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Analysis of Heat Transfer in Elliptical Piston Profile in Diesel Engine

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Abstract

Heat transfer is a predominant factor in Diesel engines, and it plays a major role in engine performance. Heat transfer occurs in Diesel engine from cylinder to its outer casing of the engine. The experiment is conducted in Splendor heavy duty Diesel engine with elliptical piston profile and heat transfer analysis is carried out. This project is carried out by two methods, theoretical approach and numerical simulation. Theoretical approach is done with the calculation of pressure, temperature, and volume at each angle of crank rotation. Finally, the rate of heat transfer is calculated by correlation. Numerical simulation is done by analyzing the elliptical piston profile using ANSYS Multiphysics software. Modeling and heat transfer analysis are performed. Finally, the numerical and theoretical results are compared. On comparison, numerical results are well agreed with the theoretical results.

Keywords:
Diesel engine, piston, elliptical profile, heat transfer, ANSYS.

1. Introduction

The Internal Combustion (IC) engines have undergone significant advancements since their introduction in the early 16th century, and the latest trend is to make them greener. The influence of fuel-powered mechanical engines in the modern world is substantial enough, so that we cannot avoid them for emission reduction reasons. Their application extends from lawn mowers to powering heavy military ships and jets. The latest trend in the IC engine industry is to develop power plants with higher efficiency and to make them running on alternative fuels to meet modern emission norms.

There are different IC engine configurations used to generate mechanical output from chemical energy, namely reciprocating engines (single and double piston) and rotary engines. In general, a double piston engine delivers more power than a single piston engine for the same configuration. This thesis uses an analytical model developed in spreadsheet form and a Computational Fluid Dynamics (CFD) model to analyze the operating characteristics of an Opposed Piston Engine (OPE).

The parameter used for the simulation is operating gas pressure and material properties of piston. To evaluate the material properties of piston the maximum principal stress, minimum principal stress and von misses stresses were calculated. These stresses were calculated for three different materials by comparing we found out that sic reinforced zrb2 composite material provides less stress concentration and more stability at higher temperature. For stability checking at higher temperature thermal analysis were carried out. This research work suggests a new type of sic reinforced zrb2 composite material that can sustain at higher temperature (1680K) and pressure (18 MPa). The structure of piston was modeled by using solid edge software. Finite element modeling and analysis were performed using ansys 14. The natural frequency and vibration mode of the piston were obtained and its vibration characteristics are analysed. The free vibration analysis show that the natural frequency of vibration varies from 1.28e-5 Hz to 274.44 hz [1].

Damaged or broken parts are generally too expensive to replace, or are no longer available and this is particularly relevant to the automobile industry owing to the ever-increasing accidents. Reverse engineering (re) has been successfully employed to for possible recovery of a damaged or broken part. In this paper, we present a framework which successfully uses re to generate a cad model of a damaged internal combustion (IC) engine piston and then use the state-of-the-art ansys finite element analysis package to perform a linear static and a coupled thermal-structural analysis of the component. Further, a parametric evaluation of the material properties vis-à-vis operating conditions is carried out to generate a relational database for the piston to arrive at optimal design solutions under different operating conditions [2].

The finite element analysis is performed by using computer aided design (CAD) software. The main objective is to investigate and analyze the thermal stress distribution of piston at the real engine condition during combustion process. The paper describes the mesh optimization with using finite element analysis technique to predict the higher stress and critical region on the component. The optimization is carried out to reduce the stress concentration on the upper end of the piston i.e. (piston head/crown and piston skirt and sleeve). With using computer aided design (cad), pro/engineer software the structural model of a piston will be developed. Furthermore, the finite element analysis performed with using software ansys [3].

It is found out that the temperatures of the piston top and the first circular groove are relatively High after calculating the temperature field and based on the results the optimization scheme of adding the Cooling oil chamber is applied to the piston structure. Results show that, after optimization, the maximum Temperature of the piston top is decreased to 264_, and the temperature at the first ring is decreased to 204_, thus improving the working condition of the piston ring. Secondly, thermal analyses are performed on piston, coated with Zirconium material by means of using a commercial code, namely ANSYS. The effects of coating on the thermal behaviors of the pistons are investigated. The finite element analysis is performed by using computer aided design software. The main objective is to investigate and analyze the thermal stress distribution of piston at the real engine condition during combustion process. This thesis describes the mesh optimization by using finite element analysis technique to predict the higher stress and critical region on the component. In this work, the main emphasis is placed on the study of thermal behavior of functionally graded coatings obtained by means of using a commercial code, ANSYS on aluminum and zirconium coated aluminum piston surfaces. The analysis is carried out to reduce the stress concentration on the upper end of the piston i.e. (piston head/crown and piston skirt and sleeve). With using computer aided design NX/Catia software the structural model of a piston will be developed. Furthermore, the finite element analysis is done using Computer Aided Simulation software ANSYS [4].

