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A Method of Increasing Hard-Alloy Wear Resistance via Aerodynamic Impact

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Abstract—The paper presents the effect of an increase in wear resistance after several operating cycles of hard-alloy plates is investigated and the results of investigations. The plate is heated to one-third of the melting temperature and subjected to air fluctuations with frequencies of 160–800 Hz. A hypothesis on how aerodynamic impacts occur on hard alloy surfaces is presented. An experimental way to strengthen the surface layer of metal cutting plates is described. It is revealed that under industrial condition the mean time between failures for the plates processed by mentioned procedure is 1.8–2.2 times higher than for the standard delivery plates.

Keywords: wear resistance, hard alloys, metal cutting plate, aerodynamic impact

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INTRODUCTION

The efficiency of the technological process of mechanical processing and the quality of processed surfaces are connected with the wear resistance of the working face of the cutting tool in the contact with a processed material subjected to friction, adhesion, and brittle wear [1]. Deformation hardening and heat softening precede brittle failure. The intensity of the aforementioned types of wear depend on the abrasiveness of the processed material, the microstructure of the working faces of the cutting tool, and the temperature in the cutting area and heat conductivity of both the processing and the processed materials [2–4]. The wear resistance of a tool can be determined using the relationship between wear h_3 and the time of tool operation, within which it reaches one of dulling criterion, i.e., resistance T.

The main ways to increase the wear resistance are the hardening and modification of the working face by applying wear resistant coatings and implanting ions [5–8]. However, as a rule, these methods do not influence the impact strength of hard alloys, which are widely used for cutting tools.

One of the unique properties of hard alloys is high strength under compression (3.5–7.0 GPa), i.e., higher than for other materials [9]. The characteristics of the tool during turning operations, lateral bending strength, and correlations between parameters are determined experimentally [10–12]. During milling, when the cutting edge is subjected to thermal shock and tensile stress, especially when it leaves the cutting area, high strength during lateral bending is only an indirect indicator of the fracture strength [12].

The impact resistance is a better criterion for characterizing the hard alloy strength than the bending strength. It is determined by critical stress intensity K_{1C}, which increases if the cobalt content and grain size of the WC are increased (Fig. 1) [13, 14].

It has been revealed that the cyclic strength of sintered hard alloys decreases if the temperature is increased, and the fatigue characteristics of WC–Co materials depend mainly on the microstructure. The growth rate of the fatigue crack decreases if the grain size of the WC or the cobalt content is increased [15].

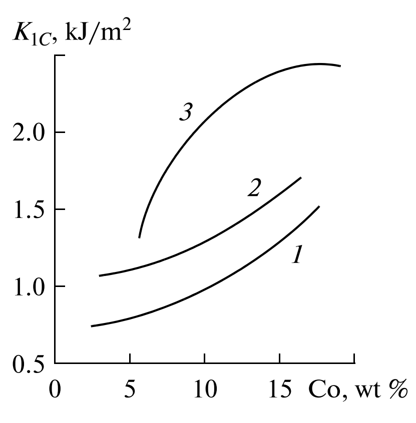

Fig. 1. Relationship between critical stress intensity K_{1C} for WC-based alloy and cobalt content for different sizes of grain: (*1*) 1.5 μm; (*2*) 2.8 μm; (*3*) 7.5 μm.

HYPOTHESIS

The process of the wear of contact surfaces of hard alloys is intensified because dislocations in the grains of the carbide phase are distributed nonuniformly, its density in the local volumes is increased, and thermally instable structures form. These structures are slip bands, which initiate microsplits and the explosion of grains of the carbide phase [1, 15].

In hard alloy, which is overdeformed material, dislocations are distributed inside of the subgrains and, to a lesser extent, along their boundaries. Under small deformations, the dislocation densities are close over lattice and blocks microdistortion values.

Instrumental materials, which are characterized by a finely dispersed polycrystalline structure and are deformed and heated during cutting, accumulate a great number of dislocations and vacancies, as a result of which the adhesion and diffusion activity increase. The polycrystalline structure and high number of structural defects formed during cutting accelerate the diffusion when processed and instrumental materials interact with each other.

