Wear properties of as plated Ni-2.5%P and Ni-5%P-SiC on Al356

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Abstract

As plated Ni-2.5%P alloy and Ni-5%P-SiC composite coatings were prepared on Al356 surfaces, using two type electroless bath solution, alkaline bath for low P and basic for composite plating. The coatings were characterized by optical and scanning electron microscopy, XRD, microhardness, reciprocating wear testing and adhesion test (ASTM B571). The results show that a sound and homogeneous deposit can be produced using an optimum bath formulation. Maximum thickness was 50 µm. Microhardness of Ni-2.5%P was near to Ni-5%p-SiC. Also, wear properties of composite coating better than Ni-2.5%P, but adhesion was poorer than Ni-2.5%P.

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Introduction

Aluminum is characterized of three main properties on which its application is based: a low density of approximately 2.7 gr/Cm³, high mechanical strength achieved by suitable alloying and heat treatments, and high corrosion resistance of the pure metals¹.Cast aluminum alloys have many potential industrial applications, owning to their good specific strength, module and excellent casting properties. Obtaining higher microhardness and better wear resistance through surface modification of Al alloys has become in surface engineering.²One of the best alloys for automotive industry is Al356. There are new methods that obtained better wear resistance of Al356 such as laser surface alloying (LSA), ²⁻⁴ thermal spray coatings using ceramic and cermets coatings^{5, 6} or using ferrous powder.⁷

Other technology is nickel-based ceramic composite coatings (NCC) consist of nickel matrix with dispersed particles of silicon carbide, hexagonal boron nitride (hBN) or silicon nitride. Silicon carbide particles improve hardness, while silicon nitride and boron nitride particles add self lubricating properties. The addition of phosphorus to nickel increases hardness and helps the coating resist wear and scuffing even at elevated temperatures.⁸

We cannot heat treat Ni-P on Al356 to achieve high hardness and improve wear resistance, because negative effect on microstructure of substrate. Therefore we have to increase wear behavior by Ni-P composite coating.

It is known that composite coatings which can be obtained by dispersion of micron sized SiC particles into metal matrix provide enhanced hardness and wear resistance. Combination between Ni-P and SiC particles has proven to be the most cost effective and best performing one in an application area where abrasive wear resistance in the main requirement.⁹

In this study, a comparative examination on the wear resistance of electroless Ni-LP particle-free and Ni-MP-SiC coatings in as plated condition is presented.

Experimental

The experimental material was an Al356 aluminum alloy (7%Si, 1%Mg) that was solution and aging treatment (89HV). The natural oxide layer on the surface of cast aluminum alloy will affect the adhesion between the plated layer and the substrate. The removal of the natural oxide layer and the subsequent formation of new layers to passivate the active surface are key steps in the replating process for electroless nickel. When aluminum alloys are directly immersed in electroless nickel solution, because of the large potential difference between aluminum ($\varphi_{Al+3/Al}$ = -1.662 V) and nickel ($\varphi_{Ni+2/Ni}$ =-0.250 V), the displacement reactions between Al and Ni⁺² will have a very strong tendency to occur. This will result in poor adhesion of the nickel to the aluminum alloy. In general, zinc, whose standard potential ($\varphi_{Zn+2/Zn}$ = -0.763 V) is closer to that of aluminum than that of nickel, is used to form an underlayer via a zincating process.¹⁰

Autocatalytic nickel (SiC free and SiC composite) coatings were prepared using two different solutions to produce different P contents. Two type of solution (alkaline & basic) were designed in the test as shown in table 1.

Constituent	Bath 1	Bath 2
Nickel sulfate (g/l)	30	21
Sodium hypophosphite (g/l)	10	25
Complex agent A (g/l)		32
Complex agent B (g/l)		2.2
Complex agent C (g/l)	50	
Complex agent D (g/l)	100	
Stabilizer A (mg/l)	2	
Stabilizer A (mg/l)		2
Stabilizer A (mg/l)		10
SiC (g/l)		15-40
рН	8.9-9.2	4.6-4.9
Temp. °C	88-91	92-95
Agitation	Mechanical	Air & Mechanical
pH Adjustment	NH ₄ OH	NH ₄ OH

Table1 show bath formulation of both solutions and conditions

SiC powder with particle size of $1-5\mu m$, was pretreated then add to a proper solution, without any surfactant, then agitation with ultrasonic wave, sufficiently. Because the $1-5\mu m$ SiC powder would settle readily to bottom of the glass vessel, therefore, to suspend this particles, mechanical and air agitation were adopted. Phosphorus content was determined by energy-dispersive X-ray spectroscopy (EDX) using scanning electron microscope (SEM). SiC concentration in the coating was measured by optical microscopy using an image analyzer program.





Figure 1. a) Optical micrograph of Ni-LP etch in H_2O_2 b) optical micrograph of Ni-P-SiC c) SEM micrograph of Ni-P-SiC



Figure 2 shows the plating rate versus time of plating.

