Article ID: 1003 - 6326(2004)04 - 0718 - 05

Influence of solid contaminants in oil on wear characteristics of nano-Al_2O_3/Ni composite coating ①

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Abstract: Solid contaminants in lubrication system will cause severe wear of sliding components. In order to improve the wear resistance of the material in oil containing solid contaminants, the brush plated nano-Al_2O_3/Ni composite coating was prepared and the influence of the sand content and sand size on the tribological property of the coating in oil containing solid contaminants was tested with ball-on-disc tester. The results show that the wear volume increases with increasing the sand content and sand size, and the wear resistance of the composite coating is 20% higher than that of the high-speed plain nickel coating. The main wear mechanisms of the coatings are abrasive wear and adhesive wear. And due to the nano-particle strengthening effect, the wear resistance of the composite coating is improved.

Key words: composite coating; nano-particles; wear; solid contaminant

CLC number: TG 175 **Document code:** A

1 INTRODUCTION

The solid contaminants are usually involved in the lubrication system either by dust through the engine inlet port or generated from the wear loss of the materials[1,2]. These fine particles accelerate the wear of sliding components[3,4]. It has been reported that over 50% of bearing failures are caused by impurities in the supply lubricant[5]. Consequently, improving the wear resistance of these components becomes a research subject of top priority and great industrial importance. With the newly developed nano-materials[6], recently the brush plated composite coating prepared by the co-deposition of nano-particles with matrix metals has received increasing attention in view of its high hardness, low friction coefficient and total inertness to any acid or other chemical attack[7-9]. The principal purpose of the present work is to study the feasibility of replacing the current high-speed nickel coating with nano-Al_2O_3/Ni composite coating to improve the wear resistance of material in oil containing solid contaminants.

2 EXPERIMENTAL

The Al_2O_3 nano-particles (as shown in Fig. 1) with a size of about 30 nm were added into the high-speed nickel plating solution with the content of 20 g/L and the suspension was sufficiently stirred before brush plating. The nano-Al_2O_3/Ni composite coating was brush plated with a voltage of 12 V and a relative velocity between the negative and positive pole of 10 m/min.

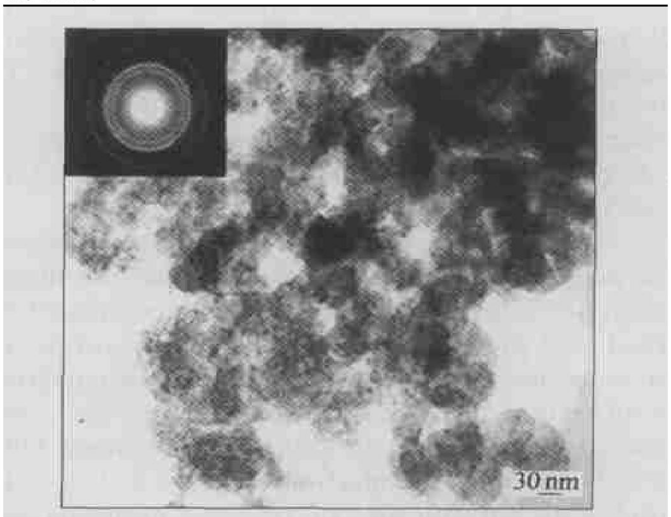

Fig. 1 TEM image of Al_2O_3 nano-particles

The friction and wear tests in oil containing solid contaminants were conducted on a T-11 (made in

① **Foundation item:** Project(50235030) supported by the National Natural Science Foundation of China; project(1999065009) support by the National Key Fundmental Research and Development Program of China

Received date: 2004 - 01 - 05; **Accepted date:** 2004 - 04 - 20

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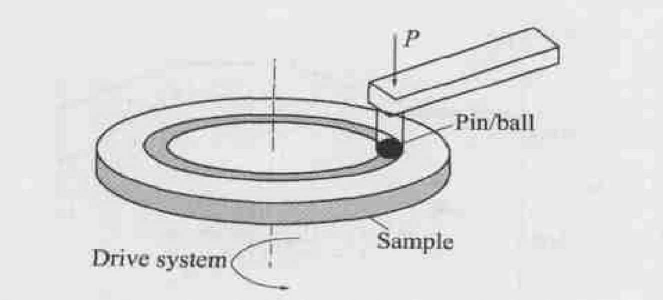

