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makcay@pau.edu.tr***Abstract**

It is known that the efficiency of internal combustion diesel engines changes %38-42. It is about %60 of the fuel energy dismissed from combustion chamber. To save energy, combustion chamber component are coated with low thermal conduction materials. In this paper, give an eye to thermal barrier coating and ceramic materials which are used for making low heat released engines.

Keywords: *Thermal barrier coatings, ceramics, diesel engines*

INTRODUCTION

The quantity of the energy acquired from the fuel is not an intended level because of the factors in the combustion chamber of the engine. Some of the factors are, design of the combustion chamber, lack of adequate turbulence in the combustion chamber, poor oxygen at the medium, lower combustion temperature, compression ratio and advance of injection timing. It is thought that combustion temperature is the one of the most important factor among the aforementioned factors. All of the hydrocarbons can not be reacted with oxygen chemically at the during combustion time. With this aim, coating combustion chamber components with low thermal conductivity materials becomes a more important subject at these days. For this reason, combustion chamber components of the internal combustion engines are coated with ceramic materials using various methods. [1]

The efficiency of most commercially available diesel engine ranges from 38% to 42%. Therefore, between 58% and 62% of the fuel energy content is lost in the form of waste heat. Approximately 30% is retained in the exhaust gas and the remainder is removed by the cooling, etc. More than 55% of the energy

which is produced during the combustion process is removed by cooling water/air and through the exhaust gas. In order to save energy, it is an advantage to protect the hot parts by a thermally insulating layer. This will reduce the heat transfer through the engine walls, and a greater part of the produced energy can be utilized, involving an increased efficiency [2].

The major promises of thermal barrier coated engines were increased thermal efficiency and elimination of the cooling system. A simple first law of thermodynamics analysis of the energy conversion process within a diesel engine would indicate that if heat rejection to the coolant was eliminated, the thermal efficiency of the engine could be increased [3].

Thermal barrier coatings were used to not only for reduced in-cylinder heat rejection and thermal fatigue protection of underlying metallic surfaces, but also for possible reduction of engine emissions [4].

Thermal insulation brings, according to the second law of thermodynamics, to engine heat efficiency improvement and fuel consumption

reduction. Exhaust energy rise can be effectively used in turbocharged engines. Higher temperatures in the combustion chamber can also have a positive effect in diesel engines, due to the ignition delay drop and hardness of engine operation [2].

THERMAL BARRIER COATINGS

Thermal barrier coatings are duplex systems, consisting of a ceramic topcoat and a metallic intermediate bond coat. The topcoat consists of ceramic material whose function is to reduce the temperature of the underlying, less heat resistant metal part. The bond coat is designed to protect the metallic substrate from oxidation and corrosion and promote the ceramic topcoat adherence [5]. A thermal barrier application is shown in figure 1.

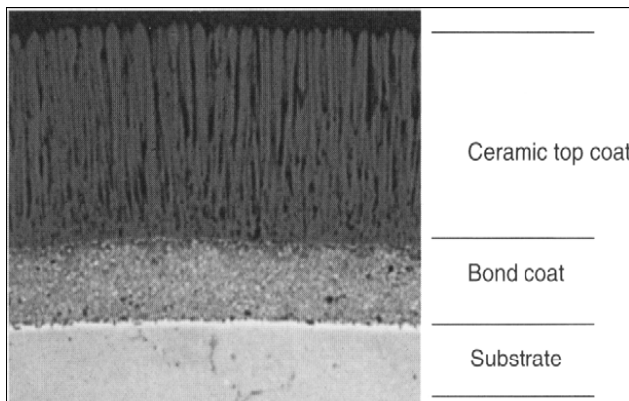


Figure 1. Thermal barrier coating consisting of metallic bond coat on the substrate and ceramic top coat on the bond coat[6].

In a diesel engine almost %30 of the fuel energy is wasted due to heat losses through combustion chamber components. For that reason, lots of research activity has focused on applying thermal barrier coatings to diesel engines. Figure 2 shows a cross-sectional view of the diesel engine combustion chamber and points out the components that might be effectively coated with thermal barrier coatings.

In figure 2, 1 indicates piston head, 2 indicates cylinder liner, 3 indicates seating of intake valve, 4 indicates seating of exhaust valve, 5 indicates cylinder head, 6 indicates intake valve and 7 indicates exhaust valve.

