Thermo Mechanical Analysis of a Piston with Different Thermal Barrier Coating Configuration

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Abstract— *Performance of an automobile depends on various aspects. Engine performance can be enhanced by minimizing weight of the automobile and maximizing the thermo mechanical capability of the engine components, especially the piston. In the present work a piston has been analyzed numerically with a FEA software named ANSYS Workbench to evaluate its thermo mechanical capability under a predefined thermal and structural load. To enhance the performance of the engine, weight of the piston has been kept minimum by optimizing different dimensions. In this process of optimization the stress has also been kept under a certain limit and this process of optimization has been done in a software named SolidWorks. To improve the thermal performance of the piston different Thermal Barrier Coatings (TBC) have been imposed and their thermo mechanical performance have been evaluated through couple-field analysis in ANSYS. Many data has been generated regarding different dimensions of coatings with different material properties. These data may be used in further research to optimize material property and dimensions of Thermal Barrier Coating.*

Keywords— *FEA, ANSYS, TBC, Thermo-mechanical analysis, Solidworks, Optimization.*

I. INTRODUCTION

Enhancement of the efficiency of an engine always been a subject of research since the development of automobile. Efficiency of an engine depends on many factors. It depends upon the design of cylinder head where swirling of air-fuel mixture increases the probability of maximum burning of fuel and reduces the percentage of the unburnt fuel in the exhaust. Efficiency of an engine also depends upon the heat retaining capability of the piston material. But the contradictory fact is that if a material retains much heat its thermal stress will be increased drastically. For this reason it always been a matter of research to find out optimum coating dimensions to get the best heat retention without increasing the stress much in the piston cinder assembly. Before the nitty gritty of the present work is to be discussed, few theoretical processes in piston design have been discussed below.

An engine is a device which transforms one form of energy into another form. Most of the engines convert thermal energy into mechanical work and therefore they are called Heat engines. The heat engine can be an internal or external combustion engine.

An internal combustion engine (IC engine) is an engine in which the combustion of fuel, such as petrol or diesel, takes place inside the engine cylinder. In petrol engine, air and petrol is mixed in correct proportion in the carburettor and then passed into the cylinder. The mixture is ignited by means of a spark production by the spark plug. Since the ignition is done by spark, the petrol engine is called Spark Ignition engine (SI engine). In the diesel engine, the air entrapped in the cylinder during the suction stroke is highly compressed during compression stroke. This compression increases the air temperature beyond the self-ignition temperature of diesel. The desired quantity of diesel in the form of fine spray is then admitted into the cylinder near the end of the compression stroke. The turbulent hot air ignites the diesel. Since the ignition is done by compression of air, the diesel engine is called Compression Ignition engine (CI engine).Compared with petrol engines, the diesel engines are more economical due to high thermal efficiency.[1]

In an external combustion engine, on the other hand, the fuel is burnt outside the engine For example, in a steam engine or a steam turbine, the heat generated due to the combustion of fuel is employed to generate high pressure steam which is used as the working fluid in a reciprocating engine or a turbine [2]

Piston is considered to be one of the most important parts in a reciprocating engine in which it helps to convert the chemical energy obtained by the combustion of fuel into (useful work) mechanical power. Piston is the moving component that is contained by a cylinder and is made gas-tight by piston rings. It is either moved by the fluid or it moves the fluid which enters the cylinder. Internal Combustion Engines are used in most of automobiles and mechanical machineries. In Internal Combustion Engines there are many reciprocating parts which are responsible for giving the motion to the engine. The piston is apart without which no internal combustion engine can work i.e. piston plays a vital role in almost all types of vehicles. The main function of the piston of an Internal Combustion Engine is to receive the impulse from the expanding gas and to transmit the energy to the crankshaft through the connecting rod. Engine pistons are one of the most complex components among all automotive and other industry field components. The engine can be called the heart of a vehicle. There are lots of research works proposing, for engine pistons, new geometries, materials and manufacturing techniques, and this evolution has undergone with a continuous improvement over the last decades and required thorough examination of the smallest details. Notwithstanding all these studies, there are a huge number of damaged pistons. Damage mechanisms have different origins and are mainly wear, temperature, and fatigue related. The fatigue related piston damages play a dominant role mainly due to thermal and mechanical fatigue, either at room or at high temperature. The piston must also disperse a large amount of heat from the combustion chamber to the cylinder walls. Internal Combustion Engines employ trunk type pistons which are open at one end and consist of flowing components [1]:

Piston Head or crown: -It is the top portion of the piston which withstands the gas pressure inside the cylinder. It has flat, concave or convex shape depending upon the construction of combustion chamber.

Piston Rings: - They act as seal and prevent the leakage of gas past the piston. Piston rings are also called compression rings.

Oil Scraper ring: -It prevents the leakage of lubricating oil past the piston into the combustion chamber.

Piston Skirt: -It is the lower part of the piston below the piston rings which acts as bearing surface for the side thrust exerted by the connecting rod.

Piston Pin: - It connects the piston to the connecting rod. It is also called Gudgeon pin or wrist pin.

Piston is essentially a cylindrical plug that moves up & down in the cylinder. It is equipped with piston rings to provide a good seal between the cylinder wall & piston. Gas sealing is achieved by the use of piston rings. These are a number of narrow iron rings, fitted loosely into grooves in the piston, just below the crown. The rings are split at a point in the rim, allowing them to press against the cylinder with a light spring pressure. Two types of ring are used: the upper rings have solid faces and provide gas sealing; lower rings have narrow edges and a U-shaped profile, to act as oil scrapers. There are many proprietary and detail design features associated with piston rings.[3]

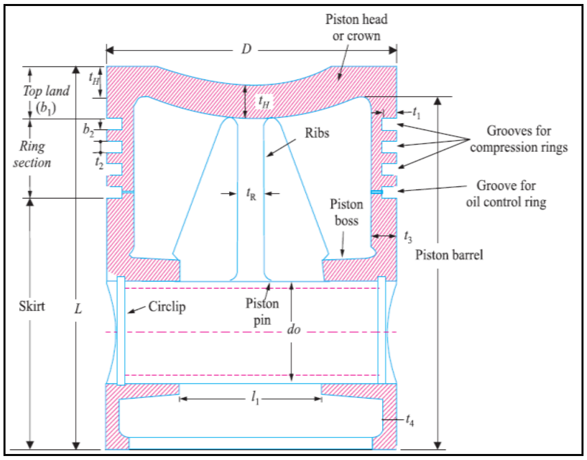

Fig. 1 Piston for IC Engine [3]

The top of the piston is called head or crown and parts below the ring grooves is called skirt. Ring grooves are cut on the circumference of the upper portion of the piston. The piston bosses are those reinforced sections of the piston designed to hold the piston pin or wrist pin.

A. Functions:

a. To reciprocate in the cylinder as a gas tight plug causing suction, compression, expansion and exhaust strokes.

b. To receive the thrust generated by the explosion of the gas in the cylinder and transmit it to the connecting rod.

c. To form a guide and bearing to the small end of the connecting rod and to take the side thrust due to obliquity of the rod.

Piston in an IC engine must possess the following characteristics:

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

B. Piston Design

The pressure applied on piston head, temperatures of various areas of the piston, heat flow, stresses, strains, length, diameter of piston and hole, thicknesses, etc., parameters are taken into considerations.

Design Considerations for a Piston:

In designing a piston for an engine, the following points should be taken into consideration:

It should have enormous strength to withstand the high pressure.

