Hindawi
Advances in Materials Science and Engineering
Volume 2020, Article ID 7934842, 9 pages
https://doi.org/10.1155/2020/7934842

Research Article

A Study on the Wear Characteristics of Al7075 with Changes in Surface Roughness and Ti Thin Film Deposition Time

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Received 29 May 2020; Revised 8 September 2020; Accepted 15 September 2020; Published 25 September 2020

Academic Editor: Stefano Sorace

Mechanical parts have a problem of wear when used in extreme environments. Aluminum, most used in the industrial field, is a representative material of light weight, but its wear resistance is not good. To resolve the wear problem of such materials, research and development of surface thin film deposition technology has been increasing. Wear resistance was investigated after the Ti thin film was deposited by sputtering, one of the main methods of this technique. The smaller the surface roughness value and the thicker the thin film, the better the wear resistance. However, when a thin film is deposited for a predetermined time or less, the bonding strength with the base metal is lowered and the wear resistance is confirmed as low.

1. Introduction

Mechanical parts require light and high wear resistance. Aluminum alloys, which are representative materials of light weight, are widely used in manufacturing fields such as the automotive, aerospace, and defense industries because of their excellent mechanical properties and excellent ductility and high strength, toughness, and fatigue resistance [1–4]. However, when parts are used in the industrial field, there is a problem that wear occurs more than the basic properties of the material [5–7]. The resistance of the material can be increased by improving surface conditions such as hardness and roughness and reducing the coefficient of friction. For thin film deposition technology, techniques using hard materials such as chromium and titanium are best known. Therefore, in order to improve the wear problem, we intend to apply the surface thin film deposition technology [8].

Surface thin film deposition technology is a technique to improve the mechanical properties by forming a thin film on the surface of the material and is well known as one of the main methods for improving the mechanical properties and wear behavior of the material [9–12]. In surface thin film deposition technology, properties of coating methods such as deposition rate, thin film thickness, and bonding of substrate and coating can greatly affect surface quality [13]. Various methods such as sputtering, PLD (pulsed laser deposition), and DLC (diamond-like carbon) have been studied for the manufacture of thin films [14], and among them, magnetron sputtering methods having high adhesion are most commonly used [15, 16]. Majzoobi et al. [8] studied the fatigue behavior of Al7075 alloy by applying surface treatment technology and Ti coating. As a result of the experiment, it was found that fatigue life can be greatly reduced at high working stress.

Metal surface roughness is an important factor in determining mechanical properties. The surface of the material looks smooth, but in reality, there is surface roughness depending on the type of machining. This is an important factor in determining the mechanical properties of the surface. Depending on the purpose of use, there should be no roughness to prevent wear. Therefore, surface roughness is directly related to the life of the equipment. However, the Ti coating material, which has the advantage of wear resistance, is accompanied by tribological phenomena such as abrasion and fusion due to the extreme friction with the counterpart material and the harsh working environment [17]. Therefore, the selection of surface roughness is a very important factor.

In this paper, the wear characteristics were investigated by sputtering Ti thin films on Al7075-T6 with a different surface roughness. The surface roughness was measured by applying a surface roughness to the base metal, and a Ti thin film was deposited to perform the wear test. In addition, the surface of each specimen was observed using an indentation and a SEM (scanning electron microscope).

2. Materials and Methods

In this study, Al7075, which is widely used as an aircraft component, was selected as the base metal and the components of Al7075 are shown in Table 1. The base metal was processed into a cylindrical shape having a diameter of 32 mm and a thickness of 10 mm. To investigate the wear characteristics according to surface roughness and thin film deposition time, a total of 16 specimens were prepared by combining four types according to surface roughness and four types according to thin film deposition time. Roughness was measured by polishing the surface with sandpaper #400, #800, #1600, and #0.3 μm size alumina powder, and then, Ti thin films were deposited up to 90′ at 30′ intervals. The unit of surface roughness is Ra, which is the roughness value of arithmetic mean.

The equipment used for thin film deposition is the DC magnetron sputtering equipment. Sputtering is a process in which gas particles collide with the target, and the target particles are released and deposited on the surface. Target was made of Ti and sputtered at the same time by fabricating specimen holder to sputter four kinds of specimens with a different surface roughness at once under the same conditions. Table 2 shows the conditions used to deposit the thin films. The test conditions for all specimens were set identical except for the deposition time. In addition, the surface roughness and deposition time for each specimen are summarized in Table 3.

