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TRIBOLOGICAL PROPERTY OF WC CERMET COATINGS SPRAYED BY USING AN IMPROVED HVOF PROCESS

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ABSTRACT

An improved HVOF spray process called “Gas-shrouded HVOF” (GS-HVOF) has been developed over the past several years. By using an extension nozzle at the exit of a commercial HVOF spray gun, GS-HVOF is capable of controlling the oxidation of sprayed materials during flight as well as achieving higher velocity of sprayed particles. These features result in extremely dense and clean microstructure of the sprayed coatings. The process has been successfully applied to corrosion resistant alloys such as SUS316L, HastelloyC, and alloy 625 as well as cermets such as WC-Cr_3C_2-Ni. Wear properties of WC cermet coatings were measured by using a pin-on-disk wear tester. The specific wear rates of the coatings prepared by the GS-HVOF with a reducing (fuel rich) flame were close to that of chrome plating. The wear amount of the heat-treated GS-HVOF coatings could not be detected after testing. It is believed that transition to mild wear appeared early because of the increased surface oxidation due to the heat treatment.

1. INTRODUCTION

Hard chrome plating is widely used to deposit a film for wear resistance. The effect of hexavalent chromium to the environment and the operator’s health is a big problem. Therefore, research for alternatives of chrome plating is widely carried out in the world. HVOF-sprayed cermet coating is one of such alternative candidates. HVOF process owes both its heat source and acceleration force to a supersonic jet flame made from a high-pressured mixture of oxygen and fuel. This technique enables us to obtain sprayed particles with a speed over 500m/s and with a temperature up to around 2000 ℃. Such particles impinge onto a target substrate often in the semi-molten state and pile up to form coatings.

However, for some cermet powders, it is difficult to make a dense coating. When one intends to decrease the coating porosity by usual HVOF equipment, such spray conditions tend to increase the degree of oxidation of the sprayed coating. The increase of oxidation can be reasons of lowering abrasive wear resistance of the sprayed coating. Therefore, we have developed a gas-shroud attached HVOF (GS-HVOF), which can introduce an inert gas at the exit of the barrel into the shroud attachment. With this modification, it is possible to suppress the oxidation of sprayed particles while raising the velocity of sprayed particles.

In a number of real applications coatings are rubbed repeatedly. In this case, the wear mode is dominated by the adhesive wear. Therefore, it is important to examine the severe-mild wear transition of such coatings in the adhesive wear in the laboratory. In this paper, we investigate the wear property of coatings by using a pin-on-disk wear tester and discuss the severe-mild wear transition.

2. EXPERIMENTAL

Coatings were prepared with a commercial HVOF and the GS-HVOF thermal spray equipment, which use kerosene and oxygen to generate a supersonic combustion flame. A commercially available cermet powder (WC/20Cr_3C_2/7Ni) with size distribution from 15 to 53 µm was used as the feedstock. The substrate was JIS SS400 low carbon steel and its surface was blasted by alumina grit and degreased by ultrasonic cleaning in acetone. Thickness of all the coatings was aimed at about 300µm. Table 1 shows detailed spraying conditions used for spraying, i.e., fuel flow rate, oxygen flow rate, the fuel to oxygen ratio and combustion pressure Pc. F/O is the fuel to oxygen ratio, where F/O=1 corresponds to the stoichiometoric mixture ratio for complete combustion. Coatings were prepared by the oxidizing flame, the reducing flame and with the gas shroud, which operates with the reducing flame.

Wear property of the coatings was evaluated by using a pin-on-disk type wear tester. Coated disk surfaces were polished with diamond grinding, and finished with buffing so that their surface roughness had a Ra 0.01-0.02mm. Furthermore, some GS-HVOF coatings were heat treated in air atmosphere before

Table 1 Spray Condition

	Fuel	Oxygen	F/O	Pc
Unit	dm^3/min	dm^3/min	-	MPa
Oxidizing flame	0.32	897	0.73	0.63
Reducing flame	0.44	826	1.09	0.67
Gas shroud	0.44	826	1.09	0.67

wear testing. The samples were heated at a rate of 20℃/min up to 500℃ and held at the temperature for 30h. The diameter of the iron pin used in the experiment was 4mm. After applying ultrasonic cleaning to the pin and the disk in acetone for 1 hour, they were fixed to the test apparatus. The pitch circle diameter was 20mm. In this experiment, the sliding velocity was fixed at 0.25m/s for the entire test. The load between the pin and the disk was 10 N in the tests. The wear amount of coatings was measured after 3000m sliding. The displacement of the top surface of the pin was measured by using a gap sensor during the wear test. For comparison, the wear amount of chrome plating was also measured. Coatings, sliding surfaces and wear debris were observed by optical microscope and were analyzed by SEM (EDX), XRD techniques.

3. RESULTS AND DISCUSSION

The hardness on the cross section of coatings was measured by a Vickers hardness tester at a 3N load. Coatings hardness increased with the increase of spray particle's in-flight velocity which was measured by the in-flight thermal sprayed particle analyzer at the substrate position. Coating hardness was not changed by the heat-treatment.

