THERMO MECHANICAL STRESS ANALYSIS OF S.I ENGINE PISTON PROVIDING TBC ON TOP SURFACE

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Abstract- The main aim of TBC (thermal barrier coating) is to reduce heat flux into the piston and to protect the piston from thermal stress as well as corrosive attacks due to fuel contaminants. In this study the coating material is **$MgZrO_3$ ceramic materi**al is taken for coating the top surface of the piston. The thermo mechanical stress analysis of S.I Engine piston coated on top surface with ceramic material has been studied by using finite element method on ANSYS software in which SOLID226 element is used for coupled field analysis. When no coating is provided on top surface of piston, the von mises stress obtained is 138.68 MPa and the deflection is 0.065 mm. the value of principal stresses and deflection are calculated at various coating thickness. When full coating is done on piston top, the von mises stress obtained is minimum at 1 mm thickness. The value of stress is 123.10 MPa and the deflection is 0.0565 mm under the same boundary condition and thermo-mechanical loading.

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Keywords – TBC, Principal stresses, Thermal Stress, Deflection, material property, SI Engine, Engine Dimensions, ANSYS Software

I. INTRODUCTION

A piston is a cylindrical engine component that slides in the cylinder by force acting on the piston head due the combustion of gases. The piston acts as the movable end of the combustion chamber and must withstand pressure fluctuations, mechanical load and thermal stress. Pistons are generally made of aluminum alloy for excellent and lightweight thermal conductivity. During the expansion or power stroke the compressed fuel air mixture is burnt under high pressure about 7 to 8 MPa in S.I engines. But the average pressure is about 3 to 4 MPa which act throughout the cycle.

The piston head is directly in contact to the hot compressed gases. During the explosion of fuel gases instantaneous temperature is nearly 2500-2000^{0}C and the average temperature is near about 600^{0}C throughout the cycle. This combined effect of pressure and temperature causes maximum stress and deformation. The combined effect of gas pressure and thermal stress is known as thermo mechanical stress.

There are various advantages of doing the coating of ceramic material on top surface of piston. The main aim of TBC (thermal barrier coating) is to reduce heat flux into the piston and to protect the piston from thermal stress as well as corrosive attacks due to fuel contaminants. There are various thermal barrier coating material. In this study the coating material is **$MgZrO_3$ ceramic materi**al is taken for coating the top surface of the piston. So that the generated normal stress and deflection is decreases during the engine cycle. The thermo mechanical stress analysis of S.I Engine piston coated on top surface with ceramic material has been studied by using finite element method on ANSYS 12 software in which SOLID226 element is used for coupled field analysis.

II LITERATURE REVIEW

Muhammet Cerit & Mehmet Coban[2014]In this paper performance of a diesel engine is improved by using plasma-sprayed magnesia-stabilized zirconium coating on an aluminum piston under thermo mechanical loading. Effects of the coating thickness on temperature and thermal stress distributions are investigated and obtained results are compared with an uncoated piston by means of the finite element method

N.D Mittal [2013] In this paper the design procedure for a piston for 4 stroke S.I engine For hero honda bike is discussed. The calculated values are compared with the original piston dimensions used in hero Honda splendor bike. In the convention design of piston, the various piston dimensions using analytical method under maximum power condition are determined. On basis of calculated values, Piston model was designed and the combined effect of mechanical and thermal load is taken into consideration. The basic data of the engine specification are taken from a located engine type of herobike.

Michael Anderson Marr et al. (2009) this paper shows the effect of coating thickness on the combustion temperature, stress distribution and the temperature gradient in the coating and the interfacial stresses. The bond coat plays an important role between the aluminum alloy and the ceramic coating in reducing the internal stresses. Internal stress may arise between substrate and top coat due to thermal shock and Thermal shock resistance of a ceramic coating depends on the thermal expansion coefficient, thermal conductivity and young'smodulus

Jesse G. Muchai et al. (2007).According to this paper main aim of applying the TBCs on top surface of piston is to reduce the heat flux into the piston and to protect the piston from the corrosive attacks due to fuel contaminants, thermal stresses and reducing emission

III. PROPOSED METHODOLOGY

3.1 objective-

A lot of researchers have done their research in different coating plate material problems. The research gap is found in the literature survey and the present work is framed in the objectives of the work. A lot of researchers have done their research in different coating plate material problems. The research gap is found in the literature survey and the present work is framed in the objectives of the work.

