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An Analysis To Thermal Load And Mechanicalload Coupling Of A Gasoline Engine Piston Coated With High Copper Boride Alloy.

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ABSTRACT:

With the definite-element analysis software, a three-dimensional definite-element analysis has been carriedout to the gasoline engine piston. Considering the thermal boundary condition, the stress and thedeformation distribution conditions of the piston under the coupling effect of the thermal load andexplosion pressure have been calculated, thus providing reference for design improvement. Results showthat, 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.

Keywords: Finite Element Method, Engine, Piston, Coupling

1.0 INTRODUCTION:

As a kind of thermal power machine, theworking process of the engine is greatly related toheat transfer, as it decides various technical data ofthe engine such as the economic efficiency. Andthe increase of heat will cause the increase of thethermal load. As the main heated part of the engine,the piston has to bear the complicated mechanicalload and thermal load subjected to periodicalchange. An analysis to the stress and thedeformation condition under the mechanical load orthe thermal load only is far from enough to reflectthe actual working condition of the piston. Areference can only be provided for the piston designwith factors influencing the thermal load found out,taking into overall consideration the piston intensityunder the coupling effect of the thermal load andmechanical load. analysed heat transfer problemsexhibiting sharp thermal gradients using theclassical and generalized finite element methods

INTRODUCTION TO PISTON:

Piston is the 'heart' of the automobile engine. It's one of the key components of the engine and it's working the hard condition. The function of the piston is bearing the gas pressure and making the crankshaft rotation through the piston pin. Piston works in high temperature, high pressure, high speed and poor lubrication conditions. Piston contact with high temperature gas directly, the instantaneous temperature can be up to 2500K. Because of the high temperature and the poor cooling condition, the temperature of the top of the piston can be reach 600~700K when the piston working in the engine. And the temperature distribution is uneven. The top of the piston bears the gas pressure, in particular the work pressure. Gasoline engine can be up to 3~5Mpa and diesel engine can be up to 6~9Mpa. It makes the piston produce the impact and bear the side pressure. The piston works in high speed (8~12m/s) reciprocating motion, and the speed is changing, so it makes a large inertial force, which makes the piston bear a great additional load. Working in these bad conditions, the piston accelerated wears, meanwhile produces the additional load, thermal stress and chemical corrosion of the gas.

THE MAIN PARAMETERS OF THE ENGINE WORKING PROCESS:

Installing EFI systems on modern engines, which can be guaranteed to get the almost the ideal composition of the mixture gas by the speed characteristic. In order to make the engine as far as possible to get enough economy and sought to reduce the combustion product's hazard, when α =1.2~1.8 that minor hazard can be reached. For diesel engines, α is always greater than one to ensure the diesel fuel which injected into the cylinder can be completely burned. When the diesel engine sucked a certain amount of air, if α is small that means it can be inject the fuel to the cylinder, also means that the suction air of the cylinder with high utilization and make a big power. Thus, α is a reflection of an indicator about the formation of the mixture gas, the perfect degree of the combustion and the performance of the engine. General range of values α when diesel engine works at full load: supercharged diesel engine: α =1.8~2.2; non-supercharged diesel engine: α =1.2~1.8It can be considered by the structure of the engine, the working condition, the cooling system, the shape of combustion chamber, the coefficient of the excess air and the speed of the engine crankshaft… It can be determined on the basis of the experimental data

2.0 LITARATURE REVIEW

HONGYUAN ZHANG, 2ZHAOXUN LIN, 1DAWEI XU(2013)"And the increase of heat will cause the increase of the thermal load. As the main heated part of the engine, the piston has to bear the complicated mechanical load and thermal load subjected to periodical change. An analysis to the stress and the deformation condition under the mechanical load or the thermal load only is far from enough to reflect the actual working condition of the piston. A reference can only be provided for the piston design with factors influencing the thermal load found out, taking into overall consideration the piston intensity under the coupling effect of the thermal load and mechanical load.

Lanka Tata Rao 1 , Katakam Satyanarayana , M.S.S.Srinivasa Rao(2014) piston made of Al Alloy, acts as heart of the I.C. engine and is a crucial part of internal combustion engines. When the combustion of fuel takes place inside engine cylinder; high temperature and pressure are developed due to combustion of the fuel. Because of high speed and at high loads, the piston is subjected to high thermal and structural stresses. If these stresses exceed the designed values, failure of piston may take place. Experimental investigation carried out on computerized VCR diesel test rig to determine the variation of pressure with crank angle in the cylinder at particular compression ratio. The temperature variation of gases was further evaluated using the results obtained from the experimentation.

