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Modeling and Analysis of an IC Engine Piston by CAD Modeling, Static and Thermal Analysis

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ABSTRACT

In an Internal Combustion Engine, Piston is one of the major parts of the combustion cycle. In the Process of increasing efficiency and power of the engine, thermal and static loads on the piston increases resulting in reliability issues and breakdown of component before the completion of its life cycle. Pistons need to be light in weight so that we don't have to use a lot of counter weight on the crank shaft to balance it and so, keep the engine weight to minimum. Also, a heavier piston will generate lot more vibrations than a lighter one. One more factor to be considered is the Thermal Expansion of the material, since to improve efficiency the tolerance space between the cylinder wall and piston should be minimal. But at the same time, we need to ensure that the piston is thermally sound and strong enough to withstand the loads. This paper discusses about the thermal loads and statics stress applied on the piston during the power stroke using four different materials chosen on the basis of strength, density, Thermal Conductivity. The parameters for the simulation are combustion cylinder pressure, temperature and material properties of piston. Analysis is performed using Autodesk Fusion 360. The results are used to develop a trade-off between the material selected for piston.
Keywords: Piston, Deformation, Thermal stresses, Static-stress, Autodesk Fusion 360, Titanium, Aluminium 7075, Aluminium 6061, Grey Cast Iron A48 Grade 40.

Introduction

An An Internal Combustion Engine is that kind of prime mover that converts chemical energy to mechanical energy. To increase the efficiency and power of the engine, new manufacturing techniques have been developed with accurate tolerance to the parts. With all this new innovation, parts get subjected to even more thermal and static loads and have to be complaint in order to function as intended.

1.1 Piston

Piston is a component in reciprocating engines. It is the two and for moving component that is contained by a cylinder and is made gas tight by piston rings. Its purpose is to transfer force from expanding gas to the crankshaft via a connecting rod.

The piston design on the picture is widely used in diesel engines. Maximum pressure in the combustion chamber can reach 7MPa and maximum temperature of the piston surface can exceed 900 ⁰ C. Therefore, it is important to improve the cooling of the piston Gas sealing is achieved by use of piston rings.

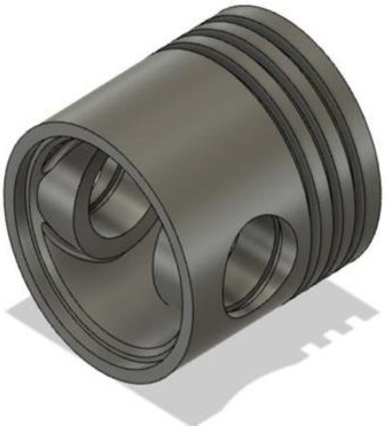


Fig -1: CAD model of piston

These are a number of narrow iron rings, fitted loosely into grooves in the piston, just below the crown. The rings are split at a point in the rim, allowing them to press against the cylinder with a light spring pressure. Two types of ring are used: the upper rings have solid faces and provide gas sealing; lower rings have narrow edges and a U-shaped profile, to act as oil scrapers.

For our study, Piston in an IC engine must have

- Good resistance to distortion under heavy forces and high temperatures.
- High heat dissipating rate.
- Minimum weight but enough strength to resist the pressure

2. STUDY MATERIALS

The materials chosen for this work are Aluminum 7075, Aluminum 6061, Gray Cast Iron A48 Grade 40, Titanium. The relevant mechanical and thermal properties of these materials and alloys are listed in the tables below.

2.1 Aluminum 7075

Aluminum 7075Has the least yield, ultimate strength and maximum thermal conductivity amongst the four materials. It has a high content of copper and Nickel. The piston of this type of alloy has great heat resistance, resistance to burnout and increased thermal conductivity.

Density	2.81E-06 kg / mm^3
Young's Modulus	71700 MPa
Poisson's Ratio	0.33
Yield Strength	145 MPa
Ultimate Tensile Strength	276 MPa
Thermal Conductivity	0.173 W / (mm C)
Thermal Expansion Coefficient	2.34E-05 / C
Specific Heat	960 J / (kg C)

Table -1: Aluminum 7075 Properties

2.2 Aluminium 6061

Aluminium 6061 as the least density, young's modulus and maximum thermal expansion coefficient amongst the four materials. It too has a high content of copper and Nickel.