It should have minimum weight to withstand the inertia forces.

It should form effective oil sealing in the cylinder.

It should provide sufficient bearing area to prevent undue wear.

It should have high speed reciprocation without noise.

It should be of sufficient rigid construction to withstand thermal and mechanical distortions.

It should have sufficient support for the piston pin [8].

Procedure for Piston Design parameters:

The procedure for piston designs consists of the following steps:

Thickness of piston head (t_H)

Heat flows through the piston head (H)

Radial thickness of the ring (t_1)

Axial thickness of the ring (t_2)

Width of the top land (b_1)

Width of other ring lands (b_2) [8]

II. PROBLEM DEFINITION

In the present work the job has been done in three steps. In the first part of the job in the present work, a piston has been modelled in Solidworks with dimensions mentioned by Ch.Venkata Rajam et al in their work [5]. The piston has been imposed with a load of 2 MPa and it has been optimized for minimum volume and stress not more than 90 MPa. Here the materials of the piston which have been considered are Aluminium Alloy and Titanium. In the second part, the modified model of the piston has been imported in to a FEM software named ANSYS Workbench and a Couple field or Thermo Mechanical analysis has been done there. This thermo mechanical analysis has been done on bare pistons as mentioned above as well as in Thermal Barrier Coated piston also.

In the last part of the work, Thermal Barrier Coatings have been incorporated in the Aluminium alloy piston with different coating materials and with different coating dimensions. The coating dimensions have been referred from the work of M. Cerit et al as mentioned in reference [25].

Lastly all the results regarding temperature distribution and stress distribution from the thermo mechanical analysis done on the bare pistons made of Aluminium alloy (Al Si) and Titanium and TBC piston made of different coating material and with different coating dimensions have been compared and conclusions have been drawn.

III. REVIEW OF FEW PREVIOUS WORK

Many works have already been done on the enhancement of engine efficiency by incorporating thermal barrier coatings with different materials and with different dimensions.

A work on optimization of a piston has been done by Ch.VenkataRajam et al in the year of 2013 [5]. They have considered a piston from a practical example which has been considered in the present work as a base model. Many work has been done on the design optimization with bare pistons as well as pistons with thermal barrier coating in recent years. Ajay Ray Singh et al. [6] described the stress distribution and thermal stresses of three different aluminium alloy pistons by using finite element method in the year of 2014. Shuoguo Zhao [7] presented a structural analysis of the piston in 2012. He analysed the piston by Pro-E software to improve and optimize the structure of the piston. Aditya Kumar Gupta et al. [8] analysed the piston, which were consists of two steps. They were Designing and Analysis. S. Srikanth Reddy et al. [9] in 2013 investigated the thermal analyses on a conventional (uncoated) diesel piston. In 2012 Yaochen Xu et al.[10] analyzed a piston by ANASYS software to get the deformation, thermal and stress distribution of the piston. S. Bhattacharya et al. [11] worked on a piston of a two stroke spark ignition internal combustion engine which had maximum power of 6.5 kW at 5500 RPM. They were Designing and Analysis. They used Aluminium 4032 alloy as the piston material. Dr. L.N. Wankhade et al. [12] measured the stress and temperature distribution on the top surface of a piston. The structural model of the piston would be developed using CATIA V5 software. Then they imported the CAD model into the Hyper Mesh for geometry cleaning and meshing purpose. Amit B. Solankiet al. [13] described design analysis and optimization of hybrid Piston for 4 stroke single cylinder 10 HP (7.35 kW) diesel Engine. They used high strength cast steel for piston crown and light alloy like aluminium alloy for piston wall. Using FEM they investigated the stress distribution of piston and analyzed the actual engine condition during combustion process. To avoid the failure of the piston, the stresses due to combustion were considered. Sasikiran Prabhala et al. [14] replaced the steel components with aluminium components to reduce the weight. The strength of aluminium components was not enough compared to steel components. Therefore, they were taking the aluminium alloy because the aluminium alloy exhibits the strength like the steel. Deovrat Vibhandik et al. [15] compared the behavior of the combustion engine pistons which were made of different type of materials under thermal load. Geometrical model of the piston was developed by CAD software. The model was based on the actual engine piston of TATA MOTORS four stroke diesel engine. Vaishali R. Nimbarteet al. [16] investigated and analyzed the stress distribution of piston at actual engine condition. In their paper, pressure analysis, thermal analysis and thermo-mechanical analysis of the piston was performed. For analyzed the piston they used operating gas pressure, temperature and material properties of piston as parameter. Piston was analyzed using boundary conditions, which includes pressure on piston head during working condition and temperature distribution from piston head to skirt. K Venkateswara Raoet al. [17] designed a 5B.H.P diesel engine piston. They modeled the piston using Pro-E software. They used Cast Aluminum, Aluminum MMC and Brass as piston material. Structural analysis was done on the piston by applying the pressure to determine the strength of the piston using 3 materials. Thermal analysis was done to find out the temperature distributions, heat transfer rate of the piston. Vinod Yadavet al.[18] illustrated design procedure for a piston for 4 stroke petrol engine for Hero bike. They analysed by the comparison with original piston dimensions which was used in bike. They considered the combined effect of mechanical and thermal load while determining various dimensions of the piston. Kethavath Vishalet al [19] worked with the design and analysis of piston. Here the piston design, analysis and the manufacturing processes were studied. Purpose of the investigation was the measurement of piston transient temperature at various points on the piston, from cold start to steady condition and comparison with the results of finite element analysis. Dilip Kumar Sonar et al [20] designed a piston using CATIA V5R20 software. Complete design was imported to ANSYS 14.5 software and analyzed. Aluminium alloy was selected for structural and thermal analysis of piston. Hitesh Pandey et al [21] studied the pressure due to expanding combustion gases in the combustion chamber space at the top of the cylinder which generate thermal stresses due to presence of heat involved on the reciprocating masses. They worked with the use of different materials for IC engine piston and a comparative study was made to achieve the best possible result. A. R. Bhagat et al. [22] described the stress distribution of piston for four stroke engine. The main objectives were to investigate and analyze the thermal stress distribution of piston at the real engine condition during combustion process. Using finite element analysis technique, they presented the mesh optimization to get the higher stress and critical region on the piston. P. Carvalheira et al. [23] compared two different materials for the engine piston. One of the materials was Aluminium Alloy A390-T5 and another was Ductile Iron 65-45-12.They compared the two materials with the help of Finite Element Analysis (FEA) and chose the best suited material for piston. To predict the thermal and mechanical stresses on the piston, a number of FEA were done and thus they optimized the piston shape. Muhammet Cerit[24]described temperature and stress distributions in a partial ceramic coated spark ignition (SI) engine piston. He investigated the effects of coating thickness and width on temperature and stress distribution and made a comparison with results from an uncoated piston. He observed the coating surface temperature increase with increasing the thickness in a decreasing rate. With 0.4 mm coating thickness surface temperature of the piston was increased up to 82 °C.

M. Cerit et al. [25] investigated the effect of partially thermal barrier coating on piston temperature distribution and cold start HC emissions of a spark ignition (SI) engine numerically and experimentally. They performed thermal analysis for both standard and coated pistons by using ANSYS. They used a single cylinder, water cooled SI engine for both standard and coated cases. The result of their analysis shown that the surface temperature of the coated piston part was increased up to 100◦C, which leads to an increase in air fuel mixture temperature in the crevice and wall quenching region. Thus, cold start HC emissions considerably decrease compared to the standard engine without any degradation in engine performance. Maximum decrease in HC emissions was 43.2% compared to the standard engine.

