

Performance Analysis of Thermal Barrier Coating on Piston

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ABSTRACT: Within the last few years there has been a rapid increase in the utilization of aluminum-silicon alloys, particularly in the automobile industries, due to their high strength to weight ratio, high wear resistance, low density and low coefficient of thermal expansion. The advancements in the field of application make the study of their wear and tensile behavior of utmost importance. In this present investigation, Aluminum based alloys containing 7%, 12% and 14% weight of Silicon were synthesized using casting method. Compositional analysis and tensile studies of different samples of same composition have shown near uniform distribution of Si in the prepared alloys. Study of microstructure has showed the presence of primary silicon. Tensile tests were carried out with universal testing machine. Yield strength and ultimate tensile strength has increased with increase in silicon percentage. Wear behavior was studied by using computerized pin on disc wear testing machine. Resistance to wear has increased with increase in silicon amount. The worn surfaces were analyzed using scanning electron micros

KEYWORDS: Thermal Barrier Coating, Aluminium alloy, Piston

1. INTRODUCTION

The desire to reach higher efficiencies, lower specific fuel consumptions and reduce emissions in modern internal combustion (IC) engines has become the focus of engine researchers and manufacturers for the past three decades. The global concern over the decreasing supply of fossil fuels and the more stringent emissions regulations has placed the onus on the engine industry to produce practical, economical and environmentally conscious solutions to power our vehicles. Over the years, a variety of different approaches have been taken to attain improvements in efficiency and reduce emissions in existing engine designs. The introduction of new technologies has played a role in making advancements to this century-old technology. Lighter and stronger materials, advanced manufacturing processes, improved combustion chamber designs, advanced exhaust after-treatment technologies, and new computational means for designing, analyzing and optimizing the internal combustion engine are just a few of the advancements we have made to achieve significant improvements in performance, efficiency and emissions. However, over 60% of the fuel energy we put into our engines is still being wasted due to the inherent inefficiencies in today's internal combustion engines.

II. THERMAL BARRIER COATINGS

The most common coatings currently used in high temperature engine applications are Yittria stabilized zirconia due to their very low thermal conductivity and a coefficient of thermal expansion which is higher than the vast majority of insulating ceramics. Coating thicknesses used in engine applications have varied from 0.1mm to 4.5mm, with thicker coatings theoretically providing greater resistance to heat flux. The most common way of applying these coatings has been through plasma spraying which has been used to apply coatings both selectively to specific engine components (i.e. valves, cylinder head, and piston crown) and to the entire combustion chamber. The primary challenges posed by thermal barrier coatings within engine environments stem from their durability. Due to their low coefficients of thermal expansion (CTE) in comparison to the metallic substrates upon which they are applied, ceramic TBCs are prone to

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cracking, spalling and eventual failure resulting from the cyclic thermal stresses created by the temperature differential between the coating and the substrate. In an attempt to alleviate these problems, new nano-structured ceramic and metal-based TBCs with CTEs more comparable to typical metallic substrates have been studied, with some promising results. Typical material properties of yttria-stabilized zirconium (YSZ), metallic TBCs and a typical aluminum piston material are shown in table. The increased surface temperatures in a TBC-coated combustion chamber may also result in the degradation of engine lubricants, while decreasing the volumetric efficiency of the engine due to heating of the intake charge. As will be discussed, the higher temperatures may also have significant effects on combustion and thus engine emissions. Though not currently used in production engines, a great deal of research has been conducted studying the use of TBCs in both compression and spark ignition engines as a means of managing heat losses. In the following, a brief overview of the available work in the two research areas is given.

