International Journal of Scientific & Engineering Research, Volume 8, Issue 3, March-2017
ISSN 2229-5518

Thermal barrier coating on IC Engine Piston to improve Engine efficiency

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Abstract*:* The piston is considered as most important part of I.C engine. High temperature produced in an I.C engine may contribute to high thermal stresses. Without appropriate heat transfer mechanism, the piston crown would operate ineffectively which reduce life cycle of piston and hence mechanical efficiency of engine. The literature survey shows that ideal piston consumes heat produced by burnt gases resulting in decrease of Engine overall Efficiency. In this project work an attempt is made to redesign piston crown using TBC on piston surface and to study its Performance. A 150 cc engine is considered and TBC material with different thickness is coated on the piston. 3D modeling of the piston geometry is done 3D designing software Solidworks2015. Finite Element analysis is used to calculate temperature and heat flux distribution on piston crown. The result shows TBC as a coating on piston crown surface reduces the heat transfer rate within the piston and that will results in increase of engine efficiency. Results also show that temperature and heat flux decreases with increase in coating thickness of YSZ.

Key words: Finite Element Analysis, Piston crown, TBC, YSZ

INTRODUCTION

An Internal Combustion Engine is that kind of prime mover that converts chemical energy to mechanical energy. In I.C Engine, engine can be called the heart of a vehicle and the piston may be considered the most important part of an engine. It is the moving component that is contained by a cylinder and is made gas-tight by piston rings. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crankshaft via a piston rod. Piston in an IC engine must possess the 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.

Piston Terminology:

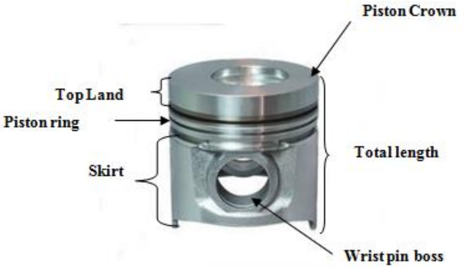

Fig1: Piston terminology

1) Crown: It is top surface of piston which is subjected to tremendous force and heat during normal engine operation.
2) Piston ring: It is part on piston having ring shape which seals the gap between piston and cylinder wall.
3) Skirt: It is portion of piston closest to crankshaft that helps align the piston as it move in cylinder block.
4) Wrist pin boss: It is bore that connects the small end of connecting rod to piston by a wrist pin.
5) Total length of piston: Total length of piston is the length from piston crown to bottom of piston. It is sum of Top land length, length of Ring section and skirt length.
6) Ring land: It is reliefs cut into the side profile of piston where piston ring sit
7) Ring Groove: An area located around the perimeter of the piston that is used to retain the piston ring.
8) Top land: The portion from piston crown to top ring land is called top land.

SELECTION OF IC ENGINE

Different two wheeler IC engine pistons are studied for its performance and Durability. In this project work two wheeler 150cc Honda Unicorn Engine is considered.

Engine type = air cooled 4-stroke
Bore × Stroke (mm) = 57×58.6
Displacement = 149.5CC
Maximum Power = 13.8bhp at 8500rpm
Maximum Torque = 13.4Nm at 6000rpm
Compression Ratio = 9.35/1
Mechanical Efficiency = 80%

PISTON GEOMETRY DESIGN

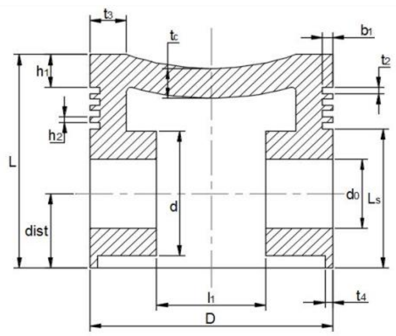

Fig 2: Detail view of cross sectional piston

Mechanical Efficiency, $\eta = \frac{B.P}{I.P}$

$B.P = \frac{2\pi NT}{60} = \frac{2 \times \pi \times 6000 \times 13.4}{60} = 8.420$ KW