Fig. 2 Schematic diagram of T-11 test rig

Poland, Fig. 2 shows the schematic diagram) "ball-on-disk" testing machine. The brush plated lower disk specimen made from 1045 steel was rotating, with a dimension of d25.4 mm × 6.1 mm (the coating thickness was 0.1mm). The upper ball specimen made from Si_3N_4 ceramic was stationary, with a diameter of 6.35 mm. All tests were commenced at a rotating radius of 10 mm, a normal load of 30N and a sliding speed of 0.4 m/s. The contaminant sand was composed of SiO_2 (74% – 76%) and Al_2O_3 (14% – 16%). Particles sizing was carried out in the laboratory using standard sieving procedures. The sand with required quantity was added to the oil and the mixture was stirred immediately prior to performing a test. The cyclic lubrication mode with 50 mL diesel oil was adopted. The wear volume was calculated by measuring the width of wear trace using an optical microscope(with a precision of 0.01 mm). Each test was repeated three times, and the average was adopted as the experimental data.

The surface morphologies of the coatings before and after wear testing were examined by Quanta200 scanning electron microscope(SEM). The distribution of the nano-particles in the composite coating was revealed by transmission electron microscope(TEM). The micro-harness indentations were made into the cross-section to avoid the substrate effect. The measurements were performed using JMT-3 hardness tester with a load of 0.5 N for 15 s. The oil samples were analyzed by OLYPUSBX41 ferrograph.

3 RESULTS AND DISCUSSION

3.1 Surface morphology

Fig. 3 depicts the typical surface morphologies of the coatings by SEM. Both the high-speed nickel coating and n-Al_2O_3/Ni composite coating show the nodular surface morphologies. But the microstructure of the composite coating is much more fine and dense than that of the high-speed nickel coating resulting from the nano-particle nucleation effect[10].

3.2 Wear behavior

Fig. 4 shows the variations of the wear volume with sand content(the sand size less than 50 μm) and sand size(the sand content of 400 mg/L) for the

