ARC BOND SPUTTERING EQUIPMENT FOR DEPOSITION OF INNOVATIVE INDUSTRIAL COATINGS

Chavdar Pashinski[1], Milko Angelov[2], Velko Rupetsov[3], Dimitar Petrov[4], Petar Shindov[4], Stefan Dishliev[5]
[1]Central Laboratory of Applied Physics - Bulgarian Academy of Sciences, Plovdiv, Bulgaria
[2]Milko Angelov Consulting Co., Plovdiv, Bulgaria
[3]Technical College of Smolyan - Paisii Hilendarski University of Plovdiv, Smolyan, Bulgaria
[4]Technical University - Sofia, branch Plovdiv, Plovdiv, Bulgaria
[5]University of Food Technologies, Technical Faculty, Plovdiv, Bulgaria
e-mail: pashinski@yahoo.com

Abstract: The deposition of coatings is widely used in the modern industry. The pursuit of a high quality and an environmental friendliness increasingly extends the application of the PVD technology. This article describes one designed and manufactured equipment for Arc Bond Sputtering deposition which is able to create coatings with valuable industrial properties. Its most important assemblies are shown and the principles in its design are explained. At the end two promising coatings deposited by this equipment are described: a nanocomposite Ti/TiN/TiCN/nc-TiCN:a-C/nc-TiC:a-C/a-C and a superlattice Ti/TiN/CrN-ml. Their experimentally determined value of the wear rate is comparable with the best known results for similar coatings.
Key words: Arc Bond Sputtering, coatings, DLC, nanocomposites, PVD

INTRODUCTION

The deposition of hard, wear resistant coatings on parts and tools is an important trend in the modern industry, which increases rapidly [1, 2]. Such coatings possess a wide range of properties - a high hardness and wear resistance, a low coefficient of friction, an excellent adhesion, a remarkable thermal stability and oxidation resistance, etc. Thus they allow significant increase in the machining speed and simultaneously the lifetime of the coated tools [1, 2].
Physical vapour deposition (PVD) is a fundamental method for growth of condensate coatings with similar properties. Both variants thereof, which have acquired the most practical importance, are Vacuum Arc Deposition (VAD) and Magnetron Sputtering (MS). The VAD allows a high-speed growth of the layer and the vapour's particles have a higher degree of ionization (the last favours the creation of complex compounds in the coatings). Also, the etching of the samples, which is feasible by this method, significantly increases the adhesion of applied layers. On the other hand, by this process large cluster formations are deposited (so-called "droplets") which affect the properties of the layer mainly detrimentally. These droplets absent when using the MS, but the achievable deposition rates and the degree of ionization are lower, although the Unbalanced Magnetron Sputtering (UBMS) deals with the latter disadvantages largely. In a nutshell, both methods have their advantages and disadvantages when depositing coatings.
The last has created the idea that these two methods could complement each other. This resulted in one combination of them in a single coating process - Arc Bond Sputtering (ABS) [3, 4, 5]. In this process, typically the etching and deposition of the first adhesive layer is made by the VAD and the main functional layers are grown by the UBMS. The layers have very good mechanical properties, although the presence of a small amount of droplets (deposited in the beginning of the process when using the VAD), somewhat reduces their chemical resistance [4]. The fundamental difficulty in the design of an ABS equipment is to make cathode units capable of operating as vacuum arc evaporators and unbalanced magnetrons (consecutively) - this solution saves space and reduces the equipment's cost [3].
This article examines the structure of one designed ABS equipment HVP100RHD (Fig. 1a) and its capabilities to deposit coatings for industrial applications. Two similar coatings are investigated here (the focus is on their wear resistance): a nanocomposite Ti/TiN/TiCN/nc-TiCN:a-C/nc-TiC:a-C/a-C and a superlattice Ti/TiN/CrN-ml.

