UDK 620.18:621.785.53

B. VASILJEVIĆ, B. NEDIĆ

Possibility of Application of Tribometric Investigations Nitrided Layers

In the paper are presented measurements of metallographic and tribological characteristics of nitrided layers of screw drills, obtained by large number of different nitriding procedures and regimes. For each applied procedure the measurements were done of depth, micro-hardness and microstructure of nitrided layers, and then the cutting forces and wear were measured of drills in machining by drilling. By measuring of friction forces and coefficient, and wear scare during investigations on the PIN-on-DISC tribometer, the tribological characteristics were obtained of the nitrided layers, which are compared in this paper with results of metallographic investigations.

Keywords: *Nitriding, Cutting tools, Metallographic and Tribological investigations*

1. INTRODUCTION

Considering that the phenomena on contact surfaces of tool and working piece are of decisive influence on the function that the tool is performing, the development occurred of the whole series of different procedures of tool surfaces modifications, in order to increase their life.

In high-speed cutting steels in the surface layer occur changes in structure and chemical composition. The carbon-nitrided layer is formed whose thickness depends on saturation of melt, temperature and process duration. Beneath the carbon-nitrided layer the diffusive layer exists, which represents the multi-phase zone, in the form of αsolid solution, carbide, nitride, and carbon-nitrided phases, in which dominate phases of the Fe_3 (CN) type. Increase of temperature and process duration time of nitriding, lead to growth of carbon-nitrided layer, what causes brittleness, irregularity and formation of carbon-nitride net along the grain boundaries.

For high-speed cutting steels that are used for manufacturing the cutting tools, thickness of the carbon-nitride layer should not be greater than 1-3μ [1], while the diffusive zone thickness is within limits 0.05 - 0.12 mm. By cutting tools nitriding one achieves the increase of surface layers hardness, what is directly related to increase of tools cutting part life. In this way, the tool costs are reduced, the possibility is created for substitution of "higher-valued" high-speed cutting steels (cobalt steels) with high-speed cutting steels of lower properties (the molybdenum steels), which then can also machine the hardly machinable materials, etc. Increase of wear resistance at elevated temperatures enables application of tools with higher cutting speeds, as well as with larger chip cross-sections.

2. EXPERIMENTAL INVESTIGATIONS

Realized experimental investigations of nitrided cutting tools were performed on drills made of molybdenum steel - S-6-5-2, of 4.7 mm diameter. The nitriding procedures were:

Procedure 1. Nitriding in melt of cyanide-cyanite salts, at temperature of 560°C, with nitriding times of 5, 10, 15, 20, 25, and 30 minutes.

Procedure 2. Nitriding in the melt of salts alkaline-cyanites and alkaline-carbonates without cyanite salts, with nitriding times of 5, 10, 15, 20, 25, and 30 minutes. (TENIFER).

Procedure 3. Gas nitriding in ammonia at temperature of 520°C, with nitriding times of 30 and 60 minutes.

Procedure 4. Gas nitriding in mixture of ammonia and nitrogen at temperature of 520°C, with nitriding times of 60 and 120 minutes.

Dr Bogdan Vasiljević,
Dr Bogdan Nedić,
Faculty of Mechanical Engineering
Kragujevac

Procedure 5. Gas nitriding in mixture of ammonia and exo and endo gas in shaft furnace DEGUSA, with nitriding times of 30 and 60 minutes.

Procedures 6 and 7. Gas nitriding in mixture of ammonia (50%) and endo-gas (50 %), nicotriding, procedure 6 with nitriding times of 15, 30, 90 and 150 minutes, and procedure 7 with nitriding times of 15, 25, 35, 45, 60, 90, and 120 minutes.

Procedure 8. Nitriding in melt of cyanide-cyanite salts (procedure 1) and vapor oxidation, with nitriding times of 5, 10, 15, 20, 25 and 30 minutes.

Procedure 9. Vapor oxidation in preheated water vapor at temperature of 520°C and over-pressure of 20 mbar, with nitriding time of 30 minutes.

Procedure 10. Ion nitriding, plasma nitriding at temperature of 400°C, with time for keeping in nitrogen atmosphere of 30 minutes.

Procedures 11, 12 and 13. Coatings of TiN, TiAlN, TiZrN.

Procedure 14. Without nitriding (14a: S-6-5-2 not-nitrided drills, 14b: S-6-5-2-5 not nitrided).

3. INVESTIGATION RESULTS

Within this paper is presented an analysis of the portion of results of very extended investigations of the nitrided tools characteristics, that are related to metallographic and tribological investigations, like: micro-hardness (fig 1), nitrided layer depth (fig 2), micro-structure (fig 3 to 10), cutting forces, tool wear, friction and wear coefficients of the tool nitrided layer surface.