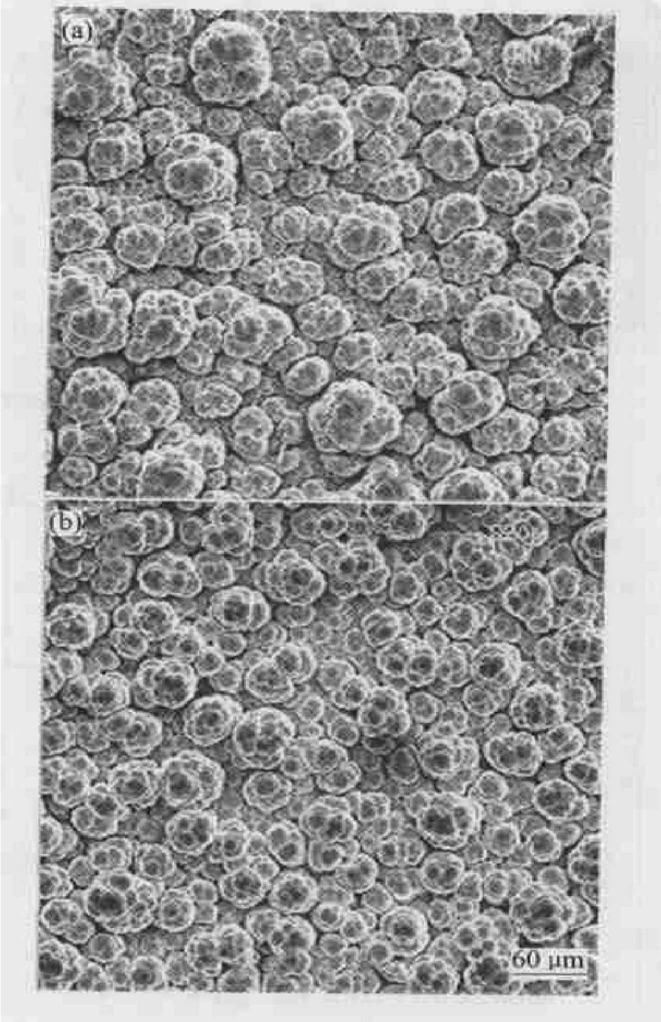

Fig. 3 Surface morphologies of coatings
(a) —High-speed nickel coating;
(b) —n-Al_2O_3/Ni composite coating

high-speed nickel coating and n-Al_2O_3/Ni composite coating. It can be seen that the wear volumes of the high-speed nickel coating and the composite coating increase with increasing sand content and size, however, the wear volume of the n-Al_2O_3 composite coating is 20% lower than that of the high-speed nickel coating in the same test condition. Moreover, the wear volume of the high-speed nickel coating increases slowly at the sand content below 200 mg/L and the sand size less than 30 μm, beyond which the wear volume increases dramatically. The result for n-Al_2O_3/Ni composite coating shows the same trends, however, the sand content and sand size at which the wear volume increases rapidly are 400 mg/L and 40 μm, respectively, higher than those of the high-speed nickel coating. This means that the composite coating can work in higher sand content and larger sand size than the high-speed nickel coating without severe wear.

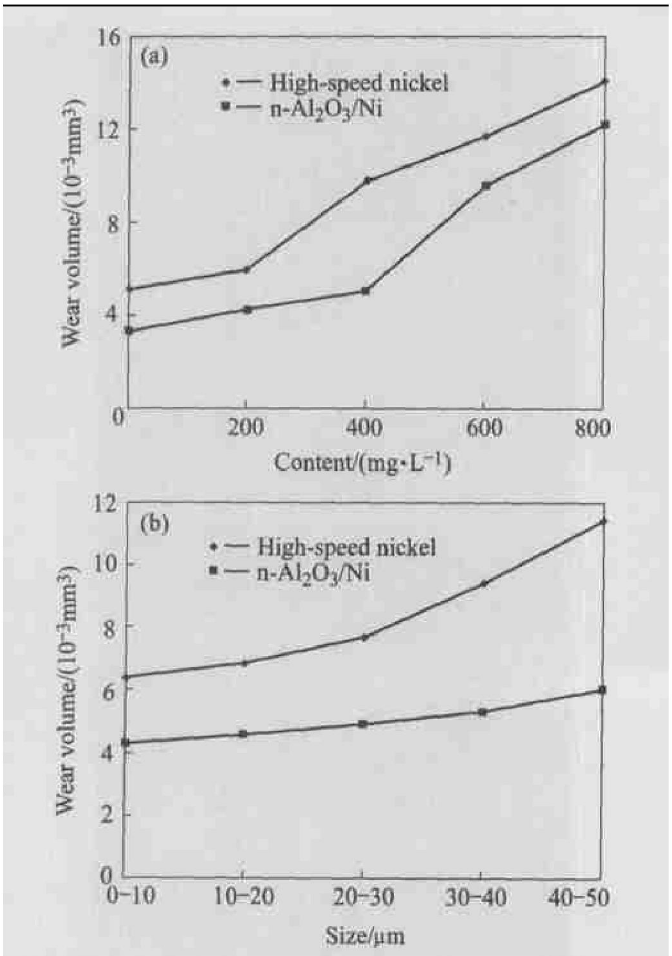

Fig. 4 Variation of wear volume with sand content(a) and sand size(b)