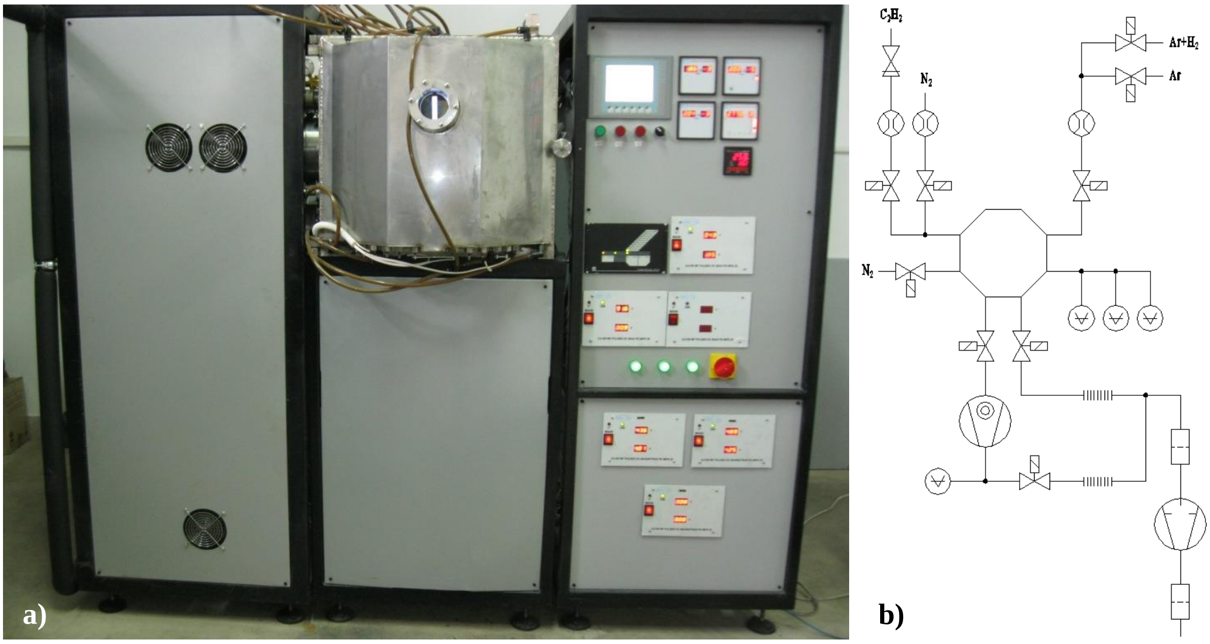

Figure 1. The HVP100RHD equipment: a) overall view and b) schematic diagram of the vacuum system

CONSTRUCTION OF THE EQUIPMENT

Vacuum System

The working chamber is almost one regular octagon. This shape allows a rational arrangement of the cathodes, especially an implementation of a Closed Field Unbalanced Magnetron Sputtering (CFUBMS) scheme of their work [3]. The internal dimensions are W500 x H450 mm, where "W" is the span of the octagon. It was made of stainless SS304L steel and its walls are water cooled.

On three of the walls of the vacuum chamber rectangular planar cathodes were placed by a flange and a tubular water-cooled anode was mounted laterally, in the vicinity thereof, to increase the plasma volume and the ionization degree. On the chamber's door several tubular heaters with total power of 6 kW were installed through which samples can be heated to ca. 400 °C. On the bottom of the chamber one high load HV current/rotation feedthrough was assembled which drives a carousel with the samples and fed them the bias voltage. The carousel itself is one modular planetary gear with three axes of rotation, providing continuous movement of the specimens in the chamber during the coating process.

