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Thermal Analysis of Ceramic Coated Aluminum piston used in C-I Engine using ANSYS

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KEYWORDS: *Temperature, piston crown temperature, thermal barrier coating, coating thickness*

ABSTRACT: *The aim of this work is to determine the temperature of the ceramic coated aluminum piston crown used in compression ignition engine. The ceramic coating used in this experiment are stabilized magnesium zircronia and Mullite. The coating is done on the piston up to 1.5mm thickness (in three layers i.e., 0.5mm, 1mm and 1.5mm). A bond layer of 0.2mm thickness consisting of NiCrAl is laid between the substrate and the ceramic coating. The temperature on the piston crown with ceramic coatings is investigated and compared with uncoated piston using ANSYS FEA software. The piston model is axis-symmetric with PLANE77 elements which behave as axis-symmetric elements. It is observed that the temperature on the coated piston crown is high when compared with the uncoated piston and also the temperature increases with increase in the coating thickness. By achieving higher temperature on the piston crown, the combustion chamber temperature increases thereby, increasing high thermal efficiency. The piston body temperature is also reduced with the increase of coating thickness.*

1. INTRODUCTION

Problem definition: The piston model used in the simulation is a diesel engine piston. Thermal stress analyses have been carried out by means of the finite element technique, which is a powerful numerical tool. Analyses have been performed for various conditions: an uncoated piston crown and a ceramic-coated piston crown with a ceramic top coat ranging in thickness of 0.5mm, 1mm and 1.5mm. The coating is composed of a 0.2 mm bond coat (NiCrAl) and the ceramic coat of Magnesia stabilized zirconia or Mullite (MgZrO3 and $3Al_2O_3$-$2SiO_2$) deposited onto the piston crown or substrate (SUBS) by air plasma spraying. The nodal temperature on the piston are examined. The temperature difference of the uncoated piston and the coated piston are tabulated and results are presented.

2. DESCRIPTION

The piston model used in the analysis is a diesel engine piston. It is modeled in Ansys. Thermal stress analysis has been carried out by means of finite element technique. The axis-symmetric view of the piston model is taken for analysis.

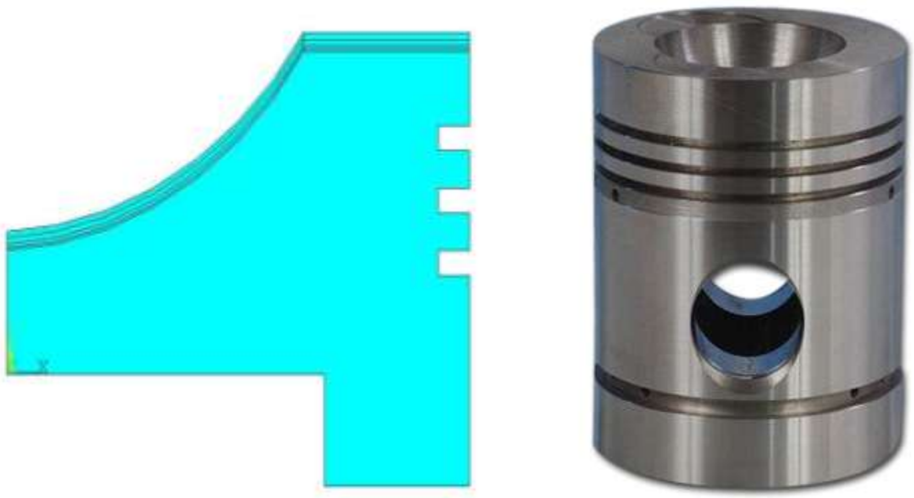

Fig 1: Axis-symmetric view of piston

The piston is modeled with the and used for analysis.The coating is given on the piston crown. Analysis has been performed for various conditions; an uncoated piston crown and a ceramic coated piston crown with a ceramic top coat ranging in thickness from 0.5 to 1.5mm.

