A STUDY OF THERMAL BARRIER COATING (TBCs) FOR AUTOMOTIVE COMPONENT

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AGREEMENT

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Untuk Ibu Dan Ayah Tersayang…

Hanya Engkau Sahaja Ilham Hidupku…

Akan Ku Buktikan Kepadamu…

Yang Aku Juga Boleh Berjaya Seperti Orang Lain…

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ABSTRACT

Heat is a form of energy that very useful to human and sometimes being wasted. Almost all components of the engine produce a lot of heat during engine operation. Some of the heat will be use to generate extra power such as application of turbocharger. During turbocharger operation, heat will be developed in the housing of the turbocharger, and some of heat will be transfer to atmosphere. The project aim to minimize heat loss through a housing of the since heat is form of energy, it is expected that minimum of heat will be lead to higher efficiency of turbocharger. Therefore to prevent the heat being transfer to atmosphere, Thermal Barrier Coating is deposited on the surface of the housing turbocharger, a system exchange no heat with it surrounding, it can be use to operate the compressor than efficiency of engine will be increase. This project will be focusing on selected of the best material for TBC base on the general properties of thermal barrier coating such as low thermal conductivity, high resistance to spallation, good erosion resistance, phase stability and pore morphological stability. In this research/project by using the CES Edu Pack analysis it is found that Zirconia with Magnesia is the best of the material TBC for turbocharger application and it can reduce heat loss around 16.90%.

ABSTRAK

Haba merupakan bentuk tenaga yang sangat berguna kepada manusia dan kadang-kadang ia disia-siakan begitu sahaja. Hampir semua komponen automotif menghasilkan haba selama enjin beroperasi, sebahagian daripada haba akan digunakan untuk menghasilkan tenaga tambahan seperti aplikasi *turbocharger*, dalam operasi *turbocharger* haba akan dihasilkan dalam perumahan *turbocharger*, sebahagian akan terbebas ke atmosfera. Haba yang dihasilkan melalui perumahan turbocarjer akan menggerakkan turbin dan pemampat, dengan mengurangkan haba yang dibebaskan ke atmosfera sistem adiabatik digunakan pada perumahan turbocarjer, *'Thermal Barrier Coating'* akan digunakan pada permukaan perumahan turbocharger, dimana sistem ini tidak membebaskan haba ke atmosfera, haba tersebut boleh digunakan bagi menjalankan pemampat dan akan meningkatkan kecekapan pada enjin tersebut. . Projek ini akan menekankan pemilihan bahan terbaik bagi digunakan untuk TBC berdasarkan sifat umum *Thermal Barrier Coating* seperti kekondaktivian yang rendah, ketahan pemecahan yang tinggi, ketahanan hakisan yang baik, kestabilan fasa dan kestabilan morfologi. Dalam kajian ini, dengan mengunakan *CES Edu Pack* analisis, didapati bahawa Zirkonia dengan Magnesia adalah bahan yang terbaik sebagai TBC untuk diaplikasikan kepada *turbocharger* dan ia mampu mengurangkan sehingga 16.90% tenaga.

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LIST OF SYMBOLS

ρ	=	Density
C_p	=	Constant Pressure
K	=	Thermal Conductivity
α	=	Thermal Diffusivity
ω	=	Specific Humidity
Q	=	Heat Flow
R	=	Resistance
ΔT	=	Deferent temperature outside and inside
V	=	Volume
T	=	Absolute Temperature
υ_υ	=	Specific volume
P	=	Pressure
µ	=	Dynamic viscosity, head coefficient, Degree of saturation
A	=	Area

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Thermal barrier coatings are highly advanced material usually applied to metallic surfaces, such as gas turbine or aero-engine parts, operating at elevated temperatures, as a form of Exhaust Heat Management [13]. These coatings serve to insulate components from large and prolonged heat loads by utilizing thermally insulating materials which can sustain an appreciable temperature difference between the load bearing alloys and the coating surface. In doing so, these coatings can allow for higher operating temperatures while limiting the thermal exposure of structure.

Thermal barrier ceramic-coatings are becoming more common in automotive applications. They are specifically designed to reduce heat loss from engine exhaust system components including exhaust manifolds, turbocharger casings, exhaust headers, downpipes and tailpipes. This process is also known as Exhaust Heat Management. When used under-bonnet, these have the positive effect of reducing engine bay temperatures, therefore lessening the intake temperature [13].

Thermal barrier coatings consist of four layers: the metal substrate, metallic bond coat, thermally grown oxide, and ceramic topcoat [13]. The ceramic is desirable for having very low conductivity while remaining stable at nominal operating temperatures typically seen in applications. Recent advancements in finding ceramic topcoat identified many novel ceramics (rare earth zirconates) having superior performance at temperatures above 1200 °C, however with inferior fracture toughness. This ceramic layer creates the largest thermal gradient of the TBC and keeps the lower layers at a lower temperature than the surface [5].

1.2 Objectives

- The objective of this project is to determine the best material of thermal barrier coatings (TBCs) for automotive component.

1.3 Scopes

The scopes of this project are:

- Literature review on related topics.
- Selected automotive component to coating.
- To analyze the potential material of TBC applied for selected automotive component by using CES Edu Pack.
- Heat transfer analysis of selected material.

1.4 Problem Statement

When the part of engine is operate, the heat can be produced by the engine or another automotive components. Normally the heat transformed to the environment as waste, therefore it is possible to recover this heat loss thus increase efficiency of the engine. It is in line with the 1st low Thermodynamic which mentions that '*energy can be neither created nor destroyed during a process, it can only change forms'*. Therefore it is predicted that if some potential component being insulated with thermal barrier coating the heat loss from that component can be minimized, thus it will lead to higher engine efficiency.

