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Numerical validation of thermal analysis of an automobile piston using ANSYS

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Abstract

The main purpose of the preliminary analyses presented in the book is to compare the behavior of the combustion engine piston made of different types of material under thermal load. FEA analysis is carried out using ANSYS software. Development of the finite element analysis model is also presented. The piston is loaded by a temperature field inside it. Appropriate average thermal boundaries conditions such as temperature were set on different surfaces of the 3D model.

In this work, thermal analysis are investigated on a conventional diesel engine piston, made of multiple material at the multiple times. Using transient thermal workspace we calculate heat flux in the piston and the temperature distribution on it. The analysis is carried out to know the thermal and mechanical load effect on the upper end of the piston, so that using this data we can increase life of the piston.

Keywords: I.C engine, Piston, Heat Flux,

1. Introduction

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 temperature at work and this working condition may cause the 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 due to high temperature and pressure of fuel. Piston 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.

Figure 1: Conventional piston [1]

In order to increase the efficiency of operation and better functionality, the piston material should satisfy the following

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requirements:

- Light weight
- Good wear resistance
- Good thermal conductivity
- High strength to weight ratio
- Free from rust
- Easy to cast
- Easy to machine
- Nonmagnetic Nontoxic

Piston should be designed and fabricated with such features to satisfy the above requirements.

2. Literature Review

Ch.Indira priyadarsini and et.al [3], the main objective is to analyze numerically a heat transfer in the conventional piston of four stroke spark ignition engine which is determined mainly as a function of temperature from crown to skirt. Piston was modeled using solid works, boundary conditions were calculated analytically from experiment and a study state thermal analysis was performed using Ansys Workbench. The piston undergoes thermal and mechanical stress during operation due to which the deformation in the piston take place. The magnitude of this deformation depends upon the piston material and the load applied on it by the expanded gases. Using Ansys we can find the best material for piston by analysis of piston implementing different materials having better properties to bear these stress. K.S.Mahajan and et.al [4], focus on the structural analysis of piston, working under thermal and mechanical loads. Thermal analysis was carried out on uncoated piston to verify the temperature changes at the various regions using Ansys. The study of thermal stresses generated due to temperature differences at different materials junctions used was analyzed. The stresses due to the mechanical loads were studied to finally determine the structural behavior of pistons. The Thermal Stress Distribution is a function of coating thickness. With increase in thickness, the maximum temperature increases on piston crown. The von-Misses stress decreases with the increase in the coating thickness on the surface of the piston.

F.S Desilva et.al [5], carried out a case study on the fatigue of pistons used in different applications and found, fatigue is not the biggest reason for all the piston damages but it remains a problem as these days more consideration is made into fuel consumption obtained by reduced weight which resulted in the thin walls for the piston and higher stresses. S. Srikanth Reddy et.al [6], investigated the thermal analysis on a conventional uncoated diesel piston which is made of aluminium silicon alloy for design parameters. The thermal analyses are performed on piston by means of using a commercial code, namely ansys. 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. 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). 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.

V G Cioată et.al. [7], says that the piston is one of the most important components of the internal combustion engine. Piston fail mainly due to mechanical stresses and thermal stresses. He determine them by using the finite element method, stress and displacement distribution due the flue gas pressure and temperature, separately and combined. The fea is performed by cad and cae software. He finds that Due to the constructive complexity and complex mechanical and thermal loads the piston is subjected to, the accurate determination of the unitary stresses and deformations is required.

By using cad and cae software in designing parts/assemblies of parts, the designer has the opportunity to analyze various constructive variants in a short time, thereby optimizing the designing work. Lokesh Singh et.al [8], Said by researching on piston analysis that piston is a component of reciprocating engines. Its purpose is to transfer force form expanding gas in the cylinder to the crank shaft via piston rod and a connecting rod. It is one of the most complex components of an automobile. In some engines the piston also acts as a valve by covering and uncovering ports in the cylinder wall. In present, work a three dimensional solid model of piston including piston pin is designed with the help of catia and solidworks software. The thermal stresses, mechanical stresses and couples thermo-mechanical stresses distribution and deformations are calculated. After that fatigue analysis was performed to investigate factor of safety and life of the piston assembly using Ansys workbench software. Aluminium-silicon composite is used as piston material. The stress analysis results also help to improve component design at the early stage and also help in reducing time required to manufacture the piston component and its cost. K. Sridhar et.al [9], Carried out thermal barrier analysis for uncoated Aluminium alloy and ceramic coated Aluminium alloy pistons and found that maximum surface temperature of the ceramic coated piston is increased approximately by 28% for Zirconium stabilized with magnesium oxide coating, 22% for Mullite coating and 21% for Alumina than the uncoated Aluminium alloy piston. Ceramic coatings on the piston surface can increase the temperature of the combustion chamber due to the insulation property of the coatings. The thermal strength of the base metal can also be improved. This increase in the combustion chamber temperature of the engine results in the improved thermal efficiency.

