Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 13, Issue 1, January 2022: 310-321

Investigate the Design Variables of Piston and Optimize the Piston Design for IC engine

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Received: 01.01.2016, Accepted: 01.01.2016

Abstract

The main purpose of this research project is to investigate and analyze the distribution of piston energy in a real engine. Engine pistons are one of the most complex parts among all parts of the automotive or other industrial field.Different design of piston heads such as Deep cylindrical piston head (D1), Shallow re-entrant piston head (D2), Hemispherical existing piston head (D3), Various alloys such as Alcoa alloy (M1), Nimonic alloy (M2), Stainless Steel Grade 201L (M3) have been used in current research. Several tests were performed on a model designed with cover materials such as Alumina (C1), Magnesia (C2), Titanium (C3). Injuries have different origins and are closely related to aging, temperature, and fatigue. Between fatigue, heat exhaustion and mechanical fatigue, whether indoors or at high temperatures, play a prominent role. In the current operation, the piston is built using the CATIA V5R20 software. The complete design is installed in ANSYS 18.0 software and combination of 9 piston models are from MINITAB SOFTWARE and analysis is performed.

Keywords: Coating; Stress, Temperature; Catia; Ansys, Minitab.

Introduction

The piston is considered to be the most important part of the I.C. engine. The maximum temperature produced in I.C. The engine can contribute to high thermal stress. In addition to the proper heat transfer system, the piston crown will work improperly to reduce the life cycle of the piston as well as the efficiency of the equipment. The engine can be called the heart of the car and the piston can be considered as the most important part of the engine. Many research projects are proposing new geometry, building materials, and engine piston production techniques, and these changes have been continuously improved over the past few decades and require a thorough examination of very small details [1] [2] [3].

The piston is part of repeating IC engines. In the engine, its purpose is to transfer energy from the rising electric current to the crankshaft with a piston rod. Piston tolerates cyclic gas pressure and inertia force at work, and this operating condition can cause piston fatigue damage, such as piston side wear, piston head fracture and more. Therefore, there is a need to expand the design of the piston by considering several parameters in this work, the selected parameters are to analyze the piston using compressive forces acting on the piston and thermal analysis of the piston at different temperatures of different strokes. This analysis can be helpful to the design engineer of the piston modification during design [4].

In this work, we determine the values of different pressures using pressure analysis, thermal analysis and thermomechanical analysis form in which we can find different areas or regions where the potential for piston injury is possible.The main requirement for piston formation is to measure the temperature distribution of the piston area, which enables us to improve the thermal properties of the piston structure at low cost [8]. An internal combustion engine is a type of drive that converts chemical energy into mechanical energy. In the engine, its purpose is to transfer energy from the rising electric current to the crankshaft with a piston rod. The piston in the IC engine must be strong enough to withstand gas pressure, be lightweight, be able to move back and forth with minimal noise, have adequate insertion to prevent aging, shut off gas from above and oil from below. , must dissipate heat generated during combustion, Must have good resistance to change under heavy force and extreme temperatures [10].

Literature review

This paper describes the distribution of pressure on the internal combustion engine piston using FEA. FEA is implemented in CAD and CAE software. The main objectives are to investigate and analyze the thermal pressure and the distribution of the piston mechanical pressure in the actual engine condition during the combustion process. The paper describes the FEA method for predicting high pressure and critical area in the segment. Using the CATIAV5 software, a piston structure model will be developed. Using the ANSYS V18.0 software, simulation and pressure analysis are performed [5].

The piston is part of repetitive IC engines. It is a moving element consisting of a cylinder and made of gas-tight piston rings. In the engine, its purpose is to transfer energy from the rising electric current with a piston rod to the crankshaft. In the engine, heat transfer occurs due to differences in temperature and from high temperatures to low temperatures. Therefore, there is a heat transfer to the gases during the stroke and the first part of the pressure stroke, but during the heating and extension processes, the heat transfer from the gases to the walls takes place. Therefore, the piston crown, piston ring and piston skirt must be of sufficient strength to withstand pressure and friction between contact points. In addition, as an integral part of the engine, the operating condition of the piston is precise [6-7].

