THE EFFECT OF GAS FLOW RATIO ON TRIBOLOGICAL PROPERTIES OF TICN LAYERS ON ALUMINIUM SUBSTRATE

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Abstract

TiCN layers are widely used for their high hardness and abrasion resistance. Their structure, chemical composition and mechanical properties are affected by deposition parameters. In the present work, there were studied four TiCN layer deposited on Al substrate under variating C_2H_2/N_2 process gas flow ratio.

Keywords: Cathodic arc deposition, TiCN coatings, aluminium substrate, tribological properties, wear resistance

1. INTRODUCTION

Application of thin layers provides a wide range of possible uses, e.g. in optics, electronics, electrotechnics and engineering. For example, extremely hard diamond-like carbon layers applied on cutting tools can increase their lifespan several times.

There are three basic layer deposition processes - Chemical Vapor Deposition (CVD), Plasma Assisted Chemical Vapor Deposition (PACVD) and Physical Vapor Deposition (PVD). While the layer is formed from gasses in CVD, solid targets are used in PVD [1]. Cathodic arc deposition is a PVD technique in which an electric arc is used to vaporize material from cathode target. The vaporized material then condenses on a substrate, forming a thin film. Cathodic Arc Deposition in various gas mixtures enables formation of different layers combining the material from the solid target and gasses in various ratios.

Titanium carbo-nitride layers (TiCN) are known for their very high hardness, high level of adhesion to substrate, relatively high thermal conductivity and low coefficient of friction against steel. They can be applied e.g. in milling, turning, drilling and cutting tools or for drawing, stamping, pressing and forming tools for the processing of high- and low alloy steels. Like TiN, TiCN are also suitable for applications in plastic moulding and in the decorative sector. Preferred application is the cutting of steels difficult to machine; high-performance cutting and for metal forming. [2] The morphology, structure and composition of TiCN have been investigated in several studies [3,4].

An increasing share of aluminium alloys in load-bearing and significantly stressed parts of structures results in greater demands on these alloys. The further development of aluminium alloys is focused primarily on improving the mechanical properties of already existing alloys. Coating of components and tools made of aluminium or different kinds of duralumin is an application that perfectly illustrates the basic meaning of this process. It allows for the creation of components of materials that are lightweight, inexpensive and well machined, and applies a coating that provides it with sufficient hardness and other required properties. [5,6]

The article presents an investigation of the an influence of coating deposition parameters, at constant of both cathodic arc current and bias voltage, on the surface morphology and tribological properties of the TiCN coatings deposited by the cathodic arc evaporation method on an the aluminium alloys substrate at a variating gas ratio.

2. MATERIALS AND METHODS

Disks with the size of Ø 25 mm × 5 mm were used as a substrate material. Chemical analysis of the element representation is performed at three different points on the surface of the aluminium substrate. Average values and standard deviations are described in the **Table 1**.

The discs were ultrasonically cleaned in acetone and ethanol for 5 minutes. Immediately after the cleaning procedure, the substrates were placed into a vacuum chamber and mounted on a carousel. Finally, they were cleaned in a glow discharge of argon plasma, followed by substrate surface bombardment with titanium ions. TiCN thin coatings with a different composition were deposited by the cathodic arc evaporation of a pure titanium cathode (99.99%) in various gas mixtures of C_2H_2 and N_2 (see **Table 2**) at a constant pressure. To achieve good adhesion of the coatings to the substrate, contact transition layers of Ti and TiN were deposited. The research was conducted on the samples labelled A, B, C and D.

The deposition parameters, fixed for all coatings are: cathodic arc current of 85 A; deposition temperature of 400°C; constant work pressure of 1.5 Pa and negative bias voltage of 40 V. The deposition time for Sample D is 60 min and for all of the others it is 120 min.

