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# Modeling and Analysis of Piston Profile and Skirt on Combustion Engine by Using Rapid Prototyping and FEA Approach

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**ABSTRACT:** In this study an attempt has been made to understand the effect of Various Piston Profile on the Performance and emission Characteristics in a Combustion Engine Provides an Opportunity to reducing the noise Pollution, emission of harmful Particulates, Smokes, increasing the Mileage & Performance. Thus the Unwanted skirt is removed from the both side of the piston is formed Wear Resistance, Easily Reciprocating & Cooling engine. This describes the stress and temporal and stress distribution of the piston by using FEA. The main objectives are to investigate and analyse the thermal and stress distribution of piston at the real engine condition during combustion process. The paper describes the materialistic optimization with using finite element analysis technique to predict the higher stress and critical region on the component. The optimization is carried out to reduce the stress concentration on the upper end of the piston i.e. (piston head/crown and piston skirt and sleeve).

**KEYWORDS:** Piston, skirt, Piston Profile, dome, flat

## I. INTRODUCTION

Piston is considered to be one of the most important parts in a reciprocating Engine, reciprocating pumps, gas compressors and pneumatic cylinders, among other similar mechanisms in which it helps to convert the chemical energy obtained by the combustion of fuel into useful (work) mechanical power. The piston acts as a movable end of the combustion chamber Piston is essentially a cylindrical plug that moves up & down in the cylinder it is equipped with piston rings to provide a good seal between the cylinder walls, Pistons are designed with features which perform specific functions during engine operation. The piston head or crown receives the majority of the initial pressure and force caused by the combustion process. The piston pin area is exposed to a significant amount of force due to rapid directional changes. It is also subjected to thermal expansion caused by the transfer of heat from the head to the body of the piston. The piston pin area is subject to more thermal expansion than other areas of the piston

In this work our Objectives of the paper is:

- To develop structural analysis of the piston
- To develop structural modeling of piston
- To develop thermal analysis of the piston

## II. OBJECTIVES

The following objectives are formulated for this research work: Manufacturing of New modify piston with different dipping time Modify recess inserts. Performing different compression ratio model to enhance the strength of bonding region and to implement a suitable process. Machining for both the crown head with a Lathe machining tool in order to reduce cycle time studies using Taguchi's robust design. Evaluating the surface integrity of machined pistons by the way of measuring surface roughness and bond testing

### III. PROBLEM DESCRIPTION

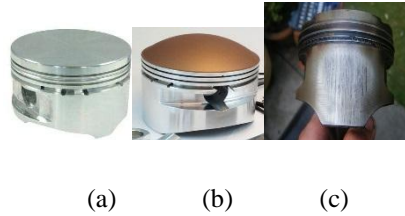
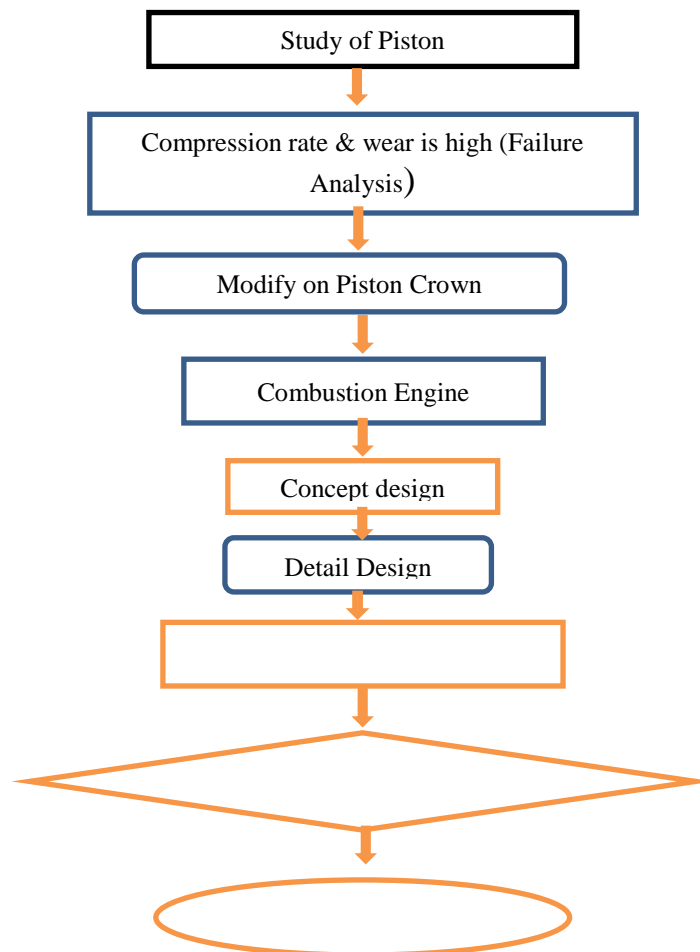


