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Design and Thermal Analysis of $Y_2O_3ZrO_2$ Ceramic Coated IC Engine Piston Based on FEA

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Abstract

This paper includes the design and thermal analysis of an uncoated & coated IC engine piston made of aluminium-silicon alloy. Thermal analysis is performed on pistons cylinder comprised of aluminium alloys covered with artistic material ($Y_2O_3ZrO_2$). The bonding is done by unique material (Ni-Cr-Al). Designing is done by appropriate machine design approach and the piston dimensions are determined by finite element analysis (FEA). FEA was performed using ANSYS. The coating effects on the thermal behaviour of the pistons are also investigated.

Keywords: Finite element analysis, thermal barrier coatings, coating of piston, thermal analysis of piston

INTRODUCTION

To control the thermal stresses and deformation in piston, the calculation of temperature distribution on piston is very important. With the help of temperature distribution, we can optimize the thermal aspects of the piston design economically. A large amount (60%) of the total engine mechanical power lost is generated by piston ring assembly [1]. The materials used in cylinder assembly are divided into the specified howl sets such as cast iron-aluminium composites and unique steel composites. The thermal expansion coefficient of aluminium alloy is 80% higher than the cylinder bore material which is made of cast iron. To expand the IC motor's warm effectiveness, thermal barrier coatings (TBC) is used. Another reason of using TBC is the continuous increase in fuel prices and reduction in supply of high-quality fuel [2]. The TBC frequently comprises of solid earthenware, for example, zirconia, which thermally protects the framework while continuing high temperature inclinations and, now and again, enormous temperature contrasts. The security coat is an intermetallic combination that gives oxidation obstruction at high temperatures and helps in the grip of the TBC to the substrate [3, 4]. Principle points of TBCs utilizations of the cylinder surface are to decrease the warmth transition into the cylinder, to shield the cylinder from warm anxieties, destructive assaults because of fuel contaminants and lessening discharges [5–7]. This also protects cylinder from corrosion attack, hot air, excessive heat discharges and decreases power transfer to cylinder and fuel use [8]. TBC improved combustion, reduced emission, and provide the potential for higher thermal efficiencies of the engine. In cylinder work would increase due to lower heat rejection from the combustion chamber through thermally insulated components [2, 9]. Many experiments have been carried out to see if these ceramic properties can be used to increase thermal efficiency by reducing heat losses and mechanical efficiency by removing the need for cooling systems. More heat is supplied to the

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exhaust system as cylinder cooling losses are reduced. The thermal efficiency of low heat rejection engines (LHR) is improved by this efficient energy recovery by exhaust. Installing heat recovery systems, on the other hand, necessitates a significant amount of effort; numerous changes to the engine configuration are needed. In the absence of heat recovery systems, some of the heat is converted into piston function, which improves thermal efficiency. As a result, LHR engines that do not have exhaust heat recovery systems are worth investigating.

MATERIALS USED

Because of their low conductivity and relatively high coefficients of thermal expansion, zirconia-based ceramic coatings are used as thermal barrier coatings to minimize harmful interfacial stresses**.** Yttrium zirconium oxide ($Y_2O_3ZrO_2$) has outstanding mechanical properties, warm stun blockage and properties for impact [10]. Material properties of the YSZ, Ni-Cr-Al (bonding material) and piston material made of Al-Si alloy are listed in Table 1.

Table 1. Material properties of different material [15].

S.N.	Properties	Al-Si alloy	Ni-Cr-Al (bonding coat)	YSZ (ceramic)
1	Young's Modulus (MPa)	90000	90000	11250
2	The Poisson's ratio	0.53	0.27	0.22
3	The Thermal Conductivity (W/mm °C)	155	16.1	1.4
4	The thermal expansion coefficient × 10^{-6} (1/°C)	21	12	10
5	Density (kg/m^3)	2700	7870	5650
6	Specific heat (J/kg °C)	910	764	640

THERMAL ANALYSIS

The thermal analysis was done by finite element methods. The dimensions of the piston are found by using machine design approach [11]. The sketch is modeled in ANSYS design modeler with the help of dimensions which are determined using machine design approach. The desired piston was shown in Figure 1.