Table 1 Chemical composition of Al substrate according to EDS analysis

Element	Composition [At. %]
Mg	1.6±0.1
Al	Bal.
Si	0.3±0.1
Cu	2.3±0.1

Table 2 Layer deposition parameters

Flow rate	Sample A	Sample B	Sample C	Sample D
C_2H_2/N_2 [sccm]	20/160	30/140	75/150	93/80
C_2H_2/N_2 [vol. %]	11.1/88.9	17.6/82.4	33.3/66.7	53.8/46.2

The evaluation of the coating surface morphology was performed using a Dektak ™ XT mechanical profilometer according to ISO 25178 standard [7]. Three measurements over different areas of 100 x 100 μm for each coating have been made. The CETR UMI Multi-Specimen Test System in "Ball-on-Disc" mode was used to estimate the tribology properties of the coatings according to the ASTM G99-95 standard [8]. The coefficient of friction (CoF) between the unit and the coatings is determined during the test measurement.

The structure and chemical composition were evaluated using scanning electron microscope Zeiss Ultra Plus equipped with an energy dispersive spectrometer Oxford X-Max 20. EDS analysis were performed at 7 kV, the structures were evaluated at 2 kV.

3. RESULTS

3.1. Scanning Electron Microscopy

The structure of investigated layers is shown in **Figure 1**. All layers have sponge-like nanocrystalline morphology. The surface is rough, contains a lot of pores. It obvious, that the C_2H_2/N_2 process gas flow ratio directly affects the resulting chemical composition of the layers (see **Tables 2** and **3**).

Table 3 Chemical composition of the layers according to EDS analysis

Sample	**C [at. %]**	**N [at. %]**	**Ti [at. %]**	**C/N [-]**
Sample A	26.4	30.8	35.8	0.9
Sample B	36.3	35.1	28.6	1.0
Sample C	49.9	29.1	21.0	1.7
Sample D	57.1	28.3	14.6	2.0

