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Improving the Heat Transfer Rate for Multi Cylinder Engine Piston And Piston Rings

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Abstract: A piston is a component of reciprocating engines, pumps and gas compressors. It is located in 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. The alloy from which a piston is made not only determines its strength and wears characteristics, but also its thermal expansion characteristics. The normal temperature of gasoline engine exhaust is approximately 650ºC (923ºK). This is also approximately the melting point of most aluminum alloys and it is only the constant influx of ambient air that prevents the piston from deforming and failing. For this purpose testing different types of materials such as aluminum alloys and alloy steel piston. In this project we design the two models of pistons flat head & convex heads by using solid works software, and analyzed statically and thermally by using solid works simulation. And find out the vonmisses stresses, total deformation, heat distribution, and heat flux. By comparing the above results of flat head and convex head piston the heat flux is more for 6061-T6 aluminum alloy than the cast iron material. Therefore 6061-T6 material is the best suitable material for piston. By comparing the above results of piston ring the heat flux is more for Alloy steel than the cast iron material. Therefore Alloy steel material is the best suitable material for piston ring.

Keywords: Heat Transfer Rate, Multi Cylinder Engine Piston, Piston Rings.

I. INTRODUCTION

A. Heat Engines

Any type of engine or machine which derives heat energy from the combustion of fuel or any other source and coverts this energy into mechanical work is termed as a heat engine. Heat engines may be classified as:

- External Combustion Engines
- Internal Combustion Engines

External Combustion Engines (E.C. Engines): In this case, combustion of fuel takes place outside of the cylinder as in case of steam engines where the heat of combustion is employed to generate steam which is used to move a piston in a cylinder.

Internal Combustion Engines (I.C. Engines): In this case, combustion of the fuel with oxygen of the air occurs within the cylinder of the engine. The internal combustion engines group includes engines employing mixtures of combustible gases and air, known as gas engines, those using lighter liquid fuel or spirit known as petrol engines and those using heavier liquid fuels, known as oil compression or diesel engines.

Even though internal combustion engines look quite simple, they are highly complex machines. There are hundreds of components which have to perform their functions satisfactorily to produce output power. There are two types of engines

- Spark ignition engine (S.I engine)
- Compression ignition engine (C.I engine)

According to the cycle of operations again these engines are classified as

- Two-stroke engines
- Four-stroke engines

Parts of an I.C. Engine:

- Cylinder
- Cylinder head
- Piston
- Gudgeon pin
- Connecting rod
- Crankshaft
- Crank
- Crank case
- Flywheel
- Governor
- Valves and valve operating mechanism

Working Cycles: An internal combustion engine can work on any one of the following cycles:

- Constant volume or Otto cycle
- Constant pressure or Diesel cycle
- Dual combustion cycle

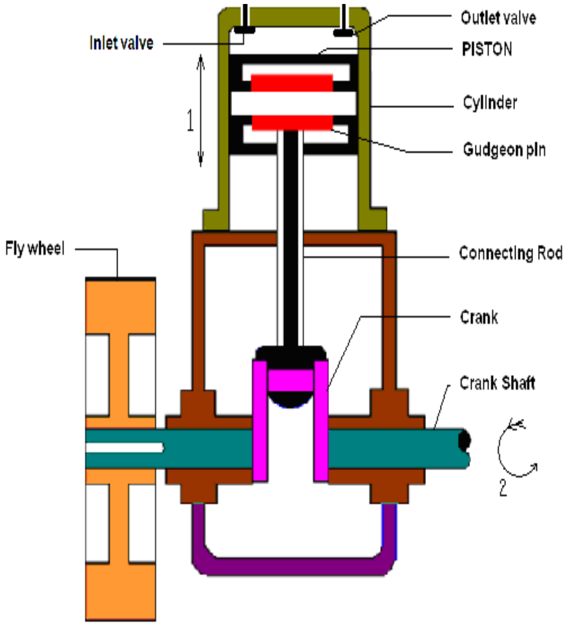


Fig.1.Parts of an I.C Engine

II. DESIGNING OF PISTON

A. Design of Piston

Considering diameter of piston as 100 mm, and material is cast iron piston. For 15 kw power and speed as 2200 rpm. Assuming required data.

Piston Head: Based on strength consideration, the thickness of piston head is given by:

$$t_1 = \sqrt{\{(3P_{in} D^2) / (16\ S_{tp})\}} \quad \textbf{(1)}$$

Where

P_{in} = Maximum gas pressure, in (N/mm²) = 5 Mpa

D = Diameter of piston or Cylinder bore, in (mm) = 100 mm

S_{tp} = Allowable tensile stress of piston material,

= 37.5 N/mm² for Cast Iron

$t_1 = \sqrt{\{(3*5*100^2) / (16*37.5)\}} = 16$ mm

Based on Heat dissipation the head thickness is determined as:

$$t_1 = \{(1000H) / (12.56K\ (T_c - T_e))\} \quad \textbf{(2)}$$

$=\{(1000*5421.8)/(12.56*46.69*10^{-2}*(205))\}= 14.78$mm

Where

H = Heat flowing through the head (KW)

$= C * m * Cv * P_b = 0.05*0.15*44*10^3*17.278 = 5421.8$ Kj/h

C = Constant = 0.05

m = mass of the fuel used (i.e. fuel consumption), in (K_g/KW/S) = 0.15 K_g/Kw/h

C_v = Higher Calorific value of the Fuel = 44 x 10³ KJ/K_g for Diesel

P_b = Brake power of the Engine per cylinder (KW)

$= \{(PLAn) / (60x10^3)\} = \{(0.5*120*10^{-3}*0.00785*2200) / (60*10^3)\} = 17.278$kw

P = Brake mean effective pressure = 0.5 Mpa

L = Stroke length = 120 mm

A = Area of the piston at its top side, in (mm²) = $(\Pi/4)*100^2 = 0.00785$m²

n = Number of power strokes per minute = 1

k = Heat conductivity factor (KW/m/˚C)

$= 46.6x10^{-3}$ for Cast Iron

T_c = Temperature at the centre of piston head (˚C)

T_e = Temperature at the edge of piston head (˚C) = 205˚C for cast iron

TABLE I: Piston Dimensions

Piston Diameter(D)	100mm
Length Of The Piston (Lp)	105mm
Thickness Of Piston Head (T1)	5.25mm
Height Of Top Part(Lh)	52.5mm
Length Of Skrit (Ls)	70mm
Thickness Of Ring Land(X1)	9mm
Thickness Of First Ring (X2)	4mm
Axial Thickness (T4)	3mm
Thickness Of Barrel at Open End Of Piston(T6)	10.5mm
Pin Outer Diameter(dp)	25mm
Piston Inner Diameter(Di)	68.55mm
Thickness Of Crown Wall (T5)	7.5mm
Inlet Port	30mm
Outlet Port	25mm
Spark Plug	20mm
Gudgeon Pin	20mm
Cylinder Height	195mm
Clearance Volume	5mm
TDC TO BDC	60mm
Compression Ratio	12