A thermo mechanical FE analysis of the engine piston made of composite material was shown. A selected engine is installed in one of the popular polish tanks. The proposed new material is characterized by a low hysteresis – the differences of the coefficient of thermal expansion for heating and cooling are not significant. The results obtained for the piston made of a new material were compared with those for the current standard material. The piston was loaded by a temperature field inside it. Appropriate averaged thermal boundary conditions such as temperatures and heat fluxes were set on different surfaces of the FE model. FE analyses were carried out using MSC. Marc software. Development of the FE model was also presented. Geometrical CAD model of the piston was developed based on the actual engine piston, which was scanned using a 3D laser scanner. A cloud of points obtained from the scanner was processed and converted into a 3dimensional solid model. FE model of a quarter part of the piston was developed for the preliminary analyses presented in the Paper 4-node tetrahedron finite elements were applied since there was no axial symmetry of the considered object. The temperature field inside the piston was determined and presented in the form of contour bands. Contours of displacement and stress in a radial direction were shown as well [5].

The four stroke Otto engine uses just one of the four strokes to perform work. This causes various problems: The engine runs jerkily, and this can only be prevented by a large flywheel, which needs a lot of space and weights pretty much in addition. In this thesis, thermal loads and pressures produced in the multi cylinder diesel engine Toyota 86 Car by varying compression ratios 14:1, 15:1, 18:1, 20:1 and 25:1 are calculated by mathematical correlations And also calculating the effect of these thermal loads on piston and piston rings by varying materials Cast Iron, Aluminum Alloy 6061 for piston and Cast Iron and Steel for piston rings.FEA transient thermal analysis is performed on the parametric model to validate the effect of thermal loads on piston and piston rings for different materials. The optimum value of compression ratio and the better material is determined by analysis results to improve the heat transfer rate of multi cylinder engine piston and piston rings. Dynamic analysis is done on the piston by applying the pressures developed and also static analysis by applying the maximum pressure [6].

Piston is a disc which reciprocates within a cylinder. It is either moved by the fluid or it moves the fluid which enters the cylinder. The main function of the piston of an IC engine is to receive the impulse from the expanding gas and to transmit the energy to the crankshaft through the connecting rod. The piston must also disperse a large amount of heat from the combustion chamber to the cylinder walls. Piston is made of cast aluminum 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 I am going to replace cast aluminum LM25 with Aluminum Alloy 7475-T761 and Aluminum Alloy 6061. These two materials have high strength and Elongation. The aim of project is to design a piston for 150cc engine using Design calculations. 2D drawing is created by using parameters obtained and a 3D model of piston is designed using parametric software Pro/Engineer by using 2D drawings. Couple field Analysis is done on the piston by varying parameters like thickness etc. and also by considering materials Aluminum Alloy 7475-761 and Aluminum Alloy 6061. Analysis is done to verify the best combination of parameters and material for two wheeler piston, which is done in Ansys [7].

Simplified finite element model of spark ignition (SI) engine to analyze combustion heat transfer is presented. The model was discredited with 2D thermal elements of global length 0.001. The fuel type is diesel. Internal nodal temperature of cylinder body is defined as 21000^{o}C to represent occurrence of gasoline combustion. Material information and isotropic material properties are taken from published report. The transient heat transfer analysis is done for the instant of combustion. The model is validated by comparing the computed maximum temperature at the piston surface with the published result. The computed temperature gradient at the crucial parts are plotted and discussed. It has been found that the critical top surface suffered from thermal and the materials used to construct the engine parts strongly influenced the temperature distribution in the engine. The model is capable to analyze heat transfer in the engine reasonably and efficiently [8].

A numerical computer simulation program was developed for the interpolation of the three dimensional temperature field of a body on the basis of a few measured temperatures. Inverse techniques are applied, ensuring that the temperature distributions meet measured temperatures and that the interpolation satisfies the governing differential equation and essential physical restrictions. Finite Element methods are used the formulation of both, the forward and the inverse problem. Exemplary, inverse techniques are applied to analyze the temperature field of a combustion engine piston. The number and positions of measured temperatures is varied to find an optimum configuration for practical applications. The piston ring holograms were recorded and the holographi plate replaced on the holder after development. The piston ring was subjected to thermal stress as it was illuminated by

Laser beam acting as the object beam. This process led to generation interferograms which were captured by a CCD camera at different temperatures. The captured interferograms were analyzed using atmosfringe version 3.3 software. From the analysis, the peak to valley (P-V) aberrations measured for each of the piston ring varied for the same temperature value. The P-V aberrations ranging from 0.0128λ to 1.2989λ were obtained. From this result, it was evident that the three rings on the piston different unique structural characteristics due to their function [9].

