Ceramic Coating on Piston Top in IC Engine to Reduce Thermal Losses

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Abstract-*Since high fuel prices and environmental damage are one in every, of the most concerns of the planet without delay, various styles of engines are developed to beat this environmental damage. one in all the most sorts of IC engines that play a significant role in overcoming this challenge is that the LHR engine during this project, a simulation study was conducted using the Ansys commercial software to research the impact of thermal protective coatings (TBCs) on the performance of a single-cylinder engine. There have been results made with a regular (uncoated) piston, derived as two separate thermal barriers of ceramic Magnesia Stabilized Zirconia (MSZ) and Yttria-stabilized zirconia (YSZ) insulated pistons, fastened with a thickness the results of the pistons have shown better performance all told operating conditions over the unmodified piston. This analysis is intended for a good range of bounds coating and has significant differences in temperature distribution between the coated piston and also the normal piston.*

Key Words: Magnesia Stabilized Zirconia, Yttria Stabilized Zirconia (YSZ), ANSYS, Thermal & Structural Analysis

1. INTRODUCTION

This project deals with the employment of limit coating on the top of the piston so the temperature inside the chamber increases. The aim of this paper is to convert a traditional engine into a low-temperature engine and increase engine efficiency. it's answerable for the utilization of boundary coating on the piston head so the temperature inside the chamber rises. Efforts to enhance engine efficiency through construction repairs are on the increase today, applications for ceramic coverings for burning engines are growing rapidly to enhance engine performance, a low-temperature combustion chamber that conducts pottery ends up in a rise in temperature and pressure on the inner combustion engine cylinders. in our own way to enhance the efficiency of diesel engines is to use a limit coating (TBC) system within the combustion chamber. A layer of bond coat (BC) and a layer of ceramic top coat (TC) that may be employed in parts with various techniques are called TBC systems.

2. Piston

The piston is one of the main and most heated components of IC engines. Where most heat is been produced and requires coating to reduce thermal losses in the IC engine. Piston plays an important role in IC engine its function is to-

- Acts as a seal to protect the high combustion pressure to flow outside.
- And also to receive the explosion and transmit the force to the crankshaft.

Following are the piston dimensions of the Hero bike 4-stroke engine that we have considered.

Parameter	Dimensions
Piston length	**37mm**
Piston diameter	**49.5mm**
Exterior diameter of a pinhole	**12.7mm**
Interior diameter of a pinhole	**6.6mm**
Axial thickness of the piston ring	**0.8mm**
The radial thickness of the ring	**2mm**
The ring groove's depth	**2.01mm**
The separation in the rings	**2.6mm**
Height of the top land	**5.6mm**
The thickness of the piston at top	**6.65mm**
The piston's thickness at its open end	**1.64mm**

Table -1: piston dimensions

2.1 Geometrical Modeling

Modeling is carried out in Solidworks 2020 software by referring to piston dimension table no.1. The material applied on the conventional piston is aluminum alloy and the following are the properties of aluminum alloy:

Elastic Modulus	**73.7 Gpa**
Ultimate Tensile strength	**480 Mpa**
0.2% yield strength	**420 Mpa**
Poisson's ratio	**0.33**
Thermal conductivity	**147 W/M/°C**
Coefficient of thermal expansion	**25.9 * 10^6 1/°C**
Density	**2767.99 Kg/m3**

