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Fractal and multifractal characteristics of PVD coatings

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Analysis and modelling

ABSTRACT

Purpose: The goal of this work is the fractal and multifractal characteristics and tribological properties of the TiN and TiN+multiTiAlSiN+TiN coatings obtained by cathodic arc evaporation PVD process on the multi-edge plates made from the Al_2O_3 + $SiC_{(w)}$ oxide tool ceramics.

Design/methodology/approach: The results of the chemical and phase composition researches, tests of mechanical properties, including thickness, microhardness and roughness were evaluated. The characterized structure and surface topography of analyzed coatings, presenting fractal and multifractal character, was confirmed. To estimate the fractal dimension and multifractal spectra, measurements obtained from atomic force microscope (AMF) images, projective covering method (PCM) was used.

Findings: The researches were carried out to confirm that the fractal dimension and parameters, describing the multifractal spectrum shape, may be used for characterizing and comparing coating surface obtained by cathodic arc evaporation PVD process and of the substrate material made from Al_2O_3 + $SiC_{(w)}$ oxide tool ceramics.

Research limitations/implications: Relationship between parameters describing the multifractal spectrum and physical properties of the examined materials calls for further work.

Originality/value: Fractal and multifractal analysis gives possibility to characterise in the quantitative way the extent of irregularities of the analysed surface.

Keywords: Computational material science; PVD coatings; Multifractal geometry; AFM

1. Introduction

Aluminium oxide (Al_2O_3) or alumina is one of the most versatile of refractory ceramic oxides and finds use in a wide range of applications [11]. The high *hot* hardness of alumina have led to applications as tool tips for metal cutting (though in this instance alumina matrix composites with even higher properties are more common) and abrasives. The TiN coating is one of the first coatings used successfully to machine steel in industry and still the most recognized, distinguished by it`s attractive bright gold colour. The PVD TiN coating was first used on High Speed Steel (HSS) tooling because it could be applied below 500°C, the temperature at which HSS starts to soften [4, 5, 11].

Nowadays, this kind of coating is successfully deposited onto different kind of ceramic composites in to two basic processes, such as CVD and PVD techniques and their variations. To improve the mechanical, tribological, cutting properties or other qualities, multicomponent coatings are deposited. These coatings are used for machining (carbon, alloy, and stainless steels, cast irons, and aluminum alloys) and protecting dies, moulds, punches, and a range of metal stamping and forming tools [2, 5, 9, 11, 13].

Studying the connections between fractal and multifractal geometry of surfaces and their formation and function utilizes several different approaches. When the physics is well understood, simulation techniques can be used to explore the generation and properties. It is very important to understand and establish straightforward connections between these parameters [1, 3, 5-8, 15, 16].

2. Materials and methods

2.1. Materials

The researches were carried out on the multi-edge plates made from Al_2O_3+$SiC_{(w)}$ oxide tool ceramic uncoated and coated with mono, multilayer and multicomponent hard wear resistant coatings. The coatings TiN and TiN+multiTiAlSiN+TiN were deposited in the cathode arc evaporation CAE PVD process.

2.2. Experimental procedure

Phase composition of the obtained coatings was definite using the DRON 2.0 X-Ray diffractometer, using the filtered radiation from the cobalt lamp with the voltage of 40kV and current intensity 20mA. The measurements were done in the 2Θ angle ranging 25-95°.

The microhardness tests of the coatings were done on the SHIMADZU DUH 202 ultra microhardness tester. Test conditions were selected so that the required and comparable test results would be obtained for all analyzed coatings. To eliminating influence of the substrate on the measurements results, loading of penetrator at 0,07 N was used.

Examination of the coating thickness were made using the "kalotes" method, consisting the measurements of the characteristic parameters of the crater developed as a result of wear on the specimen surface made by steel ball.

Analysis of the topography of the substrate surface and deposited coatings were done on the scanning electron microscope and on the Digital Instruments Nanoscope E atomic force microscope (AFM). The scanning range were 5 and 2 µm respectively.

To measurement of fractal and multifractal dimensions, projective covering method (PCM) presented in [10, 12] was used.

3. Results and discussion

Phase composition of the substrate and PVD coatings were examined using X-Ray qualitative phase analysis method. Occurrences of the TiN and TiN+multiTiAlSiN+TiN coatings were found in the X-Ray diffraction patterns (Fig. 1), moreover, occurred reflexes of the Al_2O_3+$SiC_{(w)}$ oxide tool ceramic.

It was found out basing on the metallographic examinations on the scanning electron microscope that all coatings obtained in cathodic arc evaporation PVD process are characterised by the laminar structure. The layers of the compound coatings arecharacterised by tight adhesion to each other and to the substrate from the oxide tool ceramic (Fig. 2) [4].

