STRUCTURAL & THERMAL ANALYSIS OF IC ENGINE PISTON USING DIFFERENT MATERIAL

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ABSTRACT

In this work Structural and thermal analyses has been carried out on the piston of 4 stroke petrol engine. Piston model is designed in the CAD software called "SOLIDWORKS" and structural and thermal analyses are performed on this model. The stress, strain and deformation are analyzed for the piston by applying pressure on it in Structural analysis. The thermal flux, temperature distribution is analyzed by applying temperature on the piston surface in Thermal analysis. By observing the both analyses results, we can decide whether our designed piston is safe or not under applied load conditions. Thus in the end a comparative study is made by showing different results of Analysis of piston using three different materials viz; Al 6061, Al 7050 T7451, Gray Cast iron . And a meaningful effort has been done to find out the best suitable material for the Piston.

KEYWORDS- Displacement, Engine piston, Factor of safety, Heat flux, Structural Analysis, Thermal Analysis Solidworks, von mises stress, von mises strain.

I.INTRODUCTION

The piston is a component of the internal combustion engine. It forms a mechanism called crank mechanism with the help of connecting rod and crankshaft. The main function of the piston is to transform the pressure generated by the burning air-fuel mixture into force, acting on the crankshaft. Piston contributes in heat dissipation generated during combustion to the walls of the cylinders. It ensures the sealing of the combustion chamber, preventing gas leakages from it and oil penetration into the combustion chamber and guides the movement of the connecting rod. Piston also ensures to the continuous change of gases in the combustion chamber and thus generates the variable volume in the combustion chamber. Zeng et al. [2] has setup a geometry model of a diesel engines piston in UG graphics. The temperature fields of the piston for burning diesel and DME separately are calculated using finite element analysis tool. The result shows that The temperature of the DME fueled diesel engine decreases along the piston axis from top to bottom. The temperature of the piston of DME fueled engine increase as a whole comparing with burning diesel. However, the temperature field distribution has no significant change decreases and then increases from the combustion chamber center to the edge, and decreases again to the edge of the piston top. Saad et al. [1], has done numerical analysis to analyze the stresses due to thermal cycle with different aluminum alloy of piston .Finite element method was used to evaluate the coupling field (thermal –stress) on the piston. ANSYS5.4 Finite element code is used to carry out the modeling process to determine the coupling stress .Two models with three dimensions are created .The first is used to evaluate the temperature distribution through the piston volume, and the second is used to evaluate the thermal stress distribution due to heat gradient and different materials. The result show the maximum range of temperatures is 4.3 °C and increases with decreasing of material thermal conductivity .Thermal stress is concentrated on the piston edges and depends on the material types. Reddy et al. [6] In that work, the main emphasis is placed on the study of thermal behavior of functionally graded coatings obtained by means of using a commercial code, ANSYS on aluminium and zirconium coated aluminium piston surfaces. The analysis 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). With using computer aided design NX/Catia software the structural model of a piston will be developed. Furthermore, the finite element analysis is done using Computer Aided Simulation software ANSYS.

II.MATERIAL PROPERTIES

Material properties are tabulated in the table given below

Table No.-1

Material	Elastic modulus (N/mm^2)	Density (Kg/m^3)	Yield strength (Mpa)	Tensile strength (Mpa)	Poison Ratio	Thermal conductivity (w/(m-k))
Al 7050 T7451	72000	2830	470	525	0.33	157
Al 6061	69000	2700	227.53	240	0.33	154
Gray cast iron	66178	7200	228	151.66	0.27	45

III.DESIGN OF PISTON

Piston in an IC engine must possess the following characteristics:

- ✓ Strength to resist gas pressure.
- ✓ Must have minimum weight.
- ✓ Must be able to reciprocate with minimum noise.

- ✓ Must have sufficient bearing area to prevent wear.
- ✓ Must seal the gas from top and oil from the bottom.
- ✓ Must disperse the heat generated during combustion.
- ✓ Must have good resistance to distortion under heavy forces and heavy temperature.

From machine design and data hand books, following dimensions of the piston have been calculated according to the given design procedure. The dimensions are in terms of SI Units.

3.1. DESIGN FOR AL 7050 T7451

- ➢ Thickness of the piston head (t_h)

$t_h = \sqrt{(3PD^2)/(16\sigma_t)}$

Where P= maximum pressure in N/mm²

D= cylinder bore/outside diameter of the piston in mm.