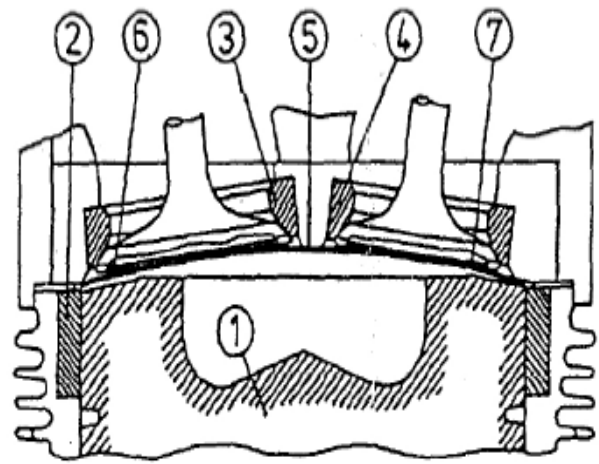


Figure 2. Potential thermal barrier coated components in a diesel engine combustion chamber [7].

The design of the thermal barrier coatings and the environment in which it operates impose restrictions on the materials of construction. Table 1 lists some of the property requirements of the ceramic coating of the thermal barrier coating system.

Table 1. Materials requirement for ceramic thermal barrier coating [6].

Property	Requirement	Rationale
Melting point	High	Operating environment at high temperature
Thermal conductivity	Low	Temperature reduction inversely proportional to thermal conductivity
Coefficient of thermal expansion	High	Expansion should be close to that of super alloy substrate and bond coats on which coatings are deposited
Phase	Stable	Phase change in thermo cyclic environment is structurally detrimental
Oxidation resistance	High	Operating environment highly oxidizing
Corrosion resistance	Moderate to high	Operating environment may be corrosive
Strain tolerance	High	Operating environment imposes large strain ranges

ADVANTAGES OF THERMAL BARRIER COATINGS FOR DIESEL ENGINES

Some advantages of thermal barrier coatings on diesel engines are below.

- Low cetane fuels can be burnt.
- Improvements occurs at emissions except NO_x
- Waste exhaust gases are used to produce useful shaft work,
- Increased effective efficiency,
- Increased thermal efficiency,
- Using lower-quality fuels within a wider distillation range,
- The ignition delay of the fuel is considerably reduced,
- The faster vaporization and the better mixing of the fuel,
- Reduced specific fuel consumption,
- Multi-Fuel capability,
- Improved reliability,
- Smaller size,
- Lighter weight,
- Decreased the heat removed by the cooling system,
- The first start of engine on cold days will be easier,
- Decreasing knocking and noise caused by combustion [2, 8-20].

MATERIALS FOR THERMAL BARRIER COATING

The selection of thermal barrier coating materials is restricted by some basic requirements. They are high melting point, no phase transformation between room temperature and operation temperature, low thermal conductivity, chemical inertness, thermal expansion match with the metallic substrate, good adherence to the metallic substrate and low sintering rate of the porous microstructure. So far, only a few materials have been found to basically satisfy these requirements. There are some ceramics which are used for thermal barrier coating below.

Zirconates

The main advantages of zirconates are their low sintering activity, low thermal conductivity,

high thermal expansion coefficient and good thermal cycling resistance. The main problem is the high thermal expansion coefficient which results in residual stress in the coating, and this can cause coating delamination [21].

Yttria Stabilized Zirconia

%7-8 yttria stabilized zirconia has high thermal expansion coefficient, low thermal conductivity and high thermal shock resistance. Disadvantages of yttria stabilized zirconia are sintering above 1473 K, phase transformation at 1443 K, corrosion and oxygen transparent [22].

Mullite

Mullite is an important ceramic material because of its low density, high thermal stability, stability in severe chemical environments, low thermal conductivity and favorable strength and creep behavior. Compared with yttria stabilized zirconia, mullite has a much lower thermal expansion coefficient and higher thermal conductivity, and is much more oxygen-resistant than yttria stabilized zirconia. The low thermal expansion coefficient of mullite is an advantage relative to yttria stabilized zirconia in high thermal gradients and under thermal shock conditions. However, the large mismatch in thermal expansion coefficient with metallic substrate leads to poor adhesion. The other disadvantage of mullite is crystallization at 1023-1273 K [21, 22].

Alumina

It has very high hardness and chemical inertness. Alumina has relatively high thermal conductivity and low thermal expansion coefficient compared with yttria stabilized zirconia. Even though alumina alone is not a good thermal barrier coating candidate, its addition to yttria stabilized zirconia can increase the hardness of the coating and improve the oxidation resistance of the substrate. The disadvantages of alumina are phase transformation at 1273K, high thermal conductivity and very low thermal expansion coefficient [22].

Spinel

Although spinel has very good high temperature and chemical properties, its thermal expansion coefficient prevents its

usage as a reliable choice for thermal barrier coatings [21].

Forsterite

The high thermal expansion coefficient of forsterite permits a good match with the substrate. At thicknesses of some hundred microns, it shows a very good thermal shock resistance [21].

