The Wear behavior of Plasma Sprayed WC-12%Co Coating Based on the Powder Manufacturing Method

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Introduction

Tungsten carbide-cobalt is the most widely used for various wear environment (abrasive, adhesive, erosive) because of the very high hardness of WC and good toughness of Co which is well bonded with WC and shows good wettability when deposited on the substrate.

Of the advanced deposition techniques, plasma thermal spray coating has attracted considerable attention recently due to its advantages of wide range of coating material, rapid thick coating and few limit of substrate size and shape. But plasma spray coating quality depends on various factors such as substrate preparation, process equipment & parameter, and spray powder characteristics.

Powder manufacturing method is one of the most important factors for coating quality because it influences on powder characteristics such as powder particle composition, shape and size distribution, microstructure (density, constituent arrangement etc.) as well as powder flowability which eventually determine the coating microstructure, mechanical property and wear behavior.

Wear resistance of coatings is not only related with coating properties such as hardness, bond strength, friction coefficient and surface roughness but also affected by coating microstructure and phase distribution. Although there are many wear data on WC-12%Co coating, there is little information about the wear mechanism of this coating.

In this study we examined the characteristics of WC-12%Co powders manufactured by different methods, and their influence on the coating microstructure(carbide type, size, distribution, porosity), mechanical property, and wear resistance.. Furthermore the wear behavior of coatings were investigated by examining worn surfaces with SEM & EDS.

Experimental procedures

WC-12%Co with three different powder manufacturing method (fused & crushed, sintered & crushed, agglomerated and sintered) were selected for coating materials and a low-carbon mild steel (carbon content: 0.16%) was used as the substrate material. Disk specimen (40mm φ, 4.5mm t) aimed at sliding wear test was prepared as a substrate and air plasma spray technique was used for coating deposition .

Cross sectional microhardnesses were measured with vickers microhardness tester with a 200g load and Sebastian IV coating adherence tester was used to measure the cohesive bond strength of coatings.

To evaluate wear resistance and friction coefficient of coated layers pin-on-disk type sliding wear test without lubrication at room temperature was carried out. SKH51 ($HRC61 \fallingdotseq 720HV_{200}$), a kind of high speed tool steel, was selected as a mating material (10mm φ pin). Wear tests were carried out at the rotating speed of 300rpm under the load of 6.362kg and during tests experiment has stopped every 1.7km sliding distance to measure the weight loss. The total final sliding distance tested was 5.1km. Friction coefficient was calculated by measuring the friction force during the test.

SEM and EDS were used to characterize the powder, coating microstructure and wear surface. XRD(40kV, 25mA, Cu k_α radiation) was used for phase identification and relative fraction (%) of retained carbide (WC) and decomposed carbides (W_2C, $Co_xW_yC_z$). Porosity (% area), carbide fraction (% area) were measured with image analyser and Mitutoys Surftest501 analytical profilometer was used to measure the surface roughness.

Result and discussion

The main characteristics of the powders used in this study are summarized in Table 1. and some of coating properties are listed in Table 2.

Although powders were manufactured with three different methods these have almost the same range of particle size and the microstructure of carbides binded with cobalt rich phase. But the powder manufacturing method influences intensively on the particle shape, density, and constituent (carbides) characteristics.

Among WC coatings WC2 coating has not only the lowest porosity and the smallest size distribution of pores but also the highest content of total carbides including retained carbide (WC) and decomposed carbide (W_2C etc.).

The microhardness of WC1 coating is lower than that of WC2 and WC3 coatings because of its lower total amount of carbide and different microstructure i. e the elongated lamellar structure with relatively larger grain size of carbides compared to small carbides dispersion structure of WC2 and WC3 coatings. The microhardness of WC2 coating is slightly higher than that of WC3 coating. This may be because WC2 coating has higher content of total carbides including retained carbide (WC) and decomposed carbide (W_2C, etc.). And the higher porosity of WC3 coating can also contribute to it.

Fig 1. shows that WC2 coating reveals the best wear resistance which is reversely proportional to weight loss. WC1 coating exhibits the poorest wear resistance because of its poorest microstructure (with the detrimental effect of brittle W_2C) and relatively lower hardness (with very small amount of carbides) comparing to WC2 and WC3 coatings. The slightly lower wear resistance of WC3 coating than that of WC2 coating is due to its lower and very wide distribution range of microhardness. The relatively smaller amount of carbides and the higher pore content of WC3 coating with large pore size which is known to act as crack nucleation site and help crack propagation may also contribute.

The worn surface of WC2 coating exhibits no clear plastic deformation or abrasive mark. But the smooth smearing surface and dark region on which the crack formation and particle fragmentation can be found. The mapping result of dark region indicates that Fe transfer from the mating material has occurred during wearing and oxygen was inflowed. Reacting with atmosphere at high temperature from frictional heating, hard brittle iron oxide tribo-films is believed to be formed. Although this could act as thin lubricant film which decreases the friction coefficient, in most cases this film is very brittle. With applied load and friction force, crack could initiate in the oxide films and propagate through the wear surface of coating layers, and then the subsequent fracture of particles (splats) causes coating layer spallation and/or delamination. As a result the dominant wear mechanism of WC-12%Co coating is adhesion, particle (splat) fracture, tribo-film formation by material transfer, fatigue crack, and delamination (spallation of coating layers).

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Table 1 Characteristics of starting powders

powders		WC1	WC2	WC3
chemical composition (weight %)		88%WC-12%Co	88%WC-12%Co	88%WC-12%Co
C content (weight %)		4	5.49	5.3
manufacturing method		fused & crushed	sintered & crushed	agglomerated & sintered
particular shape		irregular blocky	irregular blocky rounded	spherical spongy
particle size range(㎛)		5-45	15-53	15-53
X-ray diffraction Phase identification	major	WC W_2C	WC	WC
	minor	$Co_xW_yC_z$	$Co_xW_yC_z$	$Co_xW_yC_z$

Table 2 Properties of air plasma sprayed coatings

Spray powder	Porosity (% area)	Mean pore size (㎛)	Carbide (%)				Mean carbide size (㎛)	Surface roughness (㎛)		Microhardness range (HV 200g)	Bond strength (kg/㎠)
			Total	Phase fraction				Ra	Rt		
				WC	W_2C	$Co_xW_yC_z$					
WC1	4.22	1.49	43	40.3	24.6	35.1	3.60	6.52	43.3	791~856	716
WC2	3.96	1.50	60	86.7	7.4	5.9	1.43	10.82	56.25	835~917	720
WC3	6.50	2.95	55	85.7	8.4	5.9	1.38	10.67	53.6	723~907	723

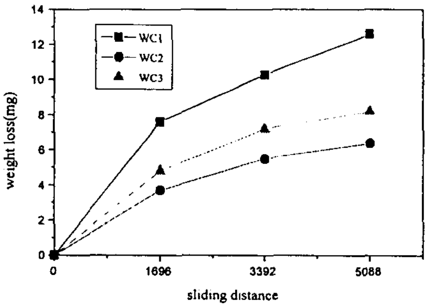

Fig 1. Weight loss of coatings with sliding distance