The piston dimensions calculated by using standard formulas and the normal stresses and deformation are calculated by using ANSYS Software At various thickness of full Coating of ceramic material ($MgZrO_3$) on top surface

3.1 conventional design of piston-

3.1.1 Engine specification:-

Table -3.1: piston material specifications

Engine Power **(P)**	7.5hp @ 8000rpm
Maximum pressure **(Pmax)**	90 Bar /9MPa
Cylinder bore **(D)**	50 mm
Stroke **(L)**	50 mm
Compression ratio	9:1
Air fuel ratio @ max. power condition	12:1
Petrol density	719.7 kg/m^3
Calorific value of petrol	47000 kj/kg

3.1.1 a) Thickness of piston head on the basis of strength criterion:-

According to strength criteria piston head can be treated as flat circular plate of uniform thickness fixed at outer edge and subjected to uniformly distributed gas pressure over the entire surface area.

According to Grashoff's formula, the thickness of piston head is given by:-

$$T_h = D\sqrt{\frac{3}{16}} = D\sqrt{\frac{3\ 9}{16\ 85}} = 7.04 \text{ mm}$$

b) Thickness of piston according to heat dissipation

$$T_h = \left[\frac{}{12.56\ (-)}\right] 10^3$$

Where, The value of thermal conductivity for aluminum alloy, K = 175 W/m/^{0}C

The values of permissible temperature difference, (T_c-T_e) = 75^{0}C for aluminum alloy

The amount of heat conducted through piston head (H) is given as

$$H = (C \times HCV \times m \times BP) \times 10^3$$
$$= 0.05 \times 47000 \times 0.069 \times (7.5.746) \times 10^3$$
$$= 907229.25W$$

Where, C is the ratio of heat absorbed by piston to the total heat developed in the cylinder (C=5% or C=0.05)

3.1.2 Radial width of ring (b):-

$$b = D\sqrt{3} = 50\sqrt{3}\ \frac{0.42}{85} = 1.925 \text{ mm}$$

3.1.3 Depth of ring groove:-

It given as 1.03b to1.04b = 1.04*1.925=2.002 mm

3.1.4 Axial thickness of piston rings (h):-

h= 0.7b to b (in mm) = 1.07 mm

3.1.5 Width of the top land (h1):-

$h_1 = T_h$ to $1.2\ T_h$ so take h_1 = 7.04 mm

3.1.6 Length of piston:-

L= Width of top land + length of ring section + length of skirt

Length of skirt is taken as 0.5D = 0.5*50 = 25mm L = 7.03+3*1.05+2*2+25 = 37.18mm

3.1.7 Calculated value of dimension of piston

The values are calculated analytically by using the standard design formulas and obtained values of piston are listed below in the table 3.2

Table 3.2: calculated dimension values

Parameter	calculated value
Piston length	37.18 mm
Piston diameter	50 mm
Pin hole external diameter	14.13 mm
Pin hole internal diameter	8.478 mm
Piston ring axial thickness	1.07mm
Radial thickness of ring	1.925mm
Depth of ring groove	2.02mm
Gap between the rings	2.5mm
Top land thickness	7.04mm
Thickness of piston at top	7.04mm
Thickness of piston at open end	1.8mm

3.2 ANALYSIS OF S.I ENGINE PISTON

3.2.1 Modeling of piston:-

Modeling of Piston is done in the ANSYS WORKBENCH and dimensional modal is shown below. Dimension of model is in mm In this the dimensional model is made on ansys workbench and then it is transported to ANSYS APDL and the volume view of the piston is made.