IV. FEA MODELLING AND VALIDATION

In this section a previous work has been validated with different software and then few modifications have been done on the different configurations of the Thermal Barrier Coating (TBC) on the piston head. A detailed methodology on the work progress has been discussed here.

Optimization of the piston has been done using solid works software to improve the Design specifications and it has been observed that the optimized values satisfy the value which has been derive from the optimization using ANSYS in reference [5].The optimization which has been done over here is multi objective optimization and the objectives Function are mass minimization and stress limitation below 90 MPa.

Objective Function: Minimize mass

Subject to constraints:
Maximum Von-misses stress<Allowable or design stress
Following parameter where scope for material removal

- Radial Thickness of the ring
- Axial Thickness of the ring
- Thickness of the Barrel
- Width of the Top Land
- Width of other ring lands

Optimization Methodology followed

- At first, a piston has been created in Solid works with the dimensions determined by empirical formula using few input parameter like piston diameter and length which has been taken from reference [5].
- Then the material Al-Si alloy has been assigned as piston material.
- Next, the simulation option has been selected from toolbar.
- New study has been selected followed by study advisor.
- Fixer has been imposed to the hole of piston pin in both sides.
- External pressure of 2 MPa has been applied to the piston head.
- Then fine mesh has been created with 5 mm element size.
- After creating mesh, solution has been done.
- Next, Create new design study has been selected for optimization methodology.
- There 3 optimization parameters has been added which are variables, constraints and goals.
- In variable part, top land thickness, radial thickness of ring, axial thickness of ring, ring land and piston barrel thickness have been taken as input from which the material can be removed. Here, minimum value, maximum value and steps for calculation are also incorporated for solution.
- In constraints part, Maximum Von-misses stress < Allowable or design stress i.e. 90MPa
- The goal of the optimization has to minimize the mass of piston.
- Then solution has been allowed to optimize the piston dimensions.
- After optimization, it is checked whether Maximum Von-misses stress is less than Allowable or design stress.

TABLE I
PARAMETER FOR AL-SI ALLOY PISTON

SL. No.	Parameter	Before Optimization	After Optimization
1	Volume	997033.80 mm3	743225.30 mm3
2	Radial thickness of the ring(t1)	5.24 mm	3.75 mm
3	Axial thickness of the ring(t2)	5 mm	3.75 mm
4	Thickness of barrel(t3)	14.34 mm	9.5 mm
5	Width of the top land(b1)	10.84 mm	10 mm
6	Width of other ring lands(b2)	4 mm	3 mm
7	Von-misses stress	52.5 MPa	67.3 MPa

The length of the piston (152 mm) and diameter (140 mm) of the piston has been fixed and changed the other dimensions using optimization. The radial thickness of the piston has affected more as it is very small in size and the temperature and heat flow are very high to this size of thickness. Before optimization value has been given as 5.24 mm and after optimization the value has been obtained as 3.75 mm. The axial thickness of the piston ring before optimization has been given as 5 mm; it has been changed to 3.75 mm after optimization, since the more and more heat and stress applied through groves as it is very near to the head of the piston. The thickness of the barrel before optimization has been given as 14.34 mm. It has much affected in variation of size after applying pressure and temperature loads and has been changed to 9.5 mm after optimization. The thickness of barrel has been reduced by 34%.The width of the top land has not much affected while comparing with the thickness of the barrel. The initial value i.e., before optimization has been given as 10.84 mm and has been changed after applying pressure which has been directly applied on the piston head. The value after optimization has been obtained as 10 mm. The width of the other lands i.e., near piston rings are 4mm in size and has changed due to pressure and heat applied on rings through groves. The value after optimization has been obtained as 3 mm. Width of other ring lands of the piston has been reduced by 25%. The volume of piston before optimization is 997033.80 mm^3 and after optimization is 743225.30 mm^3. The volume of the piston has been reduced by 25%.The mass of the piston before optimization is 2.76 kg and after optimization is 2.05 kg using Al-Si alloy. The mass of Piston has been reduced by 25% after optimization.

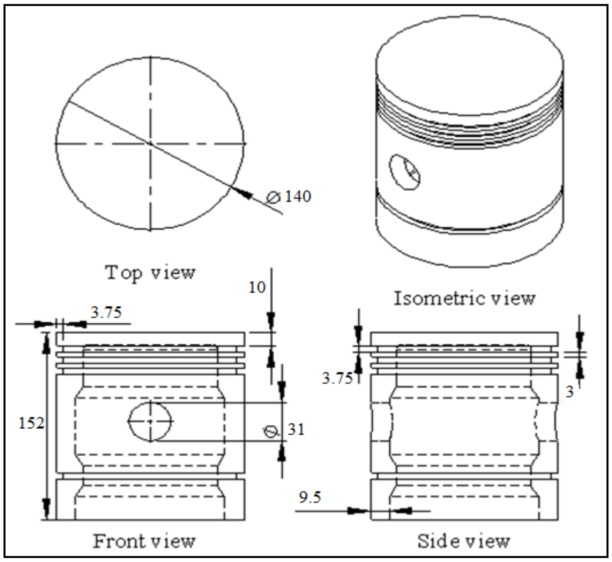

Fig. 2 Drawing of the Piston after optimization

Equivalent (Von-misses) Stress before optimization: The von misses stress initially has been taken as 52.5 MPa. Al-Si alloy has been used as piston material.

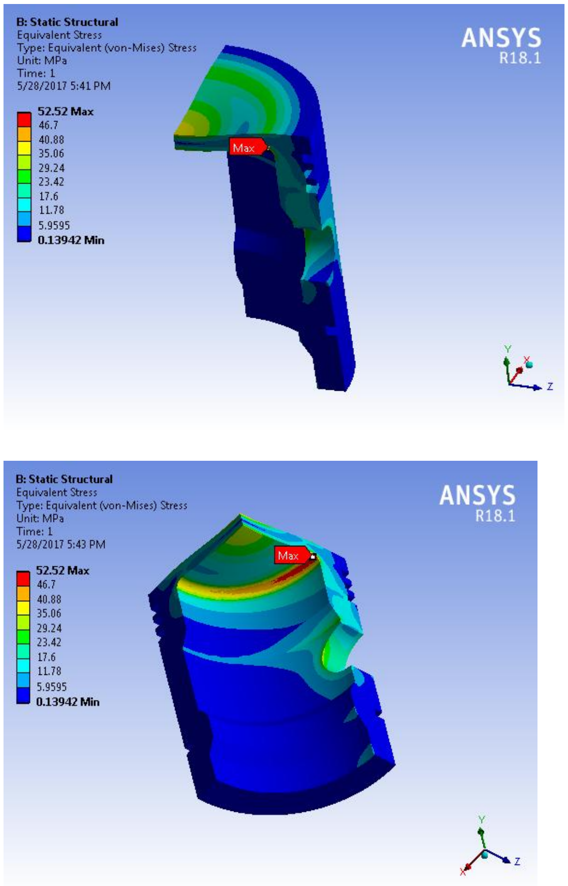

Fig. 3 Equivalent Stress before Optimization

Equivalent (Von-misses) Stress after optimization: After optimization Von-misses Stress is obtained as 67.36 MPa. The allowable stress for Al-Si alloy has been taken as 90 MPa. Max. Von-misses stress is less than Allowable or Design stress. Von-misses stress has been increased by 28%.

