

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 12, December 2018

Thermal analysis of coated and uncoated AlSiCTiB₂ Piston using ANSYS

Selvaraj.S¹, and Sugunthan.D²

¹ Assistant Professor, Alagappa Chettiar Government College of Engineering and Technology, Karaikudi, India

² PG scholar, Alagappa Chettiar Government College of Engineering and Technology, Karaikudi, India

ABSTRACT: In this work, Thermal analyses are performed on coated and uncoated piston of AlSiCTiB₂ with various coating thicknesses from 0.1 mm to 0.45 mm, excluding the bond coat layers. The main objective was to investigate and analyse the thermal stress distribution of coated and uncoated AlSiCTiB₂ pistons. Using SolidWorks software, the structural model of a piston was developed. Furthermore, the finite element analysis is done using the commercial finite element software ANSYS.

KEYWORDS: Diesel engine, Zirconium material, Mullite material.

I. INTRODUCTION

The combustion of gas on the top of the piston generates a considerable amount of heat, and the piston must also transmit heat to the cylinder walls, where it is absorbed by cooling water or air. The modern IC engines run around 5000 rpm and hence will generate considerable inertia force, which can be controlled if the piston is light weight. In an engine, its purpose is to transfer force from expanding gas in the cylinder to the crank shaft via a piston rod or connecting rod. It is the most important part in an engine; the piston endures the cyclic gas pressure and the inertial force at work, and this working condition may cause fatigue damage to the piston, such as piston side wear, piston head or crown cracks, and so on [1]. Although the researchers claim that diesel engines may be converted to alcohol engines without sacrificing efficiency or emission standards, in most of their studies, the detailed performance and combustion characteristics have not been disclosed. It is well known that the engines lose some of the energy developed in the combustion chamber through the cooling system. If this heat transfer is restricted by the ceramic materials, the engine's combustion performance can be improved [2]. The coating is applied to the piston head of a diesel engine, which increases the temperature of the top surface during the combustion of fuel and decreases the temperature difference between the piston surface and gas to reduce heat transfer. Some of the additional heat energy in the cylinder can be converted into useful work, increasing power and efficiency. Reducing heat transfer also increases exhaust gas temperatures, providing greater potential for energy recovery with a turbocharger. Additional benefits include protection of metal combustion chamber components from thermal stresses and reduced cooling requirements. The bond coat is applied to the substrate because of the adhesion of the ceramic material. NiCrAl is used as a bond coat, which has oxidant-resistant properties.

The thermal barrier coating consists of a ceramic top coat (MgZrO₃) as well as (CaZrO₃) or other coating materials like Mullite, ZrO₃, Al₂O₃, grey cast iron, and bond coat NiCrAl. The porous top coat, which is bonded to the bulk material via the bond coat, can protect the underlying air cooled material by significantly reducing the operating temperature. The metallic bond coat also serves to protect the material from oxidation and corrosion. The bond coat has been used to improve the corrosion resistance and prolong the lifetime of nickel-based superalloys at high operating temperatures. Thermal barrier coatings, mostly ZrO₂ and ZrO₂-based thick and thin films, are used because of the properties of these materials, such as oxidation, erosion, and corrosion resistance, high hardness, and thermal and chemical stability at cryogenic and high temperatures [3].

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 12, December 2018

Here, the materials for the piston that have been considered are Aluminium silicon carbide titanium diboride. In the second part, the modified model of the piston has been imported into a FEM software named ANSYS Workbench, and thermomechanical analysis has been done there. This thermomechanical analysis has been done on bare pistons, as mentioned above, as well as in Thermal pistons. In the last part of the work, thermal barrier coatings have been incorporated into the Aluminium silicon carbide titanium diboride piston with different coating materials and different coating dimensions. The coating dimensions have been referred from the work of M.Cerit et al., as mentioned in reference [4].

Lastly, all the results regarding temperature distribution from the analysis done on the bare pistons made of Aluminium silicon carbide titanium diboride (AlSiCTiB₂) and TBC pistons made of different coating materials and with different coating dimensions have been compared, and conclusions have been drawn. A work on the optimization of a piston has been done by Ch.Venkata Rajam et al. in the year 2013 [5].

In recent years, much research has been conducted on the design optimisation of bare pistons as well as pistons with thermal barrier coating. Ajay Ray Singh et al. [6] described the stress distribution and thermal stresses of three different aluminium alloy pistons by using the finite element method in the year 2014. In 2012, Yaochen Xu et al. [7] analyzed a piston using ANSYS software to get the deformation, thermal, and stress distribution of the piston.