In this paper, the piston fastened and tested Von mist using the ANSYS load mounted. Distribution of voltage distribution was performed on various parts of the piston that were bonded to detect pressure due to gas pressure and temperature fluctuations. Vonmisses pressure increased by 16% and deviation increased after good performance. But all the parameters fit well with the design considerations. Since the shape and weight of the piston affect the performance of the engine. With specific object analysis software, three-dimensional element analysis is performed on the fuel engine piston [8]. Taking into account the thermal boundary condition, the stress and conditions of the piston deformation distribution are calculated under the thermal coupling effect and the explosion pressure, thus providing a design improvement reference. The results show that the main cause of piston safety, piston degradation and high pressure temperature is, so it is possible to reduce the piston temperature by structural adjustment. This paper includes the simulation of a 2-stroke engine piston to determine its thermal, thermal, mechanical and thermal-mechanical stress [9].

The distribution and size of the above power parameters are useful in the construction, analysis of failure and efficiency of engine pistons. The piston model was developed for robust machining and was submitted to ANSYS for pre-processing, loading and operation. The material model chosen was the 10-node tetrahedral solid solids 87. The imitation parameters used in this paper were piston material, combustion pressure, inertial effects and temperature. This function describes the distribution of piston voltage using a standard factor (FEM) method. FEM is made using computer engineering (CAE) software. The main objective of this project is to investigate and analyze the distribution of piston pressure in the actual engine condition during the combustion process. The report describes mesh development using the FEM process to predict high pressure and critical area in the segment. The impact of crown stiffness, drum thickness and surface piston height on the distribution of pressure and total deterioration is monitored during piston study of four-stroke engines. All preparation is done based on statistical analysis. FEA analysis was performed using ANSYS to determine the correct geometry. This paper describes the distribution of pressure and thermal stress of a piston of three different aluminum alloys using a standard factor (FEM) method [10].

Coating material selection

Thermal Barrier Coatings are used to provide a barrier against heat flow. Thermal Barrier Coatings perform an important function of protective components such as a gas turbine and air car parts operating at high temperatures. Alumina, Magnesia and Titanium coating materials were applied to the top piston in terms of Low thermal conductivity and High Young's Modulus. The thick layer on the piston crown rises from 0.2 mm to 0.6 mm to study the nature of the research in different layers.

Finite element analyses

The amount of heat transfer through a piston is calculated using Finite Element Analysis software. ANSYS 18.0 is a limited object analysis tool used to study component performance. In this project, the focus is on studying the number of heat transfer and temperature variations throughout the piston area. The analysis of the finished feature is performed on both the blank piston and the piston covered with different thickness. Describe the size of the element as 1 mm of piston interaction.

Minitab software design of experiment

DOE (design of experiments) helps you investigate the effects of input variables (factors) on an output variable (response) at the same time. These experiments consist of a series of runs, or tests, in which purposeful changes are made to the input variables. Data are collected at each run. We use DOE to identify the process conditions and product components that affect quality, and then determine the factor settings that optimize results.

Analytical calculations for piston

Analytical calculations were performed with cast iron piston. Performing analytical calculations, material structures and dimensional information must be identified and thus all parameters considered for piston construction are calculated using a single analytical problem.

Piston considerations

When designing an engine piston, the following points should be considered:

1. It should have a high resistance to high pressure.
2. It should have a low weight to withstand the force of inertia.
3. It must form an effective oil seal to protect us.
4. It should provide enough carrying space to prevent unnecessary aging.
5. It should be accompanied by high speed without noise.
6. It must be of construction strong enough to withstand thermal and mechanical changes.
7. It should have adequate piston pin support.

The Physical and material properties of Aluminum Alloy are given below:

Density – 2770 (Kg/m^3)

Poisson Ratio – 0.33

Young Modulus – 7.1x10^{10} (Pa)

Tensile Ultimate Strength – 3.1x10^8(Pa)

Tensile Yield Strength – 2.8x10^8(Pa)

Compressive Yield strength – 2.8 x10^8(Pa)

Calculations : Analytical Design

mp = mass of the piston (Kg)

V = volume of the piston (mm^3)

th = thickness of piston head (mm)

D = cylinder bore (mm)

pmax = maximum gas pressure or explosion pressure (MPa)

σt = allowable tensile strength (MPa)

σut = ultimate tensile strength (MPa)

F.O.S = Factor of Safety = 2.25

k = thermal conductivity =174.15(W/m C)

Tc = temperature at the centre of the piston head (^{0}C)

Te = temperature at the edge of the piston head (^{0}C)

HCV = Higher Calorific Value of fuel (KJ/Kg) = 47000 KJ/Kg (petrol)

BP = brake power of the engine per cylinder (KW) =4KW.