III. MODELING OF PISTON

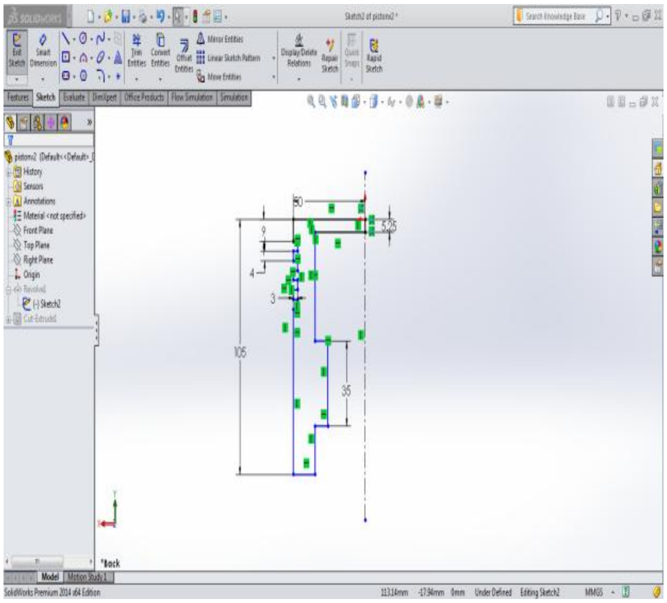


Fig.2.

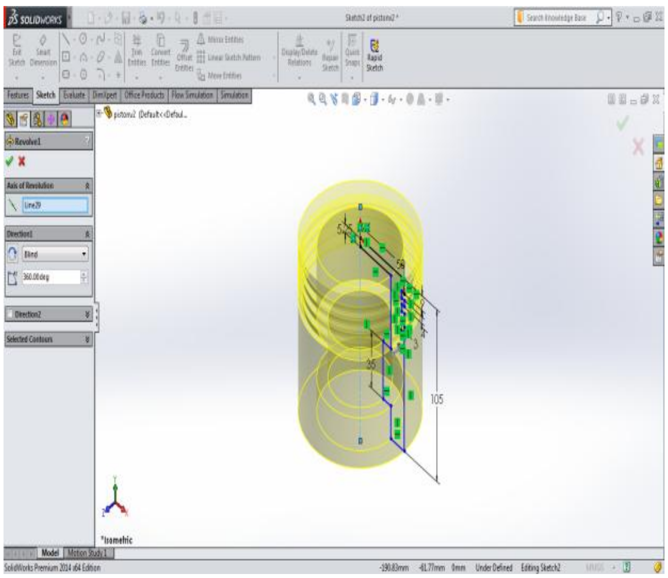


Fig.3.

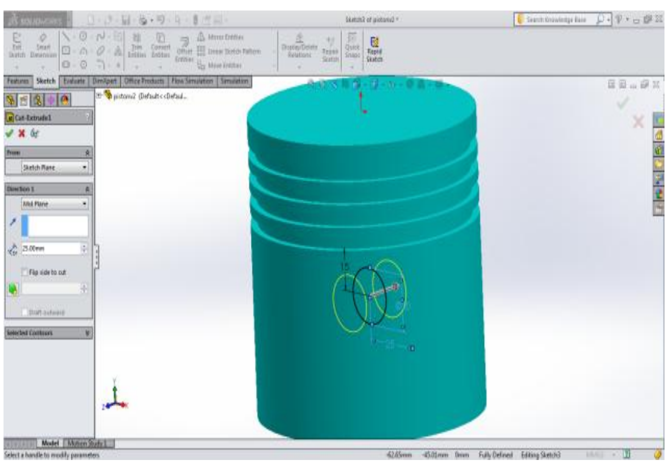


Fig.4.

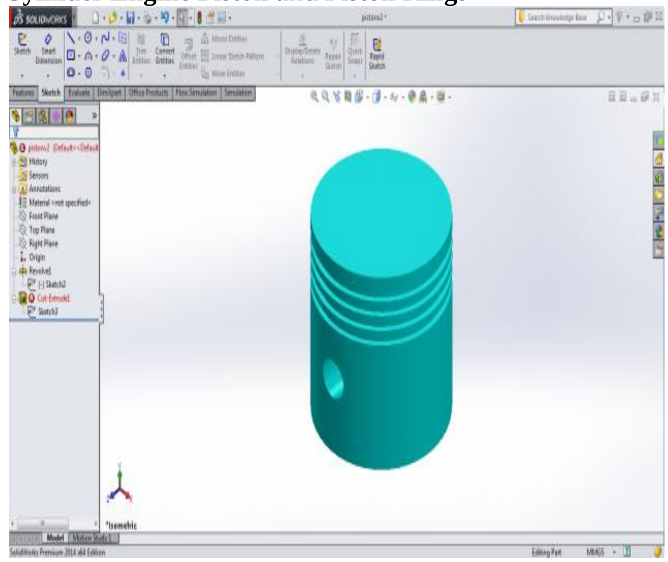


Fig.5.

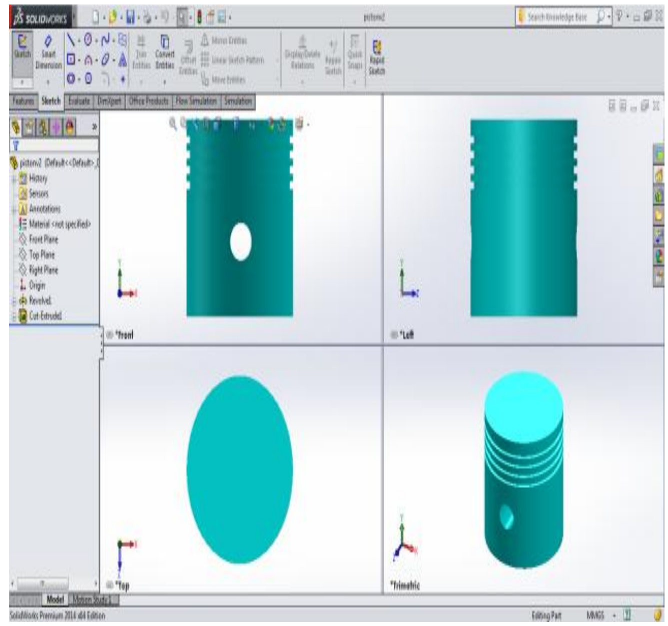


Fig.6.

