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PVD Coatings Applied on the Tool Steels

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Abstract

The paper deals with the properties of thin coatings deposited on the tool steels. The TiAlN coat was applied by PVD technology on the Vanadis steel produced by powder metallurgy. Development of a new technology of coat deposition is connected with adequate evaluation of coated parts. The quality of a thin coating – substrate system was determined by measuring properties.

Introduction

Modern progressive cutting tools are characterized by use of hard coatings on thier surface, which ensures good properties: high hardness, wear resistance, thermal stability and corrosion resistance. The main function of coatings is to prolong the durability of tools. To realise these goals it is necessary to study the physical and chemical processes on the tool surface.(1) Thin coatings give a new feature to the substrate surface and consequently change the properties of coated parts. Evaluation of some properties of thin coating – substrate systems need the specific methods and procedures.

Experimental materials and methods

This experiment used specimens prepared from the material Vanadis. Vanadis 4 – Super Clean is high – speed steel produced by powder metallurgy. This steel offers an especially good combination of wear resistance and ductility.(2) It is intended for tools used for pressing and accurate cutting, for drawing and deep - drawing tools and tools for cutting operations. The structure of the steel, following its heat treatment to a hardness of 60 HRC (Rockwell), was martensitic – carbidic, Figure 1.

Figure 1. The structure of high-speed steel Vanadis 4, etched.

The specimen surface was prepared by polishing, which was required for high – quality deposition process.(3) The surface micro – geometry by mean arithmetic deviation of the assessed profile R_a and maximum height of profile, R_z, at the measured length L = 15 mm before and after deposition of thin coatings was measured according to STN EN ISO 4287. The chemical composition of experimental material is shown in Table 1.

Table 1. Chemical composition of Vanadis 4.

Steel	Actual chemical composition [wt. %]					
	C	Si	Mn	Cr	Mo	V
Vanadis 4	1.2	1.0	0.4	8.0	1.5	4.0

The coatings of Ti – based were deposited on substrate surface using the reactive cathode arc method.(3) Technological parameters of the process are listed in Table. 2. The structure and properties of thin coatings were determined particularly by the character and technological parameters of the deposition process.(5) An important factor is the preparation of substrate surface before deposition: its cleanness, micro – geometry and hardness.(3, 4) Therefore specimen surface was cleaned directly in the coating chamber by a steam of neutral argon radicals. The result of this chosen process were thin coatings: TiAlN-multilayer and AlTiN deposited on the high - speed steel Vanadis 4.

Table 2. Technological parameters of deposited process.

Coat	Coat thickness [μm]	Substrate - steel	Technological parameters			
			Substrate temperature [°C]	Nitrogen pressure [Pa]	Accelerating voltage [V]	Coat period [min]
TiAlNmulti	2.43	Vanadis	480	0.25	20	
AlTiN	2.16		450		80	

Microhardness is one of the important characteristic mechanical properties of the coated parts. This characteristic was measured by static indentation method according to the Vickers method by using a load of 50g.

The structure of thin coatings on the steel substrate was observed by scanning electron microscopy. From fracture surface, obtained by brittle failure at the temperature of liquid nitrogen, thickness of thin coat was measured, too.

Calotest is a method for the assessment of thin coating thickness. The measured dimensions present coating thickness. The adhesion properties of the coated system were evaluated by scratch test. The critical load was determined on the basis of morphology of failure following the notch test.

The chemical composition profile in depth direction was performed by GDOES (Glow Discharge Optical Emission Spectroscopy) method. Emission Spectroscopy is established on the basis of assessment of qualitative and quantitative analysis specimens.

Results and Discussion

Measurements carried out on the polished surface of the substrate prepared for deposition of Ti – based system, shows that the value of R_a and R_z increases for both kinds of coating. Micro-geometry parameters of substrate and coated samples are presented in Table 3.

Table 3. Micro – geometry parameters.

