International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 7 Issue 7 Ver II || July 2018 || PP 57-65

Different Thermal Barrier Coatings on Modified Piston

Kumar. M[1], Balaji. K[2], Suresh. G[3]
[1]*(P.G. Scholar, Department of Mechanical Engineering, VEMU Institute of Technology, Andhra Pradesh, India)*
[2]*(Assistant Professor, Department of Mechanical Engineering, VEMU Institute of Technology, Andhra Pradesh, India)*
[3]*(Associate Professor, Department of Mechanical Engineering, VEMU Institute of Technology, Andhra Pradesh, India)*
Corresponding auther: Kumar. M

Abstract : *The project aims at to increase the performance of the engine by Thermal Barrier Coating (TBC) and to decreasing the heat lost to cooling water and also to increase the swirl for better combustion of Bio-diesel. It is mainly focusing on structural and thermal analysis of TBC coated piston. Design using Solid works and optimization of helical grooves using ANSYS software packages. Various tests were performed on the designed model with regards temperature, stress and deformation. Yttria-stabilized zirconia (YSZ) coating is comparable to 4mm alumina and 1mm mulite coating in terms of preventing the temperature. Finally, when compare the thickness of a ysz coating material is better to use on the piston head. The effect of varying compression ratios can be studied in detail so we can check withstanding capacity of the piston.*
Keywords – *ANSYS, Optimisation, Piston Head, Solid Works, Thermal Bearing Coatings.*

Date of Submission: 20-06-2018 Date of acceptance: 06-07-2018

I. INTRODUCTION

The big quantity of pollution emitting out from the exhaust of the car automobiles run on fossil fuels is also increasing as that is proportional to variety of cars. In view of heavy intake of diesel fuel concerned in not best delivery area but also in agricultural sector and also fast depletion of fossil fuels, the look for opportunity fuels has turn out to be pertinent aside from powerful gas utilization which has been the priority of the engine producers, customers and researchers involved in combustion a However, they possess whilst they're utilized in diesel engines, as they have low certain numbers (less than 10) and excessive latent heat of evaporation. That too maximum of the alcohol produced in India is diverted for Petro–chemical industries.

Pistons are generally made up of high alloy steels. Piston rings area units spherical bronze jewelers that match into grooves within the piston partitions and guarantee a comfortable suit of the piston within the cylinder. They help offer a seal to prevent leakage of compressed gases across the piston and to save you lubricating oil from entering the combustion chamber. In piston engines, a crankshaft allowed for the speedy rotation of a shaft through a rod set up on a transferring plug. With a propeller installed at the cease of the shaft, the engine ought to energy a plane. Sheathed internal a cylinder, it is able to strength the engine or automobile.

II. Literature Review

Ekrem Buyukkaya et al., (2017) conducted a study on Isothermal circulation in the piston body and heat flow rates to cooling water and air underneath the piston at four diverse engines burdens are portrayed for both with and without protection coating. The outcomes show a 6% decrease in heat misfortune through the piston with the utilization of a protection covering on the cylinder wall.

Dipayan sinha et al., (2017) focused on performance of an Engine relies up on different viewpoints. Engine performance can be improved by limiting weight of the automobile and boosting thermos mechanical ability of the Engine components, especially the piston.

Venkatareddy k et al., (2016) states that a piston is a component of Reciprocating engines, reciprocating pumps, gas compressors and pneumatic cylinders, among other comparative components .it is the moving part that is contained by a chamber and is made gas –tight by cylinder rings.

Sathish kumar et al., (2016) represents outline strategy for a piston for four stroke petrol engine for hero splendour-pro bike and investigation by its examination with original piston measurements. The plan methodology includes assurance of different piston dimensions using analytical method under greatest power condition.

Vaishali R.Nimbarte et al., (2015) exploration work is to investigate and analyse the stress distribution of piston at actual engine condition. The parameters used for the investigation is operating gas pressure, temperature and material properties of piston. In I.C. Engine piston is most perplexing and vital part for smooth running of vehicle piston ought to be in appropriate working condition.

B.A. Devan et al., (2015) this study, work is carried out to discover the thermal dispersion on various piston materials used. In IC engine, piston is a standout amongst the most essential and complex part, so it is imperative to keep up piston in good condition with a specific end goal to keep up the best possible working of the engine.

