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Saving of Thermal Energy in Air-Gap Insulated Pistons Using Different Composite Materials for Crowns

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Abstract— The present work was aimed at an increase in the thermal energy using composite crown materials to the pistons. The heat loss to the coolant was minimum in the piston with crown made up of Si3N4/Al-alloy composite. The saving in thermal energy could increase the engine thermal efficiency.

Index Terms— piston crown, silicon carbide, silicon nitride, thermal analysis.

1 Introduction

A piston essentially consists of a long cylindrical casting closed at the top end open at the bottom end, with wrist pin attached at the center, which transmits the thrust to the connecting rod and then to the crank shaft. The piston provides the means where by gas loads are transmitted to the connecting rod/crank shaft system i.e. it transforms heat energy into the mechanical energy. The piston acts as a cross head to react cylinder wall size loads in the connecting rod/crank system. The piston is a carrier for the gas and oil sealing elements (piston rings). The piston design should be such that the seizure does not occur. It should have the shortest possible length so as decrease the over all size of the engine. It should offer sufficient resistance to corrosion due to some products of combustion. It should lighter in weight so that the inertia forces created by its reciprocating motion are minimum. It must have longer life. The material used for the piston at one time was cast iron, which has good wearing qualities. As the technology developed, the aluminum alloy containing replaced cast iron as the piston material.

In most of the internal combustion (IC) engines about 25% of the energy is lost through the coolant about 30% is consumed through friction and other losses, several methods are adopted for achieving low heat rejection to the coolant using ceramic coating on the piston [1] and creating air gap in the piston [2]. Flat top pistons have been replaced by the dashed pistons, domed pistons and pistons with intricate contours to swirl the fuel mixture and promote better fuel atomization. The shape of the piston crown controls the movement of air and fuel as the piston comes up on the compression stroke. This, in turn, affects the burn rate and what happens inside the combustion chamber. Several metal matrix composites are developed various applications. The metal matrix compound are found suitable to the applications in the aerospace and the automobile industries.

The second law of thermodynamics necessitates the inevitable heat loss to the coolant in IC engine. Any saving in this part of the energy distribution would either increase the energy loss through exhaust gases or increase the power output. In view of preventing energy loss, the present work is proposed to use different crown materials and to study their influence cooling rates.

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2 Materials Methods

The materials used for the piston crown were Al alloy, silicon carbide (SiC) reinforced Al-alloy metal matrix composite and silicon nitride (Si_3N_4) reinforced Al-alloy metal matrix composite. The finite element analysis using ANSYS was employed to model and analyze the piston for the thermal analysis. The material properties are given table 1. The 2-D and 3-D geometrical modeling (Chennakesava, 2008) of the piston is shown in figure 1. The plane-55 element (Chennakesava, 2009) was used to mesh the piston bottom, air gap and piston crown. The element edges for the piston bottom, air gap and piston crown were 1.0 mm, 0.5 mm and 0.2 mm respectively. The meshed model of 2-D piston is shown in figure 2. The thermal heat flux was applied on the top of crown. The convection heat transfer coefficient was applied on the bottom portion of piston.

TABLE 1
MATERIAL PROPERTIES

Material	Density	Young's modulus	Thermal expansion	Thermal conductivity
Al-alloy	2700 kg/m3	79 GPa	25.0×10-6/K	174 W/m-K
SiC	3100 kg/m3	410 GPa	4.0×10-6/K	120 W/m-K
SiN	2370 kg/m3	297 GPa	3.7×10-6/K	43 W/m-K

3 Results and Dicussion

This section deals with the discussion of results on the temperature distribution and the comparison of the performance of three crown materials.