Table -2: Aluminium alloy properties

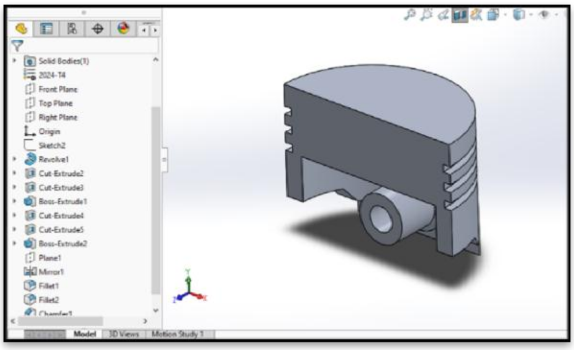

Fig -1: 3D- half section of the piston

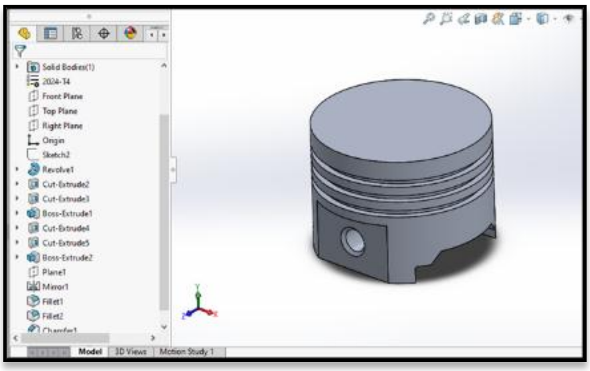

Fig -2: 3D- a model of piston

2.2 Boundary conditions for analysis

Thermal analysis is performed using the temperature distribution at the piston head, top land, ring region, and skirt as shown in table no. 3.

THERMAL BOUNDARY CONDITION	TEMPERATURE 0C	HEAT TRANSFER COEFFICIENT (W/m2K)
COMBUSTION CHAMBER	350	300
REGION BETWEEN PISTON HEAD AND LINER	330	160
RINGS	250	120
REGION BETWEEN RINGS	200	140
PISTON UNDER SKIRT	140	600

Table -3: Temperature and heat transfer coefficient for piston parts

For structural analysis, we have taken fixed support at the surface of the pinhole, and pressure force is given to the piston head as shown in fig -3.

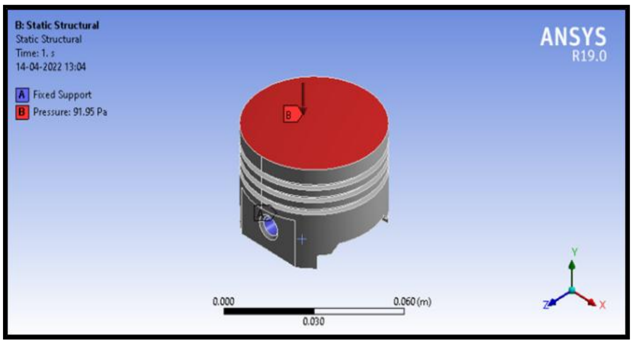

Fig -3: Boundary conditions for structural analysis.

2.3 Ansys results for conventional piston

The analysis is carried out in Ansys software 2021. Following are Ansys results for conventional piston heads.