II. METHODOLOGY

In the present study, a TBC has been deposited on the top surface of the piston. The piston has not completely coated the top surface. The outer region of the top surface of the piston has been coated with a low conductivity ceramic material, partially stabilized zirconia or other coating materials like Mullite, ZrO₃, Al₂O₃, Grey cast iron. Then, a 0.15 mm of NiCrAl bond coat and various thicknesses of ceramic MgZrO₃ or other coating material layers have been coated on the outer region of the top surface of the piston. The thicknesses of 0.1, 0.15, 0.25, 0.35, and 0.45 mm were taken into consideration in this investigation. Then, Steady state thermal analysis have been carried out to investigate the effect of thermal barrier coating on temperature gradients on the top surface of the piston. The thermomechanical analyses have been performed by using ANSYS.

Piston Material: Aluminium silicon carbide Titanium Diboride (Al-SiC10%-TiB25%)

Coating Material:

Bond coat:

- NiCrAl (Nickel Chromium Aluminium)

Top coat:

- CaZrO₃ (Calcium Zirconate),
- Mullite,
- ZrO₂,
- Grey cast iron,
- Al₂O₃

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 12, December 2018

MODELLING OF PISTON USING SPECIFICATION OF KIRLOSKAR ENGINE

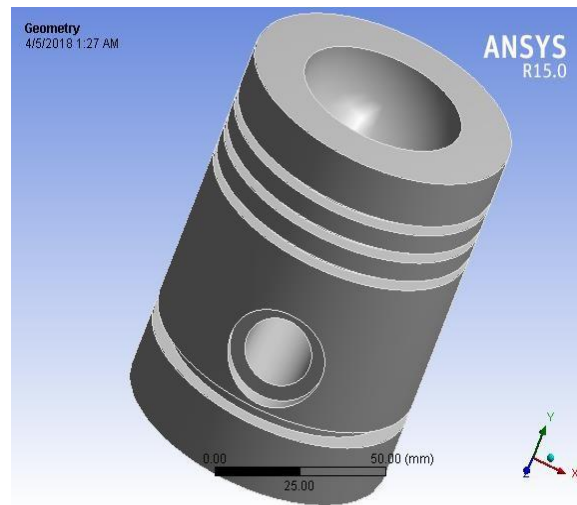


Fig 1: Modelling of piston

The main objective is to investigate and analyse the thermal stress distribution of the piston at the real engine condition during combustion process. The analysis is carried out to maintain the temperature concentration on the upper end of the piston.i.e. Piston head/crown using ANSYS software. Piston model is created in Solid works software using the calculated analytical dimension. Analysis of both the uncoated and coated piston is performed using the software namely ANSYS workbench15.

Table 1 - Boundary Conditions

Piston position	Temperature (T) °C	Convective heat transfer coefficient (h) w/m ² c
Combustion chamber	600-800	800
Lateral surface Temperature	400-550	230
Ring temperature	160-380	200
Piston skirt and pin temperature	85	60

MESH GENERATION:

The collection of nodes and elements form the finite element mesh. Each element is of simple shape for which the finite element program has information to write the governing equations in the form of stiffness matrix. The unknowns at each element are the stress and displacement at the node points, which are the points at which the elements are connected. The finite element program will assemble the stiffness matrix for the entire model.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 12, December 2018

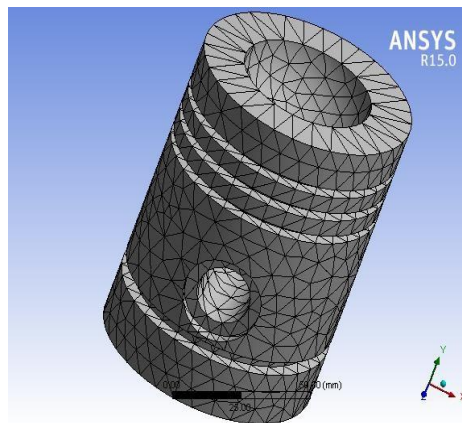


Fig 2: Meshed model of piston

This stiffness matrix is solved for the unknown displacements, stress given the known forces and boundary conditions. From the displacements at the nodes, the stress in each element can be calculated.