Table.1.TBC materials property

Thermal Property	Yttria- stabilized zirconia	Metallic TBC	Aluminium-silicon alloy
Application method	Plasma Spray	Wire arc thermal spray	Plasma spray
Thermal conductivity(W/m.K)	1.2	1.22	1.49
Co-efficient of thermal expansion(1/k)	9.8	15	2.2
Density(kg/m ³)	5700	7077	2996
Specific heat capacity(J/Kg/K)	490	255	875
thermal diffusivity(m ² /s)	4.9	6.8	6.5
Porosity(%)	10	7.5	8.5
Average Roughness, Ra (µm)	7-12	12-20	6-15

III. TBCs IN ENGINES

The purpose of applying thermal barrier coatings to engine components is to impede heat flow by increasing the thermal resistance at the interface between high temperature combustion gases and metallic surfaces. Thermal barrier coatings provide a means of doing this due to their very low thermal conductivities in comparison to the metallic substrates upon which they are applied. This reduction in heat loss to the metallic components translates to higher gas temperatures, which can lead to greater work output and therefore improvements in efficiency. Likewise, the metallic substrates will be exposed to lower peak temperatures as a result of the coatings, and thus reduce the thermal stresses in the engine components

3.1 MATERIAL OF TBC ENGINE

The main application as piston in engines made the Al -Si 12% alloys famous among the groups of aluminium alloys called piston alloys. They have high mechanical properties at elevated temperatures up to approximately 1500 °C. Simultaneously, these alloys possess excellent abrasion and corrosion resistance, low coefficient of thermal expansion and high strength-to-weight ratio. Typically pistons are cast from near eutectic Al-Si alloys due to their high strength over weight ratio and good thermal conductivity and are resistant to fast temperature changes. Additions of Mn or Cr and Fe have improved the performance which could be explained by their microstructure .The piston alloy development yielded in a low-Si alloy with high strength and larger elongation-to-failure. The high strength is achieved by increased amount of Fe, Cu and Mg, following the recent demand to use more and more recycling and scrap materials. Thermal cycle fatigue experiments require the measurement of stress, strain and temperature at the same time. The failure can be predicted from the accumulated plastic strain either by Manson-Coffin equation for low cycle fatigue or by Basque equation for high cycle fatigue. The diffusion coefficient in Al is so high, that precipitates can grow even at room

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temperature. The activation energy for self-diffusion is $Q = 142$ kJ/mol. The goal of this paper is to characterize the thermal fatigue behaviour of the commercially sale and thermal expansion properties; thermal fatigue was studied in order to compare the three different alloys.

3.1.1 ALLOY

An alloy is a material that has metallic properties and is formed by combination of two or more chemical elements of which at least one is a metal. The metallic atoms must dominate in its chemical composition and the metallic bond in its crystal structure. Commonly, alloys have different properties from those of the component elements. An alloy of a metal is made by combining it with one or more other metals or non-metals that often enhances its properties. The physical properties, such as density and conductivity, of an alloy may not differ greatly from those of its component elements, but engineering properties such as tensile strength and shear strength may be considerably different from those of the constituent materials.

3.1.2 ALUMINIUM ALLOY

In recent years aluminium alloys are widely used in automotive industries. This is particularly due to the real need to weight saving for more reduction of fuel consumption. The typical alloying elements are copper, magnesium, manganese, silicon, and zinc. Surfaces of aluminium alloys have a brilliant lustre in dry environment due to the formation of a shielding layer of aluminium oxide. Aluminium alloys of the 4xxx, 5xxx and 6xxx series, containing major elemental additives of Mg and Si, are now being used to replace steel panels in various automobile industries. Due to such reasons, these alloys were subject of several scientific studies in the past few years.

3.2 ANALYSIS OF THERMAL BARRIER COATING IN MATERIALS

The use of Thermal Barrier Coating (TBC) materials in IC Engines to improve their thermal efficiency. Firstly, thermal analyses are investigated on two conventional (uncoated) single cylinder Petrol Engine models, made of Grey Cast Iron (GRADE ASTM 40). Secondly, thermal analyses are performed on two different specially designed petrol engine models, each of its combustion chambers being coated with two different Thermal Barrier Coating materials namely structured aluminum silicon alloy; by means of using a commercial code called ANSYS. Finally, the results obtained from all four thermal simulations are compared with each other. The effects of coatings on the efficiency of engines are investigated. Further investigations on these results reveal that there is a considerable reduction in heat loss through combustion chamber when TBCs are used. According to Otto cycle, for an ideal petrol engine the expansion process ought to take place under isentropic conditions (No heat transfer). Engines coated with TBCs restrict heat losses to a maximum extent thereby allowing expansion process to occur in near isentropic conditions. This in turn increases the net available energy. Therefore a raise in thermal efficiency of the engine can be achieved.