III. Types Of Pistons

1. Trunk pistons:

Trunk pistons are lengthy relative to their diameter. They act as a piston and top of the cylindrical crosshead. Because the connecting rod is angled for tons of its rotation, there may be additionally a side pressure that reacts alongside the side of the piston in opposition to the cylinder wall. A longer piston facilitates to aid this. Trunk pistons have been a common design of piston since the early days of the reciprocating inner combustion engine. They were used for both petrol and diesel engines, although excessive speed engines have now adopted the lighter weight slipper piston. Trunk pistons had been extremely large diameter and double-appearing. Their 'trunk' turned into a slender cylinder established in the centre of the piston.

2. Crosshead pistons:

Huge sluggish-pace Diesel engines may require additional help for the aspect forces on the piston. Those engines generally use crosshead pistons. Prevent outflow of compressed gases across the piston and to avoid wasting you grease from getting into the combustion chamber. The primary piston is chargeable for fuel sealing and contains the piston jewelers. The smaller piston is purely a mechanical manual. It runs inside a small cylinder as a trunk guide and also carries the gudgeon pin. The friction of both piston and crosshead may be most effective half of that for a trunk piston. Because of the additional weight of these pistons, they are now not used for high-speed engines.

3. Slipper pistons:

A slipper piston is a piston for a petrol engine that has been reduced in size and weight as much as possible. In the extreme case, they are reduced to the piston crown, support for the piston rings, and just enough of the piston skirt remaining to leave two lands so as to stop the piston rocking in the bore. A secondary benefit may be some reduction in friction with the cylinder wall, since the area of the skirt, which slides up and down in the cylinder is reduced by half. However, most friction is due to the piston rings, which are the parts which actually fit the tightest in the bore and the bearing surfaces of the wrist pin, and thus the benefit is reduced.

4. Deflector pistons:

Deflector pistons are utilized in -stroke engines with crankcase compression, wherein the gasoline goes with the flow inside the cylinder must be cautiously directed so one can provide efficient scavenging. Most engines today use Schnuerle porting instead. This places a pair of transfer ports in the sides of the cylinder and encourages gas flow to rotate around a vertical axis, rather than a horizontal axis.

IV. Various Materials Used For Pistons

Table 1: Properties of Different Metallic Alloys and Ceramics

Metal and alloys	Allowable Temperature (°C)	Strength (MPa)	Bulk Density (gm/cc)	Thermal Conductivity (W/m-K)	Specific Heat (J/kg-K)	Thermal Expansion Coefficient ($10^{-6}/K^{-1}$)	Young's Modulus (Gpa)
Aluminium	200	150	2.75	155	915	21	71
Cast iron	500	250-300	7.2	40-55	480	10-12	80-120
Superni-90	800	700-1100	8.0	12	461	13	200
Silicon Nitride	1300	300-800	2.8-3.3	8-35	710	3.0-3.5	160-300
silicon carbide	1400	350-550	3.0-3.2	20-60	650-1100	3.4-4.4	330-430
Zirconia Toughned	1000	200-1000	5.2-6.1	2.2-3.8	400-700	8.0-11.4	140-210
Aluminium Titanate	950	10-45	3.35	1.4-2.5	1000	3.5	20

V. Methodology

In this project, we considered CI engine piston and we have modified (grooves has been engraved on the piston head) the piston head, we have modeled the TBC coating and assigned different material ceramic material for it. We have modeled it in Solid Works 2013. A coupled analysis (steady-state thermal & static structural) analysis has carried out to evaluate heat transfer rate throughout the piston, temperature gradients on the piston head, equivalent stress &total deformation in the standard coated and non-coated modified pistons by using a finite element (FE) code called ANSYS.

For better result we considered the mesh size is 5mm and coarse mesh. All the elements of the standard piston are in hexahedral shape. Piston, ring and coating materials are assumed to be uniform and homogeneous, as uniform shapes and forms of elements play important role for high accuracy of the results. A path has modelled in ANSYS from the piston crown up to the piston base, so the heat transfer rate, stress and deformation can be analysed throughout the piston, so we easily determine the rate of heat transfer from the piston crown with and without coated piston.

Different thickness size of the Thermal Barrier Coating of three different materials (ALUMINA, YSZ, and MULITE) has considered analysing to evaluate the temperature variation along piston. The different sizes of Thermal Barrier Coating are mentioned in the above Table. The methodology of this project has 3 major part which are listed below

- Calculation of various data of the modified piston.
- Modelling of modified piston & coating
- Pre-processing of the model.

