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# Design and Analysis of 4 Stroke Petrol Engine Piston by Using Coating Material

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***Abstract— We all know that function of Piston is to convert the thermal energy to mechanical energy under the high temperature and gas pressure. The main objective of this project is to improve the structural and thermal behaviour of the piston and this is done by using a coating of a material on the piston. Model of the piston is developed from Hero Splendor-Pro engine specifications by theoretical calculation. Finite Element Analysis performed using analysis software ANSYS Workbench for the (uncoated) piston of aluminium alloy material and ceramic (Nickel chromium aluminium - NiCrAl and Aluminium oxide - $Al_2O_3$) coated piston of composite (Aluminium silicon carbide – AlSiC) material. Structural analysis is to evaluate the total deformation, equivalent stress and equivalent elastic strain; and thermal analysis to evaluate the temperature distribution and total heat flux. By the result of analysis, we would be able to find whether ceramic coating for the piston is feasible or not.***

***Keywords— IC Engine Piston, Ceramic Coating, Composite material, FEA, ANSYS.***

## I. INTRODUCTION

Automobiles are being a basic necessity in this modern era and we all know very well, because of the increased use of vehicles, there is a requirement to improve performance and reduce cost of automobile components. For the betterment of these components we need to understand the new technologies which are helpful in development of components with improved build quality.

A Piston is a reciprocating component, contained within the cylinder in IC engines. Due to combustion of fuel, piston reciprocates. This reciprocating motion of piston, passes to crankshaft by the connecting rod which it into rotary motion. In this process, high thermal stress acts on the top surface of piston.

Therefore, to reduce the thermal stress acting on the piston head surface, we strive to improve the design or choose the best material for the piston.

## II. ANALYTICAL DESIGN

According to function of the piston, suitable design and selection of material is required.

### *A. Material Selection*

When discussed about thermodynamics, one thing we need to keep in the mind that the properties of material change with temperature. Piston is generally made using Aluminium alloy materials but at high temperature it has poor strength and high coefficient of thermal expansions. To overcome this problem, Piston is made of AlSiC composite material and a coating is done on the piston head. There are two different layers of coating, totalling of 500µm thickness. First layer generally preferred NiCrAl with thickness of 150µm and for the second layer which is known as ceramic layer, different type of ceramic materials like Mullite or Aluminium oxide or Zirconium oxide are used. $Al_2O_3$ is the best material for the last layer of coating as deduced from the literature survey.

| Property/ Materials | Al alloy | $Al_2O_3$ | NiCrAl | AlSiC |
|---|---|---|---|---|
| Density (kg/m$^3$) | 2680 | 3000 | 8220 | 2700 |
| Poisson's ratio | 0.34 | 0.21 | 0.27 | 0.3 |
| Young's modulus (GPa) | 78.6 | 2150 | 200 | 90 |
| Co-efficient of expansion (1/℃) | $19.4\times10^{-6}$ | $4.5\times10^{-6}$ | $12.2\times10^{-6}$ | $21\times10^{-6}$ |
| Tensile ultimate stress (MPa) | 380 | 690 | 1241 | 610 |
| Tensile yield stress (MPa) | 315 | 69 | 1034 | 480 |
| Thermal conductivity (W/m℃) | 138 | 1200 | 16.1 | 155 |
| Specific heat capacity (J/kg℃) | 900 | - | 764 | 990 |

TABLE I: PROPERTY OF SELECTED OF MATERIALS

*B. Theoretical Calculations*

Design calculations of piston are done by taking the reference as a 4 stroke single cylinder air cooled Hero Splendor – Pro 100cc engine specifications.

| Engine Type | Air Cooled 4-Stroke Single Cylinder |
|---|---|
| Max Power | 6.15kw @8000rpm |
| Max Torque | 8.05N.m @5000rpm |
| Bore Diameter | 50mm |
| Stroke Length | 49.5mm |
| Engine Capacity | 97.2cc |
| Starting | Kick Start/Self Start |
| Compression Ratio | 9.9:1 |

