STUDY REGARDING TO FRICTION AND WEAR OF TiN THIN FILMS

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Abstract: We have studied in this paper, from tribological point of view, TiN coatings deposited on steel substrates by reactive magnetron sputtering, under the variation of the substrate bias voltage. Special attention will be given to the correlation between these process parameters and some tribological properties, such as the static friction coefficient and the wear behavior.

1. Introduction

Surface improving behavior using applied coatings has become a well-established technology and it is an extremely versatile mean of improving component performance [1]. In order to maintain or increase the lifetime of tools or any other tribological characteristics, a large variety of different hard coatings has been developed, tested and used in industry.

The present paper reports the influence of preparation conditions (such as power applied at the Ti target and bias voltage) on the tribological properties of TiN thin film deposited by reactive magnetron sputtering.

2. Theoretical and Experimental Background

2.1. Static Friction Coefficient

To establish the static friction coefficients for all the coatings, a typical method such as the inclined plane slope was used. This apparatus (Figure 1) can estimate the friction coefficient value from typical angular measurements [1][2], involving the correlation between the friction angle α and the static friction μ coefficient. At the same time, the friction couple that is in a resting position is inclined by the aid of a plane with variable vertical adjustment, until the sliding phenomenon appears in the couple. This apparatus can be seen in the Tribological Laboratory of "Transilvania" University of Brasov.

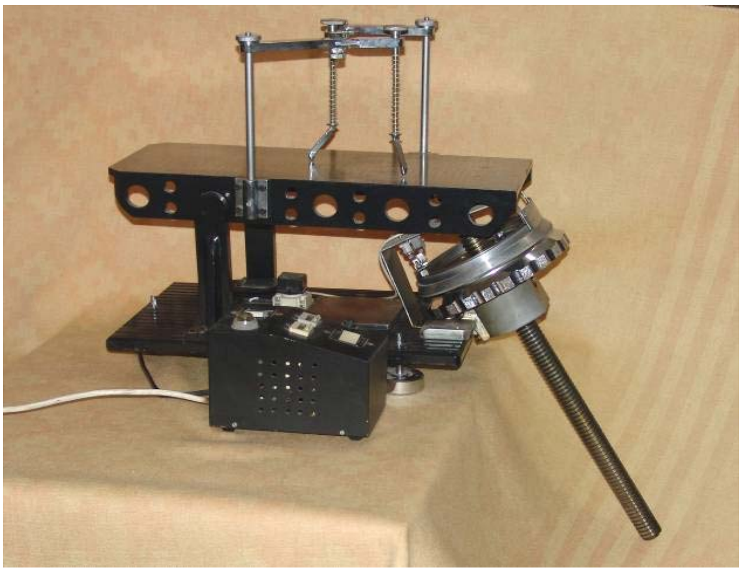

Figure 1. Tribometer based on angular measurements

The angular value α_l for which the sliding occurs is in direct correlation with the static friction coefficient μ_s according with:

$$\mathrm{tg}\,\alpha_l = \mu_s \tag{1}$$

2.2 Wear

The wear behavior of the coatings (abrasion wear) has been estimated using a custom made Pin-on-disk tribosystem (Figure 2) [1]. This apparatus can be seen in the Tribological Laboratory of "Transilvania" University of Brasov.