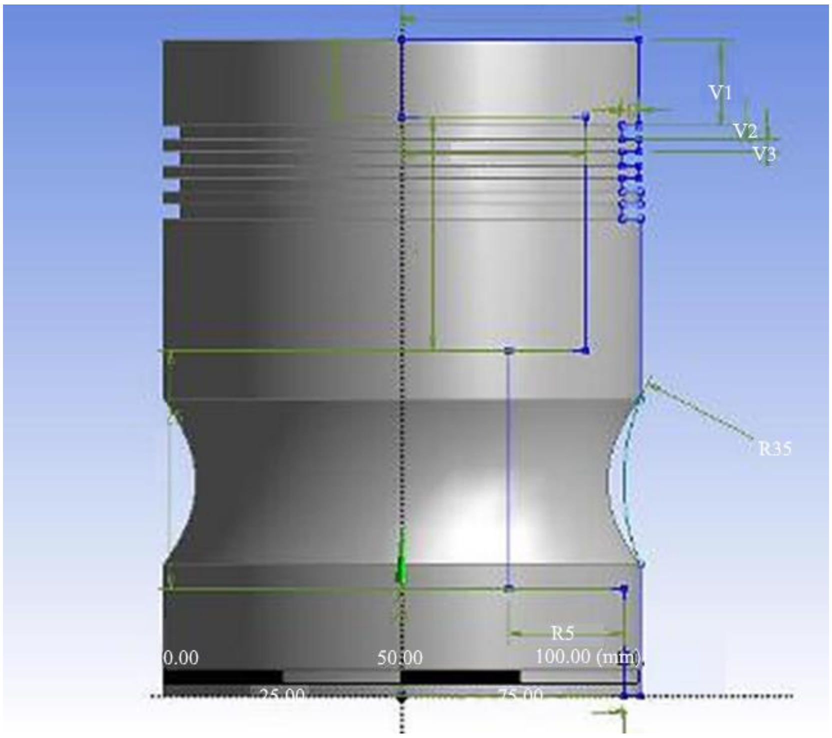

Figure 1. Front view of piston (uncoated).

The ANSYS code was used to construct the piston model's finite element mesh in Figure 2. The quantities of components acquired after default setting in ANSYS are 6419 and the quantities of hubs are 11701 for the uncoated cylinder [12].