In I.C. Engine piston is most complex and important part therefore for smooth running of vehicle piston should be in proper working condition. Pistons fail mainly due to mechanical stresses and thermal stresses. Analysis of piston is done with boundary conditions, which includes pressure on piston head during working condition and uneven temperature distribution from piston head to skirt. The analysis predicts that due to temperature whether the top surface of the piston may be damaged or broken during the operating conditions, because damaged or broken parts are so expensive to replace and generally are not easily available. The CAD model is created using CATIA V5 tool. CAD model is imported into the Hyper Mesh for geometry cleaning and meshing purpose. The FEA is performed by using RADIOSS. The topology optimization of the model is done using OptiStruct module of Hyper Works software. Piston is to be one of the most important parts in a reciprocating engine in which it helps to convert the chemical energy obtained by the combustion of fuel into useful mechanical power. The purpose of the piston is to provide a means of conveying the expansion of the gasses to the crankshaft, via the connecting rod, without loss of gas from above or oil from below. 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. The stresses due to combustion are considered to avoid the failure of the piston. Intensity of thermal and structural stresses should be reduced to have safe allowable limits. This review introduces an analytical study of the thermal effects and structural stresses on engine piston in the four stroke engine and analytical method to find out the stresses acting on the piston [10].

2. Model generation

Opposed Piston engine in piston, Part Modeling Help provides procedures for modifying part features and resolving failures. From the above modeling concept we modeled the component and the representation of the Opposed Type Piston Engine.Then the model is converted in to the IGES format which is most suitable and easy access for any other software’s. Using the IGES format we can import the functionally model from SOLIDWORKS to ANSYS. Now we can make any analysis like thermally and structurally etc.

3. Analysis

3.1 Solution Background

In this project to determine in varies kind’s application it’s especially following this process. In this causes are consisting in thermally following this cause’s .are different profiles concave and convex analysis given below.

3.2 Thermal Analysis

This section describes the analysis used to oppose piston engine in Different concave with convex profiles. Externally apply top concave of this position assembly. The heat generation, Boundary conditions and convective heat transfer coefficients are calculated for use in the different FEM model configurations. FEM model parameters such as coolant properties, air flow characteristics, surface temperatures, and Heat transfer of the model in opposed piston inside of the piston and radically apply to the load characteristics are defined. In all of the analysis cases, the assumptions used to create the FEM models are listed within their respective section. FEA meshing settings are also discussed, along with the methods used within the FEM model to reduce computing resource demands. **Error!**

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Reference source not found. Shows the High speed ball bearing sub-assemblies and direction of cooling air flow passing over them.

3.2.1 Boundary Conditions

However, the local heat generation within the opposed piston Engine in Full Assembly, during normal operation directly impacts the type Top surface of the piston area.

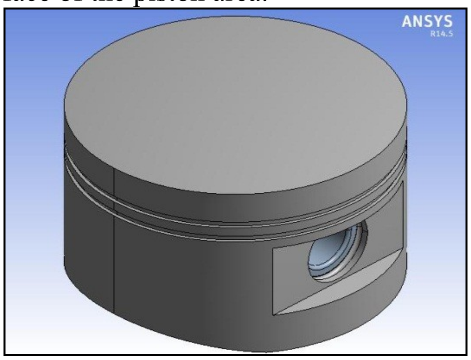

Figure 1 Piston Profile Geometry

Therefore specific values are calculated for each of the Top surface of the piston material and utilization of this. The positions of the Materials wound Top on surface are shown in Error! Reference source not found. The heat generation values within the engine Top surface are calculated using the measured current passed through the Piston with surface in concave with convex on this year and the resistance of the selection of materials.

$$R_{AMB} = R_{REF}\left(\frac{T_{AMB} + 234.5}{T_{REF} + 234.5}\right)$$

Where:

R_{AMB} = resistance measured at ambient temperature, ohms
R_{REF} = resistance corrected to T_{REF}, ohms;
T_{AMB} = ambient temperature, 25 °C (77 °F).

Due to the heavy load that Heating passing through in Piston profile analysis lifts during withdrawal and insertion steps, the engine fins are supplied more current during stepping operations than when holding the drive Piston Profile on concave convex are stationary and rotatable . Although the Methods of function spend the majority of their operating life in hold-mode with reduced current supplied only to the static conditions with rotational continually to apply the different class of speeds are applicable following resins.