Density	2.7E-06 kg / mm^3
Young's Modulus	68900 MPa
Poisson's Ratio	0.33
Yield Strength	275 MPa
Ultimate Tensile Strength	310 MPa
Thermal Conductivity	0.167 W / (mm C)
Thermal	2.36E-05 / C

Expansion Coefficient	
Specific Heat	897 J / (kg C)

Table -2: Aluminium 6061 Properties

2.3 Gray Cast Iron A48, Grade 40

Grey Cast iron has the maximum density, young's modulus but the least specific heat amongst the four materials, and is cheapest of all.

2.4 Titanium High Strength Alloy

Titanium has the maximum yield, ultimate strength and minimum thermal conductivity and Thermal Expansion Coefficient amongst the four materials, but is costliest of all

Density	4.43E-06 kg / mm^3
Young's Modulus	113770 MPa
Poisson's Ratio	0.34
Yield Strength	882.5 MPa
Ultimate Tensile Strength	951.5 MPa
Thermal Conductivity	0.0067 W / (mm C)
Thermal Expansion Coefficient	8.6E-06 / C
Specific Heat	526.3 J / (kg C)

Table -4: Titanium Properties

3. PRE-PROCESSING

The Setup of study and applying of boundary conditions is done by keeping in mind the extreme temperatures and pressures that are acted on the piston during combustion cycle

3.1 Meshing

Element Order	Parabolic
Create Curved Mesh Elements	Yes
Max. Turn Angle on Curves (Deg.)	45
Max. Adjacent Mesh Size Ratio	1.5
Max. Aspect Ratio	10
Minimum Element Size (% of average size)	20

Table -5 : Local Mesh Settings

A total Number of 195111 nodes was created to get more accurate results.

Type	Nodes	Elements
Solids	195111	129281

Table -6: Nodes and elements in mesh

3.2 Boundary conditions

Based on the relative research work and combustion calculations suitable boundary conditions are applied on particular faces to obtain better and more accurate results.

3.2.1 Thermal analysis Boundary conditions

Type	Applied Temperature
Value	900 C

Table -7 : Applied Temperature

Fig -2: Temperature boundary condition

Type	Convection
Convection Value	540 W / (m^2 C)
Ambient Temperature	22 C

Table -8 : Convection 1

Fig -3: Convection 1 Boundary Condition

Type	Convection
Convection Value	110 W / (m^2 K)
Ambient Temperature	22 C

Table -9 : Convection 2

Fig -4: Convection 2 Boundary Condition

Type	Convection
Convection Value	300 W / (m^2 K)
Ambient Temperature	22 C

Table -10 : Convection 3

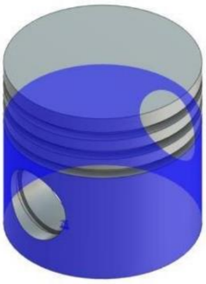


Fig -5: Convection 3 Boundary Condition

Type	Convection
Convection Value	200 W / (m^2 K)
Ambient Temperature	22 C

Table -11 : Convection

Fig -6: Convection 4 Boundary Condition

Type	Convection
Convection Value	450 W / (m^2 K)
Ambient Temperature	22 C

Table -12 : Convection 5

Fig -7: Convection 4 Boundary Condition

3.2.2 Static analysis Boundary conditions

Type	Pressure
Magnitude	6.75 MPa

Table -13 : Pressure

Fig -8: Pressure

Fig -9: Constraints

4. ANALYSIS

Finite element analysis method is used to perform analysis on the piston when it is subjected to thermal and mechanical loads. To perform the finite element analysis of the piston an analysis software Fusin 360 is used.

4.1 Thermal Analysis

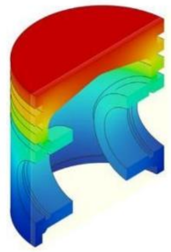


Fig -10: Cross Sectional view of temperature distribution (Al 7075)

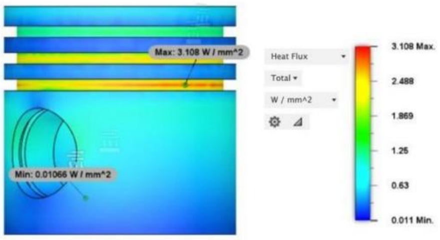


Fig -11: Heat Flux distribution (Al 7075)

Name	Minimum	Maximum
Temperature	409.2 C	900 C
Heat Flux	0.01066 W / mm^2	3.108 W / mm^2
Thermal Gradient	0.06163 C / mm	17.96 C / mm
Applied Heat Flow	-1.665E-10 W / mm^2	2.541E-08 W / mm^2