If the dislocation density in metal is increased, the hardness rises and, on average, the hardness of the deformed body is proportional to the stress that acts during deformation. It is known from dislocation theory that the stress of deformation during different hardening mechanisms is proportional to the square root of the dislocation density. Residual stresses and latent energy depend on the dislocation density and distribution. The density of the slip bands decreases over the depth of the deformed layer approximately according to exponential law. If martial's hardness increases, the number of different types of dislocation increases in the closely packed planes of initial structure, which form due to high-energy impacts during manufacturing or hardening.

On one hand, the dislocation formations in the material are a barrier for dislocation displacement and, on the other hand, they are barriers for the elastic displacement of structural elements that greatly decreases the material's ability to quickly absorb the mechanical energy during shock load; i.e., its impact strength drops.

MATERIALS AND METHODS

The procedure of the developed method is as follows: hard-alloy plates are heated uniformly over the total volume to a temperature at which the self-energy of movable dislocations on crystal lattice defects rises without structural variations.

The conditions of aerodynamic impact should be chosen such that the energy of acoustic oscillations is scattered and absorbed mainly by structural defects. The energy absorbed by defects in the crystal lattice relieves the strain and blocks the dislocation mobility, as well as increases the mobility of frozen dislocations and promotes their motion. Acoustic oscillations under the chosen conditions initiate the motion of dislocations and increase the density of the movable dislocation. As a result, in the deformed structure, the existing subboundaries split and new boundaries form that move towards the propagation of acoustic oscillations.

If acoustic oscillations are superposed, stresses that act on the dislocations change their value and sign. Upon changes in both the magnitude and sign of the voltage, the dislocations move away from the obstacles and generate a new impulse to consistently overcome them. In addition acoustic oscillations influence greatly onto existed oxide film, which deforms and destroys, if deformation intensity is increased still more. Hereby, conditions necessary and sufficient for dislocation going out to the surface are formed.

The presented two-cycle aerodynamic impact with acoustic oscillations of different intensities in each cycle causes the following: in the second cycle, less movable dislocations go toward the surface, while in the first cycle, the more movable dislocations reach the surface.

Acoustic oscillations with air pressure of 1.5–2.0 bars and air consumption of 2.5–2.9 m^3/h for the first cycle and air consumption of 4.4–5.0 m^3/h for the second cycle make it possible to generate optimal (over energy density and superposed acoustic waves) impacts for different types of dislocations that differ in value and density, as well as to adapt the process to industrial conditions, which makes it efficient.

RESULTS AND DISCUSSION

We investigate the aerodynamic impact on phase transformations in the structure of standard samples manufactured in the form of five-faced plates made of T15K6 alloy according to GOST Russian State Standard 3882–74.

The slices are taken from the end face of the plate. The microstructure of the material is examined on etched and unetched samples. Samples are etched by 4% water solution of picric acid. Images are fixed with a MICRO 200 metallographic complex using a video camera and are displayed on a PC monitor.

We determined the sizes of structure components using ImageSP software. We mark the examined objects (carbide phases) with colors. In microphotos, we mark carbides WC and (Ti, W)C and determine a share of area occupied by the examined phase with respect to photo the area.

The data show that the aerodynamic impact increases the proportion of TiC–WC carbide, and decreases shares of WC carbide and of a binder (Table 1).

Table 1. Share of area occupied by examined phase with respect to image area

Sample	Share of area for WC, %	Share of area for (TiC–WC), %	Share of area for carbides, %	Share for binder, %
Standard	21	69.48	90.48	9.52
Processed	17.73	76.60	94.33	5.67

It can be seen from Fig. 2 that aerodynamic impacts delete tracks caused by plate grinding and scratches caused by different things.

X-ray analysis is performed using a DRON-3 diffractometer with Bragg–Brentano focusing and β filters. The investigation makes it possible to determine the phase composition of the samples (Table 2).

