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Piston Analysis with Different Material Subjected to Thermal Analysis

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Abstract: The piston operates for long periods in high temperatures and high load conditions as the main heating component of the engine. The piston has large heating surface and poor heat dissipation characteristics, rendering the thermal load a big issue. This paper is a numerical method for calculating thermal stress caused only by uneven temperature distribution using thermal mechanical FEM (Finite Element Method). The main focus of this work is to study thermal behavior by means of the application of commercial ANSYS code on aluminum alloys, grey cast iron and Metal Matrix Composite (MMC) piston surfaces of functionally graded materials. The analysis helps to lower tension at the top of the piston (head / crown piston and skirt / sleeve). The tension is determined by the analysis. SolidWorks software will develop a piston structural model with computer-aided design. The finite element analysis also takes place using the ANSYS program for computer aided simulation. As the result, a material that has better thermal conductivity can be identified among the three materials mentioned above. In conclusion, from all the process, final material will be chosen for better thermal conductivity to be used on the piston.

Keywords: Piston, Simulation, Temperature Distribution, Thermal Behavior, Thermal Analysis

1. Introduction

The piston is reciprocating part of the engine which undergo thermo-mechanical loading. In engine combustion of the fuel takes place due to which lot of amount of heat is liberated which leads to increase in the temperature rise and high pressure is also produced which falls on the piston. The temperature of the piston may lie within the range of 300-600 k and pressure increased value up to 15 MPa. So, the requirement for the design of the piston is its strength so that it can withstand maximum pressure and high temperature resistant material so that it can tolerate maximum temperatures, and thermal stresses get minimized.in addition to the strength and temperature resistant of the material, it should be light weight. Piston is connected to the connecting rod, piston reciprocating motion is transferred to the

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crankshaft through connecting rod. Light weight reduces the inertial force to start the motion.it decreases fuel consumption and increases its efficiency. The material of the piston should be chemically stable and should have low thermal expansibility.[1]

Production of many metals (cast iron, grey iron, ductile iron, compacted graphite iron, 3000 series aluminium alloys, copper alloys, silver, and complex steels) are aided by a production technique also referred to as thermal analysis.[4] Thermal analysis is a critical, analytical, and characterization tool in the field of materials sciences. Thermal analysis is a branch of materials science where the properties of materials are studied as they change with temperature. Several methods are commonly used. Thermal analysis is also often used as a term for the study of heat transfer through structures. Many of the basic engineering data for modelling such systems comes from measurements of heat capacity and thermal conductivity.

Aluminium alloys containing cerium are being developed and implemented in high-temperature automotive applications, such as cylinder heads and turbochargers, and in other energy generation applications.[2] It gains its strength from the presence of an $Al_{11}Ce_3$ intermetallic phase which is stable up to temperatures of 540 °C, and retains its strength up to 300 °C, making it quite viable at elevated temperatures. Recent work has largely focused on adding higher-order alloying elements to the binary Al-Ce system to improve its mechanical performance at room and elevated temperatures, such as iron, nickel, magnesium, or copper, and work is being done to understand the alloying element interactions further.[6]

Grey cast iron is characterized by its graphitic microstructure, which causes fractures of the material to have a grey appearance. It is the most commonly used cast iron and the most widely used cast material based on weight. Most cast irons have a chemical composition of 2.5–4.0% carbon, 1–3% silicon, and the remainder iron. Grey cast iron has less tensile strength and shock resistance than steel, but its compressive strength is comparable to low- and medium-carbon steel. These mechanical properties are controlled by the size and shape of the graphite flakes present in the microstructure and can be characterized according to the guidelines given by the ASTM.[5]

The metal matrix composite can be confused with an alloy. However, according to the definition, the second component or the reinforcement should exist as another phase in considerable amounts. Scientists from East and West or N.A.T.O and Warsaw countries tried numerous combinations of matrices and reinforcements since work on MMCs began in the late 1950s. This led to some developments in the aerospace field, but the resultant commercial application was limited. The introduction of ceramic whiskers as a discontinuous reinforcement and the development of 'in-situ' eutectics were studied in the early 1960s for high temperature applications in aircraft engines. It was in the late 1970s and early 1980s that the automobile industries started to take MMCs seriously. In the last 20 years, metal matrix composites have developed from a mere lab interest to a distinct and flourishing class of materials with numerous 3 applications and huge commercial markets. However, MMC technology is still in its embryonic stage of development, and other important systems undoubtedly will emerge.[8]

With the definite-element analysis software, a three-dimensional definite-element analysis [3] has been carried out. 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.