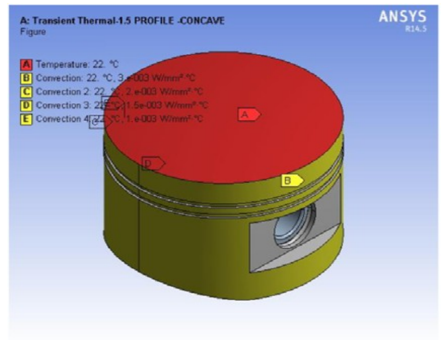

Figure 2 boundary Conditions

3.3 Heat transfer coefficients

The heat transfer coefficients for the external piston profile of Heat transfer of the housing with piston in ax symmetric part method with grooves areas are calculated as input to the heat transfer analyses. The heat transfer coefficient is calculated for the inner diameter (ID) of the Pressure Housing, which is exposed to External engine of this above piston. The heat transfer coefficients are also calculated for the external Pressure Housing area below the External Heat method to follows, the External profiles followed in this method are followed, and the Pressure Housing area immediately above the piston profile method; all of which are exposed to external Methods to followed in piston profile. Error! Reference source not found. Shows the convective heat transfer regions and their respective lengths.

3.4 Meshing

Basically a mesh is required because by physics or mathematical theory we are solving the variables like flow and heat transfer and any other variable at these cell centers or nodes. Also the theoretical methods that are used for any CFD study like the fine difference method (FDM), finite element method (FEM) and the finite volume method (FVM) actually solve the variable at these discrete cells/ nodes. The Meshing models are

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analyzed using ANSYS Workbench Version 14.5 as outlined in Section **Error! Reference source not found.** The models are meshed using the ANSYS default settings for path conforming volume with a relevance of 0.5 on a scale of -100 to 100. Similar setting the mesh relevance to a maximum of 100 refines the mesh to 185237 nodes and 95422 elements, an almost three-fold increase in number of mesh nodes. The refined mesh is shown in **Error! Reference source not found.** Introducing Different materials as well as different revolution of this process.

3.5 Material properties

The materials for the inner, outer ring and balls are linear isotropic structure steel. Young's modulus is $2X10^5$MPa, Poisson's ratio is 0.3.

4. Results and discussion

4.1 Deformation and total heat flux concave profile analysis in heat flux analysis

The maximum ranges of Heat flux Concave profile analysis in profiles concave to produce in 5.75E-13 w/mm^2 and aluminum al6067 Directional deformation process. The maximum ranges of Heat flux convex profile analysis in profiles concave to produce in 5.75E-13 w/mm^2 and aluminum al6067 Directional deformation process. The maximum ranges of Heat flux convex profile analysis in profiles concave to produce in 2.50E12 w/mm^2 and aluminum Al6067 Directional deformation process.

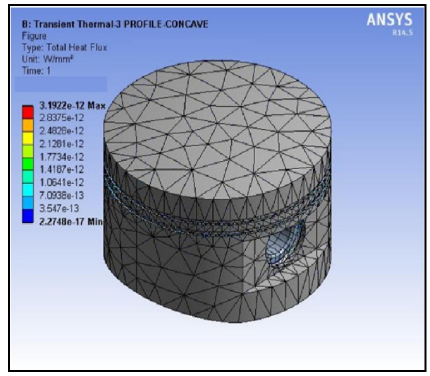

Figure 3 Default ANSYS volume Mesh

Summary

Piston skirt may appear deformation at work, which usually causes crack on the upper end of piston head. Due to the deformation, the greatest Heat flux consisting concentration is caused on the upper end of piston, the situation becomes more serious when the stiffness of the piston is not enough, and the crack generally appeared at the point A which may gradually extend and even cause splitting along the piston vertical. The stress distribution on the piston mainly depends on the deformation of piston. Therefore, in order to reduce the Heat flux concentration, the piston crown should have enough Heat to reduce conduction the deformation. The optimal mathematical model which includes deformation of piston crown and quality of piston and piston skirt. The FEA is carried out for standard piston model used in opposed piston engine and the result of analysis indicate that the maximum stress has changed from Concave with convex best Heat flow analysis Concave 4.5 profile its best profile and biggest deformation has been reduced .