TRIBOSS PD-102 friction and wear tester was used to analyze the wear resistance of each specimen. The ball used in the experiment was a zirconia ball (ZrO_2) with a diameter of 12.7 mm. In addition, the rotation speed of the ball was set to 60 RPM and the experiment time 30 minutes; the load was 0.2 kg, and the ball on disk test sliding track diameter of the device was 11.5 mm.

The wear tracks produced after the experiments were observed using an SEM. In addition, the component analysis was carried out using EDS (energy dispersive spectroscopy), which can analyze the composition and content of the sample in a short time.

After the wear test, the AIS-3000 indentation equipment was used to measure the hardness of each specimen. Indentation is a device that can repeatedly measure the change in indentation depth according to indentation load by using a small indenter and evaluate the hardness and tensile properties through the result. This method is a Vickers hardness measurement, and the unit is Hv. The test was measured 10 times for each specimen, and the average value was calculated.

3. Results and Discussion

3.1. Surface Roughness. Table 4 shows roughness values according to the polishing type, and data on the average values were measured five times for each specimen. As a result of the measurement, the higher the particle size, the lower the surface roughness value, and the #alumina polished specimen had a roughness of about Ra (roughness value of arithmetic mean) = 0.23.

3.2. Thin Film Thickness. Figure 1 is a SEM photograph of thin film thickness. The thickness of the 30′ deposited specimen was 0.51 μm, the thickness of the 60′ deposited specimen was 1.10 μm, and the thickness of the deposited specimen for 90′ was measured to be 1.58 μm. Therefore, it can be seen that the thin film thickens by about 0.5 mm each time it is deposited for 30 minutes.

3.3. Surface Hardness. Table 5 shows the surface hardness values of each specimen. Both the specimen and the base metal on which the thin film was deposited showed hardness values between about 150 and 160 Hv regardless of surface roughness and thin film thickness. The standard deviation values for this data are shown in Figure 2. This result is considered because the indenter is pressed deeper than the thickness of the thin film during the hardness measurement.

3.4. Coefficient of Friction. Figure 3 shows the friction coefficient according to the surface roughness. According to Lee [18], the lower the surface roughness value, the lower the friction coefficient, and according to Song et al. [19], the higher the thickness is, the lower the friction coefficient is. In this paper, results similar to the above documents are also shown. Looking at the graphs in Figures 3(a)–3(c), it can be seen that, as the deposition time increases, the friction coefficient decreases. Thus, in general, Al materials belonging to roughness of approximately $R_a = 0.3{\sim}0.45$ are considered to have improved wear resistance as the thin film becomes thicker.

On the contrary, in Figure 3(d), 16* of the graph, the friction coefficient is rather high. Therefore, wear resistance is considered to be inferior. It is thought that this is because the thin film is excessively thick and the base metal and the bonding strength are weakened. Also, the 30′ sputtered specimen showed similar coefficient of friction as the base metal. Thus, it is judged that the wear resistance is not affected when the thin film is below a certain thickness.

Based on the above results, the best wear resistant specimen was 12* which was sputtered for 60′ after polishing

Table 1: Chemical compositions of Al7075-T6.

	Chemical components									
Al7075	Al	Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Etc.
	87.1~91.4	0.4	0.5	1.2~2.0	0.3	2.1~2.9	5.1~6.1	0.18~0.28	0.2	0.15

Table 2: Sputtering conditions for thin film deposition.

Film material	Ti
DT (deposition time)	30′, 60′, 90′
Base vacuum (torr)	5.0×10^- 6
Working vacuum (torr)	2.0×10^3
Plasma factor (w)	200
Temperature	RT

Table 3: Deposition time according to surface roughness.

		Surface roughness (sandpaper polishing number)			
		#400	#800	#1200	#Alumina (0.3 μm)
Deposition time (min)	0′	1*	2*	3*	4*
	30′	5*	6*	7*	8*
	60′	9*	10*	11*	12*
	90′	13*	14*	15*	16*

Table 4: Surface roughness value (average).

Type	#400	#800	#1200	#Alumina
Surface roughness (Ra)	0.45	0.35	0.31	0.23

with #alumina. In addition, quantitative analysis was performed through surface observation and wear comparison.