Silvio Memme [10], Investigated and compared a baseline copper coating piston. It was found reducing surface roughness of both coatings increased in-cylinder temperature and pressure as a result of reduced heat transfer through the piston crown. These increases resulted in small improvements in both power and fuel consumption, while also having measurable effect on emissions. Engine modification with copper coating on piston crown and inner side of cylinder head improves engine performance as copper is better conductor of heat and good combustion is achieved with copper coating.

Ravindra Gehlot et.al [11], analyzed ceramic coated diesel engine piston and found a significant increase in the pistons top surface temperature occurs with coating having holes. Although, the substrate temperature is decreasing with increase the radius of the holes. S. Srikanth Reddy et.al [12], Performed thermal analysis using Ansys and optimized the piston using finite element analysis. The influence of ceramic coating thickness on temperature variations are studied by finite element method using ansys. S. Krishnamani et.al [13], the temperature distribution analyses were conducted for the ceramic coating thickness of 0.3 mm over the piston crown surface. The results of the piston coated with two different coatings were analyzed. Dr.K.Kishor [14], determined the temperature distribution across the piston, liner and cylinder head of conventional Engine and Copper Coated Engine to study the performance of lubricating oil with the help of finite element method using ansys software package.

Hongyuan zhang [15], introduced the principle of thermal analysis for the combustion engine piston, gets the heat exchange coefficient of the piston top and the heat exchange coefficient distribution of the piston and the cooling water through calculation, calculates the temperature field of the piston with the finite element method and modifies the calculation model by repeatedly comparing the result with the measured temperature. Sonia Kaushik [16], 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 2640ºC, and the temperature at the first ring is decreased to 2040ºC, thus improving the working condition of the piston ring. Lizhi Wen et.al. [17], carries out the temperature of the top of piston is highest, meanwhile, the parts of top compression ring is also higher, which is related to the size of the oil ring groove tremendously for it will cut down the heat transfer from the piston top to the skirt section. In a word, the heat which accumulates on the top of the piston leads to such consequences. The temperature of the piston ring zone is much more important to the reliability of the engine. If the temperature of the ring zone is too high, which would make the lubricating oil spoilage and carbonize, then lead to piston ring cohered, the elasticity lost, the ring groove abraded and transformed, even worse, scuffing of cylinder bore. Having analyzed the temperature field of the piston, the thermal load is too high, so it is necessary to redesign the piston to improve the heat transfer performance of the noumenon and the structure of the piston. Hong-Zhan Yi et.al. [18], says that Piston is the core component of oil engine, its quality is directly related to engine performance. Piston often work in the condition of high temperature, high speed and high pressure under the periodic variation of high mechanical and heat loading. When the temperature increasing, material strength limit go down. Compared with a thermal analysis or a structural analysis, the real practical work of piston is in a large difference. Thermal analysis will be combined with structural analysis, research on its strength conditions in the work temperature can obtain actual result. Taking the piston of an engine as an example, this paper makes analysis of thermal-mechanical couple for it by using indirect couple method.

A. Vishali R.Nimbarte and et.al [19], describe that, 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 not easily available.

B. Dilip Kumar Sonar, et.al [20], Describe that, Damage mechanisms have different origins and are mainly wear, temperature, and fatigue related. Among the fatigue damages, thermal fatigue and mechanical fatigue, either at room or at high temperature, play a prominent role. In this present work a piston is designed using catia v5r20 software. Complete design is imported to ansys 14 software then analysis is performed.

