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A Study on the Friction and Wear Properties of Tribaloy 800 Coating by HVOF Thermal Spraying

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Abstract

Tribaloy 800 (T800) powder is coated on the Inconel 718 substrate by the optimal High Velocity Oxy-Fuel (HVOF) thermal spray coating process developed by this laboratory. For the study of the possibility of replacing of the widely used classical chrome plating, friction, wear properties and sliding wear mechanism of coatings are investigated using reciprocating sliding tester both at room and at an elevated temperature of 1000°F (538°C). Both at room temperature and at 538°C, friction coefficients and wear debris of coatings are drastically reduced compared to those of non-coated surface of Inconel 718 substrate. Friction coefficients and wear traces of both coated and non-coated surfaces are drastically reduced at higher temperature of 538°C compared with those at room temperature. At high temperature, the brittle oxides such as CoO, Co_3O_4, MoO_2, MoO_3 are formed rapidly on the sliding surfaces, and the brittle oxide phases are easily attrited by reciprocating slides at high temperature through complicated mixed wear mechanisms. The sliding surfaces are worn by the mixed mechanisms such as oxidative wear, abrasion, slurry erosion. The brittle oxide particles and melts and partial-melts play roles as solid and liquid lubricant reducing friction coefficient and wear. These show that the coating is highly recommendable for the durability improvement coating on the surfaces vulnerable to frictional heat and wear.

Keywords : Sliding wear test, Slurry erosion, Melts and partial-melts, 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[1-4]. Since the pollution of very toxic Cr^{6+} known as carcinogen causing lung cancer results from chrome plating solution and products, and the ceramic coatings prepared by other methods are brittle, the HVOF Tribaloy 800 (T800) coating is highly prominent candidate for the replacement of the traditional high wear resistant coatings such as hard chrome plating and ceramic coatings[4-7]. HVOF coatings have properties of high hardness, bond strength, and wear resistance. In this study, micron size T800 powder is coated by the optimal HVOF thermal spray coating process developed by this laboratory[1,8]. The friction and wear properties of the coating are investigated by the reciprocating sliding wear test at room temperature and at an elevated temperature of 538°C. The possibility of application as high heat and wear resistant coating is studied for the durability improvement and economic restoration of high speed spindles vulnerable to friction, wear and frictional heat.

2. Experimental

2.1 Preparation and Characterization of Coatings

T800 coatings of 300-350 μm thickness are prepared on the Inconel 718 substrate by the optimal coating process by using the JK3500 HVOF thermal spraying

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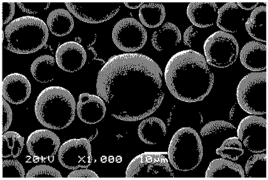

Fig. 1. SEM micrograph of Co-alloy T800 particles.

equipment. The major chemical compositions of the T800 powder prepared by Satellite Company Inc. are Co-45.7 wt%, Mo-28.4 wt% and Cr-17.6 wt%. As shown in Fig. 1 the powders are homogeneous mixture of spherical particles with diameter 5-30 μm. For the improvement of bond strength of the coatings, substrates are pre-cleaned by ultrasonic cleaning in acetone solution for 5 minutes and then are blasted by 60 mesh aluminum oxides.

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.

2.2 Friction and Wear Test

Friction and wear properties of the coatings are investigated by the reciprocating sliding wear tester (TE77 AUTO, Plint & Partners) by using the SUS 304 counter sliding ball of diameter 9.53 mm and hardness 227 Hv without using 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 coefficient, wear traces of coatings and counter sliding 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 Preparation of Coating and Coating Mechanism

According to the phase diagram, εCo phase of both Co-Mo and Co-Cr systems of T800 particles melts at a temperature lower than the pure cobalt melting point 1495°C. The sprayed particles with various sizes are molten, partial-molten or soften during the short flight time of 0.1-1 ms by the high temperature (up to 3000°C) of the flame formed by the burning of fuel gas hydrogen and oxygen. The melts, partial-melts or softens are accelerated to speeds in the range of 50-1,000 m/s and impact on the cool coating surface with supersonic speed[2]. Upon impact, a bond forms with the surface, with subsequent particles causing thickness buildup and forming a lamellar structure as shown in Fig. 2(a). The thin splats undergo quenching at a very high cooling rate, typically in excess of 10^6 K/s[2]. The splats form fine-grained coatings with very high adhesion as shown in Fig. 2(b).