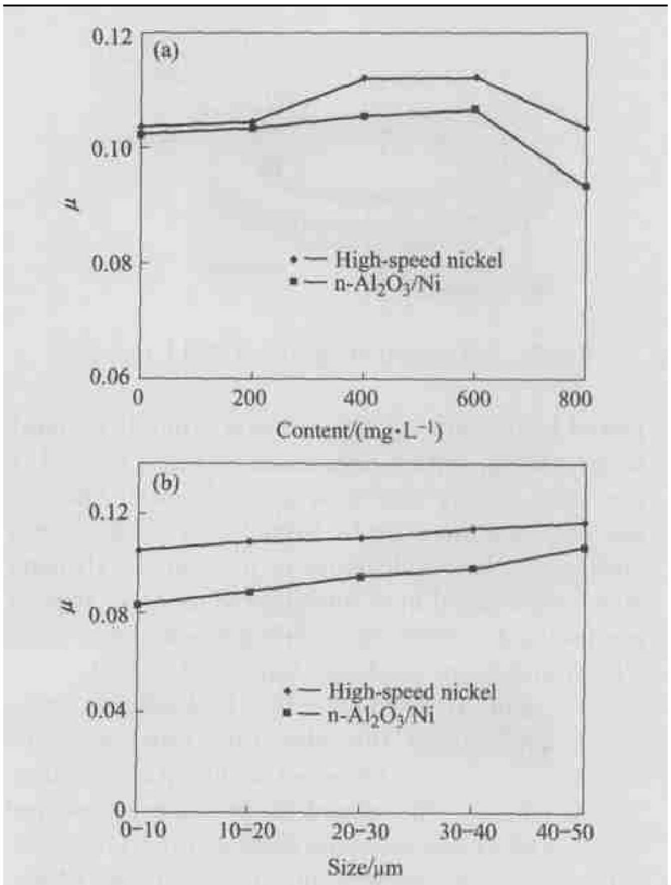

Fig. 5 Variation of friction coefficient with sand content(a) and sand size(b)

3.3 Friction behavior

The variations of the friction coefficient with sand content and sand size are shown in Fig. 5. As the sand content increases, the friction coefficients of the high-speed nickel coating and n-Al_2O_3/Ni coating both increase, but then decrease again when the sand content is larger than 600 mg/L in the oil. It can also be seen that as the sand size increases, the friction coefficients of the coatings increase all along. In all test conditions, the friction coefficient of the composite coating is found to be slightly lower than that of the high-speed nickel coating.

3.4 Wear mechanism

From the worn surfaces as shown in Fig. 6, the fine striations along the sliding direction, probably from the sands plowing their way forward, and the scratches associated with the adhesive wear are found in both coatings. Typical wear particles in the ferrogram (Fig. 7) also demonstrate that the main wear mechanisms of the two coatings are the abrasive wear and adhesive wear. However, the high-speed nickel coating shows a more severe wear than the composite coating.

The hardness of Si_3N_4 ball is far higher than

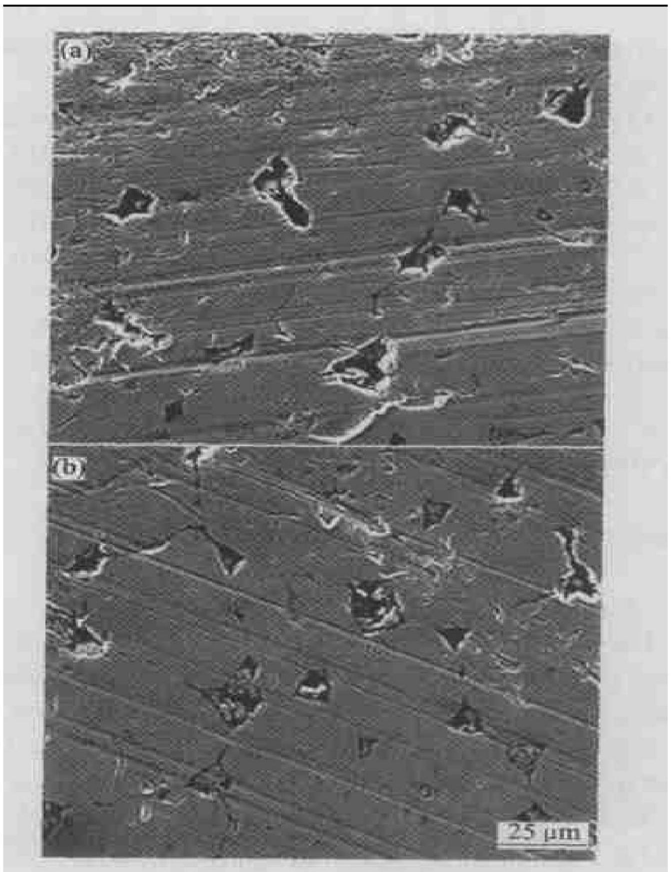

Fig. 6 Worn surfaces of coatings
(a) —High-speed nickel coating;
(b) —n-Al_2O_3/Ni composite coating