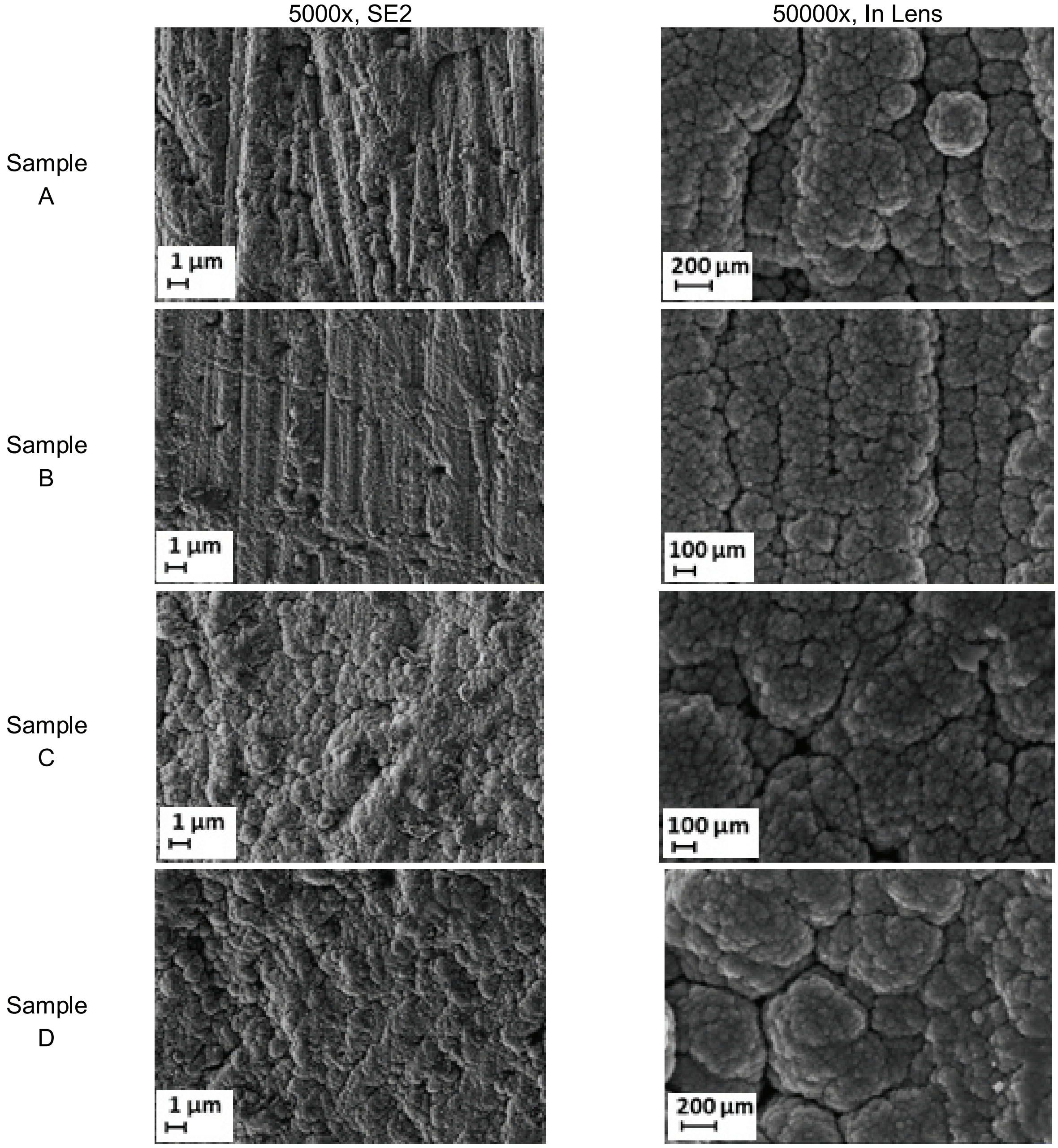

Figure 1 The surface microstructure of the investigated layers

3.2. Characteristic of surface coating morphology

A Dektak ™ XT mechanical profilometer was used to evaluate the coating surface morphology according to the ISO 25178 standard (**Table 4**). Three measurements were taken for each coating over different areas of

100 x 100 μm². The parameters used for the measurements were: stylus type with a radius of 2 μm; load of 4.9x10^{-2} mN; and range of 6.5 μm. **Table 4** shows the average values of surface roughness (Sa); the height between the lowest recesses and the highest projection (Sz); the root mean square roughness (Sq); the height between the lowest recesses and the median plane (Sv); the maximum height of the protrusion (Sp).

Table 4 Parameters of the surface morphology of TiCN coatings

Parameter	Sample A	Sample B	Sample C	Sample D
Sa [μm]	0.12±0.01	0.13±0.02	0.21±0.05	0.14±0.01
Sz [μm]	1.01±0.07	1.58±0.43	2.02±0.37	1.28±0.05
Sq [μm]	0.15±0.01	0.18±0.03	0.27±0.07	0.17±0.01
Sv [μm]	-0.46±0.02	-0.81±0.32	-0.73±0.05	-0.59±0.06
Sp [μm]	0.54±0.05	0.77±0.10	1.29±0.34	0.69±0.01

3.3. Tribology and coefficient of friction

Tribological testing (**Figure 2**) was conducted using an Al_2O_3 ceramic ball (99.5 % Corundum) with a diameter of 6.350 mm, hardness according to Vickers: < 1500 (HV10) and specific weight and 3.860 g/cm³. When evaluating the friction coefficient was used load 10 N and the path length over which the counter-body moves was 100 m. The CoF between the counterpart (ball) and the coating is determined during the measurement. The rotation speed of the table during the tribological measurements is 60 RPM.