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SPECIFICATIONS OF THE PISTON: Specifications assumed to carry out the analysis are

Cylinder bore (D)	:	87.5mm	Stroke (S)	:	110mm
Rated power	:	5.2KW	Compression Ratio	:	17:5:1
N	:	1500rpm	Stroke	:	4
No. of cylinders	:	1			

3. THERMAL BARRIER COATING

Thermal Barrier Coating materials: The operating temperature of the material can be increased by using thermal barrier coatings. The coating may not be isotropic in nature and has a ceramic-metal configuration. In general metal substrates are coated with non-homogeneous ceramic coatings. TBCs are preferred because of their low conductivity and their relatively high coefficients of thermal expansion.

The thermal barrier coat used in the analysis are Magnesia stabilized zirconia and Mullite

Magnesia stabilized zirconia:Advantages of using $MgZrO_3$:

- Low thermal conductivity 2W $m^{-1}k^{-1}$
- High fracture toughness
- High young's modulus

Disadvantages of using $MgZrO_3$:

- Low melting point 1600°C
- Very low thermal expansion coefficient

Mullite:

AdvantagesofusingMullite

- High corrosion resistance
- Low thermal conductivity
- Not oxygen transparent

DisadvantagesifusingMullite

- Crystallization
- Very low thermal expansion coefficient

Bond Coat of NiCrAl:

- A bond coat of 0.2mm consisting of NiCrAl is used to provide adhesion between the piston and the ceramic layer.
- The main aim of bond coat is to provide corrosion resistance.
- And also it has the advantage to balance the thermal coefficient of expansion of the substrate, i.e., piston and the ceramic coat.
- Both Ni and Cr are good oxidizing materials and increases bond strength.
- In the absence of bond coat, there might be chances of crack propagation at the surface.

Table 1: Material properties of piston and coating material:

Component	Material type	Young's modulus, GPa	Poisson's ratio	Thermal expansion coefficient x10^{-6} /^{0}C	Thermal conductivity, W/m ^{0}C
Ceramic coating	$MgZrO_3$	46	0.20	8	0.8
Ceramic coating	$3Al_2O_3$-2SiO2	3000	0.33	7.3	18
Bond coat	NiCrAl	90	0.27	12	16.1
Body of piston	Aluminum	79	0.34	25	174

4. RESULTS AND DISCUSSIONS

The ceramic coatings layer of thickness 0.5 mm, 1 mm and 1.5 mm are simulated. It is observed that the values of maximum temperature at the crown center of the pistons on the coating surface for MgZro3 are 539.258 ^{0}C, 576.129 ^{0}C and 586.575 ^{0}C respectively and for Mullite are 458.695 ^{0}C, 505.534^{0}C and 530.557 ^{0}C. As expected, the maximum amount of increase in the temperature of the piston's crown top surface is observed for 1.5 mm thick coating. The low thermal conductivity of the ceramic coatings than the aluminum alloy resulted in maximum temperature.

