Comparison of S.C.F.S.I.C.E Piston Materials using Catia V5 And Ansys R18.2

Farheen Jahan[1], Aayush Kumar Ojha[2], Rishabh[3], Zubair Irshad[4]
[1, 2, 3, 4]Department of Mechanical Engineering
[1, 2, 3, 4] Manav Rachna International Institute of Research and Studies, Faridabad, Haryana, India,

Abstract-*With increasing versatility of usage conditions of IC engines, it is important to choose reliable materials for its components. One of the many ways to achieve design criteria is by reducing the structural weight and thus to reduce fuel consumption and increase mobility control. In IC engine reciprocating parts are responsible for giving the motion to the engine. Piston is one of the most important components of engine so it is important to consider material of the piston as a design concern. In this work, five materials, namely, brass, cast iron, gold, stainless steel and tungsten were considered and pistons were designed using CATIA V5 R20 software for each respective material according to their dimensions calculated. These designs were imported in ANSYS R18.0 software for transient thermal analysis within a domain of same boundary conditions. The effect of temperature impact from fuel combustion is studied and flow of heat flux was simulated out and graphed. All the five materials were compared for their respective suitability to be manufactured into pistons in future*

Keywords-ANSYS, CATIA, Materials, Piston, Single Cylinder Four Stroke Internal Combustion Engine

I. INTRODUCTION

Piston is one of the most important components of the engine. Improving engine design and working implies improving the design of its components also. To optimize the engine performance we should use lightweight material. However, being less dense, piston should have enough strength to withstand the pressure, mechanical and thermal stresses generated by the fuel combustion in the cylinder. Due to this combustion in the cylinder, deformation causes piston cracks and decreases its life. It is necessary to check out or analyze the stress distribution, heat transfer, thermal load, temperature distribution, mechanical load in order to minimize the stress and different loads on working condition.

II. PISTON

In an I.C engine, piston is a high speed reciprocating part. Piston reciprocates due to the impulse, generated by high-pressure exothermic combustion of the fuel at the time of power stroke cycle by which piston transfer the energy to the crankshaft via connecting rod[1]. The piston is to be high in strength but light in weight to control inertia forces. A piston is designed according to the working conditions of the engine. The material selection is a concern and following things are kept in mind while doing so:

- The material should have enough strength to bear the gas pressure,
- Excessive heat generated during the combustion process should be dissipated efficiently,
- Surface finish should be fine, keeping coefficient of friction minimum,
- Proper seal and lubrication should be maintained between the cylinder walls and the piston surface,
- The assembly should be free from any unwanted mechanical stresses,
- Force acting on the assembly should be balanced and hence inertial forces must be controlled effectively,[2]
- Piston material should be chosen wisely to minimize possible thermal stresses.

Nowadays, Cast Iron is use widely as a standard material for manufacturing of pistons of IC engines due to their overall maneuverability. Cast iron has carbon content greater than 2%, and hence gives a decent combination of mechanical properties. But, due to its low melting point and ductile nature, this material possesses certain demerits. Hence, some of other materials are considered for coating or to make alloy.

Comparison of materials to be tested:

Table 1. Comparison of materials to be tested [3][4][5]

	BRASS	**CAST IRON**	**GOLD**	**St. STEEL**	**TUNGSTEN**
Density	8600 kg/m^3	7200 kg/m^3	19300 kg/m^3	8055 kg/m^3	19300 kg/m^3

Isotro. Thermal Conductivity	111 $Wm^{-1}C^{-1}$	83 $Wm^{-1}C^{-1}$	315 $Wm^{-1}C^{-1}$	13.8 $Wm^{-1}C^{-1}$	174 $Wm^{-1}C^{-1}$
Sp. Heat	162 J/kgC	165 J/kgC	129 J/kgC	480 J/kgC	132 J/kgC
Th. ExpCoeff. (at 20 degC)	19*e-6/deg C	10.5*e-6/deg C	14 *e-6/deg C	16*e-6/deg C	4.3*e-6/degC
Ul. Tensile Strength	469 MPa	200 MPa	220 MPa	490 MPa	517 MPa
Modulus of Elasticity	97 GPa	130 GPa	74 GPa	200 GPa	400 GPa

III. DESIGNING OF THE PISTON

Design of a piston is divided in four parts:

a) Piston Head:

Thickness of the piston head:

$$t_h = 0.43D\sqrt{\frac{p_{max}}{\sigma_t}}$$ (on strength basis) [6]

b) Piston Rings:

Radial thickness of the piston ring:

$$t_r = D\sqrt{\frac{3p_w}{\sigma_t}}$$ [7]

Axial width:

$$t_a = (0.7 - 1.0)t_r$$ [8]

Width of top land:

$$b_1 = t_h - 1.2t_h$$ [9]

Width of other ring land:

$$b_2 = 0.75t_a - t_a$$ [10]

Gap between the rings:

$$g = 3.5t_r - 4.0t_r$$ [11]

c) Piston Pin:

Outside dia of pin:

$$d_o = 1.75D\frac{p_{max}}{p_b}$$ [12]

Inside dia of pin:

$$d_i = 0.6d_o$$ [13]

d) Piston skirt:

Thickness of piston barrel:

$$t_3 = 0.03D + t_r + 4.9$$ [14]

Piston thickness at open end:

$$t_4 = 0.25t_3 - 0.35t_3$$ [15]

Length of upper piston skirt:

$$l_p = L - LoR - T.L(b_1)$$ [16]

Length of ring section:

$$LoR = 3b_2 + 4t_a$$ [17]

The length of piston skirt is obtained by equating maximum side thrust (which is generally taken as 10 % of the gas load) to bearing load;

Length of skirt:

$$0.1p_{max}\frac{\pi}{4}D^2 = p_b D l_s$$ [18]

Total length of the piston: $l = l_s + l_p$ [19]

Above set of equations are used to calculate data for each of the listed materials.

IV. FIGURES AND TABLES

Table 2. Calculated Values

Design Parameters	Cast Iron	Brass	Stainless Steel	Gold	Tungsten
Cyl. bore (D)	100 mm				
Stroke	120 mm				

Maximum gas pressure	5 N/mm^2				
BMEP	0.65 N/mm^2				
Fuel consump.	0.227 kg/kWh				
Engine speed	2200 rpm				
b_1 (mm)	17.6	11	9	25	7
t_r (mm)	4	3	2	6	2
g (mm)	15	11	7.5	22	7.5
b_2 (mm)	2.625	2.0	1.25	3	1.5
l (mm)	130	117	109	140	107
t_4 (mm)	3.0	3.0	2.0	4.0	2.0
t_h (mm)	16	10	8	22	6
t_3 (mm)	11.9	10.9	5.9	13.9	5.9
t_a (mm)	3	2.5	1.5	4	1.5
d_i (mm)	21				
d_o (mm)	35				

Now, the data calculated above is used to model five pistons of each material using software CATIA V5

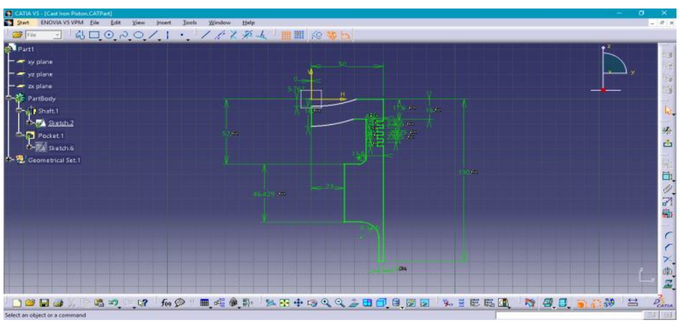

Figure 1. Parametric designing of Piston on CATIA V5

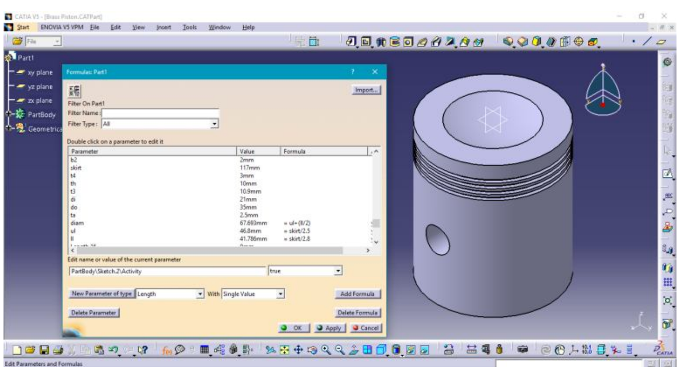

Figure 2. Parametric designing of Piston on CATIA V5

V. RESULTS OF THE ANALYSIS

The analysis performed here is a transient thermal analysis, based on temperature and heat flux distribution. Temperature, as boundary condition for the reaction probe, ramping up from 25 degC to 2000 degC over the combustion impact surface of the piston head and convection coefficient on the outer surface and the piston rings as of stagnant water (with initial boundary condition: 22 degC). The simulation occurs with the initial time step of 1*e-002 sec, minimum time step of 1*e-003 sec and the maximum time step of 0.1s.