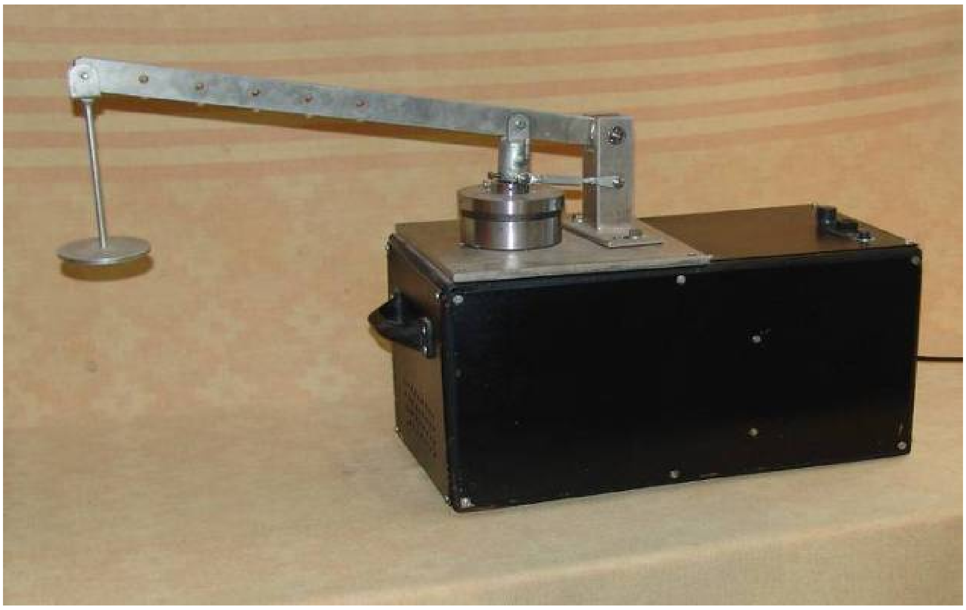

Figure 2. Pin-on-disk tribosystem

The friction distance length L_f can be established with the following relation:

$$L_f = \pi \cdot D_m \tag{2}$$

where D_m represents the average diameter from the annular track of the mobile half-couple on which the friction is produced. The following relation gives the normal load F_n in the contact zone:

$$F_n = G_1 + G \cdot \frac{L}{l} \tag{3}$$

where G_1 is the normal load in the contact zone, without supplementary loads; G is the supplementary load (case exists); L is the distance between the supplementary load place and the lever's joint; l is the distance between the pin normal load F_n and the lever's joint.

The following relation gives the wear evaluation parameter ΔG_n (in milligrams):

$$\Delta G_n = G_i - G_n \tag{4}$$

where G_i represents the sample initial mass and G_n the sample's mass at different wear periods.

The wear distance length L_n can be established with the following relation:

$$L_n = L_f \cdot n\Delta t \tag{5}$$

where n is the plateau rotating speed (rev./min.) and Δt the friction time interval (in minutes).

Before tests and after each rotation cycle, the samples were gravimetrically measured using an analytical balance Sartorius Master U11206-30 type. The wear phenomenon evolution can be estimated by the wear rate:

$$R = \frac{\Delta G_n}{\Delta t} \tag{6}$$

where Δt represents the wear time interval (in minutes).

3. Samples preparation

TiN films (containing a unique TiN phase in all the samples, δ-TiN with NaCl-type lattice) were deposited by reactive magnetron sputtering using an Alcatel SCM 659 system onto polished high-speed steel (AISI M2) samples (rolls, Ø 30×10 mm). Prior to all depositions, the substrates were hardened and two times tempered (65 HRC), and then ultrasonically cleaned and sputter etched for 15 min. in 0.4 Pa Ar atmosphere (200 W power).

All depositions were carried out at 200°C, in an Ar/N_2 atmosphere, with partial pressures $\mathrm{P(Ar)} = 0.43\,\mathrm{Pa}$, $\mathrm{P(N_2)} = 0.14\,\mathrm{Pa}$. The deposition time was, for all the samples, 2 hours. The deposition rate varied between 0.4 and 1.5 μm/h, depending on the deposition parameters.

The ion bombardment was obtained by DC biasing of the substrates in the range of 0 (grounded) to –90V (power varied from 600W to 900W).

4. Experimental results

The experimental results for the static friction coefficients were obtained on an inclined plane slope, based on angular measurements (Figure 1)[2].

In Table 1 there are presented the main process parameters and values of friction coefficients.