1.1 Problem Statement

The selection of materials also has been debated for a long time, where not all type materials are suitable to produce the piston, since the pistons is the part in the engine that had to face any circumstances that related to heat. To produce the best pistons, material selection is the most important process that need to be considered before producing it. There are three materials that have been argued for a long time, which are Aluminium alloy, Gray Cast Iron and Si-C (Metal-Matrix Composite). To clarify the problem and to choose which material is most suitable to be used to produce the pistons, these materials will be tested subjected to thermal analysis in a software which called as ANSYS.

The fact that the pistons have a high output and better accuracy as they are expected to bear higher tempers and loads depends on the literature survey conducted. Piston skirt may appear to be deformed at work, usually causing cracking on the upper end of the piston head. Due to the deformation, the highest stress concentration on the upper end of the piston is caused, the situation becomes more serious when the stiffness of the piston is not sufficient, and the crack generally appears at point A, which may gradually extend and even cause vertical piston splitting. The stress distribution of the piston depends mainly on the deformation of the piston. Therefore, in order to reduce the stress concentration, the crown of the piston should be stiff enough to reduce the deformation.

1.2 Project Objective

The specific objectives of this project include:

- To analyze which one of these materials Aluminium Alloy, Gray Cast Iron and Si-C (MMC) is suitable in term of thermal withstand among them.
- To find out and suggest optimum material for piston based on quality and economy.

1.3 Project Scope

i. The material will consist three materials which are, Aluminium Alloy, Grey Cast Iron and Metal Matrix Composite (MMC) (Si-C).
ii. The analysis comparison will be focusing on the field of temperature distribution, total deformation and total heat flux acting on the piston.

2. Methodology

The piston model has been designed by using Solidworks software and after that the analysis will be conducted by using ANSYS software. After piston model has been designed by using Solidworks software and saved in igs format, then open ANSYS software and import the piston in geometry section. To get the transient thermal analysis, click on it and key in all the details needed before enter solve button. Next, the analysis that will be analyzed are, static-structural, steady state thermal and transient thermal. All the analysis will be compared to each material and the best material will be selected between them.

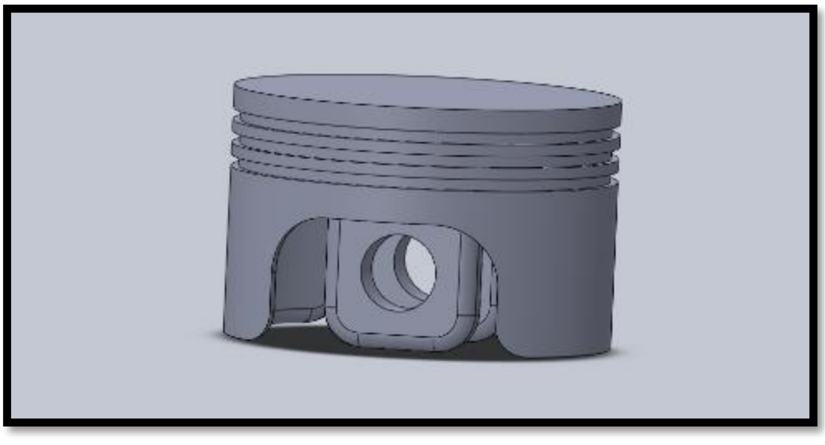

Figure 1: Piston Model

Table 1: Dimension of Engine Piston

Piston part	Dimension (mm)
Length of the piston	152
Cylindrical bore/outside dia. Of the piston	140
Thickness of the piston head	9.036
Radial thickness of the piston ring	5.24
Width of the top land	10

The first phase in this method is to design the piston model by using Solidworks software and followed the dimensions given. After finished all the designing process, save it in igs format in the desktop. For the second phase, open ANSYS software and import the design in geometry section. After that, select the material for the piston, then generate mesh on the body. Next, insert the information needed for each analysis, then select the boundaries which the boundaries are the area that will shows the reaction when the analysis begins. Lastly, click on the solve button for the final step to make the ANSYS work and calculate the data that have been inserted.

