International Journal on Emerging Technologies 14(2): 53-56(2023)

ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

Structural & Thermal Analysis of V6 Engine's Piston for Different Alloys of Aluminium

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(Received 02 August 2023, Revised 04 September 2023, Accepted 21 October 2023)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: The target of this research work is to find out the best suitable material for the piston of an internal combustion engine. In this work, the main challenge is to find out the suitable material for piston which can withstand high thermal and structural stresses and also it should be of minimum weight. For this, we have uses four different alloys of aluminium, namely AlSi, AlMgSi, AlSiC12 and Al6061 have been selected for analysis. The piston has been designed in Solidworks 2021 and then imported that model of piston in ANSYS 14.5 software to perform Static Structural and Steady State Thermal analysis of the piston. For structural analysis, pressure of 6.5 MPa has been applied assuming frictionless supports on its outer surface and the temperature of about 800^{0}C on the crown of the piston is assumed for thermal analysis, applying convection in all surfaces of the piston. Final results are like that, the AlSi and AlSiC12 are best suitable materials for the piston in terms of Structural and thermal stresses.

Keywords: Piston, Total deformation, Equivalent stress, Total heat flux, Temperature distribution, Solidworks, ANSYS 14.5.

Abbreviations: AlSi, Aluminium Silicon, AlMg Si, Aluminium-Magnesium-Silicon alloy, AlSiC12, Aluminium -Silicon -arbide-12, Al606, Aluminium alloy-6061, CAD, Computer Aided Design.

INTRODUCTION

The internal combustion engine is the main carrier in our society since its invention in the last quarter of the 19th century. The purpose of I.C. engine is to induce mechanical power from the chemical energy contained in the hydrocarbon fuel which is released during the combustion of the fuel inside the engine's cylinder. Etienne Lenoir 1859 has successfully developed the first commercial internal combustion engine, however; Nicolaus A. Otto got the credit for the development of the first modern internal combustion engine in 1866. Inside the engine there is one mechanical element known as piston which is the most important part not only for reciprocating engines but also for plunger type pumps, compressors and pneumatic cylinders. The purpose of the piston is to act as a medium to convey the force which is obtained by expansion of gases inside the cylinder to the crankshaft via a piston rod (Kaushik, 2019).

The I.C. engine has different types of cylinder arrangements, based on which it is classified in various types. Some select classifications are as follows:
(a) Inline
(b) Horizontally opposed
(c) Radial
(d) V type

The inline or the straight engine is an internal combustion engine having all cylinders arranged in one row and having no offset.

Horizontally opposed engines are too known as Flat engines because, in this type of engines the cylinders are placed on both side of a central crank shaft.

The radial engines are the type of reciprocating internal combustion engine. In this, the cylinder "radiates" outward from a central crank case like the spokes of a wheel.

A V-engine is an ordinary arrangement for IC engines. It carries two-cylinder chambers usually having the equal count of cylinders in each chamber attached to a single crankshaft. These cylinders chambers are set out at certain angle to each other to form a "V" shape when viewed from the axis of the crankshaft. V engines generally have a shorter length as compared to inline engines; however, the tradeoff is a large width V4, V6 and V8 engines are the most frequent format used in an automobile sector having four, six and eight cylinders respectively (Dhotare *et al*., 2019).

Piston is the mechanical component of an I.C. engine whose work is to transfer the forces to the crankshaft which is generated inside the cylinder after the expansion. The piston reciprocates inside the cylinder and form the gas tight contact through the piston rings (Ajay *et al*., 2018). Other than I.C. engines, Piston is also used in reciprocating pumps, gas compressors, and in pneumatic and hydraulic cylinders (Dhotare *et al*., 2019).

There are commonly three types of pistons:
a. Flat head piston
b. Dome head piston
c. Dish head piston

MATERIALS PROPERTIES

Material selection is an important process for designing and manufacturing any mechanical component. Pistons are mostly made of a Cast Aluminium Alloy due to its properties like, minimum density, suitable thermal conductivity, easy in casting & good machinability properties as compared to cast iron. The aluminium alloys which have been considered for analysis work in this research are Al-Si, Al-Mg-Si, AlSiC12, Al-6061. Properties of the selected materials are given in the Table 1 (Kumar and Singh 2019).