Table -14 : Results Summary (Al 7075)

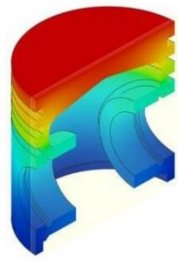


Fig -12: Cross Sectional view of temperature distribution (Al 6061)

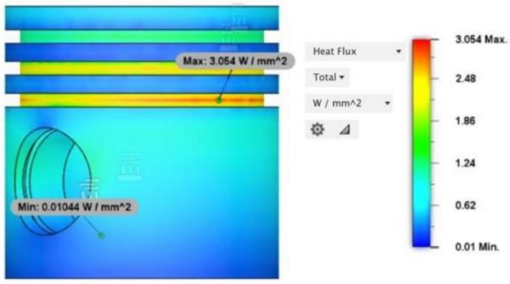


Fig -13: Heat Flux distribution (Al 6061)

Name	Minimum	Maximum
Temperature	400.6 C	900 C
Heat Flux	0.01044 W / mm^2	3.054 W / mm^2
Thermal Gradient	0.06249 C / mm	18.29 C / mm
Applied Heat Flow	-1.665E-10 W / mm^2	2.541E-08 W / mm^2

Table -15 : Results Summary (Al 6061)

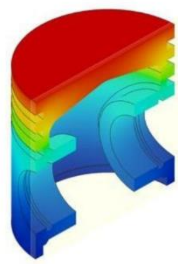


Fig -14: Cross Sectional view of temperature distribution (Grey Cast Iron A48)

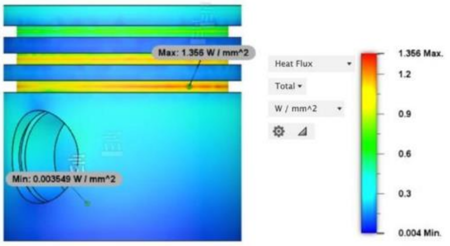


Fig -15: Heat Flux distribution (Grey Cast Iron A48)

Name	Minimum	Maximum
Temperature	139.9 C	900 C
Heat Flux	0.003549 W / mm^2	1.356 W / mm^2
Thermal Gradient	0.07387 C / mm	28.24 C / mm
Applied Heat Flow	-1.665E-10 W / mm^2	2.541E-08 W / mm^2

Table -16 : Results Summary (Grey Cast Iron)

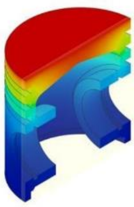


Fig -16: Cross Sectional view of temperature distribution (Titanium)

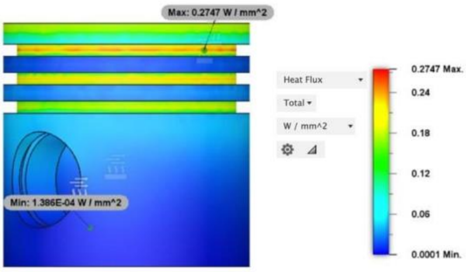


Fig -17: Heat Flux distribution (Titanium)

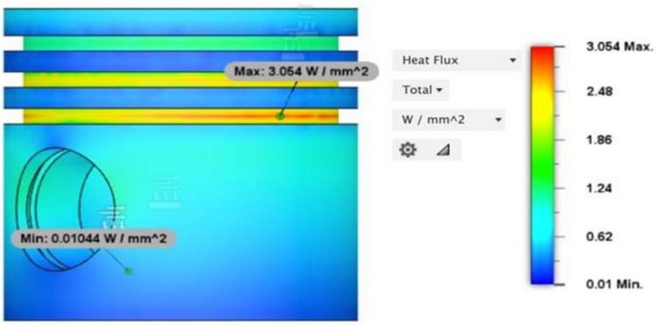


Fig -13: Heat Flux distribution (Al 6061)

Name	Minimum	Maximum
Temperature	400.6 C	900 C
Heat Flux	0.01044 W / mm^2	3.054 W / mm^2
Thermal Gradient	0.06249 C / mm	18.29 C / mm
Applied Heat Flow	-1.665E-10 W / mm^2	2.541E-08 W / mm^2

Table -15 : Results Summary (Al 6061)

