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Integrated Review of Thermo-Physical Properties of Different Ceramic Coatings to make them Suitable for Internal Combustion Engines

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Abstract- Thermal barrier coating using many ceramic powders is being done in internal combustion engines for more than two decades now. Thermal spray techniques are extensively used for coating of these powders over piston top, cylinder walls and valves of the engine. These coatings have to bear thermal stresses during combustion in the engine thus wear and tear of ceramic coating occurs. The present paper is a review of the research work that has been done to study different ceramic coatings to understand stresses in coatings, porosity and crack penetration by applying thermal shock tests and thermal torch experiment. Also the best ceramic coating material has been suggested suitable as thermal barrier coating for application in internal combustion engines.

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K. R. Sharma [α] & Debasish Das [σ]

Abstract- Thermal barrier coating using many ceramic powders is being done in internal combustion engines for more than two decades now. Thermal spray techniques are extensively used for coating of these powders over piston top, cylinder walls and valves of the engine. These coatings have to bear thermal stresses during combustion in the engine thus wear and tear of ceramic coating occurs. The present paper is a review of the research work that has been done to study different ceramic coatings to understand stresses in coatings, porosity and crack penetration by applying thermal shock tests and thermal torch experiment. Also the best ceramic coating material has been suggested suitable as thermal barrier coating for application in internal combustion engines.

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I. Introduction

The ceramic coatings on metallic materials have shown significant improvements since 1970. For the aim of the thermal barrier coatings, thermal expansion, thermal conductivity, wear properties, creep and corrosion resistance are important properties. The flame spray and plasma spray techniques are the two main coating techniques used these days. The application of ceramic for thermal barrier coating in adiabatic engines started from 1980. First of all gas turbine wings were used in the area, and then piston, cylinder liner, valve, piston crown surface were used for ceramic coatings.

The experimental bonding strength values of ceramic coatings given by some researchers [1-4] show clear changes. Literature data on the bonding strength of ceramic coatings demonstrated that the plasma-sprayed ceramic coatings have a higher bonding strength than flame-sprayed coatings do [5]. Eichhorn F et al. [6] has shown that a bonding strength value of pure alumina was less than the bonding strength of stabilized alumina. The bonding strength of a ceramic coatingwith a bonding coating is higher than that of without bonding coating. The work of Unger R H andGates et al. [7,8] shows that the adhesion strength between the substrate and the ceramic coating could be improved by a NiAl bonding coating.

Few researchers have shown that within the coating materials zirconia ceramics as wear resistance material have been extensively considered for engineering applications [9-11].

Latest works expose that microstructure and mechanical properties, such as grain size [12-16], porosity [17], hardness [18, 19], fracture toughness [20], have strong effect on abrasive sliding wear resistance of bulk ceramics and coatings under dry or lubrication circumstances. Due to reduction in the grain size of ceramics their mechanical properties would be improved [21, 22], which is helpful in improving the abrasive sliding wear resistance of bulk ceramics and coatings [23-25].

II. Plasma Spraying Technique

The plasma powder is getting through plasma gas and sprayed on substrate, this phenomenon is known to be plasma spraying technique. At plasma spray technique, the coating powder can be sent by a plasma gas. Between two electrodes plasma is formed and powder is deposited in plasma arc. The plasma gas is usually argon or nitrogen. At plasma spraying technique, when argon, hydrogen or nitrogen gases are used, oxidation problem is minimized. For this reason, plasma spraying techniques have found useful application. One of the advantages of plasma spraying is that it makes possible to coat with high melting point materials.

III. Experimental Studies

a) Thermal Torch Experiment (Flame Punching Experiment)

In this experiment for application to certain area, thermal barrier coatings are exposed to flame. In this area, some deformation is observed and lower working temperature is required. Thermal torch experiment is applied to measure the strength of coating layer to hot flame. In the experiment work of some researchers [5-7]

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flame is applied with a distance of 10mm using an oxy-acetylene torch. Pressure of acetylene is kept 100 kPa. Heat is directly applied to sample and punching times are measured. The sample dimensions are chosen according to ASTM standard to be as 100x50x1.5 mm.

a) Thermal Shock Experiment

There are many applications areas of thermal barrier coating and one of them is used in high temperature requirement area. In this area samples are exposed to thermal cycling. Thermal shock experiment is aimed to find the place in which the sample destroyed. The thermal shock experiment is applied according to ASTM C 385-58 standard. During the experiment, samples are heated at certain temperature and waited for uniform distribution of temperature and are put immediately into water to provide thermal shock.

IV. Results and Discussions

a) Thermal Resistance

In the work of Serdar et al. [26] the test results were evaluated on the basis of the time required for drilling a hole through the coated specimens. Results are shown in table 1. As it can be seen from table 2 ceramic coating greatly enhances the life of the complete composite structure. It can also be seen from table 1 that zirconia with NiAl bonding coating supplied the maximum performance (deforming in 47 s) and chromium-oxide with NiAl bonding coating illustrated the second performance (with 37 s) and finally alumina with NiAl bonding coating was deformed within 31 s giving the weakest performance. Figs. 1-4 show the view of deformed samples with/without bonding coating. During the flame tests on thermal barrier coatings resistance to high temperatures is observed as these ceramics extend the life of composite structure. The life of base materials definitely increases with the application of ceramic coating.

