EVALUATION OF TRIBOLOGICAL PROPERTIES OF HIGH-STRENGTH MATERIAL WITH DEPOSITED CrN LAYER

Mária LIČKOVÁ[1] – Erika HUJOVÁ[1] – Jozef MAJERÍK[1] – František TÓTH[2] – Pavol TÖKÖLY[1]*

[1]*Mária Ličková, Alexander Dubček University of Trenčín, Faculty of Special Technology, Pri parku 19, 911 06 Trenčín – Záblatie, Slovak Republic*

[1]*Erika Hujová, Alexander Dubček University of Trenčín, Faculty of Special Technology, Pri parku 19, 911 06 Trenčín – Záblatie, Slovak Republic*

[1]*Jozef Majerík, Alexander Dubček University of Trenčín, Faculty of Special Technology, Pri parku 19, 911 06 Trenčín – Záblatie, Slovak Republic*

[2]*František Tóth, Slovak University of Agriculture in Nitra, Faculty of Engineering, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic*

[1]*Pavol Tököly, Alexander Dubček University of Trenčín, Faculty of Special Technology, Pri parku 19, 911 06 Trenčín – Záblatie, Slovak Republic*

*Corresponding author E-mail address: pavol.tokoly@tnuni.sk

Abstract

Two basic requirements such as strength of materials and/or material requirements for the lowest mass, must be meet in the development trends of new high-strength material with high tensile strength, with fracture toughness, with ductility, with better energy-efficient, with high security and cheaper production. The highest growth is recorded in TRIP steels and alloys of Maraging - currently among the strongest materials. Availability of the martensitic steels HCM 18 (EU: 1.2709, DIN: X3NiCoMoTi18-9-5, US: 18 Maraging 300) and its features: high strength, hardness, easy workability, nearly zero dimensional changes after heat treatment, designate these steels for their using in highly stressed components in the aerospace, automotive industries, etc. The aim of the article is microstructure evaluation of HCM 18, the roughness of the substrate and selected CrN coating, evaluation of tribological properties (scratch test) and the wear rate (volume loss of material).

Keywords: high-strength material, HCM 18, thin layer, CrN coating, tribological properties.

1 Introduction

Weight reduction of machinery, improving the dynamic parameters in varying loading conditions in conjunction with their energy savings in operation can be efficiently carried by integrating multiple high-tech features in one product. Increasing the durability and reliability of machine components requires finding innovative ways of creating advanced materials with high yield strength, tensile strength, fracture toughness and ductility. Therefore, the development of new high strength steels and their other improvements continues. Particularly in the automotive, aviation, aerospace and shipbuilding industry will required lighter and stronger structural components, with improved energy efficiency while reducing emissions and pollution, increased security and cheaper production.

The primary importance of the use of high-strength material is to reduce the supporting cross-sections (satisfy the requirement of sufficient rigidity), and the total weight reduction of machinery. There are two basic criteria (not enough to know the absolute values of Rm and Rp0.2 – Table 1) [1, 2]:

a) high-strength materials – it takes into account the stiffness of the body:

$$\frac{R_m;R_p0,2}{E} \geq \frac{1}{150} \qquad (1)$$

b) material requirements for the lowest weight (aircraft, etc.) – demanding cyclically loaded components, significantly it manifests loading of centrifugal forces and inertia forces (ρ - density):

$$\frac{R_m;R_p0,2}{\rho} \geq 0,2 \qquad (2)$$

Table 1 *A comparison of selected high-strength materials properties according to relationship (1), (2)*

Materials	R_m [MPa]	R_p0,2 [MPa]	R_p0,2/E [-]	R_p0,2/ρ [Nm/kg]
STN 41 6341	1800	1450	1/145	0,19
98Ni300grade	1990	1960	1/95	0,24
TiAl5CrFeMo	1500	1400	1/58	0,30

Table 1 shows that steel 16341 is beyond the capabilities of conventional steel processing, and therefore the advanced high-strength steels are used in other ways to influence the structure [3, 4, 5]:

a) TMP – thermomechanical processing (purposefully controlled by a combination of shaping and phase transformations), low/high thermomechanical processing - LTMP/HTMP, Isoforming,
b) hardening martensitic matrix (maraging steels: VACO 180 – Bolzano, VACUMAR),
c) deformation induced martensitic transformation (TRIP steels),
d) same nonferrous alloys [1, 2]:
    - corrosion resisting: on basis Ni – Monel, Inconel, Incoloy; on basis Co – Stellit, MP, Vitallium,
    - heat resisting: on basis Ni a Co - Nimonic, LVN, MAR M, MA.