Manish Kumar (2017)A piston is a component of reciprocating engines, pumps and gas compressors. It is located in a cylinder and is made gas-tight by piston rings. Engine pistons are one of the most complex components among all

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automotive or other industry field components. Piston and connecting rod are connected by the piston pin at one end of connecting rod and other big end of connecting rod than connected to crankshaft. Pistons are subjected to forces generated by hot burned gases on fuel combustion and in high temperature combustion chamber discussed a heat transfer model that used quasi-steady heat flux relations to calculate the heattransfer from combustion gases through cylinder wall to the coolant in an internal combustion engine to calculate the components temperature distribution

, **,Dilip Kumar Sonar, 2,Madhura Chattopadhyay (2015)** Engine pistons are one of the most complex components among all automotive or other industry field components. The engine can be called the heart of a car and the piston may be considered the most important part of an engine. There are lots of research works proposing, for engine pistons, 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., there are a huge number of damaged pistons. From the analysis, it is evident that thermal stress was higher than mechanically induced stress hence it could be concluded that the piston would fail due to the thermal load rather than the mechanical load and hence during optimization design, this could be put into consideration to ensure that thermal load is reduced.

3.0 GEOMETRY

The image below shows the geometry of the piston. The piston created by CATIA is further imported to ansys software for further analysis. The following three types of boundary conditions are applied. Heat transfer co-efficient on the top and bottom surface, heat flux on lateral surfaces and pressure Forces.

Finite element model:

The finite element analysis to the piston is to establish the reasonable and accurate finite element model first, thus carrying out analysis by marking cell grids to obtain the accurate results finally. According to the structural symmetry of the piston, in order to be convenient for calculation and decrease workload, cut the established piston model to maintain 1/4 and then import the model to the finite element software for the finite element analysis to the piston according to the fine interface between the modeling software and the finite element analysis software. During the importing process, some details have been omitted, such as the chamfer and the snap ring of the piston pin etc

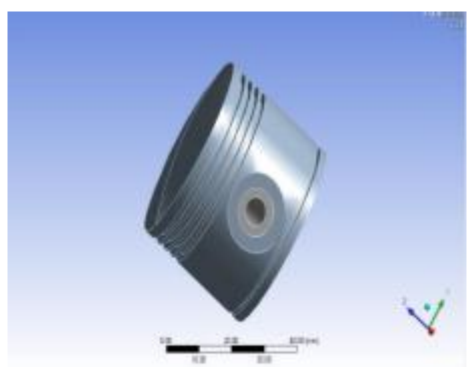

Figure.1 geometric model of the piston

Parameters of the piston:

Piston material copper alloy Poisson ratio 0.32

Elastic modulus of the piston 70GPa

Material density 8.96g / m

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Conductivity factor 160 /( ) 2 w m · K

Coefficient of thermal expansion 21 10 m/ K

Mesh Generation

During the mesh generation for the piston model,based on experiences and with several trials, theeight-node hexahedron cell SOLID70 is selected inthis paper. Figure 2 shows the final finite elementmodel after mesh generation for the piston

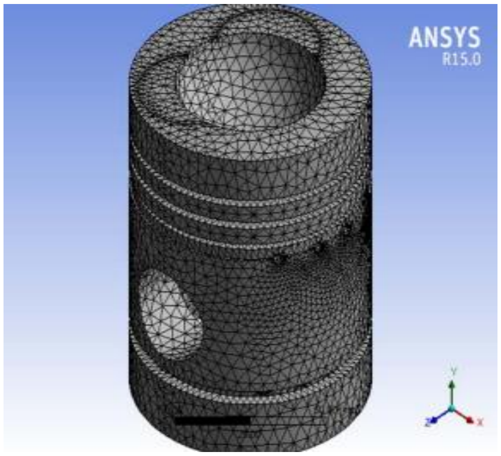

Figure 2.meshed model

Features	Specifications
Make	Kirloskar oil Engine
Type	Four stroke, Water cooled Diesel
No of cylinders	One
Combustion Principle	Compression ignition
Max speed	1500
Crank Radius	55mm
Connecting Rod length	300mm
Cylinder diameter	80mm
Stroke length	110mm