Table 2. Material properties of Coating Materials:

S.No	Parameter	AlSiC10%TiB ₂ 5%	ZrO ₂	Unit
1	Elastic Modulus	106050	100000	MPa
2	Poisson's ratio	0.314	0.22	--
3	Thermal conductivity	217.5	274.85	W/mK
4	Density	2850.5	5000	Kg/m ³

III. RESULTS AND DISCUSSION

Performance of the piston has been measured with respect to the temperature retained by the piston. Temperature at the top surface of the piston has been measured numerically with a FEA software name ANSYS Workbench. It has been shown from simulation that coated Aluminium Silicon Carbide Titanium Di-Boride piston of thickness range 0.70mm retain much more temperature than a 0.35mm coated and uncoated piston. So it can be said that a coated Aluminium Silicon Carbide Titanium Di-Boride piston of thickness range 0.70mm will perform much better than a 0.30mm and uncoated piston.

From the simulation following data has been generated.

- Case 1: Minimum temperature obtained in uncoated AlSiCtib₂ piston is 52.114 °C.
- Case 2: Minimum temperature obtained in coated AlSiCtib₂ piston with 0.35mm thickness is 43.557°C.
- Case 3: Minimum temperature obtained in coated AlSiCtib₂ piston with 0.70mm thickness is 39.106°C.

So it is clear that coating materials with different thickness can generate better temperature in the piston.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijrset.com

Vol. 7, Issue 12, December 2018

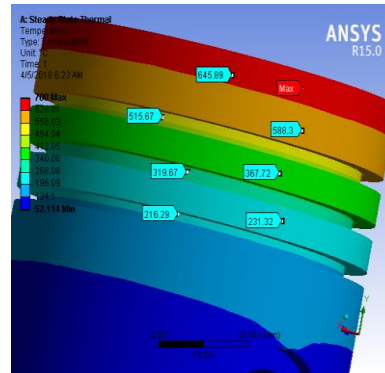
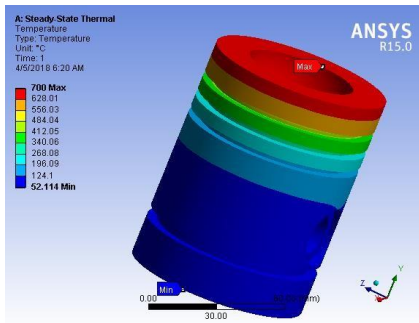


Figure: 3 (a)

Figure 3 (b)

Fig. 3 (a) and (b) Case 1: Thermal distribution of Uncoated Piston

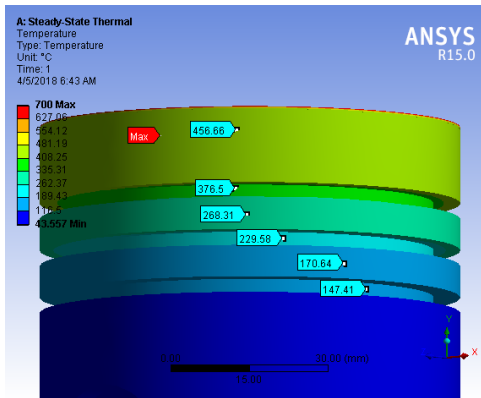
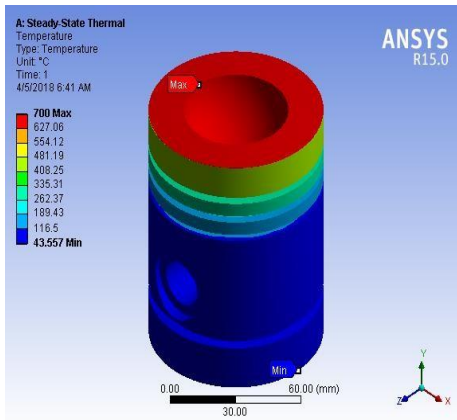


Figure: 4(a)

Figure: 4 (b)

Fig.4 (a) & (b) CASE 2: Thermal distribution of ZrO₂ coated Piston with Thickness: 0.35mm