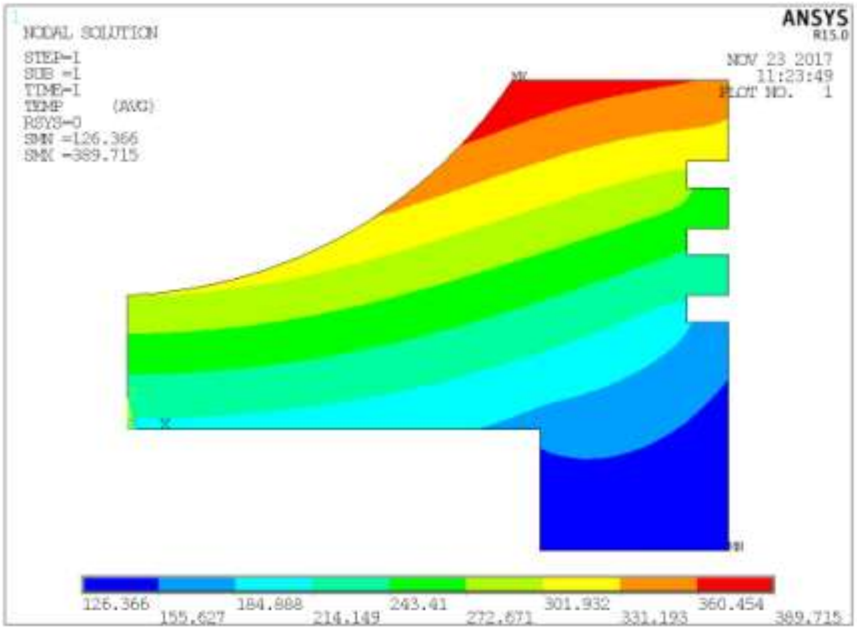
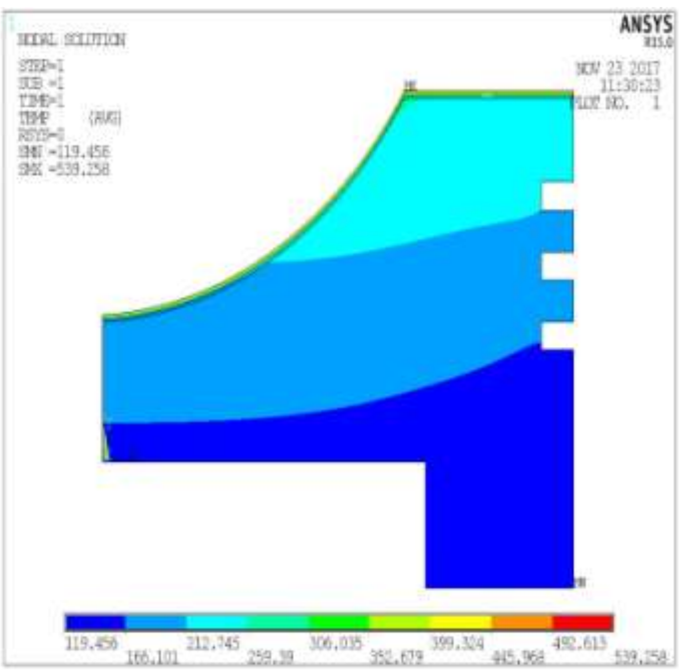
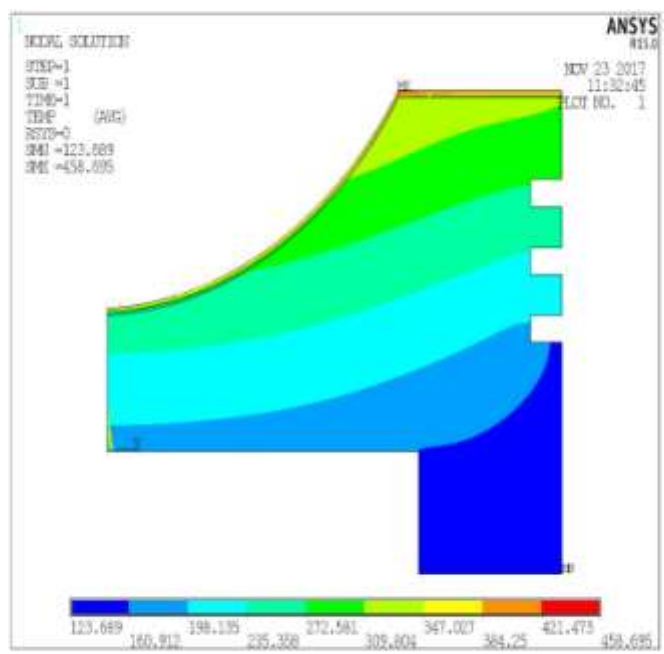


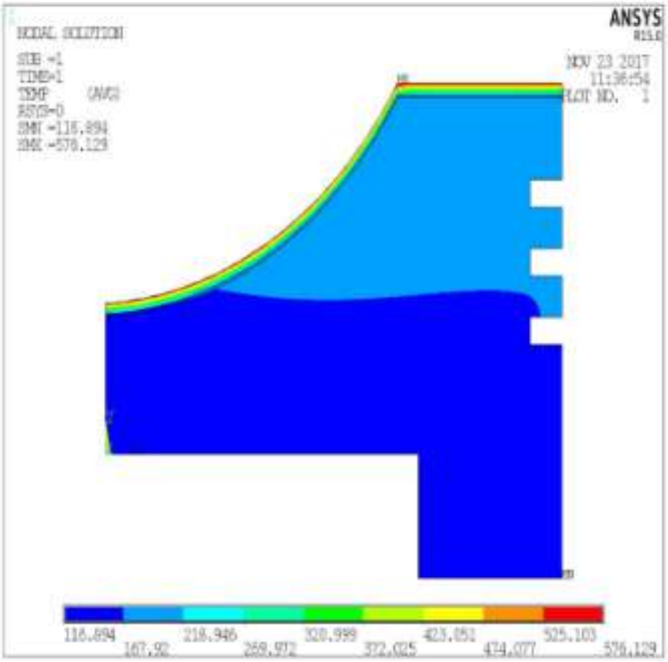
Fig 2: Variation of temperature in piston in ° Cwithout coating