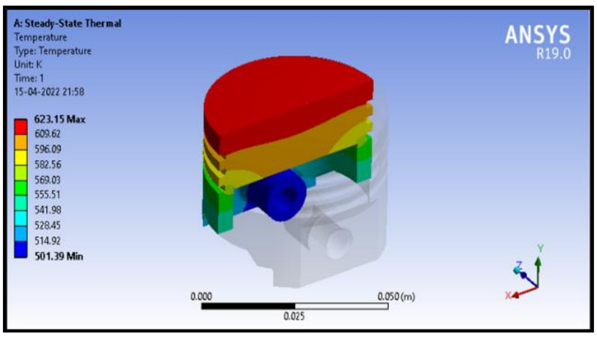

Fig -4: Temperature distribution along the uncoated piston

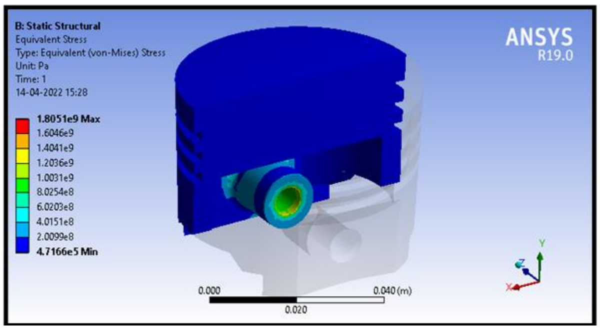

Fig -5: Stress distribution along the uncoated piston

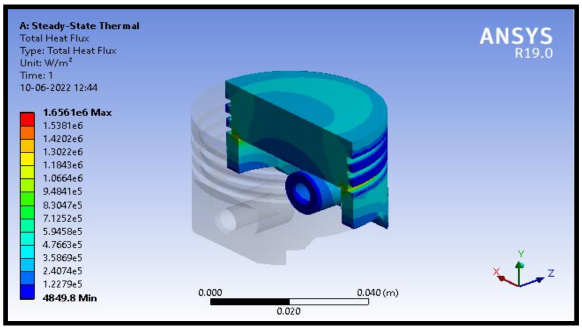

Fig -6: Heat Flux along the uncoated piston

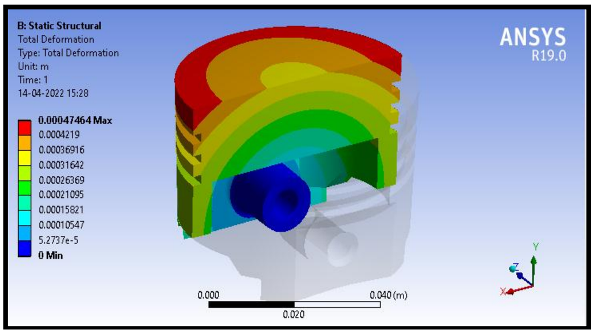

Fig -7: Total deformation along the uncoated piston

Following are the final results obtained for the uncoated piston:

Temperature Distribution	Heat flux	Total Deformation	Equivalent stress
342(in C)	1.6561*10 ^6 (W/m2)	2.9966*10^-5(m)	1.4825*10^8(Pa)

Table -4: Results for uncoated piston

3. TBC

An exceedingly sophisticated technology called a thermal barrier coating (TBC) is sprayed to metal surfaces, especially in gas turbine and aviation engine parts that work at extremely high temperatures. TBC should possess the following properties: a high melting point, low density, strong temperature resistance, corrosion-free, a high thermal expansion coefficient, and elevated surface emissivity.

3.1Ceramic coating

Any colorful hard, brittle, heat- and erosion-resistant accessory that is formed by shaping and firing an inorganic, non-metallic material at a high temperature is referred as a ceramic. Ceramic coating is nothing but a chemical polymer result applied to the surface which acts as a thermal hedge coating. As a result, it reduces the heat loss so automatically effectiveness increases. Also, it protects the structural element against high temperature. The use of pottery as thermal hedge coatings has been seen profitable pre-dominantly in repaying machines performing in homogeneous combustions and reducing thermal dispersions.

Several ceramic accoutrements can be used for coatings, for illustration, zirconia, magnesia, yttria, silicon nitride, silicon carbide, beryllia, etc. It's been seen that the most extensively used ceramic for colorful operations is zirconia.

A completely stabilized zirconia oxide isn't favorable for specialized operations and hence it's incompletely stabilized and unravel with other ceramic accoutrements like yttria, magnesia etc. which also makes it more desirable and effective for operations.

3.2Types of Ceramic material used for coating piston

1. Magnesia Stabilized Zirconia (MSZ)

It is a ceramic substance that is employed in severe service applications because of how resistant it is. Its combination of corrosion resistance, toughness, and longevity makes it perfect for machinery parts and valves in demanding applications.While performing the analysis of magnesia stabilized zirconia as a ceramic coating material different coating thicknesses are used i.e, 0.2mm, 0.4mm, 0.5mm, 0.6mm, 0.7mm, 0.8mm, and 1mm respectively. In the following Table no.7 mentioned the material properties of Magnesia Stabilized zirconia:

Sr no	Parameter	MgZrO8	Unit
1	Thermal Conductivity	8	W/m °C
2	Thermal expansion	0.00008	1/ °C
3	Density	5600	Kg/m³
4	Poisson's ratio	0.2	
5	Young Modulus	46000	Mpa