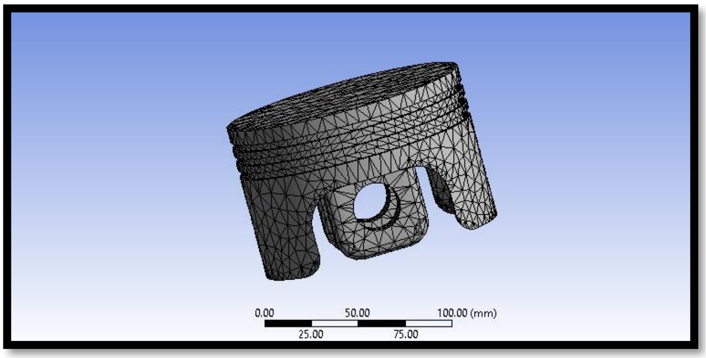

Figure 2: Mesh Body

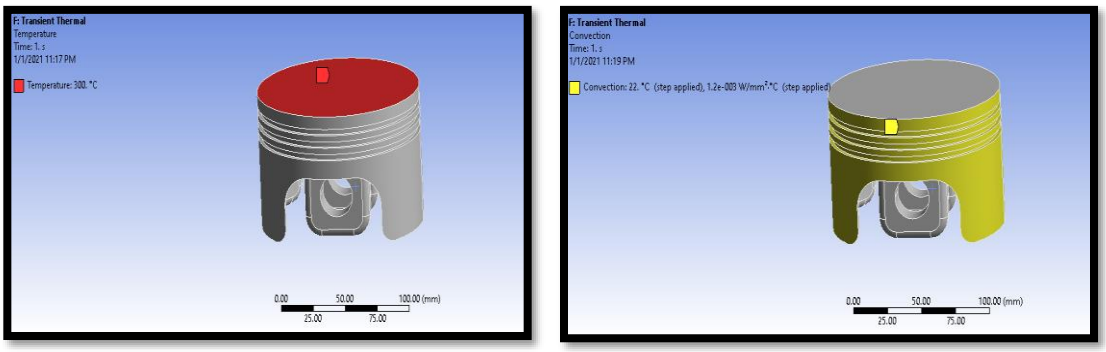

Figure 3: Boundary Condition

The final phase is to analysis and display all the data that have been generated by ANSYS for each material and discuss all the information that can be used to determine which material is great heat conductivity and very good to withstand high temperature in the engine. Lastly, give the material position and mention the reason on why it can be in that position compare to the other material.

3. Results and Discussion

The data analysis process is very important in a study. This process also discusses the test and results obtained from the studies that have been conducted. Therefore, data obtained through three type of analysis which are static structural analysis, steady state thermal analysis and transient thermal analysis have been carried out.

3.1. Static Structural Analysis on Piston

In this section, total deformation will be displayed for each material. The function of total deformation analysis is to refer the change in size or shape of the piston when pressure was applied on it. The part that will be observed is the top head of the piston. The reaction happened on the top head of the piston will be analyse for each material and it will be compared to determine which material can handle pressure well in engine.