Table 1: Properties of aluminium alloys.

Materials	Young's Modulus (MPa)	Poisson's Ratio	Density kg/m^3	Thermal Conductivity (W/m-°C)	Specific heat (Joule/kg-°C)
AlSi	2.3×10^5	0.24	2937	197	894
AlMgSi	0.7×10^5	0.33	2700	200	898
AlSiC12	1.67×10^5	0.21	22890	170	808
Al6061	0.68×10^5	0.33	2700	202	897

METHOD

For performing the analysis, three-dimensional CAD (computer-aided design) model of piston is created in solid works 2021 software by using some feature-based commands like revolve, revolve cut, Cut extrude & Extrude boss base and then after the completion of modeling, the file is then saved in the STEP format. The model of the piston is imported on two different modules of ANSYS 14.5 (i.e. Static structural & steady state thermal) for Finite Element Analysis under different parameters like 'total deformation', 'equivalent von-mises'& 'temperature distribution', 'total heat flux'. After importing the model of the piston in ANSYS software, all the required materials were added in ANSYS material library and then one by one these materials were applied on the piston and perform the structural and thermal analysis by using certain boundary conditions. In Ansys software, meshing performs the major role because this software uses finite element method means the body is divided into several small elements called as finite element. In this, all the elements are interlinked at a point known as nodal point or simply nodes. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behavior of these elements and solve them all creating a comprehensive explanation of how the system acts as a whole.

MODELLING

Modelling of three-dimensional piston is done in CAD software – Solid works by using some feature-based commands like Revolve, revolve cut, Cut extrude & Extrude boss. Before performing the modelling, some dimensions are collected from the reference papers which have been shown in the figure below

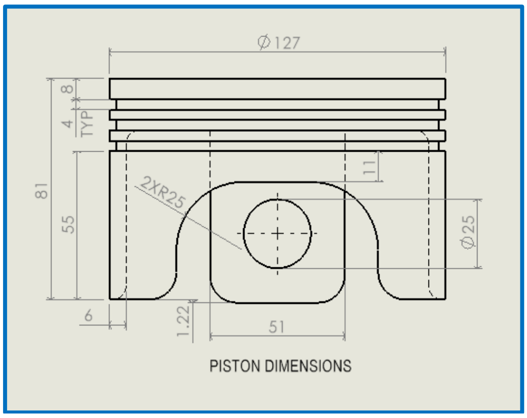

Fig. 1. Piston Dimensions.

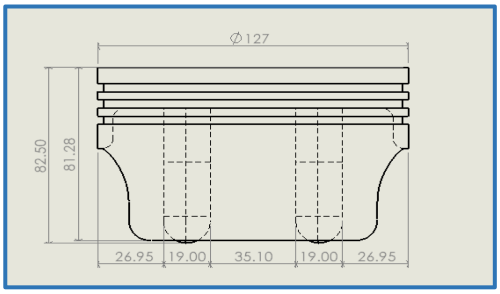

Fig. 2. Piston Dimensions.

Now, after the completion of CAD modelling, it's time for the analysis and for this, two parameters have been taken under consideration for the piston analysis. These two parameters are Structural analysis and Thermal analysis.

As we all know that without using any boundary conditions it is not possible to calculate any required result in Ansys software, therefore some calculated boundary conditions are used to make this analysis a success. Boundary conditions for Structural analysis and Thermal analysis are different.

As we know that the mechanical stress which is being applied on the piston is due to the pressure of the gasses which occurs due to the combustion of fuel. For performing this structural analysis, the value of the pressure is 6.5 MPa which is applied on the top surface of the piston head. The piston was supported by frictionless supports at two places (Kaushik, 2019).

Similarly, the crown of a piston is a part which always comes in contact with the hot gas due to combustion. By this combustion, temperature of the top land get rises up to 800°C. The coefficient of heat transfer for top land is chosen from test data of related research. The value of heat transfer coefficient for the top land has taken to be 540 W/ (m^2 °C). The transfer of heat in the middle portion of the piston, the oil film between the piston and the cylinder is taken place by the convection process (Kaushik, 2019).