Table -5: MSZ material properties

Sample Results for 0.6 mm of MSZ

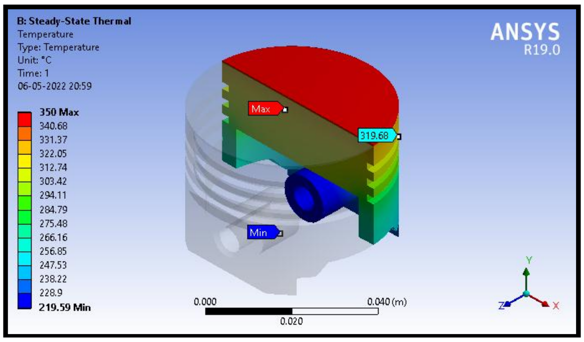

Fig -8: Temperature distribution

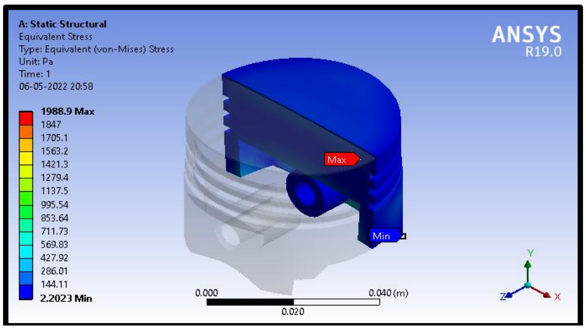

Fig -9: Stress distribution

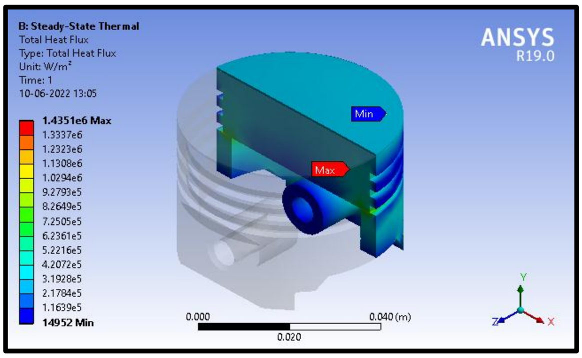

Fig -10: Heat Flux

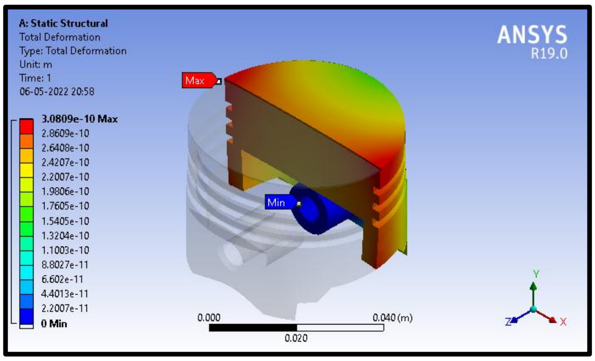

Fig -11: Total deformation

By applying MSZ coated material properties from table 5 and similar Boundary conditions as uncoated piston we get the results in Ansys software.

Following Table 6 is the result table for all thicknesses considered for Magnesia Stabilized Zirconia Analysis.:

Thickness (in mm)	Temperature Distribution (°C)	Temperature Difference in consecutive thickness(°C)	Heat flux (W/m^2) *(10^6)	Total Deformation (m)*(10^-10)	Equivalent stress (Pa)
0.2	333.56	-	1.5889	3.1741	2945.4
0.4	326.32	7	1.5271	3.1596	2945.4
0.6	319.68	7	1.4351	3.0809	1988.9
0.8	312.67	7	1.3846	3.0677	1988.9

1.0	306	6	1.3378	3.0547	1988.9
0.5	322.8	-	1.485	3.0826	2098.3
0.7	316.27	-	1.4094	3.0743	1988.9

Table -6: Result table of Magnesia Stabilized Coating

From the above table 6, we can say that 0.6mm of Magnesia coating thickness is optimum because temperature difference remains constant for consecutive thicknesses and equivalent stresses are also less as compared to other thickness.