Table 1 : Thermal torch experimental results [26]

Coating materials	Deformed time (s)
Zirconia (ZrO_2)without NiAl bonding coating	39
Zirconia (ZrO_2)with NiAl bondingcoating	47
Alumina (Al_2O_3)without NiAl bonding coating	29
Alumina (Al_2O_3)with NiAl bonding coating	31
Chromium-oxide (Cr_2O_3) without NiAlbonding coating	33
Chromium-oxide(Cr_2O_3) with NiAlbonding coating	37

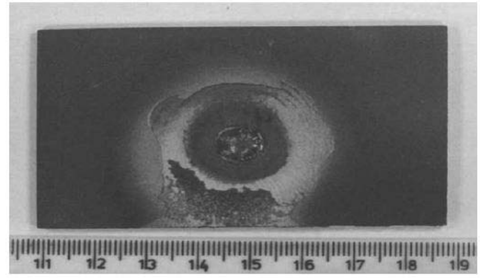

Figure 1 : Deformed Cr2O3 (Chromium-oxide) sample without bonding coating after flame torch experiment [26]

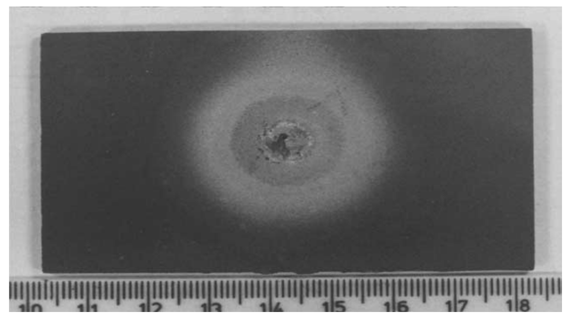

Figure 2 : Deformed Cr2O3 (Chromium-oxide) sample with bonding coating after flame torch experiment [26]

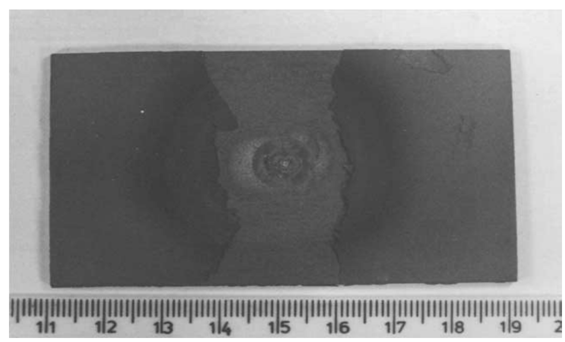

Figure 3 : Deformed Al2O3 (Alumina) sample without bonding coating after flame torch experiment [26]

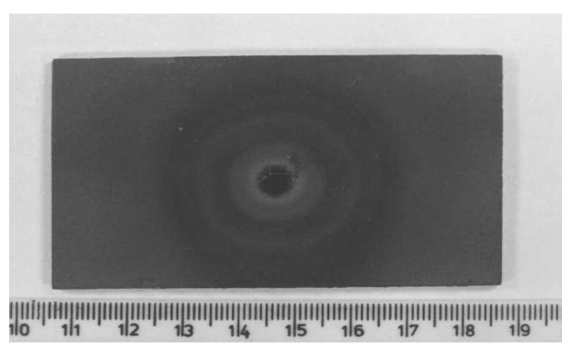

Figure 4 : Deformed Al2O3 (Alumina) sample with bonding coating after flame torch experiment [26]

b) Thermal Shock Properties

Table 2 shows the test results of thermal shock experiment shown by Serdar et al. [26]. In this test zirconia coated samples deformed at 1040 oC after 37 s and this is the best result in the experiment. Then chromium-oxide coated specimens performed the second thermal shock resistance and they are deformed at 960 oC after 33 s, and finally the alumina coated samples are deformed at 920 oC in 31 s. After thermal shock experiment it can be seen that vertical cracks are initiated in all samples and the reason for the formation of vertical cracks can be explained by thermal shock due to high cooling rate of the tests. In alumina and zirconia coated samples, the cracks are formed in much less quantity compared to other coated samples [11, 27-29].

Thermal shock tests are applied to the coated specimens in order to observe their mechanical behaviour under the stresses due to thermal expansion mismatch between the coating and the substrate. It has been shown that coatings are resistance to rapid changes in temperature in spite of the difference in their thermal expansion coefficients.

Table 3 : Thermal shock experimental results [26]

Coating materials	Substrate	Deformed time (s)	Deformed temperature (ºC)
Zirconia (ZrO_2)	With bonding coating	37	1040
	Without bonding coating	35	1000
Alumina (Al_2O_3)	With bonding coating	31	920
	Without bonding coating	20	700
Chromium-oxide (Cr_2O_3)	With bonding coating	33	960
	Without bonding coating	21	720

V. Conclusions

Thermal barrier coated samples are directly exposed to flame (for example combustion rooms in rocket and gas turbines). The view of flame application area shows significant deformation. For this reason, lower working temperature is chosen and figure of merit is decreased. There are many different usage areas of thermal barrier coatings. One of them is the high temperature area. The coating is exposed to thermal cycling. The time of cycling is lower in engine with piston. In literature, piston crown surface, cylinder cover and valve parts are coated with ceramics. Beside these, piston rings and cylinder liner are coated with ceramics. With the thermal shock and the thermal torch experiments, it is shown that the coated materials have higher resistance to high temperatures. Zirconia coating has the best properties in thermal shock and thermal punching experiments. With zirconia coating the figure of merit of engine part will be increased.

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