Bulgarian Society for NDT
International Journal "NDT Days"
Volume 1, Issue 3, Year 2018 ISSN: 2603-4018

Tribological Behavior of Chromium Coating, Modified with Diamond Nanoparticles, on Aluminum Substrate

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Abstract
The aluminum has a lot of advantages in the design of engineering products because of its low weight. On the other hand it is relatively soft metal which corresponds to poor wear resistance and high friction coefficient. In addition, the surface oxide layer of this chemically active metal, makes it a very difficult to plate. Specific pre-treatment must be applied to remove the alumina layer from the aluminum surface. The modification of the electrochemically deposited layer with nanodiamond particles additionally facilitates the process of chromium deposition.
The object of this study is to evaluate the impact of nanodiamonds on the tribological properties of the chromium coating plated on aluminum substrate. New applications are possible when the light weight of aluminum is combined with the durability of the hard chrome.

Keywords: tribology, chromium coating, aluminum substate, nanodiamonds

1. Introduction

Aluminum offers engineers weight saving advantages in their product design. However, aluminum has poor wear and friction properties. In addition, the surface oxide layer of this chemically active metal makes it a very difficult metal to plate [1]. Aluminum is an easily oxidized metal so generally there is an oxide, Al_2O_3, layer on its surface, strongly bonded to the matrix. The free energy of formation of Al_2O_3, G^0_{298} = -1582.94 kJ/mol shows high stability, therefore low reducibility of this oxide layer. An additional difficulty is a significant hydrogen overvoltage on the aluminum surface during electroplating of metals from acidic electrolytes. Due to these difficulties, an intermediate layer must be applied on the aluminum surface before metals such as chromium, nickel and the like are electrochemically deposited.
The most widely commercially used now-a-days process for preparing an aluminum surface for plating is the zinc immersion process [2]. In this process a thin and adherent film of metallic zinc or alloy of zinc replaces the aluminum oxide film. The zinc provides a surface which is more readily plated with other metals than the aluminum matrix.
Applying coating of chromium, nickel, etc. on aluminum product increases its hardness, wear and corrosion resistance [3]. This combines the high chemical and mechanical properties of the metal coating with the low weight of aluminum products, which is particularly important for engineering design.
The electrochemical chromium coatings have a wide practical application. They increase the hardness and the wear resistance of the matrix material and possess increased corrosion resistance. The modification of the chromium galvanic coatings with nanodiamond particles (ND) additionally increases these chemical and mechanical properties.
The main goal of this study is to investigate the influence of the ND on the readiness of chromium to be plated on the aluminum surface, the thickness and the continuity of the coating,

the microhardness and wear resistance of the composite material comprised of electrolytic chromium coatings with nanodiamond particles and aluminum matrix material.

2. Experimental

The research conducted in this study is directed to evaluate the tribological behavior of composite chromium coating modified with nanodiamond particles on samples of aluminum alloy containing 7 mass % silicon. The chromium was deposited on the surface of the aluminum items by electrolytic process from the traditional acidic electrolyte containing CrO_3 - 220 g/l and H_2SO_4 - 2.2 g/l. The parameters of the electrolytic process were: current density – 45 A/dm^2; duration of the process – 45 min and temperature of the electrolyte – 50ºC. The nanodiamond particles were added to the electrolyte as an aqueous suspension. Their concentration was 0, 5, 10 and 25 g/l. The nanodiamond particles were produced by detonation synthesis [3].
The thickness of the coatings was determined by light microscopy. The microhardness tests were carried out according to Vickers standard at minimum 10 points. The applied load was 50 g. The dry friction wear resistance was studied by the pin-on-plate test unit (fig. 1). During the test a rectangular 20 x 4 x 4 mm wear sample (1) was mounted in a sample holder (4) equipped with a hemispherical insert (3) ensuring proper contact between the test sample and a steel ring (2), heat treated to 55 HRC, which was rotated at a constant speed of 136 rpm. The wear surface of the sample was perpendicular to the loading direction. Double lever system was used to force the sample towards the ring at 165 N.
The loss of sample mass was measured after a sliding distance of 500 m.

