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TOOLS, POWDERS, PASTES

The Fundamentals of Synthesis of Modified Layers on Cutting-Tool Hard Alloys

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Abstract—A methodology has been elaborated for controlling the structure formation in cutting-tool hard alloys during the plasma modification of their surfaces in order to produce an ultradispersed structure in the surface layer providing a high level of performance characteristics. The paper presents a block diagram of synthesis of modified layers with an ultradispersed structure, which includes a combination of theoretical, experimental, and technological investigations. The tool life testing of the modified tools has been carried out.

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The method of surface modification of hard-alloy cutting tools by heating with a highly concentrated plasma jet is finding ever-widening applications in industry [1–3]. In our earlier investigations we demonstrated the possibility of producing a modified layer with an altered structure [4] and improved hardness and fracture toughness values [5] on working surfaces of hard-alloy tools. However, there have been no publications on how to choose the appropriate process parameters of plasma modification of hard-alloy tool surfaces in order to provide there an ultradispersed structure with a high level of performance characteristics.

To construct, analyze, and adjust the automatic control system for plasma torches to be used for surface modification, we should first elaborate a methodology of controlling the structure formation in hard alloys. Similar methodologies are currently available for other methods of surface treatment—plasma spraying [6, 7], laser technologies [8], plasma hardening [9, 10]; however, neither in this country nor abroad there have been such publications regarding the use of plasma action for the ultradispersed structure formation in the surface layer of hard alloys.

Based on our previous comprehensive investigations of thermal processes, structure, phase composition, crystal structure parameters, fracture toughness, and wear resistance of hard alloys with a modified surface layer [4, 5, 11] as well as in view of the recommendations proposed in [6–10, 12], we have come up with a block diagram of synthesis of modified surface layers on hard alloys, with a preset level of performance characteristics (Fig. 1). It represents the sequence of research stages and the tasks to be achieved at each stage. The main stages of the synthesis algorithm are the following:

1. Assigning preset values of temperatures and stresses at the nodes of a finite-element mesh in modeling.

The main controllable of the plasma treatment process in the general case [2] are the surface layer heating temperature T and cooling rate W. As found earlier [2], the cooling rate in plasma treatment processes (where no additional cooling fluids are used) can be 10^4 to 10^6 deg/s. Figure 2 shows the regions of possible realization of various plasma treatment processes depending on a ratio between T and W.

In the elaboration of a plasma treatment technology the quantities T and W are not the direct-control parameters but serve as complex parameters that are influenced by numerous factors: plasma jet power (current I, voltage U); treatment rate v (the plasma torch traveling speed); pressure p_g and flow rate Q_g of plasma gas; water pressure p_w and flow rate Q_w for plasma torch cooling; treatment distance h; shape and dimensions of a tool or workpiece to be treated; thermal and mechanical characteristics of the material to be treated (γ, λ, α, E, H_V, σ_Y); and the plasma torch design features.