3.2.2 Chemical composition of piston material:-Generally Al-Si-Cu-Mg Alloy is used for manufacturing the S.I engine piston. Alloy consists of many materials. It the mixture of many materials and these are mixed by weight percentage. The chemical composition of piston material is listed in table 3.3

Table 3.3 : Chemical composition of piston material

Component	Wt. %
Al	90.7 - 94.7
Cr	Max 0.1
Cu	3.8 - 4.9
Fe	Max 0.5
Mg	1.2 - 1.8
M	0.3 - 0.9
Si	Max 0.5
Ti	Max0.15
Zn	Max 0.25
Other, total	Max 0.05

IV. EXPERIMENT AND RESULT

1. Various stress and deflection of piston

4.1.1 Piston without coating

It is the Al alloy piston and there is no coating on the top surface. The various values are calculated by applying the boundary condition and applying max pressure 9 MPa and Temperature 600 ^{0}C

Table 4.1 : Various parameters are calculated for piston without coating

RESULTS	VALUES
Von mises stress (MPa)	138.68
Deflection (mm)	0.065

Von Mises Stress and Deflection without coating figures are shown below

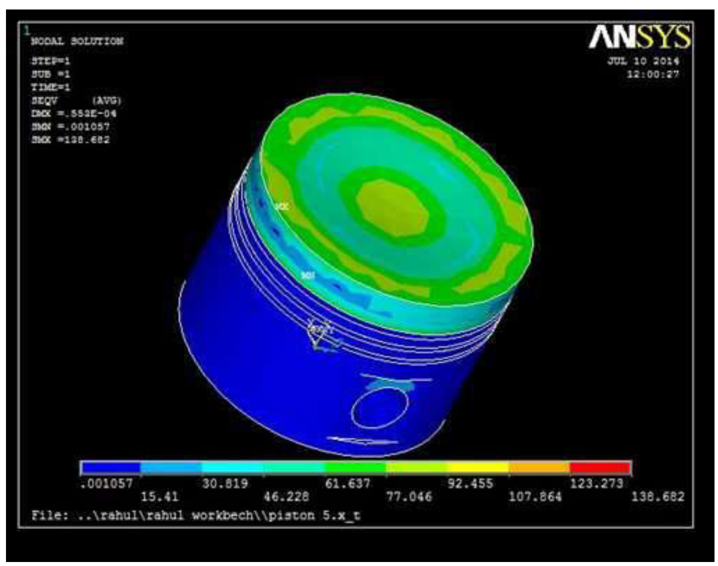


Figure – 4.1: Von mises stress

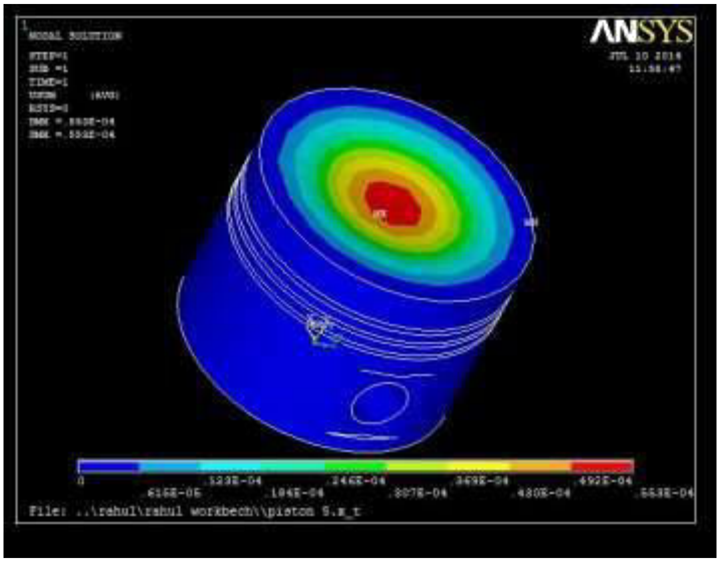


Figure – 4.2 : Maximum Deflection

4.1.2 Piston with coating layer of ceramic (mgzro3) on the topsurface :-

At various thickness of coating of ceramic material, the von mises stress and deflection are obtained and listed below in the table. First the coating is applied on full top surface and in other case partial coating is done. The value of stresses and deflection are calculated at various coating thickness and tried to optimize