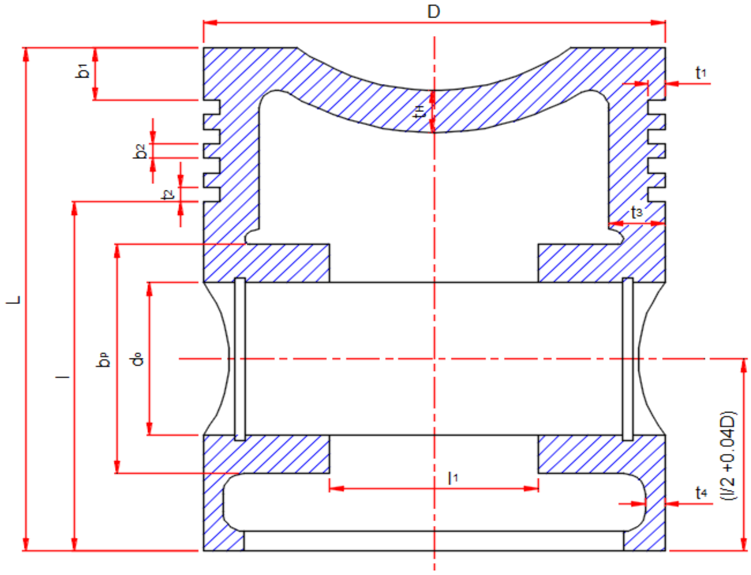


Fig1. Notationdata of the piston

Piston Design:

Table 2: Prerequisites data of a normal CI engine piston

The heat transfer coefficient of the piston head	$6*10^{-4}$
The heat transfer coefficient of the side wall	$5*10^{-4}$
The heat transfer coefficient of the inside wall	$1.5*10^{-4}$
Bore Diameter of Piston 'D'	87.5 mm
Material of Piston	Aluminum alloy
Initial Temperature of piston 'T_1'	25^0C,
Final temperature of Centre of Piston Head 'T_1'	280^0C,
the sidewall temperature 'T_2'	110^0C
inside wall temperature'T_3'	90^0C

Piston Head Or Crown 'T_h':

According to Grashoff's formula the piston Head is given by,

$t_H = \sqrt{(3p*D^2) / (16*\sigma_t)}$ in mm

Where, p = 5 N/mm^2 (Maximum gas pressure N/mm^2)

σ_t = 90 Mpa or N/mm^2 (Permissible bending stress (tensile) for the material of the piston in N/mm^2).

$t_H = \sqrt{(3*5*87.5^2) / (16*90)} = 8.93$ mm

Piston Rings:

1. Radial thickness of Piston t_1:

$t_1 = D\sqrt{(3*p_w/ \sigma_t)}$ in mm

P_W= 0.042 N/mm^2 (Pressure of gas on the cylinder wall)
σ_t = 110 N/mm^2 (Allowable bending (tensile) stress for cast iron rings)
t_1= 87.5√ (3*0.042/ 110) = 2.96 mm

2. Axial thickness of Piston t_2:
t_2= D/ (10 n_R) = 87.5/ (10*3) = 2.916 in mm
n_R = Number of rings.

3. Width of top land 'b_1':
b_1 = t_H to 1.2t_H = 1.2t_H = 1.2*8.93 = 10.716 mm

4. Width of other ling lands 'b_2':
b_2 = 0.75 t_2 tot_2 where as; t_2 = 2.916 mm

5. Piston Barrel:
Piston Barrel thickness't_3' = 0.03D + b + 4.5 mm b= t_1 + 0.4 mm
t_3 = (0.03*87.5) + (2.96+0.4) + 4.5 = 10.485 mm
Piston wall thickness 't_4' = 0.35 t_3 = 0.35*10.485 = 3.669 mm

6. Piston Skirt:
Length of the piston skirt 'l' = 0.8D = 0.8*87.5 = 70 mm
Total Length of Piston 'L' = Length of the piston skirt + Length of Ring Section + Top Land
The length of piston usually varies from D and 1.5D.

7. Piston Pin:
Diameter of piston pin 'd_o' = (πD^2/4) *p/ (p_{b1}*l_1) in mm
d_o = ($\pi 87.5^2$/4) *5 / (25*39.375) = 30.45 mm
p = 5 N/mm^2 (Maximum gas pressure N/mm^2)
p_{b1} = 25 N/mm^2
(Assume Bearing pressure of small end of the connecting rod bushing)
l_1= 0.45D =0.45*87.5 = 39.375 mm.
(Length of the piston pin in the bush of the small end of the connecting rod).
Piston Boss = 1.5 d_o = 1.5*30.45 = 45.814 mm.

8. Centre of pin:
Centre of pin is 0.02D to 0.04D above the centre of the skirt.
Centre of pin = 0.04D + 0.5l = (0.04*87.5) + (0.5*70) = 38.428 mm.