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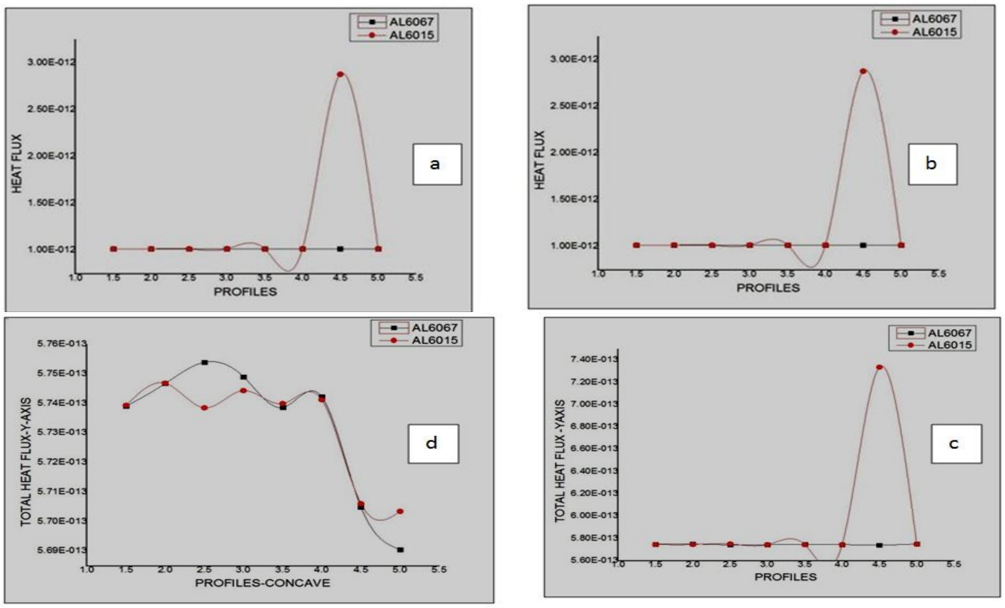

Figure 4 Heat Flux in (a) convex (b) concave & total heat flux Y-axis in (c) concave (d) convex profiles

4.2 Transient thermal analysis – concave profile

4.2.1 Concave profile at 1.5

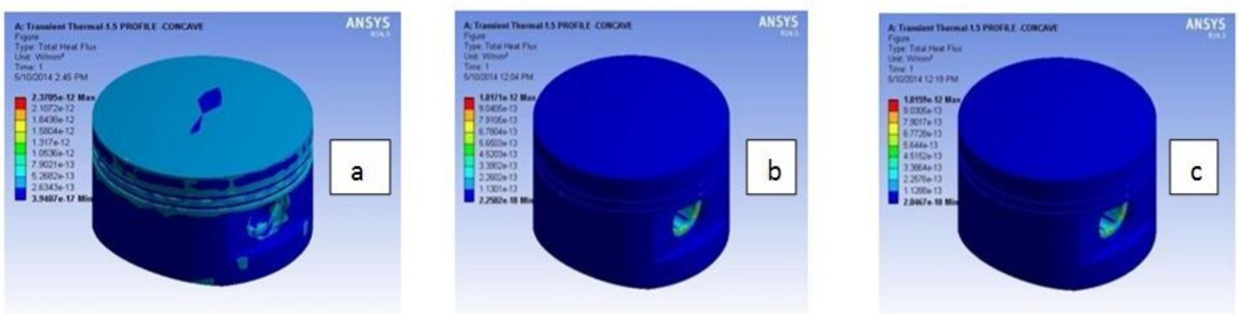

Figure 5 Concave Profile at 1.5 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

4.2.2 Concave profile at 2.0

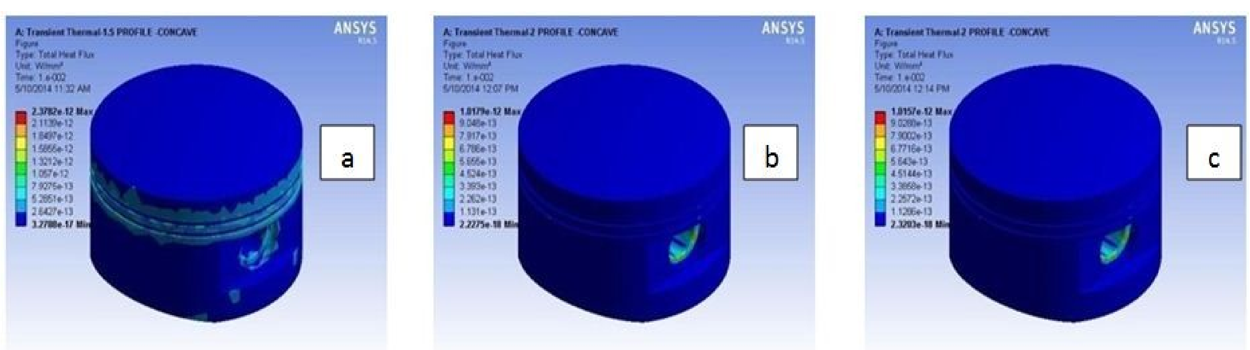

Figure 6 Concave Profile at 2.0 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