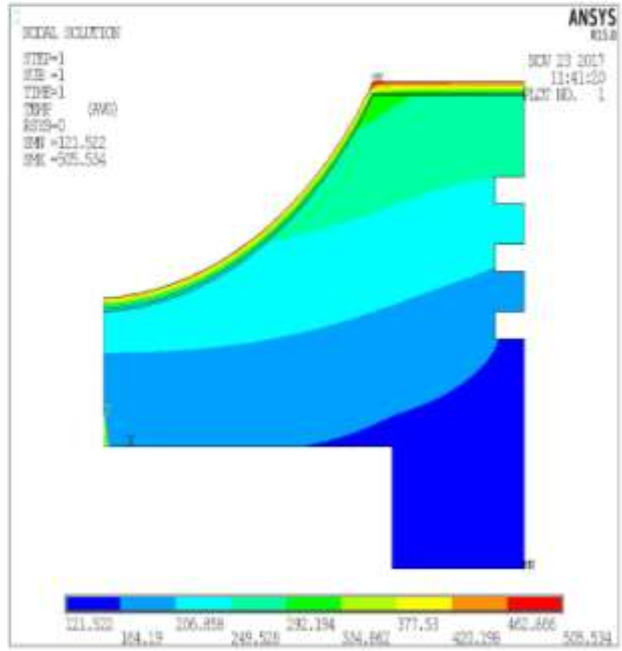


T in °C variation for 0.5mm coating thickness of MgZro3

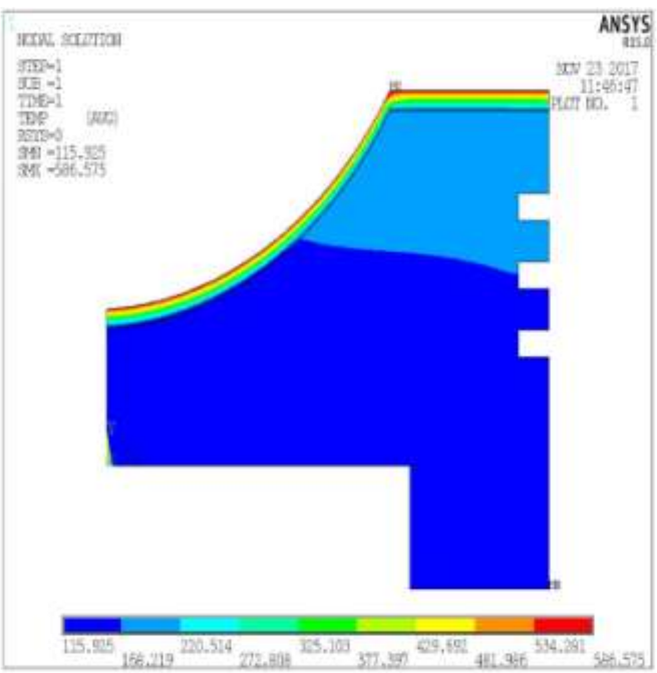
T in °C variation for 0.5mm coating thickness of Mullite