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

Where $\sigma_t = \sigma_{ut}/2.25 = 470/2.25 = 208.8$ Mpa

$t_h = 90\sqrt{(3*7)/(16*208.8)}$

t_h= 7.1mm

- ➢ Width of Top land (b_1)

$b_1 = t_h$ to $1.2t_h$

$b_1 =$ 9.12mm

- ➢ Radial thickness of Piston rings (t_1)

$t_1 = D\sqrt{(3P_w/\sigma_p)}$

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 0.0667 N/mm² For present material, σ_p is 120Mpa

$t_1 = 90\sqrt{(3*0.025/120)}$

t_1= 2.25mm

- ➢ Axial thickness of Piston ring (t_2)

$t_2 = D/(10*n_r)$

$t_2 = 90/(10*3)$

t_2= 3mm

- Width of Ring land (b_2)

b_2= 0.7t_2 to t_2

b_2= 2.1mm

- Maximum thickness of barrel (t_3)

t_3= 0.03D+t_1+4.9

t_3= 0.03*90+2.25+4.9

t_3= 9.8mm

- Length of the Skirt (l_s)

l_s= 0.6D to 0.8D

l_s= 62mm

- Piston pin diameter (d_0)

d_0= 0.28D to 0.38D

$d_{0=}$ 34mm

3.2. DESIGN FOR AL 6061

t_h= 10.2mm

b_1= 12.3mm

t_1= 2.25mm

t_2= 3mm

b_2=2.1mm

t_3= 9.8mm

l_s= 68mm

d_0= 34mm

3.3. DESIGN FOR GRAY CAST IRON

t_h= 10.24mm

b_1= 12.28mm

t_1= 2.19mm

t_2= 3mm

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b_2= 2.1mm

t_3= 9.7mm

l_s= 70mm

d_0= 34.2mm

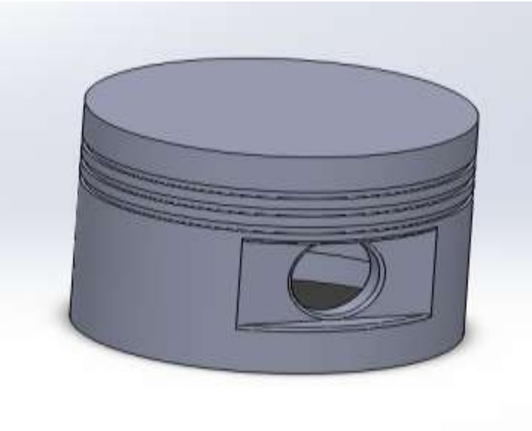

fig.1: 3D model of piston

fig.2: mesh view of piston

IV. STRUCTURAL ANALYSIS RESULTS FOR DIFFERENT MATERIALS

Structural analysis is done by applying the 7Mpa pressure on the top surface of the piston