$I.P = \frac{8.420}{0.8} = 10.52$ KW

$$I.P = P \times A \times L \times \frac{N}{2}$$

$$10.52 \times 10^3 = P \times \frac{\pi}{4} (0.057)^2 \times 0.0586 \times \frac{6000}{2 \times 60}$$

$$P = 14.06 \times 10^5 \text{ N/m}^2$$

Max pressure = $10 \times P$
= $10 \times 14.06 \times 10^5$
= 14.06 MPa

Assuming piston material as Aluminum Alloy Steel
σ_t = (100 to 160) N/mm^2
Take, σ_t = 160 N/mm^2

1) According to Grashoff's formula

Thickness of piston head

$$t_c = D \sqrt{\frac{3 \times P_{max}}{16 \times \sigma_t}} = 57 \sqrt{\frac{3 \times 14.06}{16 \times 160}} = 7.31 \text{ mm}$$

2) Design of piston ring

Radial thickness of piston ring,

$$t_1 = D \sqrt{\frac{3 \times P_w}{\sigma_p}}$$

Where, P_w = Allowable radial pressure on cylinder wall, σ_p = Permissible tensile strength
Assume, P_w = 0.025 MPa
σ_p = 110 N/mm^2

$$t_1 = 57 \sqrt{\frac{3 \times 0.035}{110}} = 1.76 \text{ mm}$$

Take, t_1 = 2 mm

Axial Thickness

$$t_2 = (0.7 \text{ to } 1)t_1$$

Take, $t_2 = 0.8\, t_1 = 1.6$ mm

3) No of piston rings

$$t_2 = \frac{D}{10 \times n}$$

$$1.6 = \frac{57}{10 \times n}$$

$$n = 3.56$$

Take n = 4

4) Width of top land

$$h_1 = (1 \text{ to } 1.2)\, t_c$$

$$= 1.1\, t_c = 8.04 \text{ mm}$$

5) Width of ring land

$$h_2 = (0.75 \text{ to } 1)\, t_2$$

$$= 0.8\, t_2 = 1.28 \text{ mm}$$

6) Radial depth of piston ring groove

$$b_1 = 0.4 + t_1 = 2.4 \text{ mm}$$

7) Maximum thickness of piston barrel at top end

$$t_3 = 0.03D + b + 4.5$$

$$= 8.61 \text{ mm}$$

8) Thickness of piston barrel at open end

$$t_4 = (0.25 \text{ to } 0.35)\, t_1$$

$$= 0.25\, t_1 = 1.827 \text{ mm}$$

9) Piston pin dia.

$$d_i = 0.03D = 17.1 \text{ mm}$$

10) Outer diameter of piston pin

$$F = P_b \times d_0 \times l_1$$

Where, P_b = bearing pressure in bush at small end of connecting rod
Assume, P_b = 30Mpa
l_1 = (2 to 2.5) d_0
Take, $l_1 = 2.5\, d_0$

$$F = P_b \times d_0 \times 2.5 d_0$$

$$d_o = \sqrt{\frac{F}{2.5 \times P_b}} = 21.87 \text{ mm}$$

11) Diameter of piston boss

$$d = 1.4 \times d_o = 30.62 \text{ mm}$$

12) Length of piston pin in the connecting rod bushing
l_1 = 45% of the piston diameter = 25.65 mm

13) Length of skirt

$$L_s = (0.6 \text{ to } 1.1)\, D$$

$$= 0.6 \times 57 = 34.2 \text{ mm}$$

The center of the piston pin should be 0.02 D to 0.04D above the centre of the skirt.

14) Total length of piston

L = Top land + ring section + skirt length

$$= h_1 + 4t_2 + 3h_2 + L_s$$

$$= 8.04 + 4 \times 1.6 + 3 \times 1.28 + 34.2$$

$$= 52.48 \text{ mm}$$

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MODELING OF PISTON

From all the geometries calculated for piston Design are modeled using Solidwork 2015.Designing and modeling of flywheel is done using SOLIDWORKS 2015. Solidworks is a solid modeler that makes use of parametric feature-based approach for creating models and assemblies. The following figures show the present as well as re-designed geometries of flywheel.