Husain Mehdi et al [21-22], the mechanical properties of aluminum, nylon, GFRP, aluminum-GFRP composite & aluminum-nylon composite were found by using experimental method, The deflection of aluminum composite beams is less than that of pure material beams, the natural frequencies of pure materials (GFRP & Nylon) are larger than those of composite beams made by them if nylon is taken as synthetic fiber with Al, but if GFRP is taken then its deflection is found to be increased when compared to pure GFRP. So, nylon suits good to make composite beam with Al as compared to other synthetic fibers like GFRP. Vipin Kumar et al [23-24], ultimate tensile strength of the alloy improved as compared to LM 12, the solidifications temperature for AlAlloy reduces and this is an important factor to consider which temperature the heat treatment not should exceed. When increase the silicon content then the melting point of aluminium alloy is decreases whereas fluidity was increases.

Satyanarayana et.al [25], Describe that, we applied temperature and convection as and we determining total temperature on the body, total heat flux, heat flux in x,y,z directions respectively And this piston also having less stress(173.8 MPa) and good safety factor 1.6102. And the thermal heat flux also less other material cast iron and cast steel. D. G.Siva Prasad et.al [26], Describe that, the analysis becomes completed on the different parameters (temperature, stress, deformation) and easily analysis the result. The different material Al alloy 4032, Alloy Steel & Titanium Ti-6A1-4V.

E. M.Srinadh, et.al [27], Describe that, the thermal flux, thermal temperature distribution is analyzed by applying temperatures on the piston surface in Thermal analysis. The structural and thermal analysis were also done on the piston and piston rings model using Cast iron and Aluminum Alloy A360. F. Parthiban S et.al [28], Describe that, existing material of the piston ring material were considered and studied, a model corresponding to its dimensions were prepared and analysis were done on them in static conditions.

G. Sandeep Jain, et.al [29], Describe that, three different materials have been selected for structural and thermal analysis of piston. For piston ring two different materials are selected and structural and thermal analysis is performed using ansys 14.5 software. H. Saigowtham Ponnathi, and et.al [30]. Describe that, in this project the design of piston, piston rings and cylinder liners are modelled in catia v6. The design of the engine parts is complex and efficiency is related to the type of material. The material is taken as aluminium fleshy alumina composite. Durat. Et.al (2012) [31], A steady-state thermal analysis was performed to evaluate the temperature gradients in the standard and two different partially stabilized ceramic coated pistons by using Abacus© finite element software. A sharp increase in the temperature of the coated area of the piston was observed as a result of finite element simulations. It is concluded that the annulus y-psz coating may contribute better, as compared to Mg-psz, to decrease the cold start and steady state hc emissions without auto ignition, since the temperature in the area shows a local sharp increase.

Gudimetal et.al, (2009) [32], has reported a cad model of a damaged internal combustion engine piston and then has used 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.

3. Problem Description

Design of an Internal Combustion Engine is very closely related to the effects, which may be caused by the temperature of the working substances. Engineers are always in search of optimum design of. engines. For optimum design of an Engine, the knowledge of rate of transfer of heat between piston and gases from the wall of combustion chambers is of great importance. Heat transfer affects the thermodynamic performance of the engine and results in thermal loading, which imposes a limit on the engine rating. An important part in the operation of an Engine is the piston and the problems related to heat flow. The primary duty of the piston is to act as a gas tight plunger, which transmit and compress the gas. It also withstands a very high temperature and pressure and absorbs a considerable amount of heat during the process. This is rejected to the cylinder walls and the crankcase of the engine. Piston is subjected to extreme condition of temperature and pressure on its top, bottom and lateral faces. Although the temperature of gas and the convective coefficient between gases, top surfaces vary cyclically even during regular working it become drastically big. The piston is one of the most stressed components of an entire vehicle because it is placed in the cylinder that has process. Therefore, it is must be designed to withstand from damage that caused of the extreme heat and pressure of process. There are many damages or failures for piston due to high pressure and heat such as piston skirt seizing, piston head seizing, piston ring damage and cylinder damage. The value of stress that obtained the damages can be determined by using finite element analysis.