A scheme of the vacuum system is shown in Fig. 1b. The pumping unit is composed by two-stage rotary-vane pump BW63 (Zakład Techniki Próżniowej "TEPRO" SA) with pumping speed 63 m^3/h and turbomolecular pump TURBOVAC 600 C (Oerlikon Leybold Vacuum GmbH) with pumping speed 600 l/s (Fig. 1b). All valves are electrically driven and the system does not need compressed air during the operation. The vacuum measuring is done by a two channel vacuum gauge Pirani PRVG 02 (Milko Angelov Consulting Co.), a single channel Penning vacuum gauge PNVG 01 (Milko Angelov Consulting Co.) and a capacitive diaphragm vacuum gauge Baratron 627B (MKS Instruments, Inc.). The latter is for an accurate measurement of the total gas presure during the coating deposition. A venting of the chamber is done by a N_2 flow which ensures a high purity and lack of moisture.

There are three gas lines where the flux control is through mass-flow controllers. Through the two N_2 and C_2H_2 are submitted and the third are fed by Ar or Ar + H_2 via switching over solenoid valves.

The batch cycle is fully automated and provides options for creating, editing and saving technological recipes. The oversight is made by 7" monochrome touch screen panel, mounted on the housing and connected to SIMATIC S7-1200 (Siemens AD) PLC (with/without external networked PC). There is a connection to the Internet or LAN to control the deposition process and for diagnostics (regular or emergency). All batch parameters are recorded on the PC's hard drive by the control system for further use.

Targets and Supplies

The cathodes are the heart of every PVD equipment. In this case, there are three (Fig. 2). Their targets have W102 x D9 x H381 mm dimensions and have a copper diaphragm type indirect cooling. Water cooled screens were included in cathode design. There are orifices for the flux of working gases near the targets so gas injection mode is realized as follows: the Ar flow is got in near the target's surface and the reactive gases flow is directed to the substrates through the plasma volume.

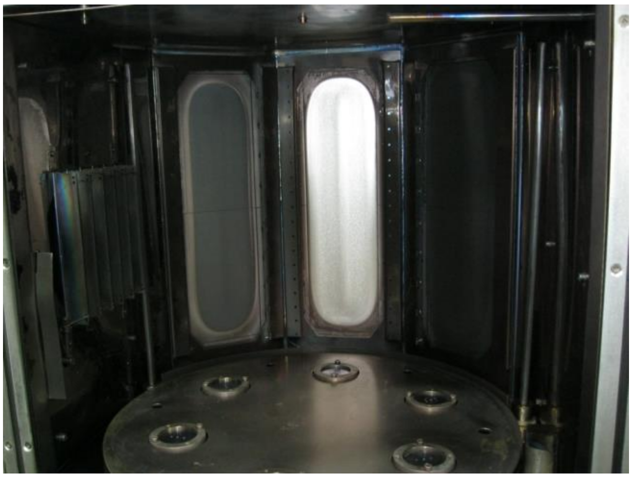

Figure 2. Disposition of the cathodes

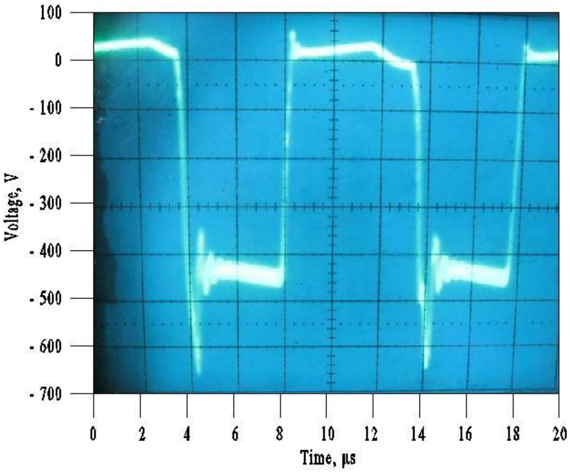

Figure 3. Oscillogram of the supply voltage

The cathodes are designed to operate in both highly UBMS and VAD processes which is done by repositioning of their magnetic systems and switching of their supplies. Furthermore, they have one movable magnetic system which scans the target surface for enhanced material utilization. The three cathodes work in the CFUBMS whereby a high degree of ionization and plasma concentration in the working volume in the vicinity of the specimens are achieved [3, 6].