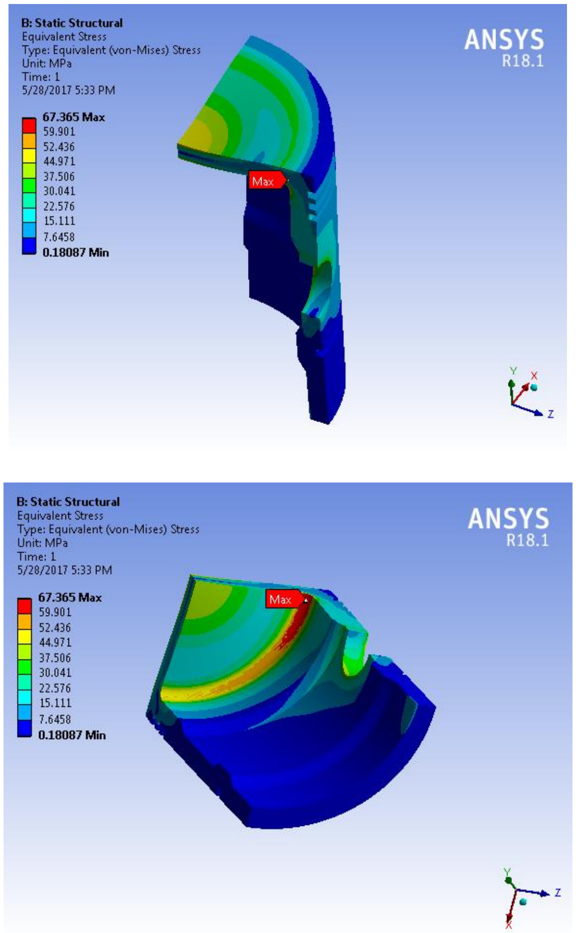

Fig. 4 Equivalent Stress after Optimization

After optimizing the piston dimensions on the basis of equivalent stresses as shown above with only structural load it has been tested for thermo mechanical loading with thermal load as well along with structural load. The material properties which has been adopted for Aluminium alloy and Titanium alloy are as follows.

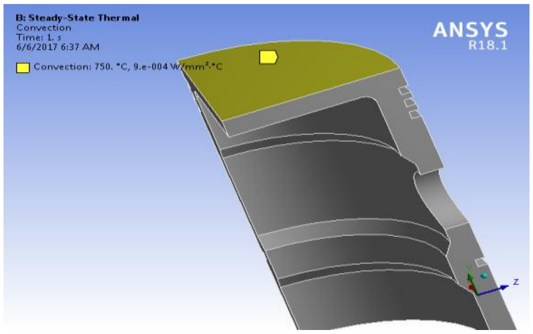

Fig. 5 Cylinder head with 750°C and Film Coeff. 9×10^{-4} W/mm^2 . °C

TABLE II
THERMO MECHANICAL PROPERTIES OF THE PISTON MATERIAL [5] ,[15]

Material	Young's modulus (GPA)	Poisson's ratio	Thermal conductivity (W/m°C)	Thermal expansion 10-6 (1/°C)	Density (Kg/ m3)	Specific heat (J/kg°C)
Al-Si alloy	71	0.33	174.15	23	2770	875
Titanium alloy	96	0.36	21.9	94	4620	522

The thermal and structural boundary conditions which have been adopted over here have been shown below-

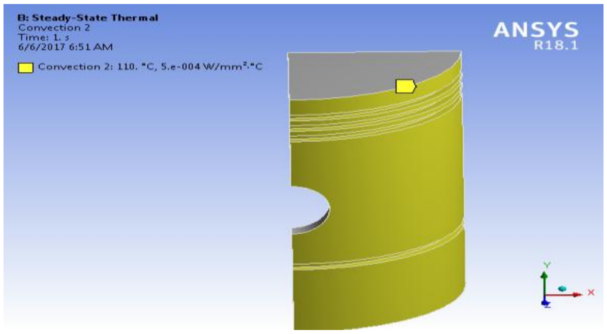

Fig. 6: Cylinder side with 110°C and Film Coeff. 5×10-4 W/mm^2 . °C

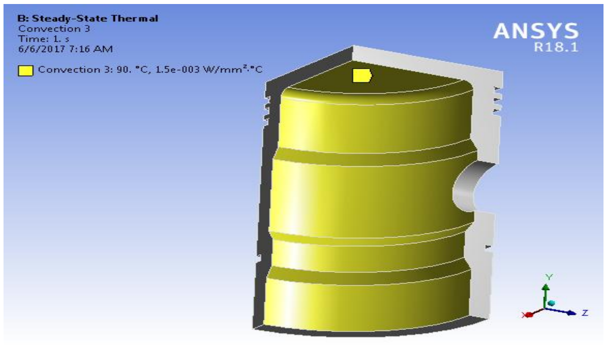

Fig. 7 Cylinder inside with 90°C and Film Coeff. 1.5×10-4 W/mm2 . °C

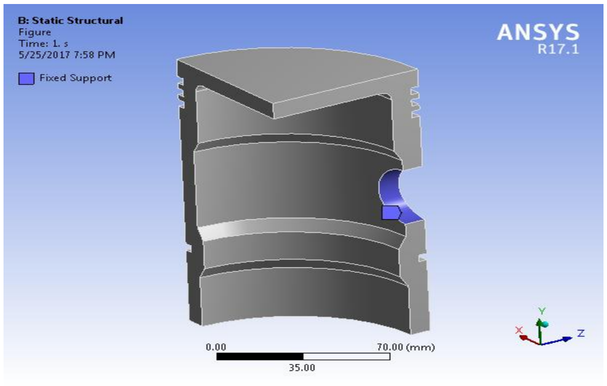

Fig. 8 Connecting Rod pin area as a fixed support

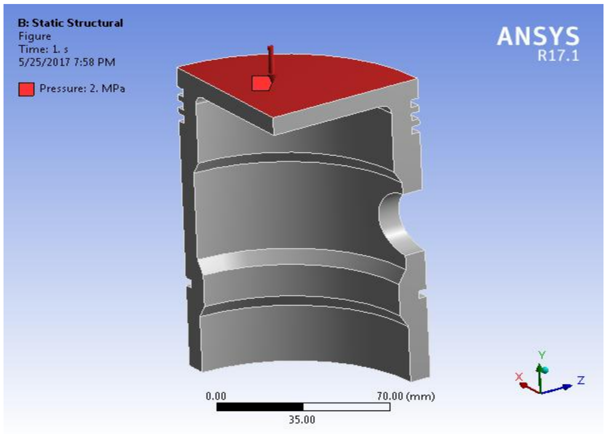

Fig. 9 Pressure load at cylinder head is 2 MPa

The thermo mechanical stress on Aluminium alloy and Titanium alloy has been evaluated after imposing the above mentioned boundary conditions and loading. After this Thermal Barrier Coating with different configurations have been applied on the piston to enhance its heat retention capability. Here TBCs with different configurations have been applied on the Aluminium alloy piston, not on Titanium piston.

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 in reference [25].Then, a 0.15 mm of NiCrAl bond coat and various thicknesses and widths of ceramic MgZrO3 layers have been coated on the outer region of the top surface of the piston. In this work we have been used 0.2, 0.3, 0.4, 0.5, 0.6mm thicknesses and 9.2, 11.2 mm widths respectively. Then, Steady state thermal and structural analysis have been carried out to investigate the effect of thermal barrier coating on temperature gradients and stress distributions on the top surface of the piston. The thermo mechanical analyses have been performed by using ANSYS.