4. Governing equations

The governing equation of different variables is taken from Ansys database. The Ansys help feature provides all related information and equation to that variables that were find out. These variables and their governing equations are given as below

4.1 Total heat flux

The Mechanical application calculates the heat flux (q/A, energy per unit time per unit area) throughout the body. Heat flux can be output as individual vector components x, y, z. You can display the x, y, z components of heat flux in different coordinate systems. Scoping allows you to limit the heat flux display to particular geometric entities. Similarly scoping allows you to get reactions at specific boundary condition objects. Heat flux results can be displayed as a contour plot. You can also capture the variation of these results with time by using a probe. Ansys can integrate in the flow domain the so-called Fourier heat flux in regions where a temperature field is defined. The Fourier heat flux is defined as

$$q = -(k(T)\nabla T \quad (1)$$

Where,

q= heat flux
k(T) = the heat conductivity.

4.2 Temperature

A transient thermal analysis involves loads that are functions of time. The first step in applying transient thermal loads is to establish initial temperature distribution at Time = 0. The default initial condition for a transient thermal analysis is a uniform temperature of 22°C or 71.6°F. You can change this to an appropriate value for your analysis. An example might be modeling the cooling of an object taken out of a furnace and plunged into water.

In a steady-state or transient thermal analysis, temperature distribution throughout the structure is calculated. This is a scalar quantity.

Scoping allows you to limit the temperature display to particular geometric entities. Similarly scoping allows you to get reactions at specific boundary condition objects. Temperature results can be displayed as a contour plot. You can also capture the variation of these results with time by using a probe.

4.3 Selecting solver and importing geometry file

The solver are taken as transient thermal for thermal analysis and static structural for the analysis of structural properties of piston. The geometry is imported to the transient thermal workspace and then the static structural is linked to the same geometry that of transient thermal. It means that the single geometry will works on both the solver and workspace. But the two solver has their own solution variables.

4.4 Calculation

The theoretical values of total heat flux for different materials are determined with the help of following equation-
Maximum Heat flux of the piston crown.

$$q = -k\frac{dT}{dx} \quad (2)$$

K = Thermal conductivity of piston material
dT = Temperature gradient (T_2-T_1)
dx = Thickness of the top land of the piston

$$q = -k\frac{(T_2 - T_1)^t}{t}$$

T_2= Temperature of the top surface of the piston crown.
T_1=Temperature of the Bottom surface of the piston crown.
t = Thickness of the top land of the piston
Maximum Heat flux in AlSi Alloy Piston

$$q = -k\left(\frac{T_2 - T_1}{t}\right)$$

$$q=-197*\frac{(400-150)}{13*10^{-3}}$$

Heat flux = 3.788 X 10^6 W/m^2

Maximum Heat flux in Al-Mg-Si Alloy Piston

$$q = -k\left(\frac{T_2 - T_1}{t}\right)$$

$$q = -200 \times\left(\frac{400-150}{13*10^{-3}}\right)$$

Heat flux = 3.846 X 10^6 W/m^2
Maximum Heat flux in AlSiC-10 Alloy Piston

$$q = -k\left(\frac{T_2 - T_1}{t}\right)$$

$$q = -190 \times\left(\frac{400-150}{13*10^{-3}}\right)$$

Heat flux = 3.653 X 10^6 W/m^2
Maximum Heat flux in AlSiC-12 Alloy Piston

$$q = -k\left(\frac{T_2 - T_1}{t}\right)$$

$$q = -170 \times\left(\frac{400-150}{13*10^{-3}}\right)$$

Heat flux = 3.269 X 10^6W/m^2

4.5 Boundary Condition

The initial temperature and pressure for transient thermal is taken as 400ºC and 5MPa respectively as surrounding or engine cylinder temperature.

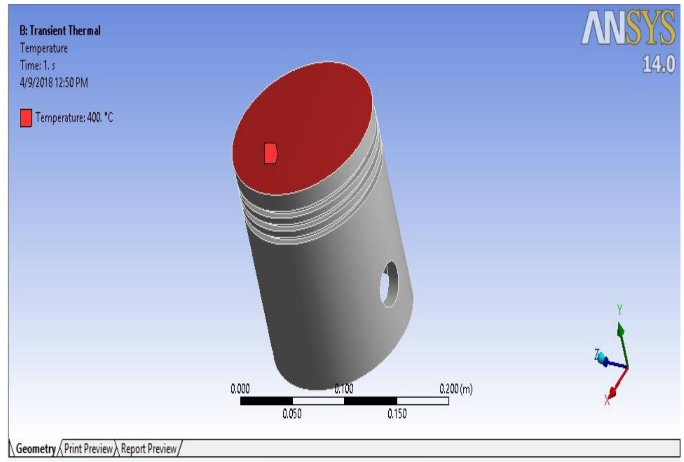

Figure 2: Boundary condition

5. Results and Discussions

The total heat flux is the one property that's can be compared to the research paper values. Further increment in analysis and solution variables can be added if the total heat flux matched with the research paper values. These heat flux will be different for the different types of materials.