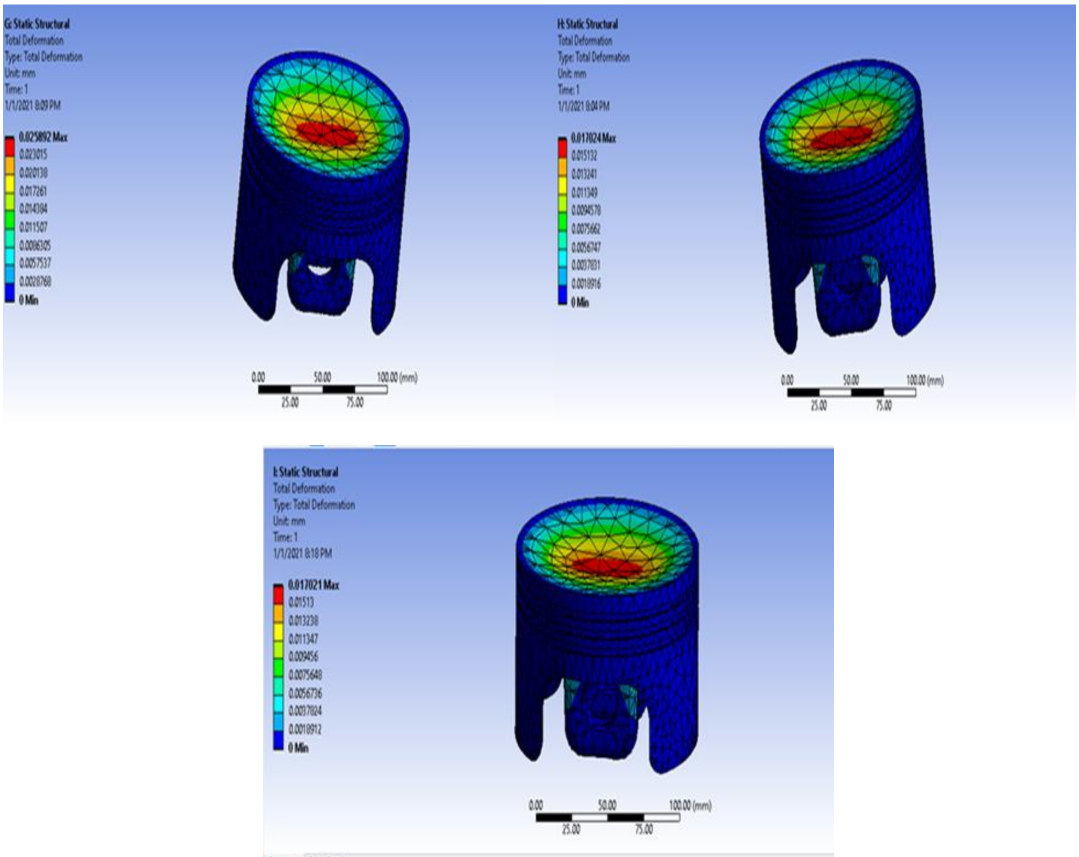

Figure 4: Total Deformation of Aluminium Alloy, Gray Cast Iron and Si-C (MMC)

Table 2: Minimum and Maximum Value of Total Deformation of Piston

Material	Minimum deformation	Maximum deformation
Aluminium Alloy	0 mm	0.025892 mm
Gray Cast Iron	0 mm	0.017024 mm
Si-C (MMC)	0 mm	0.017021 mm

Figure 4 and Table 2 shows the maximum value of total deformation for each material. For the minimum deformation the results are same for each material which is 0 mm. The total or amount of maximum pressure applied on the piston was 12 MPa. From the data in the table, aluminium alloy has the highest value of deformation compare to the others. Meanwhile, for the gray cast iron and Si-C (MMC) there is no big difference. In this section, the material that have lowest value of total deformation considered as the best material since it can handle pressure very well compare to the other materials and Si-C (MMC) has the lowest value.

3.2. Steady-State Thermal Analysis

For the steady-state thermal analysis, the function of this analysis is to evaluate the thermal analysis in which the thermal equilibrium of a system in which the temperature remains constant over time. In other words, steady-state thermal analysis involves assessing the equilibrium state of a system subject to constant heat loads and environmental conditions. The designed piston operates in high temperatures conditions, amounted to 300 degree Celsius.