Table 1. The main process parameters

Sample	I_{bias} [A]	Bias voltage [V]	Friction coefficient [μ_s]
TiN 1	0	0	0.1641
TiN 2	0.37	–90	0.4165
TiN 3	0.28	–70	0.4033
TiN 4	0.24	–60	0.2984
TiN 5	0.23	–50	0.3122
TiN 6	0.28	–80	0.2349

In Figure 3 it is presented the variation of the static friction coefficient for all the 6 semi couples of TiN.

The experimental results for wear study for those six semi couples of TiN were made using the Pin-on-disk tribosystem presented above.

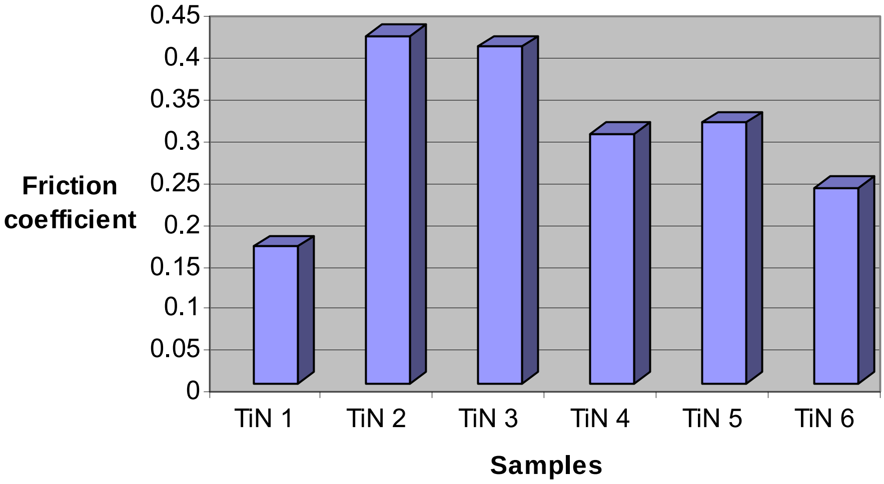

Figure 3. Variation of the static friction coefficient

According to the relations (3) and (6), for one wear cycle of 5 minutes, $L_f = 12.74\,\mathrm{m}$ and for all the five wear cycles (25 minutes) $L_n = 63.74\,\mathrm{m}$.

In the Table 2 there are presented each samples mass after each wear cycle and the final mass loss is given in Figure 4. In Table 3 is presented also each sample mass loss evolution after each wear cycle.

Taking into account the relation (5), the wear rate values has been calculated and there are presented in Table 4 and in a graphic made these ones are presented in Figure 5.

Table 2. Wear test results – the samples mass evolution after each wear cycle

Sample	G_i [mg]	G_1 [mg] t=5min	G_2 [mg] t=10min	G_3 [mg] t=15min	G_4 [mg] t=20min	G_5 [mg] t=25min	G_i-G_f [mg]	L_n total [m]
TiN 1	51594	51592	51590	51590	51589	51589	5	63.74
TiN 2	51450	51450	51449	51449	51449	51448	2	63.74
TiN 3	51555	51553	51548	51548	51547	51547	8	63.74
TiN 4	51371	51370	51370	51369	51368	51367	4	63.74
TiN 5	51320	51320	51318	51318	51318	51317	3	63.74
TiN 6	50972	50969	50965	50965	50965	50964	8	63.74

Table 3. Wear test results – the samples mass loss evolution after each wear cycle

Sample	G_i [mg]	ΔG_1 [mg]	ΔG_2 [mg]	ΔG_3 [mg]	ΔG_4 [mg]	ΔG_5 [mg]	L_f [m]
TiN 1	51594	1.7	1.9	0.4	0.4	0.5	12.74
TiN 2	51450	0.6	0.2	0.0	0.4	0.5	12.74
TiN 3	51555	2.5	4.8	0.4	0.5	0.6	12.74
TiN 4	51371	0.5	0.5	0.6	0.8	1.2	12.74
TiN 5	51320	0.5	1.5	0.2	0.4	0.2	12.74
TiN 6	50972	3.0	3.5	0.5	0.3	0.2	12.74