Micro-geometry parameters [μm]	Before deposition	After deposition	
	Substrate	TiAlNmulti	AlTiN
R_a	0.025	0.40	0.46
R_z	0.20	3.80	4.10

The structure and EDX analysis of the coatings are presented in Figures 2 and 3. Coatings have columnar structure. The character of structure depends on technological parameters: substrate temperature, gas pressure and acceleration voltage on the substrate.[5]

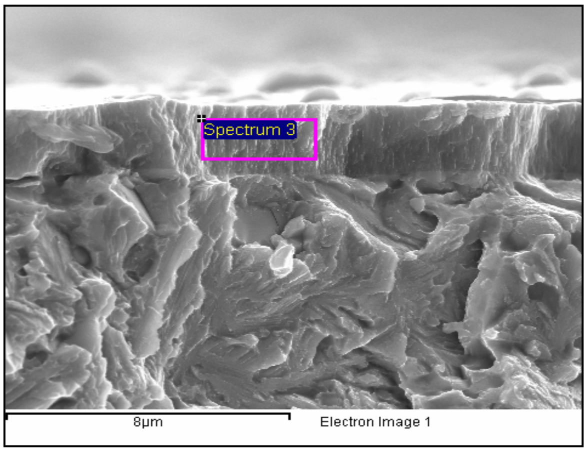


Figure 2a. The TiAlNmulti coat deposited on steel substrate, REM

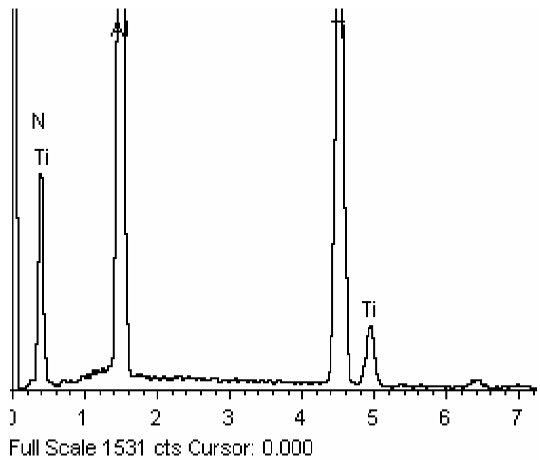


Figure 2b. EDX analysis of TiAlNmulti coating, REM

The quantitative analysis of TiAlNmulti and AlTiN coatings by EDX analysis on the scanning microscope is documented in Figures 2b and 3b. Weight average and atomic average are shown in Table 4. Existence of microparticles (Figure 4) were formed during deposition coating resulted in the increases of coated surface roughness after deposition (respective values are presented in Table 3).

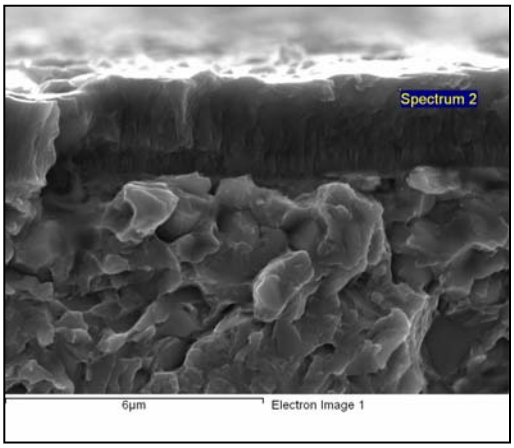


Figure 3a. The AlTiN coat deposited on steel substrate, REM

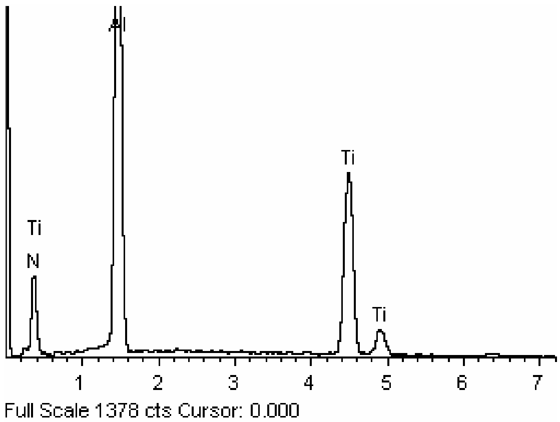


Figure 3b. EDX analysis of TiAlN coating, REM

Table 4. The quantitative element analysis of thin Coatings

	TiAlN multi		AlTiN	
Element	Weigh %	Atomic %	Weigh %	Atomic %
N	25.61	51.26	34.19	56.52
Al	11.43	11.88	31.15	26.73
Ti	62.96	36.85	34.66	16.75

Figure 4a allows one to observe microparticles which, after the deposition, were integrated in the thin coat. EDX analysis, Figure 4b, allowed to determine the respective particles consisted of Ti, Al and N.