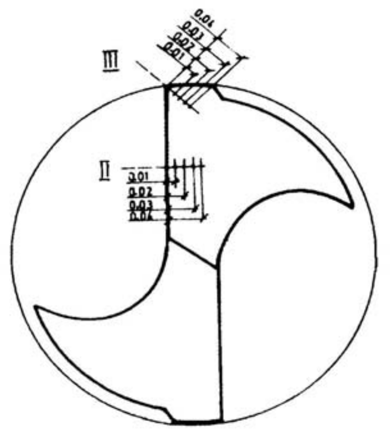

Figure 1. Measuring position of micro-hardness

Measurement of cutting forces and cutting forces' moments and the tool wear were done during drilling of the machined piece made of steel 42CrMo4, in tempered state Rm = 83±1 daN/mm^2, at machining regimes: n = 955 rpm, s = 0.1 mm/rpm, and drilling depth of ≈ 3d.

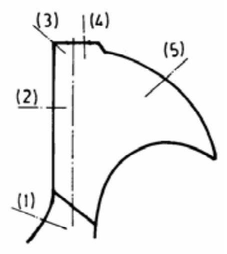

Figure 2. Measuring position of nitrided layer depth

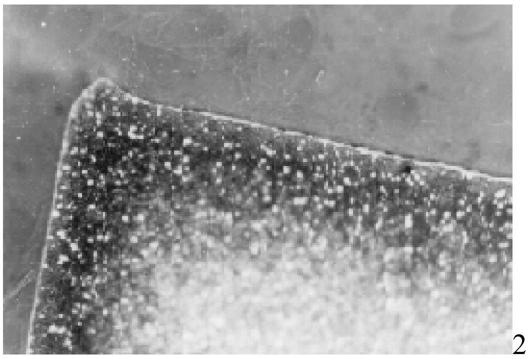

Figure 3. Nitriding in melt of cyanide-cyanite salts (10 min)

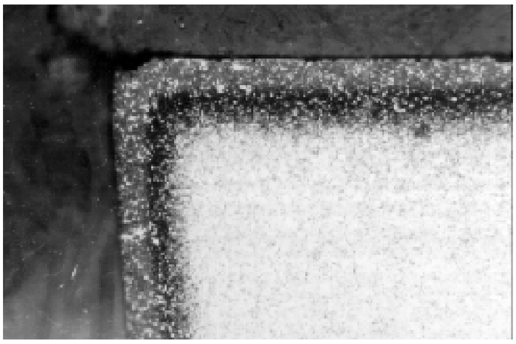

Figure 4. Nitriding in the melt of salts alkaline-cyanites and alkaline-carbonates without cyanite salts (20 min)

Figure 5. Gas nitriding in ammonia (60 min)

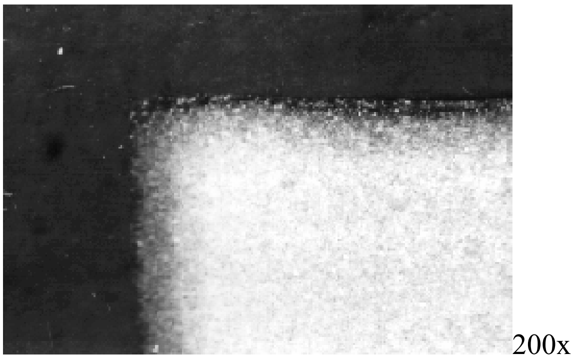

Figure 6. Gas nitriding in mixture of ammonia and nitrogen (60 min)

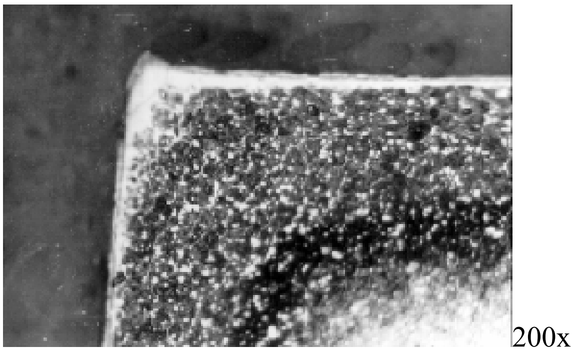

Figure 7. Gas nitriding in mixture of ammonia and exo and endo gas in shaft furnace DEGUSA (30 min)