Fig1. (a)Existing model in a Flat Top piston, (b)A Dome piston with valve reliefs or valve pockets, (c)Piston Skirt Face  
 In existing flat and dome pistons Produced High Emission,Low Efficiency, Fuel Consumption is very high, Unburned Gas is to be formed. Piston skirt subjected more friction and high problems on liner.

In this Paper the stress distribution is evaluated on the four stroke engine piston by using FEA. The Finite element analysis is performed by using FEA software's. The couple field analysis is carried out to calculate stresses and deflection due to thermal loads and gas pressure. In this project **High emission (Unburned gas), Low efficiency**, wear is high is characterized are analysed

### IV. METHODOLOGY



Ideas of various types of piston profile using in internal combustion engine and calculate engine high Performance and during at that time of unwanted skirts are removed from the piston is easily reciprocated



**V. EXPERIMENTAL SETUP**

In this work Splendour bike four stroke piston is taken as a piston specifications.

**Table1: Product specification**

PISTON SPECIFICATION		
BORE : 52.4mm	PROFILE HEIGHT : 4.1mm	PIN LENTH : 2.5
STROKE : 57.8mm	PIN FIT TO : 0.9275	COMP RATIO : 9.1 : 1

**Table2: Technical specification**

Engine Type	Air-cooled, 4-stroke single cylinder OHC
Displacement	124.7 cc
Clutch	Multi plate Wet
Ground Clearance	150 mm
Max. Power	6.72 KW (9 BHP), @ 7000 rpm
Max. Torque	10.35 N-m @ 4000 rpm
Compression Ratio	9.1 : 1
Starting	Kick Start / Self Start
Ignition	Digital – CDI Ignition (AMI) Advanced Micro Processor Ignition system
Bore	52.4 mm
Stroke	57.8 mm
Max Speed	90 Kmph

**But change in stroke value = 61.3mm (Because change in Crown Head)**

**CONCEPT DESIGN**

Pistons are designed with features which perform specific functions during engine operation. The piston head or crown receives the majority of the initial pressure and force caused by the combustion process. The piston pin area is exposed to a significant amount of force due to rapid directional changes. It is also subjected to thermal expansion caused by the transfer of heat from the head to the body of the piston. The piston pin area is subject to more thermal expansion than other areas of the piston. This occurs from the thermal expansion properties of cast aluminum alloy and the mass in the piston pin area.

**WORKING:**

Required:

- ▶ Hero Honda (Splendor) piston Dimension (52.4 x 57.8 mm)
- ▶ Various types of Piston Profile

We will take over the Piston crown in various shapes to insert on C.I engine and find out the Design procedure, fabricate on Prototype and Engine Efficiency.

**VI. MODELING**

**MATERIAL PROPERTIES**

ALUMINIUM ALLOY IS SELECTED FOR THE DESIGN AND ANALYSIS OF THE PISTON HEAD. PROPERTIES OF THE ALUMINIUM ALLOY ARE MENTIONED BELOW.

DENSITY – 2770 (KG/M3)

POISSON RATIO – 0.33

YOUNG MODULUS – 7.1x10<sup>10</sup> (PA)



TENSILE ULTIMATE STRENGTH – 3.1x10<sup>8</sup> (PA)

TENSILE YIELD STRENGTH – 2.8x10<sup>8</sup> (PA)

**DESIGNING OF PISTON**

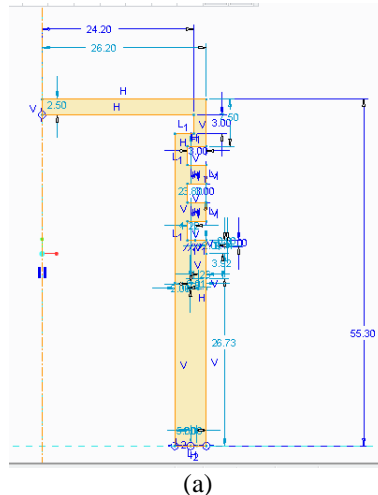


Fig 2. (a) Sketch view of piston.

