Design and Analysis of Piston in Internal Combustion Engine Using ANSYS

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Abstract – In this paper, the wok is carried out to measure the stress and temperature distribution on the top surface of the piston. In I.C. Engine piston is most complex and important part therefore for smooth running of vehicle piston should be in proper working condition. Pistons fail mainly due to mechanical stresses and thermal stresses. Analysis of piston is done with boundary conditions, which includes pressure on piston head during working condition and uneven temperature distribution from piston head to skirt. The analysis predicts that due to temperature whether the top surface of the piston may be damaged or broken during the operating conditions, because damaged or broken parts are so expensive to replace and generally are not easily available. The CAD model is created using CREO3.0 TOOL. CAD model is imported into the Hyper Mesh for geometry cleaning and meshing purpose. The FEA is performed by using RADIOSS. The topology optimization of the model is done using OptiStruct module of Hyper Works software.

Index Terms – I.C Engine, Piston Skirt, Creo 3.0, FEA.

1. INTRODUCTION

Engine pistons are one of the most complex components among all automotive and other industry field components. The engine can be called the heart of a vehicle and the piston may be considered the most important part of an engine [1]. There are lots of research works proposing, for engine pistons, new geometries, materials and manufacturing techniques, and this evolution has undergone with a continuous improvement over the last decades and required thorough examination of the smallest details. Notwithstanding all these studies, there are a huge number of damaged pistons [3]. Damage mechanisms have different origins and are mainly wearing, temperature, and fatigue related. The fatigue related piston damages play a dominant role mainly due to thermal and mechanical fatigue, either at room or at high temperature. This paper describes the displacement and stress distribution on piston of internal combustion engine by using FEA. The FEA is performed by CAD and CAE software [2]. The main objectives are to investigate and analyze the thermal stress distribution of piston at the real engine condition during combustion process. The paper describes the FEA technique to predict the higher stress and critical region on the component. The optimization is carried out to reduce the stress concentration on the piston [4].

Simulate to Innovate Hyper Works. Optimization of piston is carried out by topology criteria from the result designable and non-designable area is investigated. Applying different boundary conditions displacement and stress distribution is calculated [5]. Software used are CREO3.0 for geometry creation, Hyper Mesh for meshing, RADIOSS for analysis, OptiStruct for optimization and Hyper View for post processing.

1.1 Process Methodology

3D model of piston is imported into the Hyper Mesh for preprocessing. Preprocessing of model consist of meshing, selection of material properties, creation of load collectors and apply boundary conditions on model [7]. Then model is exported to RADIOSS for solving problem. Results of solution plotted in Hyper View which is well known postprocessor of Hyper Works software. For the optimization purpose topology optimization criteria is selected. According to topology criteria the designable and non designable space is generated and subsequently element density contour plot is generate in Hyper View [6].

Methodology

- Drawback of Existing model
- Rectifying the drawback
- Replace the Material of piston
- Analysis of piston
  - Temperature
  - Pressure
  - Total heat flux

2. INTERNAL COMBUSTION ENGINES

An Engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this thermal energy to produce mechanical work. Engines normally convert thermal energy into mechanical work and therefore they are called heat engines [8].

2.1 Heat engines can be broadly classified:

i) External combustion engines

ii) Internal combustion engines

2.2. External combustion engines:

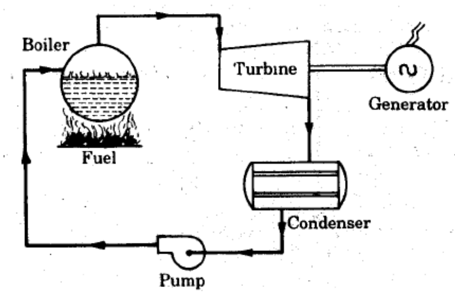


Figure 1 : External Combustion Engine

For example, in steam engine or steam turbine the heat generated due to combustion of fuel and it is employed to generate high pressure steam, which is used as working fluid in a reciprocating engine or turbine. See Figure 1.

2.3 Internal combustion engine:

Internal combustion engines can be classified as Continuous IC engines and Intermittent IC engines. In continuous IC engines products of combustion of the fuel enters into the prime mover as the working fluid. For example: In Open cycle gas turbine plant. Products of combustion from the combustion chamber enter through the turbine to generate the power continuously. See Figure 2. In this case, same working fluid cannot be used again in the cycle.