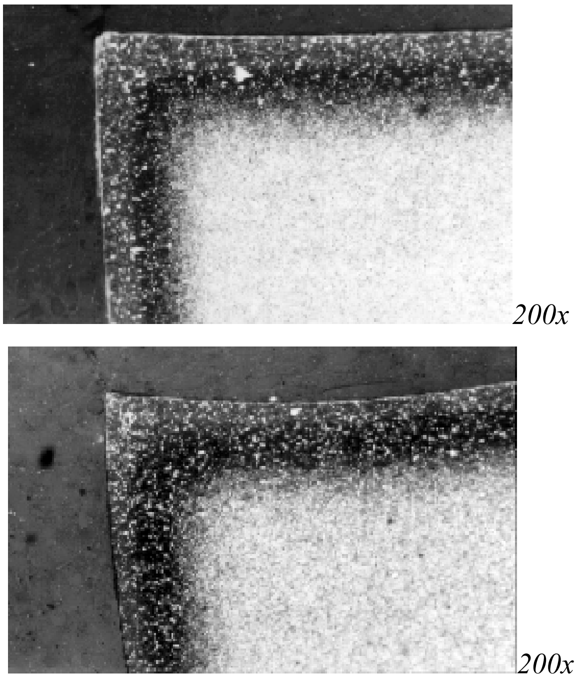

Figure 8. Gas nitriding in mixture of ammonia (50%) and endo-gas (50 %), nicotriding (90 min)

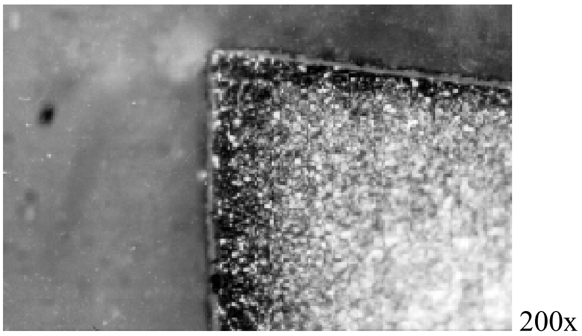

Figure 9. Nitriding in melt of cyanide-cyanite salts (procedure 1) and vapor oxidation (25 min)

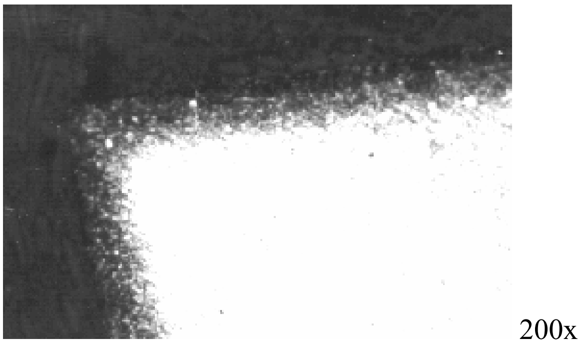

Figure 10. Ion nitriding, plasma nitriding at temperature of 400 ℃ (30 min)

Tribological investigations of the friction coefficient and wear scare width of the drill's surface layer were performed on the TPD-93 tribometer "Pin-on-disc", with contact at a point of the drill's body with disc made of 50CrMo4 of hardness 240 HB, with sliding velocity 0.6 mm/s, and external load of 30 N, fig. 11 and 12. During these investigation as "lubricant" was applied cutting fluids: UBA-5 4%.

A small part of voluminous results is presented in Table 1, from which one can obtain the basic data about metallographic and tribological characteristics of nitrided layers.

Tribological investigations of nitrided tool surfaces were done at the ending point of the grooved portion of the drill. By measuring hardness at that place, the significant deviations were noticed, so drills were grouped depending on hardness as:

- drills nitrided by procedures I, II, VII and IX, with hardness 64 HRC,
- drills nitrided by procedures IV, XI, and XII, with hardness 58-61 HRC,
- drills nitrided by procedures III, X, and XIII, with hardness 55-56 HRC,
- drills nitrided by procedures V, VI, and VIII, with hardness 50-52 HRC.