**DESIGNING CALCULATIONS**

- Bore diameter = 52.4 mm (D),
- Stroke length = 61.30 mm (L),
- Gas pressure = 9 MPa,
- BMEP = 0.5 MPa,
- Fuel consumed = 0.15 (Kg) / Brake Power (W), Speed = 2200 rpm (N)

**Step 1: Brake power (BP) .in KW**

**BP = PLAN/ (1000×60) KW**  
 P = BMEP = 0.5 MPa  
 L = Stroke length m  
 A = Cross Section area m<sup>2</sup>  
 N = Speed rpm BP = 0.5×61.30×(52.4)<sup>2</sup> ×2200×π/ (1000×4×60) = 2.423 KW

**Step 2: Thickness of the piston head by considering the heat dissipation**

**t<sub>1</sub> = D<sup>2</sup>q / [1600×K× (T<sub>c</sub>-T<sub>e</sub>)] mm**  
 t<sub>1</sub> = thickness of piston head mm  
 q = Heat flow J/s-m<sup>2</sup>  
 k = Heat conductivity W- mm/ (m<sup>2</sup>-0<sup>0</sup>c)  
 T<sub>c</sub>-T<sub>e</sub> = difference between the Temperature at center and edges =348 K  
**q = K1×C×W×BP/(A)J/s-m<sup>2</sup>**  
 K1 = Constant which represents the amount of heat soaked by piston.  
 C = Calorific value of the fuel = 47000 KJ/Kg  
 W = fuel consumed = 0.15 Kg-hr/KW  
 A = π d<sup>2</sup>/ (4) = π× (0.0524)<sup>2</sup>/ (4) = 41.154x10<sup>-3</sup> m<sup>2</sup>  
 q = 0.05× (47000×1000) × (0.15/3600)×2.423/ (41.154x10<sup>-3</sup>) = 5764.861 J/s-m<sup>2</sup>  
 t<sub>1</sub> = (52.4)<sup>2</sup>×5764.861 / (1600×460×348) = 2.50 mm

**Step 3: The thickness of the piston head using Grashoff's formula**

**t<sub>1</sub> = 0.43 D√ (P/σ<sub>t</sub>) mm**  
 P = Gas pressure in MPa  
 σ<sub>t</sub> = Allowable tensile stress MPa = 280/2.25 = 124.4 MPa  
 D = 52.4mm = 0.43×52.4 √ (9/124.4) = 6.05 mm  
 Adopt the greater value of the t1 i.e. **t<sub>1</sub> = 6 mm**

**Step 4: Piston ring properties**

The radial thickness of the ring  $t_r = D \times \sqrt{(3Pr / \sigma_t)}$  mm

Pr is pressure exerted by fuel on cylinder wall in N/mm<sup>2</sup>. (Its value varies from 0.025 to 0.042N/mm<sup>2</sup>)

$$= 52.4 \times \sqrt{(3 \times 0.042 / 124)} = 1.67 \text{ mm}$$

- The distance from top to first groove  $t_g = 1t_1$  to  $1.2t_1 = 1.2 \times 2.50 = 3 \text{ mm}$
- Number of rings  $i = 100 / (10 \times h) = 100 / (10 \times 2.22) = 4 \text{ rings}$
- The maximum thickness of piston barrel  $t_3 = 0.03D + b + 4.5 \text{ mm}$
- b is the depth of the ring grooves in mm  $b = t_r + 0.4 \text{ mm} = 1.67 + 0.4 = 6.6 \text{ mm}$   $t_3 = 0.03 \times 52.4 + 2.07 + 4.5 = 6.6 \text{ mm}$
- Thickness of the wall towards the open end of the piston  $t_4 = 0.25 t_3$  to  $0.35 t_3 = 0.25 \times 6.6 = 1.65 \text{ mm}$  to  $0.35 \times 6.6 = 2.31 \text{ mm}$
- Diameter of the piston pin  $d = \pi \times D^2 \times P_{\max} / (4 \times L_1 \times P_b)$

