Comparison of surface layer properties of AISI D2 and Vanadis 6 hardened tool steel

Porównanie właściwości warstwy wierzchniej utwardzonej stali narzędziowej AISI D2 i Vanadis 6

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Selected properties of the surface layer (SL) of AISI D2 and Vanadis 6 tool steels at hardness of 60 ±1 HRC, after grinding and hard turning with subsequent slide burnishing are presented. The influence of the mentioned mechanical treatments in relation to the geometrical structure, microstructure and stresses level in SL for tested steels were determined.

KEYWORDS: tool steel, grinding, slide burnishing, surface layer, surface geometrical structure, stresses

Machining processes should be efficient, affordable and environmentally friendly. In traditional manufacturing processes the finishing operation of tools and machine parts, of which hardness after heat treatment is higher than 45 HRC and even 60 HRC, is often grinding. For several decades in many industries, e.g. automotive, bearing, moulds and dies manufacturing, processes of grinding are gradually replaced by so called "hard machining" – HM [1].

Not always, however, HM meets the requirements for the expected surface quality. The method used to overcome these technological barriers is burnishing, which is applied both to the turned and milled surfaces [1]. This process involves the use of local plastic deformation produced in the surface layer (SL) of the workpiece due to the contact action of a hard and smooth tool (spherical, roller or other) on the surface [2]. As a result of this, the set of attributes, so called surface integrity, is given to the formed SL of workpieces – this have a positive influence on the performance characteristics of products (fig. 1) [3, 4].

Use of burnishing tools on conventional and numerically controlled cutting machines allows for shaping and finishing operations on a single workstation. In many cases, the grinding operation at another post is unnecessary, which reduces production costs. Within the framework of one fixing, further machining and burnishing operations are carried out with the tools fixed to the tool head of the machine tool. Such a method of finishing by burnishing is also advantageous in terms of shape-dimensional accuracy [5].

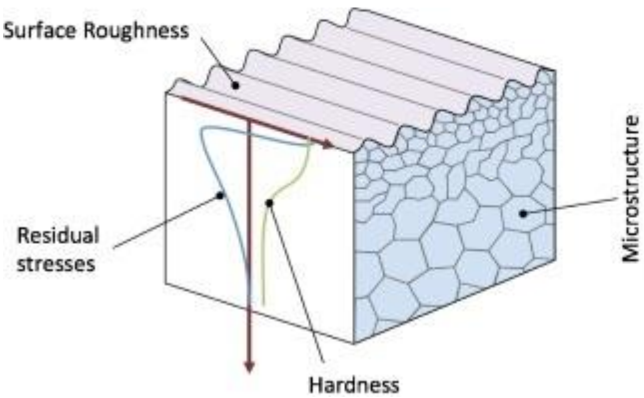

Fig. 1. Selected parameters characterizing the SL according to [4]

In the case of cold working tools, their tribological wear resistance is important, which is determined by, inter alia, properties of their SL. These properties are formed by mechanical processes, which is usually preceded by heat treatment. Also be noted that the impact on the wear of cooperating elements is due to the surface roughness and hardness of their SL. There are many types of mechanical finishing treatments that allow for the formation of an arbitrarily smooth surface, though not always guarantee the proper properties of the SL itself.

The results of this study refer to the comparison of the SL properties of two types of tool steels after grinding and hardening with subsequent slide burnishing.

Experimental

Two types of high-alloyed tool steels for cold working, from Bohler Uddeholm Company, manufactured by conventional and powder metallurgy P/M methods were selected. The chemical composition is given in table I. Shafts of Ø32 diameter of the selected materials were pre-treated by turning and then heat treated (hardened and tempered according to the manufacturer's recommendations) until a hardness of 60±1 HRC was achieved.

The microstructure of investigated steels, consisting mainly martensitic structure and undissolved carbides is shown in fig. 2.