VI. MODELLING OF MODIFIED PISTON AND COATING

By using Solid Works 2013 software and considered all the data of the conventional CI engine piston as we can see it from the Fig. 1. We modified the piston head and engrave the helical grooves on it as it can be seen in Fig. 3. The helical grooves of the modified piston head help to generate the swirl motion of air-fuel mixture in the combustion chamber. Further the swirl motion of the air-fuel mixture is easily compressible and evacuated the combustion chamber more easily as compare to the normal piston.
Steps acquire while modelling the piston
1. Drafting
2. Revolve
3. Engraving the grooves
4. Modelling of coating of different thickness

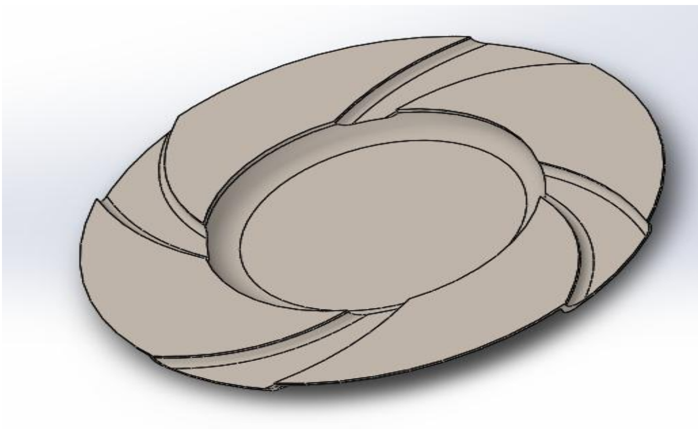


Fig. 2 Coating with thickness 0.5mm

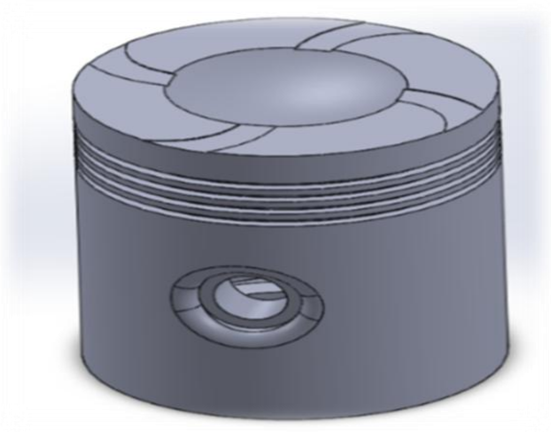


Fig. 3 Modified piston

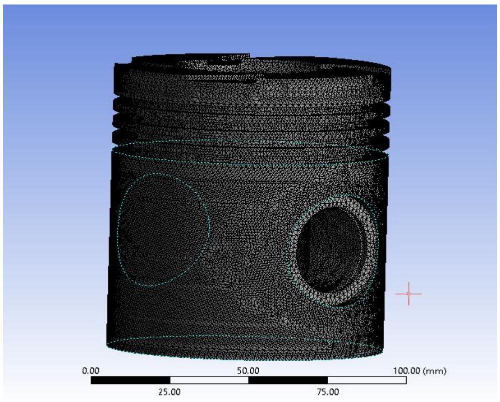


Fig. 4 Representation of the mesh

Thermal Boundary Conditions:

Heat applied on the various surface of the piston. The thermal boundary condition we have applied on the 3 surfaces as it is mentioned in the Table 3 below.

Surface consider	**Heat transfer mode**	**Coefficient of heat (10^{-4})**	**Temperature (^{0}C)**
Piston head	Convection	6	280
Side wall	Convection	5	110
Inside wall	Convection	1.5	90