2. Yttria-Stabilized Zirconia (YSZ)

Yttrium oxide is doped into zirconium oxide and hence stabilizes its crystal structure at room temperature. While performing the analysis of Yttrium stabilized zirconia as a ceramic coating material different coating thicknesses are used i.e, 0.2mm, 0.4mm, 0.5mm, 0.6mm,0.7mm, 0.8mm, and 1mm respectively. In Table no.7 the material properties of Yttrium Stabilized zirconia are mentioned:

Sr no	Parameter		Unit
1	Thermal Conductivity	16	W/m °C
2	Thermal expansion	0.00001	1/ °C
3	Density	4470	Kg/m³
4	Poisson's ratio	0.26	
5	Young Modulus	66000	Mpa

Table -7: YSZ material properties

Sample Results for 0.6 mm of YSZ

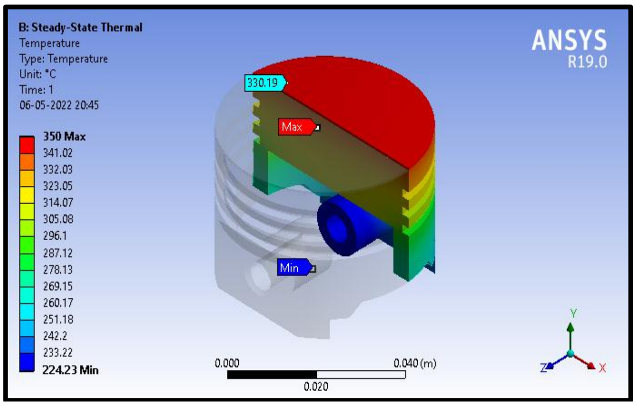

Fig -12: Temperature distribution

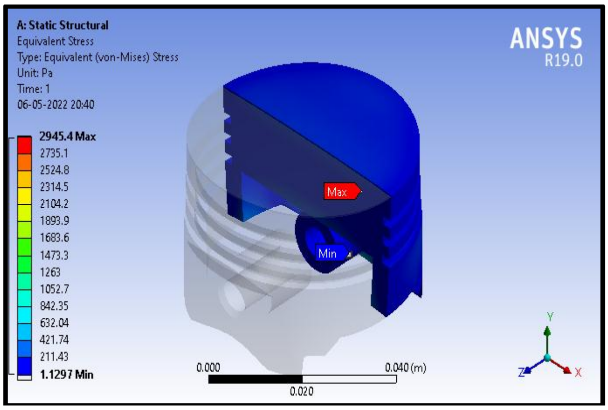

Fig -13: Stress distribution

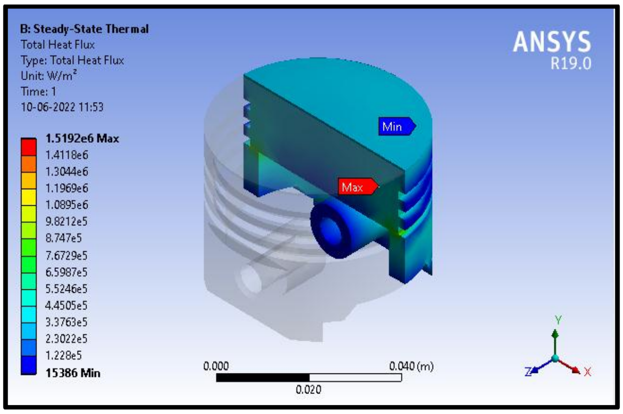

Fig -14: Heat Flux

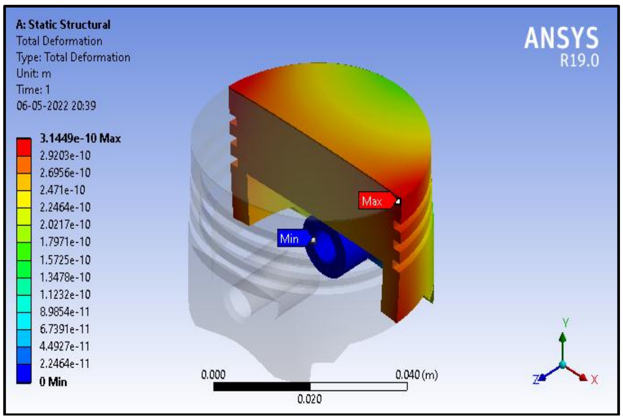

Fig -15: Total deformation

By applying YSZ coated material properties from table 7 and similar boundary conditions as uncoated piston we get the results in Ansys software 2021.