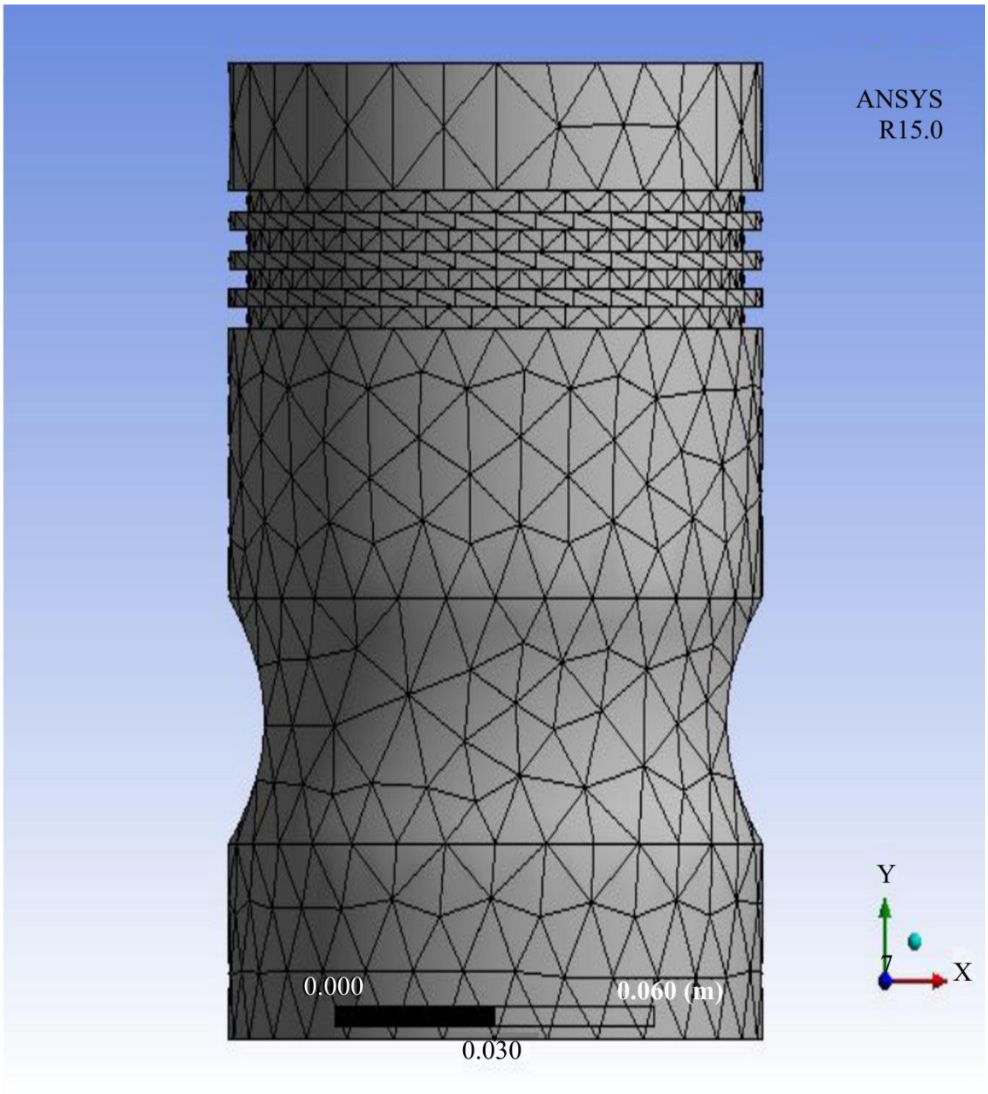

Figure 2. Meshing of piston (uncoated).

The method of warmth moves from cylinder to encompassing is on a since quite a while ago shot as convection. The set a match to move coefficient and temperature of the encompassing fluid and temperature make the limit cautioning for the warm examination. The convection is taken as a significant wonder of warmth move in the cylinder as revealed in Figure 3. Diverse temperature and warmth move coefficient are applied to the divergent regions of cylinder. The estimations of different temperature and film coefficient are dictated by subsequently condition of Hohenberg [13].

$$h_{gas}(t) = aV_c(t)^{-0.06} \times p(t)^{0.8} \times T(t)^{-0.4} \times (S_p + b)$$

Where, $h_{gas}(t)$ define as the instantaneous convective coefficient heat transfer (W/m^2K), Vc(t), P(t) and T(t) are the instantaneous volume of a cylinder (m^3), pressure (105 Pa), temperature (K), and Sp the mean piston speed (m/s), respectively. a and b are the calibration constants which are about 130 and 1.4 as defined by Hohenberg [13]. The value of temperature and heat transfer coefficient are calculated in literature [14]. The convection is taken as a significant wonder of warmth move in the cylinder as revealed in Figure 3 and Table 2.