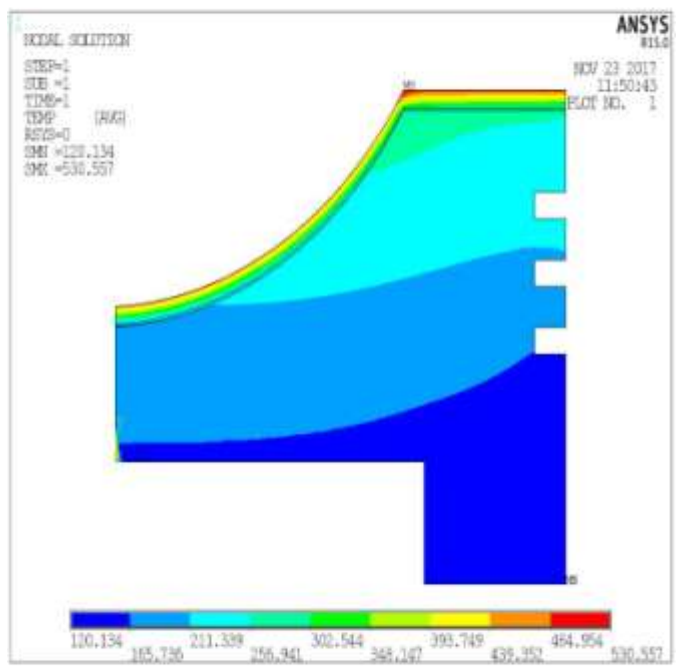
T in °C variation for 1 mm coating thickness of MgZro3



T in °C variation for 1 mm coating thickness of Mullite



T in °C variation for 1.5 mm coating thickness of MgZro3



T in °C variation for 1.5 mm coating thickness of Mullite

From the results it is observed that the temperature of the coated piston when compared to uncoated piston is more. The temperature of the coated piston increases with increase in coating thickness. And also the temperature on the piston body decreases with ceramic coating on the piston crown. With this we can say that the temperature on the body of the piston decreases with increase in the ceramic coating thickness. The coating on the piston crown radiates the heat generated by the combustion and does not allow the heat to transfer into the piston body. The amount of temperature absorbed by the piston for uncoated piston is less when compared to coated piston. So this results in increase of the efficiency of the engine and also the life of the piston increases.

And also if we observe the radial temperature of the piston increases from the center of the piston. If we observe the above results there is a temperature difference along the radial axis of the piston. The temperature increases with increase in the radius of the piston. The coating thickness also plays a prominent role in the in the increase of the radial temperature of the piston crown. As the coating thickness increases there is an increase in radial temperature from the center of the crown. This because of the increase in circumferential area from the piston center.

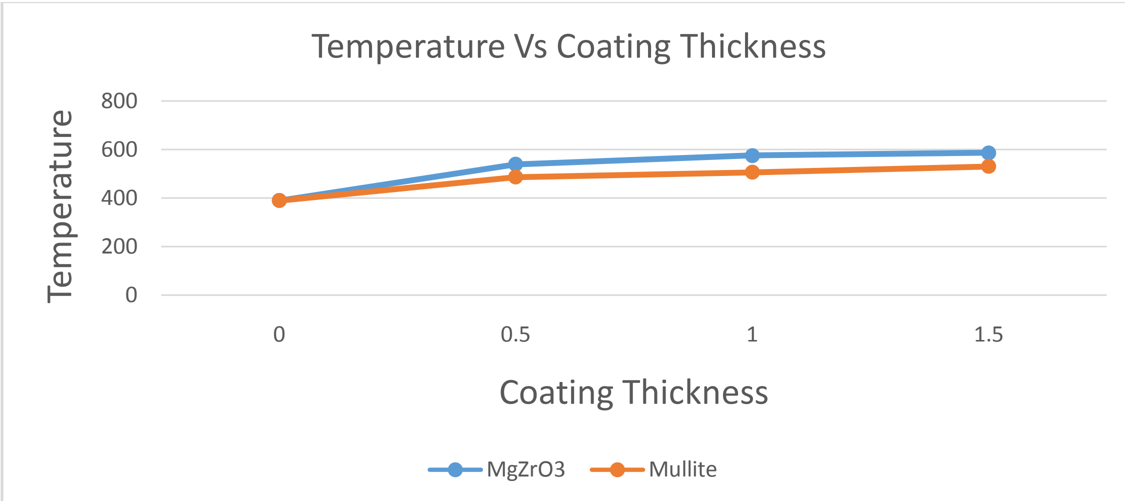
Table 2: Variation of temperature in the piston crown with coating thickness for MgZro3 and Mullite

