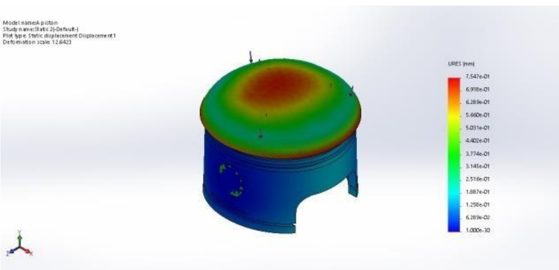
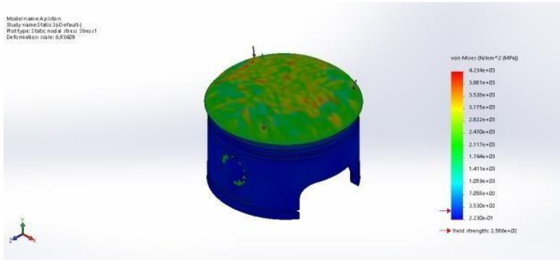


COPPER ALLOY

Stress



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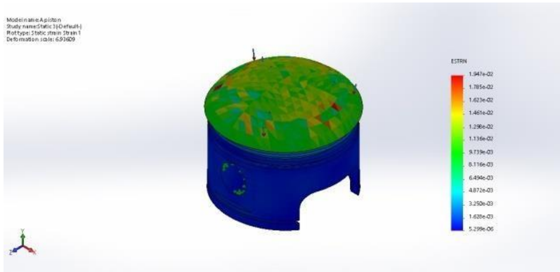

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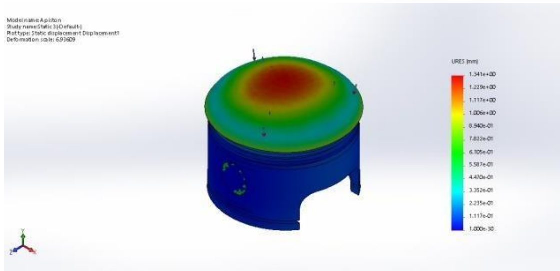
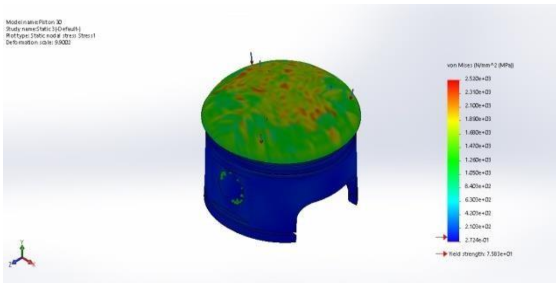


Al Alloy 2024

Stress



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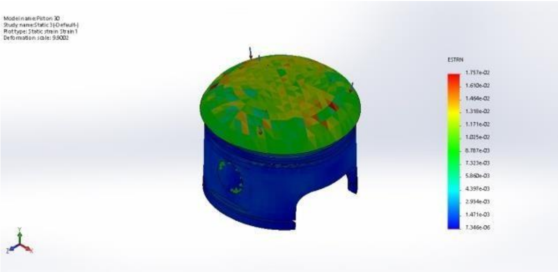

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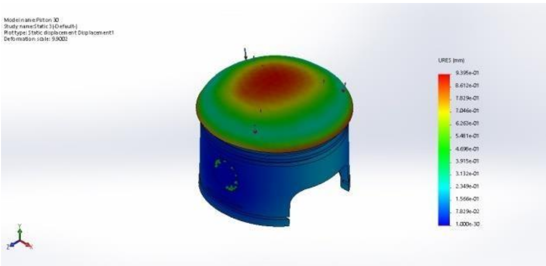

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