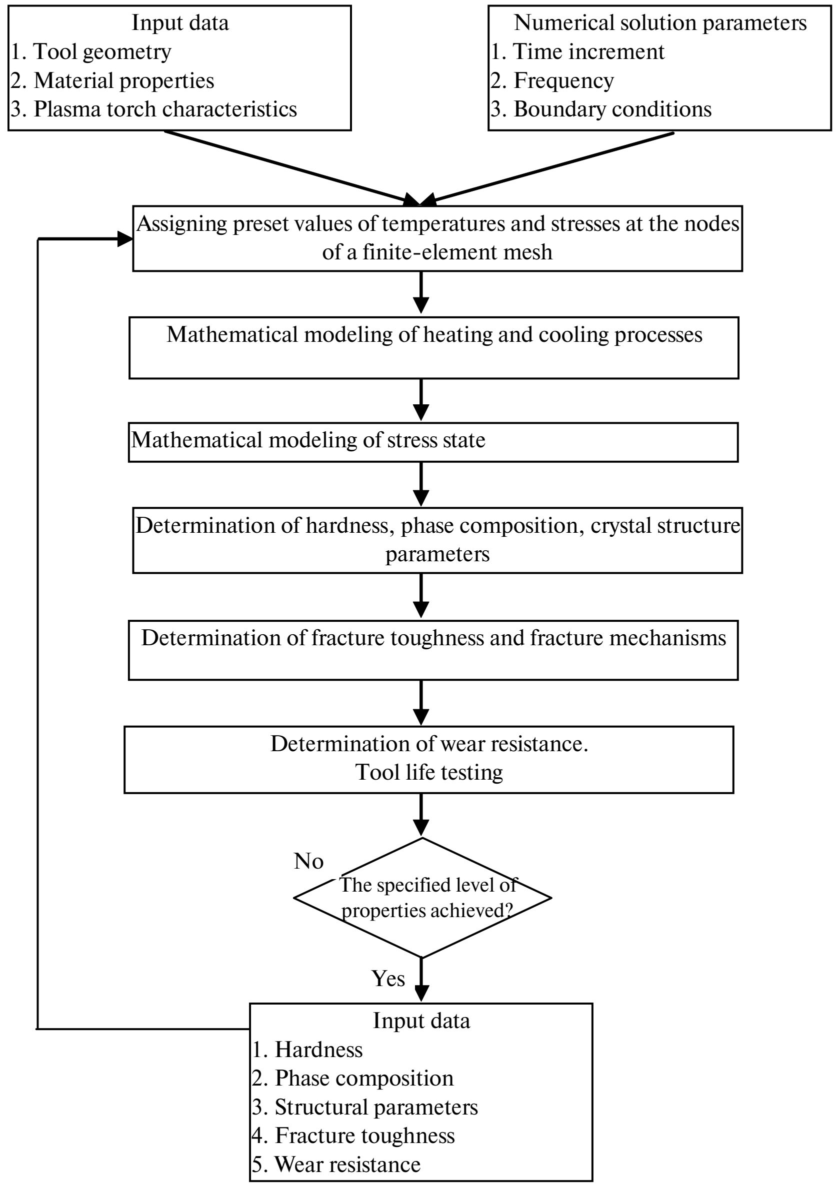


Fig. 1. A block diagram of synthesis of modified layers in cutting-tool hard alloys.

The main task for the plasma modification of a hard-alloy tool is to provide a micro- and nanostructuring of the surface layer with the formation of an ultradispersed structure. Optimal conditions of such treatment lie in the region *4* (see Fig. 2).

2. Calculation of optimal conditions of plasma treatment by using thermal models of operation. The task for investigations at this stage is to construct heat fields induced by the plasma jet action on hard alloy inserts (Fig. 3) and select optimal parameters of the plasma treatment by following the procedure given in [11].

3. Assessment of stress state by the methods of X-ray diffraction study. In doing so, stresses should be determined separately in carbides and binder.

4. Determination of hardness H_V, structural parameters (mean size of carbide particles $\bar{d}$) on reference specimens. Also, the X-ray diffraction study gives the lattice spacing of the cobalt phase a (which represents the extent of dissolving of carbides and saturation of the binder with tungsten and carbon) and the block size D [4].

5. Determination of fracture toughness K_{Ic} through local microtests using a Vickers indenter. A microfractographic study of broken surfaces is performed to clarify fracture mechanisms [5].

6. Tool life testing.

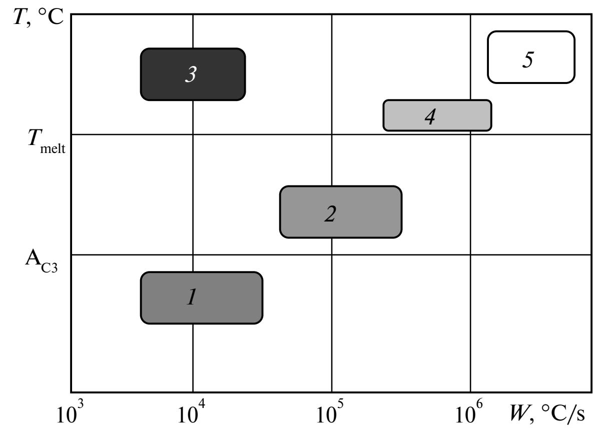


Fig. 2. Regions of optimal implementation of the plasma surface modification processes: *1*—plasma tempering; *2*—plasma quenching; *3*—plasma microfusion; *4*—plasma nanostructuring; *5*—plasma amorphization.