Coating thickness, mm	Temperature on the crown,^{0}C for MgZrO3	Temperature on the crown,^{0}C for Mullite
0.0 (no coating)	389.715	
0.5	539.258	485.695
1	576.129	505.534
1.5	586.575	530.557

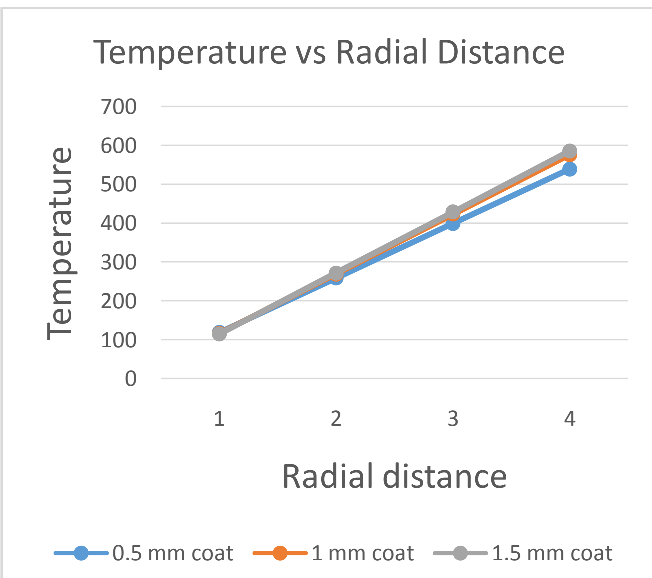
Table 2: Variation of temperature on the piston body with coating thickness for Mullite

Coating thickness, mm	Temperature on the piston body,^{0}C Mullite	Temperature on the piston body,^{0}C MgZrO3
0.0 (no coating)	126.366	126.366
0.5	123.689	119.456
1	121.522	116.894
1.5	120.134	116.894

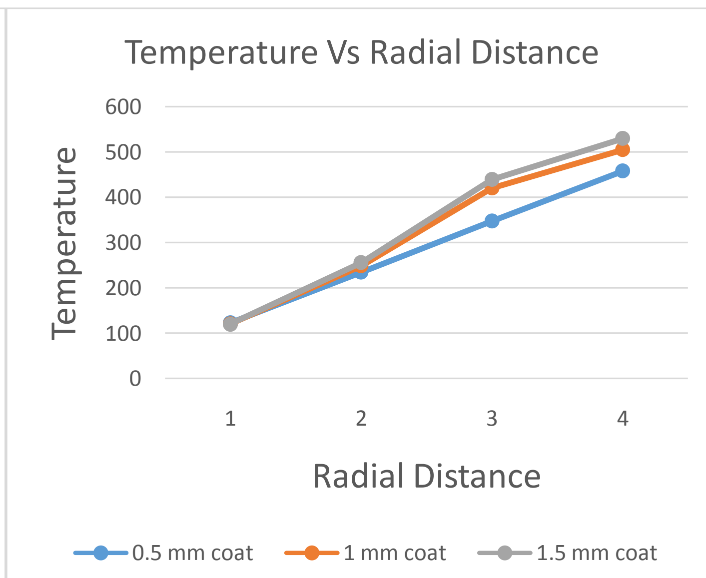
Temperature Vs Coating thickness



Temperature Vs Radial distance for MgZro3



Temperature Vs Radial Distance for Mullite



5. CONCLUSION

The FEA results obtained shows that there is a significant increase in temperature on the piston crown with increase in coating thickness because of the lower thermal conductivity of the ceramic coating. And also the temperature of the piston body decreases with increase in temperature.The percentage of increase in temperature on the piston crown for 0.5mm, 1mm and 1.5mm for Magnesium stabilized zirconia are 38, 47 and 50 respectively and for Mullite are 24, 29 and 36 respectively. The higher temperature on the piston crown allows to achieve higher combustion chamber temperature resulting in the increase of thermal efficiency of the engine. This work can be further extended using different ceramic coating with varying thickness and also an experimental setup can be made to validate the results.

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