1. Results of Mesh Generation:

Table 3. Mesh properties of CAD models

	BRASS	CAST IRON	GOLD	St. STEEL	TUNGSTEN
VOLUME	4.8402e +005 mm³	5.3597e +005 mm³	5.9669e +005 mm³	4.2381e +005 mm³	4.0733e +005 mm³
MASS	4.1626 kg	3.859 kg	11.516 kg	3.4138 kg	7.8615 kg
NODES	15401	9625	8290	24478	17359
ELEMENTS	8524	5178	4348	13892	9491

2. Results for brass material:

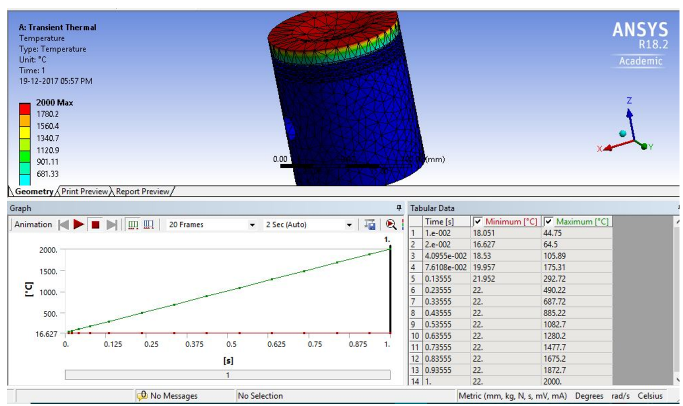

Figure 3. Effect of Temperature

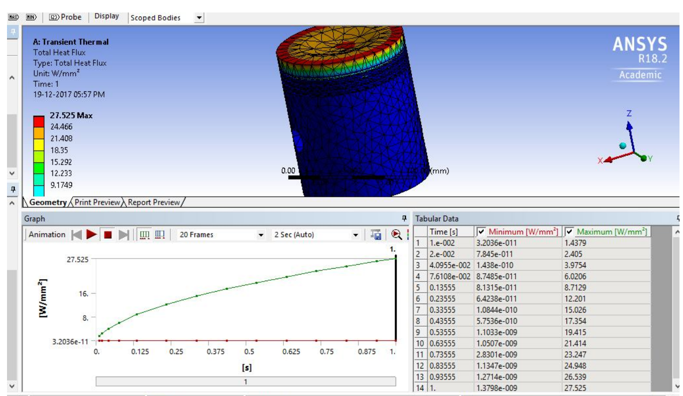

Figure 4. Effect of Heat Flux

3. Results for cast iron material:

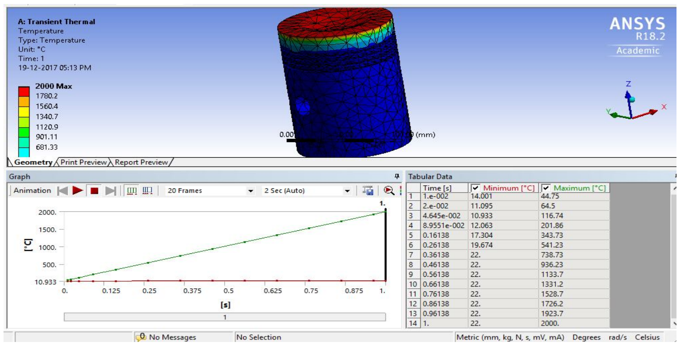

Figure 5. Effect of Temperature

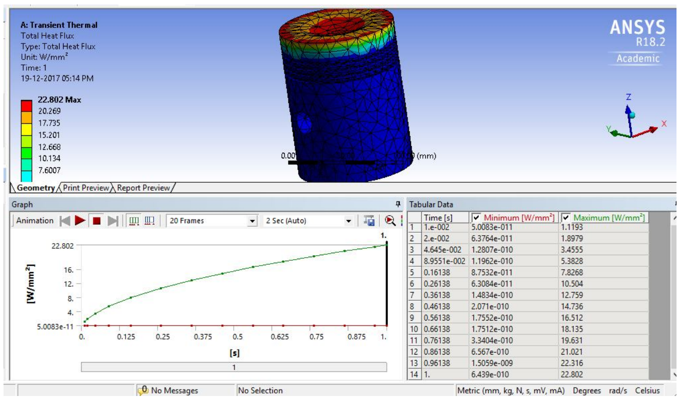

Figure 6. Effect of Heat Flux

4. Results for gold material:

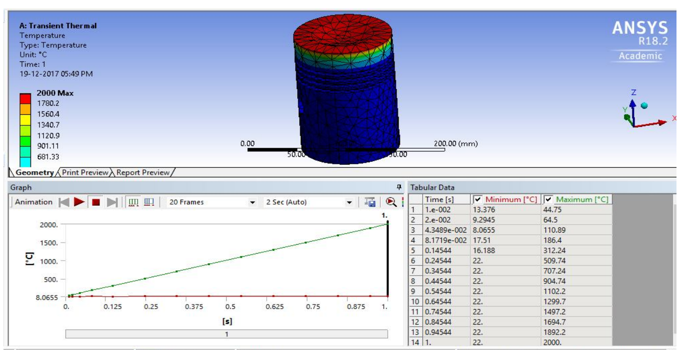

Figure 7. Effect of Temperature

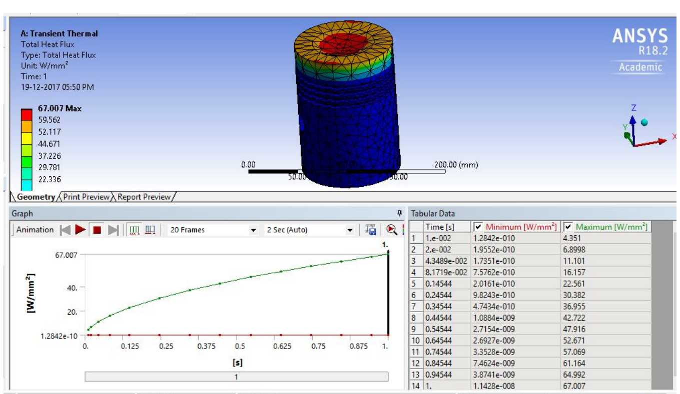

Figure 8. Effect of Heat Flux

5. Results for stainless steel material:

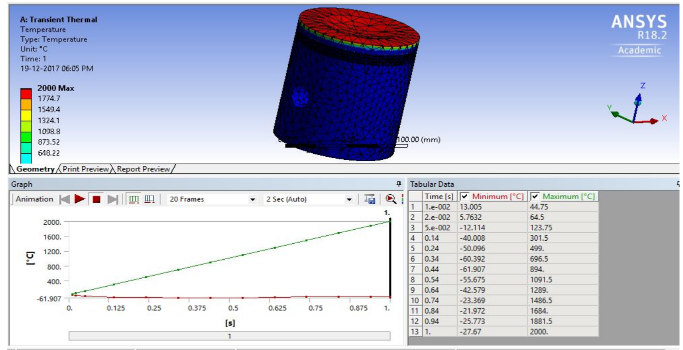

Figure 9. Effect of Temperature

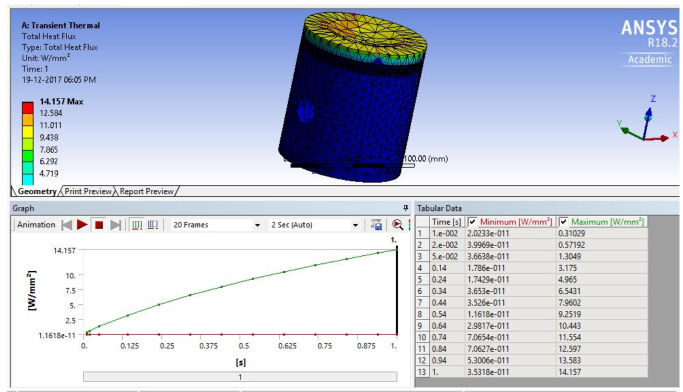

Figure 10. Effect of Heat Flux

6. Results for tungsten material:

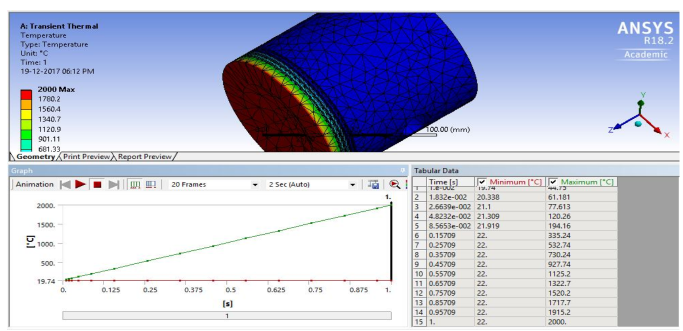

Figure 11. Effect of Temperature

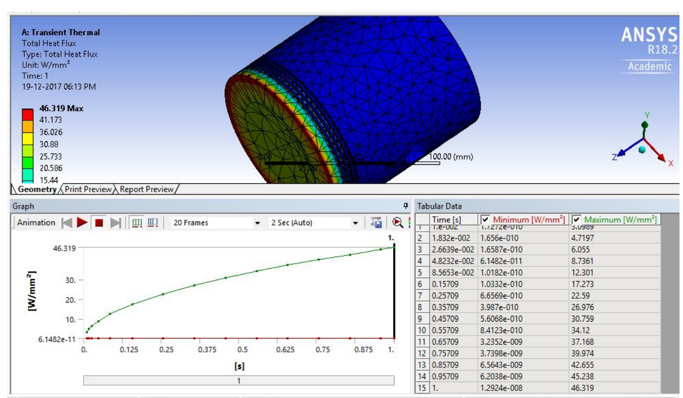

Figure 12. Effect of Heat Flux

VI. CONCLUSION