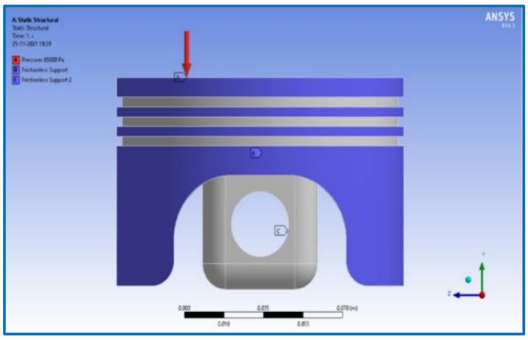

Fig. 3. Boundary condition for Static structural analysis.

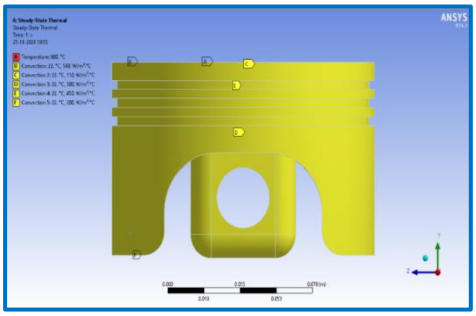

Fig. 4. Boundary conditions for Steady state thermal analysis.

RESULTS AND DISCUSSION

The overall data which we have gain after the static structural analysis and steady state thermal is mentioned here in the following tables:

Table 2: The value of total deformation on a piston occurs due to mechanical load are given below in the table.

Materials	Minimum deformation (m)	Maximum Deformation (m)
AlSi	$5.1216e^{-7}$	$1.9374e^{-5}$
AlMgSi	$2.9593e^{-7}$	$6.248e^{-5}$
AlSiC12	$9.8362e^{-7}$	$2.5902e^{-5}$
Al6061	$3.0464e^{-7}$	$6.4317e^{-5}$

Table 3: The value of equivalent von-mises stress on a piston occurs due to mechanical load are given below in the table.

Materials	Minimum von mises stress (Pascal)	Maximum von mises stress (Pascal)
AlSi	49156	$1.3922e^{8}$
AlMgSi	55062	$1.3568e^{8}$
AlSiC12	$1.5159e^{5}$	$1.2099e^{8}$
Al6061	55062	$1.3568e^{8}$

Table 4: The value of minimum and maximum temperature occurs in a piston due to thermal loads are given below in the table.

Materials	Minimum temperature (°C)	Maximum temperature (°C)
AlSi	337.87	800
AlMgSi	341.36	800
AlSiC12	304.07	800
Al6061	343.66	800

Table 5: The value of the minimum and maximum heat flux in a piston occurs due to thermal loads is given below in the table.

Materials	Minimum heat flux (W/m^2)	Maximum heat flux (W/m^2)
AlSi	5071.4	$3.5167e^{6}$
AlMgSi	4761.2	$3.5405e^{6}$
AlSiC12	4288.4	$3.2823e^{6}$
Al6061	4564.3	$3.5563e^{6}$

During the analysis it has been observed that the AlSi shows the less deformation which is equal to $1.937e^{-5}$ m as compared to other materials so it is the good material in terms of good strength.

Also, it has been observed that the AlSiC12 shows good thermal properties because it shows a minimum temperature of 304.07°C and it also shows the minimum value of heat flux which is $3.2823e^{6}$ W/m^2.

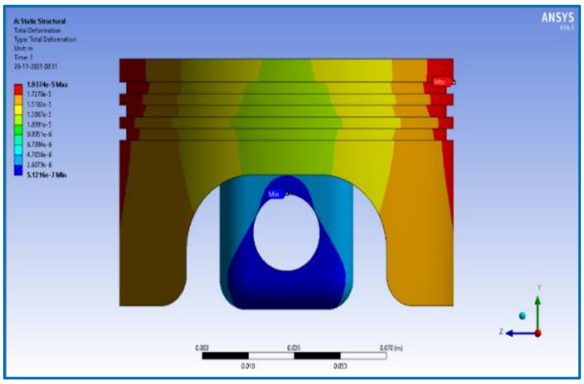

Fig. 5. Total deformation for AlSi.

