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EFFECT OF DEPOSITION PARAMETERS ON MECHANICAL PROPERTIES OF TIN FILMS COATED ON 2A12 ALUMINUM ALLOYS BY ARC ION PLATING (AIP)

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ABSTRACT:

TiN films were deposited on 2A12 aluminum alloys by arc ion plating (AIP). Parameters of bias voltage, nitrogen gas pressure were changed to examine their influence on the hardness and abrasive wear properties of the films. Vickers hardness tests reveled that high values of the films were obtained at a bias voltage of –30 V and a N_2 gas pressure of 0.5 Pa. Dry and wet rubber wheel abrasive tests were conducted to assess the abrasive wear properties. It was found that the abrasive wear rate was greatly reduced with the introduction of TiN coatings. The effects of bias voltage on the hardness of substrates during deposition process, and its influence on the surface roughness of TiN films were also reported.

KEYWORDS: Aluminum alloys; Arc ion plating; Hardness; Wear resistance; TiN film**.**

1. Introduction

Weight saving materials such as aluminum and its alloys are becoming increasingly important and have been attracting increasing attention over the past decade, specially in the automotive, aerospace, chemical industries, and electrical devices because of their high strength-to-weight ratio, high electrical and thermal conductivities, processability and recyclability and good resistance to degradation in some corrosive environments [1,2]. In the automotive industry, there is desire by designers to apply aluminum alloys more widely and extensively in order to achieve better energy efficiencies, both technical and economic considerations and more durable and recyclable goods, i.e., the aluminum alloys are used for many engine parts in toady's cars such as pistons for small automotive and internal combustion engines and parts work under high temperatures and stresses [3]. Unfortunately, the light metals mentioned above have poor wear resistance. Specially, the poor surface hardness of aluminum and its alloys and their relatively low yield strength compared to steels and other materials, give these alloys poor wear resistance in sliding situations; and make them inferior to steel regarding their antiwear properties, thus reduce life time and limit the applications where a heavy surface load-bearing is required [4,5].

Thin hard coatings are employed to improve tribological properties, such as, friction and wear, of conventional engineering materials[6]. Of these coatings, TiN coating is extensively applied due to its high hardness, low friction coefficient, beautiful color and good chemical stability; and has become the most widely used top layer coating in manufacturing [7,8]. There have been few examples of TiN coating on aluminum alloys by physical vapour deposition PVD such as ion plating method [5,9,10] , and the attention has been given to the residual stress of the coatings .However,all PVD coatings are expected to have compressive residual stresses,as it is usually found in PVD coatings prepared by the ion plating technique[11]. Indeed, little attention has been given in the literature to the effect of the deposition parameters on mecahanical and tribological properties of TiN films coated on aluminum alloys by arc ion plating AIP .In order to produce

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highly reliable parts covered with such films, these parameter must carefully be investigated. The objective of the this work is to study the effects of deposition parameters of TiN films coated by AIP on the hardness, surface roughness and abrasive wear rate properties of 2A12 aluminum alloys .

2. Experimental details

2.1 Materials and specimens

The samples of 2A12 aluminum alloys with the size of 50×25×5 mm^3 were used . Prior to coating they were polished by emery papers followed by buff polishing to a surface roughness of R_a 0.04μm . The nominal composition of 2A12 aluminum alloys is given given in Table 1.

Table 1 Elemental composition of 2A12 aluminum alloy

Element	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Al
Wt.%	0.50	0.50	3.8-4.9	0.3-0.9	1.2-1.8	-	-	0.30	-	Bal.

2.2 Coating procedure

The AIP system (Type Multi-Arcs Zon Plating TXMSG) was used to prepare thin films on aluminum alloy substrates.Fig.1 shows a schematic construction of the system. Table 2 shows the depositing conditions. First, the chamber was evacuated to below 10^{-2} Pa and then preheated at 300 ^oC within 40 min in order to discharge the gases that had adhered to the inner wall and the substrate. The system was then cooled down to 110 ^oC, and nitrogen gas was injected in the chamber at a prefixed gas pressure (0.5-2.0 Pa). An arc current of 60A was selected to prepare TiN films. The bias voltage was varied from 0 to – 80V.