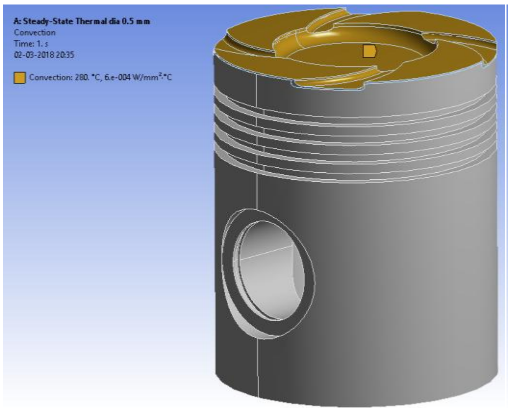


Fig. 5 Convection applied to the top surface wall

Fig. 6 Convection applied to the side surface

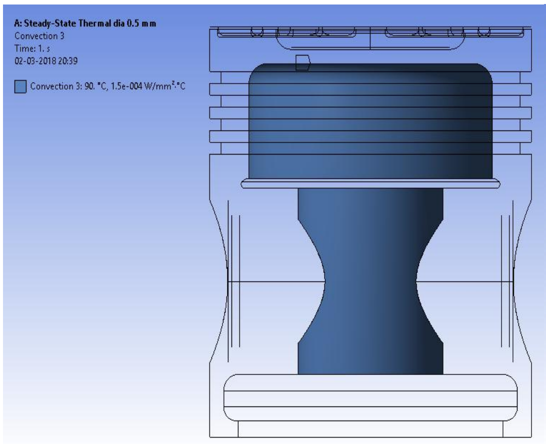


Fig. 7 Convection applied to the inside surface wall

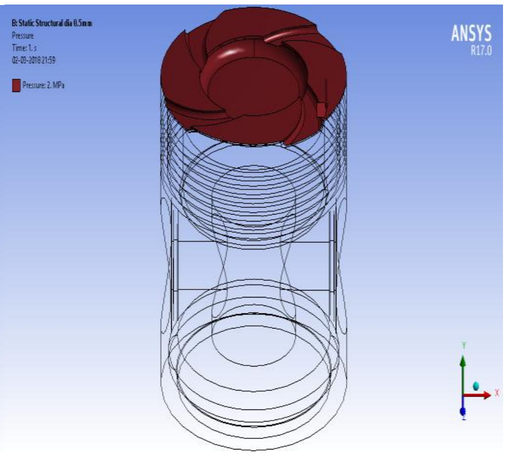


Fig. 8 Pressure applied on the piston head is 2MPa

VII. Result& Discussions

In this section we considered the evaluation of the temperature of the coating, equivalent stress, total deformation and heat transfer rate varying along the path.

Temperature Distribution: The following figure shows the temperature distribution of the piston obtained from ANSYS Software.

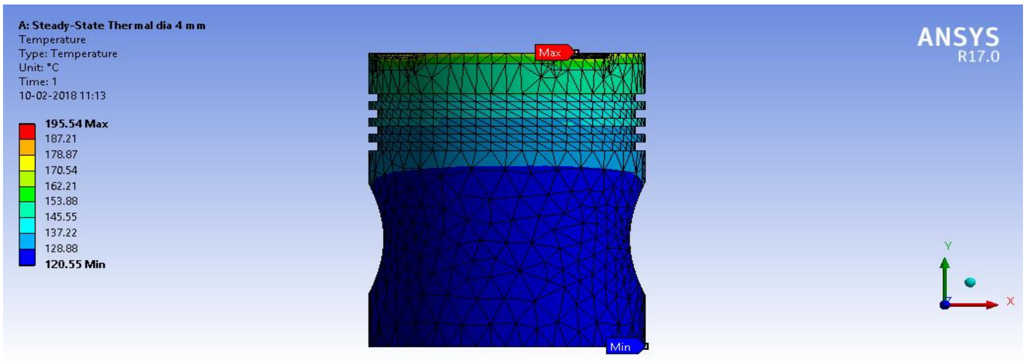


Fig. 9 Temperature distribution

Stress Distribution: The following figure shows the stress distribution of the piston obtained from ANSYS Software.

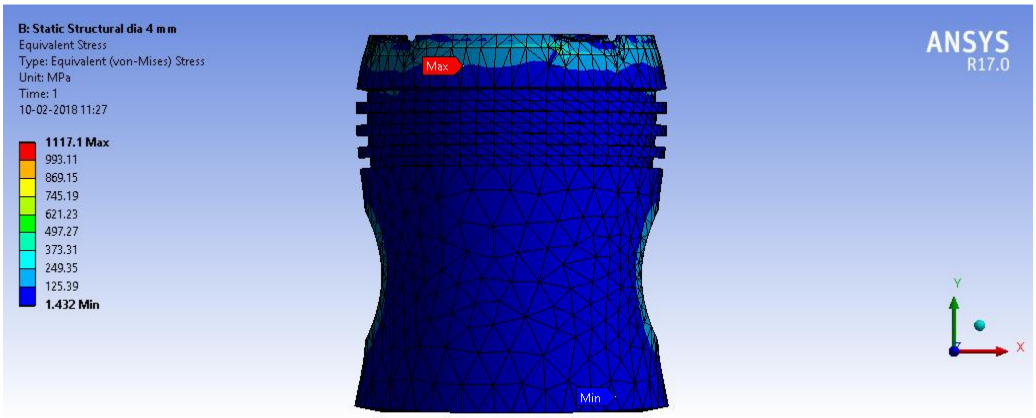


Fig. 10 Stress distribution

Total Deformation: The following figure shows the stress distribution of the piston obtained from ANSYS Software given below.