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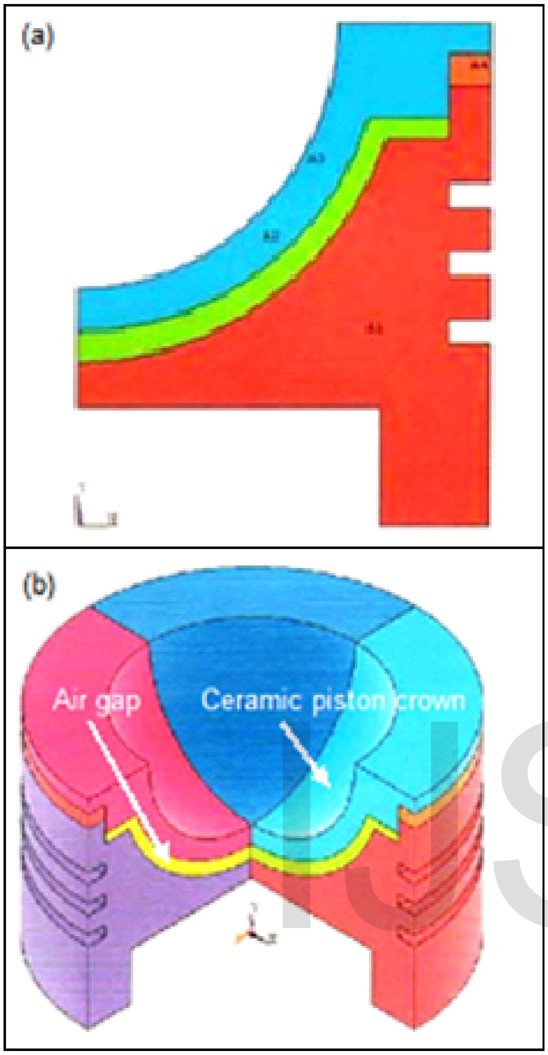

Fig. 1. 2-D and 3-D geometric modeling of piston

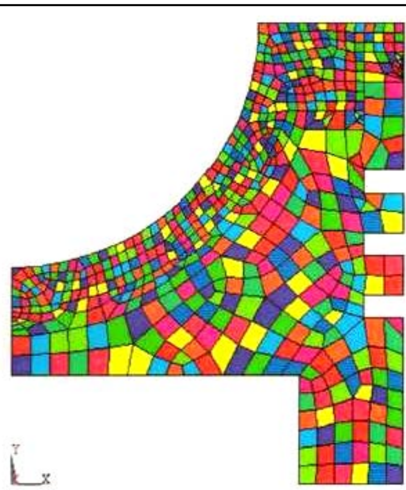

Fig. 2. The meshed 2-D piston.

3.1 Temperature Distribution

Figure 3 shows the temperature distribution in the air-gap piston with crown made up of the Al-alloy. It is observed that there is a temperature drop of 183.825^{0}C from the top of the crown to the base of piston. It is also observed that the maximum temperature is seen at the center of the crown. The temperature distribution in the air-gap piston with crown made up of the silicon carbide metal matrix composite is illustrated in figure 4. It can be noticed that there is a temperature drop of 233.289^{0}C from the top of the crown to the base of the piston. Figure 5 reveals the temperature distribution in the air-gap piston with crown made up of silicon nitride metal matrix composite. It can be observed that there is a temperature drop of 435.955^{0}C from the top of the crown to base of the piston.

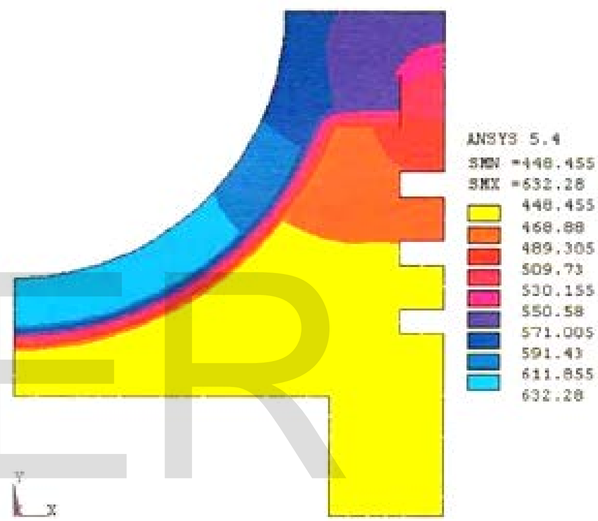

Fig. 3. Temperature distribution in the air-gap piston with crown made up of the Al-alloy.