Following Table 8 is the result table for all thicknesses considered for Yttrium Stabilized Zirconia Analysis. :

Thickness (in mm)	Temperature Distribution (˚C)	Temperature Difference in consecutive thickness(˚C)	Heat flux (W/m^2)*10^6	Total Deformation (m)*10 ^-10	Equivalent stress (Pa)
0.2	338.26	-	1.	3.166	2945.4
0.4	333.7	5	1.	3.1449	2945.4
0.6	330	4	1.	3.0607	1988.9
0.8	326.8	4	1.	3.1054	2870.2
1.0	322.49	4	1.	3.0866	2870.1
0.5	331.7	-	1.	3.1346	2945.4
0.7	328.17	-	1.	3.1151	2870.3

Table -8: Result table of Yttrium Stabilized Coating

From the above table 8, we can say that 0.6mm of Yttrium coating thickness is optimum because temperature difference remains constant for consecutive thicknesses and equivalent stresses are also less as compared to other thicknesses.

4. Thermal Cracking

The TBC system can be affected by thermal cracking for which the root cause are the induced thermal stresses. These stresses cause varied thermal expansion further cracking the coated layer.

4.1 Coating of NiCrAl

Nickel-chromium coatings are corrosion-resistant coatings. They have a varied range of applications. NiCrAl helps reduce high stress and degradation. Nickel Chromium Alloy works well with Aluminum, steel, copper, brass, and zinc substrates. In the table, no 9 material properties of NiCrAl are mentioned.

Thermal conductivity	161
Thermal Expansion	0.000012
Density	7870
Poisson's ratio	0.27
Young's modulus	90000

Table -9: NiCrAl material properties

For the analysis, we have considered a two-layer coating on the piston as shown in Fig 16.

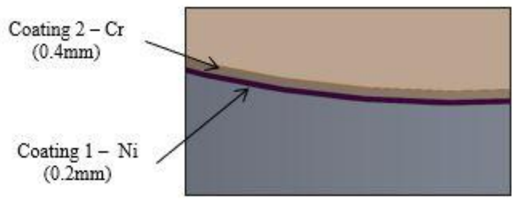

Fig -16: Close view of a 2-layer coating

Results of Ni-Cr-Al Coating

By applying the material properties from table 9 and similar boundary conditions as the uncoated piston, the Following are the final results obtained:

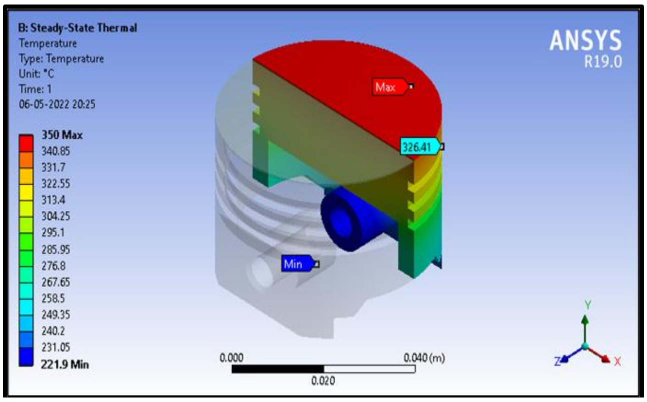

Fig -17: Temperature distribution

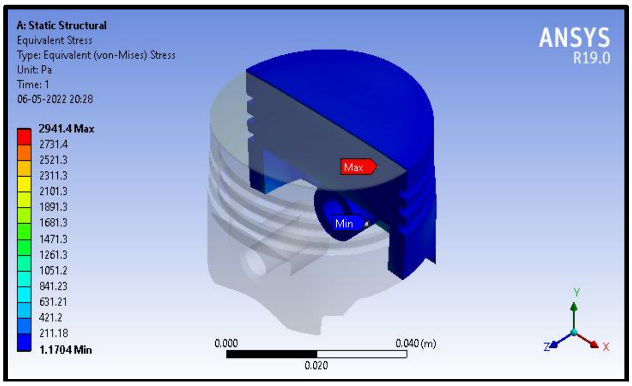

Fig -18: Stress distribution

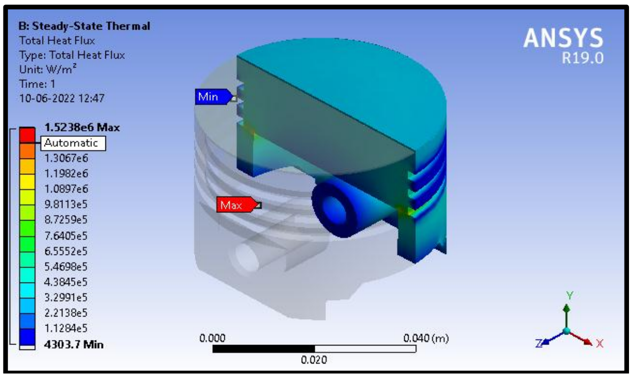

Fig -19: Heat Flux

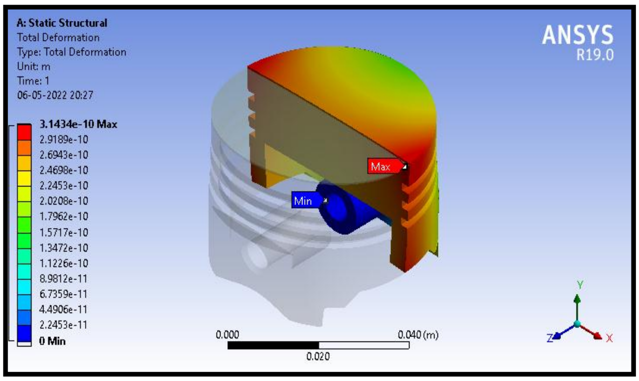

Fig -20: Total deformation

Temperature Distribution	Heat flux(W/m2)	Total Deformation(m)	Equivalent stress(Pa)
326.41(in C)	1.523*10^6	3.1434 *10^(-10)	2941.4

Table -10: Results for uncoated piston

VALIDATION

1. Temperature Distribution: Ceramic coating should result in high temperature

2. Heat Flux: Heat flux is highest in uncoated piston

3. Total Deformation: Zirconia coating should tend to result in less deformation than conventional.

Material	Thickness (in mm)	Temperature Achieved (°C)	Heat flux (W/m^2)	Total Deformation (m)
Conventional Piston (Aluminium)	**-**	**0**	**1.6561 * 10^6**	**2.9966* 10^-5**
Magnesia	**0.6**	**22.34**	**1.4351 * 10^6**	**3.0809* 10^-10**
Yttrium	**0.6**	**12.02**	**1.5192 * 10^6**	**3.0607* 10^-10**

Table -11: Validation

From the above validation table, In case of Magnesia results for temperature distribution, Heat flux and Total Deformation are 6.38%, -13.34% and 99.5% achieved respectively and similarly, In case of Yttrium are 3.43%, -8.26% and 99.7% obtained respectively.

CONCLUSIONS

This analysis was done for various thicknesses i.e 0.2mm, 0.4mm, 0.5mm, 0.6mm, 0.8mm, and 1 mm of the thermal barrier coating, and it was found that there is a significant difference in the temperature distribution between the coated piston and conventional piston. Also, it was found that the difference between the thermal distributions of consecutive thicknesses had a gradual change for both the ceramic materials. The thickness at which the optimum thermal distribution after which there is no significant change in thermal distribution is 0.6mm. A higher temperature was achieved in the ceramic-coated piston as compared to conventional. Ceramic coatings of magnesia and yttrium stabilized zirconia helps reduce the thermal losses to the surrounding. Coatings of Ni-Cr-Al can be adapted to avoid the thermal cracking problem occurring in the piston of an IC engine.

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