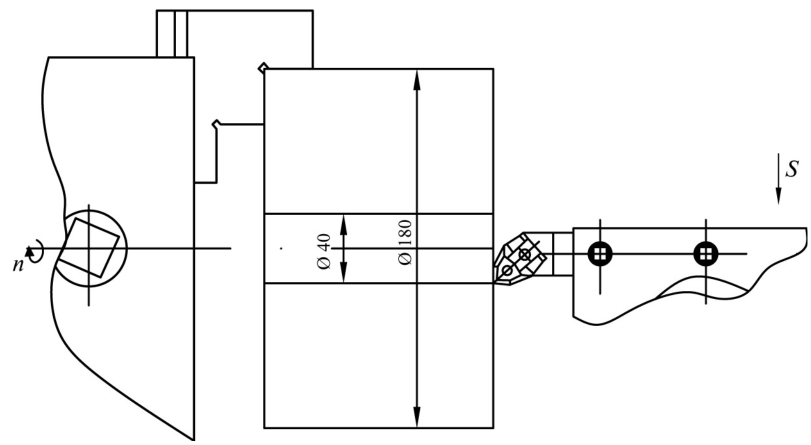


Fig. 3. Schematic representation of tool life testing of hard-alloy inserts; machining conditions: $n = 3$ rpm, $t = 1$ mm, $S = 0.037$ mm/rev.

To assess lifetime of the tools with hard alloy inserts we followed the procedure that involved machining tests in the face turning mode. The tool life period was determined by the duration of tool operation until the blunting criterion was reached, i.e., the time from mounting a new tool till the tool blunting. To assess the elaborated methodology, we carried out comparative laboratory tool life testing of conventional (reference) and hardened indexable throw-away inserts of VK8 (WC–8Co) and T5K10 hard alloys. Also, the changes we observed in the tool wear behavior were analyzed.

The tests were performed using a Mod.16K20 general-purpose lathe.. A workpiece was a disk of diameter 180 mm with a central 40-mm-diameter opening, made of steel 40Kh (hardness HRC 32–36). To maintain the experimental integrity, no coolant was used, i.e., the cutting was conducted under the dry friction conditions.

For a tool life criterion we took the width of the flank wear land $h_f = 0.5$ mm. This parameter was measured by means of a toolmaker microscope every five passes. The tool life period is found by the formula

$$T_{t.l.} = t_0 \Pi, \tag{1}$$

where t_0 is the duration of one pass, min; Π is the number of passes till the critical wear extent.

Then, the ratio of increasing tool life of the hard alloy inserts with a modified surface layer is given by

$$K_{t.l} = \frac{T^{m}_{t.l.}}{T^{n}_{t.l.}}, \tag{2}$$

where $T^{m}_{t.l.}$ and $T^{n}_{t.l.}$ are the tool life periods of the modified and non-modified (reference) inserts, respectively.

The test results (average values for ten inserts of each type) are shown in Fig. 4.

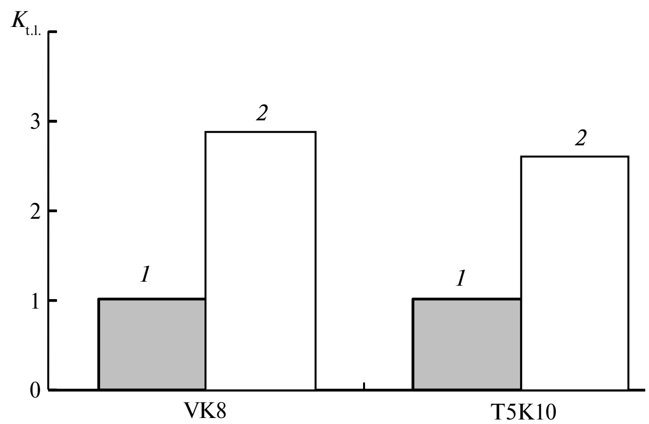


Fig. 4. The influence of plasma modification on the ratio of increasing tool life of VK8 and T5K10 inserts: *1*—no modification; *2*—plasma modification.