A. Modeling of Gudgeon Pin

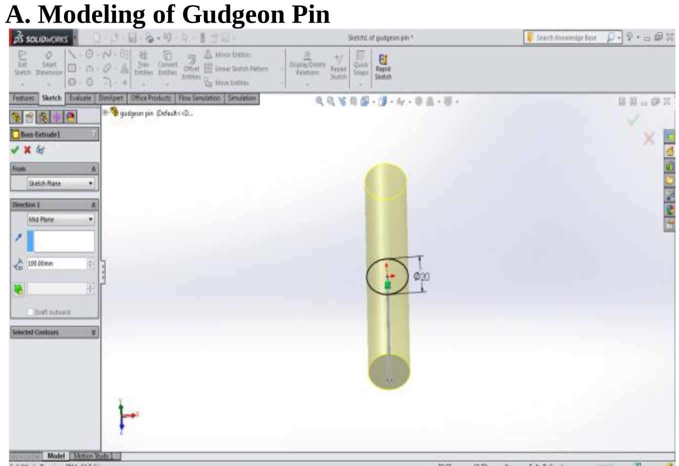


Fig.7.

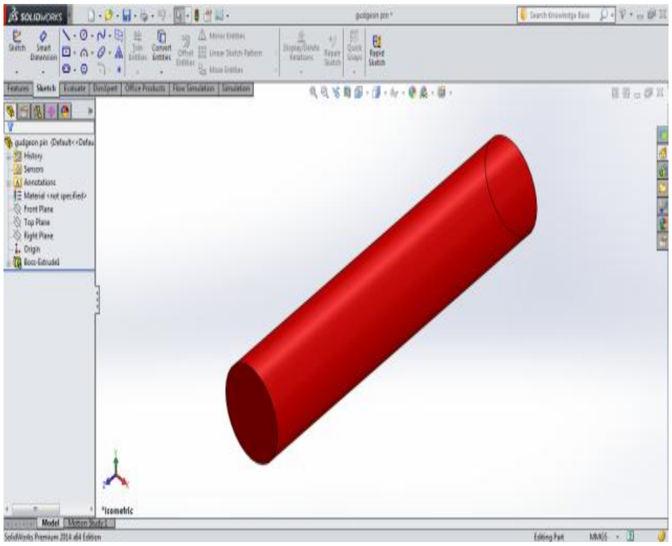


Fig.8.

B. Modeling of Cylinder

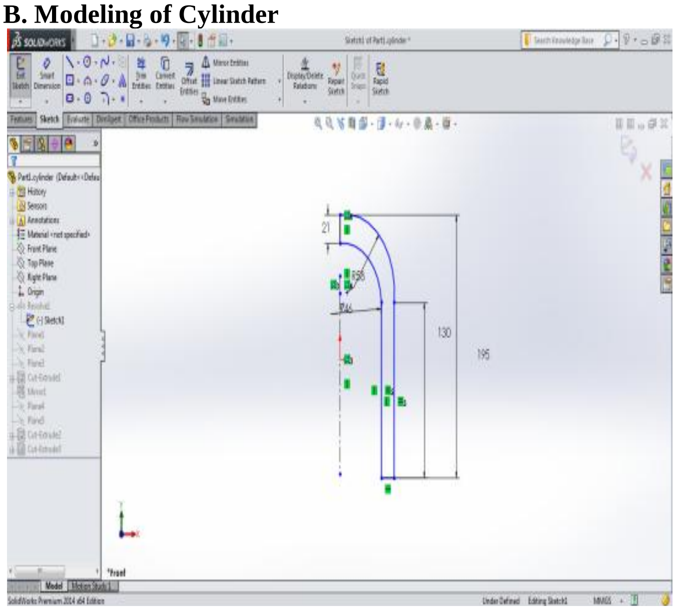


Fig.9.

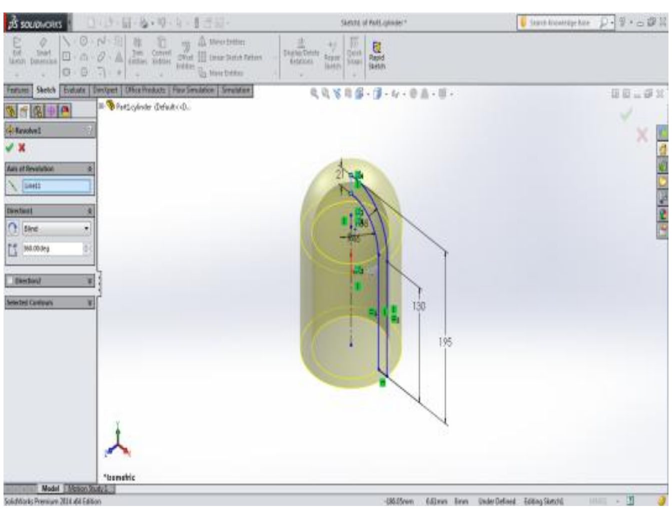


Fig.10.

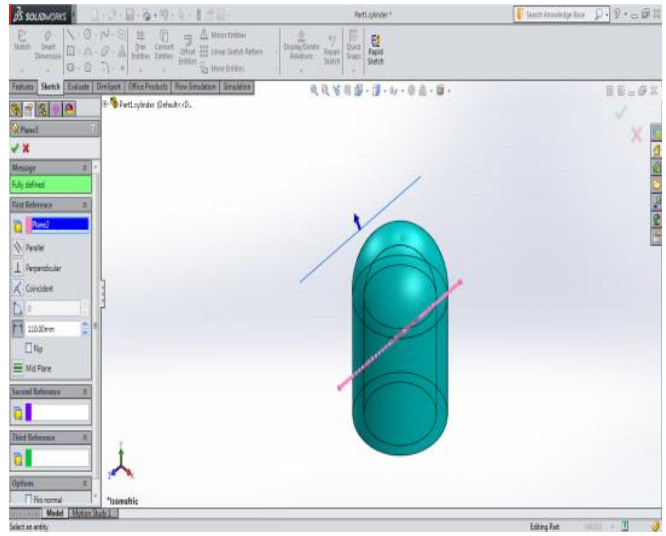


Fig.11.