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4.2.3 Concave profile at 2.5

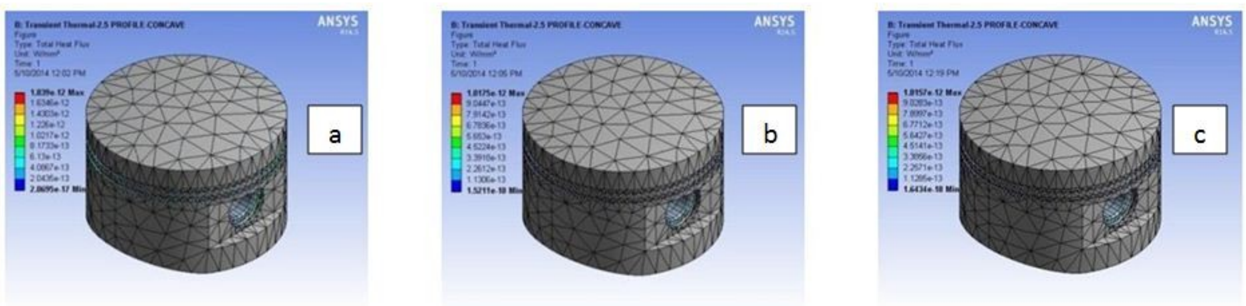

Figure 7 Concave Profile at 2.5 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

4.2.4 Concave profile at 3.0

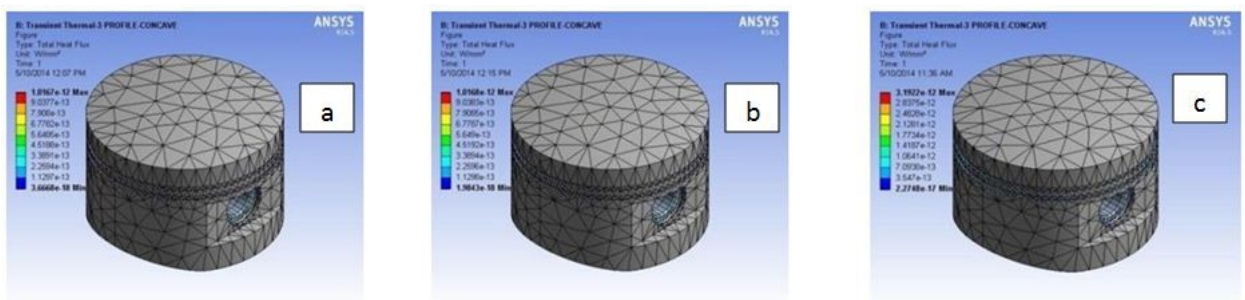

Figure 8 Concave Profile at 3.0 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

4.2.5 Concave profile at 3.5

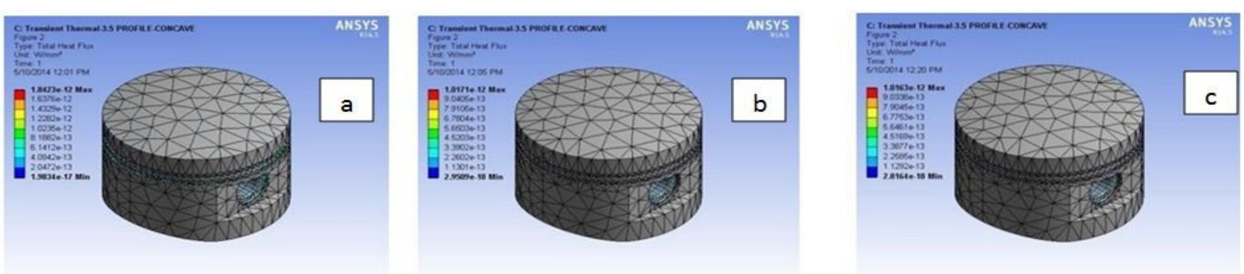

Figure 9 Concave Profile at 3.5 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