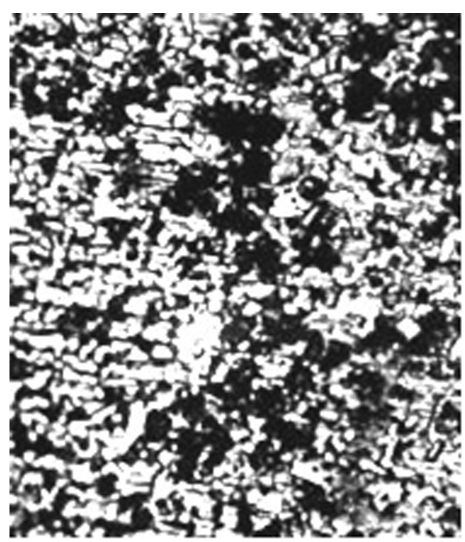
The tests have demonstrated that the plasma modification provides a significant improvement (up to threefold) of the tool life of hard-alloy inserts under the above-mentioned cutting conditions.

Upon the testing we performed a metallographic study of the structure of the worn cutting edge at the tool flank. It was found out that in the case of the inserts with a modified surface layer (Fig. 5a) the tool wear occurs in a selective mode: it is a relatively soft binder which is the first to undergo wear; then, the exposed hard carbide grains are pulled out to form pores and voids. The survived carbide grains are subjected to plastic deformation under cyclic loading and experience some shear processes resulting in the grain crushing into blocks. Due to the lack of a strong adhesion along the phase boundaries, the insert wearing process is accelerated. It is only at a distance of about 50 μm from the cutting edge, where one can observe the initial intact structure of the hard alloy (see Fig. 5b).

The modified inserts exhibit a qualitatively different wear mechanism. A strong, dense and non-deformed carbide framework of the hard alloy is observed almost in the immediate vicinity of the worn portion of the tool (see Fig. 5c). Wear occurs in a more uniform pattern, with fewer microchipped and spalled spots. The non-deformed and defect-free structure of the hardened alloy is observed even at a distance ~ 10 μm from the worn tool surface (see Fig. 5d).

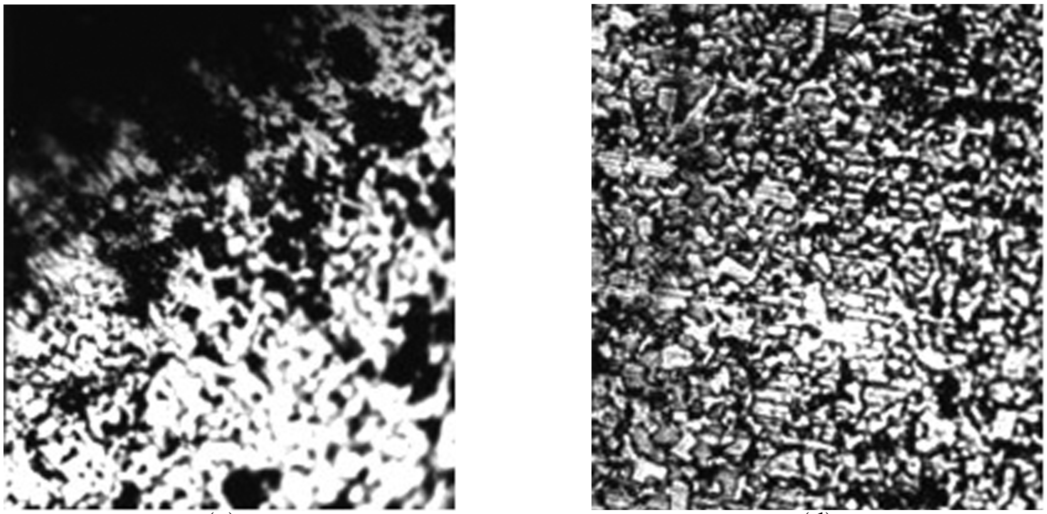
Generally, the performance tests and the study of wear mechanisms of the hardened hard-alloy tools have completely confirmed the earlier findings [4, 5] of the investigations of the structure and fracture mechanisms of hard alloys upon plasma modification of their surface layer.

(a)



(b)

Fig. 5. Microstructure of T5K10 inserts upon cutting in the case of no modification (a, b) and upon plasma modification (c, d): on the tool flank near the cutting edge (a, c), at a distance of 50 (b) and 10 μm (d) from the cutting edge.



(c) (d)

Fig. 5. (Contd.)