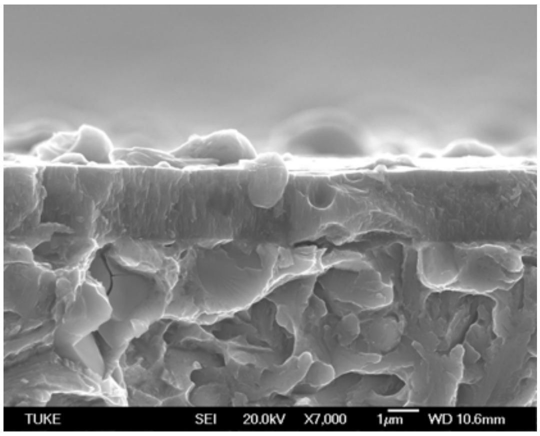


Figure 4a. Particles formed during coating, SEM

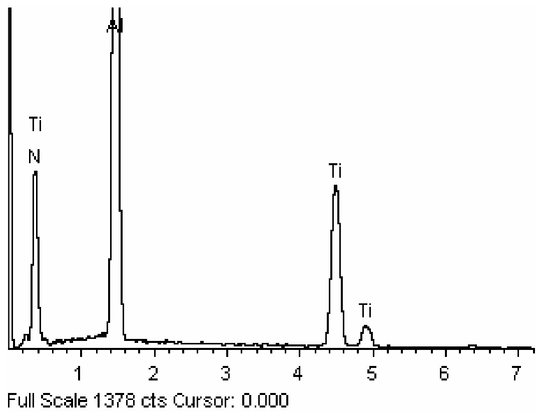
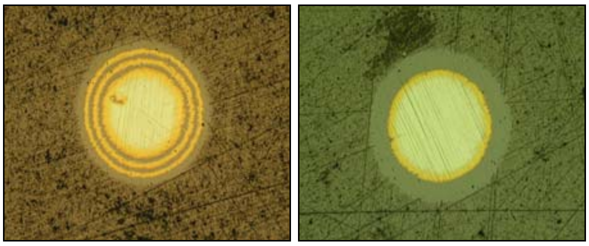


Figure 4b. EDX analysis of particles, SEM

Table 5 presents values of thin coatings thickness, which were estimated by Calotest. In Figure 5, specimen surface after Calotest was documented.

Table 5. The results of Calotest

Coating	Coatings thickness [µm]
TiAlNmulti	2.43
AlTiN	2.16



a) b)

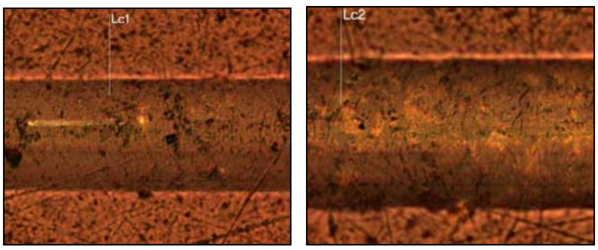
Figure 5. Calotest. The surface : a) TiAlNmulti layer b) AlTiN layer, deposited on Vanadis 4

In Table 6, the values of microhardness (according to Vickers) are assesed by using a load of 50 g. The hardness of samples was remarkably increased after deposition process. It can be implied that the thin coating with high hardness is expected to increase in wear resistance.