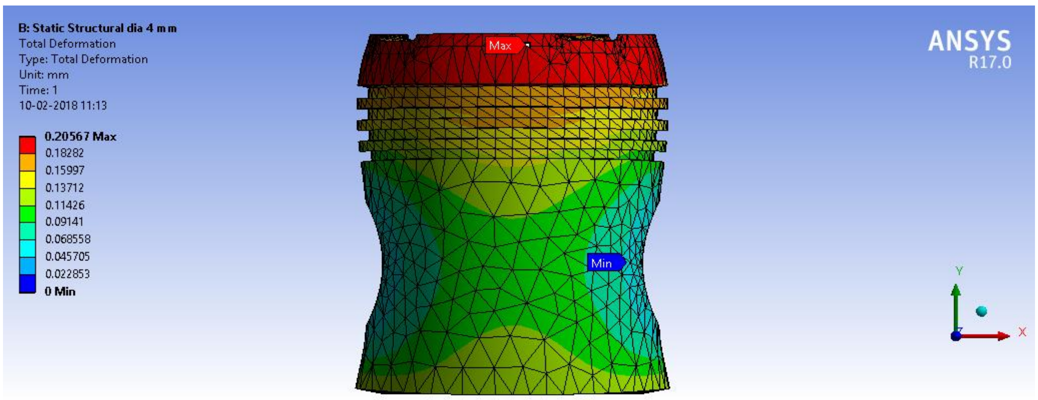


Fig. 11 Total deformation

Thermal analysis for ysz coating:

We can observe the variation of the temperature for the different coating thickness for the aluminum alloy piston. As we can see that as the coating thickness increases the temperature of the piston head increases because the thermal conductivity of the coating material is low due to which it does not allow passing the heat through it. Form Graph we can see that the heat transfer rate decreases as the path increases.Graph5.3 shows comparison of the modified piston with different sizes ysz coating on it, as we can see from the Graph5.3 the temperature is suddenly decreases up to 5mm then it gradually decreases. The maximum temperature data with different coating is mentioned

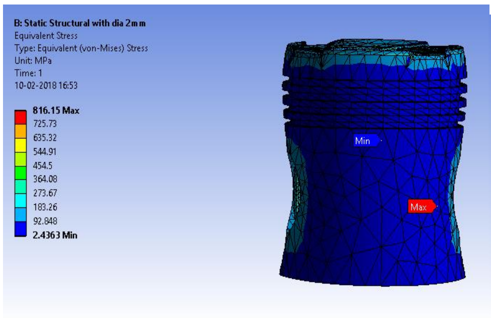


Fig. 12 2mm Aluminum coating

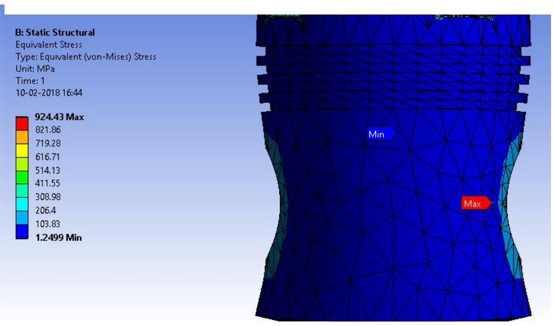


Fig. 13 3mm Aluminum coating

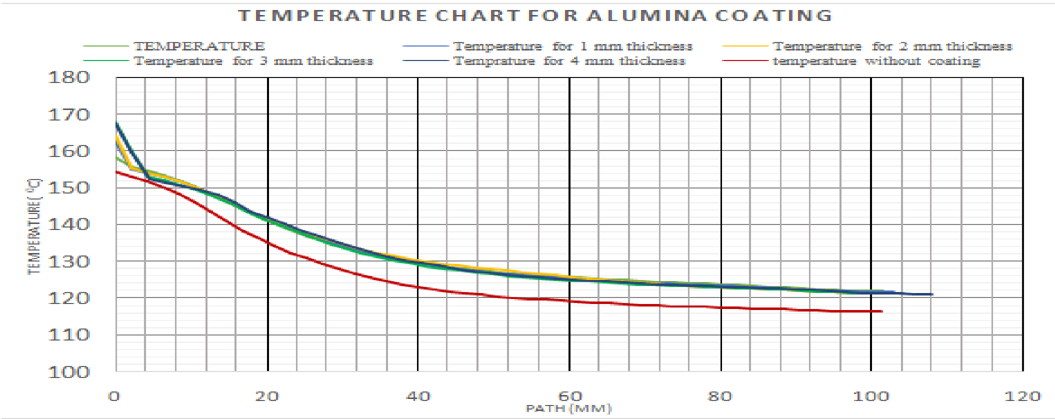
Table 4: The results of comparison between maximum temperature, total deformation and stress distribution.