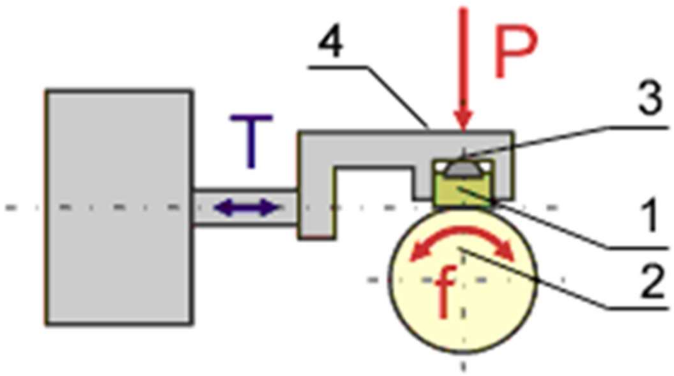

Fig. 1. Schematic view of a block-on-ring test unit

3. Results and discussion

Figure 2 shows the light microscopy images of coatings, obtained from electrolytes with different concentrations of diamond nanoparticles (C_{ND}).
It was found out that the yield of chromium on steel and the thickness of the coating is increased with the increase of the concentration of the diamond nanoparticles [2]. It is not the same with the chromium coating on aluminum and especially on this alloy. It is clearly seen from the figures that the best coating is achieved from electrolyte with concentration of nanodiamonds 10 g/l.

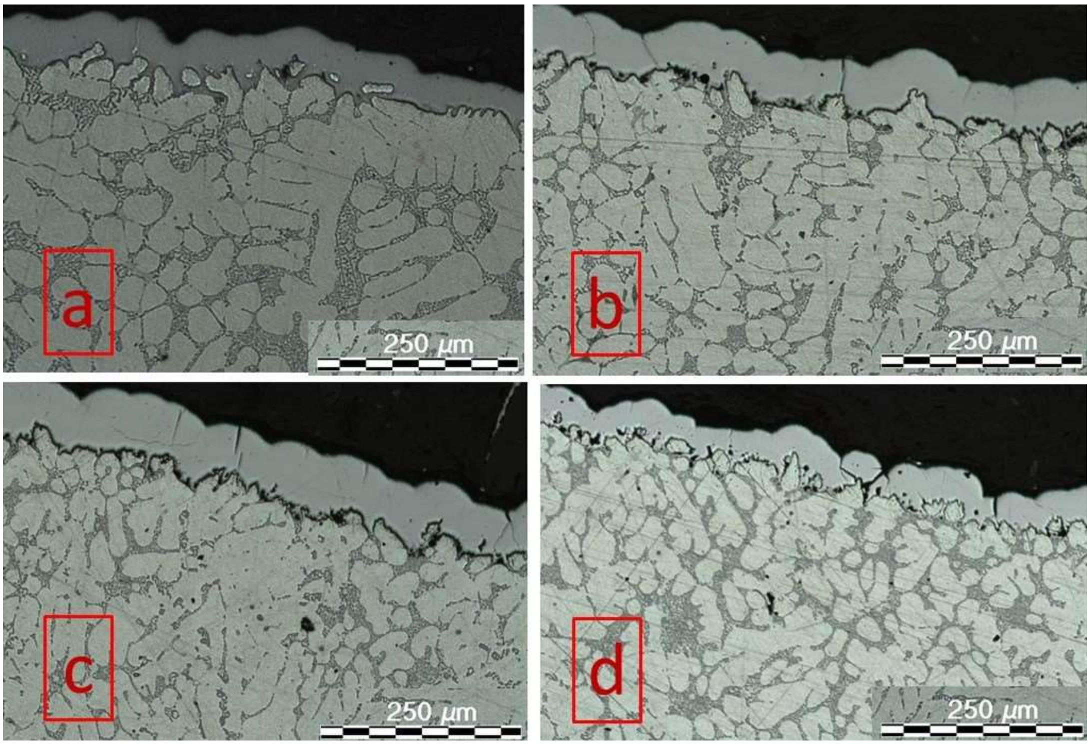

Fig. 2. Micro images of coatings obtained from electrolytes with different C_{ND}
C_{ND} = 0 g/l; b) C_{ND} = 5 g/l; c) C_{ND} = 10 g/l; d) C_{ND} = 25 g/l

The average coating thickness at different ND concentrations of the electrolyte was also measured by the microhardness tester and their values are presented in figure 3. These results well correlate with the light microscopy images (Fig. 2).