3.5. Surface Observation. Figure 4 shows a magnification 40x of the specimen surface after the wear test. In the specimen (Figure 4(a)) on which the thin film was deposited, the wear track was sharply narrowed relative to the base metal (Figure 4(b)) on which the thin film was not deposited. It is thought that this is from the increase in surface hardness of the specimen because of the thin film, resulting in less wear than the relatively soft base metal. In particular, this phenomenon was found in 90′ sputtered specimens in which thick films were deposited, and 12 specimens polished with #alumina were the most frequent. It is thought that the thin film deposited on the smooth surface is relatively easily peeled off, and the debris dropped out is partially deposited on the ball during the wear test to accelerate the wear.

Figure 5 shows the component analysis of the specimen surface: Figure 5(a) is all detected as Ti because the thin film was deposited; Figure 5(b) is a graph of the component analysis of the track part subjected to the wear test. Looking at Figure 5(b), it can be seen that O, Na, Mg, and Zn components appeared in addition to Al and Ti. This is a component contained in Al7075, an aluminum alloy, and thus appears in the analysis results. It is also believed that Ti was measured on the peeled thin film.

Table 6 summarizes the wear track widths. Measurements were made at regular intervals and averaged. The wear tracks of the 30′ and 60′ sputtered specimens and the base metal became narrower as the roughness decreased, whereas the wear tracks of the 90′ sputtered specimens became wider as the roughness decreased. It is considered that the specimens sputtered for 90′ were relatively easily peeled off because the thin films were deposited at low roughness. In addition, the longer the thin film deposition time, the narrower the wear track width. Therefore, it is thought that the thin film deposition time affects the wear resistance.

3.6. Wear Loss. Figure 6 is a graph that calculates the amount of wear by measuring the weight before and after the wear test. In the 30′ and 60′ sputtered specimens and those without thin films, the lower the roughness, the lower wear loss. In particular, it was confirmed that all 60′ sputtered specimens had lower wear loss than the base metal.

Conversely, in 90′ sputtered specimens, the amount of wear increases as the roughness value decreases. The reason for this is considered that the relatively thick thin film reduces the bonding force with the base metal and easily peels off. According to Vega-Morón et al. [20], the adhesion of the thin film deposited for 60 minutes was superior to the thin film deposited for 90 minutes. In fact, when Ti was deposited on aluminum for more than 90 minutes, a phenomenon in which the thin film detached from the base material occurred. After the wear test, it was confirmed from the SEM observation that the adhesion was poor in the specimen deposited for 90 minutes. Figure 7 is a SEM image of a thin film separation phenomenon.

Therefore, the wear resistance of 60′ sputtered (no. 12) specimens after polishing with #alumina was the best, and the surface roughness and the thickness of the thin film directly affect the wear resistance.

3.7. Graph Analysis of Average Wear Loss and Average Friction Coefficient. Figure 8 is a graph showing the average of the entire specimen according to the surface roughness and the deposition time of the thin film: Figure 8(a) is the average wear loss according to the surface roughness and thin film deposition time. According to Zuiker et al. [21], there are reports that the smaller the surface roughness, the lower the coefficient of friction, and in Figure 8, it can be seen that the friction coefficient value tends to decrease as the surface roughness value decreases. The curve according to the thin film deposition time in Figure 8(a) shows the smallest value when deposited for 60′. Figure 8(b) is a graph of the average