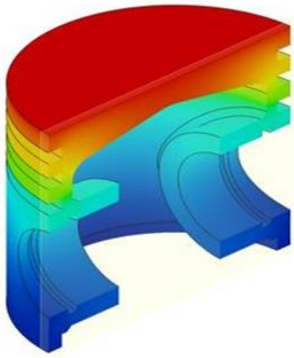


Fig -14: Cross Sectional view of temperature distribution (Grey Cast Iron A48)

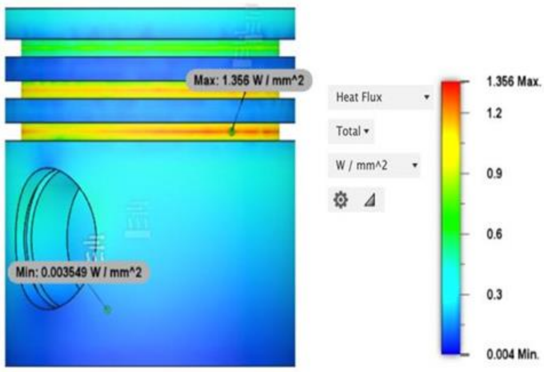


Fig -15: Heat Flux distribution (Grey Cast Iron A48)

Name	Minimum	Maximum
Temperature	139.9 C	900 C
Heat Flux	0.003549 W / mm^2	1.356 W / mm^2
Thermal Gradient	0.07387 C / mm	28.24 C / mm
Applied Heat Flow	-1.665E-10 W / mm^2	2.541E-08 W / mm^2

Table -16 : Results Summary (Grey Cast Iron)

Fig -16: Cross Sectional view of temperature distribution (Titanium)

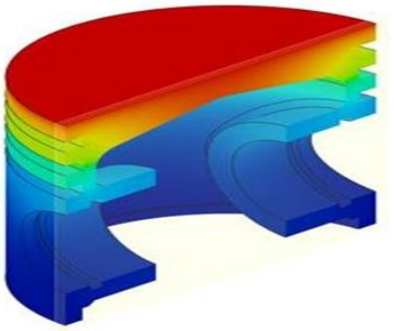
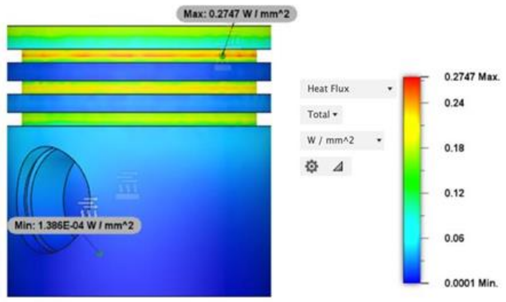


Fig -17: Heat Flux distribution (Titanium)



Name	Minimum	Maximum
Temperature	24.07 C	900 C
Heat Flux	1.386E-04 W / mm^2	0.2747 W / mm^2
Thermal Gradient	0.02068 C / mm	41 C / mm
Applied Heat Flow		
Applied Heat Flow	-1.665E-10 W / mm^2	2.541E-08 W / mm^2

Table -17: Results Summary (Titanium)

4.2 Static Structural Analysis

Note: The deformation scale is adjusted for viewing purpose for all four cases

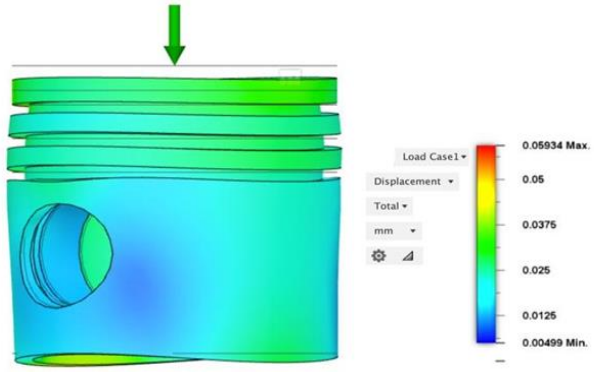


Fig -18: Displacement (Al7075)

Name	Minimum	Maximum
Safety Factor	1.9172	15
Stress		
Von Mises	0.2713 MPa	158.1 MPa
1st Principal	-25.83 MPa	88.36 MPa
3rd Principal	-173.5 MPa	14.2 MPa
Displacement	0.004987 mm	0.05934 mm

Table -18 : Results Summary (Al 7075)