In the highly UBMS mode three inverter type 2.0 kW MF pulsed DC magnetron power supplies IMPS 20 (Milko Angelov Consulting Co.) working on fixed frequency of 100 kHz are used. They are unipolar (negative pulses only) with duty cycle range from 0 to 75 %. The original accent in their conception is the addition on the front edge short (up to 600÷800 ns long), high voltage, low average current peak, superimposed with the basic average voltage pulse (Fig. 3).

It considerably increases the electron emission, ionization and current growth on the front edge respectively. This permits to limit the voltage magnitude during main pulse, which allows lower output inductance value [7]. It is well known that this value determines the delivered energy to a single arc. On the other hand, current waveform with improved current increase provides same average currents simultaneously with shorter "on" time, which limits charging of poisoned islands on the target surface.

When cathodes operate in the VAD mode, one Manual Metal Arc (MMA) welding inverter E 250 CDi (TEC.LA Srl.) with a nominal current 5 ÷ 250 A output range and maximum power of 9,4 kW is used. To this device was added one special module for remote PLC control via analog output 0 ÷ 20 mA DC.

For sample's biasing two 2.0 kW MF pulsed DC bias power supplies (Milko Angelov Consulting Co.), working on fixed frequency of 100 kHz are provided. The first one has voltage amplitude -930 V and it is used for a glow discharge cleaning and a metallic ion etching. The second one biases the samples during the deposition having voltage amplitude -100 V. An +200V/5A inverter type power supply (Milko Angelov Consulting Co.) is used for powering the anode.

All power supplies are PLC controlled.

Samples' Transportation

One appropriate movement of the samples is very important to obtain a suitable structure of the deposited on them coatings. The periodic passing of the samples near the cathodes creates so-called "modulation periods", which highly influence over the coating's properties [1, 2, 8]. Also, for processing of a large amount of samples with a small size of the sample relative to that of the chamber, more axes of rotation are required [9].

Complying with the above requirements, one special three-axial planetary mechanism with a modular structure has been designed (Fig. 4a). It possesses six spindles (2-axial satellites) and each of them can be on several levels, i. e., to have several boxes with samples. These gear boxes are with 9 or 20 positions (everyone of them is a 3-axial satellite) and may be combined on every particular spindle (Fig. 4b). The structure of the planetary mechanism allows rapid removal/insertion of the spindles (with fastened boxes and samples) minimizing the period when the chamber is opened. The motor and its gear reducer, which actuate the carousel, are capable of moving a large number of specimens, even their mass is huge (WC/Co tools for example). The carousel itself is primarily made of stainless SS304L steel.