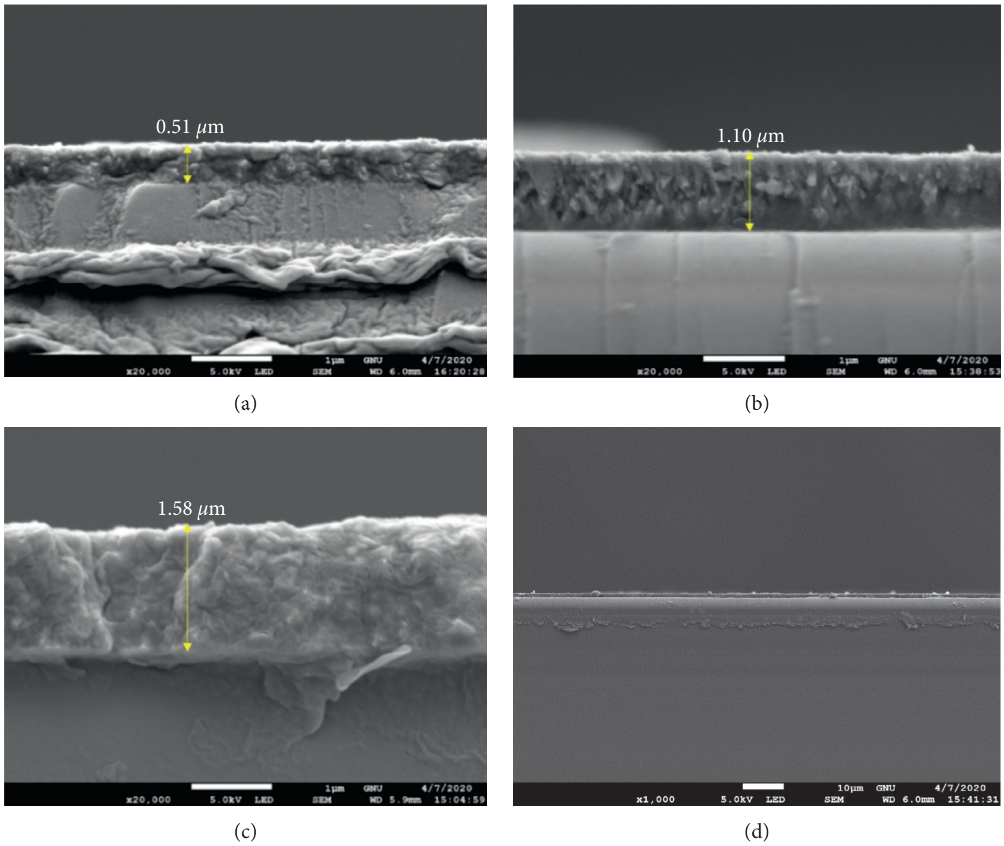


Figure 1: Photograph of thin film thickness using SEM equipment: (a) 30′ sputtered specimen; (b) 60′ sputtered specimen; (c) 90′ sputtered specimen; (d) thin film low magnification photo.

Table 5: Surface hardness value (average).

Type	1*	2*	3*	4*	5*	6*	7*	8*
Surface hardness (Hv)	148	159	157	157	147	153	150	153
Type	9*	10*	11*	12*	13*	14*	15*	16*
Surface hardness (Hv)	154	158	149	153	153	159	148	153

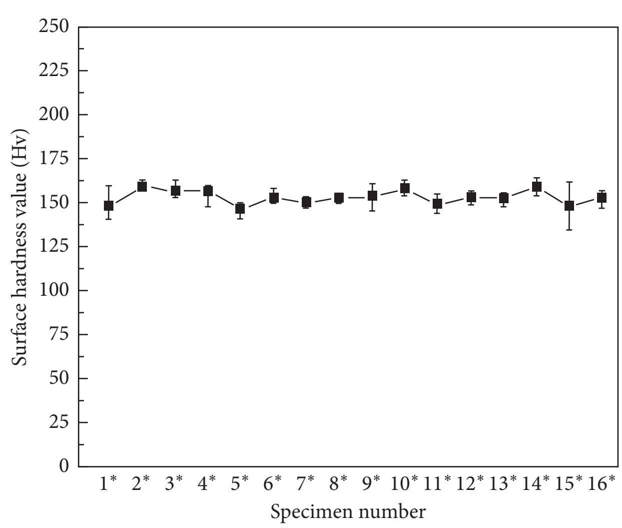


Figure 2: Standard deviation graph of surface hardness.