Discussions: The setup consists of single cylinder, four stroke, VCR (Variable Compression Ratio) Diesel engine connected to eddy current type dynamometer for loading. Setup is provided with necessary instruments for combustion pressure and crank-angle measurements. These signals are interfaced to computer through engine indicator for Pθ & PV diagrams. Provision is also made for interfacing airflow, fuel flow, temperatures and load measurement. The setup has stand-alone panel box consisting of air box, two fuel tanks for duel fuel test, manometer, fuel measuring unit, transmitters for air and fuel flow measurements, process indicator and engine indicator. Rota meters are provided for cooling water and calorimeter water **Thermal Boundary Conditions**:

In this work, finite element thermal analysis is carried out to calculate the piston temperature with the help of third kind boundary condition as below

$$-k\frac{\partial T}{\partial n} = h(T - T_f)$$

Where, T is the surface temperature, n is the exterior normal vector for the object boundary, h is the convection heat transfer coefficient, k is the thermal conductivity of object and Tf is the ambience temperature at the boundary of the object. In the thermal analysis for model in ANSYS, the convection boundary condition, as the surface load is inflicted on the outside surface. The upper part of the piston is having very high temperature because of direct contact with the gas. So a temperature of 360 degrees is provided to the upper surface of the piston. The thermal boundary conditions of the piston.

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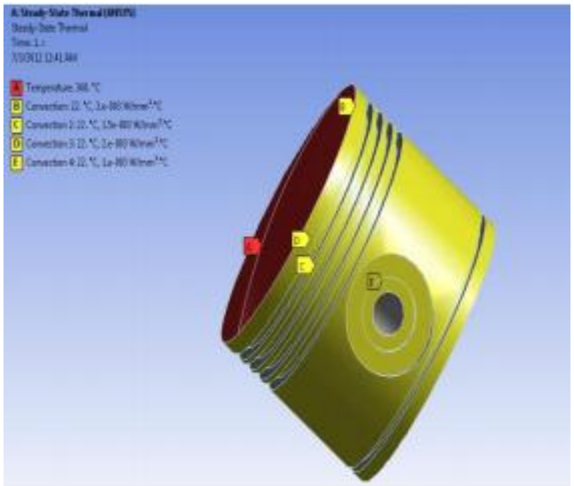

Fig 3: Thermal boundary condition

MECHANICAL LOADING:

on Piston The stress, strain and deformations are the most serious when the explosive pressure of the fuel gas achieves maximum under the condition of stable rotational speed. The maximum explosive pressure is 6.04 MPa, and it acts uniformly on the piston head. The three freedom degrees of the piston pin are restrained to let the piston in a static condition. Coupling restraints are imposed on two points on the bottom of piston in order to eliminate the revolving of the piston around the piston pin. The surface-surface contact unit between the piston pin hole and the piston pin is set from default as 'bonded' to 'no separation' to let some displacement between piston and piston pin during the movement of the piston. The above two boundary conditions are referred as displacement restraints.

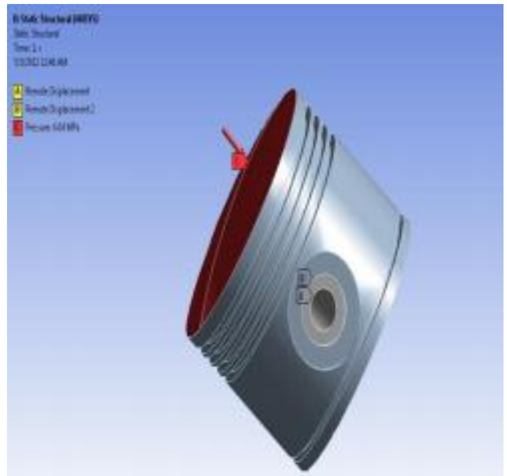

Fig 4: Mechanical boundary condition

Constraint Conditions for Mechanical Loading

Three freedom degrees of the piston pin are restrained to let the piston in a static condition to eliminate the revolving of the piston around the piston pin. The selection of the displacement boundary condition is very important to the finite element analysis. If the selection is not correct, it will affect the calculation precision. On the moment of the maximum gas pressure, the pin contacted to the surface of the pin hole.