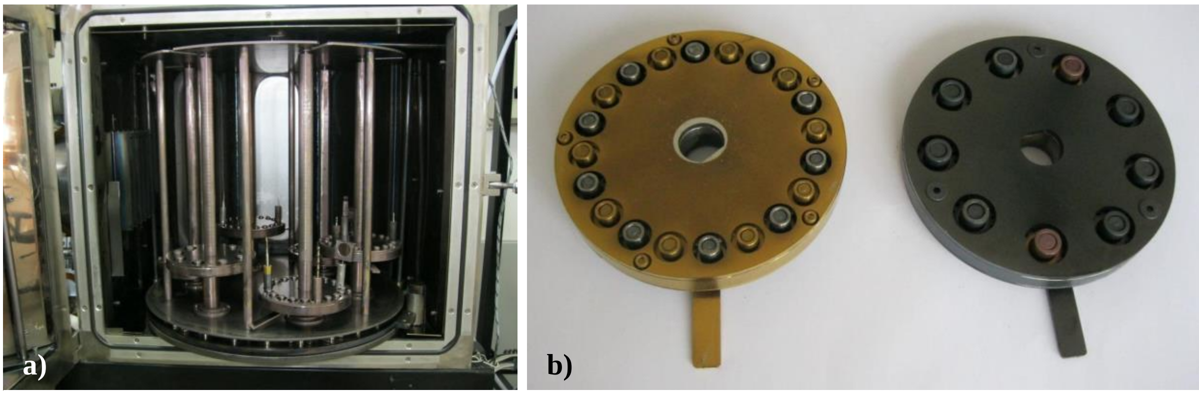

Figure 4. The carousel: a) a general view and b) two types of gear boxes

A treatment of samples with larger dimensions is done by simpler 2-axial or 1-axial developed constructions. The maximum shaft load, which may apply to the high load HV current/rotation feedthrough, is 160 kg. If the rotation stops for some reason then one special shutdown will be activated and general alarm will be switched on.

RESULTS AND DISCUSSION

The presented here HVP100RHD equipment is primarily designed for deposition of coatings on industrial instruments. Using it, some traditional and approved coatings (TiN, AlTiN, CrN, TiCN, etc.) have been deposited. The achieved quality is comparable to the best results known to the authors.

In the field of tool coatings everybody works in a permanent competition. Currently, state-of-the-art are different nanostructured coatings which significantly increase tool's lifetime. In this respect, two basic coatings have been developed: a nanocomposite Ti/TiN/TiCN/nc-TiCN:a-C/nc-TiC:a-C/a-C and a superlattice Ti/TiN/CrN-ml. The both show a complex of mechanical properties which make them attractive for industrial customers. Some samples with these coatings are shown in Fig. 5a (for Ti/TiN/TiCN/nc-TiCN:a-C/nc-TiC:a-C/a-C) and Fig. 5b (for Ti/TiN/CrN-ml with external layer of TiN).

For this type of coatings one key property is the wear resistance on which tool's lifespan is depended. For these two coatings, it was measured using a ball-on-plate tribological stand, which is circumstantially described in [10]. The conditions of the experiments was as follows: substrate - annealed 1.2343 steel (50÷52 HRC), counterpart - Al_2O_3 bearing ball, load - 1 N, sliding distance - 50 m. The obtained results are illustrated in Fig. 6.

The reported wear rate of both coatings is very low and comparable to the best results for similar coatings [11, 12, 13, 14]. The wear mechanism of the samples is not considered in details here because its survey is still underway. Nevertheless, it is clear that the Ti/TiN/TiCN/nc-TiCN:a-C/nc-TiC:a-C/a-C has a lower wear rate than Ti/TiN/CrN-ml over the all three sliding speeds (Fig. 6). This could be explained mainly by the carbon lubricant influence in the presence of small amounts of moisture in the environment. However, the above results do not prove certainly that this coating absolutely excels the other one in the wear resistance. The practical performance of the coated tools sometimes is not fully consistent with the expectations which were formed on the basis of laboratory tests [11]. Furthermore, the coatings have other important mechanical properties altogether, therefore it can be expected that the both will have their suitable fields of industrial application.