Where  $L_1 = 1.5d$

$P_b$  is bearing pressure in MPa which is 15.7 for aluminum alloys.

$$= \pi \times (52.4)^2 \times 5 / [4 \times (1.5 \times 52.4) \times 15.7] \quad d = 8.737 \text{ mm}$$

**Step 5: Theoretical Stress Calculation**

$$\sigma_b = M_b / W_b \text{ MPa}$$

Where  $M_b$  is the bending moment and  $W_b$  is the moment of resistance to the bending

$$M_b = 1/3 \times P_{\max} \times r_i^3 \text{ MNm}$$

$P_{\max}$  = Maximum gas pressure in MPa. This value varies between 2-5 MPa in case of aluminium alloys. [3]  $r_i$  = crown inner radius m

$$W_b = 1/3 \times G \times r_i^2 \text{ m}^3$$

G = Thickness of piston crown m

$$r_i = [D/2 - (s + tr + dt)] \text{ m}$$

dt = Radial clearance between piston rings and channel m

s = Thickness of the sealing part m

$$= [0.0524/2 - (0.003 + 0.001 + 0.0032)] \quad r_i = 0.0413 \text{ m}$$

$$M_b = 1/3 \times 5 \times (0.01833)^2 = 1.0264 \times 10^{-5} \text{ MNm}$$

$$G = (0.08 \text{ to } 0.1) D \text{ m} = 0.085 \times 52.4 \quad G = 8.5 \text{ mm}$$

$$W_b = 1/3 \times 0.0085 \times 0.01833^2 = 9.519 \times 10^{-7} \text{ m}^3$$

$$\sigma_b = 1.17 \times 10^{-4} / 1.14 \times 10^{-6} = 12.78 \text{ MPa}$$

The theoretical stress value obtained is less than the allowable stress (12.78 < 124 MPa). Hence the design is safe.

$$\sigma_b < [\sigma_b]$$

**CALCULATE MOMENT OF INERTIA**

$$I = \pi d^4 / 64 \text{ mm}^4 = \pi \times (52.4)^4 / 64 = 370.079 \times 10^3 \text{ mm}^4$$

$$I = 370.079 \times 10^3 \text{ mm}^4$$

**Model of Piston:**

In this study, a full three dimensional solid model including piston and pin is introduced to the ANSYS software. Some unimportant factors, such as spot fillet, bevel edge, oil hole are neglected in the model to simplify the analysis. The three kinds of the stress fields, named as thermal stress field, mechanical stress field, thermal and mechanical coupling stress field, can be obtained by the imposition of the boundary conditions and loads on the FEA model. Model of the piston.

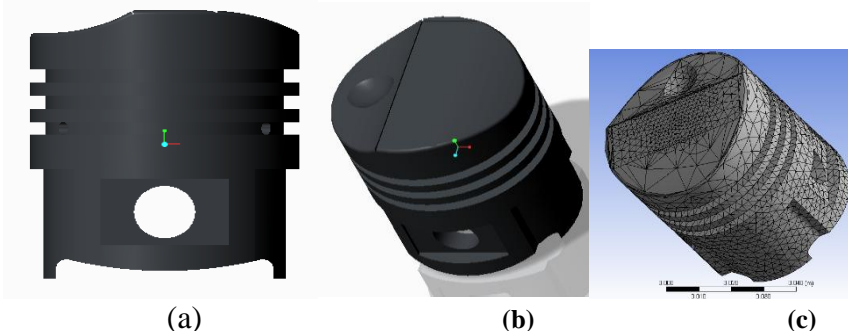


Fig2. Modeling of piston, (a) Front view, (b) isometric view, (c) Mesh generation

**Mesh generation**

Finite element mesh is generated using parabolic tetrahedral elements the vonmises stress is checked for convergence. An automatic method is used to generate the mesh in the present work. The meshing of piston is shown in fig 2(c).