We confirmed the existence of Cr_3C_2 and Cr_2O_3 by XRD. The ratio of Cr_2O_3-Cr_3C_2 was calculated by using the intensity of the main peak of each material (Fig.1). The heat-treated coating showed the highest oxidation degree in all the specimens. The XRD diffraction spectrum of the heat-treated coating shows peaks indexed to $NiWO_4$. The coating by the reducing flame showed the highest oxidation degree among the untreated specimens. The oxidation was caused by the heat of jet flame.

Figure 2 shows the specific wear rates of the coatings. The specific wear rate of the coating prepared by the oxidizing flame was greater than other coatings, because the hardness of the oxidizing coating is lower than other coatings. GS-HVOF is important to make a dense and hard coating. The specific wear rate of the coating prepared by the reducing flame and GS-HVOF flame was in the order of 10^{-9} mm^2/N and was close to that of chrome plating. The specific wear rate of the heat-treated coating is not shown, because the wear amount of the heat-treated coating could not be detected after the wear testing.

From such low wear rate (10^{-9} mm^2/N), the wear mode indicates the mild wear mode after 3000m sliding. Furthermore, the heat-treated coating indicated the peaks of $NiWO_4$, WO_3 by using XRD. It seems that the adhesive wear property was influenced by the degree of oxidation of the coatings.

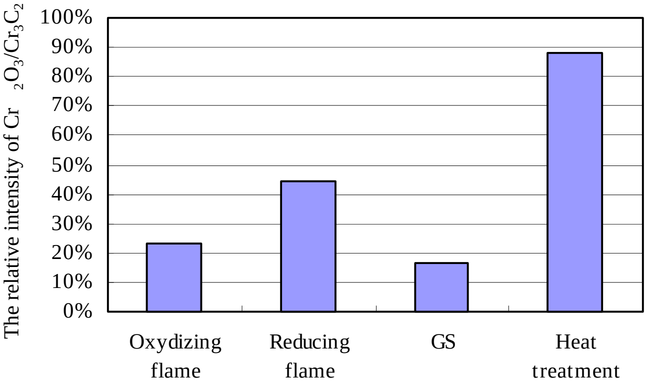

Fig.1 Oxidation degree during spraying in terms of the XRD peaks intensity ratio of Cr_2O_3/Cr_3C_2

Kato investigated the influences of oxide particles supplied to the rubbing surface during sliding on the severe–mild wear transition by using a pin-on-disc wear test 1). As a result, oxide particles were found to play an important role in reducing the amount of wear. The sever-mild wear transition distance was decreased by decreasing the size of the supplied oxide particles. He surmised that this effect is caused by forming the oxide layers on the rubbing surfaces.

The original particle size of our cermet powder feedstock is very small (about 10-50 μm). Since these small particles are oxidized by the spray flame during flight, oxides are dispersed in the coatings by thermal spray technique. Also, it is well known that the oxide in the thermal spray coatings is increased by the decrease of the spray powder size 2). We consider that the thermal spray coatings might easily generate the small oxide wear debris by wear than the generally other coatings.

As the oxidation degree of such thermal spray coating, especially on the surface is increased by the heat treatment, the small oxide wear debris could be obtained from an early wear stage. We consider that this behavior is similar to the effect of shortening the severe-mild wear transition distance by supplying the oxide particles to the rubbing surface during sliding. It can be thought that the severe-mild wear transition can be accelerated by heat treatment.

4. CONCLUSION

GS-HVOF was effective in raising the velocity of sprayed particles by more than 50m/s whereas lowering the surface temperature by about 150K. The density of coatings improved as the velocity of sprayed particles increased. Adhesive wear resistance of the coatings evaluated by the pin on disk test did not simply depend on the hardness of the coatings but also depended on the oxidation of the coatings. The degree of oxidation of the coatings was increased by heat treatment. The increase of oxidation seems to have promoted mild wear to appear early. It is important for the high wear resistance material that mild wear appears early.

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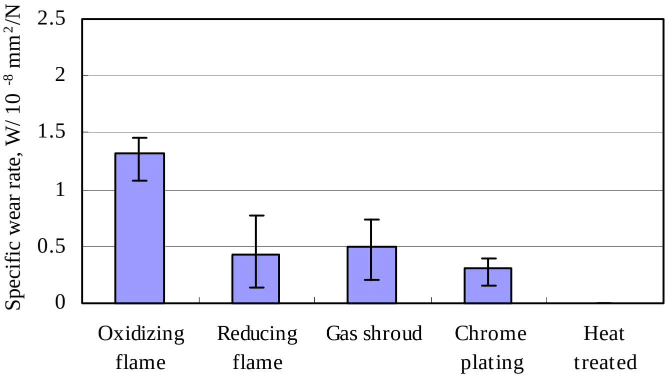

Fig.2 Specific wear rate of coatings after 3000m sliding

Each error bar shows the maximum value and minimum value of the specific wear rate obtained by 3 runs.