TABLE II: ENGINE SPECIFICATIONS

1) *Load calculations of the piston:*

a. Torque

$$P = \frac{2\pi NT}{60}$$

$$T = \frac{6150\times60}{2\times3.14\times8000} = 7.344 \text{ N-m}$$

b. Cylinder inside Pressure

$$\text{Velocity} = \frac{2\times L\times N}{60} = \frac{2\times49.5\times8000}{60} = 13060\text{mm/s} = 13.06\text{m/s}$$

$$\text{Force} = \frac{\text{Power}}{\text{Velocity}} = \frac{6.15\times1000}{13.06} = 470.90 \text{ N}$$

$$\text{Area} = \pi r^2 = 3.14\times(0.025)^2 = 1.934\times10^{-3}\text{ m}^2$$

$$\text{Pressure} = \frac{force}{area} = \frac{470.90}{0.001934} = 0.243 \text{ MPa}$$

$$P_{min} = 0.243 \text{ MPa}$$

$$P_{max} = 15\times0.243 \text{ MPa} = 3.645 \text{ MPa}$$

2) *Design of piston:*

a. Design of piston head or crown

Thickness of the piston head, according to Grashoff's formula

$$t_H = D\times\sqrt{\frac{3\times p_{max}}{16\times\sigma_t}}$$

where, $p$ = Maximum gas pressure or explosion pressure in N/mm2,

$D$ = Cylinder bore or outside diameter of the piston in mm, and

$\sigma_t$ = Permissible bending (tensile) stress for the material of the piston in MPa or N/mm$^2$ (For Cast Al alloy $\sigma_t = 152.2\ MPa$ )

$$t_H = 50\times\sqrt{\frac{3\times3.645}{16\times152.2}} = 3.35\text{mm}$$

b. Design of piston rings

Radial thickness of the ring

$$t_1 = D\times\sqrt{\frac{3\times p_w}{\sigma_t}}$$

where, $p_w$ = Pressure of gas on the cylinder wall in $N/mm^2$.= 0.025 $N/mm^2$ to 0.042 $N/mm^2$

$$t_1 = 50\times\sqrt{\frac{3\times 0.042}{152.2}} = 1.438mm$$

Axial thickness of the ring

$t_2 = 0.7t_1$ to $t_1 = 0.92t_1 = 0.92\times1.438 = 1.322mm$

Height of the top land (the distance from the top of the piston to the first ring groove)

$h_1 = t_H$ to $1.2t = 1.2\times3.35 = 4.02mm$

Height of other ring land (the distance between the ring grooves)

$h_2 = 0.75t_2$ to $t_2 = 0.75\times1.322 = 0.991mm$

c. Design of piston barrel

Thickness of the piston barrel at top land

$t_3 = 0.03D+b+4.5$

where, $b$ = Radial depth of piston ring groove which is taken as 0.4 mm larger than the radial thickness of the piston ring ($t_1$)

$t_3 = t_1 + 0.4$ mm $= 0.03\times50+1.438+4.5 = 7.438mm$

Thickness of the piston barrel at bottom land

$t_4 = 0.25t_3$ to $0.35t_3 = 0.25\times7.438 = 1.859mm$

d. Design of piston skirt

Length of the piston skirt

$l_{ps} = 0.65D$ to $0.8D = 0.5\times50 = 25mm$

Total length of the piston

$L$ = Length of skirt+ Length of ring section + Top land $= 25 + [(3\times0.911) + (2\times1.322)] + 4.02$
$= 34.397mm$

e. Design of piston pin

Outside diameter of the piston pin

$d_o = 0.3D$ to $0.45D = 16mm \approx 12mm$

Inside diameters of the piston pin

$d_i = 0.6\times d_o = 12mm \approx 8mm$

| Parameter | Calculated Values(mm) |
|---|---|
| Piston Length | $L$ = 34.397 |
| Piston Diameter | $D$ = 50 |
| Piston Pin Outside Dia. | $d_o$ = 16 |
| Piston Pin Inside Dia. | $d_i$ = 12 |
| Piston Ring Radial Width | $b$ = 1.438 |
| Piston Ring Axial Height | $h$ = 1.322 |
| Height of Top Land | $h_1$ = 4.02 |
| Height of Other Ring Land | $h_2$ = 0.991 |
| Thickness of Piston Head | $t_h$ = 3.35 |
| Thickness of Piston Barrel at top end | $t_1$ = 7.438 |
| Thickness of Piston Barrel at bottom end | $t_2$ = 1.859 |

TABLE III: DIMENSIONS OF PISTON PARAMETER

## III. ANALYSIS

We did two types of analysis: structural and thermal, using the ANSYS software. ANSYS is analysis software that gives the results according to the input parameters such as meshing and boundary conditions.

### A. Geometrical Modelling

3D model of the pistons prepared from the calculated dimensions for uncoated and coated materials, which is shown in figure 1.