TABLE III
INPUT PROPERTIES OF COATINGS [24] , [27]

Material	**Young's modulus (GPA)**	**Poisson's ratio**	**Thermal conductivity (W/m°C)**	**Thermal expansion 10-6 (1/°C)**	**Density (Kg/ m3)**	**Specific heat (J/kg°C)**
Bond coat (NiCrAl)	90	0.27	16.1	12	7870	764
Ceramic coat(MgZrO3)	46	0.20	0.8	8	5600	650
YPSZ	11.25	0.25	1.4	10.9	5650	620

TABLE IV
THE INVESTIGATED COATED THICKNESSES AND WIDTHS

Ceramic coat(MgZrO3) thickness (mm)	Bond coat (NiCrAl) thickness (mm)	Total coating (mm)	Coating width W (mm)
0.05	0.15	0.2	9.2,11.2
0.15	0.15	0.3	9.2,11.2
0.25	0.15	0.4	9.2,11.2
0.35	0.15	0.5	9.2,11.2
0.45	0.15	0.6	9.2,11.2

TABLE V
THE RESULT OF THERMAL BARRIER COATING ON PISTON TOP SURFACE

SL. No.	Coating width W (mm)	Total coating (mm)	Temperature (°C)	Equivalent Stress (MPa)	Total Deformation (mm)
1	9.2	0.2	316.21	590.24	0.47364
2	9.2	0.3	341.48	685.68	0.4675
3	9.2	0.4	378.41	586.66	0.46223
4	9.2	0.5	408.13	633.7	0.45796
5	9.2	0.6	432.47	668.96	0.45433
6	11.2	0.2	316.05	571.04	0.47274
7	11.2	0.3	341.97	560.43	0.4655
8	11.2	0.4	379.04	634.96	0.45944
9	11.2	0.5	409.43	672.19	0.45431
10	11.2	0.6	434.61	624.31	0.45005

The effects of TBC on the partially coated piston having various coating thicknesses and widths have been shown in the Table 5. The temperature variation after thermo mechanical analysis by varying coating thickness 0.2 mm to 0.6 mm it has been observed that at coating thickness of 0.6 mm ceramic coated piston has highest temperature that is higher than Titanium alloy at same boundary conditions. It has been observed that using 11.2 mm width of ceramic coating temperature is almost same as 9.2 mm coating thickness. We have been used 0.5 mm coating thickness and 9.2 mm width which retrains 408.13°C that is near about Titanium alloy temperature 414.9°C.From the result of simulation we have been chosen 0.5 mm coating thickness and 9.2 mm width as optimal coating thickness and width in our study. Surface temperatures remain almost the same in the uncoated region of ceramic coated piston. It has been observed that the temperature of the piston top surface increases with coating thickness.

V. RESULT AND DISCUSSION

In this chapter whatever results have been derived by following the methodologies which have been discussed in the previous chapter have been presented. More over all the results with different Thermal Barrier Coating (TBC) have been compared with graph plotting for the better understanding of the influences of different TBC materials on temperature distribution and stress distribution.

A. Temperature Distribution (°C)

Following figures represent temperature distribution in an automobile piston made of Aluminium-Silicon alloy, Titanium and Aluminium –Silicon with a TBC at the piston head.

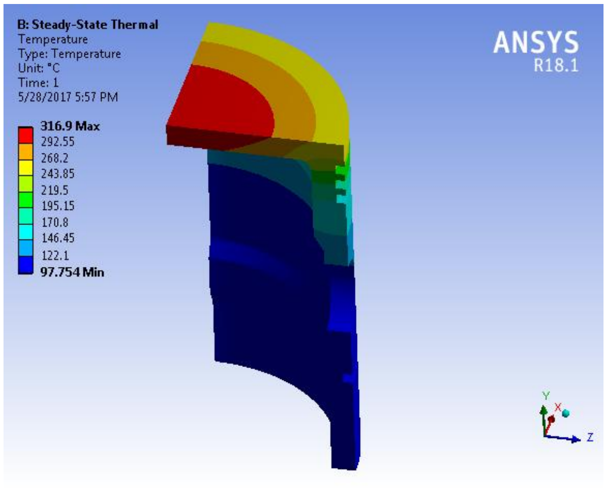

Fig 10 Al-Si alloy

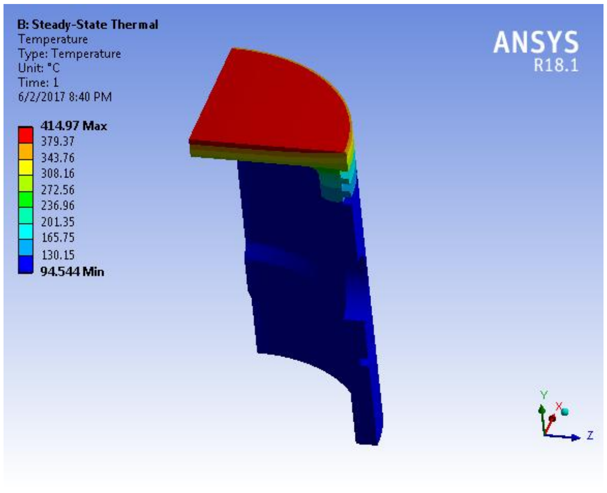

Fig 11 Titanium alloy

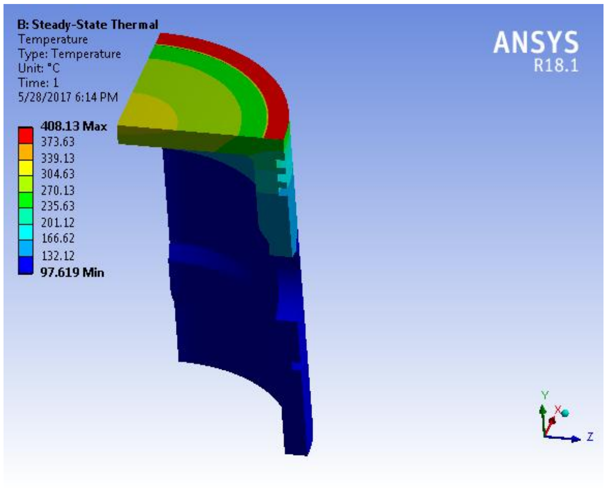

Fig. 12 Al-Si Alloy with TBC

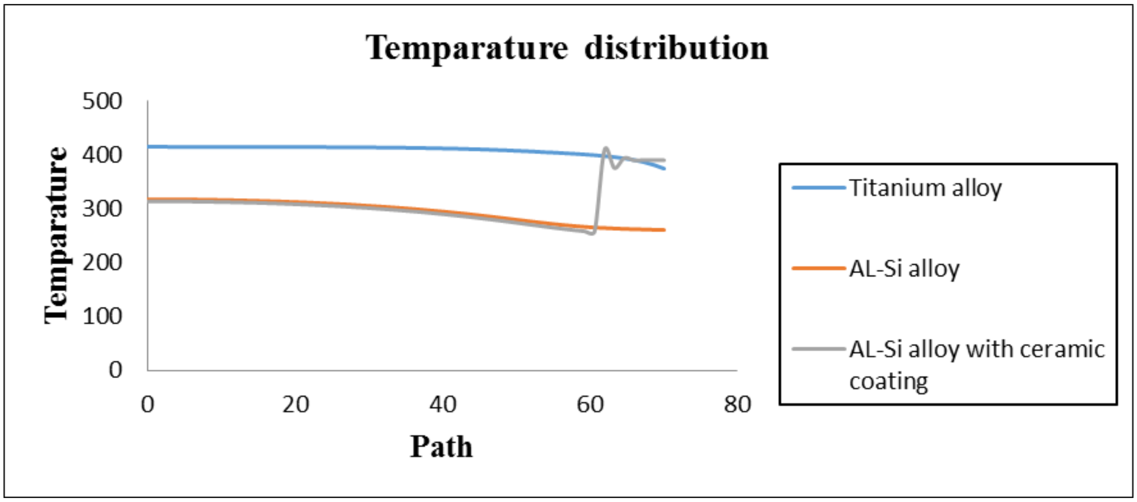

Fig 13 Temperature distribution curve

From the above contour plotting and graph it is clearly depicted that the maximum temperature occurs at the top surface of the piston. This value has been identified as 316.9°C for Al-Si alloy and the value is 414.9°C for Titanium alloy. Using TBC on Al-Si alloy temperature has been reached 408.13°C.This is near to the Titanium alloy.

