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The properties and wear behavior of HVOF spray coating layer of Co-alloy powder

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Abstract High velocity of oxy-fuel (HVOF) thermal spray coating is progressively replacing the other classical hard coatings such as chrome plating and ceramic coating by the classical methods, since the very toxic Cr^{6+} ion is well known as carcinogen causing lung cancer, and the ceramic coatings are brittle. Co-alloy T800 powder is coated on the Inconel 718 substrates by the HVOF coating processess developed by this laboratory. For the study of the possibility of replacing of chrome plating, the wear properties of HVOF Co-alloy T800 coatings are investigated using the reciprocating sliding tester with a counter sliding SUS 304 ball both at room and at an elevated temperature of 1000°F (538°C). The possibility as durability improvement coating is studied for the application to the high speed spindles vulnerable to frictional heat and wear. Wear mechanisms at the reciprocating sliding wear test are studied for the application to the systems similar to the sliding test such as high speed spindles. Wear debris and frictional coefficients of T800 coatings both at room and at an elevated temperature of 538°C are drastically reduced compared to those of non-coated surface of Inconel 718 substrates. Wear traces and friction coefficients of both coated and non-coated surfaces are drastically reduced at a high temperature of 538°C compared with those at room temperature. These show that the coating is highly recommendable for the durability improvement coating on the surfaces vulnerable to frictional heat and wear.

Key words HVOF, Co-alloy T800, Sliding wear test, Solid and liquid lubricant

1. Introduction

HVOF thermal spray coating method has increasingly been used throughout the last 50 years mainly in defense and aerospace industries [1-7]. The HVOF thermal spray coating of Co-alloy T800 (T800) is progressively replacing the traditional high wear resistant coatings such as hard chrome plating and ceramic coating by other methods since the pollution of very toxic hexa valence Cr^{6+} is well known as carcinogen causing lung cancer, which results from chrome plating solution, mist and chrome plated products, and the ceramic coatings prepared by other methods are brittle [1, 5, 7]. HVOF coatings have been applied for the surfaces requiring high hardness and strength, high wear, thermal and corrosion resistant coating [8-13]. In this study, micron size Co-alloy T800 powder is coated by the HVOF thermal spray coating processes developed by this laboratory on the Inconel 718 substrates, which is widely used in aerospace industry as jet engine material [8-11]. The surface properties such as roughness, micohardness and porosity are investigated to develope the optimal coating process. The wear behaviors of the coating are investigated by the reciprocating sliding wear test. The possibility of application as high heat and wear resistant coating is studied for the durability improvement and economic restoration of high speed spindles such as air-bearing spindle.

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2. Experimental Work

2.1. Preparation and characterization of coatings

Commercially available micron size Co-alloy T800 powder (prepared by Stellite, Inc) is coated on Inconel 718 substrate using JK3500 HVOF thermal spraying equipment by the HVOF coating processes developed in this laboratory as shown in Table 1. The major chemical compositions of the T800 are 45.7 wt% Co, 28.4 wt% Mo and 17.6 wt% Cr. As shown in Fig. 1, the powders are homogeneous mixture of spherical particles with diameter 5~30 μm.

As a precleaning, substrates are cleaned by ultrasonic

Table 1
Co-alloy T800 coating processes

process	oxygen flow rate	hydrogen flow rate	feed rate	spray distance
1	34	60	20	5
2	34	65	20	5
3	34	70	30	5
4	34	75	30	5
5	38	60	20	5
6	38	65	20	5
7	38	70	30	5
8	38	75	30	5
9	42	60	30	5
10	42	65	30	5
11	42	70	20	5
12	42	75	20	5
13	46	60	30	5
14	46	65	30	5
15	46	70	20	5
16	46	75	20	5

Flow rate; FMR = 12 scfh, Feed rate; g/min. Spray distance; inch

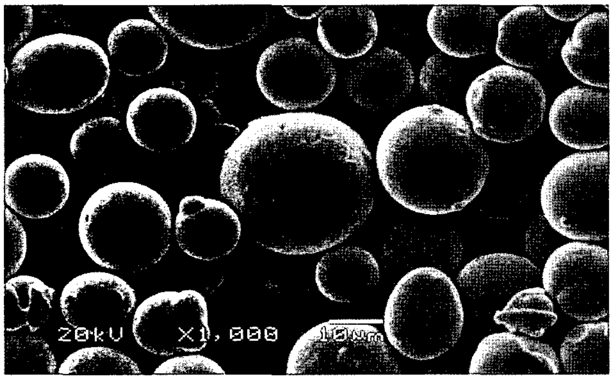

Fig. 1. Particles of T800 powder.

cleaning in acetone solution for 5 minutes and then are blast cleaned by 60 mesh aluminum oxides to increase the adhesion of the coatings. The optimal HVOF coating process is determined by the 16 experiments designed by the Taguchi program for the spray parameters of spray distance, flow rates of hydrogen and oxygen and powder feed rate carried by argon gas.