Group of researchers from Wayne State University's College of Engineering uses computers in the search for advanced materials, where their efforts led to the development of new high-strength bainitic steel with an extremely fine microstructure of ferrite and carbon stabilized austenite by isothermal hardening. This material has double the size of the yield strength, high tensile strength, almost three times the fracture toughness of existing steels, higher fatigue strength and impact resistance, better durability, lower weight. Independent tests have shown excellent results in improvised explosive ballistic attacks, making finds application in military industry [6].
As the available solution can be used tool martensitic steels HCM 18 (19 901) for the purposes of tribological properties evaluation of deposited CrN layer – chemical composition is shown in Table 2.

Table 2 *The chemical composition of the steel HCM 18 [Wt. %]*

Steel	C	Mn	Si	Cr	Al	Ni	Cu	Mo	Co	Ti	P	S
HCM 18 (19 901)	0,025	0,04	0,08	0,06	0,12	17,65	-	4,76	7,00	0,61	0,084	0,0101

Label classification steel (HCM 18), according to US - „*18 Maraging 300*“, by EU - „*1.2709*“, by DIN – „*X3NiCoMoTi18-9-5*“. This steel has a very high strength and surface hardness, is easily workable, the curable up to 54 HRC, has virtually no change in dimensions during heat treatment. The material is commonly used for highly stressed parts in the aerospace industry, pressure vessels made from it gears, extrusion tools, cold, plastic molds and tools for pressure casting, etc. [7, 8, 9].
The aim of the article is microstructure evaluation of HCM 18, the roughness of the substrate and selected CrN coating, evaluation of tribological properties (scratch test) and the wear rate (volume loss of material).

2 Materials and methods

Steel test samples of HCM 18 are made by cutting out a circular blank of diameter D = 30 mm (Fig. 1), the chemical composition is shown in Table 2. The samples were quenched in a vacuum at 860 °C and tempered at 500 °C, after heat treatment, the samples were polished with the diamond paste with a particle size 1μm. The parameters of deposition CrN coating were realized in a company LISS, Inc., process parameters are shown in Table 3.

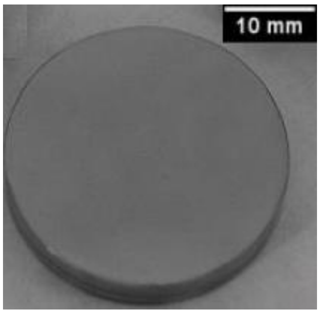


Fig. 1 *Steel test samples of HCM 18*

Table 3 *The parameters of deposition CrN coating*

Parameters	Units	CrN coating
Equipment	[-]	Platit 80
Process swagger	[-]	LARC
The voltage at the cathode	[V]	50
Substrate temperature	[°C]	220
Length deposition	[s]	2400
Pressure	[Pa]	4
Characteristic cleaning	[negative polarization of the substrate / deposition / protective atmosphere]	750V / 200V / Ar55 sccm

Before evaluating the microstructure of the coating and the substrate it was necessary to prepare the sample, i.e. to polish the sample in the transverse direction of the thin layer metallographic, then the sample was etched (to make the microstructure visibly), the thin layer region and the substrate was collected by means of REM, the thickness of the layer was measured and using EDS spectrometer were detected the elements present in the transfer layer of the microregion-substrate.

Scratch test (indentation test) was performed on UMT Tribolab, the normal force was growing (Fn = 1 to 100 N) at a constant speed as well as movement of the samples was constant. A standard Rockwell diamond indenter tip with a radius of curvature of 0.2 mm was used. An acoustic emission (AE) from the normal force Fn and the coefficient of friction value were recorded during the measurement. Violation of surface morphology was documented by light microscopy and the analysis of these results brought a value of critical load thin layer (adhesive layer).

The tribological properties of thin layer were evaluated on high-temperature tribometer with method of pin-on-disc, the counterpart was a small ball with Al2O3 and with a diameter 6 mm. Tests were performed without lubrication at room temperature and a relative humidity of 33%. The test load was 1 N, speed of the sample was 8 cm/s, and the total distance was 100 m. The calculation of the wear size was made by "ASTM Standard G99-95a" [10], volume loss of the sample surface was determined according to equation (3):

$$V_u = 2\pi R\left[r^2.\sin^{-1}\left(\frac{d}{2r}\right)-\left(\frac{d}{4}\right).\left(4r^2-d^2\right)^{\frac{1}{2}}\right] \quad (3)$$

3 Results and diskussion

The roughness of the sample was evaluated after the chemical - heat treatment, after polishing with diamond paste grain size of 1 micron, i.e. before and after application of the coating on the profilometer Mitutoyo SJ-two hundred and first. An important parameter is the arithmetic mean deviation of surface roughness (Ra = 0,42 microns) and the maximum surface unevenness (Rz = 4,27 mm). These values were measured after the coating application.

The evaluation of the microstructure (Fig. 2), of the elements contained in the thin layer (FIG. 3) and the layer thickness measurement (Table 4) were carried by highly distinctive Scanning Electron Microscopy JEOL JSM7600F.