Grinding of a cylindrical surface with electrocorund grinding wheel 1-350x50x127 type designated 99A60K7VE01-35 was carried out on a RUP 28 grinder using cooling with 2% Syncon PGA coolant solution in

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tap water. The following grinding parameters were adopted: peripheral speed of the wheel v_s 30 m/s, table feed speed v_f = 0.2 mm/min, working engagement a_e = 0.02 mm.

a) b)

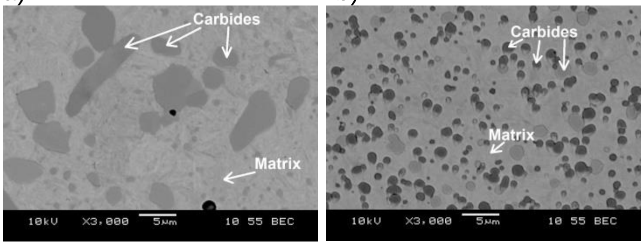

Fig. 2. Microstructure of tool steel: *a*) conventional – AISI D2 (Sverker 21) and *b*) P/M – Vanadis 6

TABLE I. Chemical composition of tested steel and method of their preparation

Steel	Chemical composition						Com-ments
	C	Si	Mn	Cr	Mo	V	
AISI D2 (Sverker 21)	1.55	0.3	0.4	11.8	0.8	0.8	*
Vanadis 6	2.1	1.0	0.4	6.8	1.5	5.4	**

* Steel made by a conventional metallurgy technology.
** Steel made by powder metallurgy technology.

In turn, turning as pre-burnishing operation and proper burnishing were performed on a numerically controlled NL2000 SY turning-milling center from Mori Seiki Company. Parameters of the operation are given in table II and table III. Slide diamond burnishing was carried out using diamond tool designed and currently manufactured at Institute of Advanced Manufacturing Technology. Working part of this tool, in shape of spherical ball of 1.5 mm diameter was made of polycrystalline diamond composite with ceramic bonding phase, namely Ti_3SiC_2 – and was presented in the paper [6].

Surfaces of both steels after selected mechanical processes were measured in 3D using contact laboratory profilometer TOPO 01P. It was equipped with a 1 mm measuring head, diamond tip with a radius of 2 μm and a cone angle of 90º. Data analysis and surface topography were developed in Mountain Map v.7 by Digital Surf.

Metallographic structures were observed with a Scanning Electron Microscope (SEM) JEOL type JSM-6460LV.

TABLE II. Turning parameters of cylindrical surfaces of investigated tool steels with PCBN insert NP-DCGW11T-302GA2 MBC020 type made by Mitsubishi

Steel	Speed v_c, m/min	Feed *f*, mm/rev	Depth *ap*, mm
AISI D2 (Sverker 21)	100	0.08	0.1
Vanadis 6	150	0.09	

TABLE III. Burnishing parameters of cylindrical surfaces of investigated tool steels

Steel	Speed *v*, m/min	Force *F*, N	Feed *f*, mm/rev	Infeed of working part, mm
AISI D2 (Sverker 21)	40	180	0.02	0.2
Vanadis 6		160		

The X-ray diffraction (XRD) measurements, on samples cut off by electro-discharge method from individual shaft segments (as shown in fig. 3*a*), were performed with a PANalytical Empyrean diffractometer using copper radiation (λCu = 1.5406 Å). Phase analysis was performed on the basis of the crystallographic ICDD PDF4+ 2016 database.

The residual stresses measurements were performed on the same diffractometer using a 5-axis table. Measurements were done in 4 directions. Due to volume limitations, the paper contains results for 2 directions defined by the angle φ: 0°, 135° (fig. 3*b*). Residual stress in the material were determined on the basis of measurements obtained for the α-Fe phase reflection (211): 2θ = 82.17°, d_{hkl} = 1.1721 Å. For the measurement and analysis of residual stresses, the $\sin^2\psi$ method was used, in which the stresses are defined by the following equations:

$$\sigma = E\,\varepsilon$$

$$\varepsilon_1 = 1/E\,(\sigma_1 - \sigma_2\,\nu)$$

$$\varepsilon_2 = 1/E\,(\sigma_2 - \sigma_1\,\nu)$$

where: σ – residual stresses, ε – lattice strain, E – Young modulus, ν – Poisson's ratio.