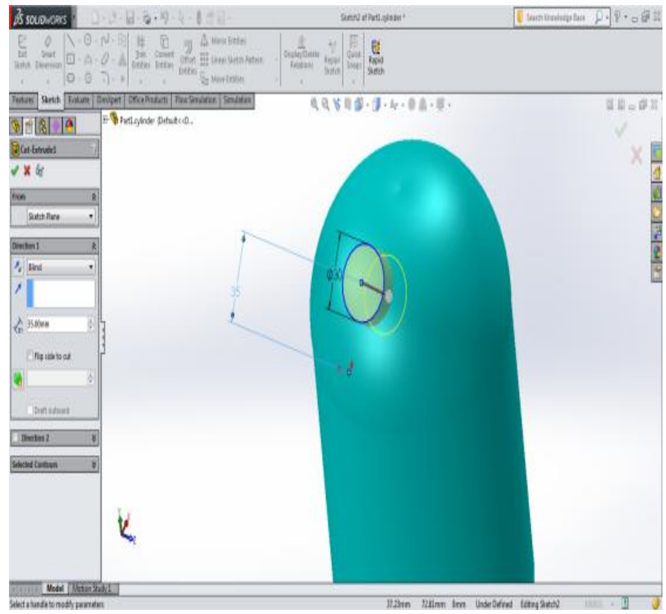


Fig.12.

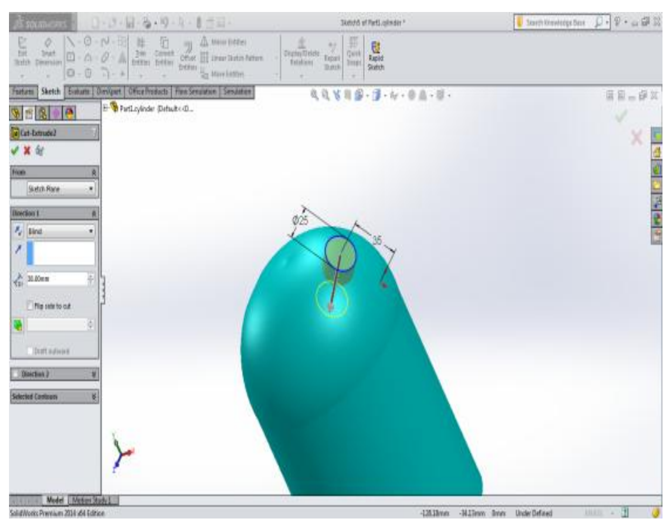


Fig.13.

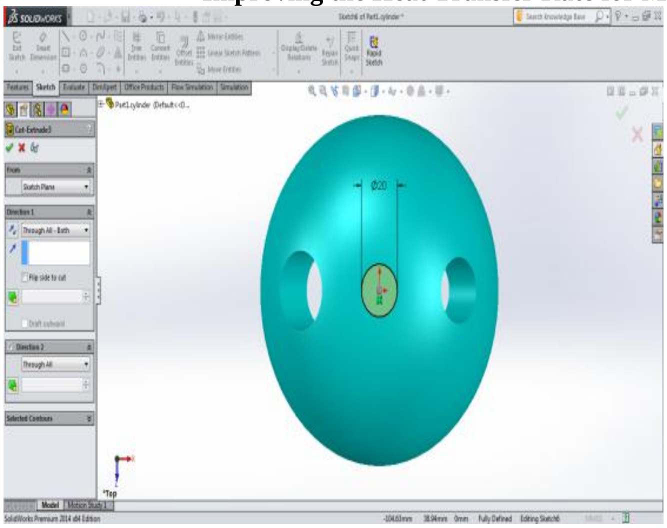


Fig.14.

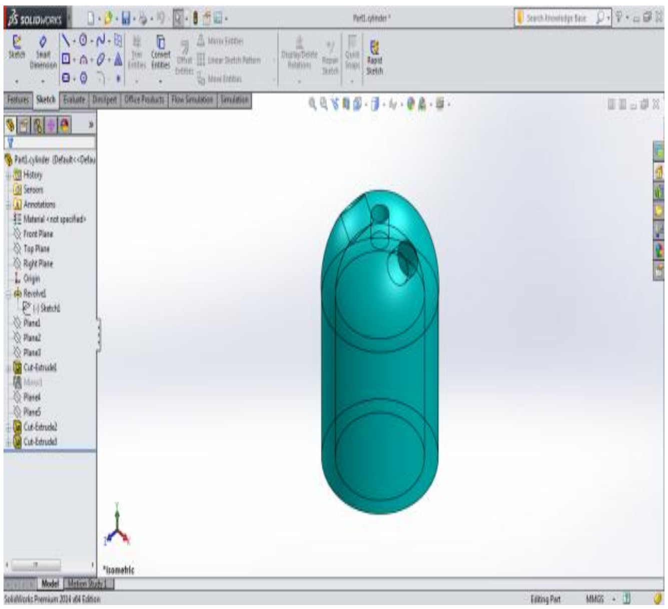


Fig.15.

C. Modeling of Piston Rings

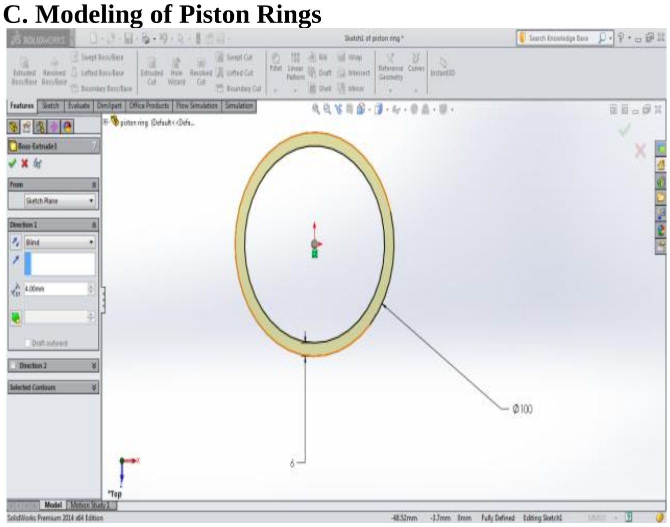


Fig.16.