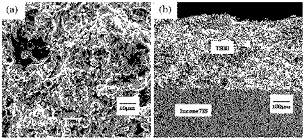

Fig. 2. SEM micrographs of T800 coating (a) surfaces, (b) cross section.

3.2 The Optimal Coating Process

Optimal coating process is determined from the best three surface coating properties of roughness, hardness and porosity prepared by the spray processes designed by Taguchi program for the spray parameters such as spray distance, fuel gas flow rates of hydrogen and oxygen and powder feed rate[8]. From these studies, the optimal HVOF coating process of 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 at spray distance of 5 inch respectively[8].

3.3 Friction and Wear Properties

The larger wear traces are expected on the coating surfaces with smaller hardness both at room temperature and 538°C since the wear volume is inversely proportional to the surface hardness in adhesive wear, but no clear relationship between the wear traces and hardness of coating is observed from the wear traces as shown in Fig. 3. This shows that the wear is not only taken place by adhesive wear mechanism but by other wear mechanisms such as oxidative wear, especially abrasion by scratching or gouging at the asperities by the counter sliding ball, slurry erosion by the mixture of solid particles and small drops of the melts and partial-melts of the attrited particles. As shown in Fig. 3, wear traces of coating at high

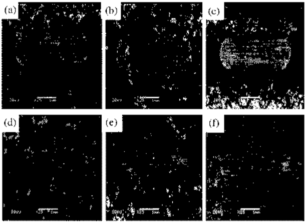

Fig. 3. Hardness of coating (Hv) and wear traces (a) 738, (b) 610, (c) 480 at room temperature, (d) 738, (e) 610, (f) 480 at high temperature of 538°C.

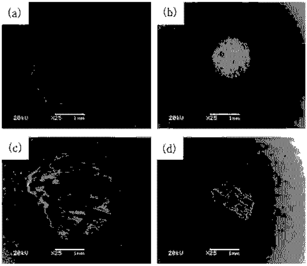

Fig. 4. Wear traces on counter sliding SUS 304 ball sliding on (a) non-coated at room temperature, (b) non-coated at 538°C, (c) coated at room temperature, (d) coated at 538°C.

temperature of 538°C are reduced more than a half compared with those at room temperature. 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[7]. The brittle surface oxides are easily attrited as debris in the severe wear environment created by the reciprocating sliding with the counter sliding ball through the complicated mixed wear mechanisms mentioned above in the wide range of temperature and pressure of the sliding spot. And the attrited oxide particles, melts and partial-melts have played roles as solid and liquid lubricant, and the role is higher at higher temperature resulting the smaller wear traces and debris at the higher temperature.

This shows that HVOF thermal spray coating of T800 is highly recommendable as a durability improvement coating on the surface vulnerable to frictional heat and wear such as high speed spindles[1,8,9].

Fig. 4 shows the wear traces on counter sliding SUS 304 ball both at room and at 538°C . The wear trace on the ball slides on T800 coating is smaller than those slide on non-coated Inconel718 surfaces, and the traces of melt by sliding on coating is larger than those by sliding on non-coated surfaces. These show that T800 coatings play a role as lubricants and are essential as a durability improvement coating. The traces on the balls by the sliding on both coated and non-coated surface are drastically reduced at high temperature compared with those at room temperature. This shows the lubricant role of the oxides is increased as the sliding temperature increases. Fig. 5 shows the relationship of weight loss by sliding versus the hardness of both coating and non-coating, and friction coefficients versus the hardness both at room temperature and 538°C.

Both the weight loss and friction coefficients of T800 coatings are smaller compared with those of non-coatings both at room temperature and 538°C. Also the friction coefficients are smaller at high temperature compared with those at room temperature for both coating and non-coating surfaces. These

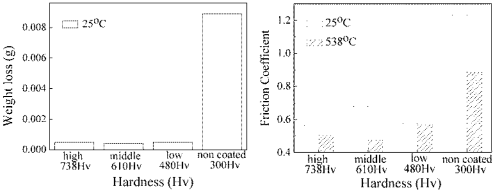

Fig. 5. Weight loss and friction coefficients versus hardness.