Results and Discussions

A typical optical micrograph of cross section of two coatings and SEM micrograph of composite coating are presented in Figure1. Numerous lamellar lines were observed through out the deposit thickness of Ni-LP. Lamellar or banded structure in the deposit can be ascribed to the variation in the composition of binary electroless alloys with thickness from interface of the deposit/substrate to the surface of the deposit. It has been reported that formation of laminates is due to the periodical fluctuations in the pH of plating solution adjacent to the deposit surface. These fluctuations, which result in variations of the phosphorus content, are postulated as being caused by hydrogen evolution, which raises the pH. And also, since alkaline baths are more dependent than acidic baths, in general lamellar structure can be seen in alkaline baths.¹¹

According to ASTM B659 the coating thickness measured by equation: $t = (m \times 10)/(d \times A)$ where as t; thickness (µm), d; density of coating material (gr/cm³), m; mass of coating (mg), A; area covered by coating (cm²).

Phosphorus content, particle concentration in the layer and coatings thickness data are presented in table 2. X-ray diffraction (XRD) was used to investigate the structural evolution of bath types of coating as function of phosphorus content. The average grain size of the deposits has been calculated from the broadening of the Ni {111} reflection by the Scherrer equation: $D=0.9\lambda/\beta Cos\theta$, where λ is the wavelength of the radiation used, β is the half-maximum width, and θ is the position of the main peak.¹²

The coating microhardness was measured on the surface using Vickers diamond indenter under 100g load. Wear test were conducted under load 10N with unlubricated condition as pin on plate reciprocating wear test. The pin was made from tool steel with 60RC hardness. The tests were carried out for same distance 1000m, and velocity the reciprocating frequency was 45 cycle min⁻¹in 30% humidity. The bond strength of coatings was examined heat quench test, according to ASTM B571. The panels with deposit thickness of ~50 μ m were heated in 200 °C, and then quenched in water, followed by observation of flaking, peeling, and cracking of the coatings, using 5X magnification.

	P%	SiC%	Thickness (µm)
Ni-LP	2.5	-	~50
Ni-P-SiC	5.6	28.7	~48

Table2. Amount of P, SiC, Thickness of Coatings

Figure 3 shows the XRD patterns both of coatings. The as deposited structure of these coatings, particles-free and composite, are nanocrystalline, consisting of supersaturated solid solution of phosphorus in nickel, with an average grain size of approximately 3 and 1.5 nm, respectively.



Fig3. Show XRD pattern of as plated Ni-P-SiC and Ni-LowP

The diffraction peaks corresponding to α -SiC, i.e. the reinforcement, phase were also detected in the diffraction pattern of composite coating. Incorporation of SiC particles or other particulate matter does not influence the structure of the as deposited NiP matrix.¹²

Hardness is probably the most extensively studied property of electroless Ni-P. As deposited hardness is normally 500 – 700 HV0.1, and decreases with increasing phosphorous content. The hardness of low phosphorous content is greater than high phosphorous contents that could be result of higher internal stresses in the deposited. Table 3 shows microhardness of the both coatings. The hardness of particles – free and composite deposit is close to each other. However, composite coating is greater than Ni-LP. The existence of the particles is a barrier to plastic deformation of the Ni-P matrix and is the main reason for the increase in hardness.

Table3 shows microhardness of the both coatings

Coating	Ni-LP	Ni-P-SiC
Microhardness HV0.1	595	625

It can be seen that under as plated conditions, adhesion of Ni-P-SiC coatings inferior to that Ni-LP, because of the SiC particles were as an inclusion in interface of coating and Al356 and prevent maximum adhesion between them.



Figure 4wear test result for both of coatings in 10N load.

It is generally accepted that, for homogeneous materials-such as metals, ceramics and plastics-the abrasive wear resistance is directly related to hardness.¹³

The results of reciprocating wear test show in Figure 4 that indicates wear resistance of Ni-P-SiC coatings in 10N load is better than that of Ni-LP.

Under identical conditions, weight loss of composite coatings is approximately from half to one-third that of Ni-LP. This suggests that wearability of Ni-P-SiC coating may be increased by factor of 2 to 3.

SEM observation on wear surfaces in figure 5 shows that forms of wear on the coatings are predominately abrasive wear mode. In composite coatings, poor bonding between the matrix and the particles could contribute pullout of the particles and, however, the existence of hard particles trapped at the interface of sliding surfaces could intensify the wear destruction. The appearance of the wear surface in Ni-LP shows that adhesion wear could be an additional wear Mechanism. The comparison between Ni–LP and Ni–P–SiC shows that trapping of silicon carbide particles in Ni–P matrix leads to an increase in the hardness and wear resistance.



Figure 5 shows SEM micrograph of two coatings after wear test a) Ni-LP .and b) Ni-P-SiC

Conclusions

- 1. With optimum alkaline bath formulation, we can obtain Ni-LP with good wear resistance and smooth structure.
- 2. At as deposited condition, the Ni-P-SiC and Ni-LP deposits were mixture of amorphous and nanocrystalline nickel phase.

- 3. The hardness and wear resistance of Ni–P electroless coating have been modified by co-deposition of silicon carbide particles within Ni–P matrix.
- 4. In comparison with Ni-LP coatings, composite coatings have higher hardness and wear resistance, as well as lower adhesion.
- 5. Abrasive wear is the most dominant mechanism of wear for Ni–P–SiC coatings and mixed abrasive and adhesion wear mechanism for Ni-LP.

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