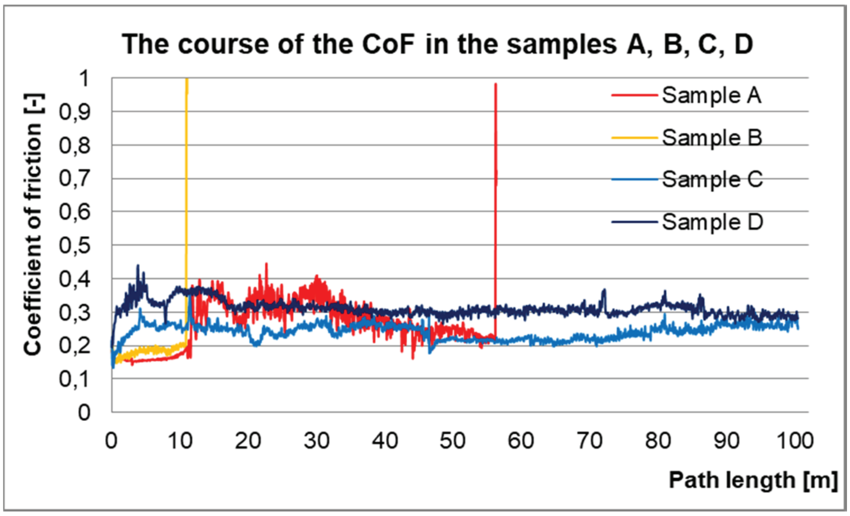

Figure 2 Comparison of the friction coefficient of the coatings at the load 10N

Figure 2 shows the dependence of friction coefficient of the investigated layers on the path length. It is clear that the planned length of the track (100m) is maintained by the coatings labelled Sample C and Sample D.

Table 5 Average values of the friction coefficient

Sample	CoF [-] the first 200 seconds	CoF [-] path length - 100 m
Sample A	0.16±0.01	0.26±0.07 (wear resistance of the coating - 56 m)
Sample B	0.18±0.01	0.18±0.01 (wear resistance of the coating - 10 m)
Sample C	0.25±0.03	0.24±0.02 (wear resistance of the coating > 100 m)
Sample D	0.33±0.04	0.31±0.02 (wear resistance of the coating > 100 m)

Table 5 describes the average values of the coefficient of friction and the standard deviation for specific values. Coefficient of friction values for Sample A and Sample B are described in **Table 5**, until damage to the coating. For Sample A after 56 meters and for Sample B after 11 meters from the start of the experiment.