2.2. Characterization of coatings

Micro-structures of T800 powder and coating, and chemical compositions are investigated by optical microscope, SEM and EDX. Surface roughness is the average of 7 measurements by surface roughness tester. Micro-hardness is the average of 9 measurements at the center of cross section of the coating layer by Micro Vickers Hardness tester. The porosity is the average value of 5 data obtained by image analyzer from the images photographed by optical microscope.

2.3. Friction and wear test

The friction and wear behaviors of coatings are investigated by the reciprocating sliding wear tester (TE77 AUTO, Plint & Partners) with SUS 304 counter sliding balls (diameter 9.53 mm and 227 Hv) without using any lubricant. The reciprocating sliding distance, frequency, speed, load and sliding test time are 2.3 mm, 35 Hz, 0.161 m/s, 10 N and 4 minutes respectively. Friction coefficients, wear traces of coatings and counter sliding stainless steel balls, and the weight of wear debris are studied both at room and at an elevated temperature of 538°C.

3. Results and Discussion

3.1. Formation of coating

According to the phase diagram [14], e-Co phase of both Co-Mo and Co-Cr systems melts at a temperature lower than the pure cobalt melting point 1495°C. As shown in Fig. 2(a), Micro-structure of coating surface shows that the particles with various sizes are molten or partially-molten during the short flight time of 0.1~1 ms by the high temperature (up to 3,500°C) of the flame formed by the burning of fuel gas hydrogen and oxygen [1, 5, 7]. And the melts and partially-melts impact on the cool coating surface with supersonic velocity (up to 1,000 m/s) [1, 5, 7]. Upon impact, a bond forms with the surface, with subsequent particles causing thickness buildup and forming a lamella structure. The thin splats undergo quenching at a very high cooling rate, typically in excess of 10^6 K/s [1, 5, 7]. The splats form fine-grained coatings of 300~350 thickness with very high adhesion as shown in Fig. 2(b). As shown in Fig. 3,

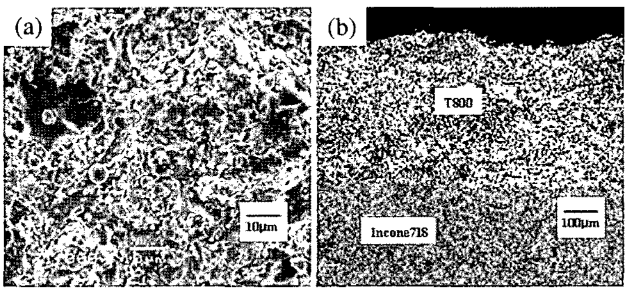

Fig. 2. SEM micrographs showing microstructure of coating of Co-alloy T800; (a) surfaces and (b) cross section.

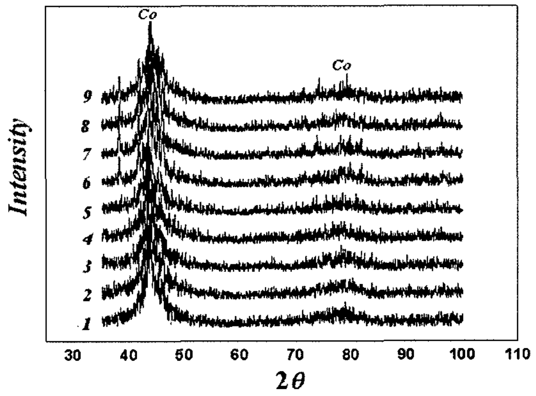

Fig. 3. XRD results showing of Co-alloy coating.