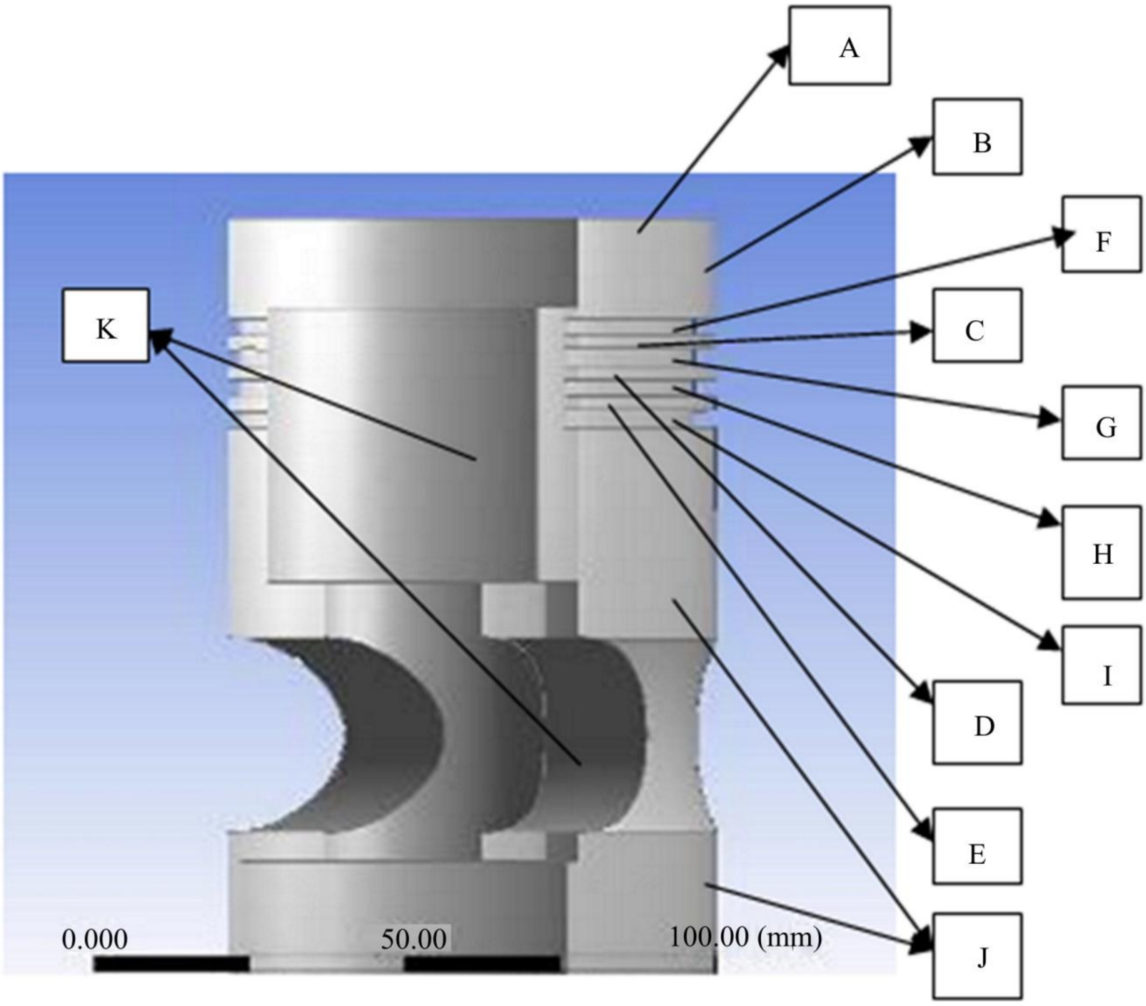

Figure 3. Thermal boundary regions.

Table 2. Convective boundary conditions [14].

Regions	Heat transfer coefficient [w/m^2°C]	Temperature[°C]
A	700	700
B	500	225
C	400	180
D	400	170
E	400	160
Ring-F	400	200
Ring-G	400	180
Ring-H	400	160
Ring-I	400	140
J	1500	110
K	1500	110

RESULTS AND DISCUSSIONS

The limited component technique is used to describe conveyance of temperature for filled cylinder fired uncoated and yttrium zirconium oxide. The allocation of temperature for the uncoated and sealed container occurs in Figure 4(a)–(b), most intense temperature exists at the top terrain of the container and the lowest temperature is at the container center [15].

