TRIBOLOGICAL CHARACTERIZATION OF THE NANOSTRUCTURED THIN FILMS DEPOSITED BY INTELLIGENT METHODS, FOR MECHATRONIC AND BIOMEDICAL APPLICATIONS

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Abstract

The main objectives of the present project are to study and to improve mechanical properties of different systems from mechatronic and biomedical domains, in order to increase their functionality and life span. This is why nanostructured thin films (e.g. Al, Cr, Ti, Ti/Al multilayers) were deposited on different steel substrates, used in mechatronic and biomedical applications. By the characterization of coated surfaces of the products used in various fields such as medicine, mechatronics, electronics, etc. depends their proper operation, durability and reliability. This is the main reason why, we studied new types of layers and multilayers using Atomic Force Microscopy and scratch tests. The main result of the realized tests is that all studied nanostructured thin films offer the possibility of increasing the lifetime of substrates, being an important factor for proper functional operation, durability and reliability of the final systems in which they are used.

Keywords

nanometric coatings, thin films, structural characterization, mechatronic methods.

Introduction

Thin films (made of materials with micro and nano structures) deposited by intelligent mechatronic methods can be used in various fields, such as mechatronics (mechatronic components), electronics, and medical (implants - dentures, orthopaedic).

During the time, in the institute we have tried different methods for obtaining materials with improved physical and mechanical properties, but it has been proven that the most important method in this process is the deposition of thin films. It has been revealed that the key factor to increase the durability of the materials coated with thin layers of nanostructured materials is to provide a tightly adhering coating on the substrate.

Thus, the project team has set the research and development of thin films deposited, by means of intelligent modern methods, on materials used in mechatronic applications such as: high-precision gears for miniaturized construction, bearings for precision equipment, components of mechatronics equipment for measuring, positioning and adjustment: races, guides, grippers, actuators, components for biomedical devices, MEMS & NEMS, etc., in order to increase the lifetime of these materials coated with thin films.

The idea of this project started from older studies, which aimed to establish methods to ensure high durability of prosthetic components. In the conclusions on severe mechanical stresses faced prosthetic elements, complex investigations were made about theoretical and experiential modelling of tribological behaviour of these biomedical components. Hip prostheses specimens were made and were coated with nanoscale thin films, respectively TiN. Scratch tests were performed with constant load and demonstrated a substantial increase of hardness for the surfaces coated with biocompatible nanostructured materials. The present project aims to extend these experiments to new types of deposited nanostructured films by various ultra-modern procedures, and to demonstrate the functionality of already formulated concept.

In the present studies, based on mentioned documentary studies and internal analysis, Ti, Cr, Al thin films and Ti/ Al multilayer were deposited on the following steel substrates:

- OLC 45 (rolled steel quality) used in the production of mechatronic actuators, roto-translational mechanisms, components for industrial robots, measuring pivots, centring pivots, gauges, bushings, etc.;
- Rul 1 (ball bearing steel) used for the production of mechatronic actuators, measuring pivots, positioning supports, manufacture of small bearings, tools, dowel drilling, gauges, etc.;
- C120 steel, used into mechatronics applications to produce moulds, punches, perception heads, sensors, calibres, etc.;
- OSC steel, used in mechatronics to produce perception heads, gauges, thread gauges, dies, etc.

These substrates were chosen because of the importance they have in engineering applications; are commonly used in mechatronic components that are subject to the phenomenon of wear throughout the operating cycle.

Besides the deposition of nanostructured thin films, this technical paper put a valuable focus on characterization of the obtained thin films surfaces with micro and nanostructures. In the present scientific article we present a part of the originally program of thin film deposition, designed to improve the functional characteristics of the components/ parts of mechatronic structures by coating with micro/ nanostructured materials and a part of the structural characterization results.

Experimental research on qualitative increase of physical and mechanical properties of steels, via deposition of thin films

In a specialized laboratory, with controlled ambient environment, deposition of Ti, Cr, Al thin films, and Ti/ Al multilayer was realized by "method of deposition by evaporation electron beam" using a TEMESCAL FC-2000 system (Figure 1). Through the process of evaporation deposition electron beam have been deposited layers of Ti, Cr, Al and multilayer Ti / Al on four types of steel: OLC 45, Rul 1, C 120 and OSC.

Figure 1: TEMESCAL FC-2000 –deposition system by electron beam evaporation

Temescal FC-2000 is a versatile evaporation system that accepts a variety of accessories to meet almost any requirement. Engineered for efficient operation and clean room compatibility, these systems combine maximum flexibility with ease of use. The FC-2000 is a fast- cycle, load-locked system that allows the source to remain under vacuum during substrate reloading.

To begin operation TEMESCAL FC-2000 were tested and put into operation the system components: control system, power supply, pumping and vacuum control air system, water system, vacuum chamber, the source beam electrons.

TEMESCAL Control System (TCS) provides a fully integrated process control, operating in ways including password protected, also provides variable monitoring, tracking and trend data archiving process.

In TCS Automatic Mode, the user performing fully automatic control of programmed recipes composed of up to twenty steps of the process; being available self-pumping and self-ventilation operations, and also automatic testing of the growth rate.