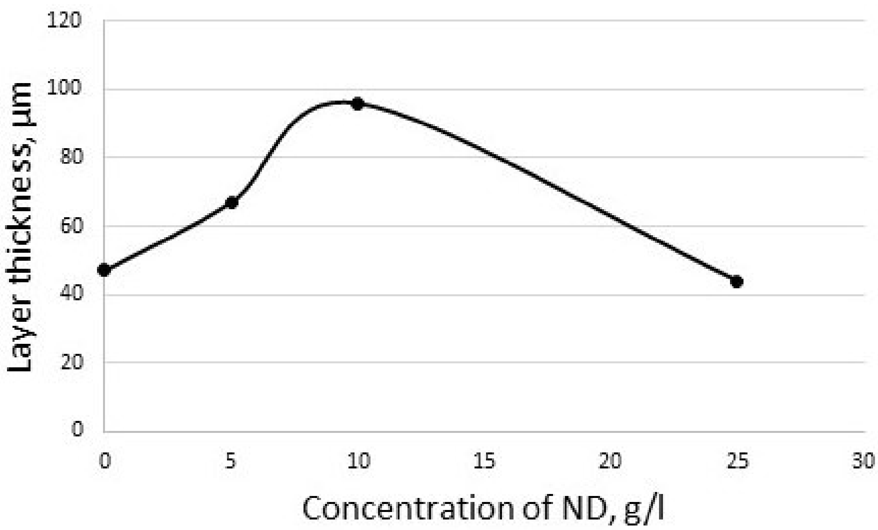

Fig. 3. Coating thickness in relation with the C_{ND}, measured by microhardness tester

The same tendency is observed when testing the mechanical properties of the coating (fig. 4). The microhardness starts from 830 kg/mm^2 (C_{ND} = 0 g/l), then increases to 980 kg/mm^2 (C_{ND} = 5 g/l) with maximum of 1140 kg/mm^2 (C_{ND} = 10 g/l) and falls down to 960 kg/mm^2 (C_{ND} = 25 g/l). The microhardness of the coating is the biggest at concentration of nanodiamonds 10 g/l.

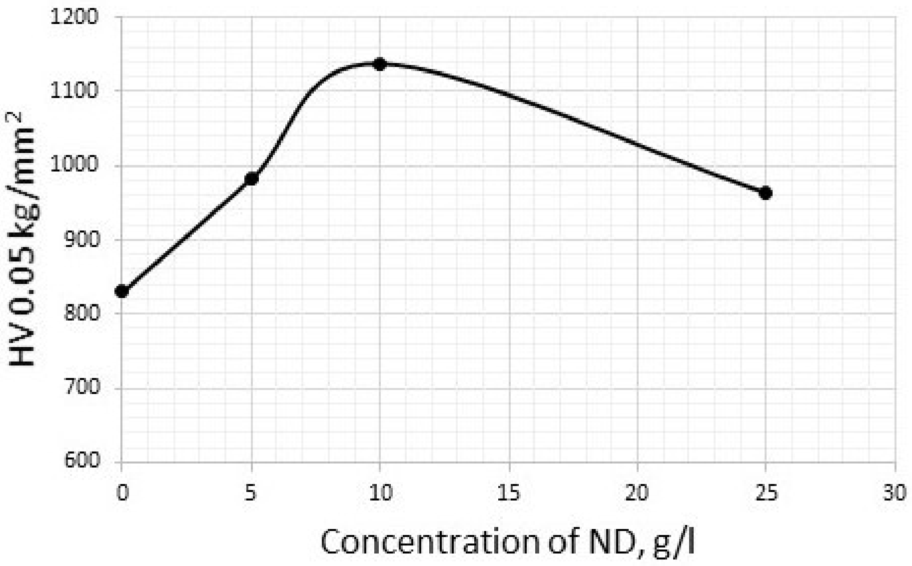

Fig. 4. Microhardness of the composite coating at different concentrations of nanodiamonds

The aluminum matrix also increases its microhardness with increasing the ND concentration in the electrolyte (fig. 5). Within the framework of the experiment the microhardness of the aluminum matrix gradually goes up and its biggest value is at C_{ND} = 25 g/l.