After studying the results, the piston head seems to be critically heated within fractions of a second. So the convective heat transfer coefficient of a material is helpful enough to dissipate it to the piston skirt which is comparatively least affected by the heat generated. Here the piston rings act as a convenient way of heat loss, by acting as fins, to the lubricant or coolant.

- Cast iron FG200 is the best suited material for these working conditions as it has the best combination of mechanical and thermal properties, both ; the total heat flux generated (within the temperature range of 25-2000 degC) is 22.802 W/mm2.
- Stainless steel can also be considered an alternative material for manufacturing of automobile piston after cast iron; the total heat flux generated (within the temperature range of 25-2000 degC) is 14.157 W/mm2 [21]

REFERENCES

[1] https://haynes.com/en-us/tips-tutorials/what-piston-and-what-does-it-do
[2] http://knol.google.com/k/-/-/2utb2lsm2k7a/4445
[3] V.R. Nimbarte, S.D. Khamankar, Stress analysis of piston using pressure load and thermal load. International journal of mechanical engineering, 2015
[4] G. Anusha, Ramlakshmi, K.M. Krishna, P.P. Kumar, Modelling and analysis of piston design through Pro/E and Ansys, International research journal of engineering and technology, 2015
[5] D.K. Sonar, M. Chattopadhyay, Theoritical analysis of stress and design of piston head using CATIA and ANSYS, International journal of engineering science invention, 2015
[6] K. Lingaiah, Machine design databook, (McGraw Hill handbooks, 1994)