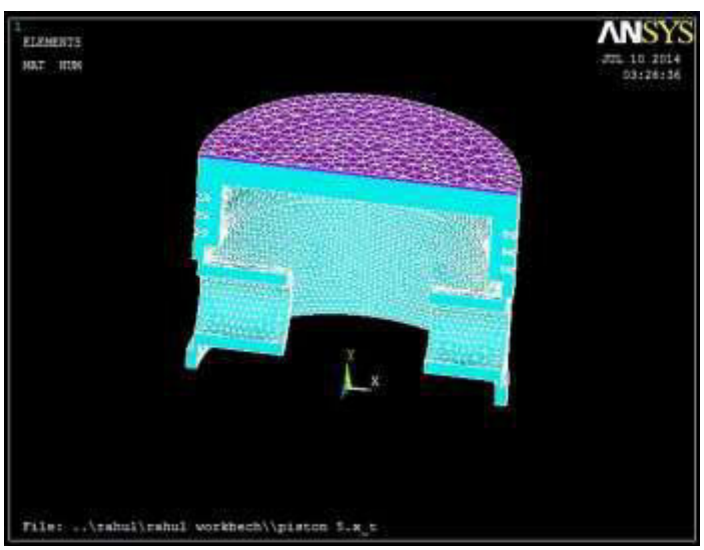


Figure – 4.3 : Sectional mesh View with full coating on top surface

4.1.2 Von misesstres and Deflection

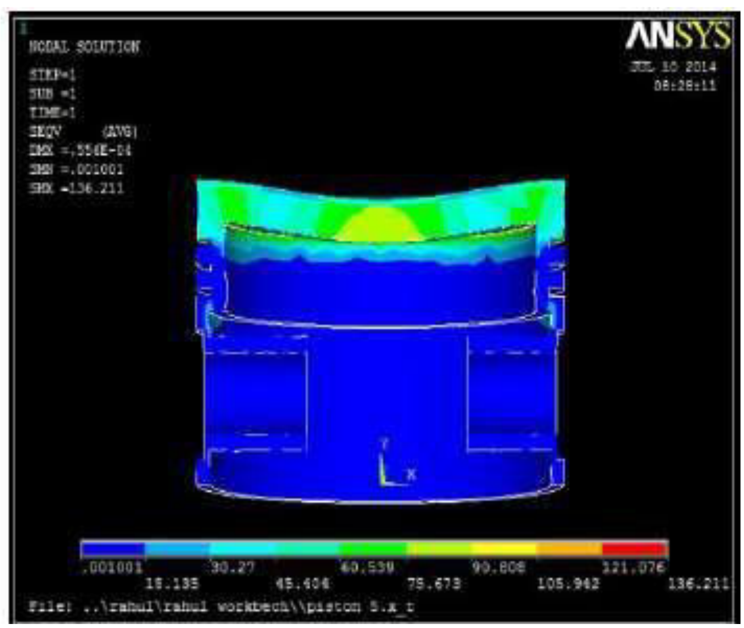
The result obtained by applying boundary condition and thermo mechanical loading on the ANSYS 12 software are listed in table below.

Table 4.2 : Various stresses when top surface of piston is coated by ceramic material

