PROPERTIES OF PLASMA SPRAYED COATINGS

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ABSTRACT

Plasma spray has attracted attention as an effective method for obtaining protective coatings. In this paper, the physical, mechanical and thermal properties of coatings are reviewed. The microstructural features of the coatings are described. The relationship between the properties of coatings and their microstructure is also discussed.

1.INTRODUCTION

Plasma sprayed coatings are used to reduce wear and improve thermal protection on a large number of components in various industries. In some cases, the conditions of application are very aggressive and therefore the resulting maintenance costs are expensive. Improved coating materials and appropriate properties of coatings are the most promising ways to solve these problems[1,2]. The optimum coating properties depend on the microstructure of coatings[1-5]. In this paper, some ceramic coatings frequently used in industries were reported. The physical, mechanical and thermal properties of ceramic coatings are reviewed. The microstructure features of coatings are addressed. The relationship between the microstructure of coatings and their properties are discussed.

2. CHARACTERISTICS AND PROPERTIES OF CERAMIC COATINGS

2.1 MICROSTRUCTURE OF CERAMIC COATINGS

The microstructure of a plasma sprayed coating in general is lamellar in nature formed by the flattened platelet of individual particles. Fig. 1 illustrates a schematic diagram of the lamellar structure. There are defects, such as microcracks and different kind of pores in the ceramic coating, which affect and are closely associated with the properties of the coating and their applications.

Owing to very rapid quenching and solidification during coating formation, sometimes, there are different crystallographic modification found in such ceramic coatings. For instance, some metastable high temperature crystallographic polymorph may be frozen in the coatings. Table 1 shows the crystallographic phase composition of plasma sprayed some ceramic coatings. Plasma sprayed Al_2O_3 is one of such cases where the crystallographic phase composition

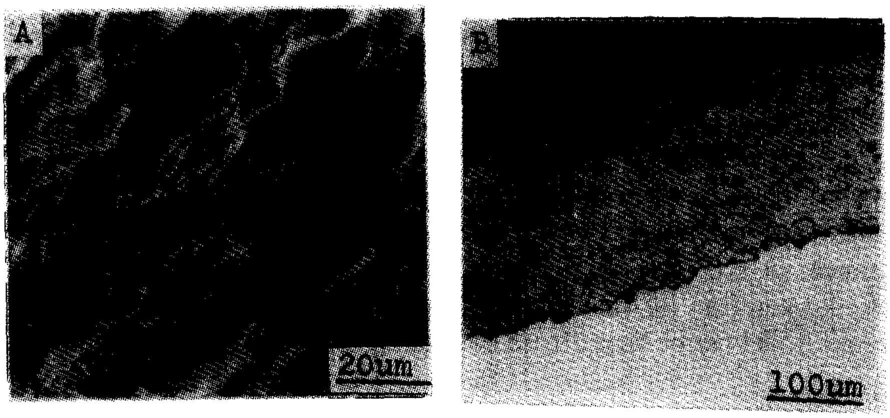

Figure 1. Typical structure of ceramic coatings: (A) the surface of ZrO_2 coating and (B) the cross section of Cr_2O_3 coating

Table 1. Different crystallographic modification of plasma sprayed coatings

Materials	Crystallographic Modification	
	Powder Phase	Coating Phase
Al_2O_3	α-Al_2O_3	γ-Al_2O_3, α-Al_2O_3, η-Al_2O_3, σ-Al_2O_3
Al_2O_3-TiO_2	α-Al_2O_3,Rutile	α-Al_2O_3, η-Al_2O_3, Anatase, Rutile, β-Al_2O_3-TiO_2
ZrO_2	C-ZrO_2, T-ZrO_2	T-ZrO_2, C-ZrO_2
WC+Co	WC	β-WC_{1-x}, α-W_2C
Cr_3C_2-NiCr	Cr_3C_2,Ni,Cr	Cr_7C_3, Cr_3C_2,Ni,Cr
NiAl	NiAl	NiAl, Ni_3Al

occurred to be related to the thickness of the coating. In a thin Al_2O_3 coating (The thickness of less than 0.1mm), the crystalline phase is mainly composed of γ-Al_2O_3 with some η-and α-Al_2O_3. The content of γ-Al_2O_3 is usually over 70%. Whereas in a thick coating, the γ-Al_2O_3 content is usually less than 20% and the coating is mainly composed of α-Al_2O_3 because of the slower cooling rate and the poor thermal conductivity of already deposited material. Generally, in Al_2O_3-TiO_2 coating, X-ray diffraction shows the presence of α-Al_2O_3, γ-Al_2O_3, rutile, anatase and spinel (Al_2O_3 TiO_2). Sometimes, other unknown "X-phases" were also observed.