4.2.6 Concave profile at 4.0

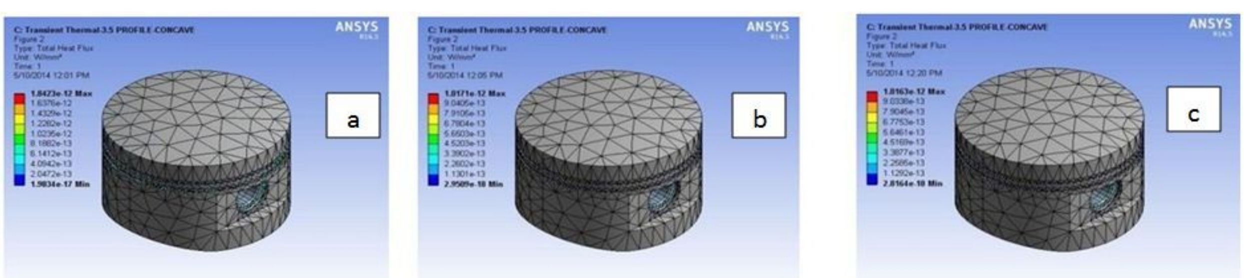

Figure 10 Concave Profile at 4.0 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

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4.3 Transient thermal analysis – convex profile

4.3.1 Convex profile at 1.5

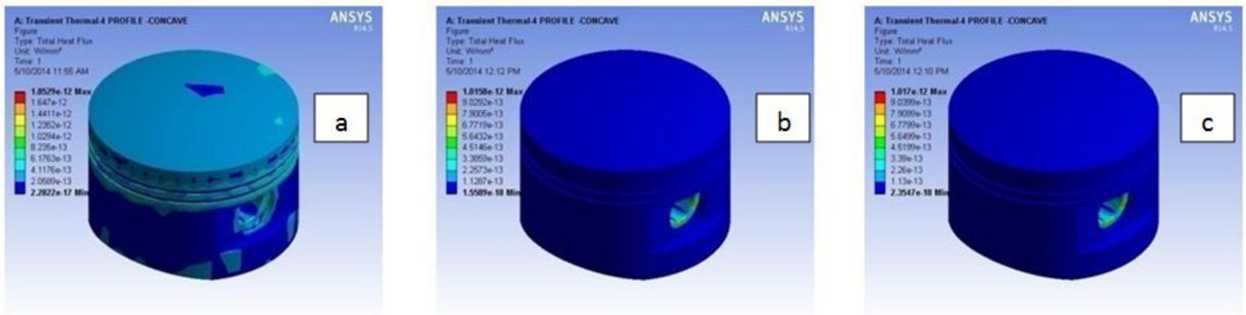

Figure 11 Convex Profile at 1.5 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

4.3.2 Convex profile at 2.0

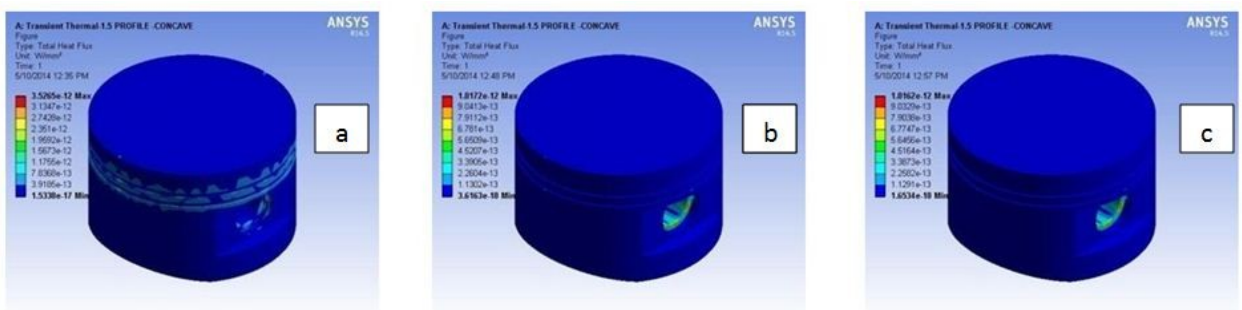

Figure 12 Convex Profile at 2.0 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

4.3.3 Convex profile at 2.5

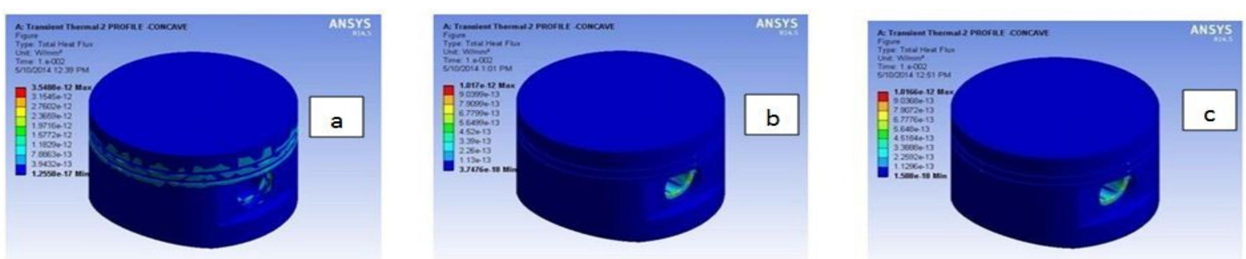

Figure 13 Convex Profile at 2.5 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