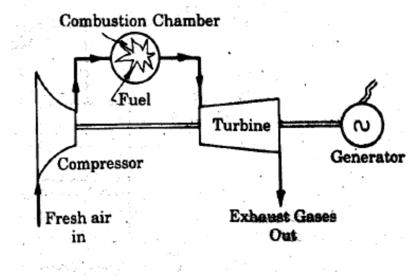


Figure 2: Continuous IC Engines

In Intermittent internal combustion engine combustion of fuel takes place inside the engine cylinder. Power is generated intermittently (only during power stroke) and flywheel is used to provide uniform output torque. The reciprocating engine mechanism consists of piston which moves in a cylinder and forms a movable gas tight seal. By means of a connecting rod and a crank shaft arrangement, the reciprocating motion of piston is converted into a rotary motion of the crankshaft [9].

They are most popular because of their use as main prime mover in commercial vehicles. The shown in figure 3 is layout of IC engine,

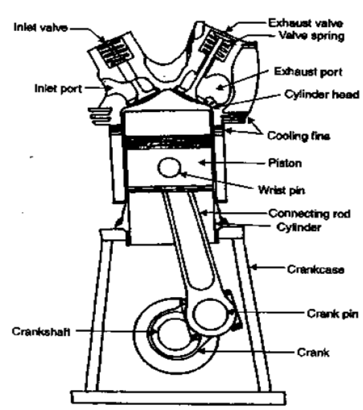


Figure 3: IC Engine

2.4 Advantages of internal combustion engines:

- Greater mechanical simplicity.
- Higher power output per unit weight because of absence of auxiliary units like boiler, condenser and feed pump
- Low initial cost
- Higher brake thermal efficiency as only a small fraction of heat energy of the fuel is dissipated to cooling system
- These units are compact and requires less space

- Easy starting from cold conditions

2.5 Disadvantages of internal combustion engines:

- I C engines cannot use solid fuels which are cheaper. Only liquid or gaseous fuel of given specification can be efficiently used. These fuels are relatively more expensive.
- 2. I C engines have reciprocating parts and hence balancing of them is problem and they are also susceptible to mechanical vibrations.

3. CLASSIFICATION OF INTERNAL COMBUSTION ENGINES

There are different types of IC engines that can be classified on the following basis.

3.1. According to thermodynamic cycle:

i) Otto cycle engine or Constant volume heat supplied cycle.

ii) Diesel cycle engine or Constant pressure heat supplied cycle

iii) Dual-combustion cycle engine

3.2. According to the fuel used:

i) Petrol engine

ii) Diesel engine,

iii) Gas engine

3.3. According to the cycle of operation:

i) Two stroke cycle engine

ii) Four stroke cycle engine

3.4. According to the method of ignition:

i) Spark ignition (S.I) engine

ii) Compression ignition (C I) engine.

3.5. According to the number of cylinders:

i) Single cylinder engine

ii) Multi cylinder engine

3.6. According to the arrangement of cylinder.

i) Horizontal engine

ii) Vertical engine

iii) V-engine,

v) In-line engine

vi) Radial engine, etc.

3.7. According to the method of cooling the cylinder:

i) Air cooled engine

ii) Water cooled engine

3.8. According to their applications:

i) Stationary engine

ii) Automobile engine,

iii) Aero engine

iv) Locomotive engine,

v) Marine engine, etc.

4. INTERNAL COMBUSTION ENGINE PARTS AND THEIR FUNCTION

4.1. Cylinder:-

It is a container fitted with piston, where the fuel is burnt and power is produced [10].

4.2. Cylinder Head/Cylinder Cover:-

One end of the cylinder is closed by means of cylinder head. This consists of inlet valve for admitting air fuel mixture and exhaust valve for removing the products of combustion.

4.3. Piston:-

Piston is used to reciprocate inside the cylinder. It transmits the energy to crankshaft through connecting rod.

4.4. Piston Rings:-

These are used to maintain a pressure tight seal between the piston and cylinder walls and also it transfer the heat from the piston head to cylinder walls.

4.5. Connecting Rod:-

One end of the connecting rod is connected to piston through piston pin while the other is connected to crank through crank pin. It transmits the reciprocating motion of piston to rotary crank.

4.6. Crank:

It is a lever between connecting rod and crank shaft.

4.7. Crank Shaft:-

The function of crank shaft is to transform reciprocating motion in to a rotary motion.

4.8. Fly wheel:-

Fly wheel is a rotating mass used as an energy storing device.