**RAPID PROTOTYPE**

Rapid Prototyping is a group of techniques used to quickly fabricate a scale model of a physical part or assembly using three dimensional CAD. Construction of the part or assembly is usually done using “3D Printing” or “additive layer manufacturing” technology. This first methods for rapid prototyping became used to produce models and prototype parts. It is unfavourable of short – run economics.



Fig 3. Prototype of piston generated by rapid prototyping

**VII. RESULTS AND DISCUSSIONS**

**Structural Analysis of flat piston:**

For analysing we using ANSYS software

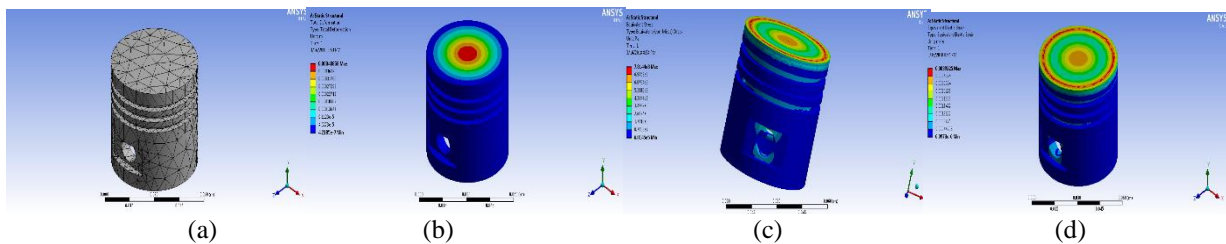


Fig 4. (a) Meshing stage, (b) Total deformation, (c)Equivalent (Von-mises) Stress,(d) Equivalent strain