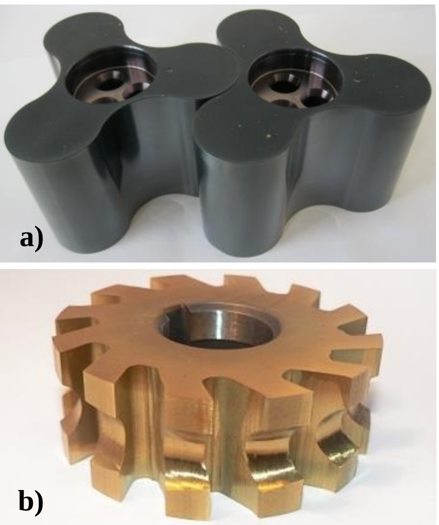

Figure 5. Coated samples: a) 3-lobed rotors and b) profile cutter

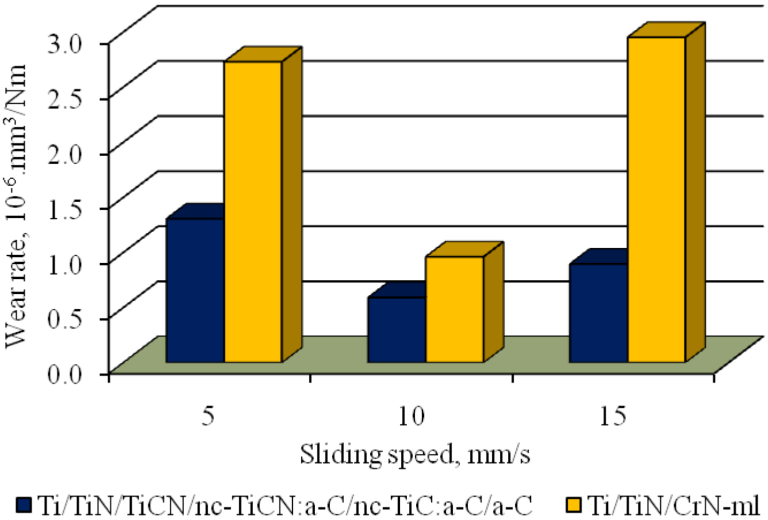

Figure 6. Diagram of wear rate vs. sliding speed (the counterpart was rotated before each test ignoring its wear)

The found nanohardness and Young's modulus of the coatings are as follows: H = 25 GPa, E = 340 GPa about Ti/TiN/TiCN/nc-TiCN:a-C/nc-TiC:a-C/a-C and H = 31 GPa, E = 360 GPa about Ti/TiN/CrN-ml. This hardness of Ti/TiN/CrN-ml was measured with bilayer period of 20 nm (10 nm TiN and 10 nm CrN). Studying of other bilayer periods showed lower hardness, the obtained results are consistent with the Hall-Petch relationship [15, 16]. It can be seen that the ratio H^3/E^2, which is proportional to the wear resistance [1, 16], is greater in the coating Ti/TiN/CrN-ml, but the commented above tests (Fig. 6) showed that this coating has a greater wear rate. This means that in this case the coefficient of friction has a determinative role in the wear resistance.
The adhesion of these coatings has been estimated by a classical Daimler-Benz test and the results could assume that they are into HF1 or HF2 grade. The lack of droplets in the coatings retains the initial roughness of the substrates. Even one negligible reduction of the roughness parameter Ra (ca. 5%) when its initial value is about 0,2 μm can be observed, probably mainly because of an elimination of a part of the peaks on the surface during the ion etching.
The complete evaluation of these coatings needs a future research including for their composition and structure. However, the obtained at this stage results allow us to affirm that they have excellent mechanical properties.

CONCLUSIONS

By the designed and built equipment HVP100RHD is possible to deposit a variety of nanostructured coatings with appropriate industrial properties. The presence of three cathodes and the possibility to flow two reactive gases create opportunity for many different combinations of their composition. The precise control over the working process and the continuous three-axial rotation of samples make possible an attainment of many different combinations of coating structure and a repeatability of the batches. Obtained results so far give a reason to assert that this equipment can fully answer the current needs of the deposition of industrial coatings.

REFERENCES

[1] S. Veprek, M. J. G. Veprek-Heijman: Industrial applications of superhard nanocomposite coatings, Surface & Coatings Technology, vol. 202, iss. 21 (2008), pp. 5063-5073, ISSN: 0257-8972.

[2] T. Cselle, O. Coddet, C. Galamand, P. Holubar, M. Jilek, J. Jilek, A. Luemkemann, M. Morstein: TripleCoatings3® – New Generation of PVD-Coatings for Cutting Tools, Journal of Machine Manufacturing, vol. XLIX, iss. E1 (2009), pp. 19-25, ISSN 0016-8580.