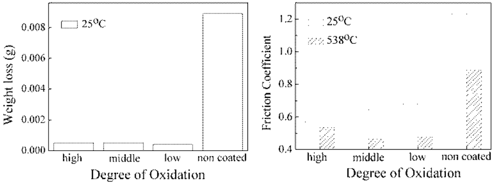

Fig. 6. Weight loss and friction coefficients versus degree of oxidation.

show that T800 coating is highly recommendable as a durability improvement coating at room and high temperature because of the superior lubricant properties of the T800 coatings. No clear relationship between the friction coefficients versus hardness and weight loss versus hardness of coatings are observed in this experiment.

Fig. 6 shows the relationship of weight loss versus the degree of oxidation and friction coefficients versus the degree of oxidation of coating and non-coating surfaces, and friction coefficients versus coating temperatures. Clear relationship between the weight loss and friction coefficients versus the degree of oxidation (prior to the sliding tests) are not observed in these tests since the preexisted oxides (native oxides) are much smaller compared with those formed during the sliding test. The friction coefficients are decreased at high temperature in comparison with those at room temperature for both coated and non-coated surfaces. This also shows that the role of oxide lubrication is more active at the higher temperature. And the weight loss and friction coefficients are drastically smaller for the coatings compared with those for non-coated Inconel 718. These observations agree with the ESTCP report of Sartwell[10] that the wear coefficients of T800 coating is remarkably smaller than those of other wear resistant coatings such as chrome plate and tungsten carbide at the sliding against 4340 steel counter sliding surface. This shows that the T800 coating is also highly recommendable for wear resistant coating to the surface vulnerable to frictional heat and wear.

4. Conclusions

The followings are concluded in this study;

1. The friction coefficients, wear traces and wear debris of T800 coating are smaller than those of non-coated Inconel718 surface both at room and at an elevated temperature 538°C. This shows that T800 coating improves the wear resistance, and also can improve the durability of high speed spindles.

2. The friction coefficients, wear traces and wear debris of T800 at an elevated temperature of 538°C are much smaller than those at room temperature. This shows that T800 coating is highly recommendable for the coating on the surfaces vulnerable to frictional heat and wear such as high speed spindles.

3. The brittle oxides such as CoO, Co_3O_4, MoO_2, MoO_3 are rapidly formed on the coating at elevated temperature and those are easily attrited by the sliding through the complicated mixed wear mechanisms such as oxidation wear, abrasive wear, slurry erosion. The attrited oxide solid particles, melts and partial-melts play a role as solid and liquid lubricants.

Acknowledgement

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References

1. T. Y. Cho, J. H. Yoon, K. S. Kim, B. K. Park, S. J. Youn, N. K. Baek, Kor. Soc., Machine Tool Engineers, Spring Conference, (2006) 291-296.
2. J. R. Davis, Handbook of Thermal Spray Technology, ASM Thermal Spray Society USA, (2004) 3-5.
3. 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 (2004) 1-3.
4. B. M. Kim, S. Y. Hwang, H. S. Choi, C. H. Lee, J. Kor. Inst. Met. & Mater., 41 (2003) 695.
5. S. Y. Park, C. G. Park, J. Kor. Inst. Met. & Mater., 42 (2004) 582.
6. H. M. Kim *et al.*, J. Kor. Inst. Met. & Mater., 38 (2000) 125.
7. F. A. Cotton, G. Wilkinson, Advanced Inorganic

Chemistry 5th Ed. Wiley Interscience, USA, (1988) 724-741.
8. T. Y. Cho, J. H. Yoon, K. S. Kim, B. K. Park, S. J. Youn, N. K. Baek, H. G. Chun, J. Korean Crystal Growth and Crystal Technology, 16-3 (2006) 121-126.
9. R. Knight, R. W. Smith, Thermal Spray Forming of Materials, Powder Metal Technologies and Applications Vol. 7, ASM Handbook, ASM International, (1998) 408-419.
10. B. D. Sartwell *et al.*, A Replacement of Chromium Electroplating on C-2, E-2, P-3, and C-130 Propeller Hubs Using HVOF Thermal Spraying Coatings, ESTCP Cost and Performance Report (PP-9922), US department of Defense, (March 2004) 1-21.