For calculations, Young's modulus and Poisson's ratio for the main phase – Fe, for reflection (211) were used. In both cases, the Young's modulus value was 211 GPa and Poisson's ratio 0.2882 [7].

a)

b)

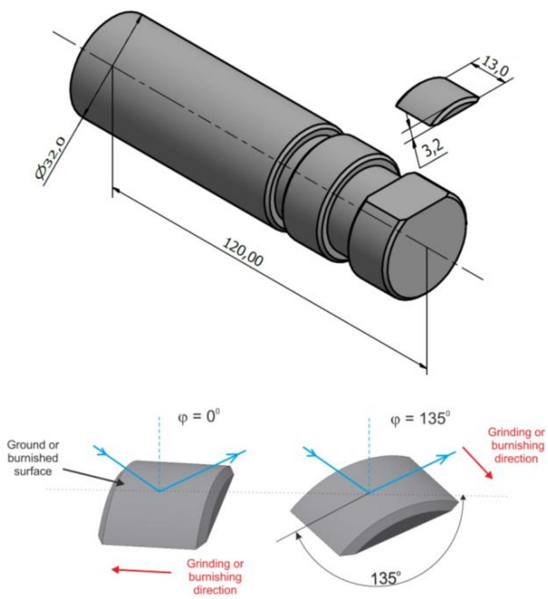

Fig. 3. Dimensions of shafts subjected to mechanical finishing processes (*a*) and the scheme of stresses measurement in two directions determined by the angle φ (*b*)

Results

Results of the surface geometrical structure (SGS) measurements after mechanical finishing treatments both for Sverker 21 and Vanadis 6 are summarized in figs. 4 and 5.

The *Sa* values obtained for the Sverker 21 steel were 0.22 μm and 0.14 μm – respectively after grinding and turning-burnishing. As a result of the surface treatment processes carried out on Vanadis 6 steel samples, a topography for which *Sa* values were 0.35 μm and 0.25 μm – respectively after grinding and turning-burnishing. In the case of both tool steels, values of the *Sa* parameter after turning before the burnishing were about 1 µm.

Microstructures of the SL of investigated steels after selected mechanical finishing treatments are shown in figs. 6 and 7. In the case of turned surfaces and then burnished, the subsurface zone achieved by large deformation of the SL is visible.

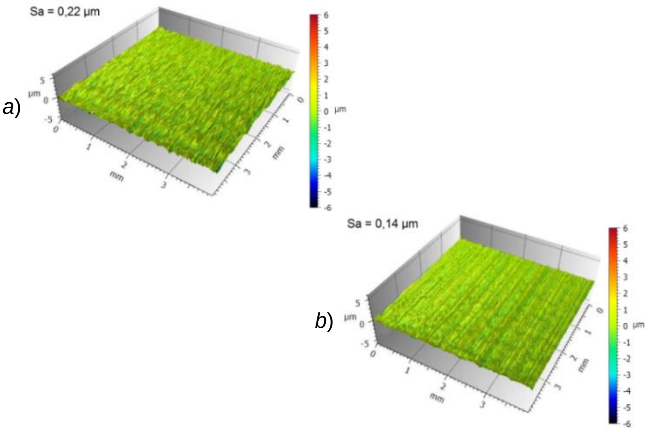

Fig. 4. 3D view of Sverker 21 steel surface topography after: *a*) grinding and *b*) turning-burnishing