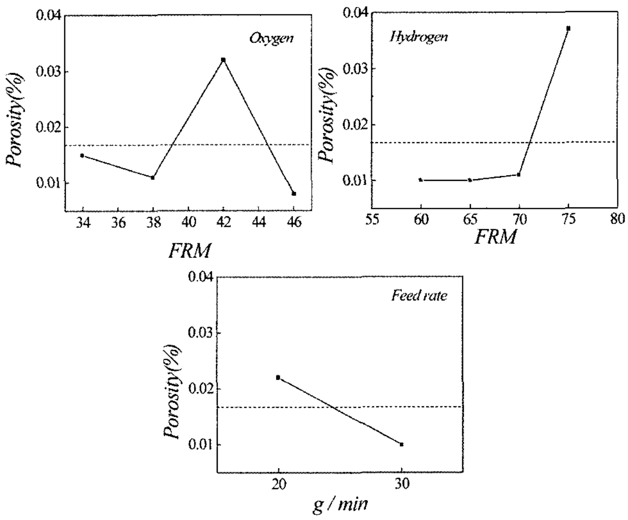

Fig. 5. Porosity vs spray parameters.

XRD shows that cobalt is in crystalline phase but the others are in non-crystalline states.

3.2. The Surface properties and optimal coating process

The optimal coating process is determined from the best surface coating properties of roughness, hardness and porosity prepared by the spray processes designed by Taguchi program for the spray parameters such as fuel gas flow rates of hydrogen and oxygen, powder feed rate and spray distance. The highest hardness of 640 Hv is obtained when the flow rates of oxygen and hydrogen, and the feed rate are 38~42 FMR and 75 FMR and 30 g/min respectively at spray distance 5 inch as shown in Fig. 4. As shown in Fig. 5, the lowest porosity of 0.01 % is obtained when the flow rates of oxygen and hydrogen, and the feed rate are 46 FMR and 60~70 FMR and 30 g/min respectively at spray distance 5 inch. The low surface roughness of 2.2 μm is obtained when the fuel gas flow rates of oxygen and hydrogen, and the powder feed rate are 42 FMR and 60 FMR and 20 g/min respectively at spray distance 5 inch as shown in Fig. 6. From these studies, the optimal HVOF coating process of Co-alloy T800 powder is that the flow rates of hydrogen and oxygen gas and the feed rate of powder are 65~70 FMR, 38~42 FMR and 30 g/min respectively at spray distance of 5 inch.

3.3. Friction and wear behaviors

The smaller weight loss by wear is expected at the coating surfaces with higher hardness since the volume of wear is inversely proportional to the surface hardness in adhesive wear, but no clear relationship between the wear weight loss and hardness of coating is

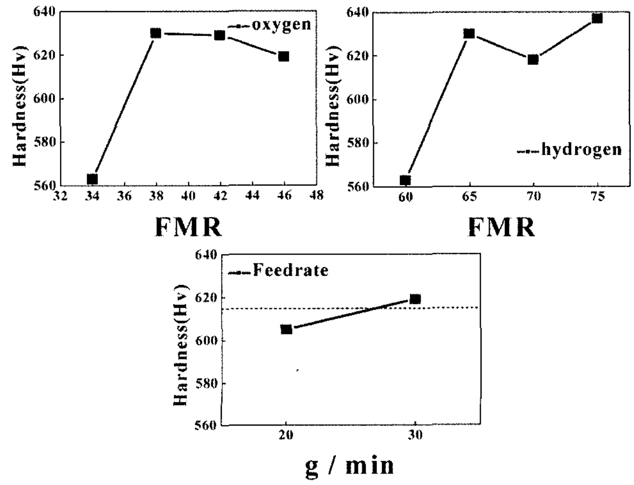

Fig. 4. Hardness vs spray parameters.

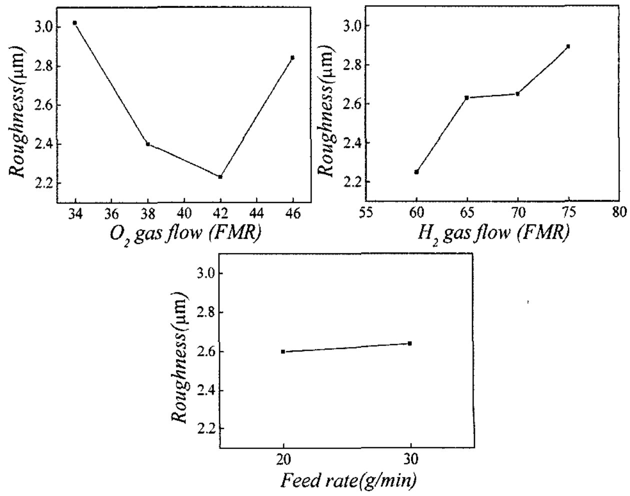

Fig. 6. Surface roughness vs spray parameters.