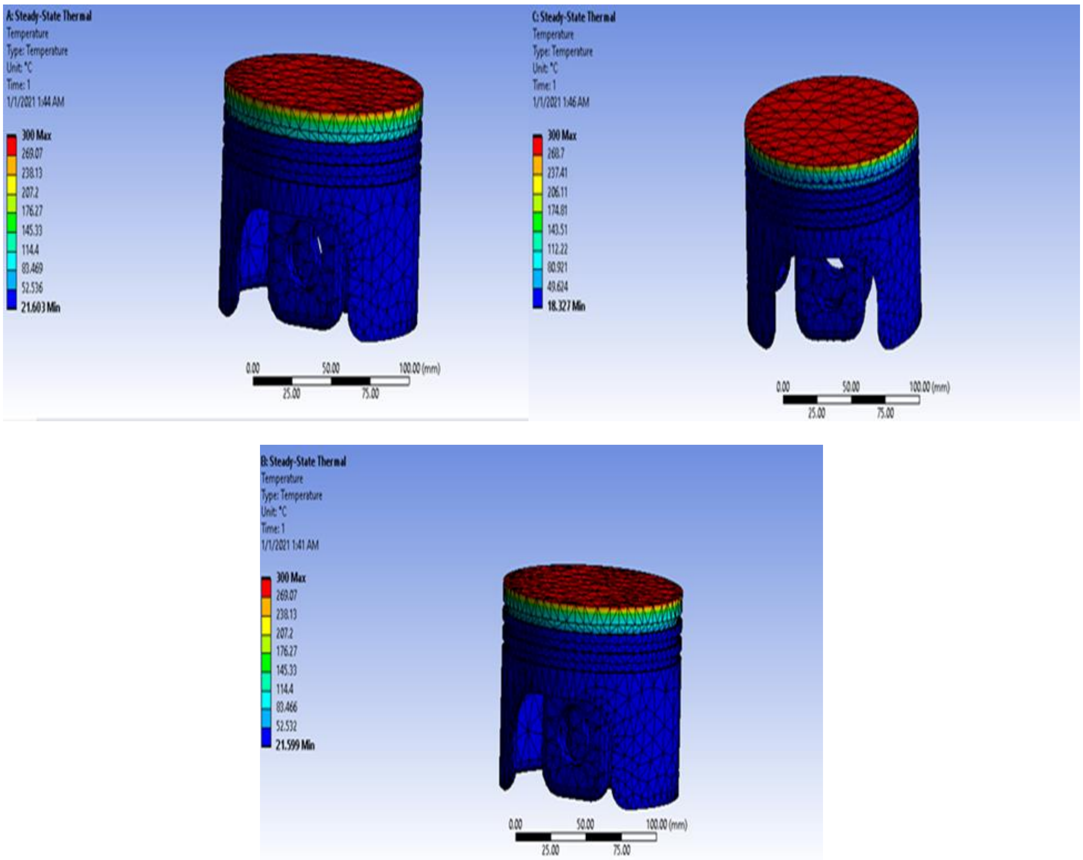

Figure 5: Temperature Distribution of Al Alloy, Gray Cast Iron and Si-C in Steady State Thermal

Table 3: Minimum and Maximum Value of Temperature Distribution in Steady State

Material	Minimum Temperature	Maximum Temperature
Aluminium Alloy	21.603°C	300°C
Gray Cast Iron	18.327°C	300°C
Si-C (MMC)	21.599°C	300°C

Figure 5 and Table 3 shows the value of minimum and maximum temperature distribution when the piston for each material have been applied maximum temperature which is 300.000 ℃. The objective of this analysis is to find out which material can withstand the heat when the maximum temperature reached in the chamber. From the data given, the value of minimum temperature for aluminium alloy and Si-C (MMC) almost same, which is the gap between them only 0.004℃. Meanwhile, for the gray cast it can withstand high temperatures and the lowest temperature on piston when thermal load is applied is just 18.327 ℃, which is very low compared to the other two materials.

3.3. Transient Thermal Analysis

Basically, in this section of analysis the difference between transient and steady-state is transient thermal established between the beginning of the event and the steady-state and it can be done at varying temperature meanwhile the steady-state thermal only can be done or established after a certain time in the system. This analysis is used to evaluate on how the system responds to fixed and varying boundary conditions over time. For fixed boundary conditions, the time to reach a steady state temperature can be evaluated. In this analysis, total heat flux will be displayed where the function of total heat flux is to know the rate of heat energy that passes through a surface or a thermal energy that transferred from one substance to another per unit time and area.

