

## Characterisation of anti-erosive properties of nanocomposite coatings by the methods of sclerometry

O V Kudryakov<sup>1</sup>, V N Varavka<sup>1</sup> and V V Ilyasov<sup>2</sup>

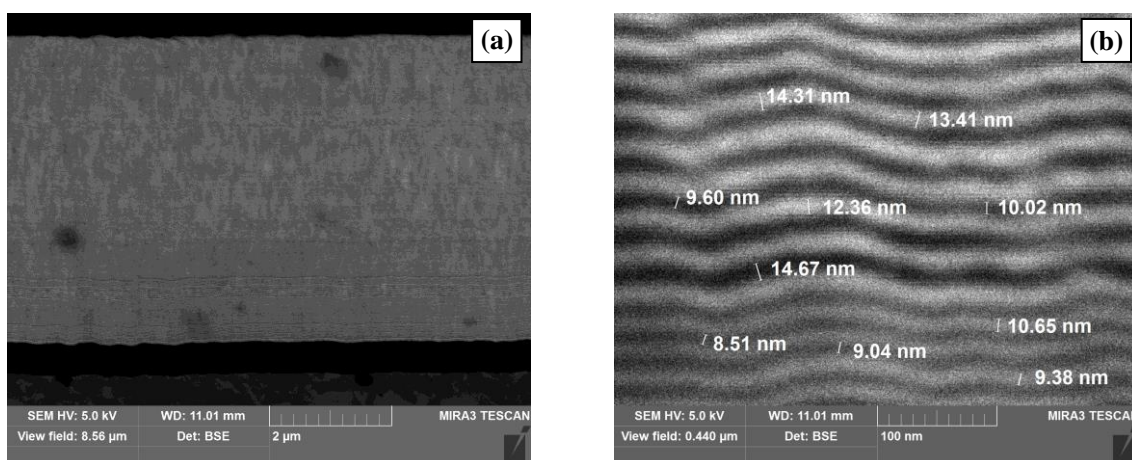
<sup>1</sup> Material Science Department, Don State Technical University, 1 Gagarin sq., Rostov-on-Don, 344000, Russia

<sup>2</sup> Physics Department, Don State Technical University, 1 Gagarin sq., Rostov-on-Don, 344000, Russia

E-mail: kudryakov@mail.ru

**Abstract.** Results of research of coatings of the different metal-ceramics systems are given. Coatings were received by ion-plasma sedimentation in vacuum in the form of multilayered composite material, which had a thickness of layers within nanometric range. Selection of composite systems is determined by applied research problem – namely designing of the anti-erosive coatings durable in the condition of drop impingement impacts. For this purpose the sclerometric studies, the bench erosive tests and optimization of the obtained data were done.

The 2D-cermet nanocomposite coatings of the following systems were selected for study: Ti/C, Ti/Mo, TiN/MoN, Ti/AlSi, TiN/AlSiN, Ti/Zr(Nb), TiN/Zr(Nb)N. Coating was performed at the ion-plasma sputtering facility with unbalanced magnetron evaporation system. Modes of coatings subsidence were chosen so that, in accordance with the Movchan-Demchishin-Thornton's diagram a solid (non-defective) nanoscale layers with a nanocrystalline structure (figure 1) and compressive stresses in the coating were obtained. Total thickness of coatings – at least 3  $\mu\text{m}$  (optimally 6–8  $\mu\text{m}$ ) with monolayers thickness ranging from 5...40 nm. Coating subsidence rate of 0.6...6.0 nm/s.



**Figure 1.** Microstructure of nanocomposite Ti/AlSi system coating with thickness 2.5  $\mu\text{m}$  in cross section of the coating at different magnifications; SEM images.