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 12, December 2018

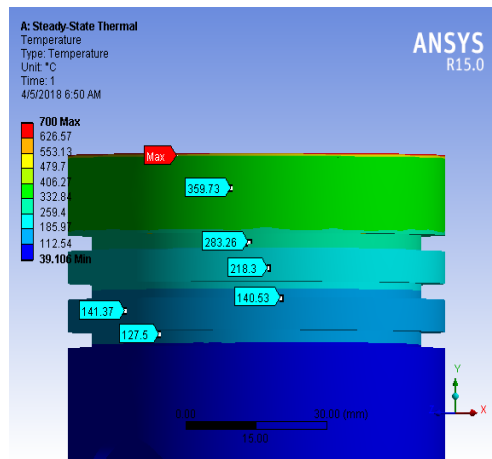


Figure: 5

Fig.5 CASE 3: Thermal distribution of ZrO₂ coated piston Thickness: 0.45mm

IV. CONCLUSION

From the analysed results, it was found that the coating on pistons with coating materials like ZrO₂ was investigated. The heat transfer properties of the AlSiCTib₂ piston were enhanced via a coating. This will further improve the hardness, structural grains, and thermal properties. Also, zirconia coatings will provide the most dramatic improvements over other coatings and uncoated materials in engine component applications where failure mechanisms that are driven by high temperatures and chemical diffusion are important for life. Due to the coating on piston materials, the hardness was increased, so the wear rate was reduced during the combustion process. Also, the corrosion resistance was increased due to the zirconia coating. Therefore, from the results, it is concluded that an increase in coating thickness increases the surface temperature and also reduces the conduction of temperature in the piston.

REFERENCES

1. Vinod kumar Yadav and Yogesh Mishra, "Design and Structural Analysis of Ceramic Coated Petrol Engine Piston Using Finite Element Method" in the International Journal of Innovative Research in Science, Engineering and Technology (2015).
2. S. Sunit Kumar Reddy and V. Pandurangadu, "Investigations On Ceramic Coated Diesel Engine With Brass Piston Material" Journal of Mechanical Engineering, Vol.ME 44, No. 1,2014
3. Lakhwinder Singh et al. "A Review on Detonation Gun Sprayed Coatings", Journal of Minerals & Materials Characterization & Engineering, 11(3), 243-265, 2015.
4. M. Cerit, V.Ayhan, A.Parlak,H.Yasar, "Thermal analysis of a partially ceramic coated piston: Effect on cold start HC emission in a spark ignition engine", Applied Thermal Engineering 31, 336-341,2011
5. Ch.VenkataRajam, P.V.K.Murthy, M.V.S.Murali Krishna, G.M.PrasadaRao, "Design Analysis and Optimization of Piston" International Journal of Innovative Research in Engineering & Science, Vol.1, (2), 2013.
6. Ajay Ray Singh, Pushpendra Kumar Sharma, G.M.Prasada Rao, "Design Analysis and Optimization of Piston, "International Journal of Innovative Research in Engineering & Science, Vol. 1(2), 2014.
7. YaochenXu ,Mo Yang, "Structure Design and Simulation of Titanium Engine Piston Based on Thermal-Mechanical Coupling Model". Master Thesis, Blekinge Institute of Technology, School of Engineering,October 2012.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 12, December 2018

8. Omotola Coker, "Coefficient of thermal expansion dependent on thermal stress analysis of thermal barrier coating using finite element model", Master of Engineering Thesis, College of engineering of southern university, 2012.
9. M. Foy, M. Marchese (1999), G. Jacucci, "Engineering plasma spray films by knowledge based simulations", proceedings of IFIP conference on, in: Arthur B. Baskin, et al., (Eds.), Cooperative Knowledge Processing for Engineering Design, Kluwer Academic Publishers, The Netherlands, 289
10. V. Sudhakar, "Performance analysis of adiabatic engine" SAE Technical Paper 840431, 1984.
11. M.H. Haselkorn, "Wear-resistant ceramic coatings for diesel engines", J. of Thermal Spray Technology Vol. 4, 1995.
12. Ekrem Buyukkaya, "Thermal analysis of a ceramic coating diesel engine piston using 3-D finite element method" Surface & Coatings Technology 202, 398-402, 2007.
13. Radoslav Plamenov Georgiev, "Design a four-cylinder Internal Combustion Engine" Project report Project and Engineering Department, Universidad publica de Naverra, 2011
14. Havstad PH, "A ceramic insert uncooled diesel engine", SAE Technical paper 860447, 1986.
15. P. Ramaswamy, S. Seetharamu, K. B. R. Varma, N. Raman and K. J. Rao, "Thermomechanical fatigue characterization of zirconia (8% Y₂O₃- ZrO₂) and mullite thermal barrier coatings on diesel engine components: effect of coatings on engine performance", Proc. Instn. MechEngrs; 214, 729- 742, 2000.