**Thermal Analysis of Flat Piston**

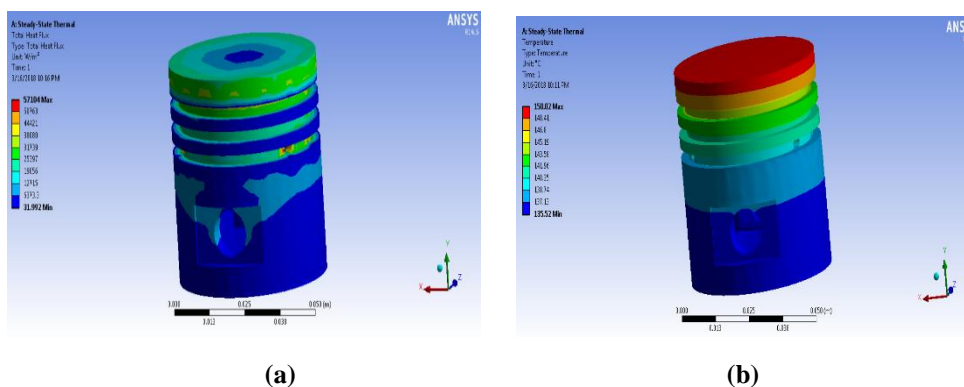


fig 5.(a) Total Heat Flux, (b) Temperature at 150 degree

**Structural and thermal analysis of dome Piston:**

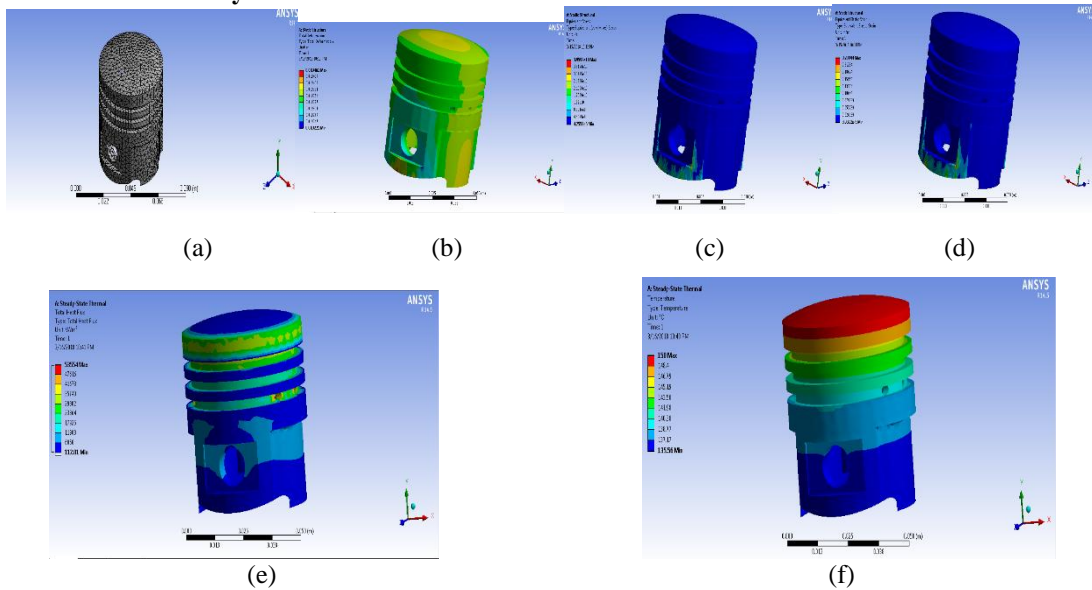


Fig 6. (a) meshing stage, (b) Total Deformation, (c) Equivalent (Von – Mises) Stress, (d) Equivalent Strain, (e) Total Heat Flux, (f) Temperature at 150 degree

**Structural Analysis of Modify Piston:**

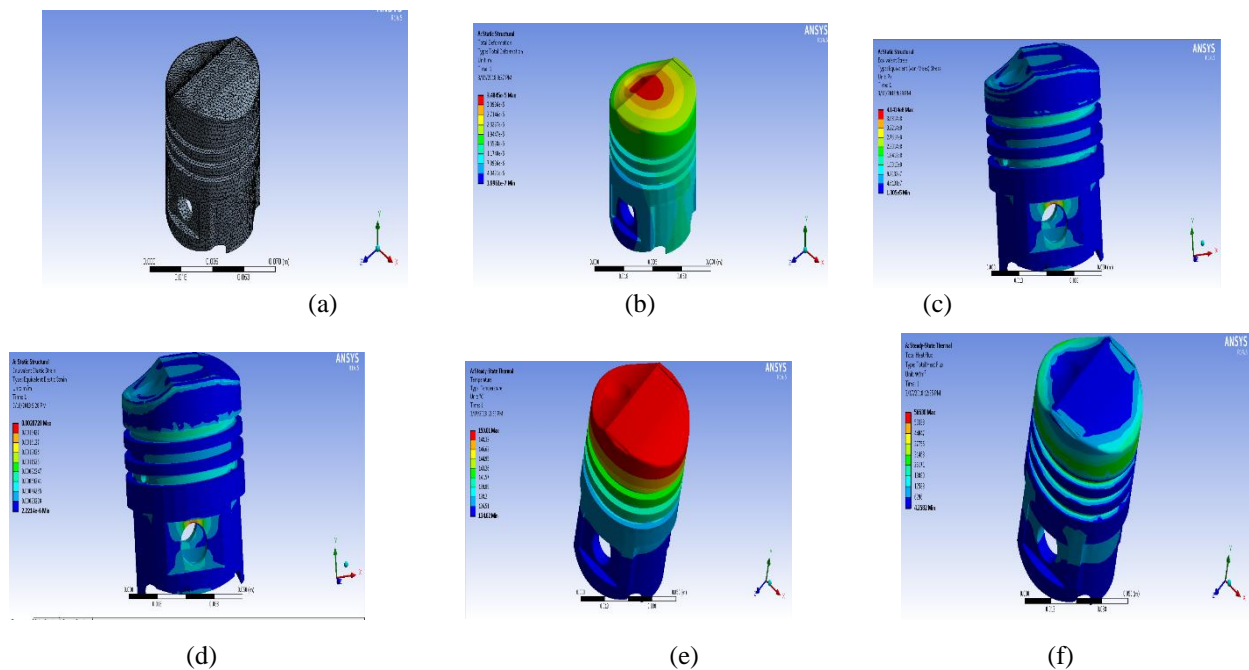


Fig 8. (a) Meshing Stage, (b) Total Deformation, (c) Equivalent (Von – Mises) Stress, (d) Equivalent Elastic Strain (e) Total Heat flux, (f) Temperature at 150 degree.