4.9. Crank Case:-

It supports and covers the cylinder and the crank shaft. It is used to store the lubricating oil.

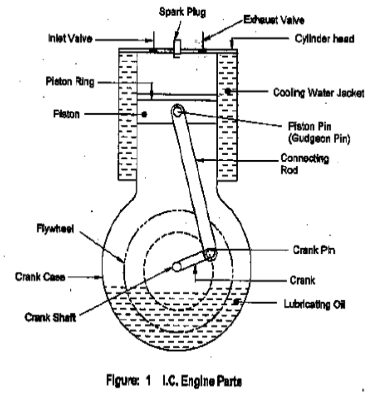


Figure 4: Crank Case

5. IC ENGINE – TERMINOLOGY

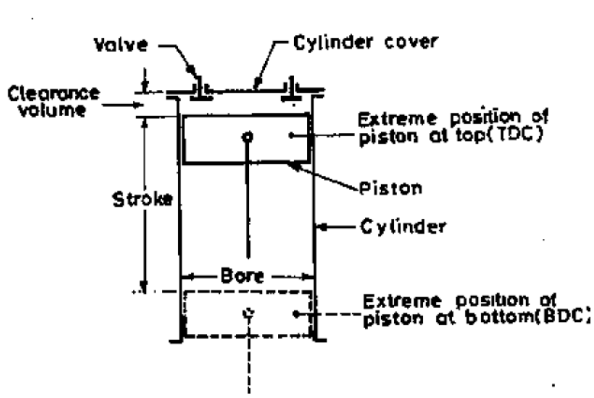


Figure 5: IC Engine – Terminology

5.1 Bore:

The inside diameter of the cylinder is called the bore.

5.2 Stroke:

The linear distance along the cylinder axis between the two limiting positions of the piston is called stroke.

5.3 Top Dead Centre (T.D.C):

The top most position of the piston towards cover end side of the cylinder" is called top dead centre. In case of horizontal engine, it is called as inner dead centre.

5.4 Bottom Dead Centre (B.D.C):

The lowest position of the piston towards the crank end side of the cylinder is called bottom dead centre. In case of horizontal engine, it is called outer dead centre (O.D.C).

5.5 Clearance Volume:

The volume contained in the cylinder above the top of the piston, when the piston is at the top dead centre is called clearance volume.

5.6 Compression ratio:

It is the ratio of total cylinder volume to clearance volume. Four-Stroke Petrol Engine OR Four stroke Spark Ignition Engine (S.I. engine).

6. FOUR STROKE COMPRESSION IGNITION ENGINE

The four stroke cycle diesel engine operates on diesel cycle or constant pressure cycle [11]. Since ignition in these engines is due to the temperature of the compressed air, they are also called compression ignition engines. The construction and working of the four stroke diesel engine is shown in fig. 4, and fig. 5 shows a theoretical diesel cycle. The four strokes are as follows:

Suction

i) Suction stroke
ii) Compression stroke
iii) Working or power or expansion stroke
iv)Exhaust stroke

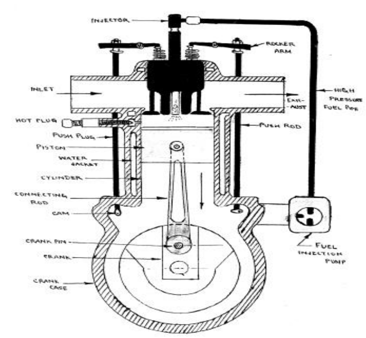


Figure 6: Four Stroke Diesel Engine

6.1 Suction Stroke:

During suction stroke, the piston is moved from the top dead centre to the bottom dead centre by the crankshaft. The crankshaft is revolved either by the momentum of the flywheel or by the power generated by the electric starting motor. The inlet valve remains open and the exhaust valve is closed during this stroke [11]. The air is sucked into the cylinder due to the downward movement of the piston. The line AB on the P- V diagram represents this operation.

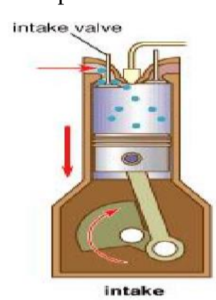


Figure 7: Suction Stroke

6.2 Compression Stroke:

The air drawn at the atmospheric pressure during suction stroke is compressed to high pressure and temperature as piston moves from the bottom dead centre to top dead centre. This operation is represented by the curve BC on the P- V diagram. Just before the end of this stroke, a metered quantity of fuel is injected into the hot compressed air in the form of fine sprays by means of fuel injector. The fuel starts burning at constant pressure shown by the line CD. At point D,fuel supply is cut off, Both the inlet and exhaust valve remain closed during this stroke [12].