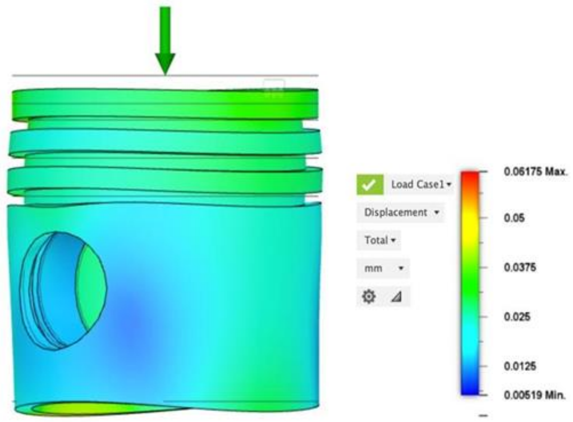


Fig -19: Displacement (Al6061)

Name	Minimum	Maximum
Safety Factor	1.74	15
Stress		
Von Mises	0.2713 MPa	158.1 MPa
1st Principal	-25.83 MPa	88.36 MPa
3rd Principal	-173.5 MPa	14.2 MPa
Displacement	0.00519 mm	0.06175 mm

Table -19: Results Summary (Al 6061)

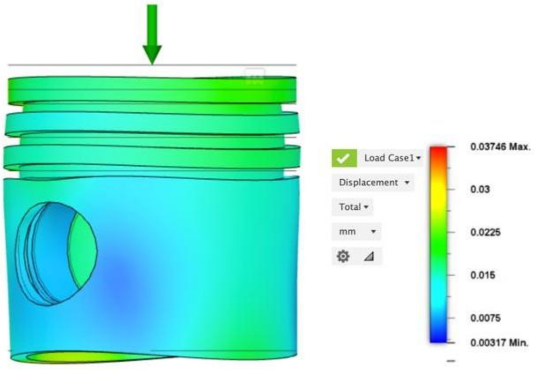


Fig -20: Displacement (Grey Cast Iron)

Name	Minimum	Maximum
Safety Factor	1.793	15
Stress		
Von Mises	0.4086 MPa	163.4 MPa
1st Principal	-14.1 MPa	80.04 MPa
3rd Principal	-169.3 MPa	13.3 MPa
Displacement	0.0027 mm	0.03384 mm

Table -20: Results Summary (Grey Cast Iron)

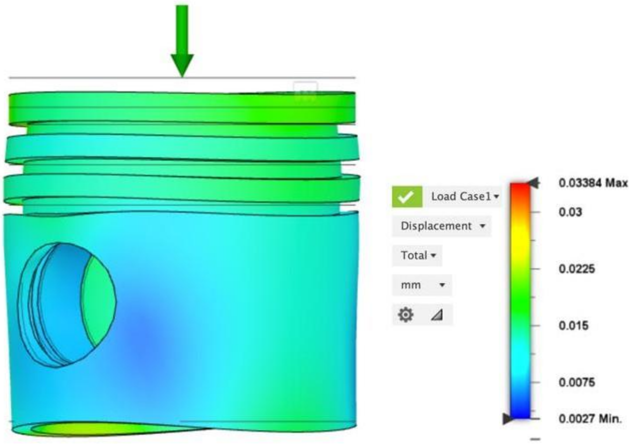


Fig -21: Displacement (Titanium)

Name	Minimum	Maximum
Safety Factor	5.609	15
Stress		
Von Mises	0.2715 MPa	157.3 MPa
1st Principal	-27.03 MPa	89.99 MPa
3rd Principal	-174.3 MPa	14.6 MPa
Displacement	0.003173 mm	0.03746 mm

Table -21: Results Summary (Titanium)

5. CONCLUSION

After performing analysis on 4 different materials namely Aluminum 7075, Aluminum 6061, Grey cats Iron A48 grade 40 and Titanium under two different load conditions (Mechanical loads, Thermal loads) we can conclude that Titanium undergoes least deformation, has highest safety factors and can dissipate higher amount of heat than compared to other materials used. So, by this Titanium can be used for High performance engines. Both Aluminum alloys can be used for pistons in low speed engines.

6. FUTURE SCOPE, CONCLUSIONS

In this work simulation is carried out for four types of materials Al 7075, Al 6061, Grey Cast Iron, Titanium are used. This work can be extended to study for various materials and for different compositions. Different kinds of materials can be applied on various parts of piston depending on the type of loads that are applied on them and analysis can be performed. Simulation and flow analysis can be carries out.

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