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Comparison of ball-on-disc and Taber wear tests in assessing wear performance of electrolessly-deposited alloys

Kongkidakarn THEERATATPONG[a], Sawai DANCHAIVIJIT[a] and Yuttanant BOONYONGMANEERAT[b]*

[a] *Department of Metallurgical Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, 10330*
[b] *Metallurgy and Materials Science Research Institute, Chulalongkorn University, Bangkok, 10330*

Abstract

In the industry, a Taber wear test is commonly employed to assess the wear resistance of coatings, which are applied on a panel of relatively large scales. On the other hand, other wear testing methods, such as ball-on-disc, is preferred in laboratory settings, as they require smaller test specimens and can determine coefficient of friction. In this study, we systematically compare the differences of Taber wear and ball-on disc by evaluating with an electrolessly-deposited Ni-P alloy systems. The Taber wear shows purely abrasive wear, whereas the ball-on-disc test offers a complex blend of wear mechanisms, and provides the coefficient of friction, useful for analyzing a wear loss measurement.

Keywords : Taber wear, Ball-on-disc, Ni-P, Tribological properties, Electroless deposition

Introduction

Wear testing is important for evaluating the wear resistance of electrodeposited coating materials. In the industry, a Taber wear test is commonly employed to assess the wear resistance of the semi-actual coating samples of relatively large scales. On the other hand, other wear testing methods, such as ball-on-disc, is preferred in laboratory settings, as they require smaller test specimens and can provide coefficient of friction. In this study, we systematically compare the differences of Taber wear and ball-on disc by evaluating with an electrolessly-deposited Ni-P alloy systems. The benefits of this study are to understand the fundamental differences of these two important test methods, and provide the approach to choose the systems appropriately for mechanical property evaluations.

The Ni-P alloy system with Co addition is selected here as a representative for the study due to several reasons. First, it is a common type of coatings that is used widely in many industries including automotive and electronic. In addition to decent corrosion resistance, high wear resistance is usually required for the coatings of this type.[1,2] Furthermore, a range of hardness and wear resistance of the materials can be tailored through an addition of alloys and heat treatment applications[3-7], allowing the examination in a wide spectrum.

Materials and Experimantal Procedures

Ni-P and Ni-Co-P alloys were prepared by the general electroless deposition method. 430 stainless steel (50mm x 20mm x 2mm) was chosen as substrate and ground with SiC sandpaper for uniform roughness. The pretreatment procedures used prior to plating were consisted of: (1) cleaning in ultrasonic bath with distilled water, soap and ethanol, (2) cleaning in (10%) NaOH at 60ºC for 15 minutes, (3) distilled water rinsing, (4) pickling in (14%) HCl for 20 minutes, (5) distilled water rinsing and (6) flashing of electroplated Ni. Finally, the samples were suddenly immersed in the electroless plating solution. The base plating solution contained nickel sulfate and cobalt sulphate which were used as the source of nickel and cobalt, respectively. Trisodium citrate was used as the complexing agent. Ammonium sulphate was used for buffering, whereas thiourea was used as stabilizer. Sodium hypophosphite was employed as a reducing agent, and a source of phosphorus. The bath pH values of all solutions were adjusted to 10 by using NaOH. The bath temperature was controlled at 85±1ºC and a plating duration was 120 minutes. The bath composition and operating conditions for electroless Ni-P and Ni-Co-P plating are detailed in table 1. After electroless coating, annealing process was performed at a constant heating rate 10ºC/minutes. in a tube furnace under a nitrogen atmosphere with

*Corresponding author E-mail : yuttanant.b@chula.ac.th

300ºC soaking temperature for 1 hour, followed by furnace cooling.

Table 1: Bath composition and operating conditions.

Type of deposit	Electroless Ni-P, Ni-Co-P	
Sample designation	NP	NCP7
Mol ratio	0	0.7
Bath composition (g/l)		
$NiSO_4 \cdot 6H_2O$	40	11.99
$CoSO_4 \cdot 7H_2O$	-	29.91
$Na_3C_6H_5O_7 \cdot 2H_2O$	35	35
$(NH_4)_2SO_4$	30	30
Thiourea 0.01% (ml/l)	8	8
$Na_2H_2PO_2 \cdot H_2O$	20	20
Operating Conditions		
pH	10.0	10.0
Temperature	85±1ºC	85±1ºC
Time	120 min	120 min
Deposit composition		
Nickel (wt.%)	97.8	52.4
Cobalt (wt.%)	0	45.0
Phosphorus (wt.%)	2.2	2.6