Table 4. Wear test results – the wear rates for each wear cycle and the medium wear rates after the total wear time

Sample	R_1 [mg/min]	R_2 [mg/min]	R_3 [mg/min]	R_4 [mg/min]	R_5 [mg/min]	R_{medium} [mg/min]
TiN 1	0.34	0.38	0.08	0.08	0.10	0.196
TiN 2	0.12	0.04	0.00	0.08	0.10	0.068
TiN 3	0.50	0.96	0.08	0.10	0.12	0.352
TiN 4	0.10	0.10	0.12	0.16	0.24	0.144
TiN 5	0.10	0.30	0.04	0.08	0.04	0.112
TiN 6	0.60	0.70	0.10	0.06	0.04	0.300

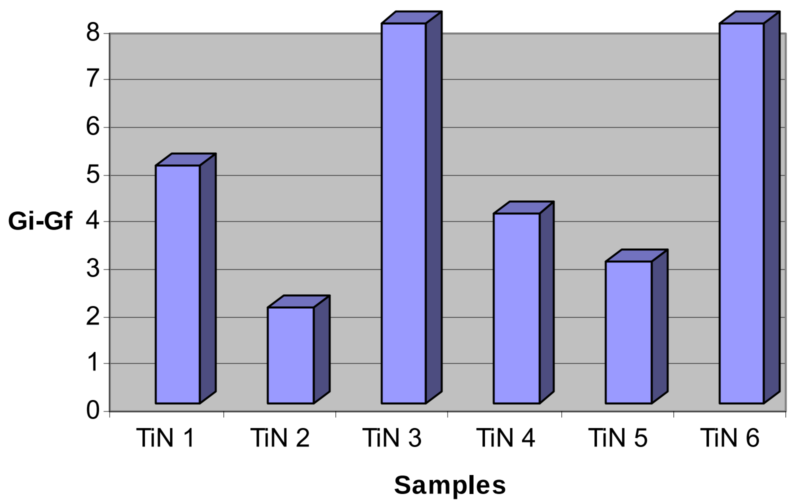

Figure 4. The sample's mass loss after the wear tests

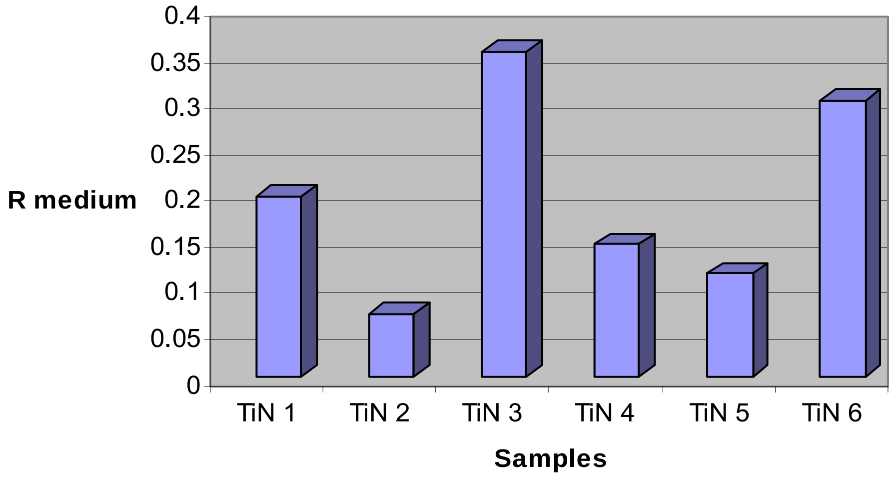

Figure 5. The sample's medium wear rates during the wear tests

5. Conclusions

Performing a statistical analysis on the surface defect density of the TiN thin films, the conclusion is that as the bias voltage increased, the defect density and defect area also increased. This is in according with the behavior of the static friction coefficient since an increase in defect density leads to the increase of the roughening of the film surface and to a decrease in wear resistance.

Regarding the wear behavior, generally we could remark that all the coatings present very good wear strength.

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