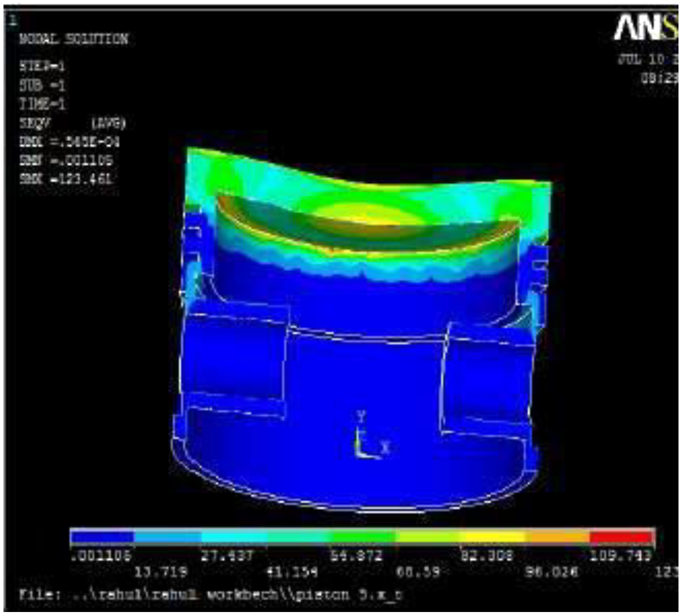
S. NO.	THICKNESS OF THE LAYER (mm)	DEFLECTION (in mm)	VON MISES STRESS (MPa)
1	0.6	0.0556	136.21
2	0.8	0.0560	124.94
3	1	0.0565	123.40
4	1.2	0.0646	127.01
5	1.4	0.0660	132.42

The results obtained listed in above table are shown below by the figures.

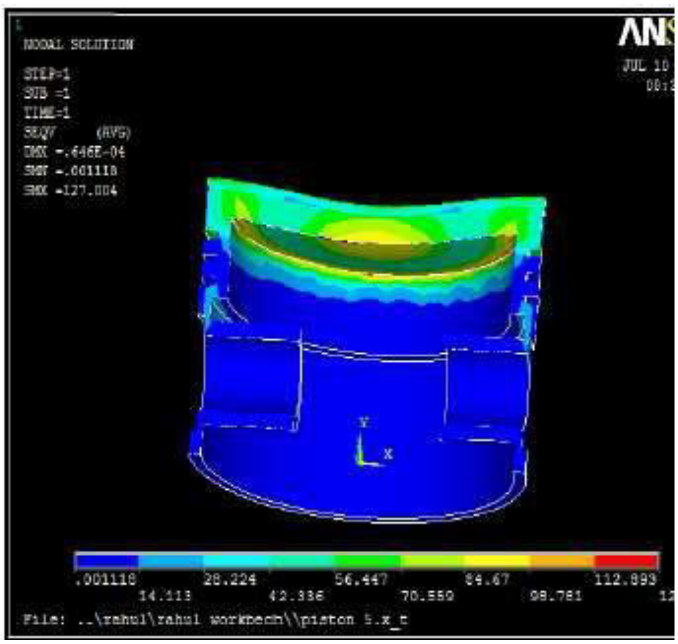
Von Mises Stress at Various coating thickness of ceramic material on top surface