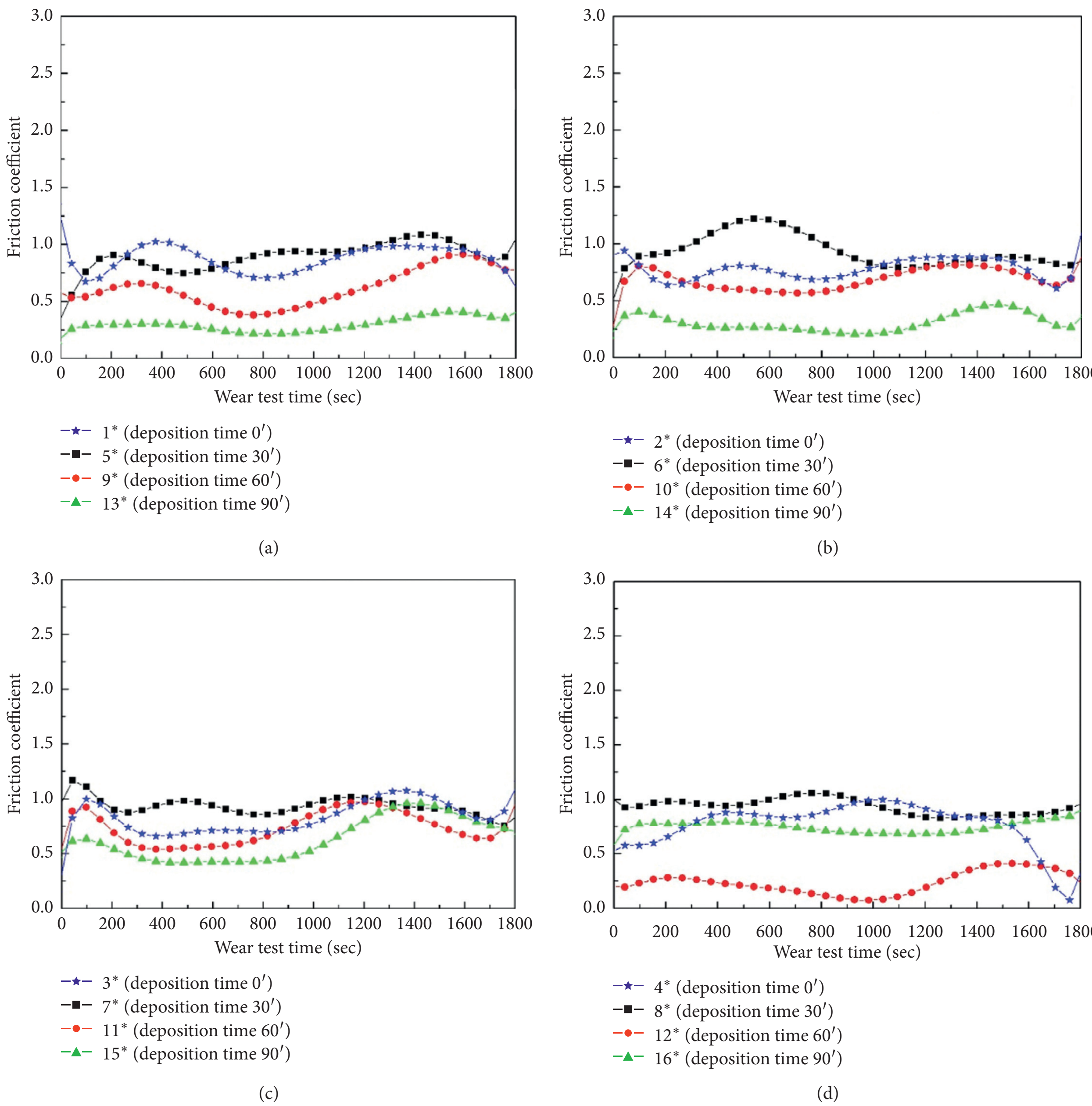


FIGURE 3: Friction coefficient graph by surface roughness: (a) polished with #400; (b) polished with #800; (c) polished with #1200; (d) polished with #alumina.