[3] W. -D. Münz, D. Schulze, F. J. M. Hauzer: A new method for hard coatings: ABSTM (arc bond sputtering), Surface and Coatings Technology, vol. 50, iss. 2 (1992), pp. 169-178, ISSN: 0257-8972.

[4] H. W. Wang, M. M. Stack, P. Hovsepian, W. -D. Munz: Macroparticle induced corrosion for arc bond sputtering CrN/NbN superlattice coatings, Journal of Materials Science Letters, vol. 20, iss. 21 (2001), pp. 1995 – 1997, ISSN: 0261-8028.

[5] E. N. Reshetnyak, V. E. Strel'nitskij: Synthesis of Hardening Nanostructural Coatings, Problems of Atomic Science and Technology, iss. 2 (54) (2008), pp. 119-130, ISSN 1562-6016 (in Russian).

[6] I. V. Svadkovski, D. A. Golosov, S. M. Zavatskiy: Characterisation parameters for unbalanced magnetron sputtering systems, Vacuum, vol. 68, iss. 4 (2003), pp. 283-290, ISSN: 0042-207X.

[7] M. Angelov: MF pulsed DC power supplies for PVD processes, Proceedings of International Workshop NANOHARD 2007, pp. 101-104, ISBN 978-954-322-238-4, Velingrad, Bulgaria, 13-16 May 2007, published by BAS, Academic Publishing House "Marin Drinov", Sofia, Bulgaria.

[8] M. Panjan, M. Čekada, P. Panjan, F. Zupanič, W. Kölker: Dependence of microstructure and hardness of TiAlN/VN hard coatings on the type of substrate rotation, Vacuum, vol. 86, iss. 6 (2012), pp. 699-702, ISSN: 0042-207X.

[9] Ch. Pashinski: Algorithm and program for synthesis of carousels for PVD technology, International Journal of Scientific & Engineering Research, vol. 4, iss. 6 (2013), pp. 870-876, ISSN 2229-5518.

[10] V. S. Rupetsov: Experimental test stand for the study of coatings resistance, Journal of Food and Packaging Science, Technique and Technologies, vol. 1, iss. 4 (2014), pp. 60-65, ISSN 1314-7773.

[11] B. Warcholinski, A. Gilewicz: Multilayer coatings on tools for woodworking, Wear, vol. 271, iss. 11-12 (2011), pp 2812-2820, ISSN: 0043-1648.

[12] Wang H., Zhang W., Yu H., Liu Q.: Tribological properties of DLC films prepared by magnetron sputtering, Physics Procedia, vol. 18 (2011), pp. 274-278, ISSN: 1875-3892.

[13] G. Mishev, S. Dishliev, H. Bohchedjiev: Study of wearresistance of nanocoatings on steel 40X13, Proceedings of the XXVI International Science Conference in honour of 65 anniversary of MTF of TU-Sofia and 100 birth anniversary of Acad. Angel Balevski, pp. 586-590, ISBN: 978-954-438-854-6, Sozopol, Bulgaria, 13-16 September 2010, published by TU-Sofia, ITUS, Sofia, Bulgaria (in Bulgarian).

[14] Q. Miao, C. E. Cui, J. D. Pan: CrN–TiN multilayer coating on magnesium alloy AZ91 by arc-glow plasma depositing process, Surface & Coatings Technology, vol. 201, iss. 9-11 (2007), pp. 5077-5080, ISSN: 0257-8972.

[15] S. Zhang, D. Sun, Y. Fu, H. Du: Recent advances of superhard nanocomposite coatings: a review, Surface and Coatings Technology, vol. 167, iss. 2-3 (2003), pp. 113-119, ISSN: 0257-8972.

[16] D. Philippon, V. Godinho, P. M. Nagy, M. P. Delplancke-Ogletree, A. Fernández: Endurance of TiAlSiN coatings: Effect of Si and bias on wear and adhesion, Wear, vol. 270, iss. 7-8 (2011), pp. 541-549, ISSN: 0043-1648.