N=1500 rpm, Compression Ratio

(r_c) =16.5, fully loaded condition.

m = mass of fuel used per brake power per second (Kg/KW s) =0.25/3600 (Kg/KW s).Value

B.P=4KW,

CV=47000Kj/kg (petrol),

N=1500, fully loaded condition.

C = ratio of heat absorbed by the piston to the total heat developed in the cylinder = 5% or 0.05

b = radial thickness of ring (mm)

Pw = allowable radial pressure on cylinder wall (N/mm^2) = 0.042 MPa

h2 = axial thickness of piston ring (mm)

t1 = thickness of piston barrel at the top end (mm) **t2** = thickness of piston barrel at the open end (mm) **do** = outer diameter of piston pin (mm)

Engine Specifications:

Bore Diameter: 80mm

Stroke Length: 110mm.

Calculation of Dimensions Of Piston For Analysis:[8]

Thickness of Piston Head (tH) : The piston thickness of piston head calculated using the following Grashoff's formula,

$t_H = D \sqrt{(3p)/(16\sigma_t)}$ in mm

P= maximum pressure in N/mm^2=8 N/mm^2.

This is the maximum pressure that Aluminium alloy can withstand.

D= cylinder bore/outside diameter of the piston in mm= 80mm. σt=permissible tensile stress for the material of the piston.= σt =280/2.25=124.4 MPa.

t_H= 8.9mm.

Heat Flow through the Piston Head (H)

The heat flow through the piston head is calculated using the formula $H = 12.56 * t_H * k * (Tc-Te)$ KJ/sec

Where

k=thermal conductivity of material which is 174.15W/mC

Tc = temperature at center of piston head in °C = 497°C. (by data book)

Te = temperature at edges of piston head in °C= **422°C**.

(Tc-Te)=**75°C**

On the basis of the heat dissipation, the thickness of the piston head is given by:

H = [C x HCV x m x BP]

= 0.05 x 47000 x 0.25/3600 x 4

=0.6527 KJ/s

$t_H = H/(12.56 \times k\ (Tc - Te))$

= Hx1000/12.56 x 174.15 x 75

=3.98mm.

Comparing both the dimensions, for design purpose we will be considering the maximum thickness, hence required thickness of piston head is 8.9mm.

Radial Thickness of Ring (t1):

$t_1 = D\sqrt{3p_w/\sigma_t}$ Where,

D = cylinder bore in mm=80mm.

Pw= pressure of fuel on cylinder wall in N/mm². Its value is limited from 0.025N/mm² to 0.042N/mm². Here P_w value is taken as 0.042N/mm² while σ_t= 124.4Mpa for aluminum alloy.

(t1): 3mm.

Axial Thickness of Ring (t2)

The thickness of the rings may be taken as $t_2 = 0.7t_1$ to t_1

$=0.7\ t_1=2.1$mm.

Number of rings (n_r) Minimum axial thickness (t_2) $t_2= D/(10*n_r)$

$n_r = 3.86$ or 4 rings.

Width of the top land (b1)

The width of the top land varies from b_1 = t_H to 1.2 t_H

=1.2 t_H = 1.2 x8.9 =10.68mm.

Width of other lands (b2):

Width of other ring lands varies from b_2 = 0.75t_2 to t_2

=0.75 t_2= 0.75x2.1=1.575mm.

Maximum Thickness of Barrel at the top end (t3):

Radial depth of the piston ring grooves (b) is about 0.4 mm more than radial thickness of the piston rings(t_1),therefore

b = 0.4 +t_1 =0.4+3 =3.4 mm t_3 = 0.03*D + b + 4.5 mm

t_3=0.03*80+3.4+4.9=10.7mm.

Thickness of piston barrel at the open end (t_4):

t_4= 0.25 t_1 to 0.35 t_1) t_4=0.25*10.7=2.675mm

Piston pin diameter (d_o):

d_o=0.03D=24mm.