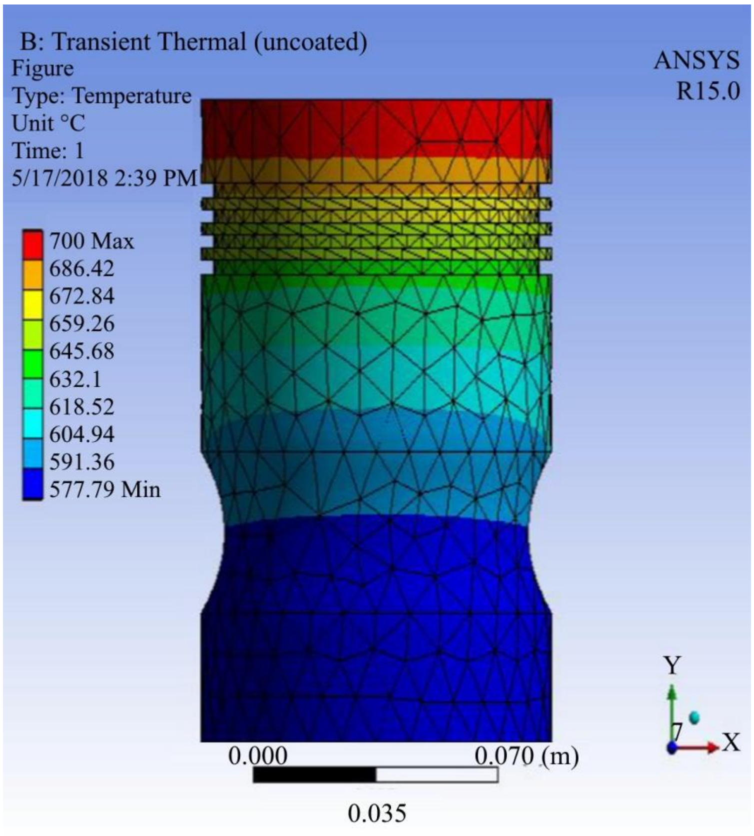

Figure 4. (a) Variation of temperature on uncoated piston.

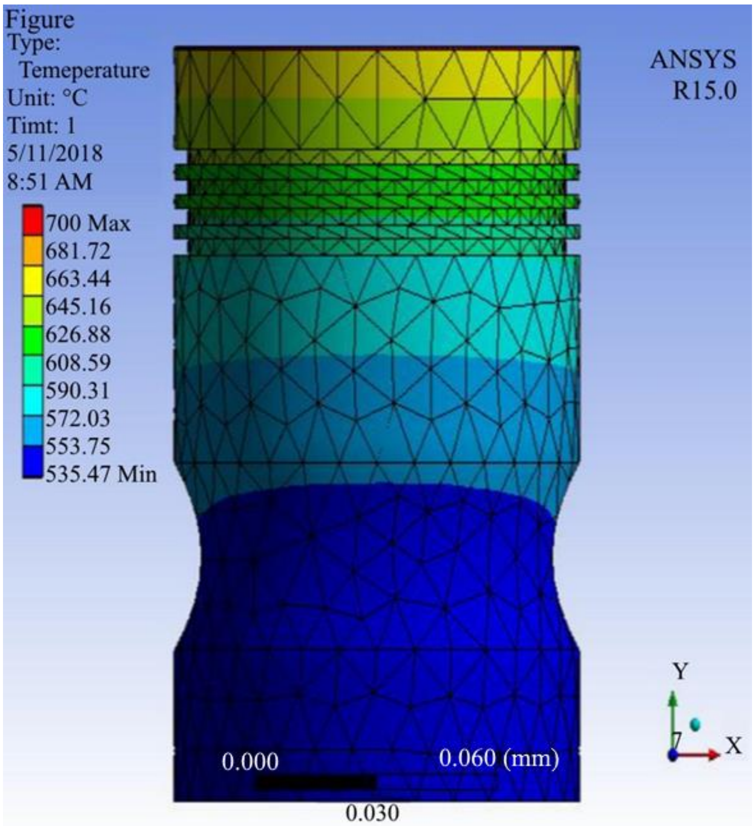

Figure 4. (b) Variation of temperature on 0.5 mm ceramic coated piston.