Table 2 Process parameters of TiN coating

Film thickness (μm)	Arc current (A)	Bias voltage	Gas pressure (Pa)
3	60	0, -30, -80	0.5,1,2

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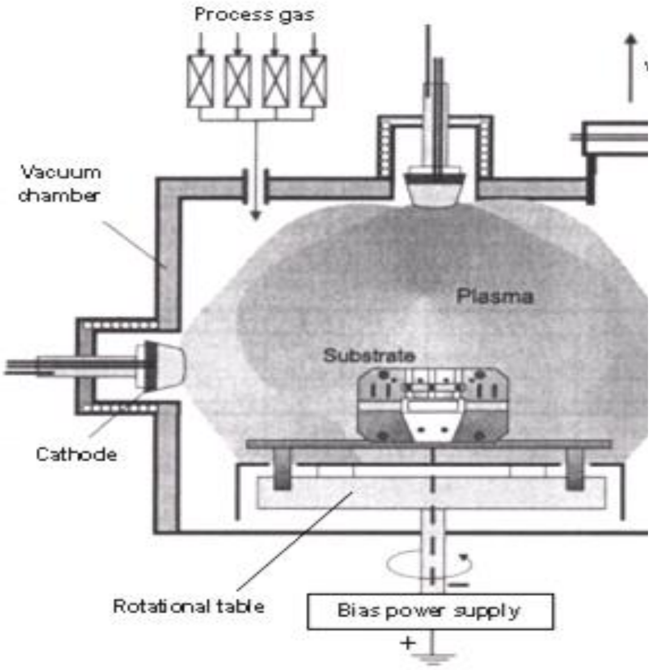

Fig.1. Schematic illustration of the apparatus for arc ion plating.

2.3 coating characterization

The coating hardness was evaluated using a Vickers micro hardness testing machine, at load of 4.9×10^{-2} N. The surface roughness (Ra) of TiN films was measured. Dry and wet sand rubber wheel abrasive wear tests were employed to investigate the anti-abrasion property of the coatings. For comparison with the abrasive wear properties of the TiN coating, an uncoated aluminum alloy substrate and an austenitic stainless steel (AISI 316L) were used as experimental test specimens.Fig.2 shows a schematic representation of the dry and wet rubber wheel abrasive tests. The pivoted arm loaded is used to hold the samples tangentially against the wheel in order to provide a perpendicular force driving the sample into the weel. In the dry abrasive wear test (Fig.2a) the nozzle transports the dry sand, while, the wheel picks up the sand slurry in wet abrasive wear test (Fig.2b), carrying the sand between the samples and the edge of the rubber wheel and thus creating a three body abrasion condition. The abrasive particles are typically silica sand with a size of approximately 60 µm. Distilled water is used to prepare the slurry for the wet test. Samples are subjected to a normal force of 10 N against the rubber wheel rotating at a constant speed of 175 rev/min. The weight loss of samples is determined by an analytical balance with a resolution of 0.1 mg.

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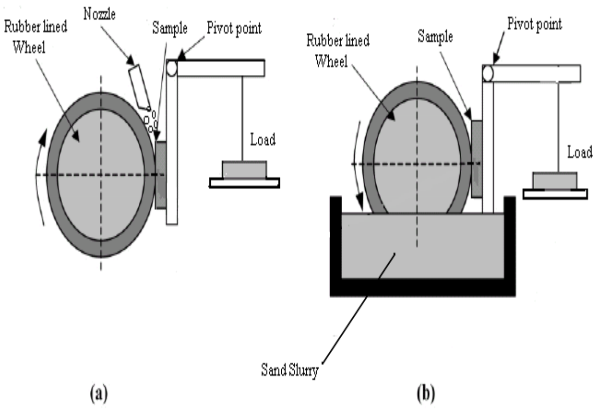


Fig.2. Schematic illustration of the (a) dry and (b) wet rubber wheel abrasive wear tests.

3 Results and discussions

3.1 Hardness

Measurements of the Vickers hardness of the TiN films deposited on 2A12 substrate at different bias voltages indicated that the highest coating hardness was 2094 HV at –30 V (Fig.3). The TiN films had an average hardness of only 1466 HV at 0 V voltage, which increased as the bias voltage changed from 0 to –30V,and thereafter as the bias voltage increased, the hardness seemed to hold a constant value. A slight decrease in hardness from the maximum at –30V, towards low value when increasing of the bias voltage, was measured; this may be due to the tempering effect of the substrate. It should be obvious that the bias voltage of –30V is the optimum condition for preparing hard coating films. Fig.4 shows the relationship between bias voltage and Vickers hardness of the substrate. The aluminum alloy substrates had an average hardness of only 135 HV .It was noticeable that the hardness of the substrates did not change after the deposition with a bias voltage of 0V,but it decreased as the bias voltage increased after –30V. However, the decrease in hardness seemed to be slight even when the voltage was at maximum value of –80V; this may be due to tempering increase caused by the bombardment of titanium ions [5].

Fig.5 shows the effect of N_2 gas pressure on the hardness of TiN films. As the gas pressure increased, the substrate hardness slightly increased, especially for the bias voltage of –80V. The noted decrease in substrate hardness due to increasing bias voltage can be prevented by increasing N_2 gas pressure, if the high bias voltage is necessary for making such films.