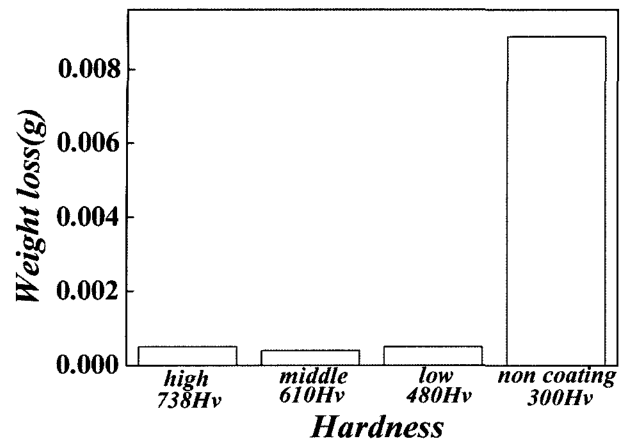

Fig. 7. Weight loss vs hardness.

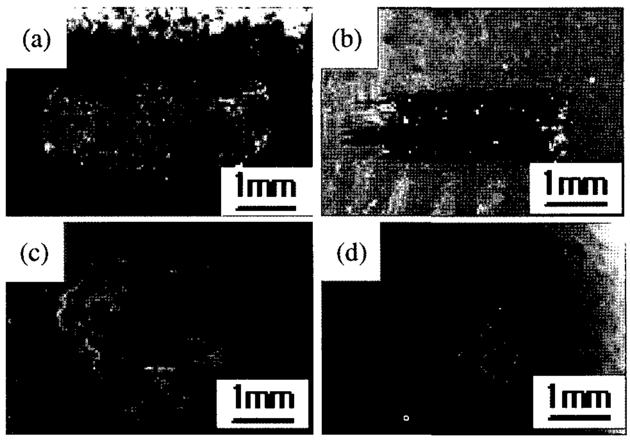

Fig. 9. Wear traces: coatings at a) 25°C, b) 538°C, and counter sliding SUS 304 surface at c) 25°C and d) 538°C.

observed as shown in Fig. 7. This shows that the wear is not only taken place by adhesive wear mechanism but by other wear mechanisms such as mechanisms of oxidation and abrasive wear assisted by solid and liquid oxide lubricants. As shown in Fig. 7, the wear weight loss of coating is much smaller than that of non-coated surface of Inconel 718 substrate. Also as shown in Fig. 8, friction coefficients of the coatings are much smaller than those of non-coated surface of Inconel 718 both at 25°C and at a high temperature of 538°C. This shows that T800 coating is highly recommendable for wear resistant coating on the surface vulnerable to frictional heat and wear such as high speed spindle operating without any lubricants.

As shown in Fig. 8, the friction coefficients at a higher temperature of 538°C are much lower than those at lower temperature of 25°C. At high temperature, the oxides such as CoO, Co_3O_4, MoO_2, MoO_3 are rapidly formed on the surface, heavily at the asperities [12, 15]. The brittle oxides are easily attrited as debris in the severe wear environment created by the reciprocating sliding through the complicated mixed wear mechanisms such as oxidation wear by direct reaction with oxygen, abrasion by scratching and gouging at the oxidized asperities by the sliding [1, 5, 15].

And the wear debris such as solid particles, the melts and partially-melts have played roles as solid and liquid lubricant, and the role is higher at higher temperature. This shows that HVOF thermal spray coating of T800 is highly recommendable for the durability improvement coating on the surface vulnerable to frictional heat and wear such as high speed spindles [8-11].

As shown in Fig. 9, the wear traces of both coating and counter sliding SUS 304 surfaces at a higher temperature of 538°C are smaller than those at lower temperature of 25°C. This also shows that T800 coating is highly recommendable for the durability improvement coating on the surface vulnerable to frictional heat and wear such as high speed spindle.

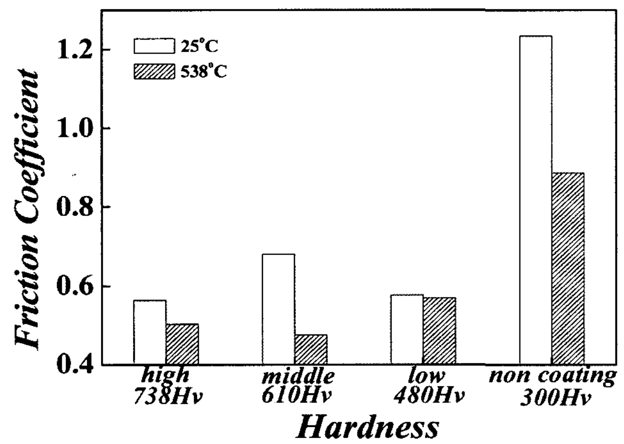

Fig. 8. Friction coefficients vs temperature.