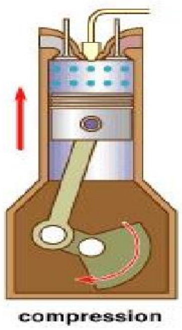


Figure 8: Compression Stroke

6.3 Working Stroke:

The expansion of gases due to the heat of combustion exerts a pressure on the piston. Under this impulse, the piston moves from top dead centre to the bottom dead centre and thus work is obtained in this stroke. Both the inlet and exhaust valves remain closed during this stroke. The expansion of the gas is shown by the curve DE [13].

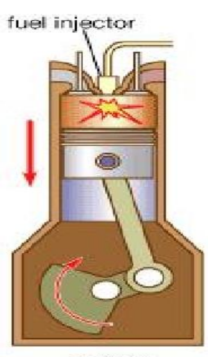


Figure 9: Power stroke

6.4 Exhaust Stroke:

During this stroke, the inlet valve remains closed and the exhaust valve opens. The greater part of the burnt gases escapes because of their own expansion. The vertical line EB represents the drop in pressure at constant volume. The piston moves from bottom dead centre to top dead centre and pushes the remaining gases to the atmosphere. When the piston reaches the top dead centre the exhaust valve closes and the cycle is completed [14]. The line BA on the F- V diagram represents this stroke.

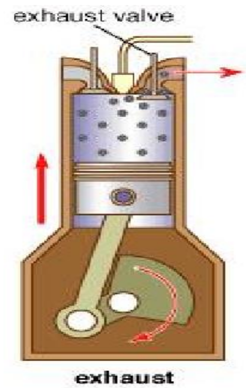


Figure 10: Exhaust stroke

7. FOUR-STROKE PETROL ENGINE (S.I. ENGINE)

The four-stroke cycle petrol engines operate on Otto (constant volume) cycle shown in Figure 3.0. Since ignition in these engines is due to a spark, they are also called spark ignition engines. The four different strokes are:

i) Suction stroke

ii) Compression stroke

iii) Working or power or expansion stroke

iv) Exhaust stroke.

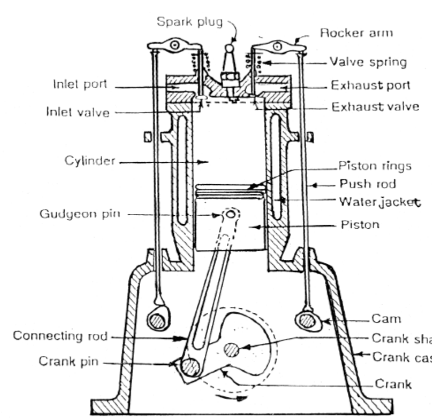


Figure 11: Four-Stroke Petrol Engine

The construction and working of a four-stroke petrol engine is shown figure 11.

7.1. Suction Stroke:

During suction stroke, the piston is moved from the top dead centre to the bottom dead centre by the crank shaft. The crank shaft is revolved either by the momentum of the flywheel or by the electric starting motor. The inlet valve remains open and the exhaust valve is closed during this stroke. The proportionate air-petrol mixture is sucked into the cylinder due to the downward movement of the piston. This operation is represented by the line AB on the P-V diagram [15].

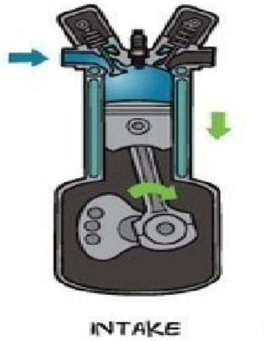


Figure 12: Suction Stroke

7.2. Compression Stroke:

During compression stroke, the piston moves from bottom dead centre to the top dead centre, thus compressing air petrol mixture. Due to compression, the pressure and temperature are increased and is shown by the line BC on the P- V diagram. Just before the end of this stroke the spark - plug initiates a spark, which ignites the mixture and combustion takes place at constant volume as shown by the line CD. Both the inlet and exhaust valves remain closed during this stroke [12].