B. Equivalent Stress (MPa):

Following figures represent contour plotting of thermal stress derived from couple field analysis of the piston due the above thermal distribution along with a gas pressure. This couple field analysis has been done on a piston made of Aluminium-Silicon alloy and Titanium alloy without any coating and on a piston of Aluminium-Silicon alloy with a thermal barrier coating.

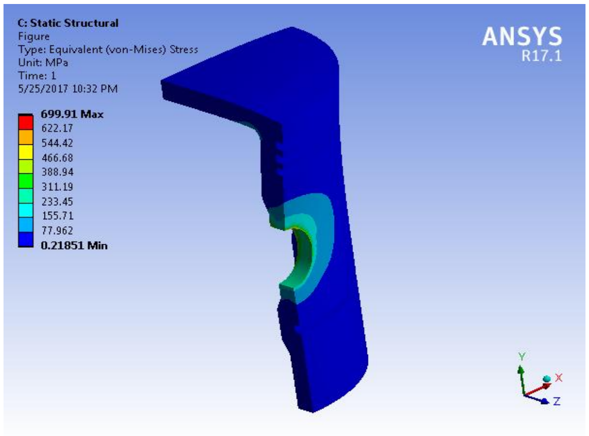

Fig 14 Al-Si alloy

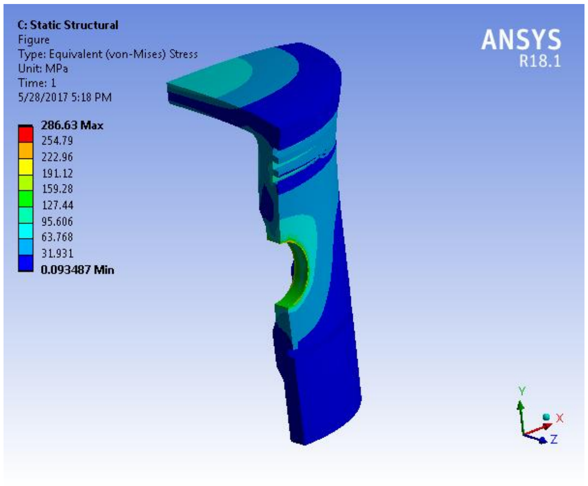

Fig 15 Titanium alloy

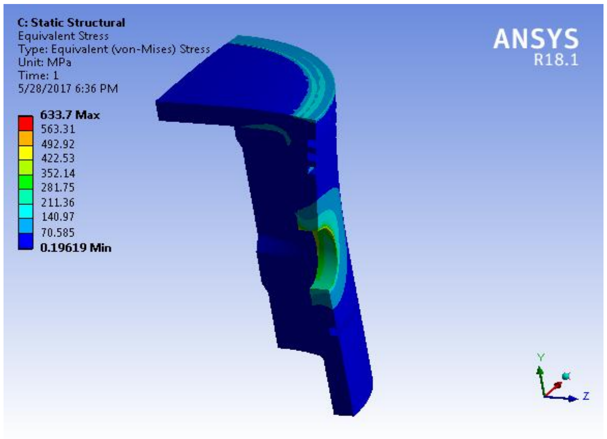

Fig 16 Al-Si Alloy with TBC

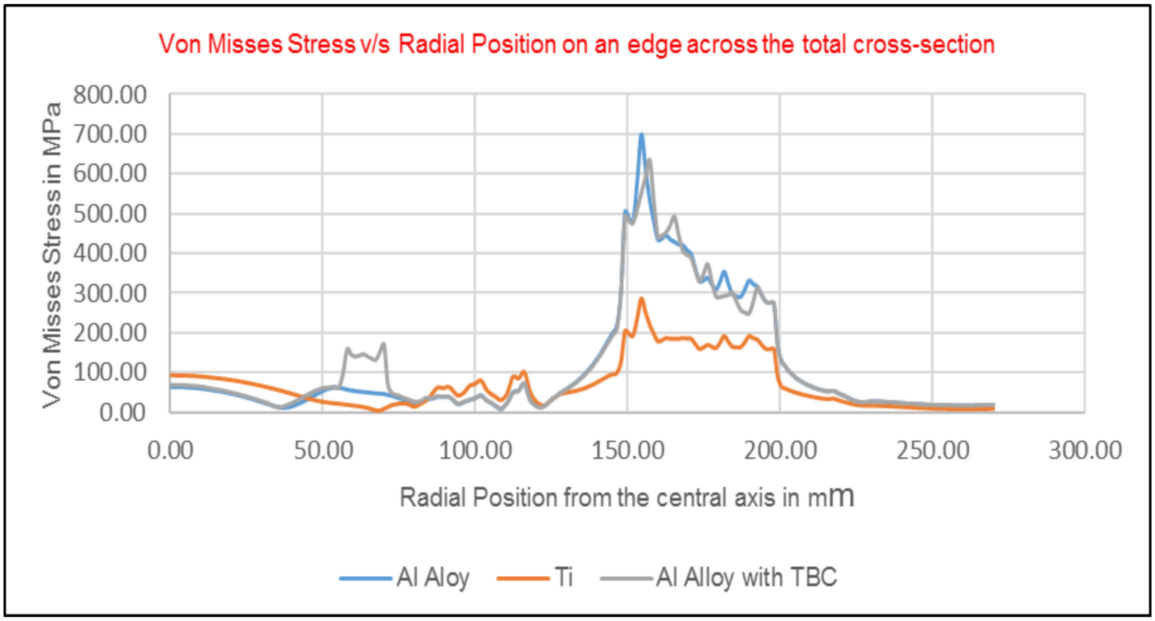

Fig 17A Equivalent stress curve-1

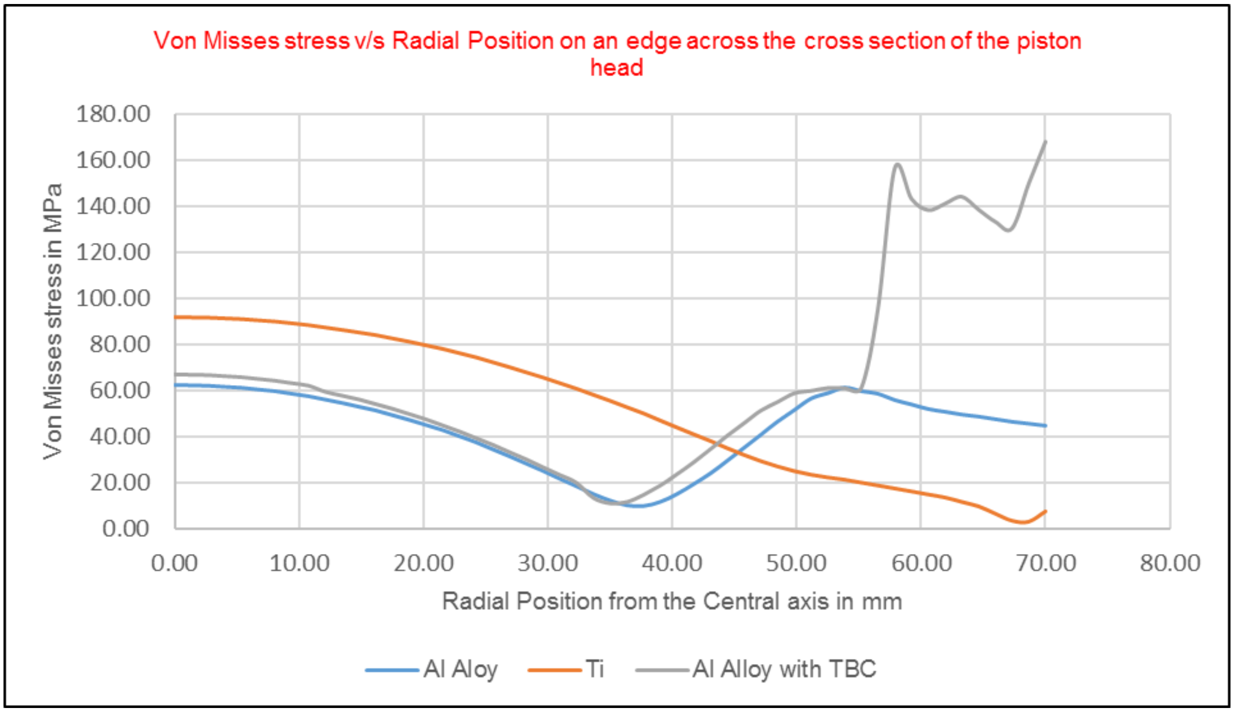

Fig 17B Equivalent stress curve-2

From the above contour plot and graph it is depicted that the maximum stress occurs on the up edge of the piston pin, the value is 699.9 MPa for Al-Si alloy, 286.63 MPa for Titanium alloy and Using TBC on Al-Si alloy stress value has been identified as 633.7 MPa.