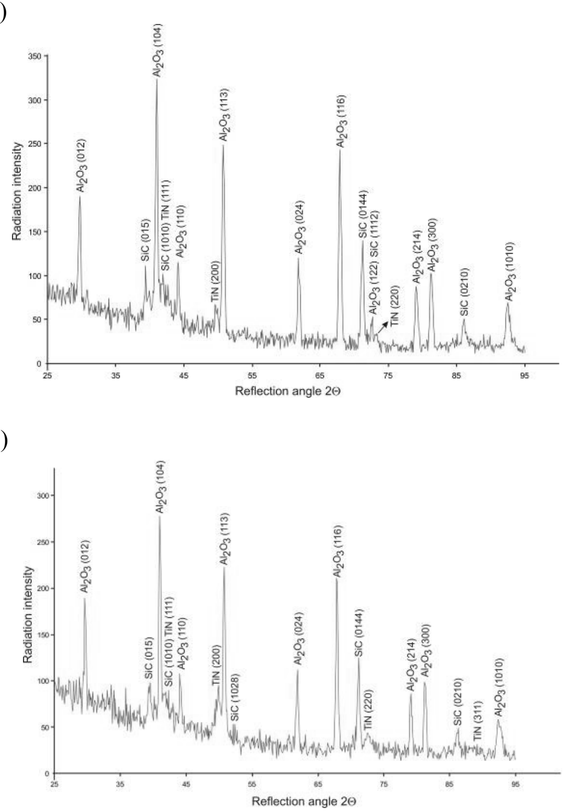

Fig. 1. X-Ray diffraction patterns of the coatings: a) TiN, b) TiN+multiTiAlSiN+TiN

The fracture and topography surface of the TiN coating deposited onto Al_2O_3+$SiC_{(w)}$ oxide tool ceramic substrate are presented in Figure 3.

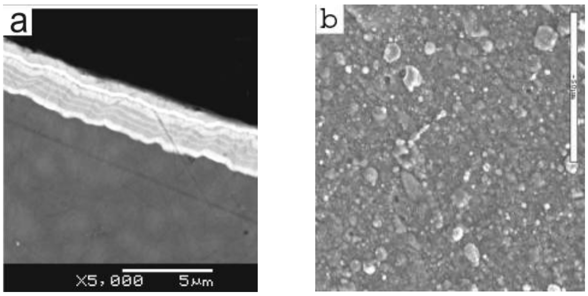

Fig. 2. Surface of a) skew microsection and b) topography of TiN+multiTiAlSiN+TiN coatings deposited onto Al_2O_3+$SiC_{(w)}$ oxide tool ceramic

The Al_2O_3 +$SiC_{(w)}$ ceramics microhardness is 18,7 GPa and grows significantly after deposition of the PVD coatings. The maximum value of microhardness of $HV_{0,07}$=40,2 GPa was observed for TiN+multiTiAlSiN+TiN coatings.

The values of microhardness and coating thickness as well, are presented in table 1.

Table 1.
Results of the mechanical properties of the examine materials

Coating	Coating thickness [µm]	Microhardness [GPa]
substrate	-	18,7
TiN	0,9	27,2
TiN+multiTiAlSiN+TiN	2,8	40,2

The projective covering method [12, 14, 15] to described fractal and multifractal character dimensions of the substrate and of the TiN and TiN+multiTiAlSiN+TiN layers was used . Topography images of the coatings surface and substrate, obtained from AFM microscope was used for its calculation (Fig. 3).

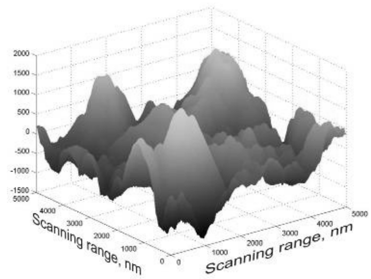

Fig. 3. Image of surface of TiN+multiTiAlSiN+TiN layers deposited onto Al_2O_3+$SiC_{(w)}$ (scanning range 5000nm)

The results obtained from AFM microscope were saved in text file as 512x512 measurements points.

a)

b)

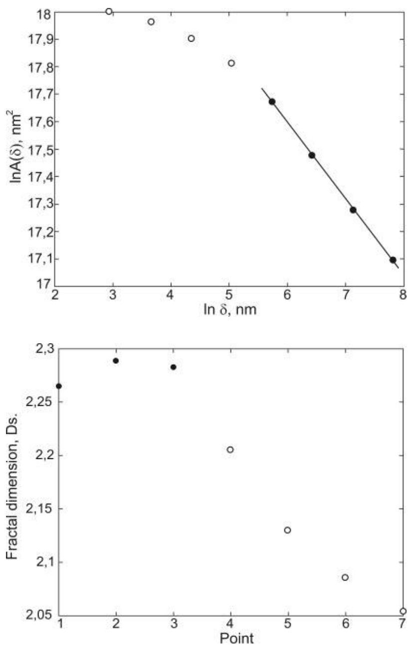

Fig. 4. a) Bilogarithmic relationship of the approximated analysed surface of the Al_2O_3+$SiC_{(w)}$ oxide tool ceramic with TiN+multiTiAlSiN+TiN coating and b) its corresponding auxiliary plot (scanning range 5000 nm)

The determined an A(δ) values are presented in bilogarithmic plots (Fig. 4a) and the auxiliary plots were made to present a changes of the fractal dimension value, determined basing on two consecutive points of the bilogarithmic diagram to assist correct selection (Fig. 4b). Using an atomic force microscope to measurements of the analysed surfaces made a possibility to defined a roughness R parameter according to [12].