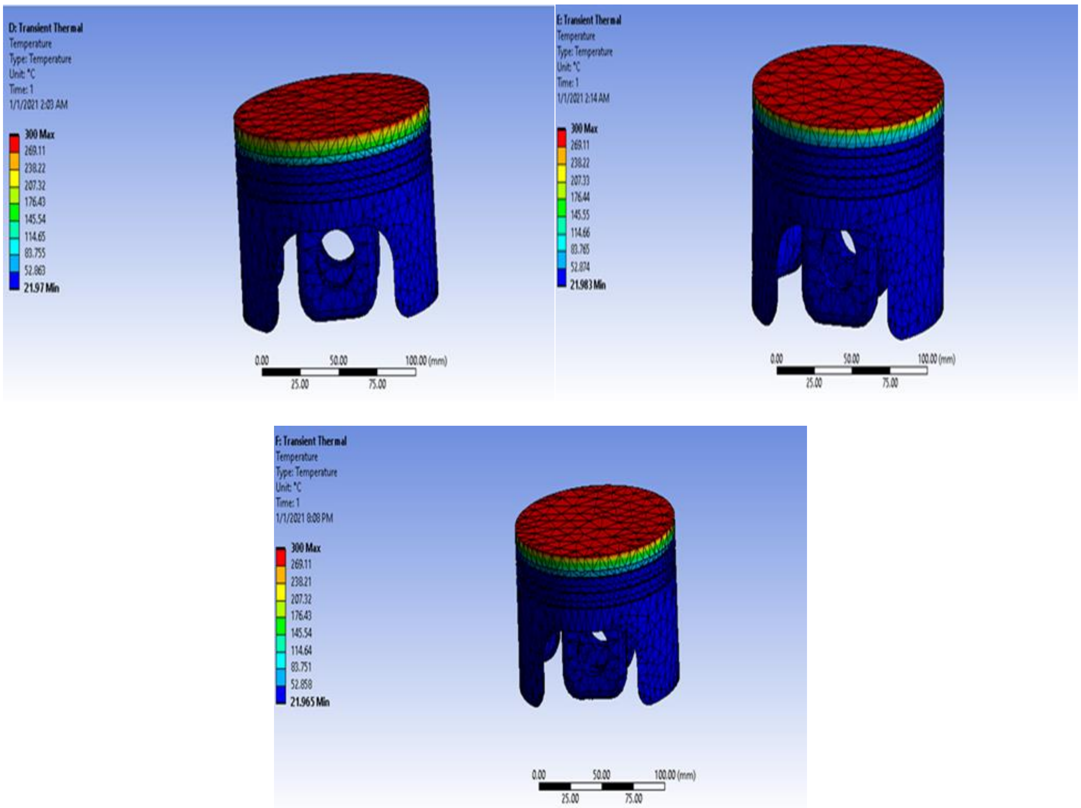

Figure 6: Temperature Distribution of Al Alloy, Gray Cast Iron and Si-C in Transient Thermal

Table 4: Minimum and Maximum Value of Temperature Distribution in Transient

Material	Minimum Temperature	Maximum Temperature
Aluminium Alloy	21.970 ℃	300 ℃
Gray Cast Iron	21.983 ℃	300 ℃
Si-C (MMC)	21.965 ℃	300 ℃

Based on Figure 6 and Table 4, it shows the value for minimum temperature in each material almost same where there are no big gap or difference. The reason transient thermal analysis was made is to know how it react when the sudden change of state occurred. Over here we can see that Si-C has a lowest minimum temperature even the difference is not so big but it still shows Si-C has the lowest compare to the others.

3.3.1 Total Heat Flux

Heat flux actually represents the amount of the heat transfer by the surface according the heat transfer coefficient condition, temperature condition and surface area.