C. Total Deformation (mm):

Following figures represent temperature distribution in an automobile piston made of Aluminium-Silicon alloy, Titanium alloy and Aluminium –Silicon alloy with a TBC at the piston head

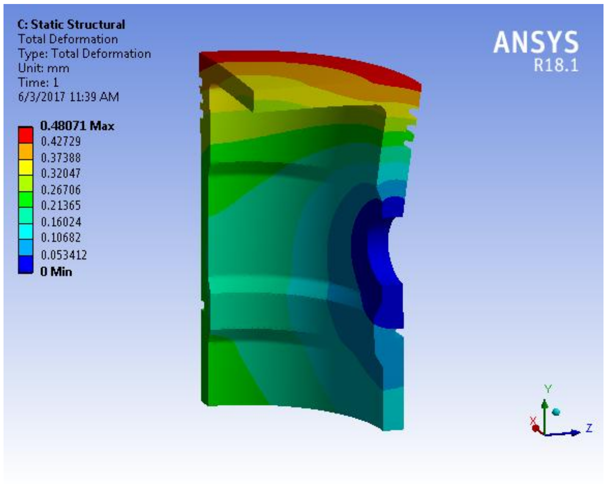

Fig 18 Al-Si alloy

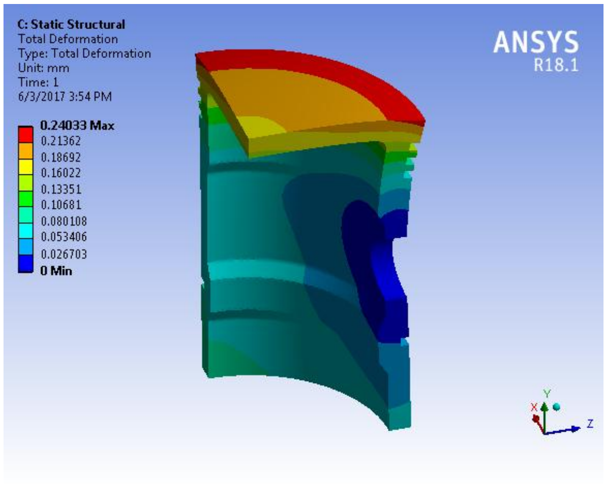

Fig 19 Al-Si alloy

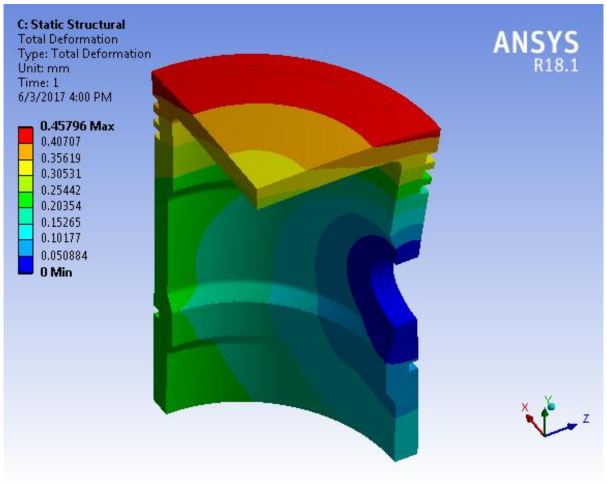

Fig 20 Al-Si Alloy with TBC

It is very much clear from the above contour plot and graph that the maximum deformation value has been identified as 0.48071 mm. for Al-Si alloy, 0.24033 mm for Titanium alloy and using TBC on Al-Si alloy deformation value has been identified as 0.45796 mm which has been observed lower deformation than uncoated Al-Si alloy piston.

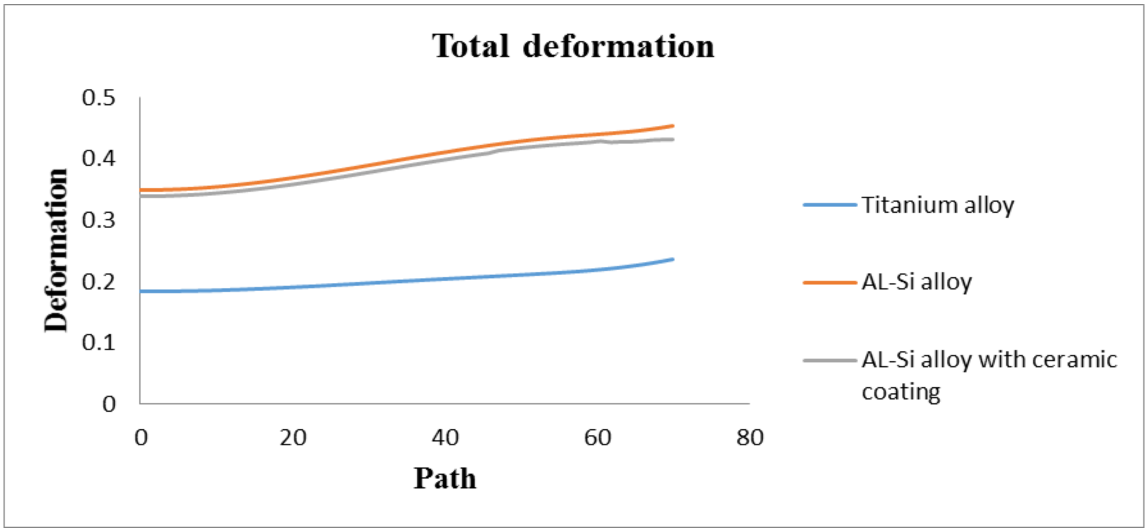

Fig 21 Total deformation curve

MgZrO3, YPSZ and combination of MgZrO3 and YPSZ comparison.