3.3 PROPERTIES OF ALUMINIUM ALLOY

A wide range of physical and mechanical properties can be obtained from very pure aluminium. The different properties are: Aluminium has a density of about 2.7g/cc which is one third (approximately) the value of steel. Unlike steel, aluminium prevents progressive oxidation by formation of a protective oxide layer on its surface on exposure to air. Aluminium alloys exhibit excellent electrical and thermal conductivities. The thermal conductivity of aluminium is twice that of copper (for the same weight of both materials used).

3.3.1 ALUMINIUM-SILICON ALLOY

Aluminium-Silicon alloys are of greater importance to engineering industries as they exhibit high strength to weight ratio, high wear resistance, low density, low coefficient of thermal expansion etc. Silicon imparts high fluidity and low shrinkage, which result in good cast ability and weldability.

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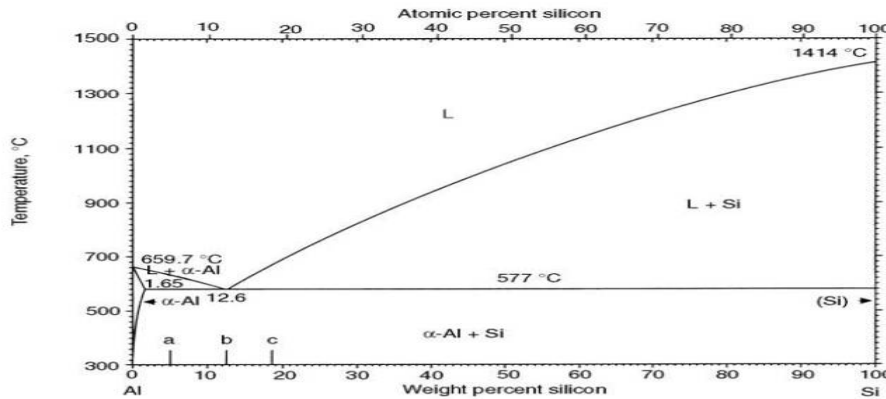


Figure 3.3.1 Phase diagram of Al-Si

IV. METHODOLOGY AND THE EXPERIMENTAL SET-UP

Feasibility study

First the basic feasibility study is made before the experimental work was carried out. The feasibility study involves the study made for the selection of thermal barrier, coating material, experimental procedure and the various parameters for coatings are studied. The study was made from literature survey and brainstorming sessions with the experts