Beside crystallographic change, surface oxidation or nitridation can also occur during deposition process. Some composition of coating may also decompose at the extremely high temperature or one component of a compound may be preferentially oxidized during the flight of the melted particles. For instance, tungsten carbide and chromium carbide probably form gaseous CO and leave W_2C, β-WC_{1-x} and Cr_7C_3 respectively[6].

2.2 THE PHYSICAL, MECHANICAL AND THERMAL PROPERTIES OF COATINGS

Table 2 lists the physical and mechanical properties of a number of the coatings. Plasma sprayed ceramic coatings usually contain some porosity from 5 to 30% in volume. From Table 2, it can be seen that a coating which contains a metal constituent usually possesses a higher strength. For instance, in the NiAl-ZrO_2 system, the bend strength depends on the content of NiAl. Besides, the addition of titania to alumina results in considerable increase in bend strength of the coating. It may be that titania containing matrix in the alumina-titania coating.

Table 2. The Physical and mechanical properties of coatings

Coating materials	Porosity (volume%)	Bulk density (g/cm)	Bend strength (Mpa)
Al_2O_3(A)	30	2.58	49.0
Al_2O_3(B)	5.7	3.23	76.0
Cr_2O_3	4.7	4.52	81.3
ZrO_2(5wt%CaO)	8.7	5.52	49.9
ZrO_2(8wt%Y_2O_3)	9.7	5.40	67.6
80wt%Al_2O_3-20wt%TiO_2	6.0	3.48	89.2
74wt%Al_2O_3-20wt%ZrO_2-5wt%Nb_2O_5	4.9	4.03	30.4
88wt%WC-12wt%Co	10.8	13.87	112.7
75wt%Cr_3C_2-25wt%NiCr	10.8	6.16	274.4
80wt%Ni-20wt%Al	5.7	6.42	343.0
53wt%NiAl-47wt%ZrO_2	7.1	6.27	169.5
50wt%W-50%wt%ZrO_2	12.2	9.32	66.6
50wt%Mo-50wt%ZrO_2	9.8	6.80	112.7

Plasma sprayed ceramic and cermet coatings, such as Cr_2O_3, Al_2O_3, TiO_2, Al_2O_3-TiO_2, WC-Co and Cr_3C_2-NiCr possess high surface hardness, low friction coefficient, good adhesive bonding to substrates and are being developed to protect metal components. The microhardness, friction coefficient and wear mass losses of some coating materials were

Table 3. the microhardness and friction coefficient of some coating materials

Coating materials	Mircrohardness (Gpa)	Friction coefficient (against stainless steel)
Al_2O_3	9.2	0.12-0.20
Cr_2O_3	10.0	0.14-0.15
TiO_2	10.2	0.10-0.15
80wt%Al_2O_3-20wt%TiO_2	10.4	0.10-0.11
88wt%WC-12wt%Co	12.1	0.11-0.13
75wt%Cr_3C_2-25wt%NiCr	10.5	0.13-0.15

investigated and showed in Table. 3 and Fig. 2 respectively. The wear mass loss curves show that the anti-wear capability of different coating materials decreased in the following order: Cr_2O_3, WC-Co, Al_2O_3-TiO_2, Al_2O_3, Cr_3C_2-NiCr.