**DISCUSSION**

By referring to the modeling result, the generated Piston Crown is not Compression Rate. However, some modification has been done to make the piston Crown dimension Compression rate. The digitizing process is done only at the side of the piston Profile for the one side part and the Revolve method is used to create the Full circular side. Another important principle for the piston head is the constant thickness. This is important because the piston head (Combustion Chamber) receives high temperature and the continuous expand and shrinkage process will avoid the crack of the Piston Head and Skirt. Since the piston Crown used in this **Rapid Prototyping project** made from the Printing process,



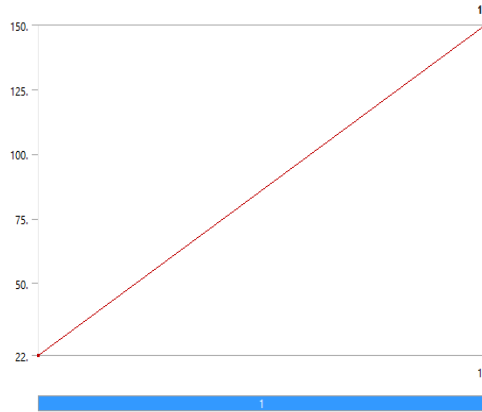
therefore the surface might not be smooth enough. The point clouds measurement on the rough surface will create unwanted lines. The digitizing measurements using the layout machine have the accuracy of ±0.1mm. The accuracy might unable to fulfil the require tolerance since the layout machine actually more suitable to get the point clouds for bigger object such as Engine.

Table 2: RESULTS OF ANALYSIS TABULATION

TYPE	Equivalent (von mises) stress (N/m <sup>2</sup> )		Equivalent Elastic Strain (mm)		Total Heat Flux (W/m <sup>2</sup> )		Temperature (Deg)	
	Max	Min	Max	Min	Max	Min	Max	Min
Flat	7.8144x10 <sup>8</sup>	6.81445x10 <sup>5</sup>	0.0039225	6.9973x10 <sup>-6</sup>	57104	31.992	150.02	135.52
Dome	3.9592x10 <sup>10</sup>	4.2558x10 <sup>6</sup>	0.23944	3.9072x10 <sup>-5</sup>	53554	112.01	150	135.56
Modify	4.1414x10 <sup>8</sup>	1.305x10 <sup>5</sup>	0.0020728	2.2214x10 <sup>-6</sup>	56630	4.2582	150.01	134.82

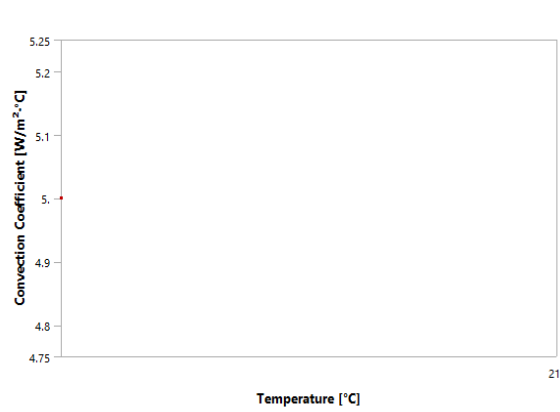
Steady State Thermal curve:

Model (A4) > Steady-State Thermal (A5) > Temperature



(a)

Model (A4) > Steady-state Thermal (A5) > convection



(b)

Fig 9. Steady state Thermal curve for (a) Temperature, (b) Convection

VIII. CONCLUSION

- Modeling and analysis of piston is done
- Modeling of piston is done in Creo 3.0 design software by using various commands
- The Creo part file is converted into IGS file and imported to Ansys workbench.
- First Static structural analysis is carried out on piston at 9MPa pressure with Thus materials such as Cast aluminium alloy using in three different Crown using in Ansys workbench.
- Maximum Equivalent Von – Mises stress, Total Deformation, Maximum
- Equivalent Von – Mises strain and maximum shear stress are noted and tabulated
- Then steady state thermal analysis is carried out at Maximum temperature 150deg and minimum temperature 30deg for the above three various Crown or Head.
- Temperature distribution and heat flux are noted for three different Profiles and tabulated.
- Modify model piston crown in a **Rapid Prototyping**
- From the tables it is concluded that the Modifying Piston Crown is showing Efficient results
- Hence Modifying Profile is preferable among the three applied Crown.

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