More practical and preferable, is the TCS Manual Mode, which allows the user matching easy process parameters, individual exploiting major components and subsystems with full protection blocking, and performing non-automatic processes for coating of a single thin film, on a whole lifecycle.

TCS Operating Mode Services provides basic-level control, lock on any valves, pumps, motors or power supply system.

The main factors that have ensured deposits accurate, pre-set parameters are:

- Electron beam sources of TEMESCAL offers improved convenience and reliability and transfer in applications, leading to specialized coatings;

- Thoroughly controller of the electron beam of TEMESCAL offers full digital operation, internal storage up to 64 user-defined models and compatibility with almost any electron beam gun;

- Programming software based on Windows ™ and a hand controller with remote control it provides precision and flexibility required by the most stringent PVD processes with electron beams.

Experimental results

Ti, Cr, Al thin films obtained had a thickness of 50 nm and the Ti/ Al multilayer 100 nm (50 nm each metallic layer). These nano-layers were deposited on various substrates of steel from those selected as highly used in mechatronics industry, for components that are in a gearing dynamic, with long direct contact, inducing wear accentuated during the whole working cycle, like: OLC 45, RUL 1, C120, OSC.

The thickness of thin films obtained was measured using quartz crystal microbalance method. A quartz crystal microbalance (QCM) measures a mass variation per unit area by measuring the change in frequency of a quartz crystal resonator. The resonance is disturbed by the addition or removal of a small mass due to oxide growth/decay or film deposition at the surface of the acoustic resonator.

In Figure 2a-d are shown images of Ti thin films deposited by electron beam evaporation on the four types of substrates enunciated before.

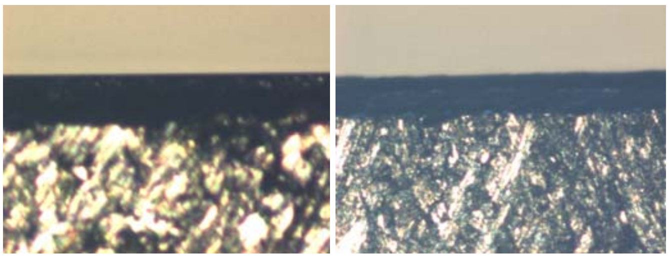
(a) (b) (c) (d)

Figure 2: Photos of Ti films deposited by the electron beam evaporation deposited on steel substrates 4: (a) OLC 45; (b) RUL1; (c) C120; (d) OSC

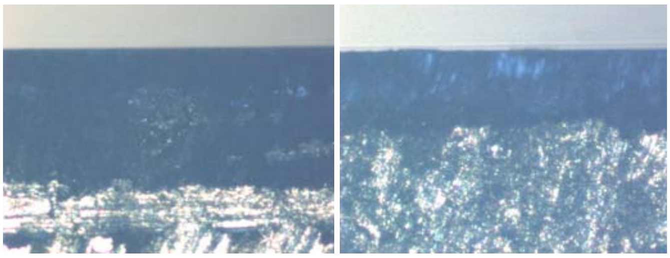
These thin films were structurally characterized using atomic force microscopy. Such a system helps to determine few parameters, in order to obtain supplementary information about the structure.

We took some instant images using the CCD camera of the NTEGRA NT-MDT atomic force microscope, in order to see the interaction points between the thin films and materials used as substrates. These information will be important in the future, for adhesion determination, when we proposed to make some physico-mechanical characterization of the obtained thin films.

In the next figure (Figure 3) it can be observed the interaction surface between the Al thin film of 50 nm and the 4 types of steel substrates. It can be clearly seen that between the layer and substrate is a good connection, the thin films materials penetrating through all the substrate material irregularities. In the case of the Ti/ Al double layer, was also clearly seen this kind of interaction between the thin layer and substrate, but also between the two layers deposited in order to obtain a multilayer.