CONCLUSION

With insulating combustion chamber components, it is available to keep combustion temperatures high. Due to high combustion temperatures thermal efficiency can be increased, exhaust emissions can be improved and fuel consumption can be decreased on diesel engines. Ceramic materials which have low thermal conductivity and high thermal expansion coefficient are used for making combustion chamber components thermal insulated.

In this paper the effects of thermal barrier coatings on diesel engines and some ceramic materials used for thermal barrier coating is taken into consideration.

For a successful coating thermal coating, ceramic material has a high melting point, high oxygen resistance, high thermal expansion coefficient, high corrosion resistance, high strain tolerance, low thermal conductivity and phase stability.

REFERENCE

- [1] Hazar H. ve Öner C. "Dizel motorlarında termal bariyer kaplamanın egzoz emisyonlarına etkisi" Doğu Anadolu Bölgesi Araştırmaları, 48-51, (2004).
- [2] Yaşar H. "Termal bariyer kaplamanın turbo doldurmalı bir dizel motorunun performansına etkileri", İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü, Doktora Tezi, (1997).
- [3] Boehman, A. L., Vittal, M., Borek, J. A., Marks, D. A. and Bentz, A. P., "The effects of thermal barrier coatings on diesel engine emissions," ASME ICE-Vol 29-3, 25-32 (1997).
- [4] Chan S., H. and Khor K., A. "The effect of thermal barrier coated piston crown on engine characteristics", Journal of Materials Engineering and Performance, 9(1), 103-109, (2000).
- [5] Saint-Ramond, B. "High insulation thermal barrier coating systems", Air & Space Europe, 3, 3/4, (2001).
- [6] Bose S., "High Temperature Coatings", 312 pages, Science Direct e-book Copyright, (2007).
- [7] Ahmanniemi, A. S., "Modified thick thermal barrier coatings", Department of Materials Engineering, Tampere University of Technology Doctoral Dissertation, (2004).
- [8] Parlak A., Yaşar H., Şahin B. "Performance and exhaust emission characteristics of a lower compression ratio LHR diesel engine", Energy Conversion and Management, 44, 163-175, (2003).
- [9] Chan S., H. "Performance and emissions characteristics of a partially insulated gasoline engine", International Journal of Thermal Sciences, 40, 255-251, (2001).
- [10] Srinivasan, K., K., Mago, P., J., Krishnan, S., R., "Analysis of exhaust waste heat recovery from a dual fuel low temperature combustion engine using an Organic Rankine Cycle" Energy, 35, 2387-2399, 2010
- [11] Uzun A., Çevik İ., Akçıl M. "Effects of thermal barrier coating on a turbocharged diesel engine performance", Surface and Coating Technology, 116-119, 505-507, (1999).
- [12] Taymaz I., Çakır K., Mimaroglu A., "Experimental study of effective efficiency in a ceramic coated diesel engine", Surface and Coatings Technology, 200, 1182-1185, (2005).
- [13] Chan S., H. and Khor K., A. "The effect of thermal barrier coated piston crown on engine characteristics", Journal of Materials Engineering and Performance, 9(1), 103-109, (2000).
- [14] Büyükkaya E., Engin T., Cerit M. "Effects of thermal barrier coating on gas emissions and performance of a LHR engine with different injection timings and valve adjustments", Energy Conversion and Management, 47, 1298-1310, (2006).
- [15] Hazar H. ve Öner C. "İçten yanmalı motorlarda seramik kaplamanın motor performansına etkisi", Doğu Anadolu Bölgesi Araştırmaları, 36-38, (2004).
- [16] Barbezat G. "Application of thermal spraying in the automobile industry", Surface and Coatings Technology, 201, 2028-2031, (2006).
- [17] Haşımoğlu C., Ciniviz M., Özsert İ., İçingür Y., Parlak A., Salman M. S. "Performance characteristics of a low heat rejection diesel engine operating with biodiesel", Renewable Energy, 33, 1709-1715, (2008).
- [18] Hazar H. and Oztürk U. "The effects of Al₂O₃-TiO₂ coating in a diesel engine on

- performance and emission of corn oil methyl ester”, Renewable Energy, 35, 2211-2216, (2010).
- [19] Karthikeyan B. and Srihar K. “Performance characteristics of a glow plug assisted low heat rejection diesel engine using ethanol”, Applied Energy, (2010).
- [20] Hazar H. “Cotton methyl ester usage a diesel engine equipped with insulated combustion chamber”, Applied Energy, 87, 134–140, (2010).
- [21] H. Samadi, and T.W. Coyle, “Alternative thermal barrier coatings for diesel engines”, 5th Congress of Iran Ceramic Society, Iranian Ceramic Society, 1–8, Tehran, Iran, (2004)
- [22] X.Q. Cao, R. Vassen, and D. Stover, “Ceramic materials for thermal barrier coatings”, Journal of European Ceramic Society, 24, 1–10, (2004).