In uncoated cylinder, the most intense and least temperature (Figure 5) are 700°C and 577.79°C respectively. The greatest temperature for both is 700°C and the base scope of the cylinder substrate for uncoated is 577.79°C and for covered cylinder is 535.47°C.

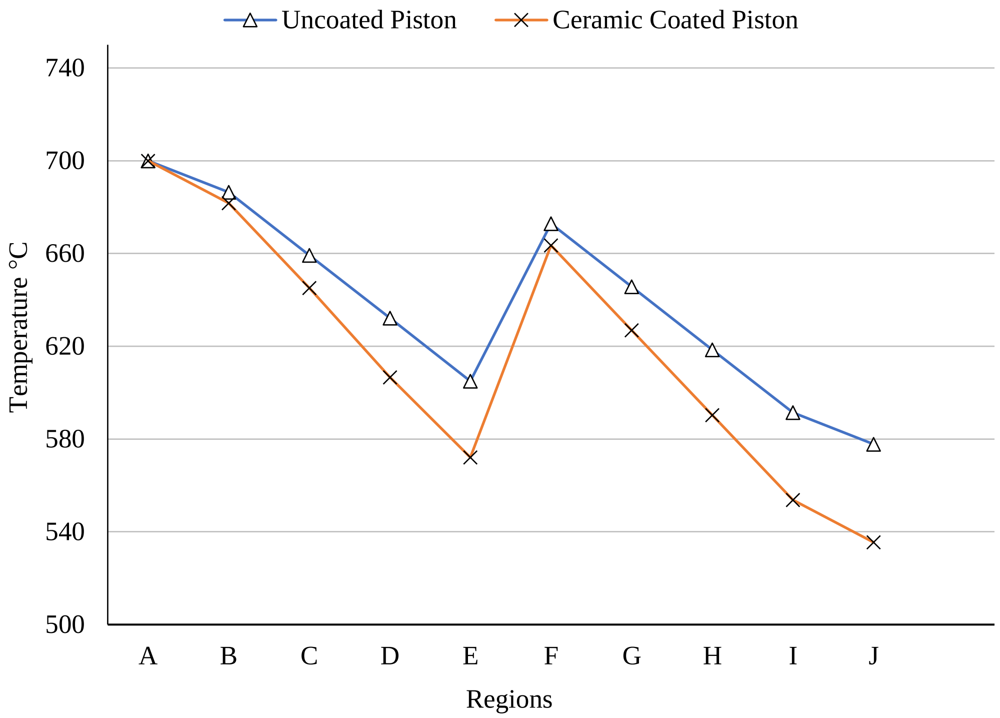

Figure 5. Variation of temperature on uncoated piston and 0.5 mm ceramic coated piston.

Figure 5 shows the temperature variation of uncoated and ceramic coated piston at different regions. Initially at region A (top surface) temperature is same for both uncoated and coated piston but moving downwards both the piston temperatures was decreased. The temperature decreased from top surface to base surface for ceramic coated piston is around 23.57% which is 17.5% more than uncoated cylinder.

CONCLUSION

The accompanying focuses might be closed from the auxiliary and the warm investigation of the cylinder which is comprised of the Al alloys and is covered with the clay material (YSZ) which is reinforced by uncommon material (Ni-Cr-Al).

- The least temperature experienced by the substrate (base metal) of cylinder is diminishes with the expansion in the coat thickness.
- The greatest temperature for both is 700°C and the base scope of the cylinder substrate for uncoated is 577.79°C and for covered cylinder is 535.47°C which is decline in temperature from top place where there is cylinder to the base surface of cylinder is around 23.57% which is more than the uncoated cylinder roughly 17.5%.

So, it tends to be inferred that mix of various covering materials with various widths can create better temperature in the cylinder keeping the expense of the covering a lot of lower than a solitary covering.

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