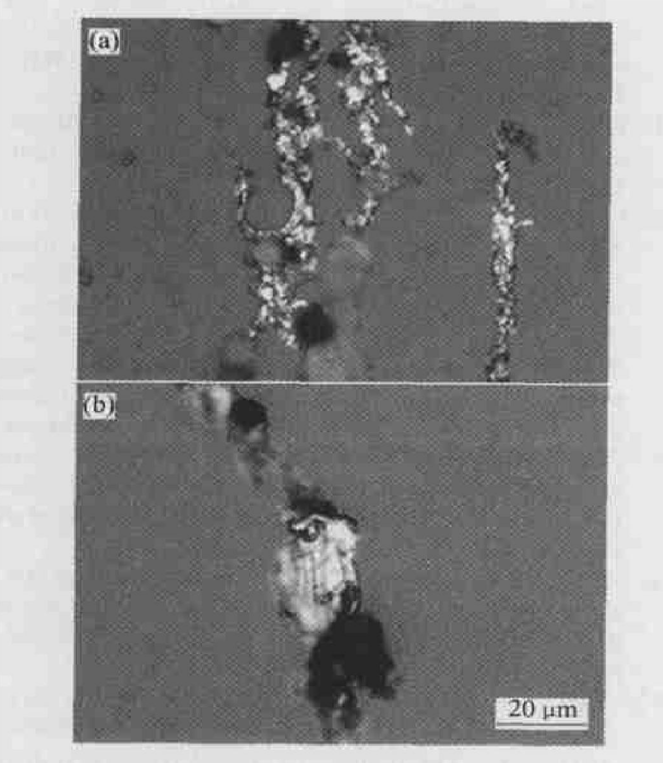

Fig. 7 Typical wear particles in ferrogram
(a) —Micro-cutting particle formed by abrasive wear;
(b) —Particle formed by adhesive wear

that of the coatings, therefore, when the sand is drawn to the contact zone, it will be embedded into the coating by the pressure. When the wear couples slide relatively, the plowing action occurs. At the same time, the heat generation during the sand plowing the coating will deteriorate the lubrication film and lead to the adhesive wear between the wear couples.

As the sand content and sand size in the oil increase, the abrasive and adhesive behaviors increase, therefore, the wear volume and friction coefficient of the coatings rise. Further increasing the sand content, the wear volume increases but the fiction coefficient decreases slowly. This is probably because that the round sand particles (Fig. 8) in the contact zone may act as "micro ball bearing" reducing the friction[11].

The excellent tribological property of nano-Al_2O_3/Ni composite coating may attribute to its high hardness and dense microstructure. Fig. 9 shows the hardness of the high-speed nickel coating and the composite coating at different temperatures. The micro-hardness of the composite coating (HV692) registers 60% higher than that of the high-speed nickel coating (HV440) at the room temperature. With the temperature elevating, the hardness of both coatings decreases, however, the hardness value of the composite coating doesn't reduce so much as that of the high-speed nickel coating. The hardness of the composite coating can maintain HV280 even at the temperature of 600 ℃, while that of the high-speed nickel coating is only HV75. Fig. 10 shows that the nano-particles are mainly located inside the matrix grains and at the grain boundaries. These fine particles can pin the dislocatiocn[12, 13] and grain boundaries[14, 15] during the plastic deformation or grain growth, which leads to the hardness of the coating increasing