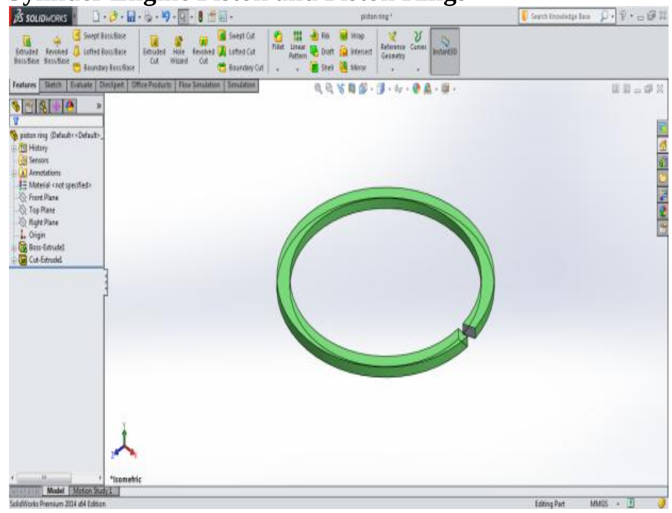


Fig.17.

IV. ASSEMBLY OF FLAT HEAD PISTON AND CYLINDER

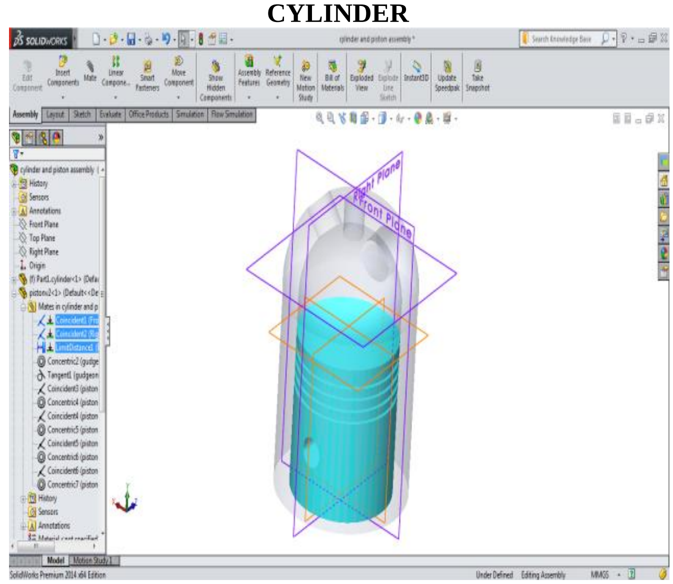


Fig.18.

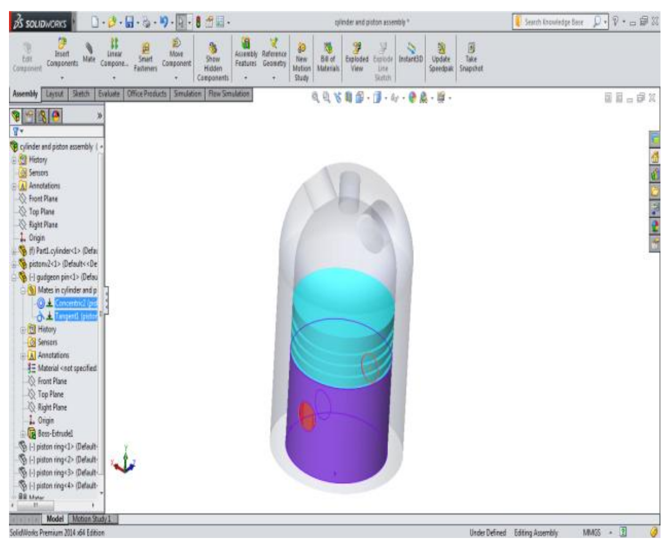


Fig.19.

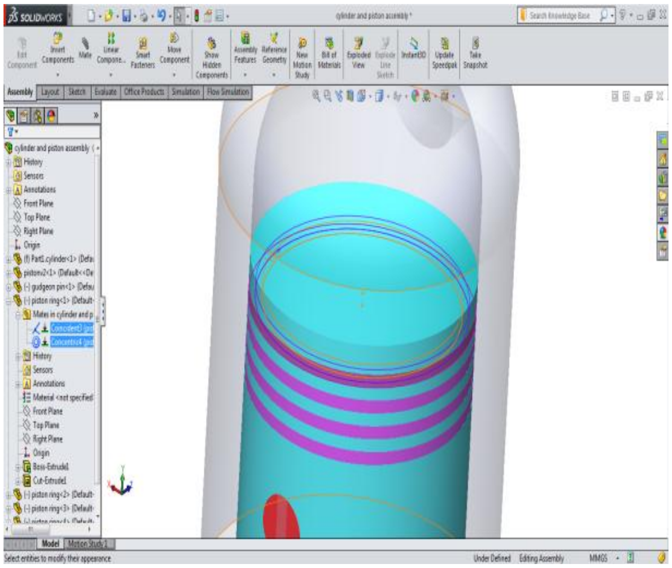


Fig.20.

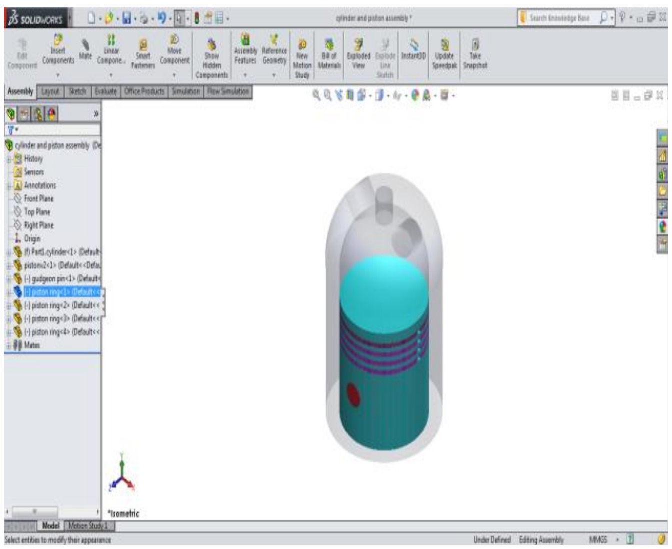


Fig.21.

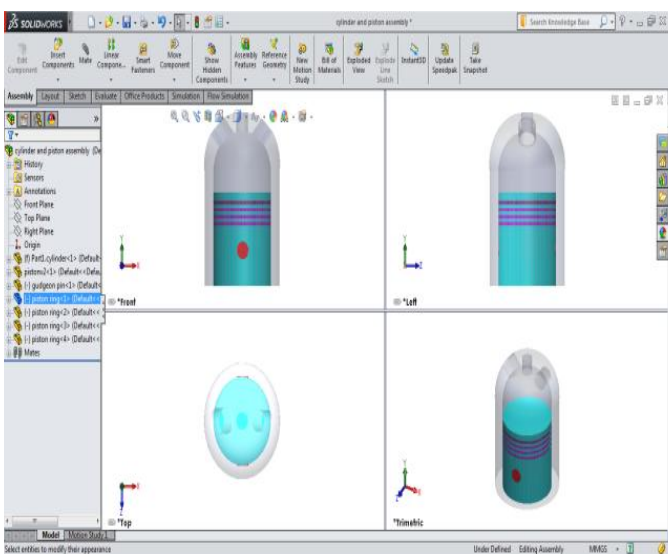


Fig.22.