The process will be the same concept with the adiabatic process. During the adiabatic process, a system exchange no heat with it surrounding as shown in (figure 1.1)

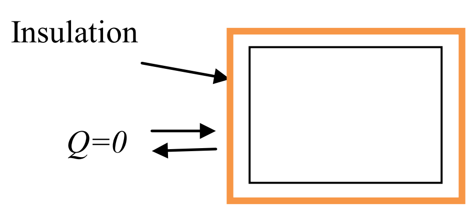

Figure 1.1 Adiabatic system

Therefore this project is proposed to determine the best material of thermal barrier coatings (TBCs) for automotive component in the aiming to produce higher engine efficiency.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction TBCs

Thermal barrier coatings are highly advanced material systems usually applied to metallic surfaces, such as gas turbine or aero-engine parts, operating at elevated temperatures, as a form of Exhaust Heat Management [5]. These coatings serve to insulated components from large and prolonged heat loads by utilizing thermally insulating materials which can sustain an appreciable temperature difference between the load bearing alloys and the coating surface.

In turbine application, higher gas temperature will lead to higher turbine (Rapp, 1990). It is shown that the thermal barrier coating is important to shield metal part. It was support by Emily A. Jarvis (1993) that "thermal barrier coatings of jet engine turbines are critical for achieving powerful, fuel-efficient aircraft".

2.2 Benefit of Thermal Barrier Coating

2.2.1 Heat Insulation

Metal failure due to overheat. Provide effective heat insulation to reduce surrounding compartment heat which will help to [3]:

- Improve surrounding parts life
- Improve parts working efficiency and performance
- Improve fuel economy due to HP & Torque increase

2.2.2 Heat Dissipation

Heat generated by electronic devices and circuitry must be dissipated to improve reliability and prevent premature failure. Metal failure due to overheat provide effective heat dissipation to reduce the heat in the part which will help to[3]:

- Improve parts working efficiency and performance
- Improve parts life

2.2.3 Improve Lubrication

Lubricating and maintaining such lubrication is critical to those friction parts (bearing);

- Improve lubrication
- Improve parts life
- Save energy

2.2.4 Corrosion Protection

Corrosion is the disintegration of an engineered material into its constituent atoms due to chemical reactions with its surroundings. In the most common use of the word, this means electrochemical oxidation of metals in reaction with an oxidant such as oxygen. Metal parts failure due to corrosion attack. Provide corrosion resistance insulation to[3]:

- Improve parts reliability
- Improve product quality (metal melting process)
- Save energy

2.3 TBC System

Modern TBC's are required to not only limit heat transfer through the coating but to also protect engine components from oxidation and hot corrosion. No single coating Composition appears able to satisfy these multifunctional requirements. As a result, a "Coating system" has evolved. Research in the last 20 years has led to a preferred coating system consisting of three separate layers to achieve long term effectiveness in the high temperature, oxidative and corrosive use environment for which they are intended to function [5]:

1. Low thermal conductivity,
2. High resistance to spallation,
3. Good erosion resistance,
4. Phase stability and
5. Pore morphological stability

2.3.1 Low Thermal Conductivity

In physics, thermal conductivity, *k*, is the property of a material that indicates its ability to conduct heat. It appears primarily in Fourier's Law for heat conduction. Thermal conductivity is measured in watts per kelvin per metre ($W{\cdot}K^{-1}{\cdot}m^{-1}$). Multiplied by a temperature difference (*in kelvins, K*) and an area (in square meters, m^2), and divided by a thickness (in meters, m) the thermal conductivity predicts the energy loss (in watts, *W*) through a piece of material [7].

2.3.1.1 Conductance

For general scientific use, thermal conductance is the quantity of heat that passes in unit time through a plate of particular area and thickness when its opposite faces differ in temperature by one Kelvin. For a plate of thermal conductivity *k*, area *A* and thickness *L* this is *kA/L*, measured in $W{\cdot}K^{-1}$ (equivalent to: W/°C). Thermal conductivity and conductance are analogous to electrical conductivity $(A{\cdot}m^{-1}{\cdot}V^{-1})$ and electrical conductance $(A{\cdot}V^{-1})$ [7].

There is also a measure known as heat transfer coefficient: the quantity of heat that passes in unit time through unit area of a plate of particular thickness when its opposite faces differ in temperature by one Kelvin. The reciprocal is thermal insulance. In summary [7]:

- thermal conductance = *kA/L*, measured in $W \cdot K^{-1}$
- thermal resistance = *L/(kA),* measured in $K \cdot W^{-1}$ (equivalent to: *°C/W*)
- heat transfer coefficient = *k/L*, measured in $W \cdot K^{-1} \cdot m^{-2}$
- thermal insulance = *L*/*k*, measured in $K \cdot m^2 \cdot W^{-1}$.
- The heat transfer coefficient is also known as thermal admittance

2.3.1.2 Resistance

When thermal resistances occur in series, they are additive. Therefore when heat flows through two components each with a resistance of 1 °C/W, the total resistance is 2 °C/W. A common engineering design problem involves the selection of an appropriate sized heat sink for a given heat source. Working in units of thermal resistance greatly simplifies the design calculation. The following formula can be used to estimate the performance [7].

$$R_{hs} = \frac{\Delta T}{P_{th}} - R_s \qquad (2.1)$$

2.3.2 Resistances to spallation

The spallation resistance, however, Is dependent on the mechanical properties of all three layers .For example the TBC top layer must have a high in-plane compliance to minimize the coefficient of thermal expansion (CTE) mismatch stress between the top TBC layer and the underlying superalloy substrate[5].