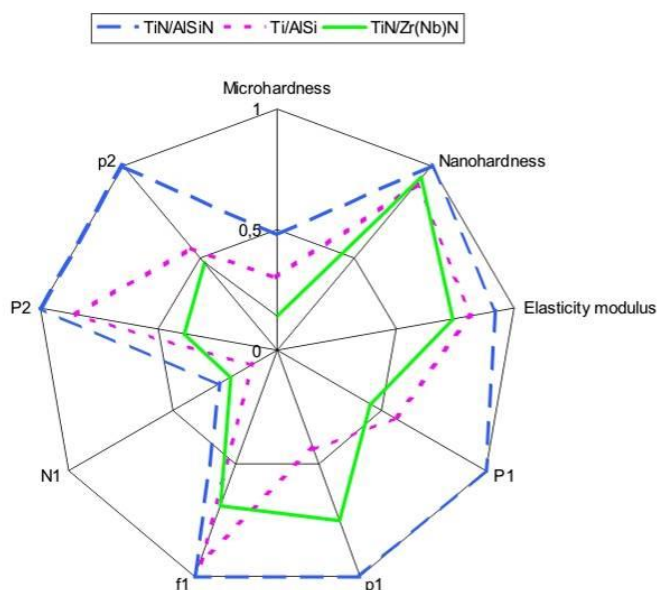
When using the value of technological parameters of application all systems provide technologically sustainable receipt of multilayer's (2D) nanocomposite coatings except those systems containing silicon. Coverings with Si represent 3D-nanocomposites because they have an ordered (modulated) heterogeneous structure, one of phases of which is amorphous silicon-containing phase (as a binder).

Physical and mechanical properties of coatings were investigated using the sclerometric methods of indentation [1] at different samples loading schemes: discrete (microhardness), a continuous one-coordinate (nanohardness) and continuous two-coordinate (scratching with varying load). To measure microhardness according to Vickers (HV) hardness gauge "DuraScan 20" was used, which uses the method of automatic (electron-optical) measurement of the print. Measurement of nanohardness was carried out with a scanning nanohardness gauge "NanoScan-3D" in a mode of instrumental continuous indentation. To determine adhesion of the coating, its resistance to scratching, the friction coefficient of the coating and the base metal, fracture energy, and other characteristics in micro- and nanorange a scratch tester with micro- (MST) and nano- (NST) modules based on an open platform of CSM Instruments (Switzerland) – a universal sclerometric instrument for measuring a number of characteristics by scratching modes either with a constant scratch load or variable one was used. In our measurements the last mode of loading, which provides scratch indenter penetration through the entire thickness of the coating to the base metal was implemented.

Erosion tests were carried out on a unique specialized stand of the Scientific and Research University of the Moscow Power Engineering Institute "Erosion-M", which is used to study resistance of materials and coatings to the effect of high-velocity liquid drops.

When analyzing the physical and mechanical properties of the coatings obtained by different methods of sclerometry, it appeared that none of them separately can be unambiguously and reliably characterize erosion properties of the coatings. Therefore multiparametric optimization is carried out for the strength properties of coatings using integration ray diagrams method. An example of such a diagram for three systems nanocomposite coatings is shown in figure 2. The axes of radiation diagram locate relative values of nine physical and mechanical characteristics:  $HV_{0.01}$ , nanohardness, elasticity modulus  $E$ , friction coefficient  $f_1$  and normal (tangential) force  $N_1$  in coating, critical applied load and depth at formation of cracks in coating ( $P_1$ ,  $p_1$ ) and at full coating chipping ( $P_2$ ,  $p_2$ ). Since the number of parameters is large enough (nine), and the individual correlation of each of them with erosive properties is not revealed, in transition to the relative values of parameters it allows to take their boost factors (densities) as equally probable.

Physical and mechanical properties of coatings in relative units



**Figure 2.** Radiation diagram of physical and mechanical properties of TiN/AlSiN, Ti/AlSi and TiN/Zr(Nb)N systems nanocomposite coatings.