Fig. 4. Temperature distribution in the air-gap piston with crown made up of the Al-alloy.

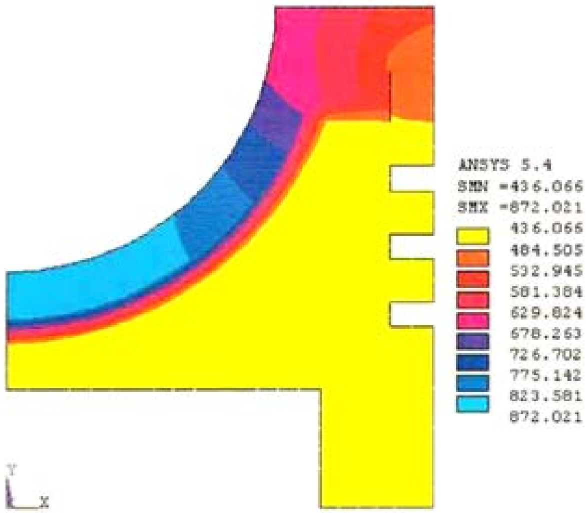

Fig. 5. Temperature distribution in the air-gap piston with crown made up of the Si_3N_4/Al-alloy composite.

3.2 Heat Flow Rate

Heat flow rates in all three types of pistons are illustrated in figures 6-8. It is observed that the heat flow rate is observed highest in the air-gap piston with crown made up Al-alloy. The heat flow rate is least in the air-gap piston with crown made up of silicon nitride/Al-alloy metal matrix composite. The air-gap piston with crown made up of silicon carbide metal matrix composite is having intermediate heat flow rate.

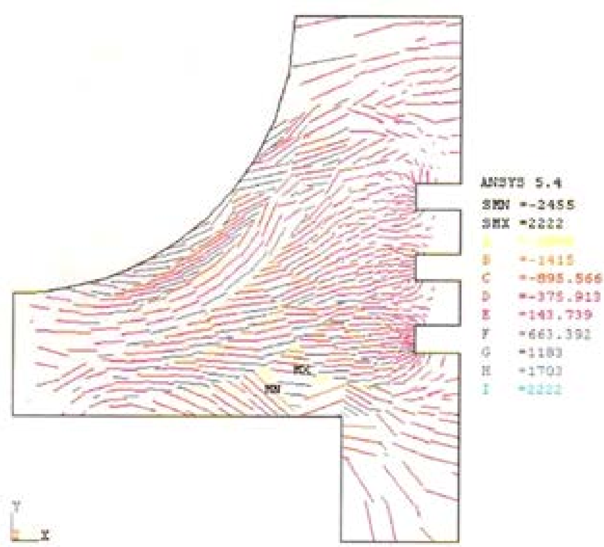

Fig. 6. Heat flow in the air-gap piston with Al-alloy crown.

3.3 Comparative Analysis of Pistons

The amount of temperature raised in a piston is directly proportional to the amount of heat saved by the piston (figure 9a). Since the heat rejection is the lowest in the piston with crown made up of silicon nitride metal matrix composite, the heat saved in this piston is highest (figure 9b) and therefore, the amount of temperature is also highest. This means that the piston with crown made up of silicon nitride metal matrix composite rejects very less amount of heat to the coolant. This saving in the thermal energy can increase the efficiency of an internal combustion (IC) engine.

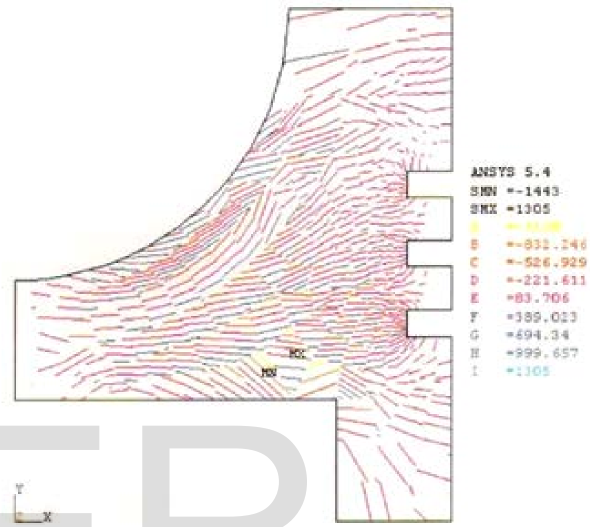

Fig. 7. Heat flow in the air-gap piston with SiC/Al-alloy composite crown.