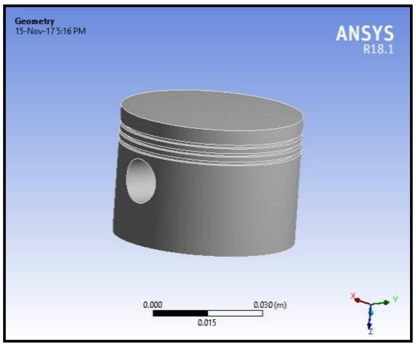


Fig 1: Piston Geometry

### B. Meshing of 3D Model

After modelling, mesh is generated and it contains 11205 nodes, 5946 elements and $3.7838\times10^{-2}$ m of minimum edge length.

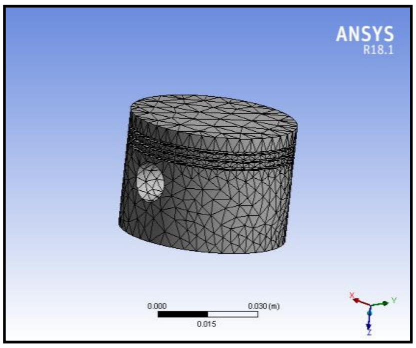


Fig 2: Meshing Model of Piston

### C. Boundary Conditions

1) *For The Structural Analysis:* Combustion of gases exerts pressure on the piston head during power stroke and the piston will move from Top Dead Center (TDC) to Bottom Dead Center (BDC) because of the fixed support with the connecting rod at pin hole. The gas pressure on top surface of piston and fixed support at piston pin hole are given as boundary condition for structural analysis. As per load calculation pressure is 3.645 MPa.

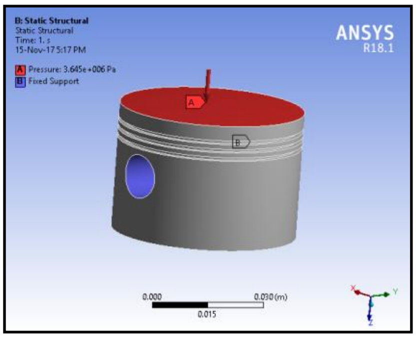


Fig 3: Structural Boundary Conditions

 

2) *For The Thermal Analysis*: Boundary condition of the thermal analysis is 350°C at head of both pistons and co-efficient of convection on surface of the piston given according to the material.

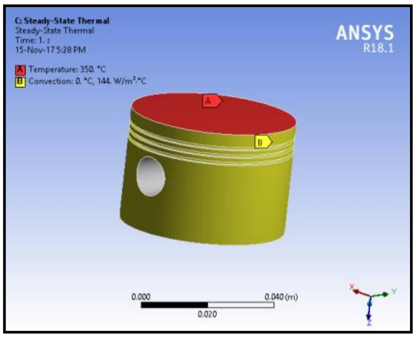


Fig 4: Thermal Boundary Conditions

*D. Analysis Solution*

The pictures of structural analysis and thermal analysis for uncoated piston and coated piston performed by ANSYS is shown in figures below.