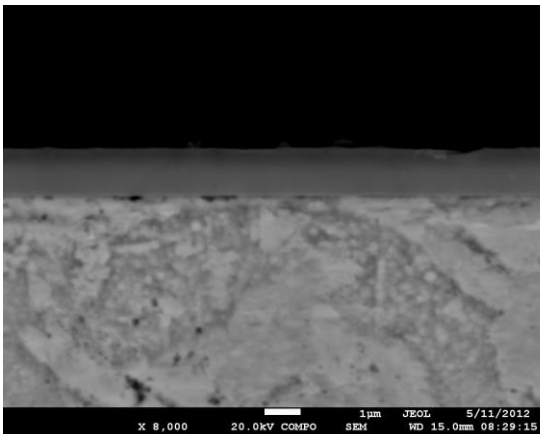


***Fig. 2** Microstructure-substrate interface layer*

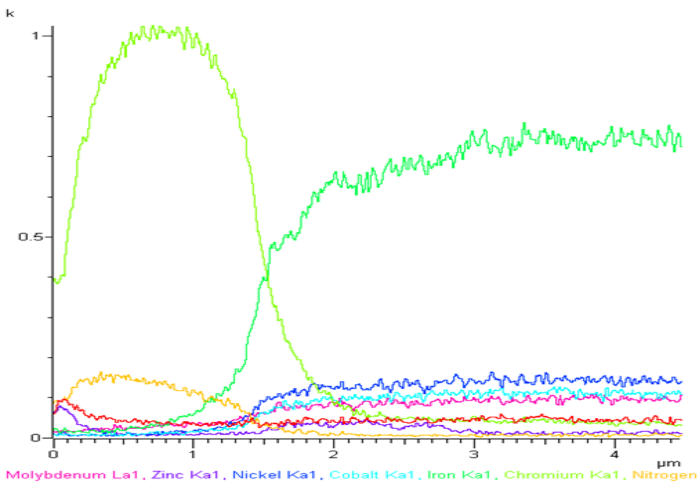
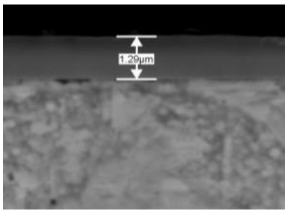


***Fig. 3** Elements contained in the deposited layer CrN*

***Table 4** The layer thickness on the substrate 18 HCM (19 901)*

HCM 18 (19 901)	**Units**	**CrN coating**
Layer thickness	[µm]	1,29
		

The image evaluation scratch tracks highlighting the violation (Fig. 4) and a comparison of the signals of interest during the EA with the behaviour coefficient of friction, was determine a critical loads damaging of the thin layer. The first significant change signal usually indicates the start of the infringement of the coating and the significant change of the friction coefficient during the measurement usually occurs on the first substrate detection., The AE signal was not recorded in the scratch test (Fig. 5), the behaviour and value of the friction coefficient is shown in Fig. 6.

***Fig. 4** Scratch test on HCM 18 coated with CrN*

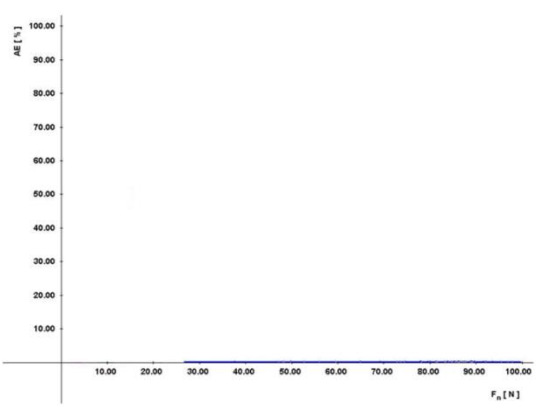


***Fig. 5** The behaviour of AE in scratch test*

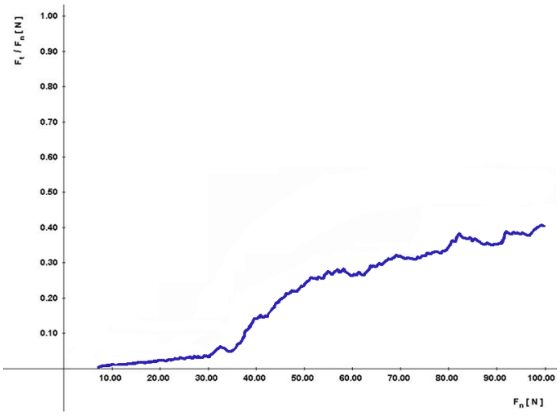


***Fig. 6** The behaviour of friction coefficient*

During the assessing of the CrN coating on the substrate HCM 18 were the critical load as follows: normal load for the first violation of layers F_{n1} = 27 N, load at layer peels F_{n2} = 35 N.