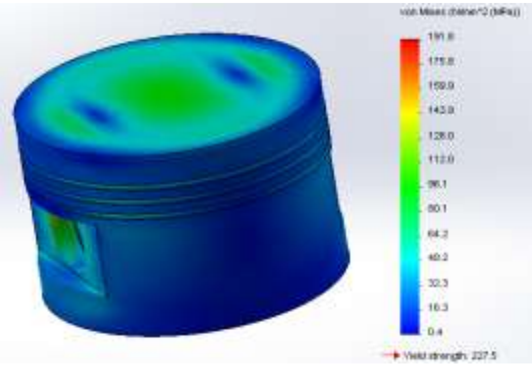

fig.3: von mises stress for Al 6061

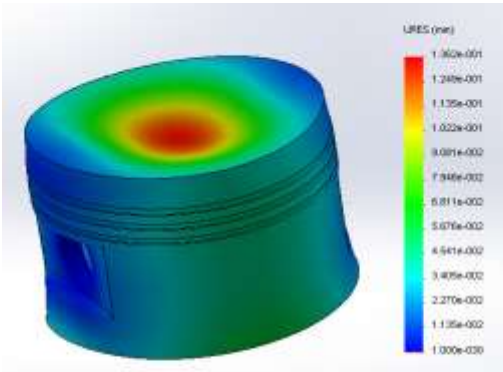

fig.4: Deformation for Al 6061

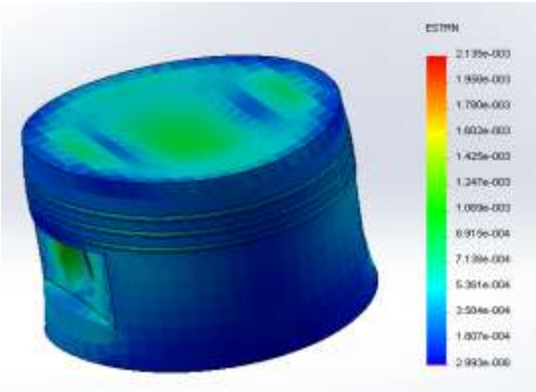

fig.5: von mises strain for Al 6061

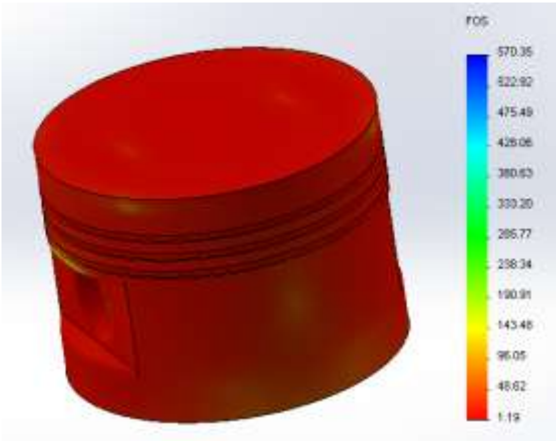

fig.6: factor of safety for Al 6061

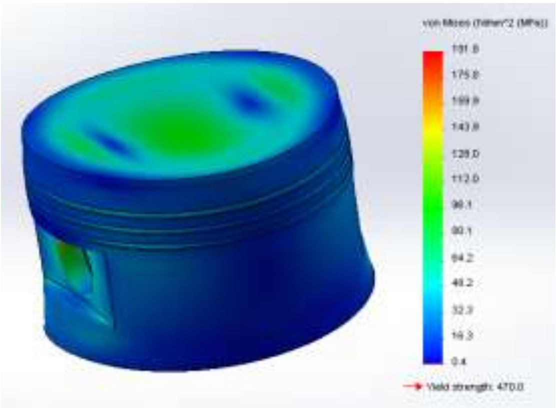

fig.7: von mises stress for Al 7075 T7451

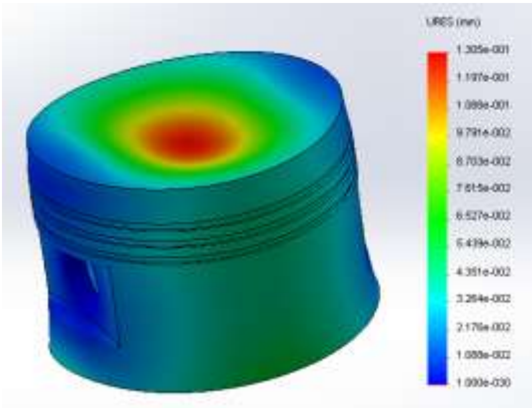

fig.8: Deformation for Al 7075 T7451

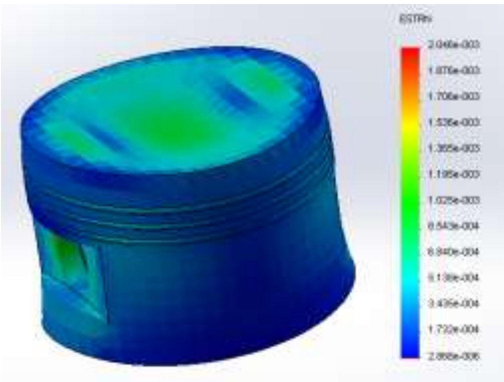

fig.9: von mises strain for Al 7075 T7451

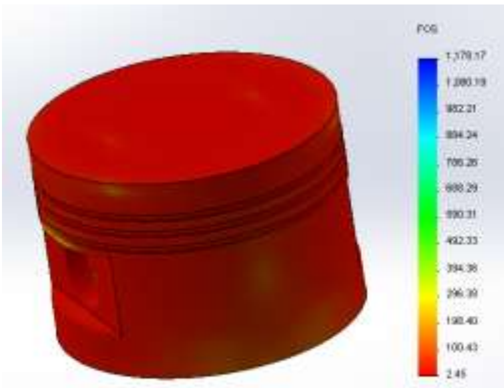

fig.10: factor of safety for Al 7075 T7451

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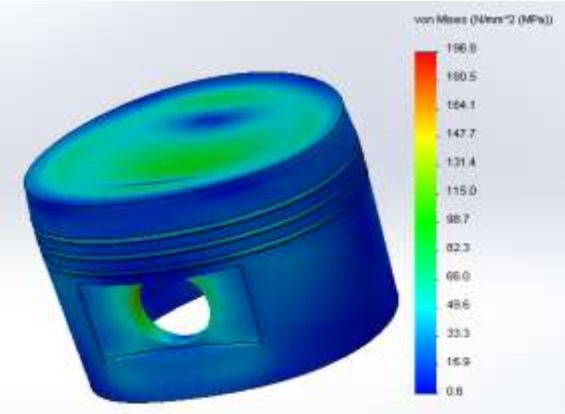