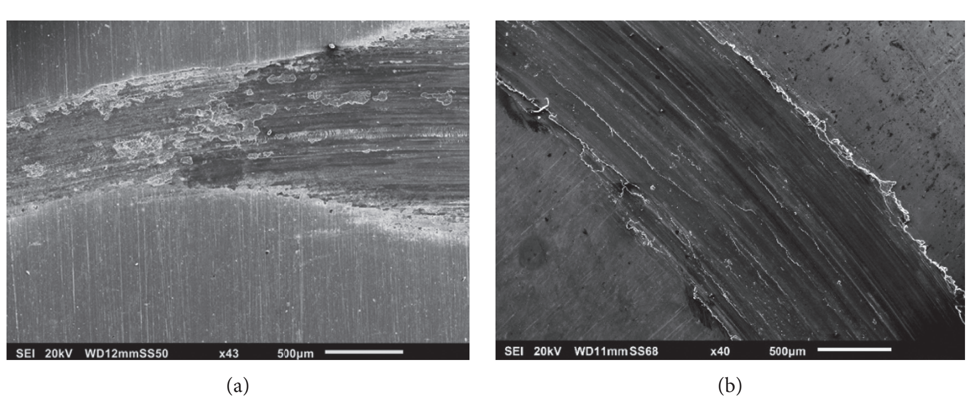
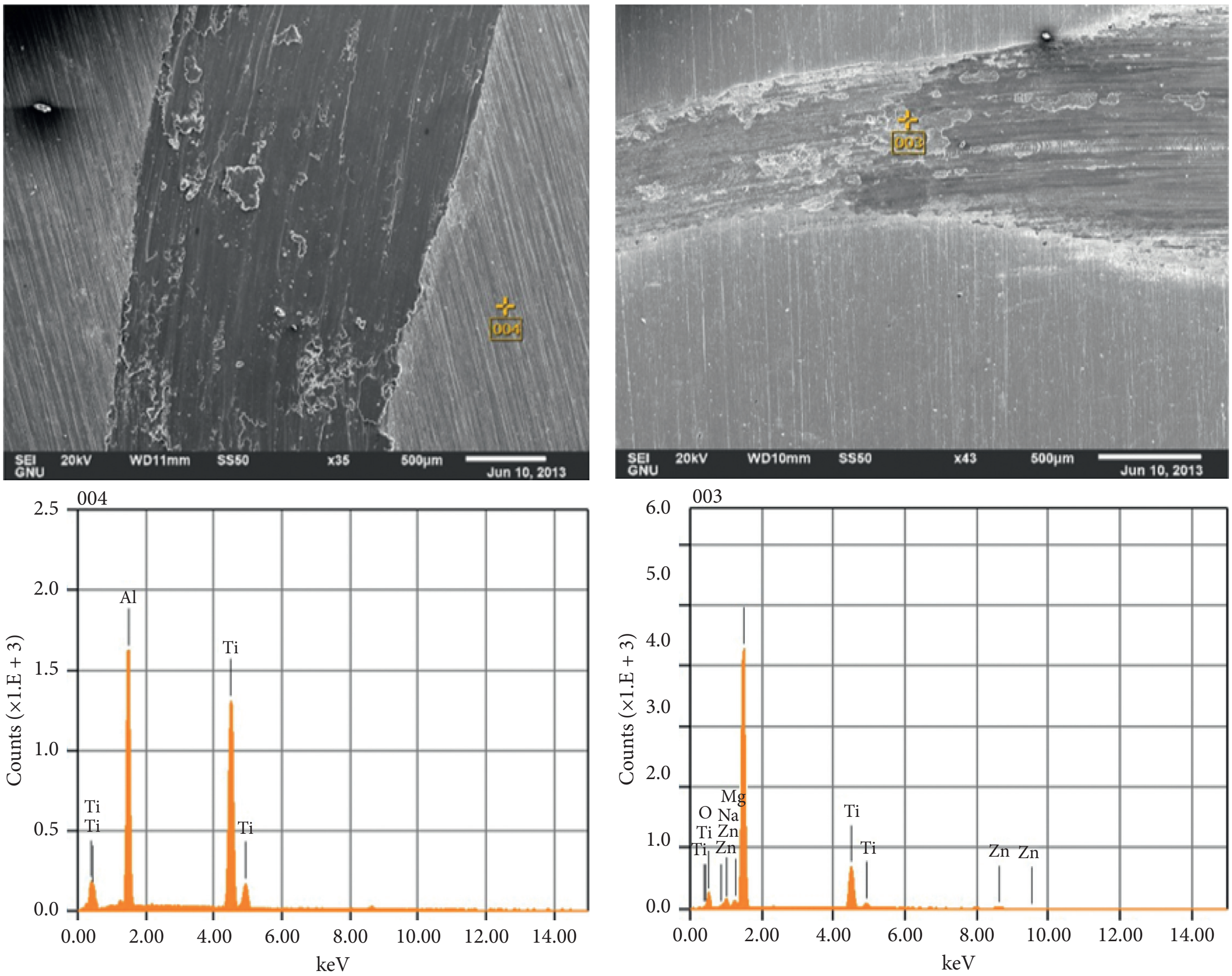


FIGURE 4: Photograph of SEM wear track: (a) thin film deposited specimen (15*); (b) specimen without thin films (4*).



Chemical Formal	Mass %	Atom %	Sigma	Net	K ratio	Line
Al	32.01	45.53	0.21	58110	0.0259660	K
Ti	67.99	54.47	0.28	78113	0.0804645	K
Total	100.00	100.00				

(a)

Chemical Formal	Mass %	Atom %	Sigma	Net	K ratio	Line
O	19.45	32.52	0.18	6661	0.0092743	K
Na	0.54	0.63	0.08	890	0.0006597	K
Mg	1.38	1.52	0.06	3281	0.0014943	K
Al	50.78	50.33	0.20	147436	0.0658805	K
Ti	24.14	13.48	0.14	39729	0.0409248	K
Zn	3.70	1.52	0.15	1824	0.0062490	K
Total	100.00	100.00				

(b)

Figure 5: Photograph of EDS analysis: (a) EDS of thin film deposition part (6^*); (b) EDS of track subjected to wear test (15^*).