[7] K. Lingaiah, Machine design databook, (McGraw Hill handbooks, 1994)
[8] S. Pattar, Sanjay S.J, V. B. Math, Static analysis of helical compression spring, International journal of research in engineering and technology, 2014
[9] W. Y. Wang, B. Liu, V. Kodur, P. E., F. ASCE, Effect of temperature and strength and elastic modulus of high strength steel, 2013
[10] M. Srinadh, K. Rajasekhararababu, Static and thermal analysis of piston and piston rings, 2015
[11] [P.C. Gope, Machine design fundamentals and applications, (PHI learning publications, 2012)
[12] P.C. Gope, Machine design fundamentals and applications, (PHI learning publications, 2012)
[13] V.B. Bhandari, Design of machine elements, (Tata McGraw Hill educations, 2016)
[14] .B. Bhandari, Design of machine elements, (Tata McGraw Hill educations, 2016)
[15] K. Lingaiah, Machine design databook (McGraw Hill handbooks, 1994)
[16] P.C. Gope, Machine design fundamentals and applications, (PHI learning publications, 2012)
[17] K. Lingaiah, Machine design databook (McGraw Hill handbooks, 1994)
[18] V.B. Bhandari, Design of machine elements, (Tata McGraw Hill educations, 2016)
[19] V.B. Bhandari, Design of machine elements, (Tata McGraw Hill educations, 2016)
[20] A. Sonthalia, S. Bhadaoria, V. Singh, Design and analysis of I.C. Engine piston using finite element analysis (ANSYS), International journal of research, 2016.aaa