A. Modeling of Convex Head Piston

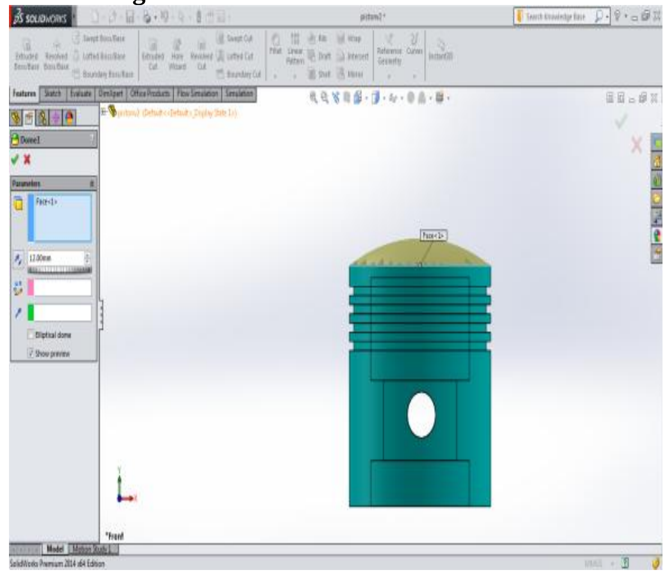


Fig.23.

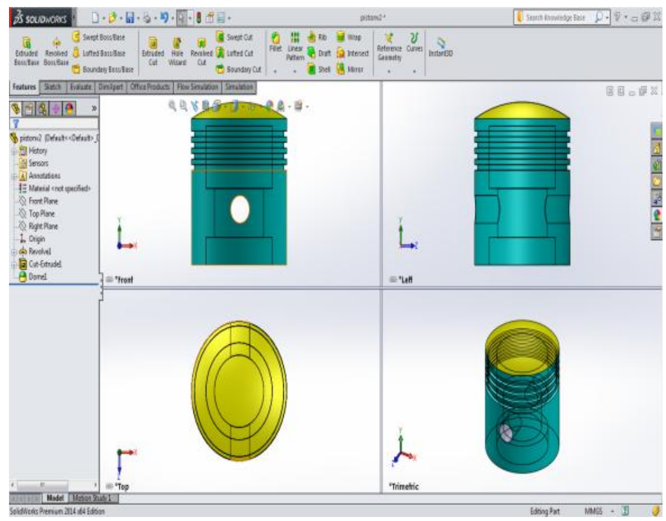


Fig.24.

V. ASSEMBLY OF CONVEX HEAD PISTON AND CYLINDER

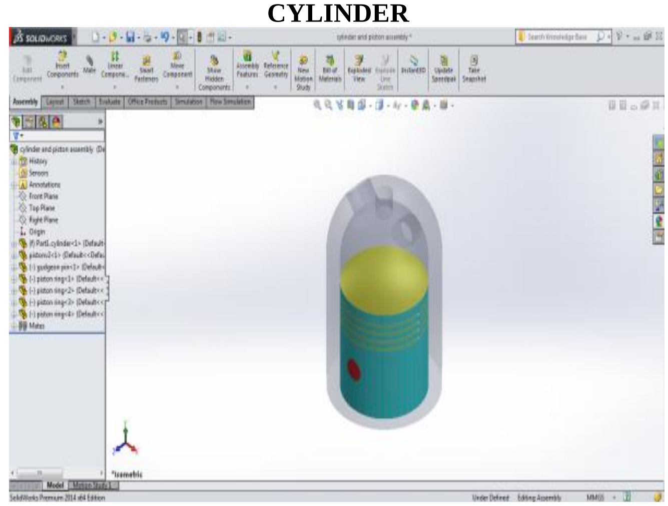


Fig.25.

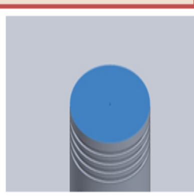
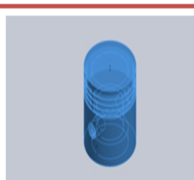
VI. THERMAL ANALYSIS OF FLAT HEAD PISTON BY APPLYING 6061-T6 ALLOY

Now the thermal analysis of flat head piston is performed by applying 6061-T6 alloy and applying a temperature of 800k on the flat face of piston and convection coefficient of 22w/m2k and bulk ambient temperature of 300k.

Material Properties:

Model Reference	Properties
	Name: **6061-T6 (SS)** Model type: **Linear Elastic Isotropic** Default failure criterion: **Max von Mises Stress** Thermal conductivity: **166.9 W/(m.K)** Specific heat: **896 J/(kg.K)** Mass density: **2700 kg/m^3**

Thermal Loads:

Load name	Load Image	Load Details
Temperature-1		**Entities:** **1 face(s)** **Temperature:** **800 Kelvin**
Convection-1		**Entities:** **27 face(s)** **Convection Coefficient:** **22 W/(m^2.K)** **Time variation:** **Off** **Temperature variation:** **Off** **Bulk Ambient Temperature:** **300 Kelvin** **Time variation:** **Off**

Name	Type	Min	Max
Thermal1	TEMP: Temperature	739.704 Kelvin Node: 400	800 Kelvin Node: 1036

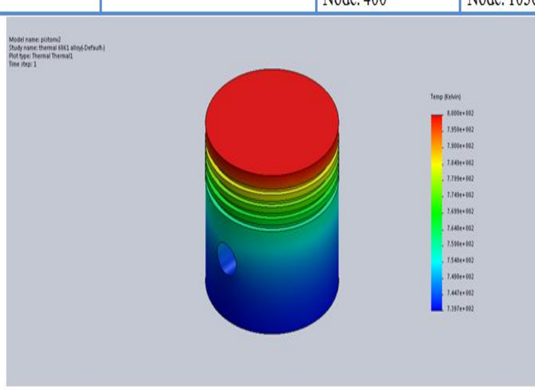


Fig.26.Temperature distribution.