Theoretical Stress Calculation:

The piston crown is designed for bending by maximum gas forces Pzmax as uniformly loaded round plate freely supported by a cylinder. The stress acting in MPa on piston crown:

σb=Mb/Wb=Pzmax(ri/δ)2 Where ,

M_b = (1/3) Pzmax r_i^3 is the bending moment, MN m;

W_b = (1/3) riδ^2 is the moment of resistance to bending of a flat crown, m3;

P_{zmax} = Pz, is the pressure, 20 Pa.

ri = [D / 2 - (s + t1 + dt)] is the crown inner radius, m.;

Where, Thickness of the sealing part s = 0.05D= 0.05X80=4mm. Radial clearance between piston ring and channel :dt= 0.0008m Radial thickness of ring (t_1) =3mm.

Therefore, ri=[0.08/2-(0.004+0.003+0.0008)]=0.0322m

Thickness of piston crown δ=(0.08 to 0.1)XD= 0.085X80=7mm.

σb= 20X[(0.0322/0.007)^2] = 423.2Pa.

Validation

σb_1= 20X[(0.0322/0.007)^2] = 423.2Pa. **(By theoretical analysis)**

σb_2= 420.57 Pa. (**By simulation analysis)**

Differences = σb_1 - σb_2

Differences = 2.63Pa

Percentage = 0.6253%

Analysis of the model

The piston model is analyzed to determine the number and parameters in which the piston is damaged. Injuries can have different origins: mechanical stress; thermal pressure; dress codes; temperature fluctuations, oxidation mechanisms; etc. In this analysis, the parameters were Pressure, Temperature, and Pressure.

When the air mixture is heated, pressure from the flammable gases is applied to the piston head, forcing the piston to look at the crankshaft. Due to the pressure on the piston head, there are two critical areas in particular: piston pin holes and areas in the piston head. The next piston will be introduced in different engines where cracks have started to occur in those areas. Gases under pressure run through the gap between the cylinder wall and the piston. The rise of the piston is opposite to the gas pressure. This creates a huge impact on the piston head leading to its damage and modification of the piston head.

Analyzing the model in ansys

After the model was designed in CATIA, the CAT FILE was converted to IGES format. This format makes the design compatible with ANSYS software. After the project has been submitted to ANSYS, the analysis process begins.

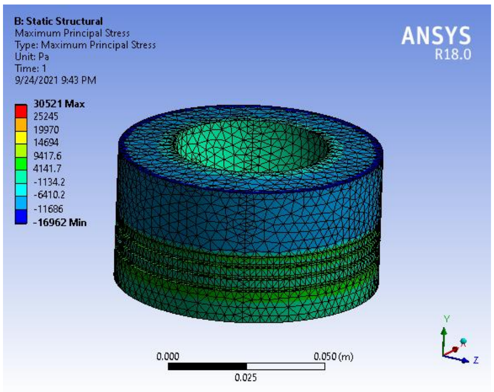
Applying material to the model

Since we are considering here the material with which he modeled Al Alloy, that is why we added this item to the design model built in CATIA. By doing so, the model will have the same Al alloy characteristics, such as density, poison ratio, young modulus, tensile strength, tensile yield strength, compressive yield strength.

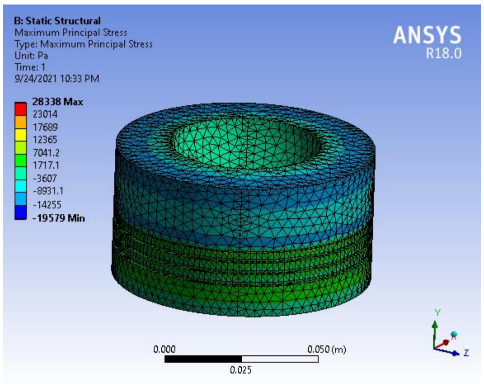
Meshing the model

Mathematically, the structure to be analyzed is divided into a match for objects of limited size of simple shape. Within each element, it is assumed that the subtraction variation is determined by simple polynomial shaping functions and the displacement of the nodes. Statistics of problems and pressure are made according to the movement of unknown nodes. From this, the measurement scales are compiled into a matrix that can be easily sorted.