Two methods of wear test were investigated. (1) Ball-on-disc method : the ball was made of tungsten carbide (WC) and the tests were operated under a non-lubricated condition. Sliding velocity was fixed at 200 rpm and sliding distance 500 m. with the contact radius of 5 mm. and load of 10 N being applied. A profilometer was used to map the contour of the worn surfaces and evaluate the wear loss volume.(2) Taber wear test : A Taber wear machine was employed with 10 N test load, 70 rpm velocity, and about 700 m sliding distance. Debris that was developed during the test was collected with a vacuum. Following the test, weight loss in milligram per 1000 cycle was determined. In addition to wear test, hardness measurements were performed with a Vickers microindenter under a constant load of 100 g. and the loading time was 20 s. Atomic force microscopy (AFM) was used to evaluate the arithmetical mean roughness (Ra) of specimens. Scanning electron microscopy (SEM) equipped with energy dispersive spectroscope (EDS) was used to examine the morphology, determine the composition of deposits and analyst wear characteristic.

Results and Discussion

Morphology

The chemical composition of Ni-P and Ni-Co-P specimens are presented in Table 1. The Ni-Co-P sample has lower Ni content than the N-P sample with comparable P contents. The effects of Co addition and heat treatment on surface morphology of specimens are shown in Figure 1. The fine nodular cluster of grains as presented in Figure 1a shows the microstructure of the as-deposited Ni-P coating. Co addition leads to enlargement of meso-scale nodular cluster which appears more prominent (Figure 1b). Moreover, heat treatment is also a factor that causes the nodular cluster enlargement in both coatings as seen in Figure 1c, d. Figure 2 illustrates the results obtained from AFM analysis from which the roughness of the surfaces could be determined, as presented in Table 2.

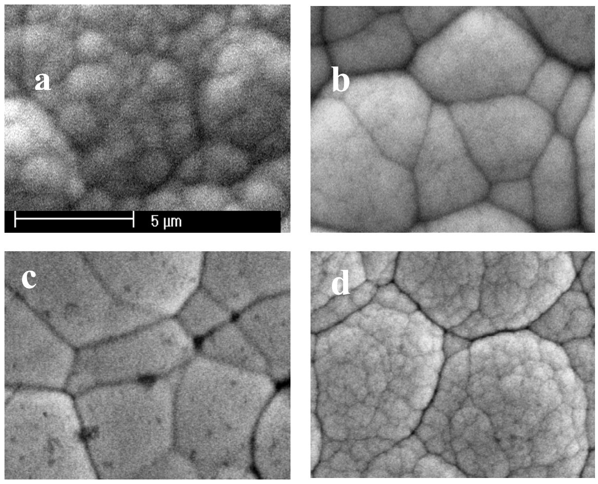

Figure 1. Microstructure of as-deposited(a)Ni-P,(b)Ni-Co-P and as-annealed (c) Ni-P, (d) Ni-Co-P coatings

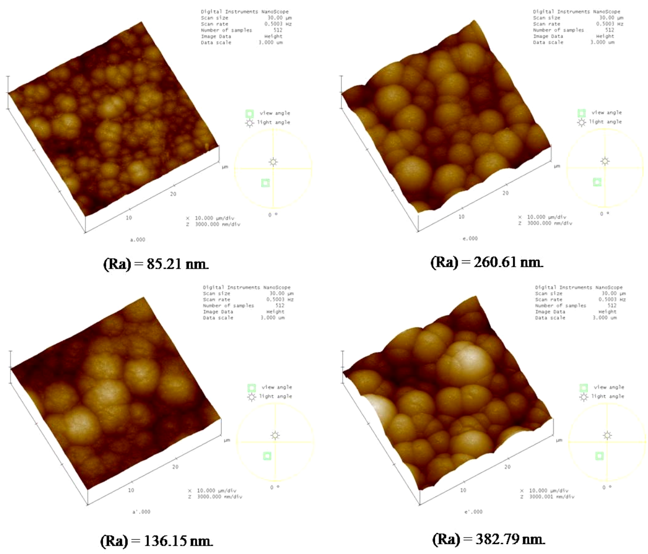

Figure 2. Surface roughness of (a) Ni-P, (b) Ni-Co-P and as-annealed (c) Ni-P, (d) Ni-Co-P coatings