Name	Type	Min	Max
Thermal2	HFLUXY: Y Heat Flux	-291639 W/m^2 Node: 8246	30372.2 W/m^2 Node: 8042

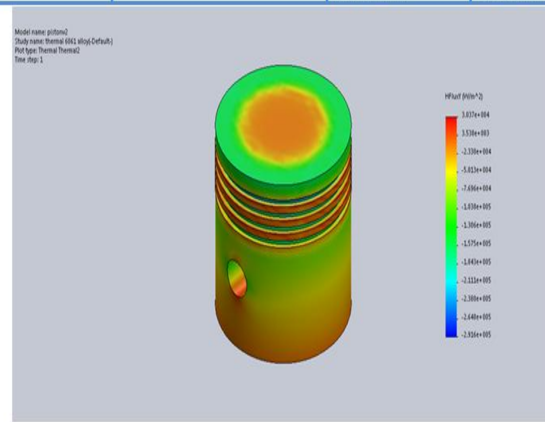


Fig.27.Heat flux.

VII. THERMAL ANALYSIS OF FLAT HEAD PISTON BY APPLYING CAST IRON

Name	Type	Min	Max
Thermal1	TEMP: Temperature	624.671 Kelvin Node: 400	800 Kelvin Node: 1036

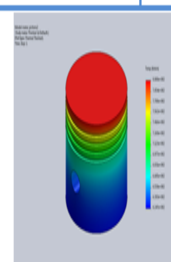


Fig.28.

Name	Type	Min	Max
Thermal2	HFLUXY: Y Heat Flux	-237180 W/m^2 Node: 8246	25686 W/m^2 Node: 8042

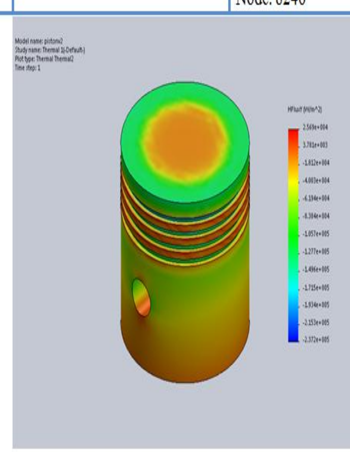
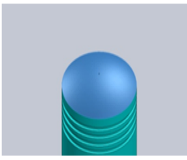


Fig.29.

VIII. THERMAL ANALYSIS OF CONVEX HEAD PISTON BY APPLYING 6061-T6 ALLOY LMATERIAL

Now the thermal analysis of convex head piston is performed by applying 6061-T6 alloy and applying a temperature of 800k on the flat face of piston and convection coefficient of 22w/m2k and bulk ambient temperature of 300k.

Thermal Loads:

Load name	Load Image	Load Details
Temperature-1		Entities: 1 face(s) Temperature: 800 Kelvin
Convection-1		Entities: 27 face(s) Convection Coefficient: 22 W/(m^2.K) Time variation: Off Temperature variation: Off Bulk Ambient Temperature: 300 Kelvin Time variation: Off

Study Results:

Name	Type	Min	Max
Thermal1	TEMP: Temperature	737.789 Kelvin Node: 488	800 Kelvin Node: 950

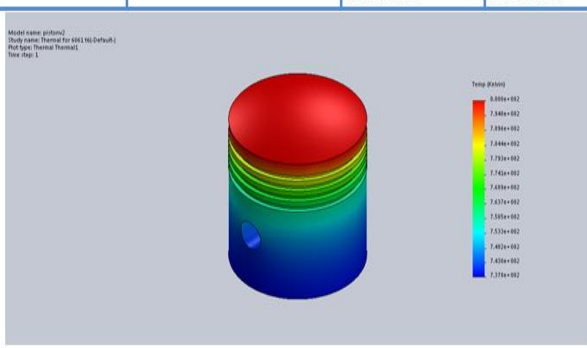


Fig.30.

Name	Type	Min	Max
Thermal2	HFLUXY: Y Heat Flux	-294057 W/m^2 Node: 7799	32080.6 W/m^2 Node: 10225

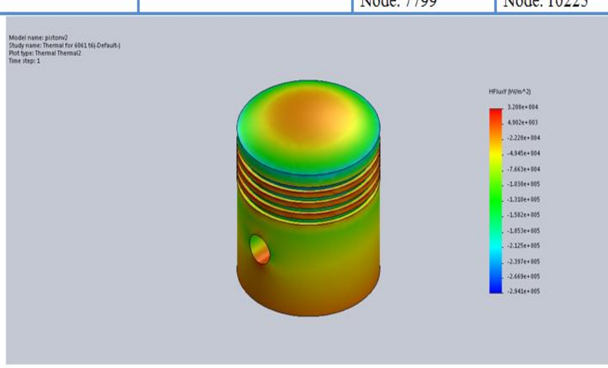
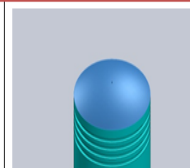


Fig.31.

IX. THERMAL ANALYSIS OF CONVEX HEAD PISTON BY APPLYING CAST IRON MATERIAL

Performing same thermal analysis as above the results obtained are as follows.

Thermal Loads:

Load name	Load Image	Load Details
Temperature-1		Entities: 1 face(s) Temperature: 800 Kelvin
Convection-1		Entities: 27 face(s) Convection Coefficient: 22 W/(m^2.K) Time variation: Off Temperature variation: Off Bulk Ambient Temperature: 300 Kelvin Time variation: Off

Study Results:

Name	Type	Min	Max
Thermal1	TEMP: Temperature	620.359 Kelvin Node: 488	800 Kelvin Node: 950

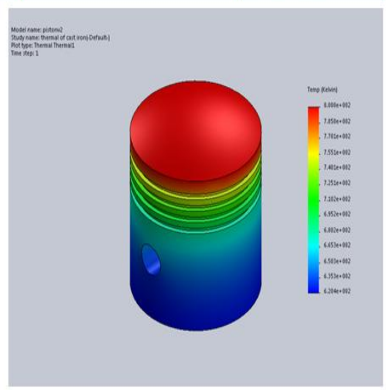


Fig.32.

Name	Type	Min	Max
Thermal2	HFLUXY: Y Heat Flux	-236952 W/m^2 Node: 7799	26425 W/m^2 Node: 10225

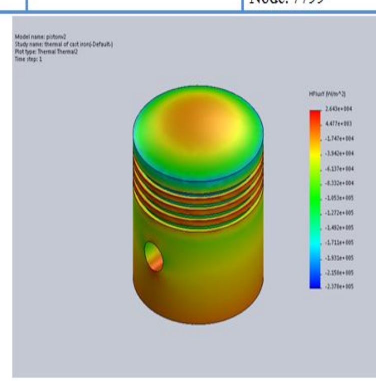


Fig.33.