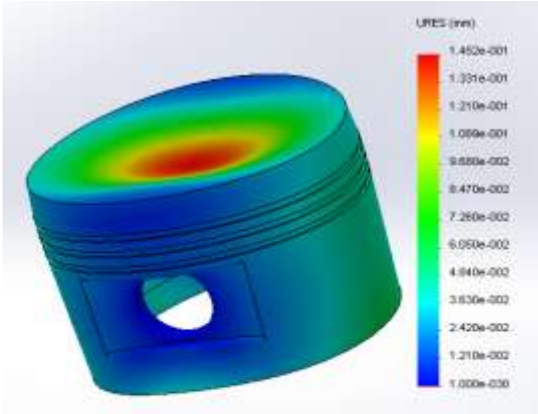
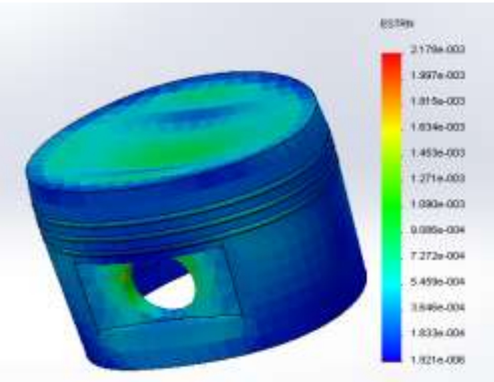


fig.11: von mises stress for gray cast iron **fig.12: deformation for gray cast iron**



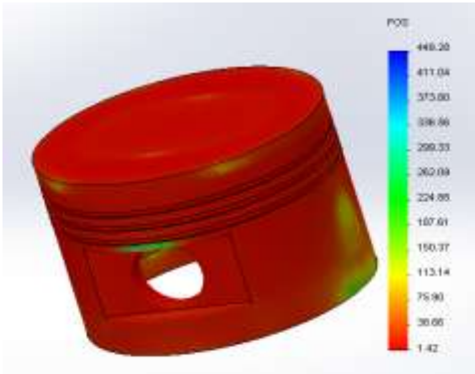
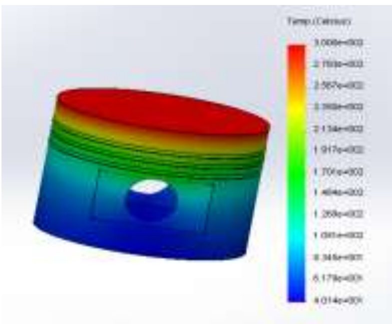


fig.13: von mises strain for gray cast iron **fig.14: factor of safety for gray cast iron**

V.THERMAL ANALYSIS RESULTS FOR DIFFERENT MATERIALS

Thermal analysis is done by applying 300^0c temperature on the top surface of the piston and a mean convection coefficient of 1200 w/m2/k on the piston.



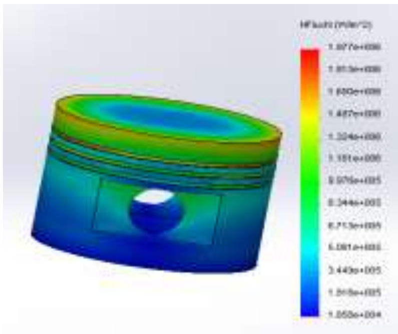


fig.15: Temp. Distribution for Al 6061 **fig.16: max. total heat flux for Al 6061**