5.1 Heat Flux

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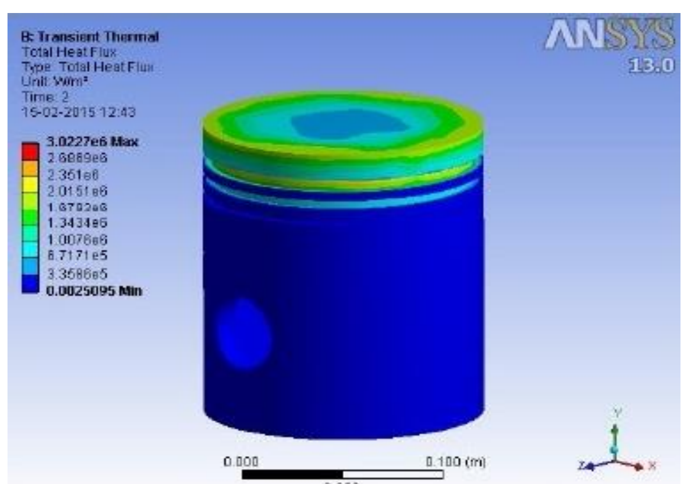
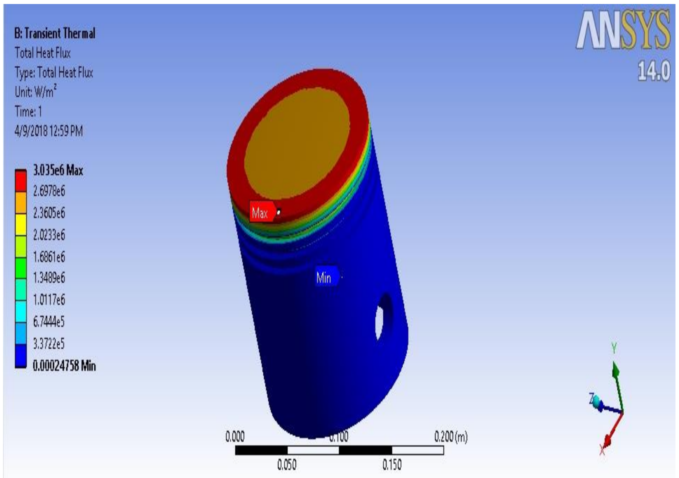
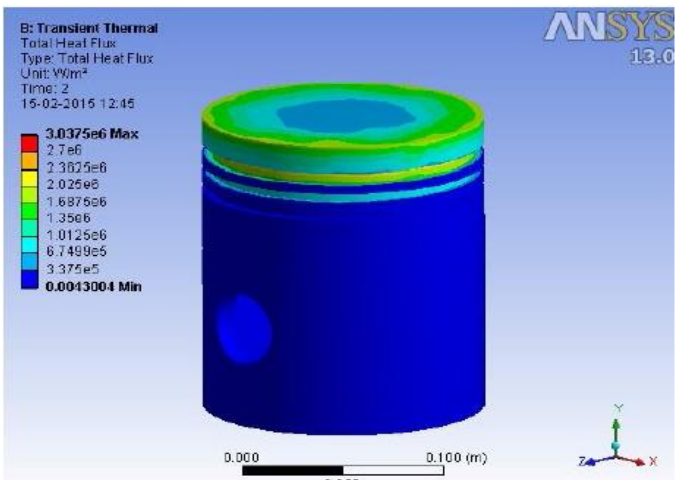


(a)