The improvement of the hard-alloy tool life is owing to a higher hardness and fracture toughness of the modified layer at the tool cutting edge (table). The treatment of hard alloys with a superpowered (up to 30 KW) highly concentrated plasma jet produces a surface layer with an ultradispersed structure and improved performance characteristics (hardness, fracture toughness, strength, wear resistance) owing to a change of the fracture and wear mechanisms. This is due to the size refinement of initial carbide grains, saturation of the binder with tungsten and thus its dispersion hardening accompanied by precipitation of ultradispersed secondary carbides as well as to an increase in adhesion bond between the carbide and binder phases [4, 5].

Performance characteristics of hard alloys upon plasma surface modification

Hard alloy grade	H_V		K_{Ic}, MPa·m$^{1/2}$		$K_{t.l.}$
	non-modified	modified	non-modified	modified	
VK8	1420	1620	12.0	14.2	2.8
T5K10	1450	1680	8.4	10.0	2.7

Thus, the investigations as outlined above have demonstrated the promising outlook for the use of plasma treatment for ultradispersed surface structuring of hard alloys in order to improve wear resistance of cutting tools.

REFERENCES

1. Lavrinenko, V.I., Sytnyk, B.V., Skryabin, V.O., et al., The influence of plasma treatment on the change of elemental composition, roughness and wear resistance of a cemented carbide tool working surface, *J. Superhard Mater.*, 2010, vol. 32, no. 4, pp. 270–273.
2. Samotugin, S.S. and Leshchinskii, L.K., *Plasmennoe uprochnenie instrumental'nykh materialov* (Plasma Hardening of Tool Materials), Donetsk: Novyi Mir, 2002.
3. Samotugin, S.S., Nesterov, O.Yu., Mazur, V.A., Cherevko, D.A., Sheremeta, O.M., Surface hardening of tool steels and alloys through heating with a highly concentrated plasma jet, *Uprochn. Tekhn. Pokryt.*, 2005, no. 3, pp. 23–28.
4. Samotugin, S.S., Lavrinenko, V.I., Kudinova, E.V., and Samotugina, Yu.S., The influence of plasma surface modification process on the structure and phase composition of cutting-tool hardmetals, *J. Superhard Mater.*, 2011, vol. 33, no. 3, pp. 200–207.
5. Samotugin, S.S., Lavrinenko, V.I., Kudinova, E.V., and Samotugina, Yu.S., The study of fracture toughness and failure mechanisms of cutting-tool hardmetals with plasma-modified surface, *J. Superhard Mater.*, 2013, vol. 35, no. 4, pp. 242–250.
6. Borisov, Yu.S., Krivtsun, and Muzhichenko, A.F., Computer modeling of the plasma spraying process, *Avtomat. Svarka*, 2000, no. 12, pp. 42–51.
7. Kharlamov, M.Yu., The use of multiprocessor computer systems for numerical modeling of arc plasma stream, *Elektron. Modelirov.*, 2009, vol. 31, no. 5, pp. 83–94.

8. Golovko, L.F. and Lukyanenko, S.O. (Eds.), *Lazerni tekhnologii ta komp'yuterne modelyuvannya* (Laser Technologies and Computer Modeling), Kyiv: Vistka, 2009.

9. Kundas, S.P., Markovnik, D.V., Ivanov, D.G., Krashanin, V.A., Il'inykh, S.A., A mathematical model of the process of plasma surface hardening of steel workpieces, *Uprochn. Tekhn. Pokryt.*, 2008, no. 3, pp. 41–46.

10. Sosin, N.A., Ermakov, S.A., and Topolyanskii, P.A., *Plasmennye tekhnologii* (Plasma Technologies), St.Petersburg: Izd. Politekhn. Univer., 2008.

11. Samotugin, S.S., Mazur, V.A., and Kudinova, E.V., Mathematical modeling of the process of plasma surface modification of hard-alloy tools, in *Visnyk SevNTU. Seriya Mashynopryladobuduvannya ta transport. Zb. nauk. pr.* (Bulletin of Sevastopol National Technical University. Series: Machine Building and Instrument Engineering. Collected Research Papers), Sevastopol, 2013, issue 140, pp. 123–130.

12. Petrova, L.G. and Chudina, O.V., Prediction of hardening of metals and alloys by using the methodology of controlling the structure formation, *Uprochn. Tekhn. Pokryt.,* 2007, no. 7, pp. 3–11.

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