Sample A

Sample B

Sample C

Sample D

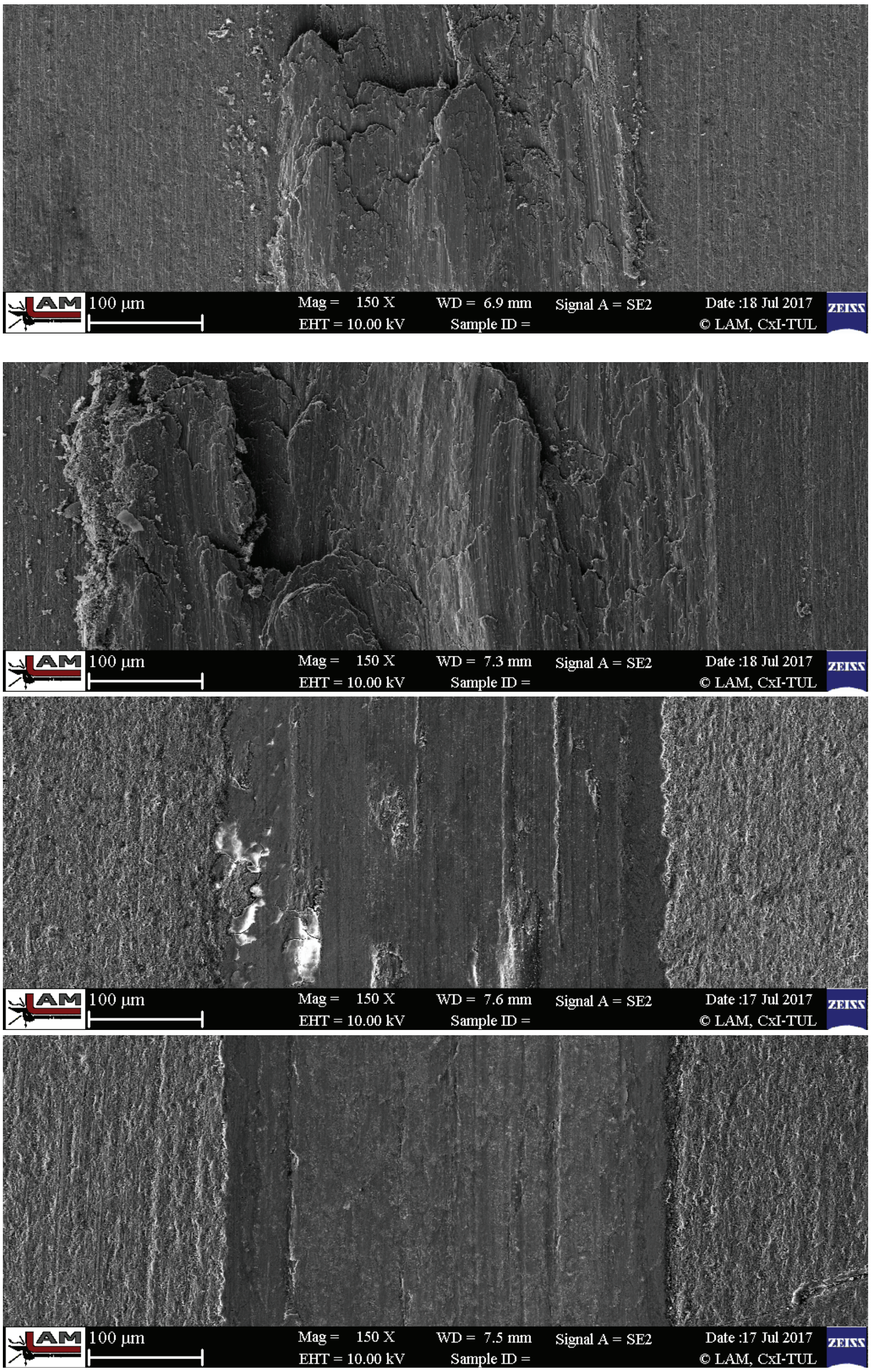

Figure 3 Illustration of thin layer damage after tribological experiments

The morphology of thin layers damage after tribological experiments is illustrated in **Figure 3**. While in the case of Sample A and Sample B the layers were destroyed after 56, respectively 11 m, and the pull-out of substrate material is obvious, the layers Sample C and Sample D well protected the substrate up to 100 m length of ball on disc track.

4. CONCLUSION

The coating of soft aluminium alloy substrate with TiCN layers significantly improves its tribological properties - CoF and wear resistance. Changing the gas ratio during the deposition of thin films affected tribological properties and the surface morphology of the examined samples. The best surface roughness was achieved for the Sample A. The layer surface roughness deteriorates with increasing ratio of the gases (C_2H_2/N_2). The highest surface roughness values were measured for Sample C using the gas ratio (C_2H_2/N_2) 75/150.

Changing the gas ratio causes a change in the structure of thin films and affects their tribological properties. The line spacing structure of samples A and B does not provide the necessary protection for aluminium alloy surfaces (see **Figure 1**, Sample A and Sample B). The change of structure in samples C and D (structure similar to the clouds) has a positive effect on tribological properties (see **Figure 2**). The resulting composition of the TiCN layers can be controlled through the setting of process gas mixture ratio. The layer with C/N = 1 showed the lowest CoF; the change of C/N led to increase of CoF. On the other hand, the layer with C/N = 1 had the shortest lifetime, the layer failure occurred already after 11 m, however layers with higher C/N stayed consist after 100 m and well protected substrate material against the wear damage.

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