Specimens	Roughness (Ra)	Taber wear Avg. weight loss (mg)	Ball-on-disc Avg. volume loss (10^6 μm^3)	Friction coefficient (μ)
Ni-P	85	55.0	2.6	0.52
Ni-Co-P	261	44.6	7.8	0.55
Ni-P’	136	37.4	1.9	0.35
Ni-Co-P’	383	22.6	5.2	0.41

Table 2. Surface roughness, wear rate and friction coefficient of as-deposited (Ni-P, Ni-Co-P) and as-annealed (Ni-P’, Ni-Co-P’) specimens

Mechanical properties

Microhardness test was performed on the as-deposited alloy coatings compared with the annealed specimens as shown in Figure 3. The as-deposited Ni-Co-P coating can enhance the hardness of Ni-P based alloys, potentially by way of solid solution strengthening mechanism of Co dissolved in Ni metrix. Heat treatment of 300ºC further improves the hardness owing to grain boundary relaxation, where annihilation of excess defects is induced in non-equilibrium grain boundaries during low temperature annealing.[8,9]

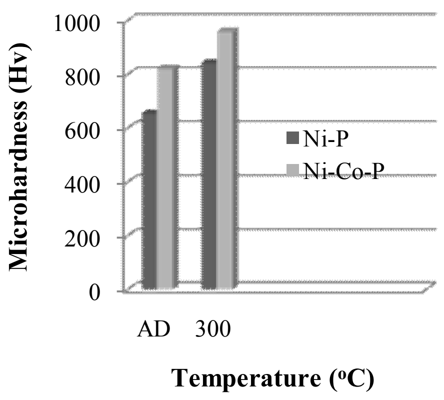

Figure 3. Microhardness of as-deposited and annealed of Ni-P and Ni-Co-P coatings

Figure 4 shows the SEM micrographs of the wear tracks. It is evidenced from the worn surfaces that the wear, with wear track showing surface plowing by asperities, was abrasive in nature. Table 2 also presents the results of wear weight loss of the specimens undergone Taber wear test. The Ni-Co-P alloy exhibits higher wear resistance than the Ni-P alloy. Furthermore, heat treatment is found beneficial for improving the wear resistance of Ni-P and Ni-Co-P coatings. The result of the wear test obtained here, which show correlation of wear resistance and hardness, relate well with Archard’s equation (eqn.1), where V is wear loss, K is wear constant, l is sliding distance, P is normal load and H is hardness.[10]

$$V = K \bullet l \bullet P / H \qquad (1)$$

From the equation above, the calculation of K value is approximately 1.7 x 10^{-3} and 1.6 x 10^{-3} for the Ni-P and Ni-Co-P alloy coatings respectively.

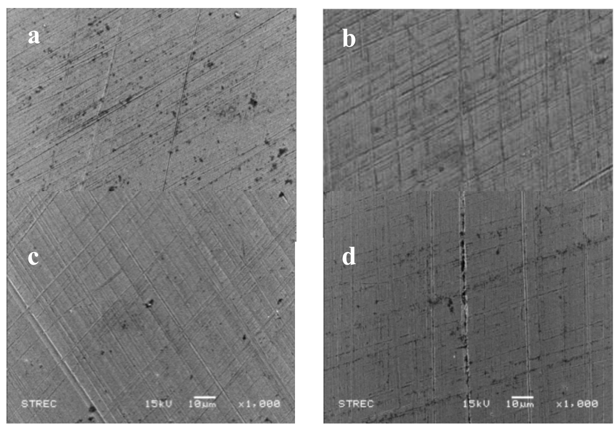

Figure 4. SEM micrograph showing wear scar generated from Taber wear test performed on coating specimens: (a) Ni-P, (b) Ni-Co-P, (c) Ni-P’, (d) Ni-Co-P’

Figure 5 shows wear depth profiles in 3D which were obtained from the profilometer. Their corresponding wear volumes are detailed in Table 2. It is observed that, although the as-deposited Ni-Co-P deposit shows higher hardness than the Ni-P alloy, the volume loss of Ni-Co-P appears higher than the Ni-P deposit. Similar observation is found for the annealed Ni-P and Ni-Co-P specimens. The Archard’s equation is therefore not applicable for these cases.