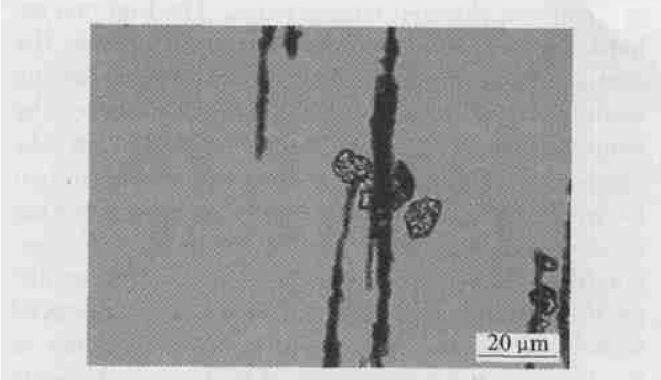

Fig. 8 Sands in ferrogram after wear test

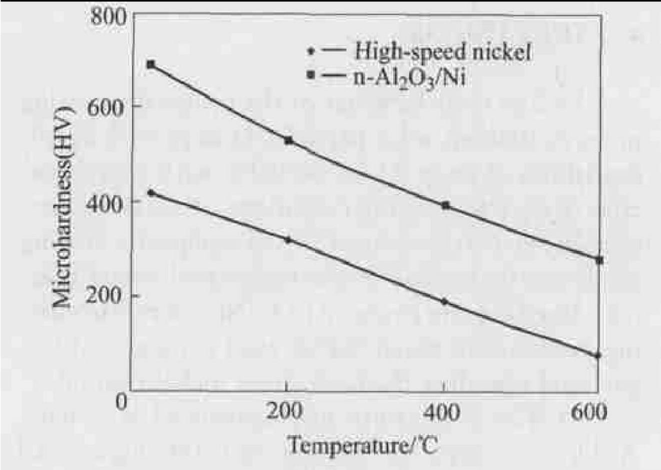

Fig. 9 Variation of micro-hardness with temperature

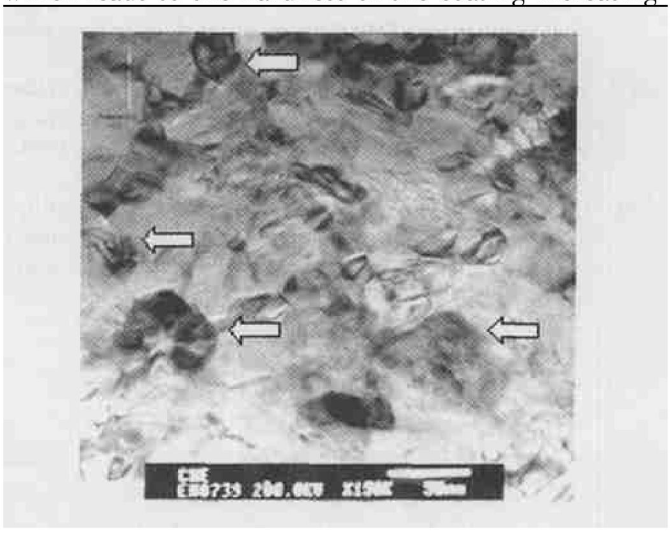

Fig. 10 TEM image of composite coating (arrow pointing to nano-particles)

both at room and elevated temperature. The high micro-hardness and dense microstructure mean that the composite coating's resistance to the micro-cutting and plowing actions is enhanced. Furthermore, the nano-particles homogeneously distributed in the composite coating[16] can reduce the direct contact between the wear couples, hence the adhesive wear of the composite coating is also decreased. Consequently, the brush plated composite coating exhibits better tribological property than the high-speed nickel coating and it is a promising technology to improve the wear resistance of sliding components of the machine.

4 CONCLUSIONS

1) The wear behavior of the composite coating in oil containing solid particles is improved by codeposition of nano-Al_2O_3 particles with nickel matrix. Under the testing conditions, the friction coefficient and wear volume of the composite coating are lower than those of the high-speed nickel coating. Furthermore, nano-Al_2O_3/Ni composite coating can work in much higher sand content and larger sand size than the high-speed nickel coating.