Figure 13: Compression Stroke

7.3. Working Stroke:

The expansion of hot gases exerts a pressure on the piston. Due to this pressure, the piston moves from top dead centre to bottom dead centre and thus the work is obtained in this stroke. Both the inlet and exhaust valves remain closed during this stroke. The expansion of the gas is shown by the curve DE.

Figure 14: Power Stroke

7.4. Exhaust Stroke:

During this stroke, the inlet valve remains closed and the exhaust valve opens. The greater part of the burnt gases escapes because of their own expansion. The drop in pressure at constant volume is represented by the line EB. The piston moves from bottom dead centre to top dead centre and pushes the remaining gases to the atmosphere. When the piston reaches the top dead centre the exhaust valve closes and cycle is completed [14]. This stroke is represented by the line BA on the P- V diagram. The operations are repeated over and over again in running the engine. Thus a four stroke engine completes one working cycle, during this the crank rotate by two revolutions.

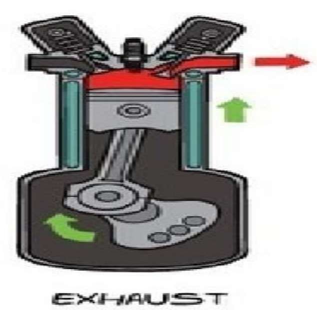


Figure 15: Exhaust Stroke

8. PISTON DESIGN

The piston is designed according to the procedure and specification which are given in machine design and data hand books. The dimensions are calculated in terms of SI Units. The pressure applied on piston head, temperatures of various areas of the piston, heat flow, stresses, strains, length, diameter of piston and hole, thicknesses, etc., parameters are taken into considerations [2,5,7].

8.1. Design Considerations for a Piston:

In designing a piston for an engine, the following points should be taken into consideration:

- It should have enormous strength to withstand the high pressure.
- It should have minimum weight to withstand the inertia forces.
- It should form effective oil sealing in the cylinder.
- It should provide sufficient bearing area to prevent undue wear.
- It should have high speed reciprocation without noise.
- It should be of sufficient rigid construction to withstand thermal and mechanical distortions.
- It should have sufficient support for the piston pin.

8.2. Procedure for Piston Design parameters:

- The procedure for piston designs consists of the following steps:
- Thickness of piston head (tH)
- Heat flows through the piston head (H)
- Radial thickness of the ring (t1)
- Axial thickness of the ring (t2)
- Width of the top land (b1)
- Width of other ring lands (b2)

8.2.1. Thickness of Piston Head (t_H):

The piston thickness of piston head calculated using the following Grashoff's formula,

$$t_H = D\sqrt{\frac{3}{16} * \frac{P}{\sigma_t}}\ (\text{in mm})$$

Where

P= maximum pressure in N/mm²

D= cylinder bore/outside diameter of the piston

σt = permissible tensile stress for the material of the piston.

8.2.2. Heat Flow through the Piston Head (H):

The heat flow through the piston head is calculated using the formula,

$\mathbf{H = 12.56 * tH * K * Tc - Te}$ (kj/sec)

Where,

K=thermal conductivity of material which is 174.15W/mk

Tc = temperature at centre of piston head in °C.

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

8.2.3. Radial Thickness of Ring (t1)

$$t_1 = D\sqrt{\frac{3 * P_w}{\sigma_t}}\ (\text{in mm})$$

Where,

D = cylinder bore in mm

Pw= pressure of fuel on cylinder wall in N/mm². Its value is limited from 0.025N/mm² to 0.042N/mm². For

Present material, σ_t is 90Mpa

8.2.4. Axial Thickness of Ring (t2)

The thickness of the rings may be taken as

t2 = 0.7t1 to t1

Let assume t2 =5mm

Minimum axial thickness (t2)