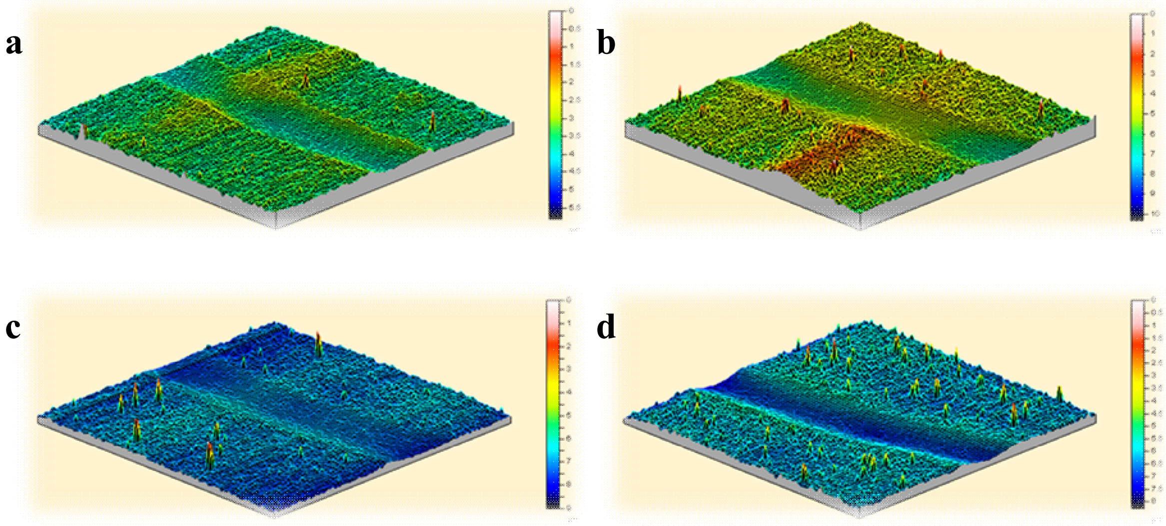

Figure 5. Wear depth profile of Ni-P and Ni-Co-P specimens evaluated by Profilometer : (a) Ni-P, (b) Ni-Co-P, (c) Ni-P’, (d) Ni-Co-P’

The wear characteristic of the worn surfaces is revealed by SEM as shown in Figure 6. The wear scars of all specimens are found to be somewhat different from those produced by Taber wear test. The wear tracks of the two conditions, both the as-deposited and as-annealed, shows surface plowing by asperities which suggests an abrasive wear mechanism. Furthermore, a lamellar structure within wear path is evidence, and hence the adhesive wear mechanism appears to mutually take place. Therefore, the ball-on-disc test provides mixed mode wear mechanisms for the electroless Ni-P and Ni-Co-P alloy deposits. The Ni-Co-P specimen, in particular, exhibits relatively high amount of lamellar structure, probably owing to high roughness which facilitate the occurrence of adhesive wear. Similar to Taber wear test, the ball-on-disc test also show that heat treatment is effective for enhancing the wear resistance in Ni-P and Ni-Co-P coatings. Specifically, the as-annealed Ni-P and Ni-Co-P show about 30% less wear loss compared to their as-deposited counterparts. This enhancement should be partly attributed to the higher degrees of hardness in the annealed specimens. Furthermore, the relatively small coefficients of friction in the heat-treated specimens (Table 2) suggest that oxide films may be developed on the surfaces and serve as lubricants that help protect the deposits’ surfaces against wear.[11-13]

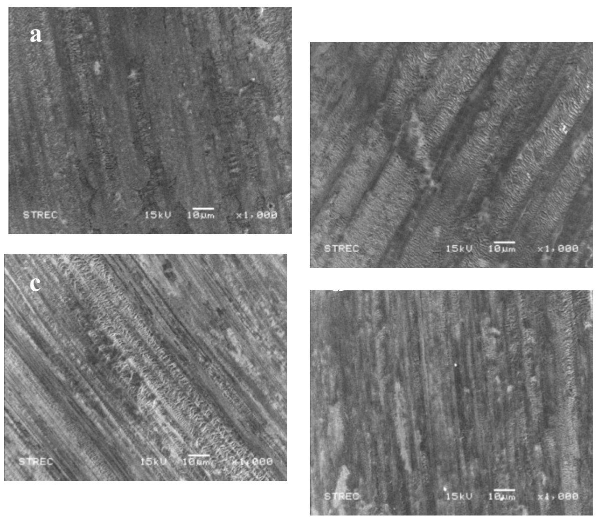

Figure 6. SEM micrograph showing wear scar generated from ball-on-disc test performed on coating specimens;(a) NP,(b) NCP7,(c) NP’,(d) NCP7’