Result and discussions



Stress analysis (Pa)



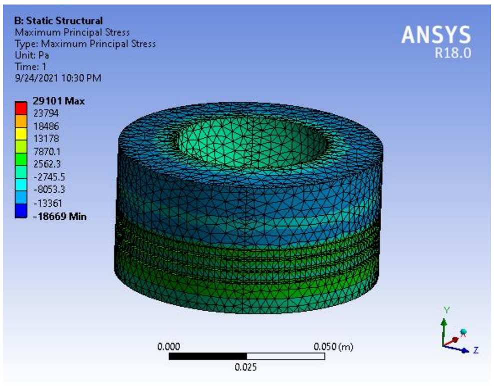


Figure 2. (a) D1M1C1

Figure 2. (b) D1M2C2

Figure 2. (c) D1M3C3

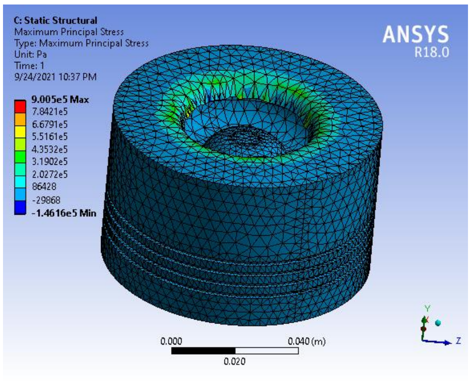


Figure 2. (d) D2M1C1

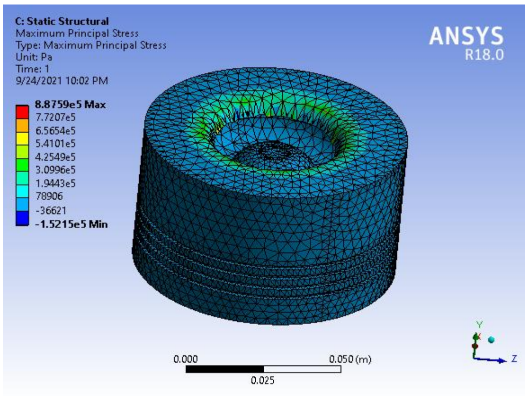


Figure 2. (e) D2M2C2

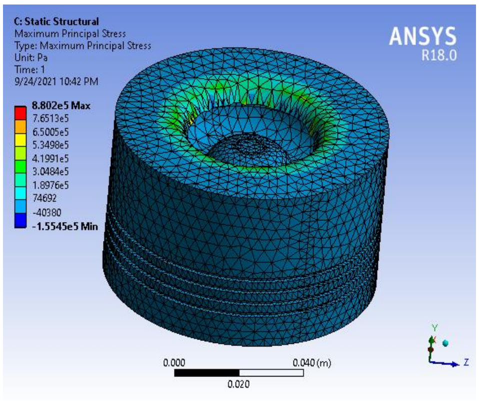
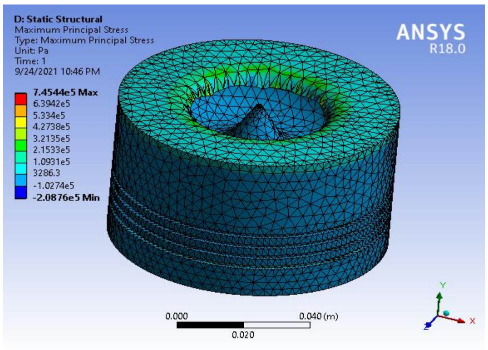
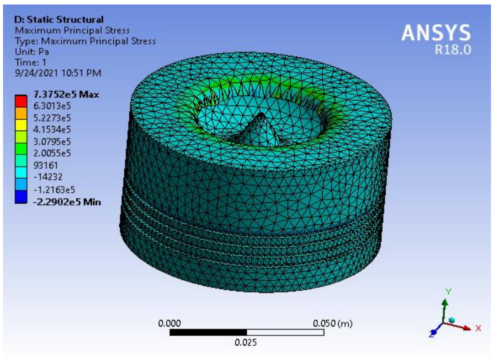