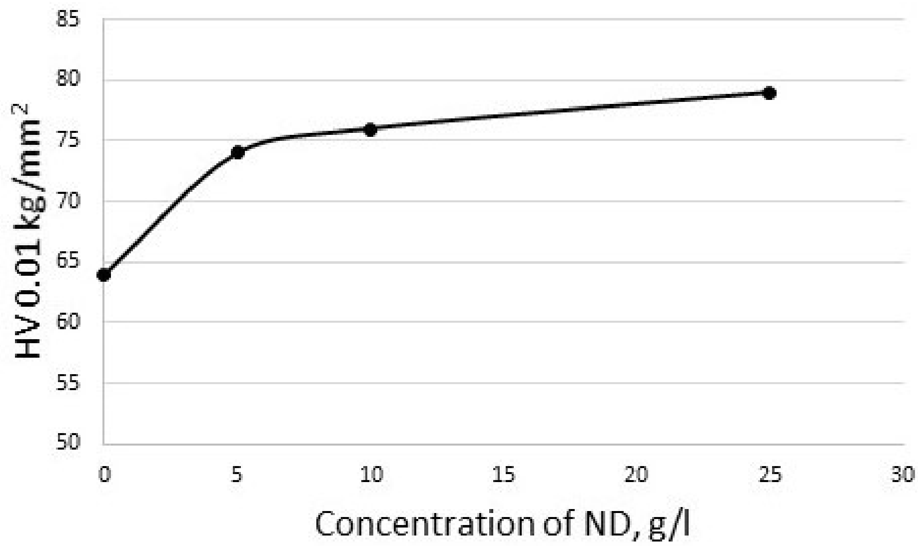

Fig. 5. Microhardness of the aluminum matrix at different concentrations of nanodiamonds

The wear resistance and the friction coefficient of the composite coating have similar behavior as the thickness and the microhardness of the coating at different concentrations of nanodiamonds (fig. 6 and 7). The best results are obtained at concentration of nanodiamonds in the electrolyte 10 g/l.

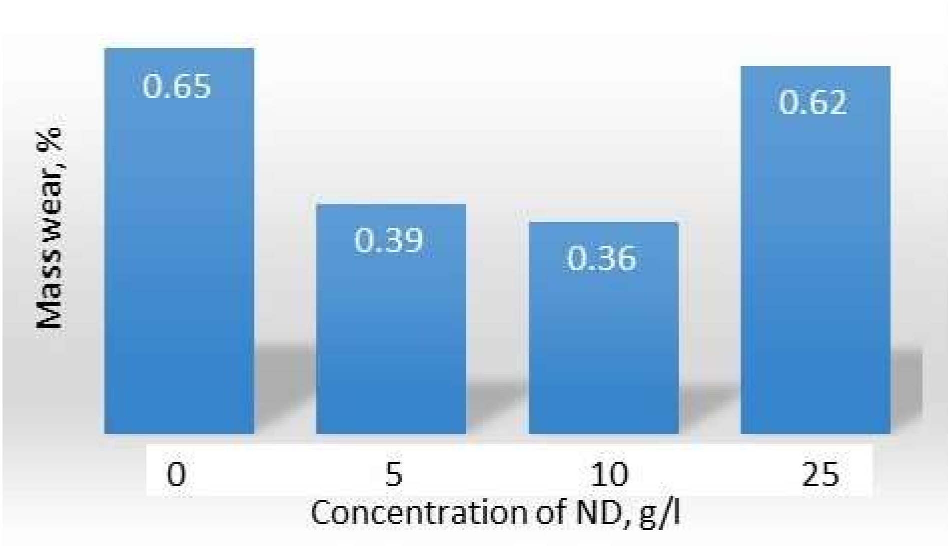

Fig. 6. Wear resistance of the composite coating expressed as mass wear at different concentrations of nanodiamonds