Conclusions

The as-deposited and as-annealed Ni-P and Ni-Co-P coating specimens have been fabricated for an evaluation of wear resistance using Taber wear and ball-on-disc tests. Hardness measurements and other microstructural examinations were executed to help analyze the data from the wear tests. With an addition of Co, improvement in hardness and enlargement of meso-scale nodular cluster were observed. Through annealing, the hardness of Ni-P and Ni-Co-P was further enhanced through grain boundary relaxation mechanism.

In applying Taber wear test, the deposits solely experienced abrasive wear. With relatively high hardness, the annealed Ni-Co-P specimens show high performance against abrasive wear. On the other hand, ball-on-disc imposes combined abrasive and adhesive wear to the deposits. Correspondingly, despite its high hardness, the Ni-Co-P alloys appeared to show higher volume loss than Ni-P coating. It can therefore be concluded that the two wear test methods provide different tribological mechanism for the test specimens. The Taber wear shows purely abrasive wear, whereas the ball-on-disc test offers a complex blend of wear mechanisms. The latter also gives the coefficient of friction data, useful for analyzing a wear loss measurement. With this understanding, in choosing a suitable wear test method, it is therefore not the simplicity of the tests that one should concern, but rather the appropriate wear conditions and mechanisms that one would like to assess.

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References

1. Hari Krishnan, K., John, S., Srinivasan, K.N., Praveen, J., Ganesan, M. and Kavimani, P.M. (2006). An overall aspect of electroless Ni-P depositions-A Review Article. *Metall. Mater. Trans. A.* **37** : 1917-1926.

2. Agarwala, R.C. and Agarwala, V. (2003). Electroless alloy/composite coatings : A review. Sadhana. **28(3)** : 475-493.

3. ASTM B733-97. (1997). *Standard Specification for Autocatalytic (Electroless) Nickel-Phosphorus Coatings on Metal. West Conshohocken*. PA 19428-2959.

4. Aly, I.H.M., Younan, M.M. and Nageeb, M.T. (2003). Autocatalytic (Electroless) Deposition of Ternary Nickel - Cobalt-Phosphorus Alloy. Trans. Inst. Met. Finish. **101** : 37-42.

5. Palaniappa, M. and Seshadri, S.K. (2007). Hardness and structural correlation for electroless Ni alloy deposits. *J. Mater. Sci.* **42** : 6600-6606.

6. Balaraju, J.N., Kalavati. and Rajam, K.S. (2009). Surface morphology and structure of electroless ternary NiWP deposits with various W and P contents. *J. Alloys Compd.* **486** : 468-473.

7. Wang, S.L. (2004). Studies of electroless plating of Ni-Fe-P alloys and the influences of some deposition parameters on the properties of the deposits. *Surf. Coat. Technol.* **186(3)** : 372-376.

8. Rupert, T. J., Trelewicz, J. R. and Schuh, C. A. (2012). Grain boundary relaxation strengthening of nanocrystalline Ni-W alloys. *J. Mater. Res.* **27(9)** : 1285-1294.

9. Sunwang, N., Wangyao, P. and Boonyongmaneerat, Y. (2011). The effects of heat treatments on hardness and wear resistance in Ni-W alloy coatings. *Surf. Coat. Technol.* **206** : 1096-1101.

10. Archard, J.F. (1953). Contact and Rubbing of Flat Surface. *J. Appl. Phys.* **24(8)** : 981–988.

11. Krishnaveni, K., Sankara N., T.S.N. and Seshadri, S.K. (2005). Electroless Ni–B coatings : preparation and evaluation of hardness and wear resistance. *Surf. Coat. Technol.* **190(1)** : 115-121.

12. Zhong-hou, L., Zhi-yong, C., Sha-sha, L., Feng, Z. and A-gan, D. (2008). Corrosion and wear properties of electroless Ni-P plating layer on AZ91D magnesium alloy. *Trans. Nonferrous Met. Soc. China.* **18(4)** : 819-824.

13. Palaniappa, M. and Seshadri, S.K. (2008). Friction and wear behavior of electroless Ni-P and Ni-W-P alloy coatings. *Wear.* **265(5-6)** : 735-740.