1) *Solution of Structural Analysis*

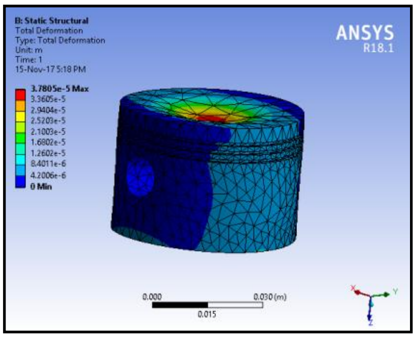


Fig 5: Total Deformation of Uncoated Piston

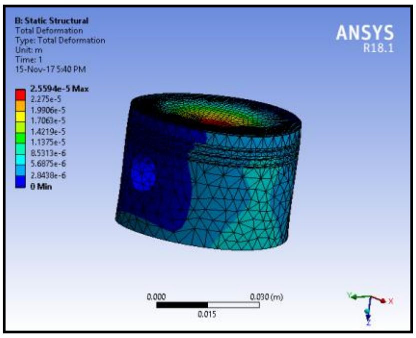


Fig 6: Total Deformation of Coated Piston

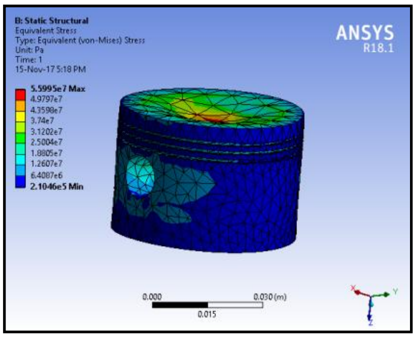


Fig 7: Stress Distribution of Uncoated Piston

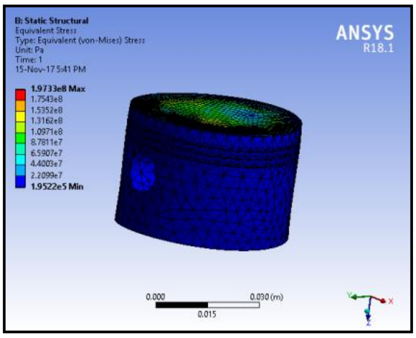


Fig 8: Stress Distribution of Coated Piston

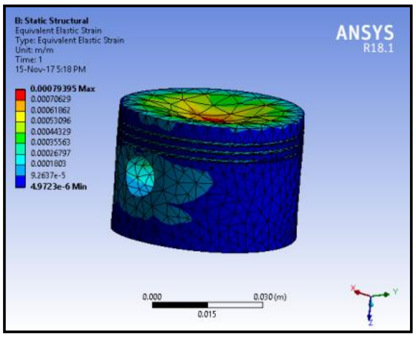


Fig 9: Strain Distribution of Uncoated Piston

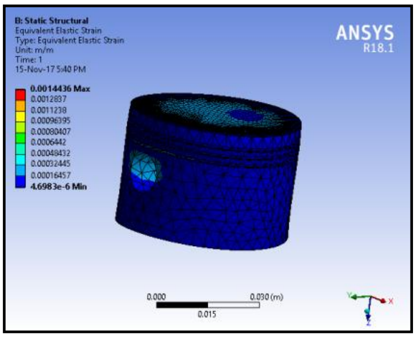


Fig 10: Strain Distribution of Coated Piston

 

2) *Solution of Thermal Analysis*:

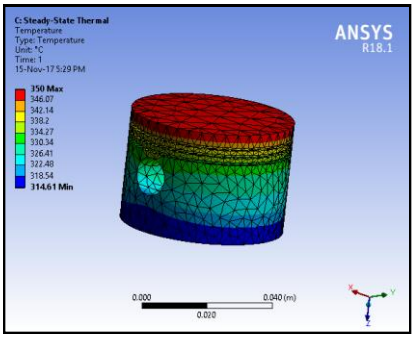


Fig 11: Temperature Distribution of Uncoated Piston

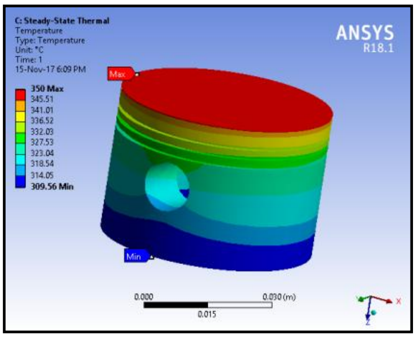


Fig 12: Temperature Distribution of Coated Piston

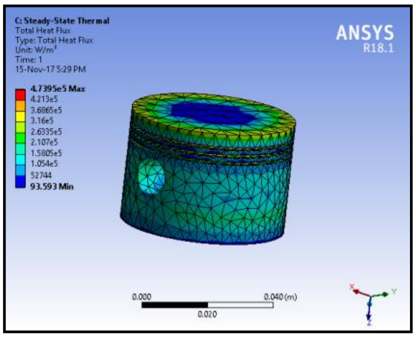


Fig 13: Total Heat Flux of Uncoated Piston

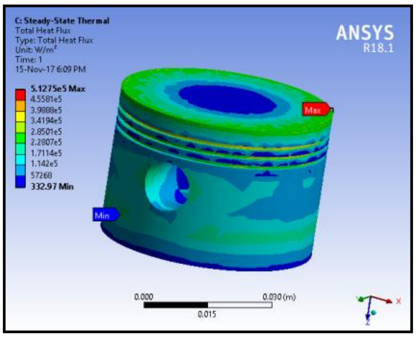


Fig 14: Total Heat Flux of Coated Piston

*E. Analysis Results*

The comparison of uncoated and coated piston analysis result in terms of structural analysis is done under the parameters: total deformation, equivalent stress, equivalent elastic strain and thermal analysis is done under two parameters temperature distribution, total heat flux is shown in table form.