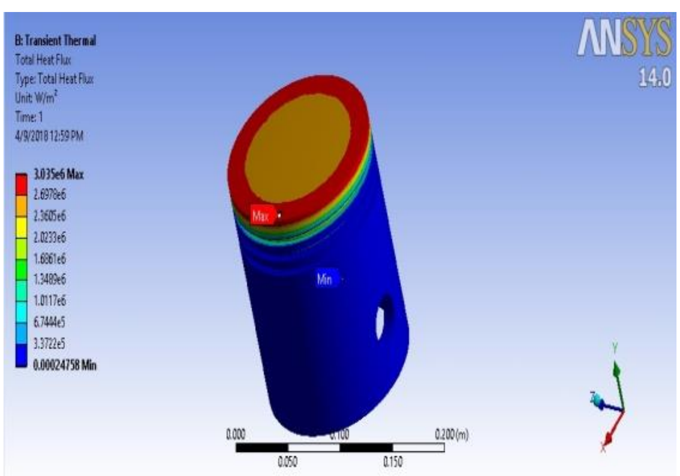


(b)

Figure 3: Total heat flux for AlSi (a) 3.0223e6 w/m² [11], (b) 3.035e6 w/m² (present value)

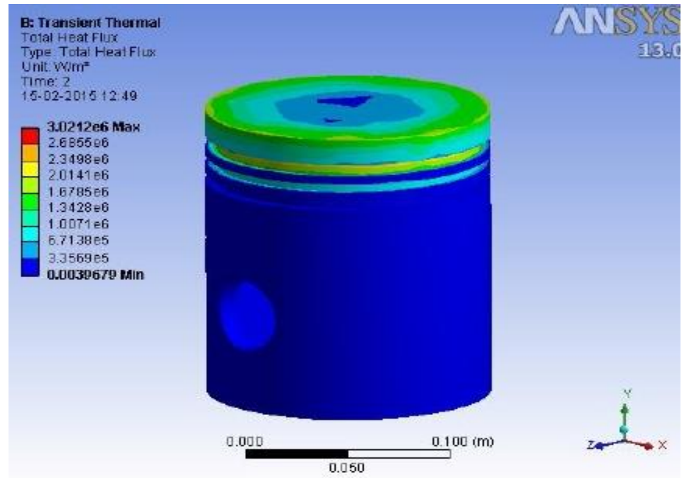


(a)

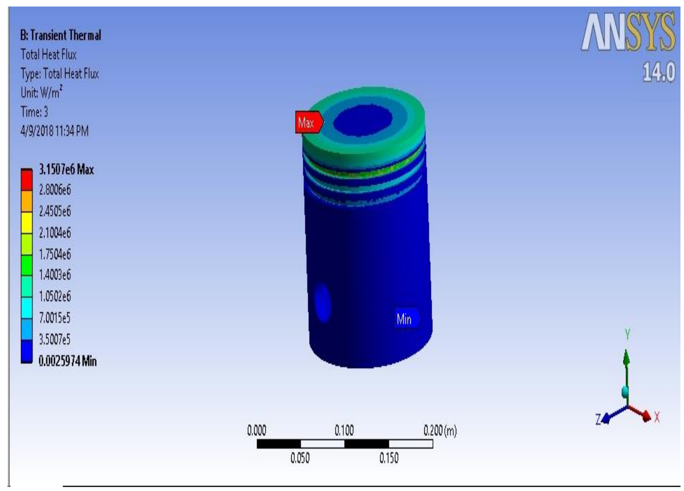


(b)

Figure 4: Total heat flux for AlMgSi (a) 3.0325e6 w/m² [11], (b) 3.028 w/m² (present value)

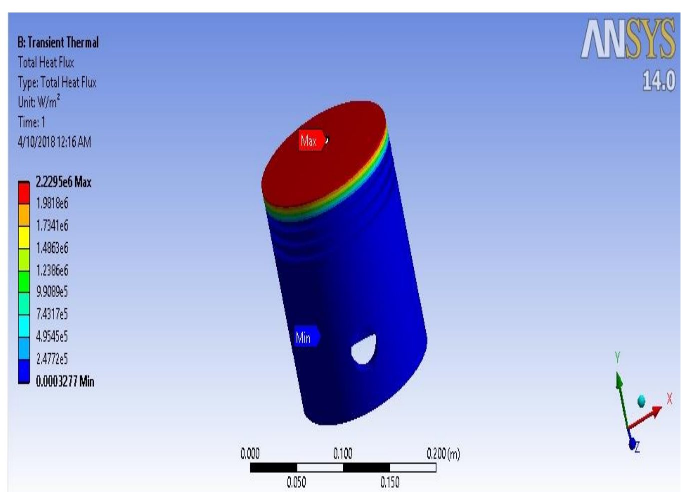


(a)