Table 1 Material properties of piston

Materials	COPPER BORIDE ALLOY Alloy
Young's Modulus	130Gpa
Density	2460 kg/m^3.
Poisson's Ratio	0.3334
Thermal Conductivity (W/m 0C)	538W/mK
Specific Heat (J/kg0C)	720
Thermal Expansion	300-1270 k

Results and Discussion:

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By applying the boundary conditions heat transfer analysis is carried out. The various boundary conditions and load is imposed on the FEA model and three different kinds of kinds of the stress field, named as thermal stress field, mechanical stress field, and thermo-mechanical coupling stress field can be obtained. Fig.6 shows the total von-mises stresses distribution on the whole surface of piston. Figures 6,7,8 shows the stresses distribution due to mechanical load, thermal load and coupled thermo-mechanical load respectively. From Fig.5, we can see that the maximum stress is 207.4 MPa, which does not exceed the material yield strength (480 MPa) and it occurs at the upper end of piston pin boss inner hole and inside the piston pin. The calculated results also indicate that the maximum thermal load is 96.014 MPa and the maximum stress of the fuel gas explosive pressure is 210.75 MPa. This fact makes clear that the explosive pressure of fuel gas is the main factor to cause the stress concentration. As shown in Fig. 9, the maximum deformation is 0.0606 mm and it occurs at the piston head. The minimum displacement is 0.00202 mm

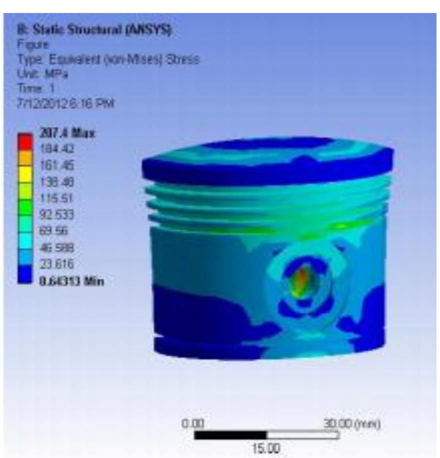

Fig 5: Total von missed stress distribution

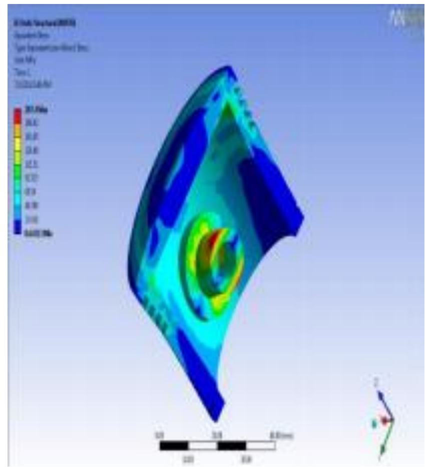

Fig 6: Total von mises stress distribution on a section of piston

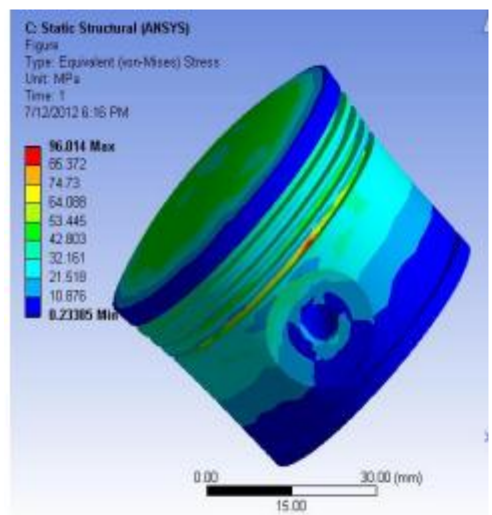

Fig 7: Thermal distribution

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Volume 04 Issue 14
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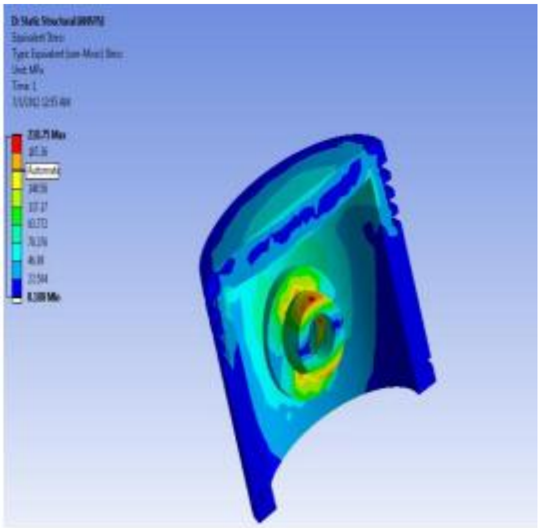