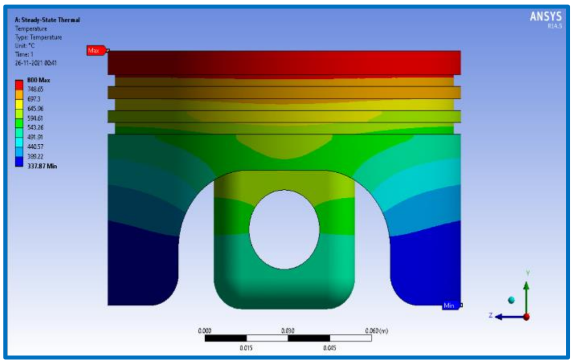

Fig. 6. Temperature distribution for AlSi.

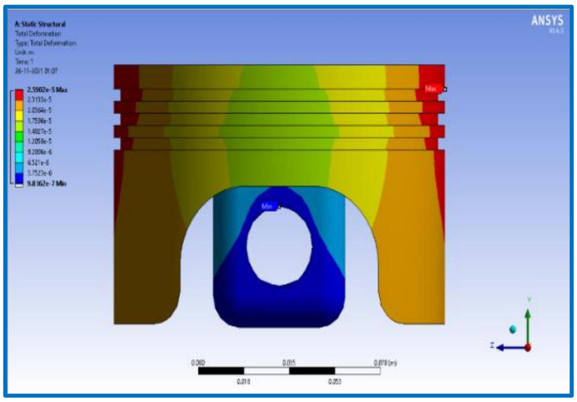

Fig. 7. Total deformation for AlSiC-12.

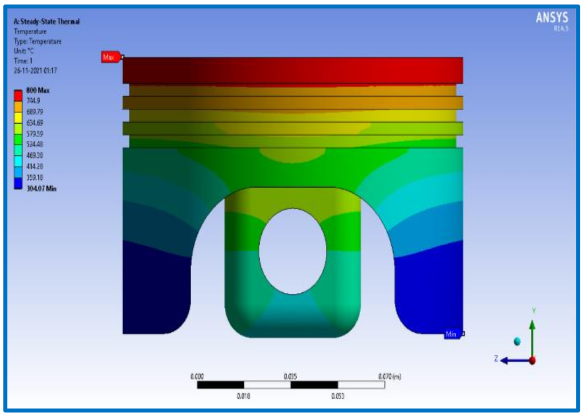

Fig. 8. Temperature distribution for AlSiC-12.

CONCLUSIONS

To get the minimum value of stress concentration and deformation, the crown of the piston must have enough stiffness. In the static structural analysis module, the piston is analysed to get the equivalent (von-mises) stress, total deformation under the high-pressure mechanical loads.

— The piston shows the least deformation in AlSi which is equal to $1.937e^{-5}$m so it is the good material in terms of deformation.

— But in terms of equivalent von- mises stress, the AlSiC12 shows the least value of about $1.2099e^{8}$Pa. Therefore, it is the best material which shows minimum equivalent von- mises stress.

In Steady state thermal analysis, the piston was analysed to observe the temperature distribution and the total heat flux under the high temperature.

— The piston shows the best thermal properties in AlSiC12 because in terms of temperature distribution, it shows a minimum temperature of 304.07^{o}C and it also shows the minimum value of heat flux which is $3.2823e^{6}$ W/m^{2}.

Hence, the overall conclusion is that in terms of structural properties, the best material for a piston is AlSi and in terms of thermal properties, the best material is AlSiC12.

FUTURE SCOPE

In future, this work can be extended to study for various materials and for different compositions. Different kind of materials can be applied on various parts of piston depending upon the type of loads that are applied on them and analysis can be performed. Different types of pistons can also be analyzed by applying the same boundary conditions as we have taken in this analysis project.

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How to cite this article: Anand Vishwakarma, Abhinav Prajapati, Ankush Singh and Amol A. Talankar (2023). Structural & Thermal Analysis of V6 Engine’s Piston for Different Alloys of Aluminium. *International Journal on Emerging Technologies, 14*(2): 53–56.