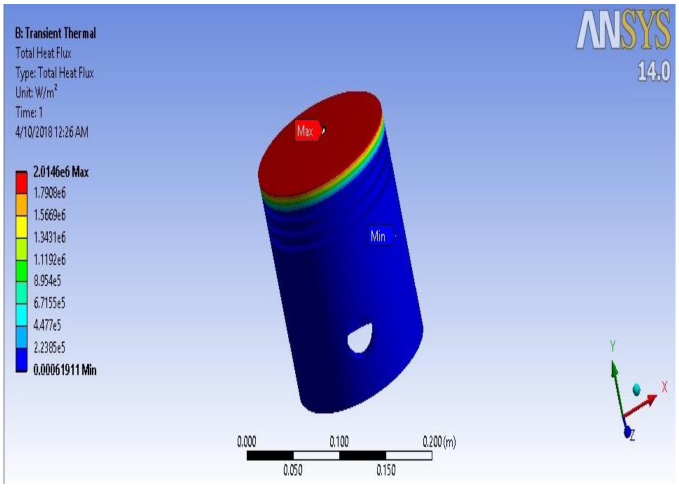


(b)

Figure 5: Total heat flux for AlSiC10 (a) 3.0242e6 w/m² [11], (b) 3.15 w/m² (present value)



(a)



(b)

Figure 6: Total heat flux for (a) Structural Steel 3.0325e6 w/m^2, (b) Cast Iron 3.028 w/m^2

From all of the above heat flux results it is clear that the variations in heat flux is not so much higher therefore the simulation or analysis is correct. It also shows the simulated heat flux values are quite near able to the theoretical values calculated through formula.

The total heat flux for structural steel and grey cast iron is calculated on the same meshing properties for the same geometry.

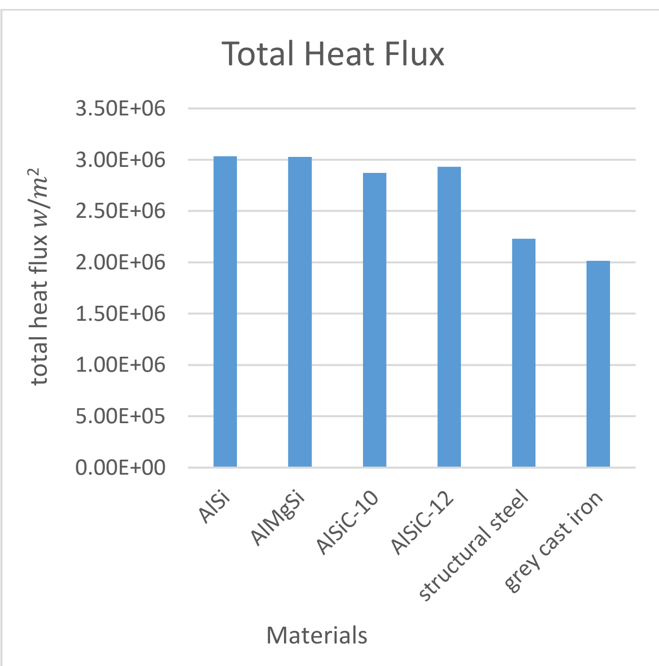


Figure 7: Comparison of Heat Flux for different material

Fig.7 shows the total heat flux of various material piston. Maximum heat flux was obtained in AlSi piston whereas minimum heat flux was obtained in grey cast iron piston.

6. Conclusion

Due to the constructive complexity and complex mechanical and thermal loads the piston is subjected to, the accurate determination of the unitary stresses and heat flux are required. The classical methods of calculation of the resistance of the piston (determination by calculation of the heat flux) are based on simplified representations of the geometric shape and loads. Using the finite element analysis for the calculation of the hat flux, enables the detailed analysis of every area of the analyzed structure, under the conditions of obtaining

The following conclusion can be drawn from analysis conducted in this study

- The maximum heat flux is obtained in AlSi piston i.e. 3.04e6 w/m^2.
- The Minimum heat flux is obtained in grey Cast iron i.e. 3.028 e6 w/m^2.

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