Table 1. Metallographic and tribological characteristics of tested nitrided layers

Nitriding procedure	Nitrided layer depth, *mm*	Micro-hardness $HV_{0.025}$	Core hardness $HV_{0.025}$	Micro-structure	Moment (*Ncm*) and cutting force (*N*)	Tool wear *mm*	Friction coeffic. μ	Wear scare width *mm*
I (5 min)	28	1063,88	869,63	Without diffusive and transient zon.	75 812,58	0,10	0,077	1,104
II (10 min)	20	1149,30	846,28	Diffusive zone distinctive	68,75 675	0,08	0,063	1,201
VII (15 min)	30	1113,94	802,33	ε - phase is partial	68,75 650	0,08	0,077	1,161
IX (30 min)	0,5	-	733,24	No nitrided layer	68,75 650	0,12	0,064	1,270
XIV	-	-	-	No nitrided layer		0,13	0,059	1,110
IV (60 min)	40	1266,11	871,62	No ε - phase noticed	68,75 800	0,09	0,056	1,114
XI	2	-	872,99	TiN coating	68,75 / 650	0,11	0,147	1,031
XII	-	-	656,78	TiAlN coating	75 / 675	0,16	0,075	1,223
III (30 min)	25	1080,18	761,71	No ε - phase	68,75 675	0,07	0,069	1,012
X (30 min)	-	-	848,28	No ε - phase	68,75 650	0,08	0,106	1,067
XIII	1	-	697,69	TiZrN coating	75 / 675	0,135	0,109	1,210
V (30 min)	50	1225,27	791,88	Phase weekly distinctive	65,6 650	0,11	0,055	1,138
VI (30 min)	45	1186,37	834,96	Distinctive phase	62,5 625	0,11	0,068	1,401
VIII (30 min)	10	1113,94	771,57	Broken net ε - phases	62,5 625	0,08	0,071	1,347

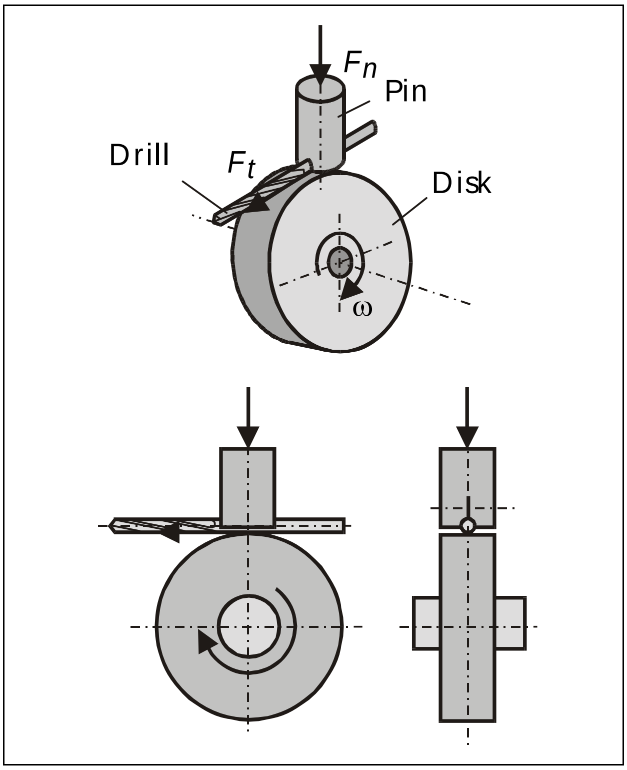

Figure 11. Measurement of the friction coefficient and the wear scare width of the nitrided layer on tribometer TPD "Pin-on-Disk"

Figure 12. Tribometer TPD-95

4. CONCLUSION

Comparative analysis of metallographic and tribological characteristics of nitrided layers of drills point to several conclusions:

- From the metallographic investigations aspect the best characteristics were obtained for procedures 4, 5 and 6 (the highest micro-hardness and nitrided layer depth), and the worst for procedures 8 and 9.
- From tribological characteristics aspect (the smallest wear scare width of the drill's surface) the best characteristics exhibited drills nitrided by procedures 1, 3, 4, 10, and the worst by procedures 2, 6, 8 and 9.
- From tribological characteristics, aspect (the smallest friction coefficient) the best properties were exhibited by drills nitrided by procedures 4, 5, and 14, and the worst drills nitrided by procedure 1, 7, and 10.
- From the aspect of the cutting forces (minimum values of the cutting force) the best properties were exhibited by drills nitrided by procedures 5, 6 and 8, and the worst drills nitrided by procedure 1.
- From the aspect of tool wear, the best properties (the minimum wear) were exhibited by drills nitrided by procedures 2, 3, 4, 7, 8, and 10, and the worst by drills nitrided by procedures 9 and 14.

Results of extended investigations have shown that by procedure IV - nitriding in ammonia and endo-gas (nicotriding) for the procedure duration of 25 minutes – the best tool properties are achieved.

These investigations have shown that by procedures of deposition the hard coatings TiN, TiAlN and TiZrN one does not obtain good results that would point to reasons for their application. For these drills the cutting forces were larger, wear is higher and so are the friction coefficients values. Reasons for this should probably looked for in thermal stresses that appear during the coatings depositions.

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