Figure 2. (f) D2M3C3





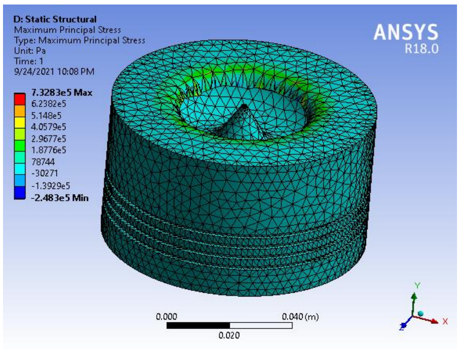


Figure 2. (g) D3M1C1

Figure 2. (h) D3M2C2

Figure 2. (i) D3M3C3

Thermal analysis (W/M^2)

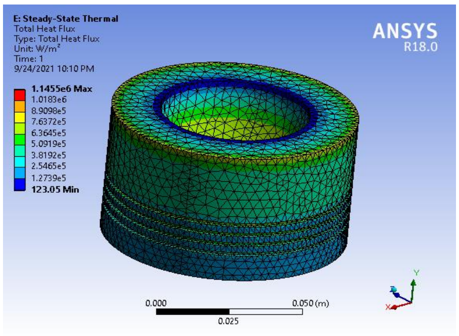


Figure 3. (a) D1M1C1

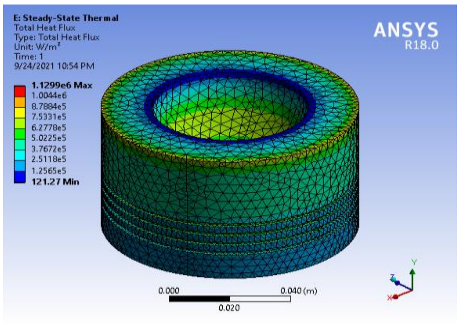


Figure 3. (b) D1M2C2

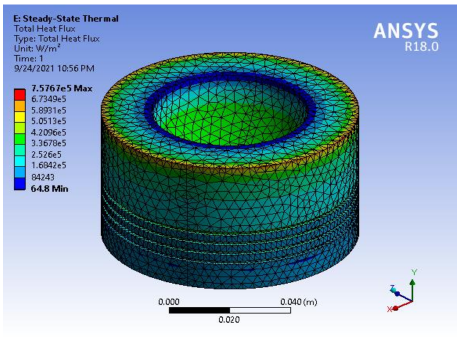


Figure 3. (c) D1M3C3

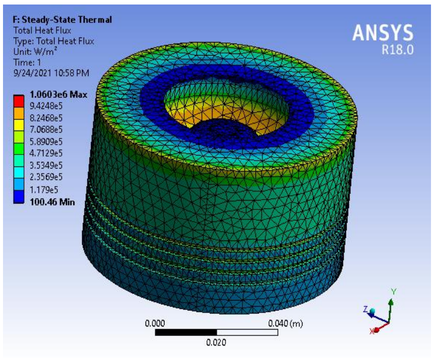


Figure 3. (d) D2M1C1

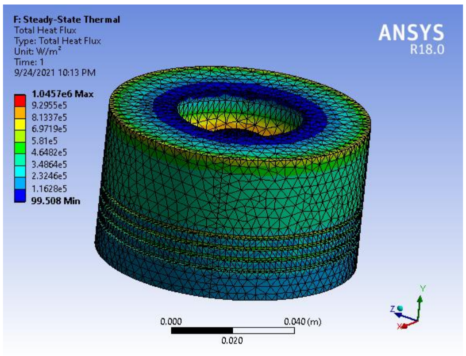


Figure 3. (e) D2M2C2

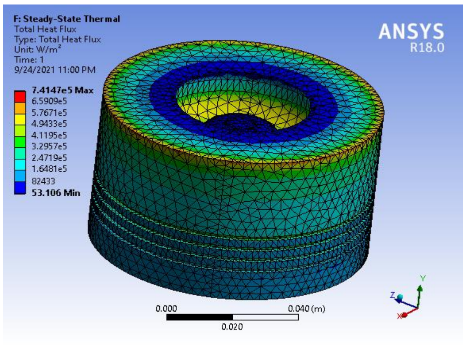


Figure 3. (f) D2M3C3

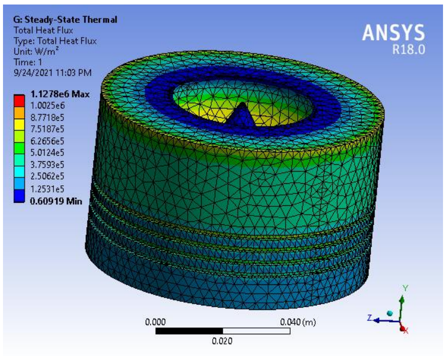


Figure 3. (g) D3M1C1

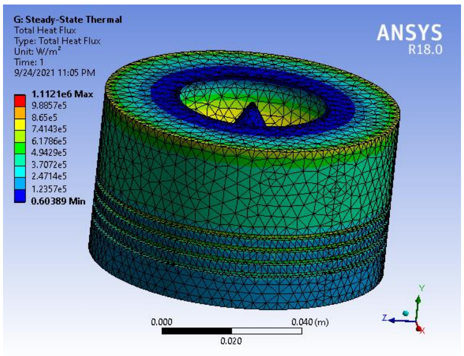


Figure 3. (h) D3M2C2

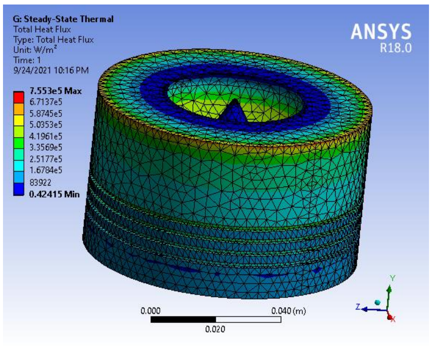


Figure 3. (i) D3M3C3

Taguchi analysis design of experiment:

Table 1

Stress (Pa)

PISTON DESIGN	MATERIAL	COATING	STRESS (Pa)
DEEP CYLINDRICAL	ALCOA ALLOY	ALUMINA	452.971
DEEP CYLINDRICAL	NIMONIC ALLOY	MAGNESIA	431.897
DEEP CYLINDRICAL	STEEL GRADE 201	TITANIUM	420.573
SHALLOW RE ENTRANT	ALCOA ALLOY	ALUMINA	1336.460
SHALLOW RE ENTRANT	NIMONIC ALLOY	MAGNESIA	1317.300
SHALLOW RE ENTRANT	STEEL GRADE 201	TITANIUM	1306.332
HEMISPHERICAL EXISTING	ALCOA ALLOY	ALUMINA	1106.331
HEMISPHERICAL EXISTING	NIMONIC ALLOY	MAGNESIA	1094.576
HEMISPHERICAL EXISTING	STEEL GRADE 201	TITANIUM	1087.6161

Table 2

Thermal (w/m^2)