$$t_2 = \frac{D}{10 * n_r}$$

Where nr = number of rings

8.2.5. Width of the top land (b1)

The width of the top land varies from

$\mathbf{b1 = tH\ to\ 1.2 * tH}$

8.2.6. Width of other lands (b2)

Width of other ring lands varies from

$\mathbf{b2 = 0.75 * t2\ to\ t2}$

8.2.7. Maximum Thickness of Barrel (t3)

$\mathbf{t3 = 0.03 * D + b + 4.5mm}$

Where,

b = Radial depth of piston ring groove

b = t1+0.4

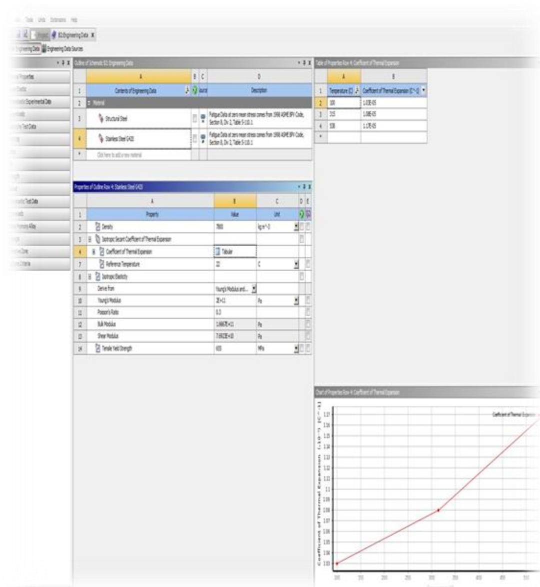


Figure 16: Engineering Details of SS Grade 420

8.3 Creo3.0-Geomentry

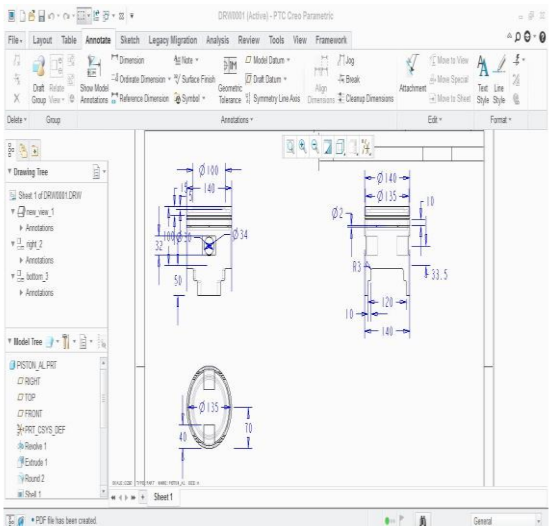


Figure 17: Diagram on sketch view

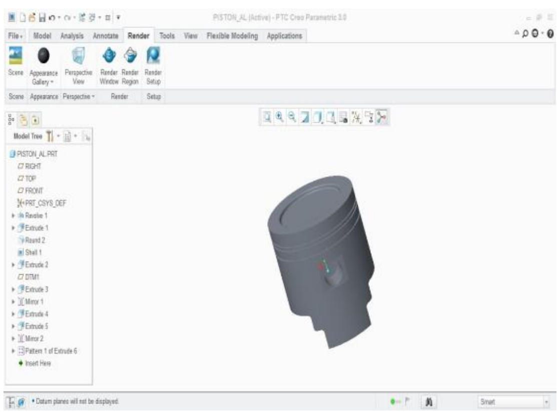


Figure 18: Diagram on sketch view

9. PISTON MODEL -ANSYS 15.0

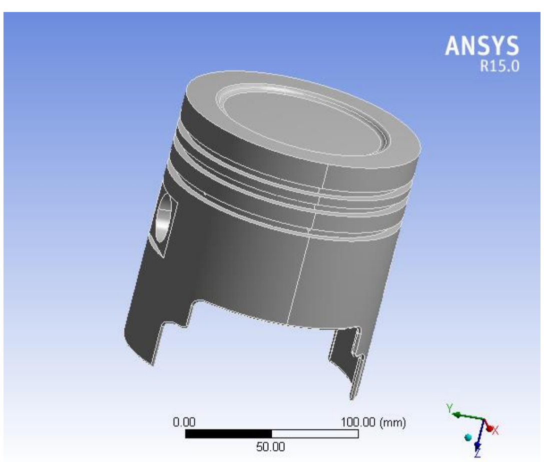


Figure 19: Modeling on piston skirt

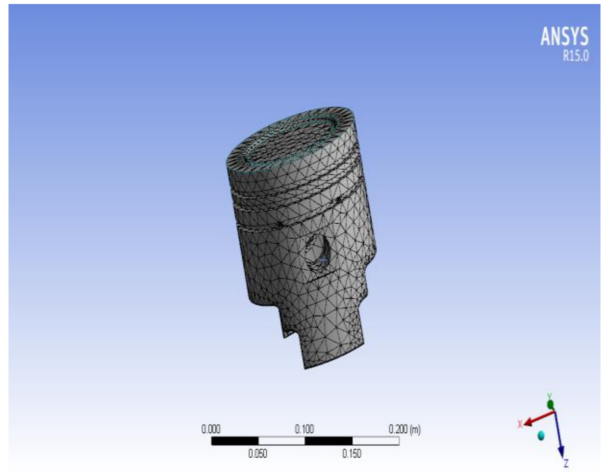
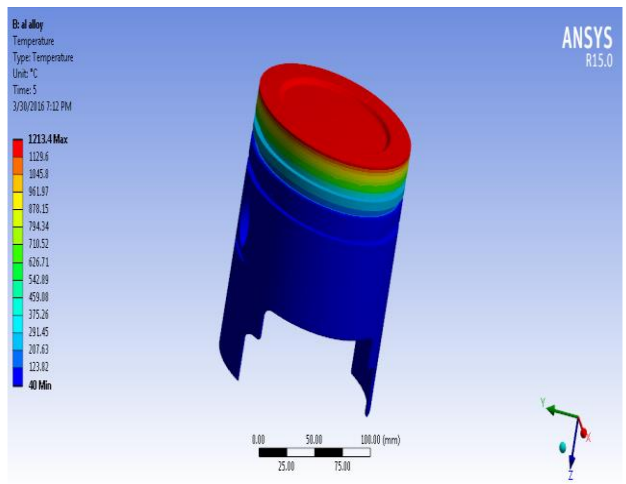


Figure 20: Mesh on hyper in piston skirt