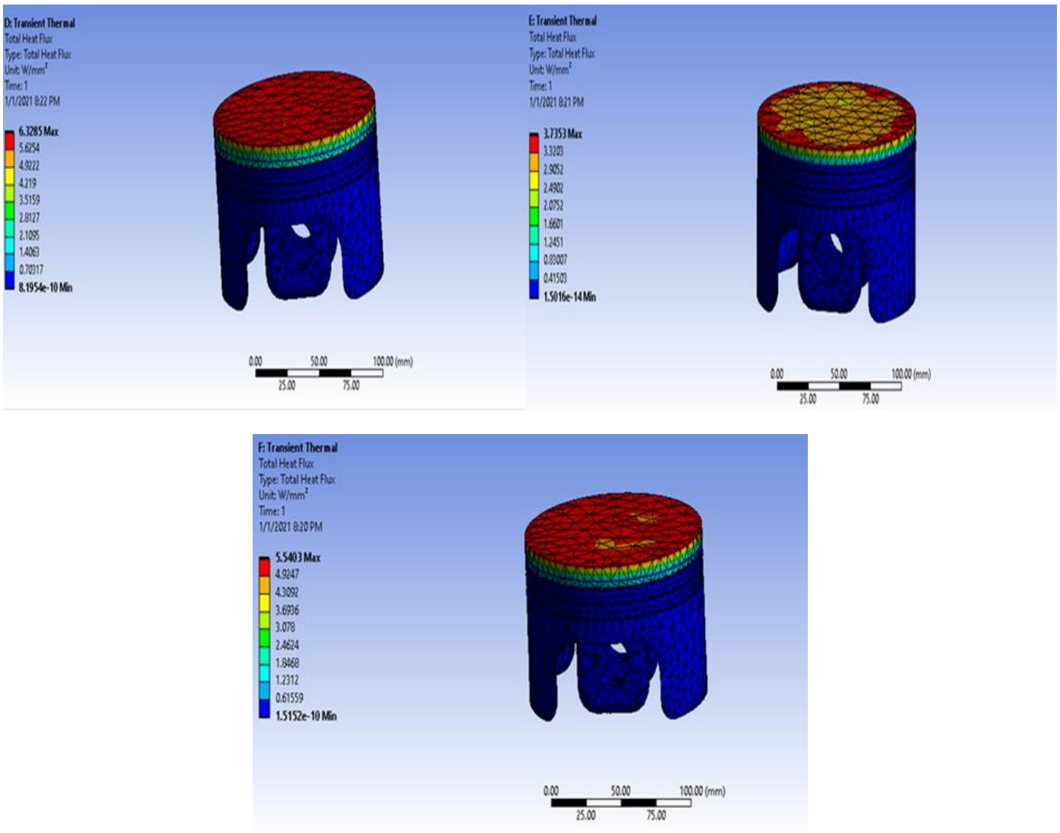

Figure 7: Total Heat Flux of Al Alloy, Gray Cast Iron and Si-C

Table 5: Minimum and Maximum Value of Total Heat Flux

Material	Minimum Total Heat Flux	Maximum Total Heat Flux
Aluminium Alloy	8.1954e-10 W/mm²	6.3285 W/mm²
Gray Cast Iron	1.5016e-14 W/mm²	3.7353 W/mm²
Si-C (MMC)	1.5152e-10 W/mm²	5.5403 W/mm²

By referring to Figure 8 and Table 5, the value of total heat flux for gray cast iron is the lowest compared to the other material which means gray cast iron is the material that can act pretty well in heat flux or it has the lowest amount of heat passed through the piston, either in minimum or maximum total heat flux. For aluminium alloy, the value for minimum and maximum total heat was height rather than the gray cast iron and Si-C (MMC) material. It shows that aluminium alloy has low thermal conductivity compare to the other.

4. Conclusion

After performing analysis on three different materials which are aluminium alloy, gray cast iron and Si-C (MMC) in aspect of thermal analysis and a static structural analysis, the results show the gray cast iron has been dominated almost all the thermal analysis where it shows that it can function well in total heat flux because the value for minimum and maximum of the total heat flux is the lowest compare to the other two material and it means gray cast iron has a good thermal conductivity even in the steady state thermal analysis, the result shows the value for gray cast iron is the lowest

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