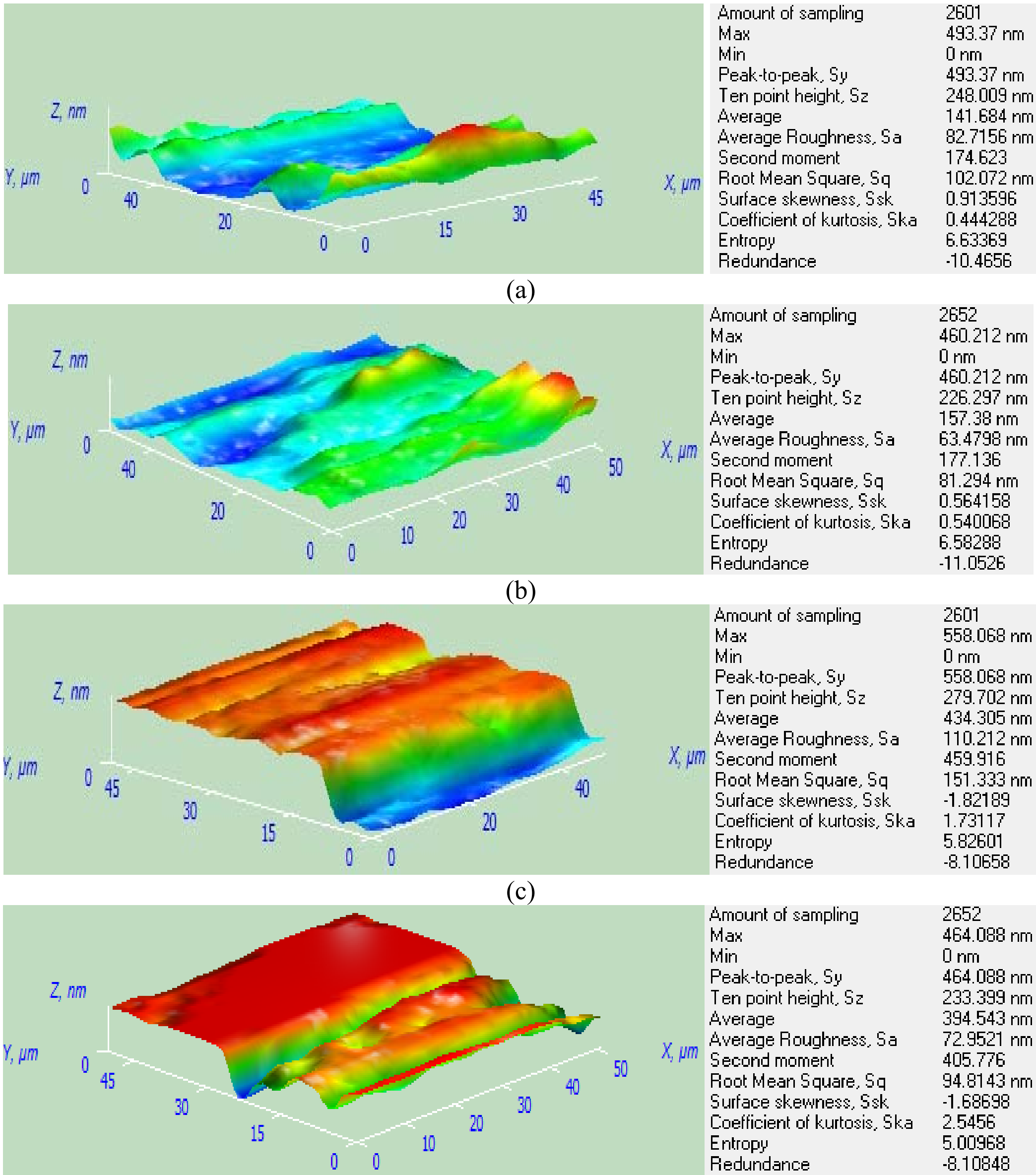
(a) (b)



(c) (d)

Figure 3: Photos of the interaction surface between the Al thin films deposited by the electron beam evaporation, and the 4 types of steel substrates: (a) OLC 45; (b) RUL1; (c) C120; (d) OSC

Using atomic force microscopy, we made surfaces scans of 50 × 50 μm, and we obtained few topographic parameters (Figure 4).



(d)

Figure 4: Atomic force microscopy analysis of Ti/ Al thin layers deposited on the 4 types of steel substrates: (a) OLC 45; (b) RUL1; (c) C120; (d) OSC

Analysing all these obtained results, we can conclude that the thin films were deposited uniformly on all the substrates used, but have a relatively high roughness. This can be due to some possible defects of the substrate.

Table 1. Mean values of the roughness (nm) of the thin layers deposited on different type of substrates using electron beam evaporation.

Thin film	Substrates	Mean roughness (nm)
Ti	OLC 45	110,571
	RUL1	110,898
	C120	78,025
	OSC	87,486
Al	OLC 45	110,005
	RUL1	74,347
	C120	78,880
	OSC	52,642
Cr	OLC 45	43,845
	RUL1	85,59
	C120	72,557
	OSC	149,135
Ti/ Al	OLC 45	84,467
	RUL1	105,063
	C120	78,025
	OSC	74,766

Conclusions

In this paper are presented a part of the results obtained after the structural analysis of nanomaterials thin layers deposited on some steel substrates using the electron beam evaporation. We choose to study metallic (Ti, Cr, Al) thin films, monolayer and multilayer, with thickness of 50 and 100 nm, because of its importance in mechatronic applications. Different types of steel used as substrates are used in applications like: high-precision gears in miniaturized constructions, high precision bearings, components of mechatronic equipment for measuring, positioning and adjustment: runways, guideways, grippers, etc., components for biomedical devices, MEMS & NEMS.

It was observed that between the deposited layers and substrates is a good connection, the thin films materials penetrating through all the substrate material irregularities. In the case of the Ti/ Al double layer, was also clearly seen a good interaction between the thin layer and substrate, but also between the two layers deposited in order to obtain a multilayer.

The main conclusion that was reached after the atomic force microscopy structural characterizations is the fact that it was proved the deposition of thin films with a uniform structure that can be tested mechanically in the next stages of the project.

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