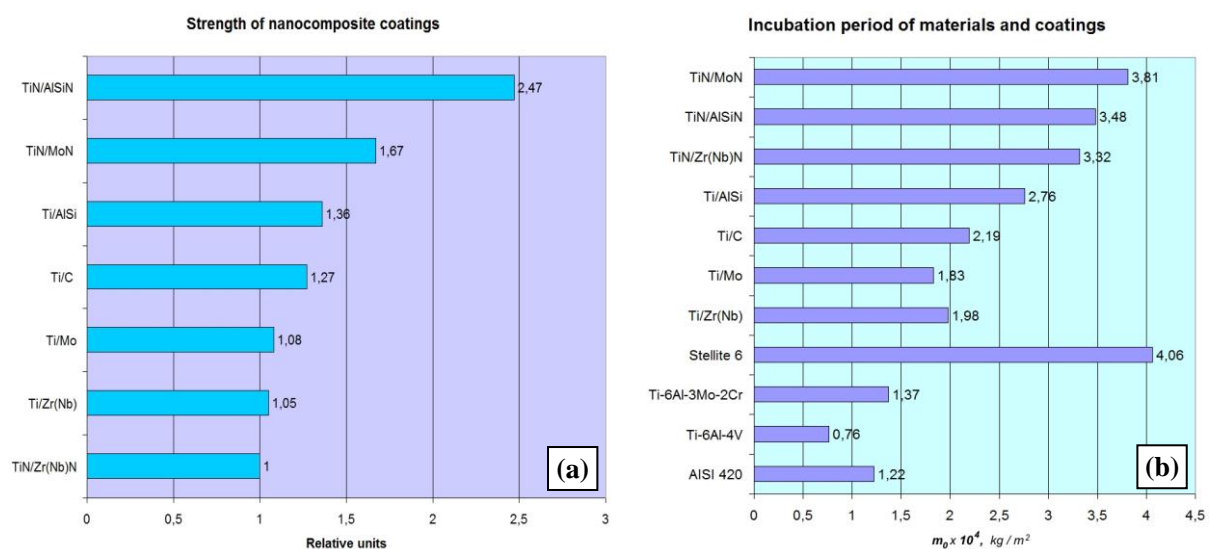
The maximum value of features obtained in tests was taken as a unit of each parameter (all coatings of the seven systems studied) except the coefficient of friction where the minimum value is taken as relative unit. The area of the polygon on the diagram corresponding to each coating was used as an integrated statistical estimation of the relative strength of coating and was a parameter optimization: the larger the area of the polygon, the greater the strength of the coating is as a whole. The area of the polygon  $S$  was calculated as the sum of squares of its constituent  $n$  triangles by the following expression:

$$S = \frac{1}{2} \left[ a_1 \cdot a_n + \sum_{i=1}^{n-1} (a_i \cdot a_{i+1}) \right] \cdot \sin \frac{2\pi}{n},$$

where  $n$  – is the number of rays (properties) of the diagram;  $a_i$  – relative value of the property.

According to the results of multiparameter optimization of ion-plasma nanocomposite coatings of the studied systems can be arranged in the following series of descending strength (i.e., the *complex* of nine physical and mechanical properties): TiN/AlSiN, TiN/MoN, Ti/AlSi, Ti/C, Ti/Mo, Ti/Zr(Nb), TiN/Zr(Nb)N (figure 3(a)). The last place in the series of TiN/Zr(Nb)N nitride system is not due to the nature and properties of the coating, but technological defects of that shape coating (topography of the substrate, discontinuities, growth effects, tension).

Comparison of the erosion resistance of the studied experimental nanocomposite coating of small thickness between themselves and other materials can only be properly carried out for the duration of the erosion's incubation period value  $m_0$ , during which the wear isn't beginning yet and the coating maintains its continuity [2–4]. These results are presented in figure 3(b).



**Figure 3.** Chart of the integral strength of nanocomposite coatings of different systems (a) and chart of erosion resistance of the some materials and nanocomposite coatings (b).

The most important result of the research appears from the comparison of data of these strength tests and erosive properties of nanocomposite ion-plasma coatings: the gradation of coating in figure 3(a) and figure 3(b) is almost the same. Thus, there is a satisfactory correlation between the *complex* of physical and mechanical properties of nanocomposite ion-plasma coatings and their erosive properties. This provides comparative qualitative predictions of resistance for various types of coatings to droplet impingement erosion, which can measure only when the benchmark or in-situ tests performed for the complex physical and mechanical properties, as measured in the laboratory by the methods of sclerometry.

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**References**

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