X. THERMAL ANALYSIS OF PISTON RING BY USING CAST IRON

Thermal Loads:

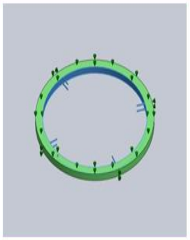
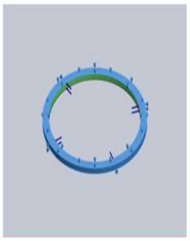
Load name	Load Image	Load Details
Temperature -1		Entities: 1 face(s) Temperature: 800 Kelvin
Convection-1		Entities: 2 face(s) Convection Coefficient: 22 W/(m^2.K) Time variation: Off Temperature variation: Off Bulk Ambient Temperature: 300 Kelvin Time variation: Off

Fig.34. Meshed model.

Study Results:

Name	Type	Min	Max
Thermal1	TEMP: Temperature	796.982 Kelvin Node: 466	800 Kelvin Node: 1

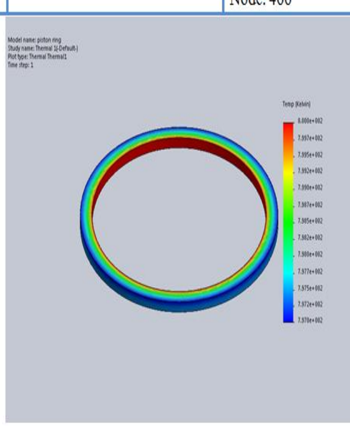


Fig.35.

Name	Type	Min	Max
Thermal2	HFLUXN: Resultant Heat Flux	10893.6 W/m^2 Node: 1069	45172.1 W/m^2 Node: 13747

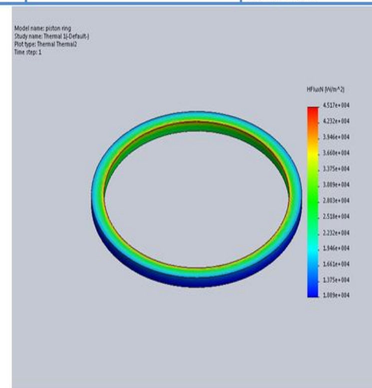


Fig.36.

A. Thermal Analysis of Piston Ring by Using Alloy Steel

Study Results:

Name	Type	Min	Max
Thermal1	TEMP: Temperature	797.282 Kelvin Node: 466	800 Kelvin Node: 1

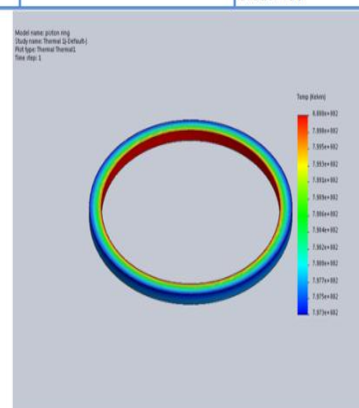


Fig.37.

Name	Type	Min	Max
Thermal2	HFLUXN: Resultant Heat Flux	10899.2 W/m^2 Node: 1069	45187.7 W/m^2 Node: 13747

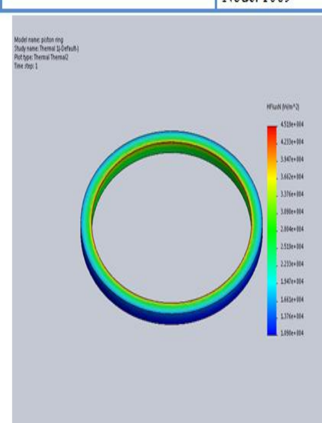


Fig.38.

XI. RESULTS AND DISCUSSIONS

The alloy from which a piston is made not only determines its strength and wears characteristics, but also its thermal expansion characteristics. Hotter engines require more stable alloys to maintain close tolerances without scuffing. The main factors influencing on piston are:

- Strength and rigidity of head thickness
- Heat distribution of piston material

If the calculated stresses are too great, it is necessary to change piston design. Such changes may be:

- Increasing the piston head thickness
- Changing the piston crown shape
- Changing the material
- Length of piston
- Piston rings

A. Comparision of Results

TABLE II: Final Results Of Piston for 6061-T6 ALUMINIUM ALLOY

Shape of crown	Flat head	Convex head
Temperature (kelvin) Maximum Minimum	 800 739.7	 800 737.7
Total Heat Flux(w/m^2)	30372	32080.6

TABLE III: Final Results of Piston for Cast Iron

Shape of crown	Flat head	Convex head
Temperature (kelvin) Maximum Minimum	 800 624.6	 800 620.3
Total Heat Flux(w/m^2)	25686	26425

TABLE IV: Final Results Of Piston Ring

Shape of crown	Alloy steel	Cast iron
Temperature (kelvin) Maximum Minimum	 800 797.2	 800 796.9
Total Heat Flux(w/m^2)	45187	45172

By comparing the above results of flat head and convex head piston the heat flux is more for 6061-T6 aluminum alloy than the cast iron material. Therefore 6061-T6 material is the best suitable material for piston. By comparing the above results of piston ring the heat flux is more for Alloy steel than the cast iron material. Therefore 6061-T6 material is the best suitable material for piston ring.

XII. CONCLUSION

- In our project we have designed a piston used in two wheeler and modeled in 3D modeling software SOLIDWORKS and then we analyze the piston with different materials like 6061-T6 alloy and Alloy steel with help of fem package solidworks simulation .In this Project we describes the stress distribution of the seizure on piston Two stroke engine by using FEA.
- By comparing results of both the materials 6061-T6 alloy and Alloy steel , the obtained results such as thermal heat transfer are within the safe zone of standard for flat head and convex head piston.
- So, far the taken bore sizes the obtained results are within the standard and design is safe. Finally the convex shape crown piston is having better design because of the stresses are low compared to aluminium alloy and heat flux generated is also low.
- By changing piston materials with different compositions we can design the piston according to their strength and heat fluxes are can also be done by using FEM.
- We Conclude & analyze the thermal stress distribution of piston at the real engine condition during combustion process.
- By comparing the above results of flat head and convex head piston the heat flux is more for 6061-T6 aluminum alloy than the cast iron material. Therefore 6061-T6 material is the best suitable material for piston.
- By comparing the above results of piston ring the heat flux is more for Alloy steel than the cast iron material. Therefore 6061-T6 material is the best suitable material for piston ring.

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