1) *Results of Structural Analysis:*

| | Total Deformation(m) | | Stress(Pa) | | Strain (Pa) | |
|---|---|---|---|---|---|---|
| | Max. | Min. | Max. | Min. | Max. | Min. |
| Uncoated Piston | $3.7805\times10^{-5}$ | 0 | $5.5995\times10^{7}$ | $2.1046\times10^{5}$ | 0.00079395 | $4.9723\times10^{-6}$ |
| Coated Piston | $2.5594\times10^{-5}$ | 0 | $1.9733\times10^{8}$ | $1.9522\times10^{5}$ | 0.0014436 | $4.6983\times10^{-6}$ |

TABLE IV: COMPARISON OF UNCOATED AND COATED PISTON BY STRUCTURAL EFFECTS

2) *Results of Thermal Analysis*:

| | Temperature (°C) | | Total Heat Flux(W/m$^2$) | |
|---|---|---|---|---|
| | Max. | Min. | Max. | Min. |
| Uncoated Piston | 350 | 314.61 | $4.7395\times10^{5}$ | 93.593 |
| Coated Piston | 350 | 309.56 | $5.1275\times10^{5}$ | 332.97 |

TABLE V: COMPARISON OF UNCOATED AND COATED PISTON BY THERMAL EFFECTS

## IV. CONCLUSIONS

The observation of numerical results of analysis is clear that ceramic coated piston of composite material has less deformation and more temperature distribution capability at high temperature conditions then the uncoated aluminium alloy piston. So, from detailed study about pistons, we came to a conclusion that ceramic coating is better for the piston.

## REFERENCES

[1] K. Venkatareddy, V. Chandrashekar Goud, "Design and Analysis of the Piston by Using Composite Materials", International Journal of Professional Engineering Studies (IJPRES), Vol. 7, Issue 1, Sep 2016.

[2] M. Sivanesan, C. Vinothkumar, "Thermal Behaviour and Optimization of Piston Coating Material (Al-Si) Used In Petrol Engine", Middle-East Journal of Scientific Research, 24 (Recent Innovations in Engineering, Technology, Management and Applications): 141-147, 2016.

[3] Molla Shehanaz, Dr. G. Shankariah, "Design and Analysis of Piston Using Composite Material", International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), Vol. 6, Issue 8, August 2017.

[4] Vinod Kumar Yadav, Yogesh Mishra, "Design and Structural Analysis of Ceramic Coated Petrol Engine Piston Using Finite Element Method", International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET), Vol. 4, Issue 6, June 2015.

[5] Shirisha, G. S. Dk. Sravani, "Thermal Analysis of IC Engine Piston Using Finite Element Method", International Journal of Mechanical Engineering and Computer Applications, Vol. 4, No. 1, Jan- Feb 2016.

[6] Vaishali R. Nimbarte, Prof. S. D. Khamankar, "Stress Analysis of Piston Using Pressure Load and Thermal Load", IPASJ International Journal of Mechanical Engineering (IIJME), Vol. 3, Issue 8, August 2015.

[7] Narsaiyolla Naresh, P. Sampath Rao, "Structural Analysis of a Ceramic Coated Diesel Engine Piston Using Finite Element Method", International Journal of Mechanical Engineering (SSRG-IJME), Vol. 1, Issue 5, Sep 2014.

[8] Sundaram.K, Palanikumar.N, "Investigation and Analysis of Piston by Using Composite Material", IJARIIE, Vol. 2, Issue 6, 2016.

[9] Deepak Kumar Yadav, Suraj Kumar, Y. Ravi Prakash Reddy, G. Veerbhadra, Pothamsetty Kasi V Rao, "Design and Coupled Field Analysis of Ceramic Coated Petrol Engine Piston", International Research Journal of Engineering and Technology (IRJET), Vol. 4, Issue 4, Apr 2017.

[10] Lanka Tata Rao, Katakam Satyanarayana, M. S. S. Srinivasa Rao, T. V. Hanumanta Rao, S. V. Umamaheswara Rao, "Stress Analysis of 4 Stroke Diesel Engine Piston", International Journal of Current Engineering and Scientific Research (IJCESR), Vol. 2, Issue 2, 2015.

[11] Ekrem Buyukkaya, Muhammet Cerit, "Thermal Analysis of a Ceramic Coating Diesel Engine Piston Using 3-D Finite Element Method", Surface & Coatings Technology, 2007.

[12] K. S. Mahajan, S. H. Deshmukh, "Structural and Thermal Analysis of Piston", International Journal of Current Engineering and Technology (IJCET), Special Issue 5, June 2016.

[13] Abino John, Jeason T Mathew, Vasdev Malhotra, Nitin Dixit, "Design and Analysis of Piston by SiC Composite Material", International Journal for Innovative Research in Science & Technology (IJIRST), Vol. 1, Issue 12, May 2015.