Initial Temperature (45^0 C)

Temperature setting (1200^0 C)

Figure 21: Aluminum alloy

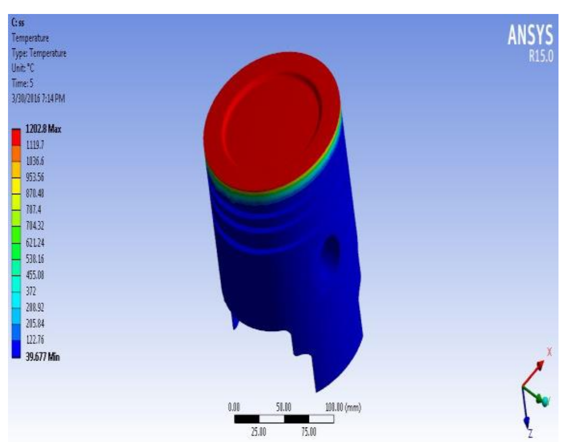


Figure 22: Stainless steel

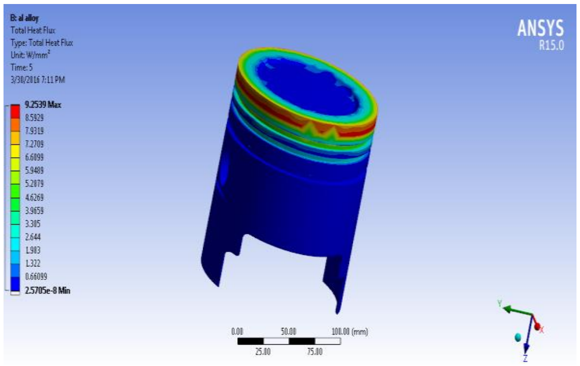


Figure 23: Total Heat Flux Aluminum alloy

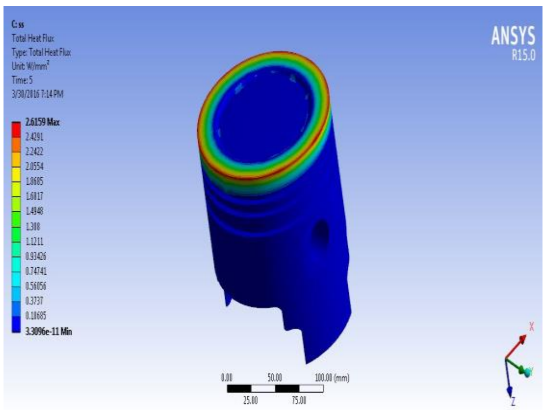


Figure 24: Total Heat Flux Stainless steel

10. CONCLUSION

To put it in a nut shell, this paper at continued engineering research on the IC engine has resulted in performance improvements through, lean burn combustion fuel injection, improved combustion area design and weight reduction.

Despite vehicle weight increased. The modified dimensioned combustion area results in reported to have reduced emission and fuel economy. The working of piston is analyzed by ansys workbench. The various properties affecting the piston performance is justified.

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