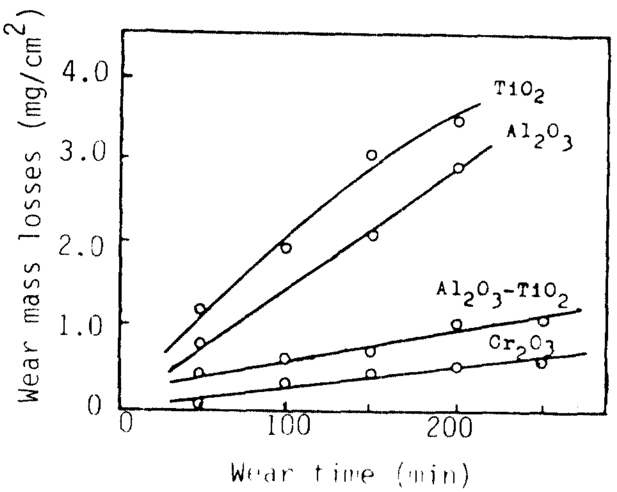

Figure 2. wear mass losses of some coatings

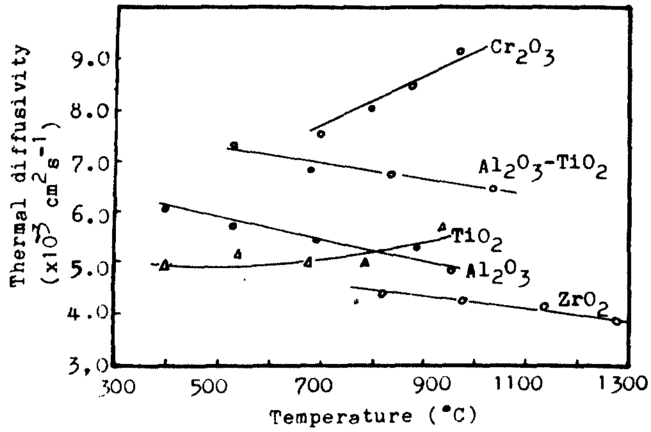

Figure 3. The thermal diffusivity of oxide coatings

The thermal diffusivity of some ceramic coatings are shown in Fig. 3. The thermal diffusivity of most oxide coatings decrease with increasing temperature. However, The thermal diffusivity of Cr_2O_3 and TiO_2 coatings show reverse trend, i.e. it increases with increasing temperature. The characteristic is advantages with respect to the wear resistance especially when these coatings are used at elevated temperature. For example, the addition of TiO_2 to Al_2O_3 improves the thermal diffusivity of the coating and thereby improves wear resistance of such coating system. From Figs. 2 and 3, it has been pointed out that the wear resistance of a coating is closely related to its thermal diffusivity. The higher the thermal diffusivity of a coating, The better its wear resistance and vice versa.

The thermal diffusivity of ZrO_2 coating is lower than that of other plasma sprayed ceramic coatings, and therefore makes it useful as a thermal barrier on metals. In addition, The thermal diffusivity of ZrO_2 coating is also lower than that of the dense bulk ZrO_2. The thermal diffusivity of dense bilk ZrO_2 is about 0.0068cm²/sec at the temperature of 1100°C. However, the thermal diffusivity of plasma sprayed ZrO_2 coating which contains the porosity of 6% in volume is about 0.0030 cm^2/sec and is lower by half as compared with that of the bulk ZrO_2 ceramic. It is due to the special lamellar structure and porousness of plasma sprayed coating[7].

The thermal expansion coefficient of oxide coating has also been investigated and data are presented in Table 3. From Table 3, it can be seen that the thermal expansion coefficient and bend strength of the coating as shown in Table 2 are related to their composition and increase with increase in the metallic content . The higher the metallic content in coating, the higher its thermal expansion coefficient and bend strength. The average coefficient of thermal expansion of graded coating increases across the thickness from ZrO_2 top coating to substrate. Therefore, thermal stress between the ceramic coating and substrate is reduced resulted from the compatibility of their thermal expansion. Therefore. The graded coating material is more thermal shock resistance than the single and duplex coatings that were also used in industries. The results of thermal shock test for different types of coating materials were listed in Table 5.

Table 4. Thermal expansion coefficients of oxide coatings ($X10^{-6}$ $^{\circ}C^{-1}$)

	Temperature(°C)				
Coating Materials	200	400	600	800	1000
Al_2O_3					
ZrO_2-5wt%CaO	8.66	9.81	9.75	9.87	9.91
ZrO_2-18wt%Y_2O_3	7.33	8.76	9.34	10.00	10.53
Cr_2O_3	6.00	6.50	6.45	5.88	
80wt%Al_2O_3-20wt%TiO_2	5.57	6.59	6.47	5.56	
ZrO_2-Ni graded coating	9.00	10.70	10.80	11.80	

Table 5 Results of thermal shock test

Coating systems	Average thermal cycles
pure stabilized ZrO_2 coating	8
Ni based alloy bond coating+stabilized ZrO_2 top coating	21
Ni based alloy bond coating+stabilized ZrO_2 composition graded coating	30

3. CONCLUDING REMARKS

This paper has focused on research and development activities in the field of plasma sprayed coating materials. Coating materials which are based on oxides, metals and mixtures of them have been described.

The microstructure of plasma sprayed coatings in general is lamellar in nature because of the special process. There are defects such as microcracks and different kind of pores in the coating, which affect on the properties of coatings. The physical, mechanical and thermal properties of coatings were measured. For example, some coatings have high microhardness and high thermal diffusivity and are suitable for wear resistance. Other oxide coatings have a low thermal diffusivity and are used as thermal protection materials. The thermal shock resistance of the thermal barrier coating was improved by manufacturing graded metal-oxide coatings.

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