It was found basing on the obtained results that the width and differences of slopes of the multifractal spectrum arms correlate with roughness of the investigated surface determined by R parameter.

a)

b)

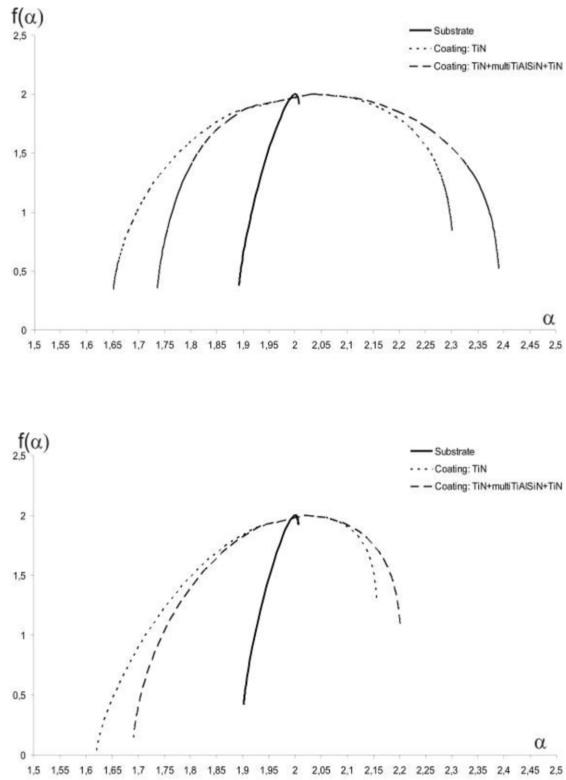

Fig. 5. Multifractal spectra's of the of the analysed coatings and substrate material a) 2000nm and b) 5000nm scanning ranges

It was found out that the lowest fractal dimension Ds and the narrowest multifractal spectrum Δα presents Al_2O_3+$SiC_{(w)}$ oxide tool ceramic, irrespective of the scanning range quantity (Fig. 5).

Deposition of the TiN coating cause increment values of the Ds and Δα parameters from Ds=2,0146 and Δα=0,1152 to Ds=2,0866 and Δα=0,6819 considered at 2000 nm scanning range and increment from Ds=2,015 and Δα=0,105 to Ds=2,1187 and Δα=0,5373considered at 5000 nm scanning range.

Deposition of the TiN+multiTiAlSiN+TiN coating cause increment of these parameters to Ds=2,12 and Δα=0,6553 considered at 2000 nm scanning range and increment to Ds=2,27 and Δα=0,5103 considered at 5000 nm scanning range.

The detailed fractal and multifractal analysis results and the roughness R parameter are presented in Table 2.

Table 2.
The results of fractal and multifractal analysis and roughness parameter R

Material type	Coating	α_{min}	$f(\alpha_{min})$	α_{max}	$f(\alpha_{max})$	$\Delta\alpha$	Δf	D_s	Roughness, µm
$Al_2O_3+SiC_{(w)}$ (Scanning range 2000 nm)	-	1,8926	0,3768	2,0078	1,9126	0,1152	1,5358	2,0146	0,018
	TiN	1,6193	0,0037	2,3013	1,3133	0,6819	1,3096	2,0866	0,641
	TiN+multiTiAlSiN+TiN	1,7357	0,3526	2,391	0,5215	0,6553	0,1689	2,12	0,606
$Al_2O_3+SiC_{(w)}$ (Scanning range 5000 nm)	-	1,9017	0,4172	2,0067	1,9186	0,105	1,5014	2,015	0,038
	TiN	1,6193	0,0037	2,1566	1,3133	0,5373	1,3096	2,1187	0,569
	TiN+multiTiAlSiN+TiN	1,691	0,1427	2,2013	1,0942	0,5103	0,9514	2,27	0,524

4. Conclusions

The paper presents research results obtained from AFM microscope of the $Al_2O_3+SiC_{(w)}$ oxide tool ceramic uncoated and coated with TiN and TiN+multiTiAlSiN+TiN coatings deposited in the PVD process.

It was found out the correlation between microhardness and fractal dimension of surface topography and analysed coatings. The higher value of microhardness analysed coatings is connected with higher value of fractal dimension of surface topography. Moreover, it was found out the correlation between roughness obtained from AFM microscope and fractal dimension Ds and $\Delta\alpha$ parameter. Increment roughness R parameter causes increment the fractal dimension Ds and $\Delta\alpha$ parameters

It was found that the microhardness of the multi-edge plates covered by TiN and TiN+multiTiAlSiN+TiN layers increase about 45% and 110%.

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