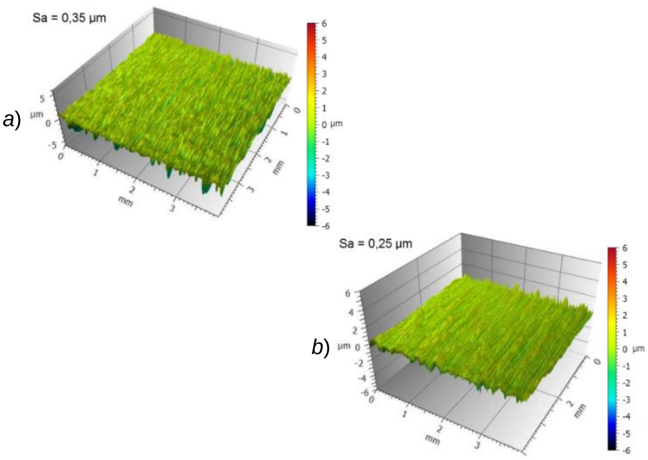

Fig. 5. 3D view of Vanadis 6 steel surface topography after: *a*) grinding and *b*) turning-burnishing

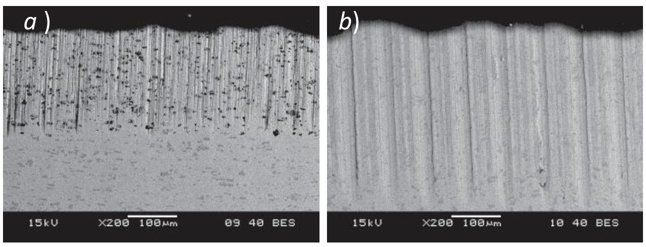

Fig. 6. Cross-sectional SEM micrographs of SL of Sverker 21 steel samples subjected to: *a*) grinding and *b*) turning-burnishing

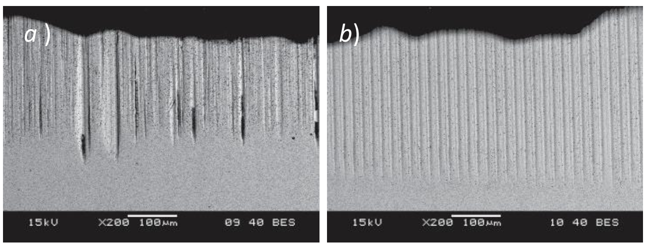

Fig. 7. Cross-sectional SEM micrographs of SL of Vanadis 6 steel samples subjected to: *a*) grinding and *b*) turning-burnishing

In turn, in table IV and table V selected results of residual stress measurements (determined for the *α*-Fe phase in investigated steels) after mechanical finishing are given.

TABLE IV. Results of stress measurements after selected mechanical surface treatments for Sverker 21 steel

Direction specified by angle *φ*	Process	
	Grinding	Turning-burnishing
0°	-1930 ±341	-2,769.3 ±397
135°	-768.8 ±156	-979 ±184

TABLE V. Results of stress measurements after selected mechanical surface treatments for Vanadis 6 steel

Direction specified by angle *φ*	Process	
	Grinding	Turning-burnishing
0°	-1751.2 ±341	-293.3 ±215
135°	-809.5 ±57	-1481 ±234

The results obtained for the Sverker 21 steel indicate an increase in the absolute values of the stress level, which ranged from 27% to 43% depending on the measurement direction determined by the angle *φ* in favor of a sequential treatment involving turning-burnishing.

For Vanadis 6 steel, the measurement in the direction of *φ* = 135° also showed an increase in the absolute value of the stress level, which in this case amounted to approximately 83% in favor of a variant involving burnishing. In turn, the measurement in the direction *φ* = 0° showed a decrease in the absolute value of the stress level to about -295 MPa.

Concluding remarks

The presented results refer to the comparison of selected properties of hardened AISI D2 and Vanadis 6 tool steel after mechanical finishing. They indicate the possibility of using a sequential turning-burnishing process to forming SL properties of steels made by conventional and P/M technology.

In the aspect of SGS, microstructure and level of residual stresses, the use of turning-burnishing treatment compared to grinding allows forming the desired SL properties of both types of investigated tool steels.

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