Fig 8: Structural stress distribution

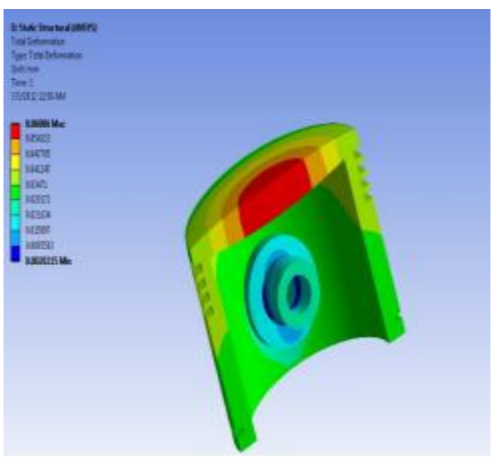

Fig 9: Total deformation

THERMO-MECHANICAL ANALYSIS:

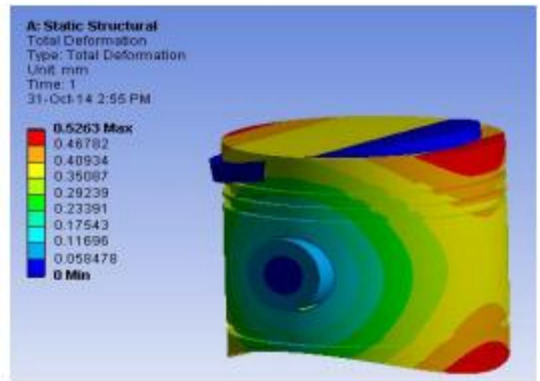

Fig 10: total deformation

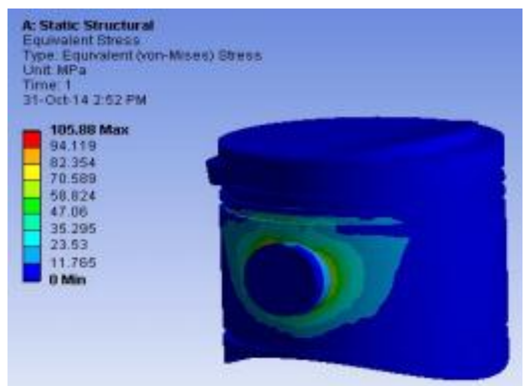

fig 11. von mises stress analysis of piston

Table 2 comparison of fem and thermo mechanical analysis

analysis	Parameters	**maximum**	**minimum**
Fem analysis	Total deformation	207 MPa	.06 mm
	von mises stress analysis of piston	244 MPa	.119 mm
Thermo mechanical	Total deformation	**0.5263**	**0**
	von mises stress analysis of piston	**105.88**	**0**

DISCUSSIONS: From this project the piston gets affected in different mechanisms.The allowable stress has been drived which the piston can undergo deforme . The factors has been studied which affects the piston the most. The stress distribution on the piston mainly depends on the deformation of piston. Therefore, in order to reduce the stress concentration, the piston crown should have enough stiffness to reduce the deformation. The deformation and the stress of the piston are mainly determined by the temperature, so it is necessary to decrease the piston temperature through structure improvement, e.g. by using the combined piston with small heat conduction coefficient and large heat conduction coefficient of the skirt and inner cylinder.

Conclusions:

The first main conclusion that could be drawn from this work is that although thermal stress is not the responsible for biggest slice of damaged pistons, it remains a problem on engine pistons and its solution remains a goal for piston manufacturers. From the analysis, it is evident that thermal stress was higher than mechanically induced stress hence it could be concluded that the piston would fail due to the thermal load rather than the mechanical load and hence during optimization design, this could be put into consideration to ensure that thermal load is reduced. It can also be deduced that individually, thermal and mechanical stress proportions have a direct influence on the coupled thermal-mechanical stress hence during design each load can be considered and reduced independently. It can be concluded that the piston can safely withstand the induced stresses during its operation. The stress obtained by theoretical calculation and FEA found to be approximately same. And it will last a problem for long because efforts on fuel consumption reduction and power increase will push to the limit weight reduction, that means thinner walls and higher stresses. To satisfy all the requirements with regard to successful application of pistons, in particular mechanical and high temperature mechanical fatigue and thermal/thermal–mechanical fatigue there are several concepts available that can be used to improve its use, such as design, materials, processing technologies,

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