Parameters materials	Piston head Temperature (^{0}C)	Total deformation (mm)	Von-misses stress (Mpa)
Without coating	154.34	$7.5*10^{-3}$	17.868
With ysz coating	218.98	0.15503	73.787
With mulite coating	184.49	0.1667	74.265
With alumina coating	167.74	0.15919	133.62

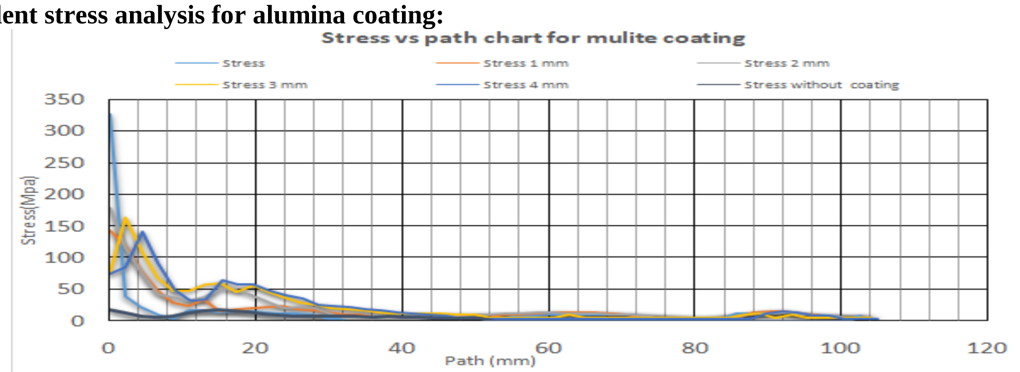
Equivalent stress analysis for mulite coating:

As we can analyse the stress variation for different thickness of the TBC which has been applied on the modified piston head. From the Graph we can analyze the stress varying along the path throughout the piston. We can see from the Graph. That as the path on the piston increases from top to bottom the Stress first increase and then decreases throughout the piston. The stress data with different thickness coating is mentioned

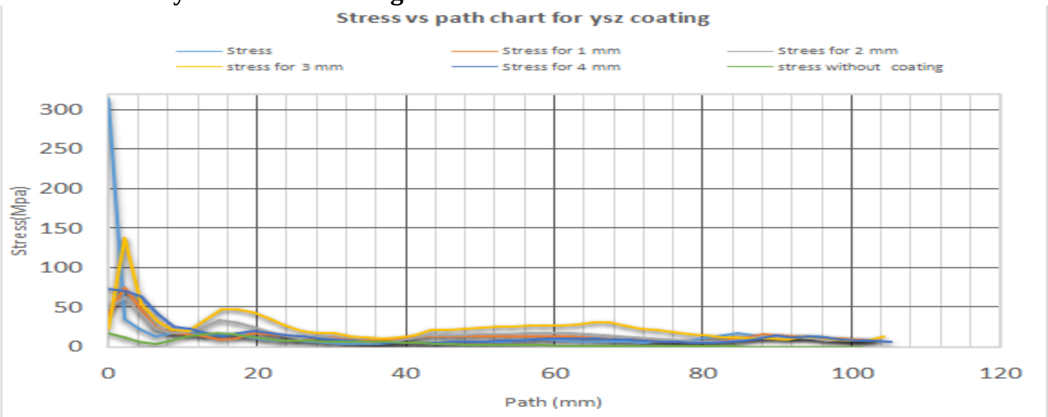
Thermal analysis for alumina coating:



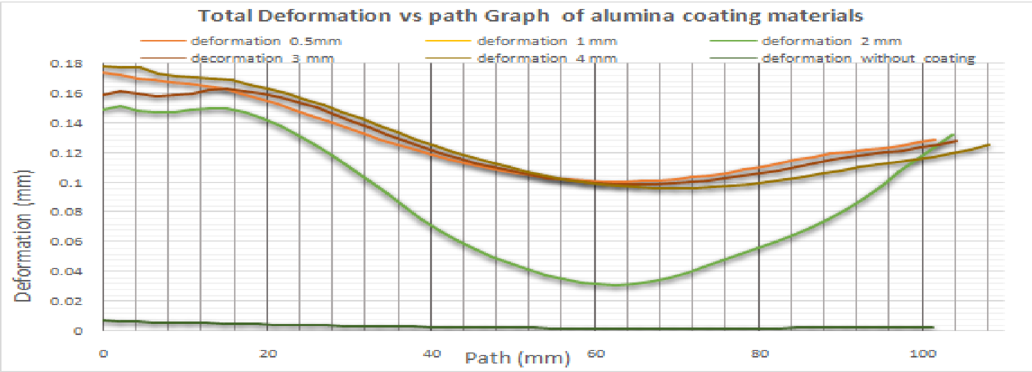
Equivalent stress analysis for alumina coating:



Equivalent stress analysis for YSZ coating:



Total deformation analysis for alumina coating:



VIII. Conclusion

By using above data, the following conclusion can be drawn.

- The deformation increases as the thickness increases.
- The stress is decreases as the thickness increases.
- The temperature increases as the thickness increases.
- The 0.5 mm thickness ysz coating material is suitable for 1 mm mulite and 4 mm alumina coating material in terms of preventing the temperature
- The deformation of 0.5 mm thickness ysz coating material is comparably quite similar to the other 0.5 mm thickness of other coating material.
- The stress due 0.5 mm thickness ysz coating material is very low as compare to the other coating material of the sane thickness.
- If we compare all the data, then we can say that the 2 mm thickness of an ysz coating material is better to use on the piston head.

References

[1]. X.Q.Cao, R.Vassen, and D.Stoever, Ceramic materials for thermal barrier coatings, Journal of the European ceramic society, 24(6), 2004, 1-10.

[2]. L.Taymaz, K.Cakir, and A.Mimaroglu, Experimental study of efficiency in a ceramic coated diesel engine, surface and coatings Technology, 200(4), 2005, 1-4.

[3]. Selman Aydin, and Cenk Sayin, Impact of Thermal Barrier Coating application on the combustion, performance and emissions of a diesel engine fuelled with waste cooking oil Biodiesel-diesel blends, computers &structures 136(15), 2005.

[4]. Ekrem buyukkaya, Tahsin Engin, and Muhammet Cerit, Effects of thermal barrier coating on gas emissions and performance of a LHR engine with different injection timings and value adjustments, Energy Conversion and Management, 47(9), 2006, 98-110.

[5]. Ekrem, and Buyukkaya, Thermal analysis of functionally graded coating AlSi alloy and steel pistons, International Journal of Engineering Trends and Technology, 202(16), 2000.

[6]. liker Turgut Yilmaz, Metin Gumus, and Mehmet Akcay, Thermal barrier coatings for diesel engines, International Scientific Conference, Gabrovo, 2010.

[7]. Marmara Gums, and Mehmet Akcay, Thermal barrier coatings for Diesel engines, International Scientific Conference, Gabrovo, 2010.

[8]. Muhammet cerit, Thermo mechanical analysis of a partially ceramic coated piston used in a SI Engine, surface and coatings Technology volume 205(11), 2011.

[9]. M.Cerit , V.Parlak , and 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(2), 2011.

[10]. A. R Bhagat, and Kedar chimote, Thermal Analysis and Optimisation of I.C. Engine piston using Finite element method, Surface and coatings Technology, 2012.
[11]. Mesut Durat, Murat Kapsiz, Ergun Nart, Ferit Ficici, and Adnan parlak, The effects of coating materials in SI engine design, Materials & Design, 36, 2012.
[12]. O.P.Singh , Yogesh Umbarkar , T.Sreenivasulu ,E. Vetrivendan , M. Kannan, and Y.R. Babu, Piston seizure investigation: Experiments, modeling and Future challenges, Engineering Failure Analysis, 28, 2013.
[13]. K. Karuppaswamy, M.P Mageshkumar, T.N Manikandan, and J Naga Arjun, The Effect of Thermal Barrier coatings on Diesel Engine performance, APRN journal of science and Technology, 3(4), No.4, 2013.
[14]. Irwin Osmond Toppo, CFD Analysis of Combustion characteristics of Jathropha in Compression Ignition Engine, International Journal of Engineering Research &Technology, 2(10), Issue 10, 2013.
[15]. S.Srikanth Reddy , and sudheer prem kumar, Thermal analysis and optimization of I.C. Engine piston using Finite element method, International Journal of Innovative Research in Science ,Engineering and Technology, 2(12), 2013.

Kumar. M "Different Thermal Barrier Coatings on Modified Piston "International Journal of Engineering Science Invention (IJESI), vol. 07, no. 07, 2018, pp 57-65