4. Conclusions

The followings are concluded in this study;

1) The coating properties depend on the spray parameters. The optimal HVOF coating process of T800 powder in this system is that the flow rates of hydrogen and oxygen gas and the feed rate of powder are 65~70 FMR, 38~42 FMR and 30 g/min respectively at spray distance 5 inch..

2) T800 coating is highly recommendable for durability improvement coating, since 1) the weight loss by sliding wear of T800 coating is much smaller than that of non-coated surface, and also 2) friction coefficients of T800 coatings are much smaller than those of non-

coated surface.

3) T800 coating is highly recommendable for surface coating on the surface vulnerable to frictional heat and wear, since the wear traces and frictional coefficients of T800 at a higher temperature 538°C is much smaller that those at lower temperature 25°C.

Acknowledgement

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References

[1] J.R. Davis, "Handbook of thermal spray technology", ASM Thermal Spray Society, USA (2004) 1.

[2] B.M. Kim, S.Y. Hwang, H.S. Choi and C.H. Lee, "Coating properties of nano structured WC-Co for process variables of HVOF", J. Kor. Inst. Met. & Mater. 41 (2003) 695.

[3] E.P. Song, J.H. Ahn, S.H. Lee and N.J. Kim, "Micro structure and wear resistance of Al_2O_3-13 wt% TiO_2 coatings plasma-sprayed using nano crystalline powders", J. Kor. Inst. Met. & Mater. 43 (2005) 438.

[4] S.Y. Park and C.G Park, "Wear properties of WC-Co nano particle coatings fabricated by detonation gun spraying", J. Kor. Inst. Met. & Mater. 42 (2004) 577.

[5] B.D. Sartwell *et al.*, "Validation of HVOF WC/Co thermal spray coatings as a replacement for hard chrome plating on aircraft landing gear", Naval Research Laboratory Report Number NRL/MR/6170-04-8762 (April 2004) 1.

[6] H.M. Kim *et al.* "The effect of post heat treatment on the wear resistance of the TiC-Fe coating fabricated by HVOF process", J. Kor. Inst. Met.& Mater. 38 (2000) p. 125.

[7] B.D. Sartwell, K. Legg and B. Bodger, "HVOF thermal spray coatings as an alternative to hard chrome plating on military & commercial aircraft, AESF/EPA", Conference for Environmental Excellence, 231, USA (1999) 1.

[8] N.K. Baek, K.S. Kim, S.J. Youn, J.H. Yoon and T.Y. Cho, "Wear behavior of Co-alloy T800 coating prepared by HVOF thermal spraying", 8th Int'l Conf., Advanced Surface Engineering (Tokyo, Japan, 2006) 81.

[9] T.Y. Cho, J.H. Yoon, K.S. Kim, N.K. Baek, S.Y Hwang, S.J. Youn and H.G Chun, "HVOF coating of Co-alloy T800 for the improvement of the performance and durability of military hardware components", 15th Aero Technology Symposium, Logistics Command ROKAF, September 15, 2006.

[10] T.Y. Cho, J.H. Yoon, K.S. Kim, S.J. Youn, N.K. Baek, B.C. Park, S.Y. Hwang and H.G Chun, "HVOF spray coating of Co-alloy T800 for the improvement of durability of high speed spindle", Kor. Soc., Machine Tool Engineers 15-6 (2006) to be published.

[11] K.S. Kim, N.K. Baek, J.H. Yoon, T.Y. Cho, S.J. Youn, S.Y. Oh, S.Y. Hwang and H.G Chun, "WC-Co HVOF thermal spray coating for durability improvement of high speed spindle", J. Kor. Surface Engineering, to be published on August 2006.

[12] F.A. Cotton and G Wilkinson, "Advanced inorganic chemistry", 5th edition, Wiley Interscience, USA (1988) 724.

[13] R. Knight and R.W. Smith, "Thermal spray forming of materials, powder metal technologies and applications", vol 7, ASM Handbook, ASM International (1998) 408.

[14] T.G Massalski *et al.*, "Binary alloy phase diagram", Am. Soc. for Metals 1 (1986) 600.

[15] A.W. Adamson, "Physical chemistry of surfaces", 4th Ed. John Wiley and Sons (1982) 404.