Table 6: Average of wear track width.

Type	1^*	2^*	3^*	4^*	5^*	6^*	7^*	8^*
Wear track width (mm)	1.39	1.40	1.40	1.32	1.60	1.50	1.38	1.47
Type	9^*	10^*	11^*	12^*	13^*	14^*	15^*	16^*
Wear track width (mm)	1.28	1.28	1.00	0.80	0.83	0.84	0.97	0.95

wear loss and the average friction coefficient according to the surface roughness. From the friction coefficient and wear loss curve, the average of specimens polished with alumina was the lowest. When combining the graphs of Figures 8(a) and 8(b), it can be seen that the $60'$ deposited specimen after polishing with alumina has the best wear resistance. This means 12^* specimens, and it can be seen that the abrasion resistance of 12^* specimens is the best even when the results such as the wear loss and the width of the wear track mentioned in the previous contents of the paper are seen.

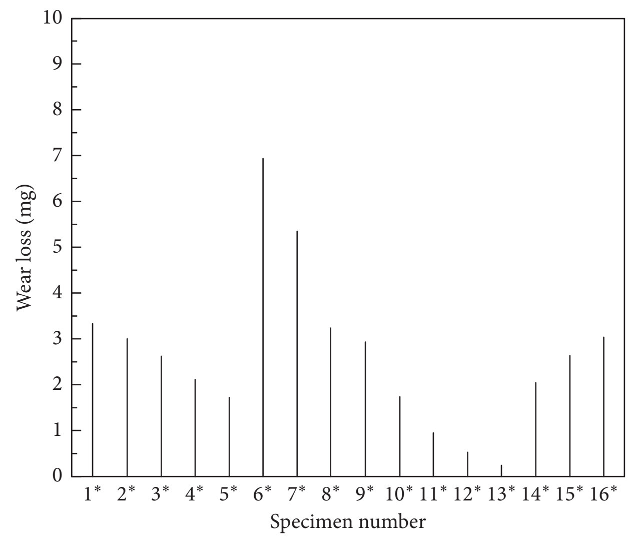


FIGURE 6: Wear loss graph by thin film deposition time.

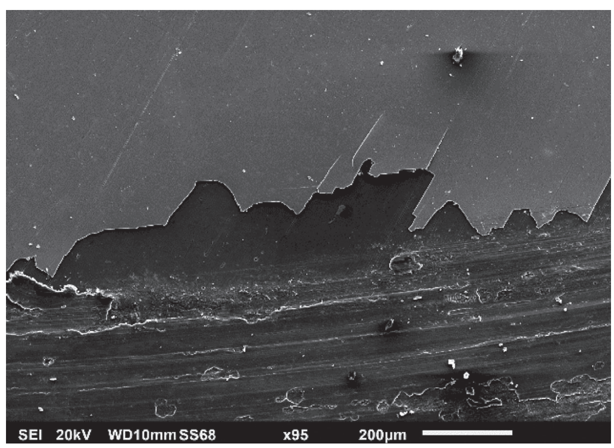


FIGURE 7: Photograph of thin film detachment around the abrasion test track (90′ sputtered specimen, 16*).