Coating thickness 0.6mm



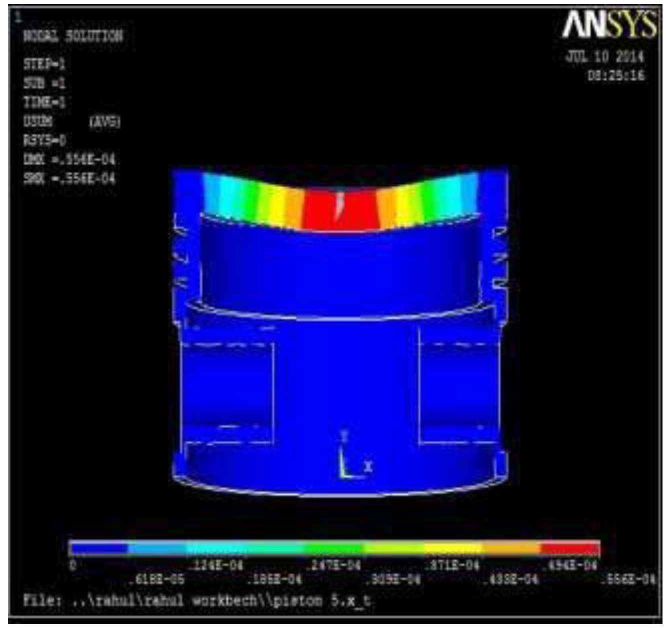
coating thickness 1mm



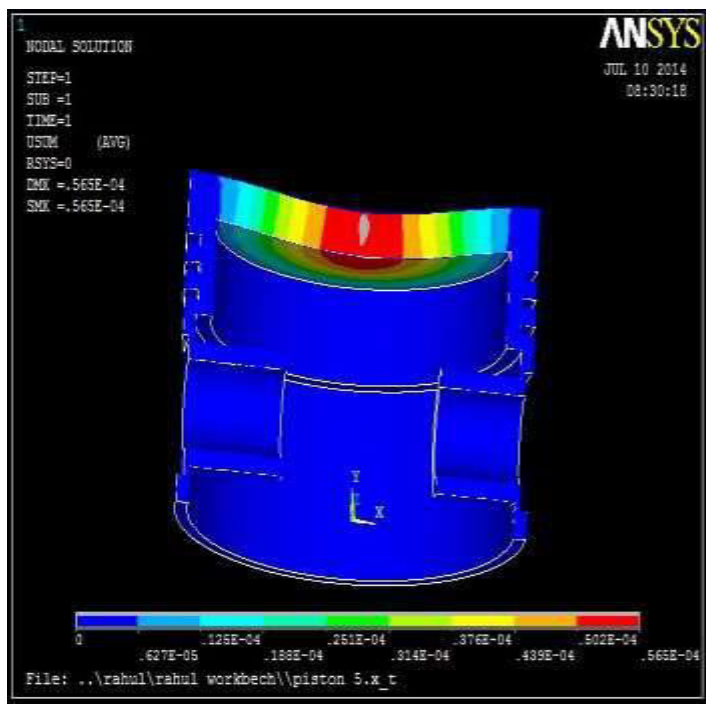
Coating thickness 1.2mm

it is clear from the obtained rersults that the von mises stress decreases with coating thickness and it gives the minimum value of von mises at 1 mm. after that normal stress again increases. So from the above results in can be concluded that coating of 1mm thickness is beneficial because at this condition the von mises stress is minimum. The value of normal stress at 1 mm coating thickness is 123.40 MPa which very less than the stress generated in the piston without coating under same loading and boundary condition

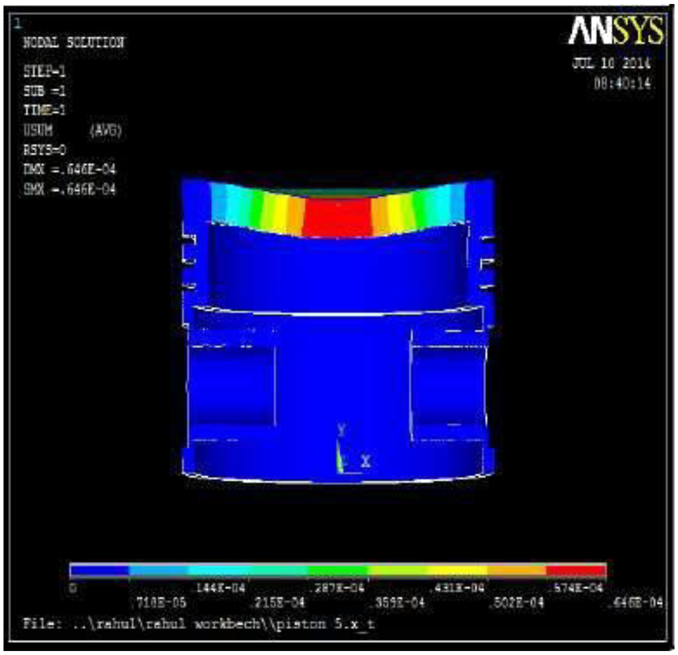
Deflection at Various coating thickness of ceramic material on top surface