A functionality of the friction coefficient was measured at a load of 2 and 5 N, the results are presented in Fig. 7 – it shows the differences are minimal, and at a load of 5 N, there is the stabilization of the measurement course to the end of almost constant. The size of wear layers CrN is shown in Fig. 8.

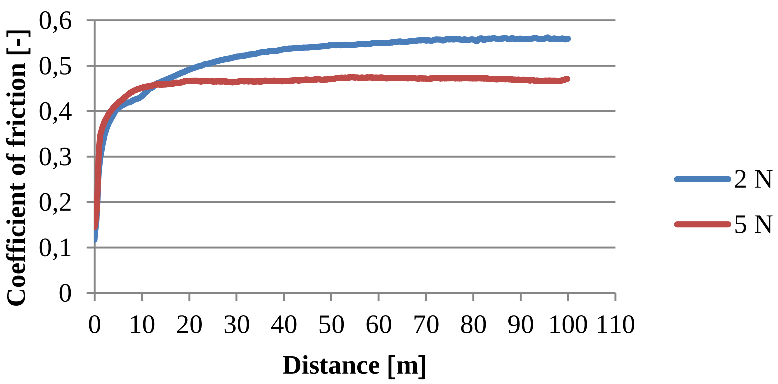


***Fig. 7** The behaviour of friction coeffiecient on HCM 18 subtrate*

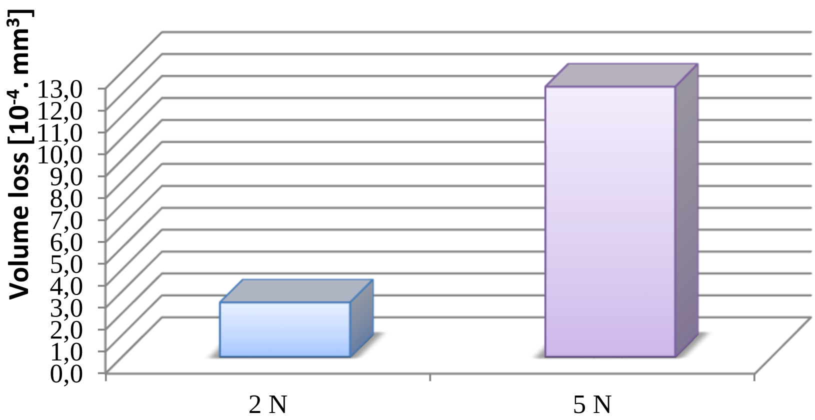


Fig. 8 *The volume of decline on CrN layer*

The evaluation of the tribological properties of CrN deposited on a substrate layer 18 HCM showed impaired adhesion, which may be caused by a very small layer thickness (1.29 mm), the signal from the AE was not recorded. Coefficient of friction layer at a load of 5 N after stabilization showed almost constant value.

4 Conclusion

To verify and confirm presented results, find the cause of faults in the measurement of the AE scratch test, it is appropriate to repeat the experiment measurement in order to formulate conclusions with the correct information value.

Acknowledgements

This paper is prepared within the project VEGA 1/0227/15 Study of tribological characteristics of the new high hard coatings on materials suitable for gearings.

References

[1] [27.5.2016], http://kmi2.uniza.sk/wp-content/uploads/2010/10/K-2.pred.pdf
[2] [27.5.2016], http://umi.fs.cvut.cz/wp-content/uploads/2014/10/01_pm_vyskopevne_a_vysokolegovane_oceli_a_slitiny_ni_a_co.pdf
[3] [27.5.2016], http://www.matweb.com/search/datasheetText.aspx?bassnum=M1820A
[4] N. Fonstein: Advanced High Strength Sheet Steels: Physical Metallurgy, Design, Processing, and Properties, Springer, 2015, 396 p., ISBN 978-3319191645
[5] M. Y. Demeri: Advanced high-strength steel: Sciencie, technology and applications, ASM International,2013, 300 p., ISBN 978-1627080057
[6] [27.5.2016], https://www.sciencedaily.com/releases/2012/11/121105140207.htm
[7] F. L. Campbell: Manufacturing Technology for Aerospace Structural Materials, Elsevier Science, 2006, 616 p., ISBN 978-1856174954
[8] P. Geck: Automotive Lightweighting Using Advanced High-Strength Steels, Society of Automotive Engineers Inc, 2014, 114 p., ISBN 978-0768079784
[9] S. Keeler, M. Kimchi, G. Coates: Advanced high-strength steels application guidelines version 5.0, Amazon, 422 p.
[10] ASTM STANDARD G 99-95a: Standard test method for wear testing with Pin-on-Disk apparatus, 2000