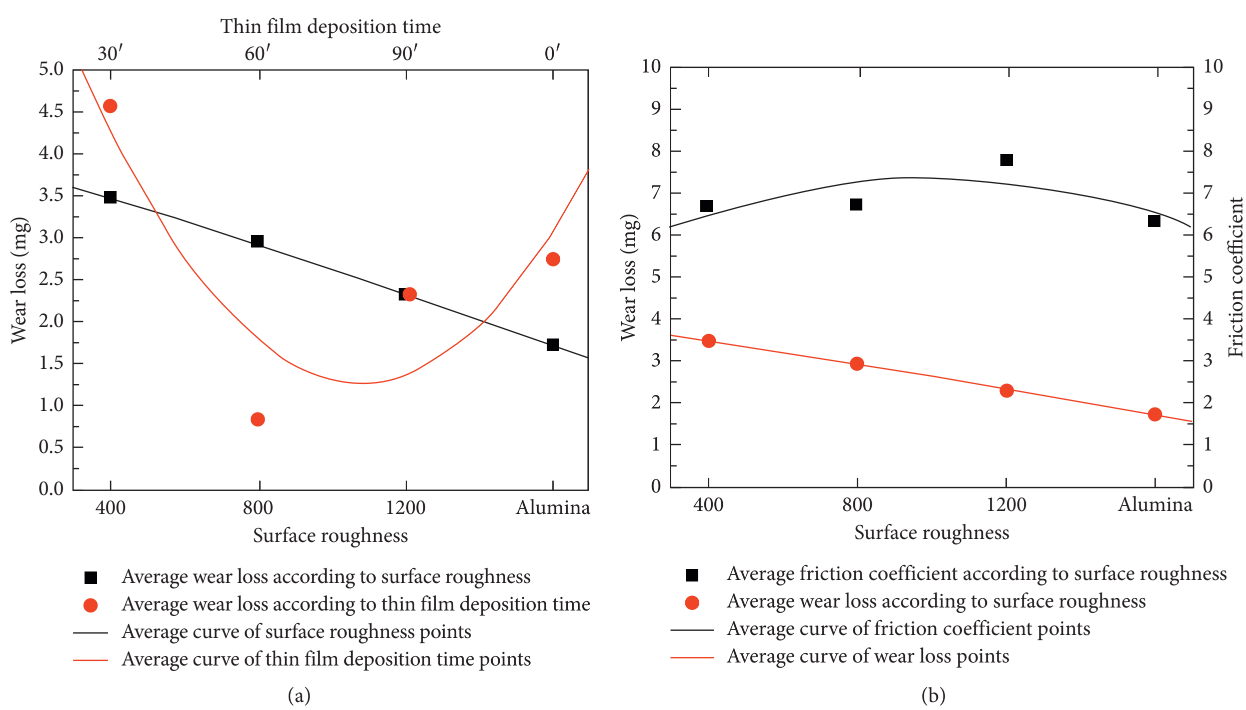


FIGURE 8: Graph organized according to average of wear loss and average of friction coefficient: (a) average of wear loss according to surface roughness and thin film deposition time; (b) the average of friction coefficient and the average of wear loss according to the surface roughness.

4. Conclusions

In this study, the wear test was conducted to investigate the effect of surface roughness and thin film thickness on wear characteristics. And the following conclusions were made:

(1) As a result of the roughness measurement, the lower the particle size of the abrasive, the lower the roughness value, and the specimen polished with alumina has a roughness of about 0.23. As a result of measuring the thickness of the thin film, it is thickened by about 0.5 μm each time the thin film is deposited for 30 minutes.

(2) As a result of the friction coefficient analysis, the smaller the surface roughness value and the thicker the thin film, the lower the friction coefficient, but the 90$'$ deposition resulted in a high friction coefficient when the surface was smooth. It is thought that the thin film detached from the base metal is transferred to the ball, which is the counterpart, and the transferred thin film debris accelerates the wear.

(3) As a result of the surface observation, the wear tracks of the specimen (a) on which the thin film was deposited were sharply narrowed relative to the base metal (b) on which the thin film was not deposited. It is thought that the thin film deposited on the smooth surface is relatively easily peeled off, and the debris dropped out is partially deposited on the ball during the wear test to accelerate the wear. When the thin film was deposited for more than 90 minutes, it was confirmed that the adhesion of the thin film was poor.

(4) As a result of analyzing the average wear and friction coefficients for the entire specimen, the lowest wear and friction coefficient values were obtained when 60 minutes of deposition after polishing with alumina. It can be seen that this corresponds to the 16* specimen.

In conclusion, the smaller the surface roughness value and the thicker the thin film, the better the abrasion resistance, but if the film becomes thicker than a certain level, 1.5 μm (90$'$ sputtering), it is considered that the adhesion between the thin film and the base metal is poor and it is easily peeled off so that it does not affect the wear resistance. Therefore, based on the above results, we have identified the most improved abrasion resistance of the 16* specimen with narrow track width and the lowest amount of abrasion, and the surface roughness and thickness of the thin film have a direct effect on abrasion resistance. Based on the results of this study, surface thin film deposition technology can be used in the mechanical and industrial fields, and further experiments on surface thin film deposition technology will be conducted based on the results of this study in the future.

Data Availability

All data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This project was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and Future Planning (no. 2018R1A5A5A05022883). And "Overseas order-linked aviation parts industry process technology development in 2019" of the Korea Institute for Advancement of Technology (KIAT) granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea (P0010339).

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