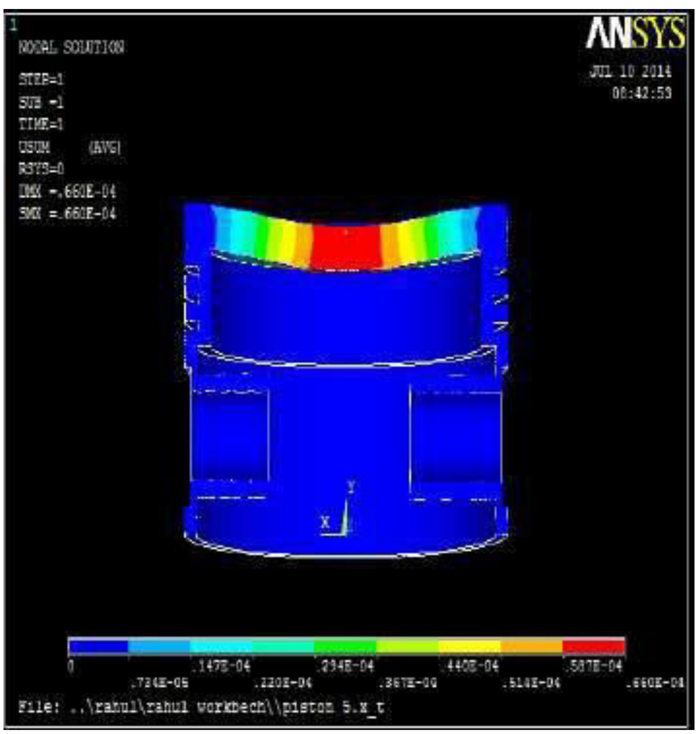
coating thickness 0.6mm



coating thickness 1mm



coating thickness1.2mm



coating thickness 1.4mm

From the above results it is observed that as the coating thickness increases the deflection also increases.. The coating thickness is provided in such a manner that the length of piston remains constant in each case the deflection is very less. At 1 mm coating thickness the deflection is 0.055 mm.

V CONCLUSION

On the basis of given engine specification, the dimension of S.I engine piston is calculated analytically by using standard formulas. The calculated values are compared with the actual dimensions and there is very less differences. Than the model analysis of piston is done and the various value of normal stress and deflection were calculated on ANSYS APDL software.

Here two cases are discussed for calculating von misses stresses and deflection

1) When no coating is provided on top surface of piston

2) When full coating of ceramic material ($MgZrO_3$ is provided on top surface of piston.

There are various advantages of doing the coating of ceramic material on the piston the coating material are called TBCs (thermal barrier coatings) Main aims of TBCs on piston surface is to reduce the heat flux into the piston and to protect the piston from thermal stresses as well as corrosive attacks due to fuel contaminants and helps in reducing emissions. The TBC coating thickness has an effect on the combustion the temperature gradient and the stress distribution in the coating.

When no coating is provided on top surface of piston, the von mises stress obtained is 138.68 MPa and the deflection is 0.065 mm. When full coating is done on piston top, the von mises stress obtained is minimum at 1 mm thickness. The value of stress is 123.10 MPa and the deflection is 0.0565 mm. under the same boundary condition and thermo-mechanical loading.

So we can conclude that when full coating is done, the von mises stress generated is minimum at 1 mm coating thickness i.e 123.10 MPa and deflection is 0.0565 mm

This is the optimum thickness of ceramic material ($MgZrO_3$) which should be done on the piston for getting the better result.

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BIOGRAPHY

Rahul Singh is working as Head of Department and an Assistant Professor in the Department of Mechanical Engineering at Government Engineering College Nowgong District Chhatarpur M.P, where He has been working since 2016. He completed his B.Tech in 2010 from Krishna Engineering College Ghaziabad U.P which is affiliated to Uttar Pradesh Technical University Lucknow and M.tech in 2014 from National Institute of Technology Bhopal. He has more than 6 years of teaching experience. His area of specialization is stress and vibration analysis. He has taught the subjects mechanical vibration, dynamics of machines, strength of materials and manufacturing technology and Machine Design. He served as Assistant Professor at Parul University Vadodara in Department of mechanical engineering from June 2014 to Dec 2015.