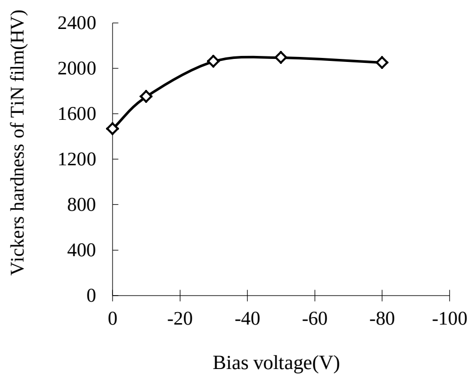


Fig.3. Vickers hardness of TiN films as a function of the bias voltage.

N_2 gas pressure dependence of Vickers hardness of the TiN films deposited at bias voltages of –80V is shown in Fig.6. It can be seen that the hardness decreased in response to increasing gas pressure from 0.5 to 2.0 Pa; Yasuhiro et.al [5],found a similar result and explained that the decrease in the hardness is due to the coarsening of TiN grain size in the film.

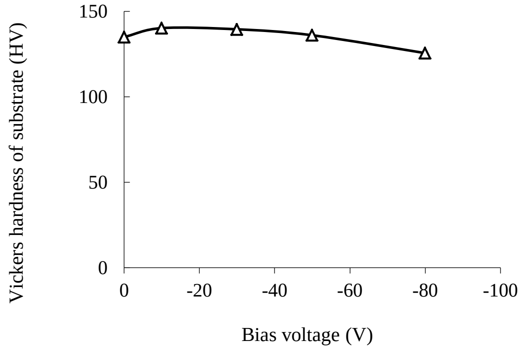


Fig.4. Vickers hardness of the substrate as a function of the bias voltage

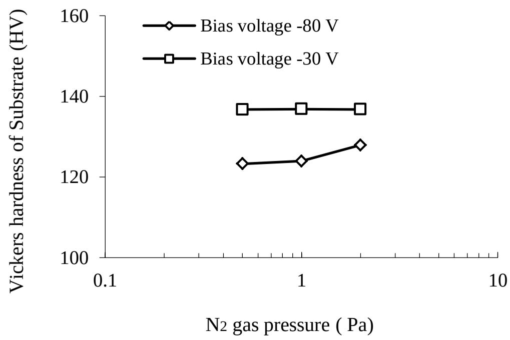


Fig.5. Vickers hardness of the substrate as a function of N_2 gas pressure.

3.2 Surface roughness of TiN film and abrasive wear test

3.2.1 Surface roughness of TiN film

The variation in surface roughness of the TiN films deposited at the bias voltage of –30 and –80V as a function of the N_2 gas pressure was presented in Fig.7. Surface roughness was decreased as the N_2 gas pressure increased. This could be expectable in consideration of the fact that TiN thin films prepared by the AIP process contain macroparticles or droplets, which emit from the target onto the film surface, cause a detrimental roughening of the surface of the substrate and reduce the luster of the films, which is undesirable for decorative and wear-resistive application [12,13].

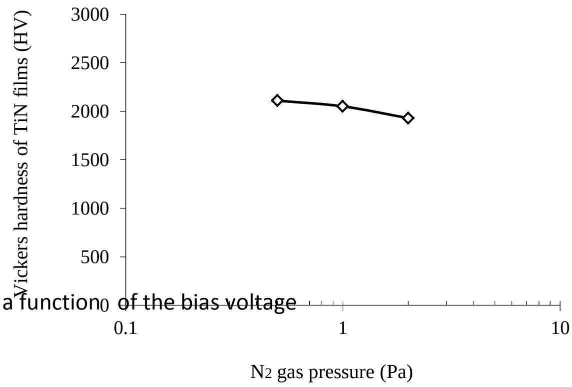


Fig.6. Vickers hardness of TiN films as a function of N_2 gas pressure.

The number of droplets in the TiN film deposited at 2.0 Pa was smaller than the one of 0.5 Pa.

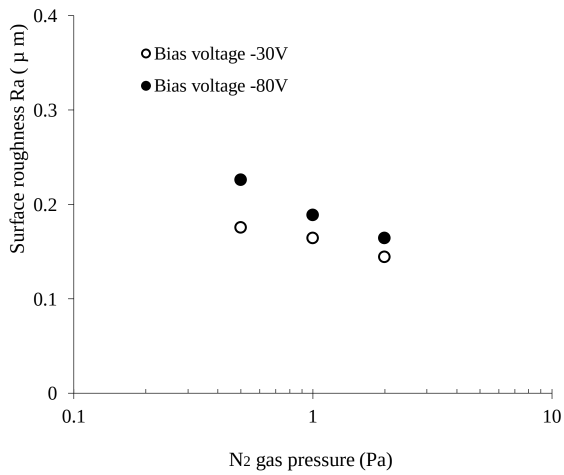
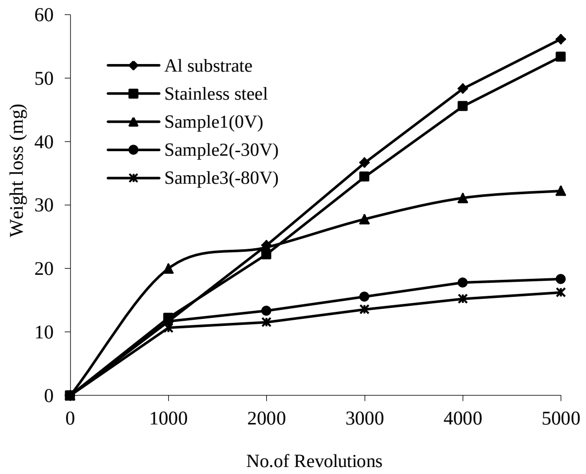