Fig 3: 3D model of piston without and with TBC Coating

COATING MATERIAL SELECTION

Thermal Barrier Coatings are used to provide a barrier to the flow of heat. Thermal Barrier Coatings (TBC) performs the important function of insulating components such as gas turbine and aero engine parts operating at elevated temperatures. Different TBC materials are short listed and best one is selected using weighted residual method. In Yittria Stabilized Zirconia (YSZ) is stands at the tops in terms of Low thermal conductivity and High Young's Modulus. The thickness coating on piston crown increases from 0.2 mm to 0.6mm to study nature of study at different coats.

Table I: Material properties of TBC

Materials	Thermal conductivity (W/m k)	Modulus of Elasticity (GPa)	Coefficient of Thermal Expansion (1/k)	Melting Temperature (k)
Zirconates	2.17	21	15.3×10^{-6}	2973
Yittria Stabilized Zirconia	2.12	40	10.7×10^{-6}	2973
Alumina	5.8	30	9.6×10^{-6}	2323

FINITE ELEMENT ANALYSIS

Amount of heat transfers through piston is calculated by using Finite Element Analysis software. ANSYS 15.0 is a Finite Element Analysis tools used to study the performance of the component. In this project, focus is study the amount of heat transfer and Temperature variation throughout piston surface. Finite element analysis is done on both uncoated piston and coated piston with different thickness. Define element size as 1mm for meshing of piston. Boundary conditions are Provide 600^{o}C temp on top surface of piston crown and convection along remaining surface with film coefficient of 0.0002w/mm^{2o}C and ambient temperature as 29^{o}C.