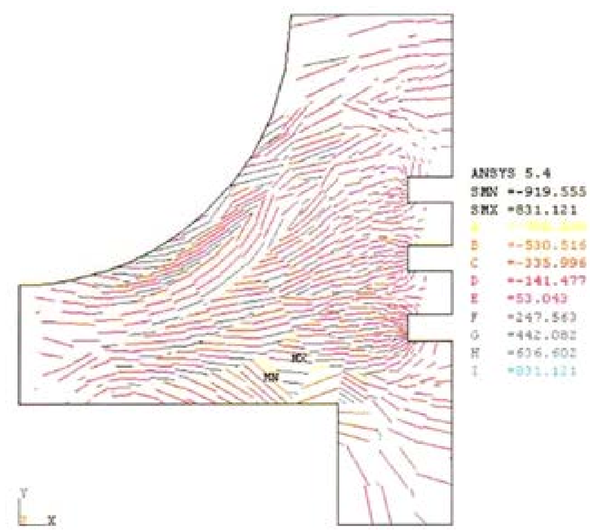

Fig. 8. Heat flow in the air-gap piston with Si_3N_4/Al-alloy composite crown.

4 Conclusion

The temperature drop of 183.835^{0}C, 233.289^{0}C and 435.955^{0}C was available in the piston crowns made up of Al-alloy,

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SiC/Al-alloy and Si_3N_4/Al-alloy composites. The heat loss to the coolant was minimum in the piston with crown made up of Si_3N_4/Al-alloy composite. The saving in thermal energy could increase the engine thermal efficiency.

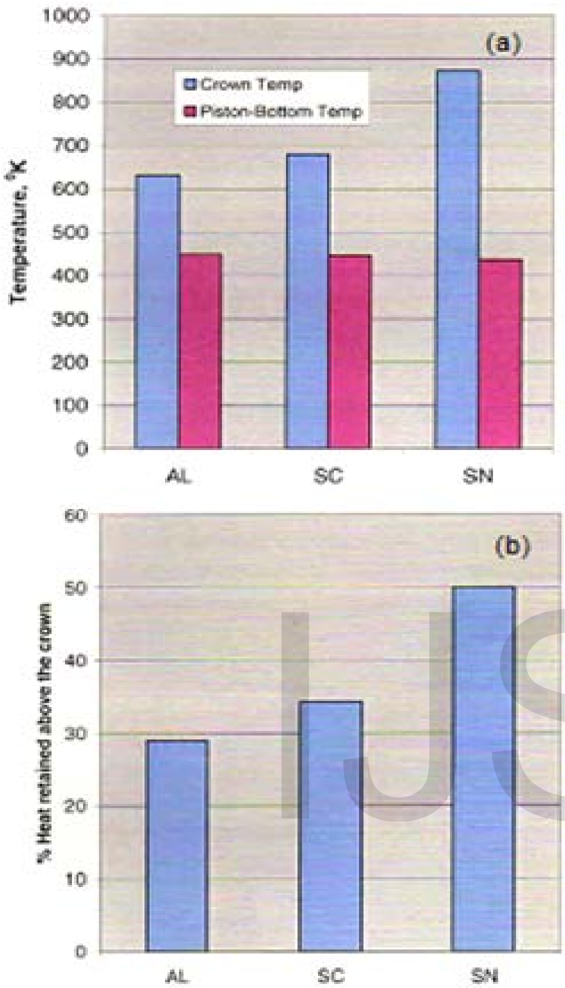

Fig. 9. Comparative analysis of pistons, (a) and percent heat retained in the pistons (b).

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