Wear 342-343 (2015) 279–287

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Vanadium nitride and titanium nitride coatings for anti-galling behavior in ironing of aluminum alloy cups

Witthaya Daodon [a], Varunee Premanond [a,*], Witthawat Wongpisarn [b], Panadda Niranatlumpong [b]

[a] *Department of Tool and Materials Engineering, King Mongkut's University of Technology Thonburi, Bangkok, Thailand*
[b] *National Metal and Materials Technology Center, Pathumthani, Thailand*

ARTICLE INFO

Article history:
Received 21 April 2015
Received in revised form
10 September 2015
Accepted 13 September 2015
Available online 25 September 2015

Keywords:
Vanadium nitride
Titanium nitride
Direct current magnetron sputtering
Aluminum
Ironing

ABSTRACT

The anti-galling behavior of vanadium nitride (VN) and titanium nitride (TiN) coatings were investigated. VN and TiN coatings were deposited on JIS-SKH51 high-speed steel substrates by direct current magnetron sputtering. The coatings were characterized for phase composition using X-ray diffraction (XRD), hardness using nano-indentation and load-to-failure between the coating and substrate using scratch testing. Ring-on-disc testing was conducted to evaluate the tribological properties between AA1050 aluminum alloy ring sliding against SKH51 discs (both uncoated and coated discs) under a lubricating condition. The coated disc samples were cathodic arc TiN, 225W–TiN, 265W–TiN, 225W–VN and 265W–VN. Imaging and chemical analyses of the wear tracks were performed using a scanning electron microscope equipped with energy dispersive X-ray spectroscopy. The chemical analysis results of wear tracks showed that aluminum did not adhere to the 225W–TiN surface as readily as the other coated samples, as evidenced by the lowest amount of aluminum transfer. Results of the transition load for adhesion revealed that all of the coated surfaces improved the adhesive wear resistance i.e., resistance to aluminum adhering on the surface, compared with the uncoated surface. The 225W–TiN coating was further evaluated using an aluminum cup ironing process. The surface quality of the cups was found to be dependent on the Al transfer to the die surface. The cups ironed by the 225W–TiN coated die were superior to the cups obtained from an uncoated die.

1. Introduction

Aluminum alloys are widely used to produce lightweight components in automobiles [1]. Aluminum, however, has a tendency to induce an adhesive wear at the tool surface during forming hence lubricant is conventionally used to prevent the adhesion of aluminum alloys to the forming tools [2,3]. Kawai et al. [4] showed that the metal adhesion in an ironing process of aluminum cups was prevented by using appropriate conditions of viscosity of lubricant and degree of reduction of Al thickness. However, a large amount of lubricant waste is a serious environmental issue.

To reduce the amount of lubricant used, low-adhesion tool materials such as ceramics and cermets as well as coatings by chemical and physical vapor deposition processes (CVD and PVD) are applied. Various types of tool material and coating combinations have been discussed in previous literature. Examples of these are presented here. Tamaoki et al. [5,6] proposed the use of an electroconductive ceramic die for a dry deep drawing of a cold rolled mild steel sheet (JIS-SPCC), and the cups were successfully deep drawn for more than 10,000 times. MoB-based cermets had been shown to have an excellent anti-galling performance in aluminum sheet forming [7]. A TiCN-based cermet die was also studied and shown to exhibit a high seizure resistance in an ironing of stainless steel drawn cups [8].

Diamond-like carbon (DLC) has also been proven to successfully reduce the Al adhesion on metal forming dies. Murakawa et al. [9] demonstrated the effectiveness of DLC coating in preventing the adhesion of aluminum to a deep-drawing die for deep-drawing of aluminum sheets without lubrication. On an ironing die, a DLC coating also exhibited an excellent anti-galling performance for dry ironing of high strength steel sheets [10].

Other coatings were also studied. A CrN-coated die was demonstrated to be effective in a deep drawing of advanced high strength steel [11]. Podgonik et al. [12] indicated that the galling resistance could be improved by using forming tools suitably coated for the type of the working material. For the forming of stainless steel, carbon-based coatings provided the best protection against the work material transfer. The forming of aluminum and aluminum alloys

---

[*] Corresponding author.
E-mail address: varunee.pre@kmutt.ac.th (V. Premanond).

http://dx.doi.org/10.1016/j.wear.2015.09.004
0043-1648/

required nitride type coatings while titanium and titanium alloys required VN coatings to show improvement in galling performance. Amongst the nitride-based coatings, VN was shown to be less prone to galling as compared to TiN, for stainless steel [13].

In the present study, VN and TiN coatings deposited by a direct current (DC) magnetron sputtering PVD with optimum deposition parameters were utilized in an ironing process of Al alloy in order to reduce the metal adhesion. The objectives of this study were to improve the surface quality of ironed aluminum cups and to reduce the die polishing time for ironing operation by reducing the tendency of aluminum adhesion on the tool surface.