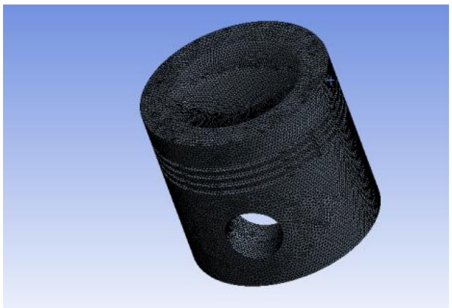

Fig 4: Meshing of IC Engine Piston

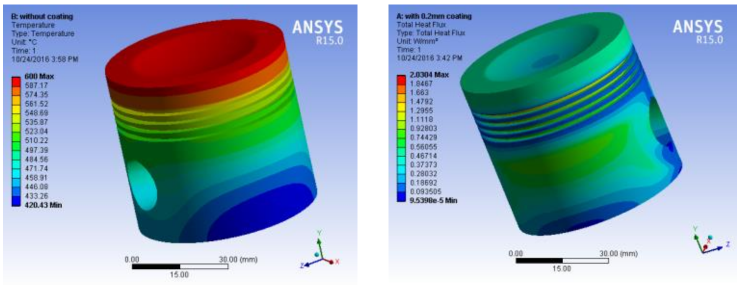

Fig 5: Temperature and heat flux distribution of uncoated piston

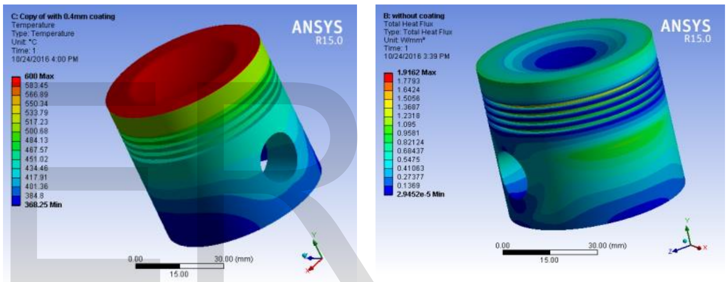

Fig 6: Temperature and heat flux distribution of 0.2 mm coated piston

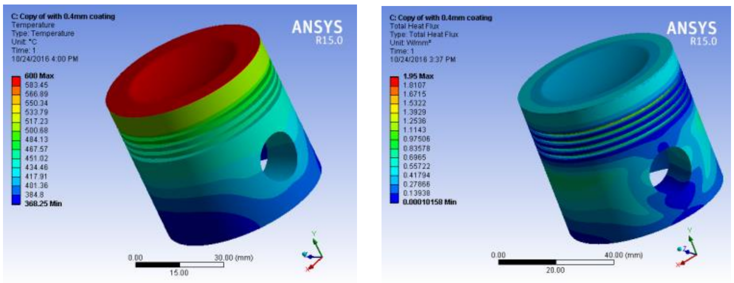

Fig 7: Temperature and heat flux distribution of 0.4 mm coated piston

RESULTS & CONCLUSION

Finite Element analysis results on piston crown with uncoated surface subjected to 600 c^{o} and coated piston crown surface subjected to lesser temperature. As the amount of coating increases temperature at the piston crown surfaces decreases. From the result it is concluded that the piston having YSZ coating on piston crown has less temperature and heat flux at top land as compared to uncoated piston resulting in saving in amount of heat which loses through piston. This saved energy increase the overall performance of the engine.

Table II: Temperature and heat flux distribution on piston crown

Piston Geometry	Temperature at top land (ºC)	Heat flux at top land (W/mm²)
Uncoated piston	600	0.95
Piston with 0.2mm coating thickness	560	0.74
Piston with 0.4mm Coating thickness	500	0.65
Piston with 0.6mm Coating thickness	473	0.467

REFERENCES

[1] Helmisyah Ahmad Jalaludina, Shahrir Abdullahb, Mariyam Jameelah Ghazalib, Bulan Abdullahc, Nik Rosli Abdullahc, "Experimental Study of Ceramic Coated Piston Crown for Compressed Natural Gas Direct Injection Engines", "The Malaysian International Tribology Conference 2013", MITC2013, 505.

[2] V. Gnanamoorthi and G. Devaradjane, "The effect of thermal barrier coating material in CI engine using higher fraction ethanol diesel blend", "Journal of Chemical and Pharmaceutical Research" , 2015, ISSN : 0975-7384, 7(2):416-422.

[3] M. L. S. Dev Kumar Sir & P. Poornima, "thermal analysis of diesel engine piston using 3-d finite element method", "International Journal of Manufacturing Technology and Industrial Engineering", Vol. 2, No. 2, July-December 2011, pp. 97-102.

[4] Ajay Raj Singh , Dr. Pushpendra Kumar Sharma, "Design, analysis and optimization of three aluminium piston alloys using FEA", "Int. Journal of Engineering Research and Applications", Vol. 4, Issue 1, Version 3, January 2014, pp.94-102, ISSN : 2248-9622.

[5] Ankit Manral, Kapil and Pankaj Kumar, "Comparing the total deformation result in static structural for ci engine piston coated with single TBC material Layer", "International Journal for Research in Emerging science and Technology ", volume-3, issue-7, jul-2016, E-ISSN: 2349-761.

[6] S.sathyamoorthi, M.prabhakaran, S.A.muhammed abraar, "Numerical investigation of ceramic coating on piston crown using finite element analysis", "International Journal of Scientific Engineering and Applied Science ", Volume-2, Issue-4,April 2016, ISSN: 2395-3470.

[7] Baalaganapathy Manohar, Miller Jothi, Udaykumar R, "The effects of thermal barrier coating on thermal stress and temperature distribution in a diesel engine piston for magnesia/yittria partially stablilized zirconia", "IJRMET" ,Vol. 6, Issue 1, Nov 2015-Apri l 2016, ISSN : 2249-5762.

[8] Sharukh K, Majo T Varghese, Steven Anto, Sijin E.B, Visakh K.K and Arun Raj A, "Experimental Analysis of YSZ Coating on an IC Engine Piston", "International Journal of Engineering And Science", Vol.6, Issue 4, April 2016, PP -106-111, ISSN: 2278-4721.

[9] Narsaiyolla Naresh, P.Sampath Rao, "Structural Analysis of a Ceramic Coated Diesel Engine Piston Using Finite Element Method", "SSRG International Journal of Mechanical Engineering", volume1, issue 5, September2014.

[10] K. Sridhar, R. Reji Kumar, M. Narasimha, "Thermal barrier Analysis in Diesel", "International Journal of Modern Engineering Research", Vol.3, Issue.3, May-June. 2013 pp-1435-1441, ISSN: 2249-6645,