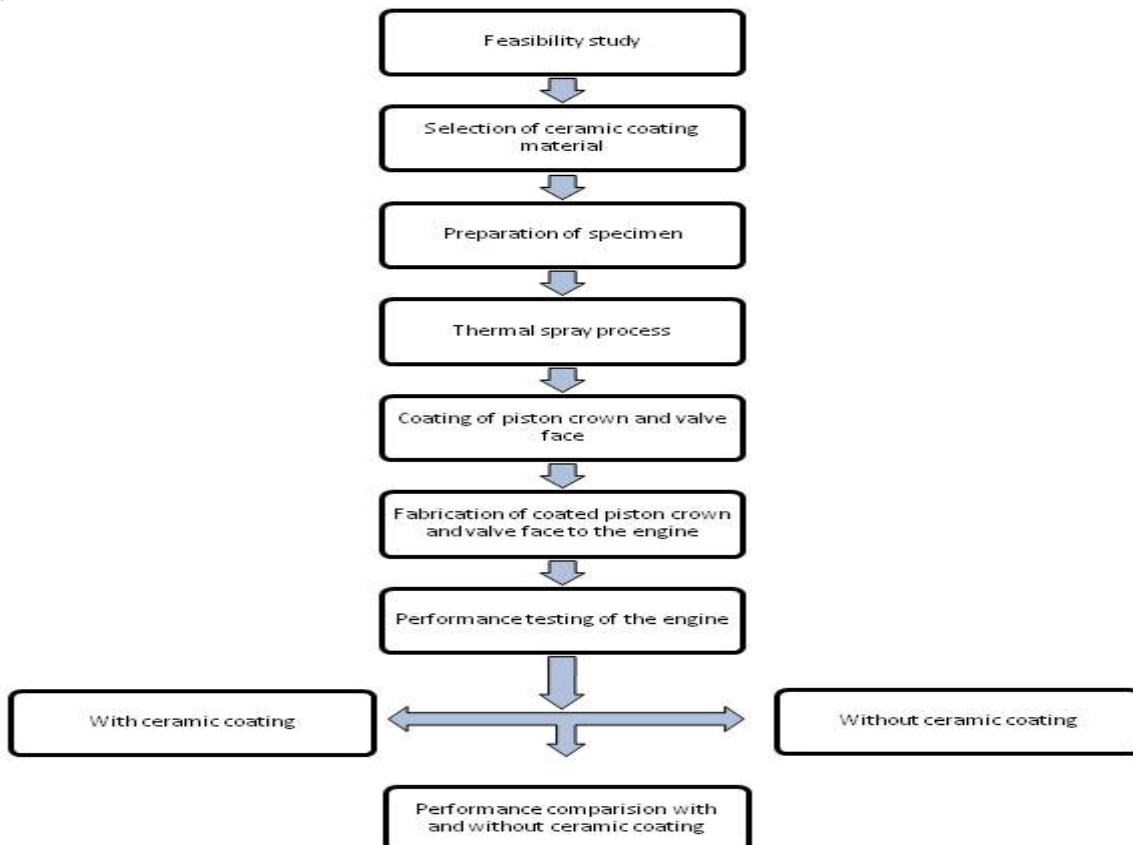


Figure 4.1 Process involved in the experiment

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V. RESULT AND DISCUSSION

At the end of 30 seconds simulation, the results of temperature distribution obtained for each of the five IC Engines discussed are as tabulated in table. We know, lower heat rejection from the combustion chamber through thermally insulated components causes an increase in available energy which in turn would increase the in-cylinder work and the amount of energy carried by the exhaust gases, which could also be utilized in later stages by using LHR (Low Heat Rejection) systems.

TEMPERATURE AT VARIOUS SECTION	Al-18%Si	GCI(ASTM GRADE 40)	STRONTIUM ZIRCONATE	BLT
On the Wall of Combustion Chamber	1173K	1173K	1173K	1173K
Cylinder Block	1000-820K	1073-550K	950-500K	730-450K
Liner Part	1173K	1173K	1050K	750K
Fins	730K	373K	373K	373K
Piston Body	1173-333K	1173-450K	1000-373K	730-373K
Valve Head	1173K	1173K	1050K	750K
Overhead Block	1173-820K	1173-373K	700-373K	700-373K

Figure 5.1 Engine body temperature of various engine materials

VI. CONCLUSION

The 3D Finite Element Thermal Analysis is thus performed on five different models of IC Engines. Upon the thermal analysis, we can see that the use of TBCs greatly reduced the heat dissipation through engine body during combustion. The following inferences are made.

- The use of TBCs in IC Engines will definitely improve the thermal efficiency.
- Furthermore, BLT TBC is found to be the most viable TBC material for use in petrol (gasoline) based IC Engine, on account of its high thermal phase stability and low thermal conductivity.
- Smaller engine cooling system is sufficient.
- More intake charge may be expected in case of naturally aspirating engines which means higher volumetric efficiency as well.
- The liner would show lesser wear because of higher hardness of TBC materials.
- The prepared aluminium-silicon alloys have homogenous distribution of silicon throughout the cast.
- The amount of primary silicon increases with the increase in silicon amount in the cast.
- Yield strength and ultimate tensile strength increases with the increase of weight percentage of silicon.
- Total elongation decreases with the increase of weight percentage of silicon.
- Hardness of the Al-Si composite increases with the increase in amount of silicon present.
- The height loss due to wear decreases when the percentage of silicon increases.

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