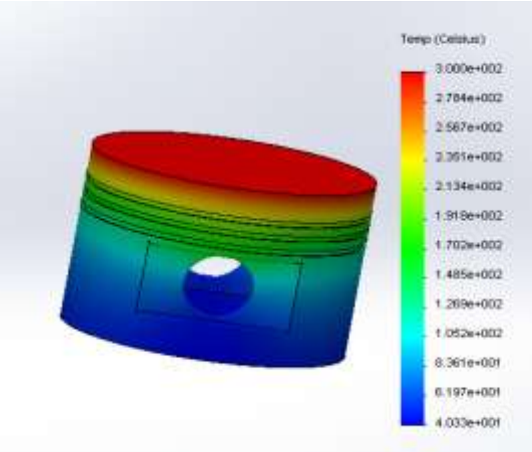


fig.17: Temp. Distribution for Al 7075 T7451

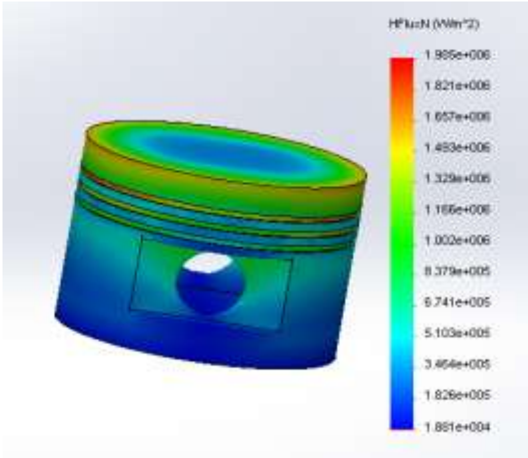


fig.18: max total heat flux for Al 7075 T7451

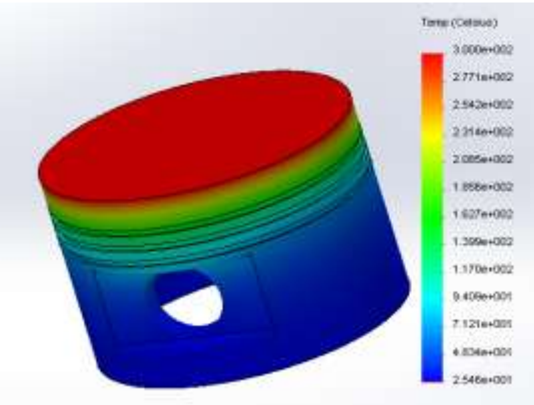


fig.19: temp. distribution for gray cast iron

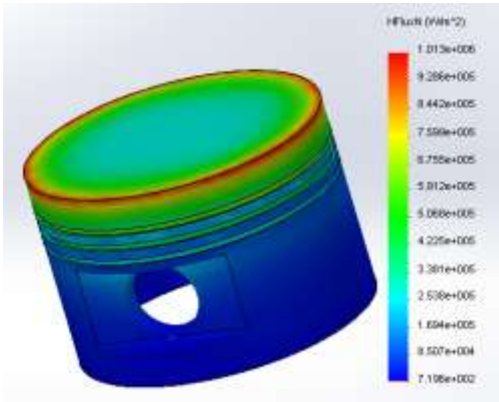


fig.20: max. total heat flux for gray cast iron

VI.RESULTS AND DISCUSSION

From the above figures all the results of the structural analysis are tabulated in the table given below.

Table No.-2

S. No.	Parameter	Al 6061	Al 7050 T7451	Cast iron
1	Max. Von mises Stress (Mpa)	191.8	191.8	196.8
2	Max. Von mises Strain	0.0021	0.0020	0.0022
3	Max. Deformation (mm)	0.1362	0.1305	0.1452
4	Minimum Factor of safety	1.19	2.45	1.42

Results of Thermal analysis are tabulated in table given below.

Table No.- 3

S. No.	Parameter	Al 6061	Al 7050 T7451	Cast iron
1	Min. Temp (^{0}c)	40	40	25
2	Res. Heat flux (w/m^2)	1.977e+06	1.985e+06	1.013e+06

It is cleared from the above figures & tables that maximum von mises stress occurs at piston's crown surface, It is clear from the Table-2 that the maximum deformation is observed in the piston made of Gray Cast iron and minimum in Al 7050 T7451. As it is expected maximum deformation is observed at the top of the centre of the piston. It is shown in the Table-2 that the maximum stress intensity is observed in Gray Cast iron with 196MPa and same for Al 7050 T7451 & Al 6061 with 191.8Mpa. Whereas the yield strength of the piston is very high in Al 7050 T7451 piston followed by Gray Cast iron and Al 6061.

Thermal analysis of piston shows that the value of maximum temperature is same for all the materials at the top surface of the piston crown, but minimum value of temperature in the piston made of Gray Cast iron. The highest value of minimum temperature is found in the piston of Al alloy. This is due to high thermal conductivity of the Aluminium alloys. Minimum temperature is in the skirt of the piston is observed as shown in figure 15, 17 & 19. Table-3 shows that max total heat flux is observed in piston of Al 7050 T7451 and piston of Gray cast iron shows the lowest value of max total heat flux.

VII. CONCLUSON

Maximum von mises stress, Maximum von mises strain and Maximum deformation are less in Piston of Al 7050 T7451 alloy in comparison of Al 6061 & Gray cast iron. Minimum Factor of safety for all the materials is more than 1 but among the all materials factor of safety of Al 7050 T7451 is highest which is 2.45. Hence it can be said that our design for Al 7050 T7451 is safe. So finally it can be concluded that Al 7050 T7451 is the suitable material for using in production of Piston.

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