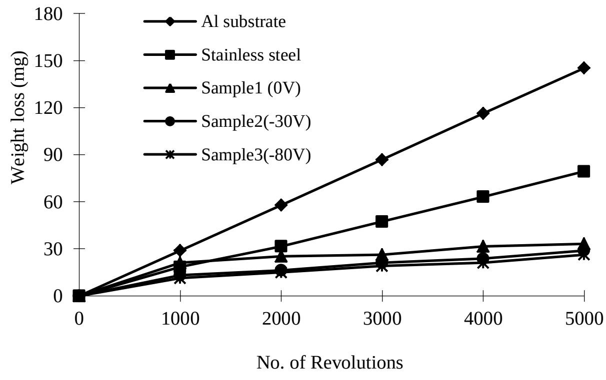
Fig.7. Effect of N_2 gas pressure on the surface roughness of TiN films.

3.2.2 Abrasive wear test

Dry and wet rubber wheel abrasive tests were carried out for the TiN-coated Al alloy samples at different bias voltage (0 to –80 V), the uncoated Al substrate and stainless (for purposes of comparison). Fig.8 shows the relationship between the cumulative weight loss and number of revolution of the rubber wheel. This figure indicates that the TiN-coated aluminum alloy samples exhibited the highest abrasive wear resistance and that the uncoated aluminum alloy had the lowest resistance to wear. This fact demonstrates that a TiN coating on a soft substrate (e.g. Al alloys) could improve the wear properties of these alloys. All samples exhibited a similar weight loss during the first 1000 revolution. After that, the wear rate of TiN coatings fell sharply, whereas the weight loss of the stainless steel and of the untreated Al alloy continued to rise at a similar rate. In comparing abrasion performance of the coated samples at different bias voltage, the weight loss decreased as the bias voltage changes from 0 to –30 V, and thereafter the weight loss seems to hold a constant value. However, it can observed that minimum weight loss was attained at – 30 V; this may be due to both high hardness and low surface roughness properties attained at –30 V. In comparing abrasion performance of the coated samples with each other, TiN-coated Al alloy samples exhibited the lowest weight loss among the others; this also may be due to both high hardness and low surface roughness properties of TiN film deposited on the aluminum substrates. Another interesting, the abrasive wear rate of the uncoated aluminum alloy in the wet test was much higher than that in dry test while the wet and dry abrasive wear rates for the coated aluminum alloy samples and stainless steel were slightly different.



(a)



(b)

Fig.8 Sand rubber wheel tests in (a) dry and (b) wet conditions.

Most likely, the reason for this is that the higher surface temperatures prevailing on the aluminum alloy due to friction from the dry sand facilitated continual re-oxidation of aluminum surface, providing a relatively hard and wear – resistant layer, such that the dry abrasive wear resistance was better. A softer and more friable hydroxide layer probably formed on the aluminum surface in the wet test, resulting in a higher wear rate.

4. Conclusions

The major conclusions arising out of the present study are as follows:

1. By using the AIP method, a firmly hard TiN coating could be deposited on aluminum alloy substrates.

2. It was found that the hardness of TiN films depended on the bias voltage, changed with increasing bias voltage with the highest value at – 30 V followed by an almost constant value up to – 80 V .On the other hand, the hardness of Al substrates decreased with increasing a bias voltage larger than –30 V, probably due to tempering increase caused by the bombardment of titanium ions.

3. The hardness of TiN films decreased in respo-

nse to increasing gas pressure from 0.5 to 2.0 Pa.This is probably due to the coarsening of TiN grain size in the film.

4. Wear properties were greatly improved by TiN deposition. In particular, the TiN / coating system at the bias voltage of –30 V exhibited excellent resistance to abrasive wear-substantially better than that of an untreated Al alloy substrate. Therefore, TiN coating deposited by arc ion plating (AIP) technique on aluminum alloys could be a promising candidate as a coating for the machine parts requiring preciseness and lightness.

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