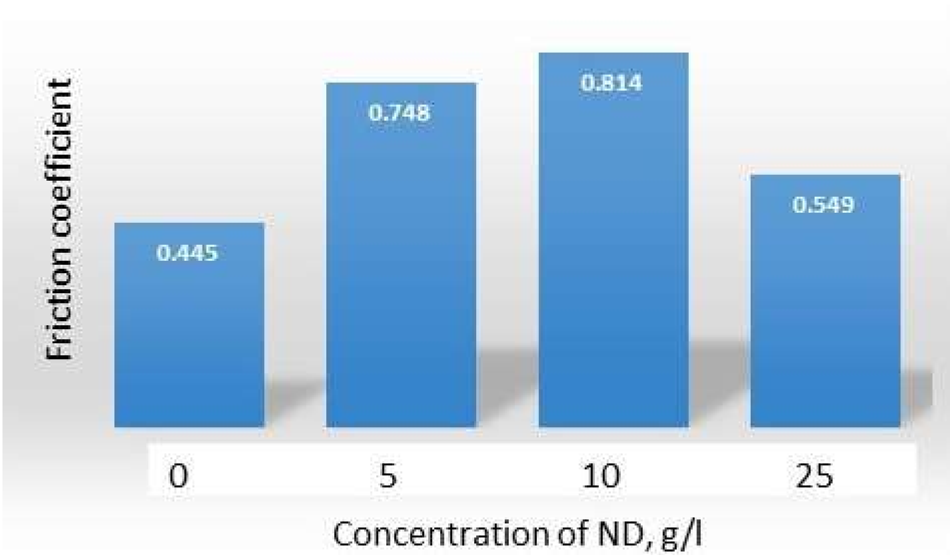

Fig. 7. Friction coefficient of the composite coating at different concentrations of nanodiamonds

The surface topography of the samples prepared at concentrations of nanodiamonds 5 and 10 g/l after the wear tests at sliding distance 500 m are shown in figures 8 and 9. The applied load is 165 N. Two types of wear mechanism can be seen, abrasive and corrosive wear. The dominate mechanism is corrosive wear. There are oxide regions on the surface after the tribological test.

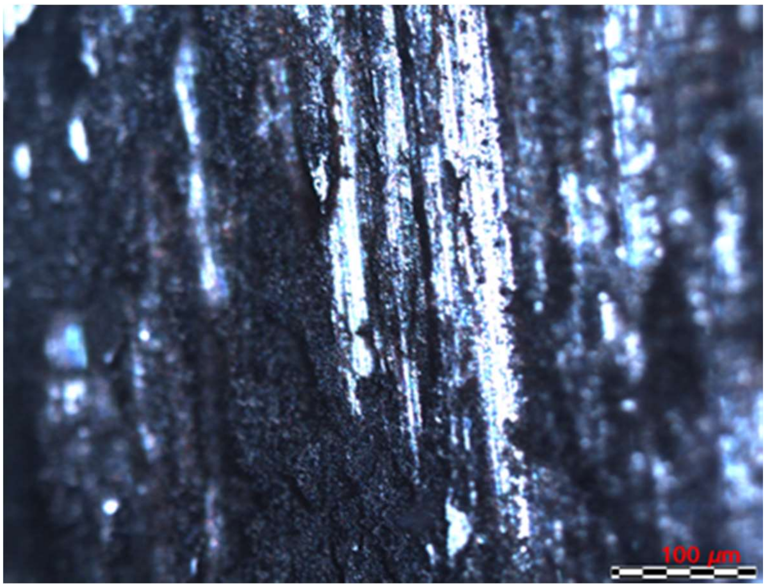

Fig. 8. Surface topography of sample with 5 g/l ND after the wear test. Applied load 165 N and sliding distance 500 m.