2) The main wear mechanisms of the nano-Al_2O_3/Ni composite coating and the high-speed nickel coating in oil containing solid particles are abrasive and adhesive wear.

3) The nano-particles improve the microstructure and the hardness of the coating, thus enhance the wear resistance of the composite coating. The n-Al_2O_3/Ni composite coating is a promising technology to strengthen and repair the sliding components working in oil containing solid contaminants.

REFERENCES

[1] Khorshid E A, Nawwar A M. A review of the effect of sand dust and filtration on automobile engine wear[J]. Wear, 1991, 141: 349-371.

[2] Mehan R L, Flynn P L, Giammarise A W. Evaluation of piston ring materials in oil containing an abrasive using a ring-on-block test machine[J]. Wear, 1991, 147: 41-57.

[3] Pascovici M D, Khonsari M M. Scuffing failure of hydrodynamic bearings due to an abrasive contaminant partially penetrated in the bearing over-layer[J]. Journal of Tribology, 2001, 123: 430-431.

[4] Sep J, Kucaba-Pietal A. Experimental testing of journal bearing with two-component surface layer in the present of an oil abrasive contaminant[J]. Wear, 2001, 249: 1090-1095.

[5] Khonsari M M, Wang S H. On the role of particulate contamination in scuffing failure[J]. Wear, 1990, 137: 51-62.

[6] GONG Rong-zhou, SHEN Xiang, ZHANG Lei, et al. Status and expectation of research on metal matrix nanocomposites[J]. The Chinese Journal of Nonferrous Metals, 2003, 13(5): 1311-1320. (in Chinese)

[7] MA Ya-jun, ZHU Zhang-xiao, DING Lian-zhen. Wear resistance of Ni/Nano-Al_2O_3 composite coatings plated by composite brush plating[J]. Journal of Tsinghua University, 2002, 42(4): 498-500. (in Chinese)

[8] XU Bin-shi, DONG Shi-yun, MA Shi-nin. Microstructure and friction wear characteristics of brush plated n-Al_2O_3/Ni composite coating[J]. Materials Protection, 2002, 35(6): 6-8. (in Chinese)

[9] ZHANG Yu-feng. Study of wear resistance of nano meter nickel-zirconium dioxide composite brush deposits at high temperature[J]. Electroplating & Finishing, 2000, 19(4): 18-21. (in Chinese)

[10] XIE Hua, CHEN Wen-zhe, QIAN Kuang-wu. Crystallization of Ni-P-ultrafine diamond (UFD) composite coating[J]. The Chinese Journal of Nonferrous Metals, 2001, 11(4): 621-625. (in Chinese)

[11] LI Yue-ying, LIU Yong-bin, CAO Zhan-yi. Friction and wearing behavior of aluminum matrix fly ash particles reinforced composites[J]. The Chinese Journal of Nonferrous Metals, 2003, 13(5): 1161-1165. (in Chinese)

[12] Moller A, Hahn H. Synthesis and characterization of nanocrystalline Ni/ZrO_2 composite coatings[J]. Nanostructured Materials, 1999, 12: 259-262.

[13] Ferkel H, Muller B, Riehemann W. Electrodeposition of particle-strengthened nickel films[J]. Materials Science and Engineering A, 1997, A234-236: 474-476.

[14] Müller B, Ferkel H. Al_2O_3-nanoparticle distribution in plated nickel composite films[J]. Nanostructured Materials, 1998, 10(8): 1285-1288.

[15] GUO Zhong-cheng, ZHAI Da-cheng, YANG Xian-wan, et al. Effects of addition of rare earth on properties and structure of Ni-W-B-SiC composite coatings[J]. Trans Nonferrous Met Soc China, 2000, 10(4): 538-541.

[16] JIANG Bin, XU Bin-shi, DING Pei-dao, et al. Microstructure and contact fatigue behavior of nano-SiO_2/Ni coating prepared by electro-brush plating[J]. Journal of Southwest Jiaotong University, 2003, 11(1): 46-52. (in Chinese)

(Edited by YUAN Sai-qian)