2. Experimental procedures

2.1. Tool and workpiece materials

JIS SKH51 high-speed steel with chemical composition (wt%) of 0.8C, 3.75Cr, 4.73Mo, 1.78V and 5.50W was employed as substrates for coating and as tool material for ironing dies. The substrates and dies were hardened to 63 ± 2 HRC and finished by grinding followed by lapping prior to the coating process. The measurement of surface roughness is done by 2D stylus method using 8 mm measured length with 0.8 mm cut-off. The surface roughness of the substrates and dies are 0.01 ± 0.003 µm R_a and 0.02 ± 0.01 µm R_a, respectively. AA1050 H14 aluminum alloy rings with the dimensions as shown in Fig. 1 and aluminum alloy sheets of the same grade having a thickness of 0.5 mm were used as the workpiece material. The chemical composition of AA1050 H14 alloy is shown in Table 1 and the mechanical properties of SKH51 and AA1050 H14 are shown in Table 2.

2.2. Coatings and deposition processes

VN and TiN coatings were deposited using PVD via DC magnetron sputtering technique. The substrates and dies were ultrasonically cleaned with methanol and acetone, then dried with hot air before being placed in the deposition chamber. Pure Ti (99.995%) and Pure V (99.5%) were used as sputtering targets for the deposition of TiN and VN respectively. Ar and N_2 were used as the working and reactive gases respectively. The base pressure of the chamber was below 5.0×10^{-6} mbar. The substrates and dies were etched for 15 min in an argon plasma using the argon pressure of 7×10^{-3} mbar, a bias voltage of 600 V and a pulsed frequency of a dc power supply set at 200 kHz. Coating parameters of pressure, flow rate and DC pulse frequency were optimized to obtain stoichiometric phase compositions of TiN and VN. The resulting range of the deposition parameters of TiN and VN coatings in this study are given in Table 3.

TiN coated samples via a cathodic arc technique typical of a commercial coating used on ironing dies were also prepared for comparison. The cathodic arc coating parameters are shown in Table 4.

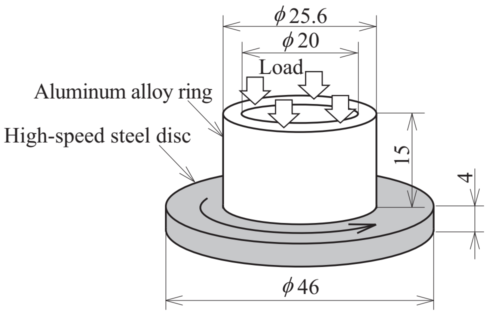

Fig. 1. Ring-on-disc test (scale in mm).

Table 1
Chemical composition of AA1050 H14 alloy. [14]

Element	Si	Fe	Cu	Mn	Zn	Ti	Other	Al
wt%	0.25	0.4	0.05	0.05	0.05	0.03	0.03	Bal.

Table 2
Mechanical properties. [15]

	Poisson ratio	Young's modulus [GPa]	Hardness [HV]
SKH51	0.29	207	772
AA1050	0.33	69	36

Table 3
Magnetron sputtering PVD deposition parameters of TiN and VN coatings.

Parameter	Specification	
	TiN	VN
Target (50.8 mm dia.)	Ti (99.995%)	V (99.5%)
Substrate	SKH51	SKH51
Target to substrate distance [mm]	90	90
Base pressure [mbar]	5.0×10^{-6}	5.0×10^{-6}
Sputtering pressure [mbar]	5.0×10^{-3}	5.0×10^{-3}
Ar flow rate [sccm]	4	6
N_2 flow rate [sccm]	1.03	1.7
Power [W]	225 and 265	225 and 265
DC pulse frequency [kHz]	50	75
Substrate temperature [°C]	390 ± 10	340 ± 10
Deposition time (min)	60	60

Table 4
Cathodic arc PVD deposition parameters of TiN coating.

Parameter	
Target material (140 mm dia.)	Ti
Substrate bias voltage [V]	24
Ar flow rate [sccm]	45
N_2 flow rate [sccm]	1500
Substrate to target distance (mm.)	460
Base pressure [mbar]	1.0×10^{-5}
Arc current [A]	150
Substrate temperature [°C]	350 ± 10
Deposition time (min)	45

2.3. Coating characterization

The coatings were characterized for phase composition using X-ray diffraction (XRD). Crystallographic phases were deduced by comparing the experimental diffraction patterns with the Joint Committee on Powder Diffraction Standards (JCPDS) data. The hardness, coating adhesion and thickness of the coatings were characterized by nano-indentation, scratch testing and calotest, respectively. Surface roughness of coated and uncoated-surfaces was measured using a mechanical stylus profiler. The reported hardness, coating adhesion, thickness and surface roughness values are the averages of at least 3 measurements.

2.4. Ring-on-disc test

To evaluate the tribological properties of the coatings, sliding wear tests were conducted on a friction and wear test machine