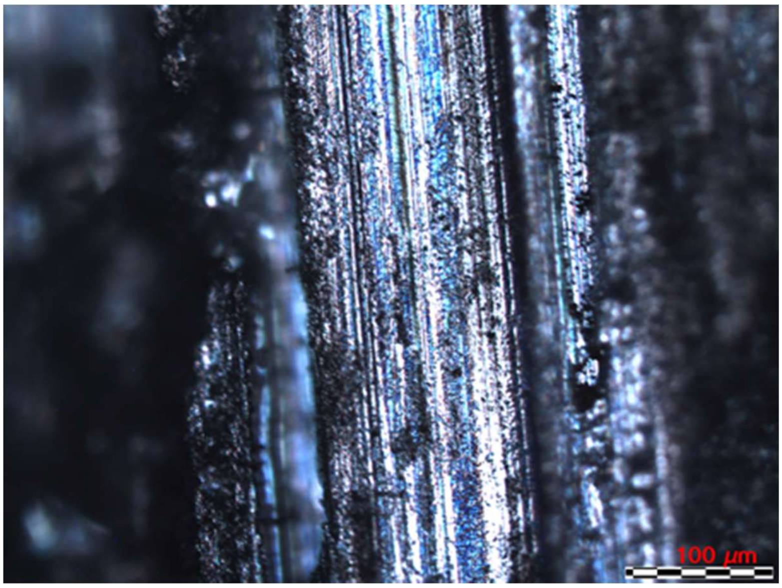

Fig. 9. Surface topography of sample with 10 g/l ND after the wear test. Applied load 165 N and sliding distance 500 m.

The typical wear mechanism of the sample with 25 g/l ND after the wear test at sliding distance 500m is abrasive wear, but there is small amount of adhesive wear (fig. 10).

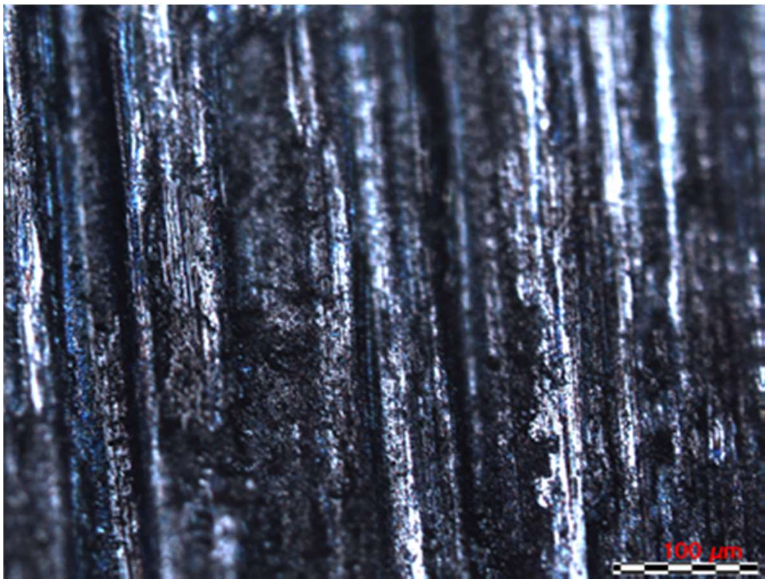

Fig. 10. Surface topography of sample with 25 g/l ND after the wear test. Applied load 165 N and sliding distance 500 m.

4. Conclusions

The nanodiamond particles in the electrolyte enhance the process of electrolytic chromium deposition on aluminum items.
The chromium coating adheres very well on the substrate aluminum with thickness of up to 90 µm.
The chromium coating increases the wear resistance and improves the friction of the aluminum products.
Two types of wear mechanism can be seen, abrasive and corrosive wear. The dominate mechanism is corrosive wear. There are oxide regions on the surface after the tribological test.

Acknowledgements: The financial support of the Fund "Scientific Researches" at the Ministry of Education and Science, Contract No DN 07/8/15.12.2016 is gratefully acknowledged.

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