PISTON DESIGN	MATERIAL	COATING	THERMAL (w/m^2)
DEEP CYLINDRICAL	ALCOA ALLOY	ALUMINA	462.127
DEEP CYLINDRICAL	NIMONIC ALLOY	MAGNESIA	455.834
DEEP CYLINDRICAL	STEEL GRADE 201	TITANIUM	1124.481
SHALLOW RE ENTRANT	ALCOA ALLOY	ALUMINA	427.755
SHALLOW RE ENTRANT	NIMONIC ALLOY	MAGNESIA	421.865
SHALLOW RE ENTRANT	STEEL GRADE 201	TITANIUM	1100.439
HEMISPHERICAL EXISTING	ALCOA ALLOY	ALUMINA	454.986
HEMISPHERICAL EXISTING	NIMONIC ALLOY	MAGNESIA	448.653
HEMISPHERICAL EXISTING	STEEL GRADE 201	TITANIUM	1120.964

Conclusions

The first major conclusion that can be drawn from this work is that although heat stress is not caused by the majority of damaged pistons, it remains a problem for engine pistons and its solution remains the goal of piston manufacturers. It is concluded that the smallest stress obtained is 420.57 Pa, as shown in Table 1, using (Deep cylindrical piston head) Design 1, Material 3 (Stainless Steel Grade 201L) and Coating 3 (Titanium). It is also concluded that the smallest Thermal (w/m^2) obtained is 421.87 w/m^2, as shown in Table 2, using (Shallow re-entrant piston head) Design 2, Material 2 (Nickel-Chromium) and Coating 3 (Titanium).The percentage difference between the analysis results and the piston analysis results is very small. Therefore, the design of the piston is safe.

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