Now in the present work above mentioned analysis has been simulated again with same boundary condition and loading conditions on an Aluminium-Silicon alloy piston with Magnesium-Zirconium oxide thermal barrier coating material (MgZrO3), Yttrium compound based thermal barrier coating material (YPSZ) and combined material of these two TBCs. The temperature distribution, equivalent stress distribution and deformation have been shown graphically

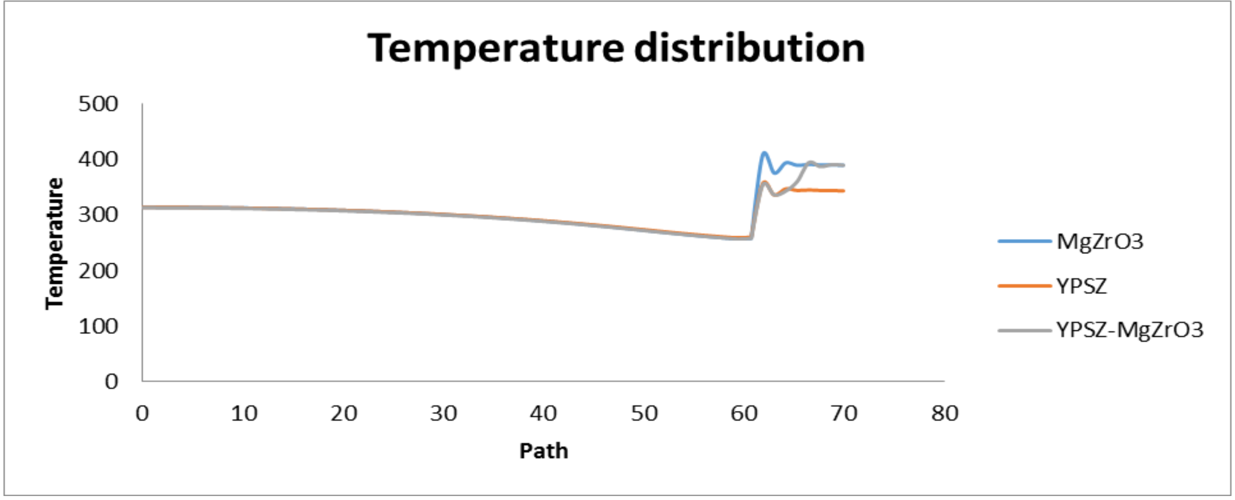

Fig. 22 Temperature distribution comparison with MgZrO3, YPSZ and combination of MgZrO3 and YPSZ

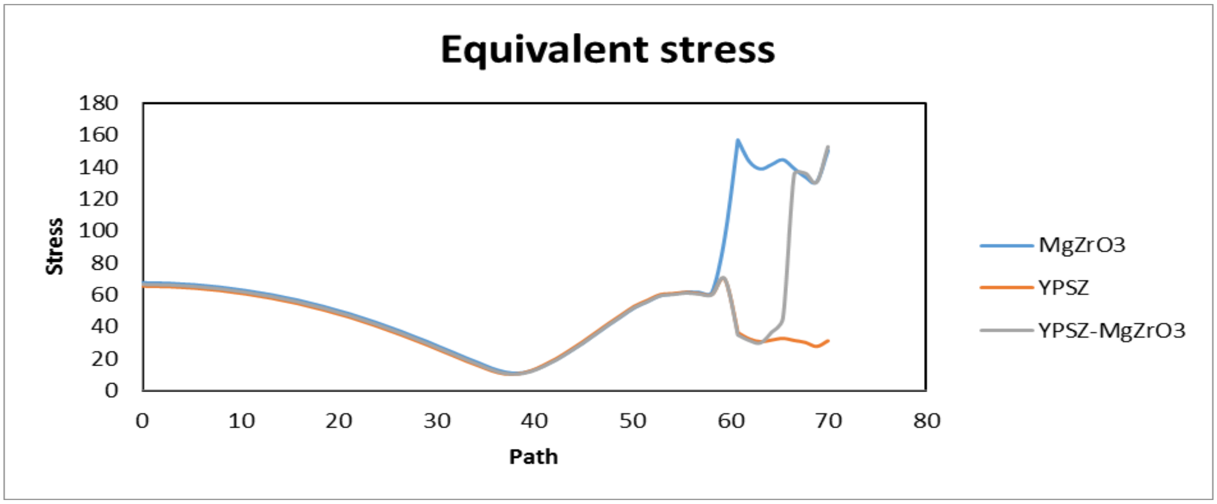

Fig 23 Equivalent stress distribution comparison with MgZrO3, YPSZ and combination of MgZrO3 and YPSZ

VI. CONCLUSION AND FUTURE SCOPE

A Conclusion

In the present work, job has been done in few stages. First the dimensions of a piston which have been referred from [5], have been optimized against two objectives i) Mass minimization and ii) Constraining of stress below 90 MPa. After this, the piston has been given a coating of NiCrAl as bond material and MgZrO3 as thermal barrier with difference thickness and width. 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 a Titanium piston retrain much more temperature than an Al-Si piston. So it can be said that a Titanium piston will perform much better than an Al-Si piston. But cost of Titanium piston is much more than an Al-Si piston. To compromise between cost and performance MgZrO3 coating has been put on Al-Si piston in the present work and it has been shown that the temperature retained is near about that of Titanium piston. In this simulation optimum thickness and width of the coating on Al-Si piston has been optimized using ANSYS.

Another coating material named YPSZ (Yttria Partially Stabilised Zirconia) has been used and simulated in the present work. In the simulation first MgZrO3 and YPSZ have been used separately and singularly with above mention optimized thickness and width. Then a combination of YPSZ and MgZrO3 has been used for the purpose of reduction of cost without much compromising the performance.

From the simulation following data has been generated.

i. Maximum temperature retained by Al-Si alloy is 316.9 °C.
ii. Maximum temperature retained by Titanium alloy is 414.9 °C.
iii. Maximum temperature retained by MgZrO3 with 0.5 mm thickness is 408.13 °C.
iv. Maximum temperature retained by YPSZ with 0.5 mm thickness is 357 °C.
v. Maximum temperature retained by combination of MgZrO3 and YPSZ with 0.5 mm thickness and width of 4.6 mm for MgZrO3 and YPSZ each is 396.08 °C.

So it can be concluded that combination of different coating materials with different widths can generate better temperature in the piston keeping the cost of the coating much lower than a single coating.

B. Future scope of the work:

For further betterment of the performance of the piston simulation can be done with different coating material having different dimensions with all the simulation result optimization can be done for best possible combination of materials and dimension values. Furthermore research can be extended also in the regain of material properties to find out different coating materials which can retrain region able amount of temperature in the piston without increasing the cost of the piston much.

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