Table 6. Values of microhardness

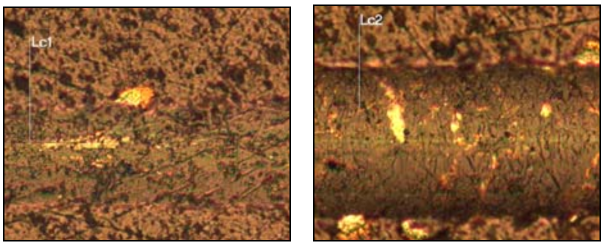
Sample	Microhardness HV 0.05
substrate	1830
TiAlNmulti	2535
AlTiN	2750

Figures 6 and 7 show the notch morphology of coating surface after the scratch test in the place where the coating had detached from the substrate. The values of critical load, presented in Table 7 were obtained by metallographic analysis of the failure of coated specimens at the place where the coating started to detach (formation first breach on the coating), Lc_1, and the place where the coating was detached from the surface, Lc_2, at a notch.



a) b)

Figure 6. Scratch test: TiAlN multi coating on the steel substrate: a) start position of coating detachment, b) detachment of coating from substrate – first adhesive break of coat



a) b)

Figure 7. Scratch test : AlTiN coating on the steel substrate: a) start of position coating detach, b) detachment of coating from substrate – first adhesive break of coat

Table 7. Results of scratch test

Coating	Lc1 [N]	Lc2 [N]
TiAlN multi	45.5	57.5
AlTiN	24.5	49.0

The GDOES profile of each element is presented in Figures 8 and 9. Behaviour of element profile in Figure 8 corresponds to multilayer coating (well visible in Figure5a). The depth profile in Figure 9 shows composition homogeneity of thin AlTiN coating – substrate system. The continuous change of dependents of element profile indicated a good quality of thin coating – substrate systems.

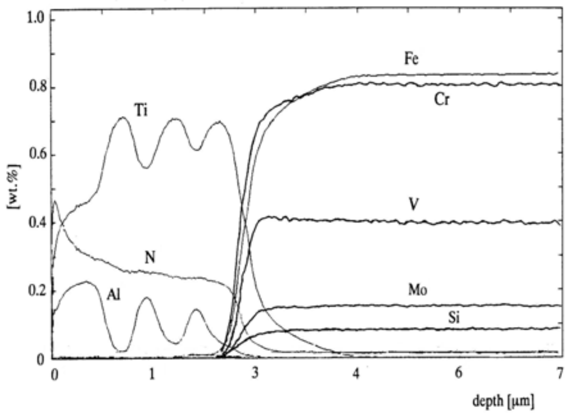


Figure 8. GDOES depth profile of TiAlN multi coating deposited on Vanadis 4.

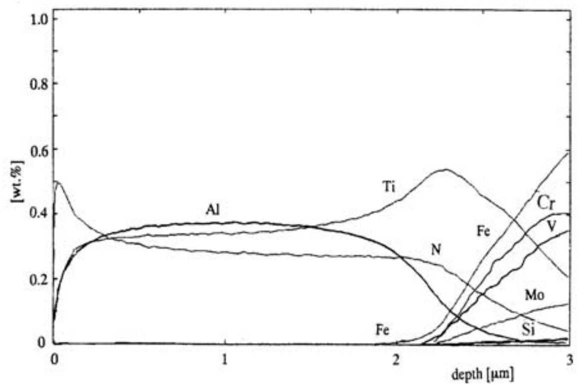


Figure 9. GDOES depth profile of AlTiN multi coating deposited on Vanadis 4.

Conclusions

1. The technological conditions of the coating deposition process have a remarkable influence on microgeometry coating surface. The presence of microparticles on the coating surface had direct influence on the increase of mean arithmetic deviation R_a and maximum height of of profile R_z

2. The hardness of samples is remarkably increased after deposition of thin coatings.

3. The structure of coatings is columnar.

4. The GDOES profile of the elements shows composition homogeneity of thin coatings - substrate system. The continuous change of dependents of profile of elements indicated the good quality of the thin coating - substrate systems.

5. The scratch test has shown good adhesion coating to substrate. According to[7] coating with Lc_2 reached 49 N and thus provides sufficient protection of structural parts against the mechanical loading.

Acknowledgement

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