4.3.4 Convex profile at 3.0

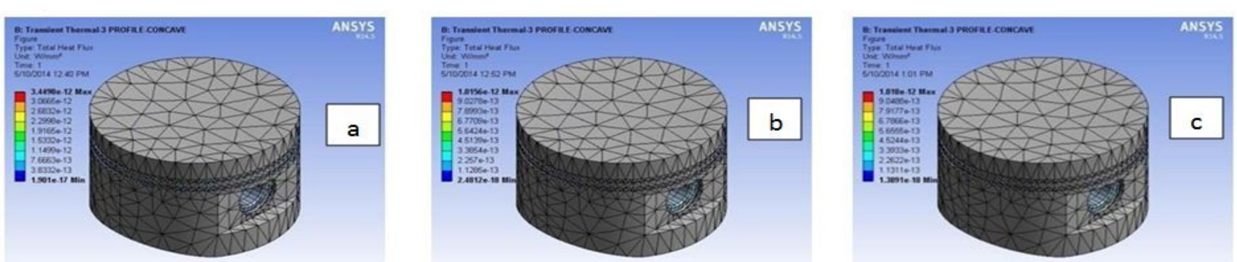

Figure 14 Convex Profile at 3.0 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

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4.3.5 Convex profile at 3.5

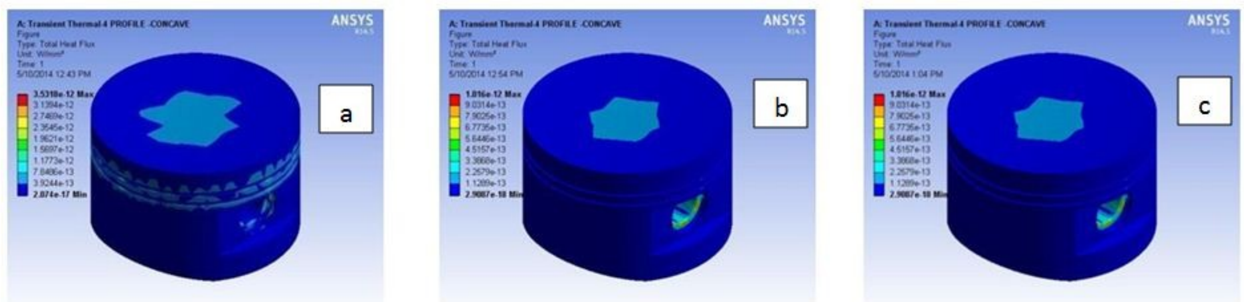

Figure 15 Convex Profile at 3.5 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

4.3.6 Convex profile at 4.0

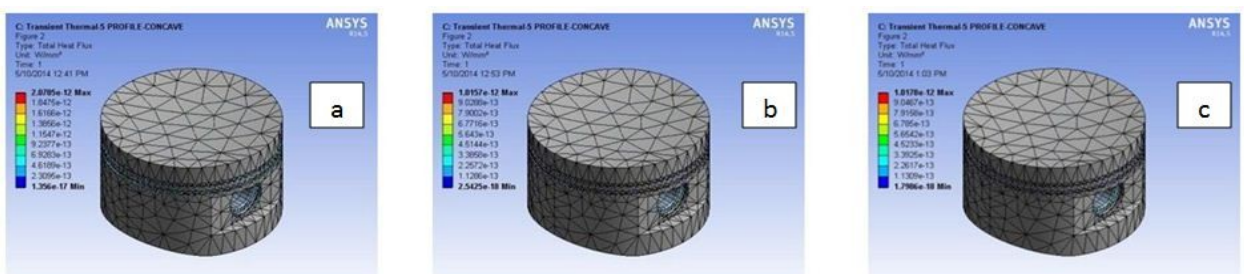

Figure 16 Convex Profile at 4.0 profiles for (a) Alumina (b) Alumina 92 % (c) Alumina 96 %

Future scope

Piston skirt may appear deformation at work, which usually causes crack on the upper end of piston head. Due to the deformation, the greatest stress concentration is caused on the upper end of piston, the situation becomes more serious when the stiffness of the piston is not enough, and the crack generally appeared at the point A which may gradually extend and even cause splitting along the piston vertical. 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 optimal mathematical model which includes deformation of piston crown and quality of piston and piston skirt.

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