At an equal ratio between WC and TiC–WC carbides, the line intensities are redistributed, since the stressed state of alloys changes due to structural transformation and variations in the phase disposition caused by aerodynamic impact. Variations in the ratio between carbide phases can be explained by distortions that are ordered and balanced at the dislocation level due to aerodynamic impact.

Figures 3 and 4 depict masks for tungsten WC carbides and histograms of their distribution according to size class over area. We reveal that, for all of the samples, the area of grains of tungsten carbide is no higher than 16 μm^2. It can be seen that, in the plates subjected to aerodynamic impact, phases are redistributed and refined. For the standard sample (Fig. 3a), in the examined segment, the number of grains with areas of 1–2 μm^2 is 35–43 pieces and, with an area of 14–16 μm^2, there are 1–2 pieces. At the same time, for the processed sample (Fig. 3b), the number of grains with

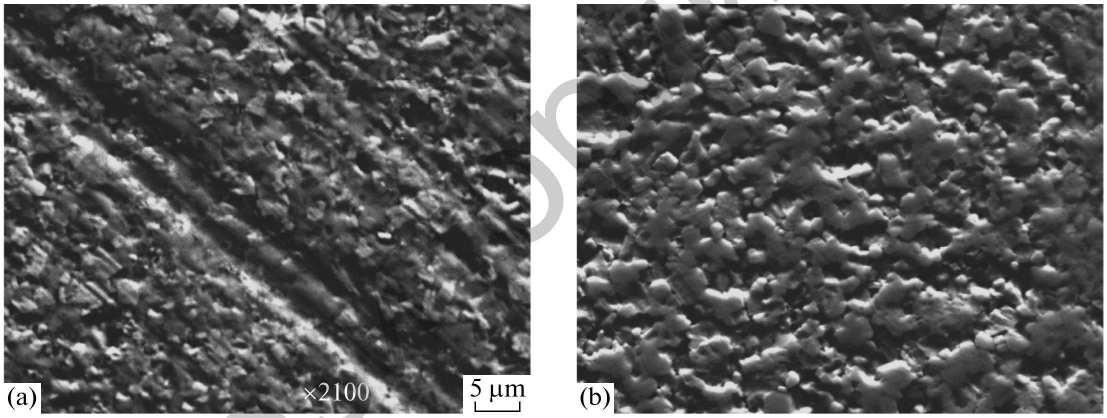

Fig. 2. Photos of sample surfaces obtained with a scanning electron microscope: (a) standard and (b) processed.

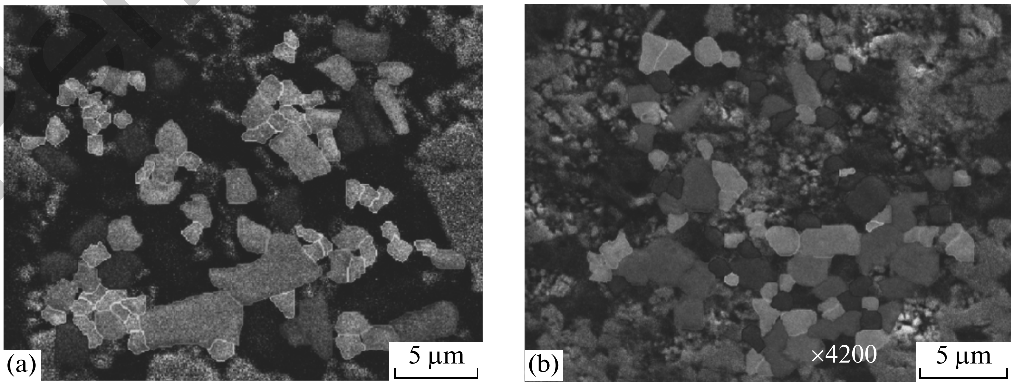

Fig. 3. Masks for marking tungsten carbide grains in T15K6 samples: (a) standard and (b) processed.

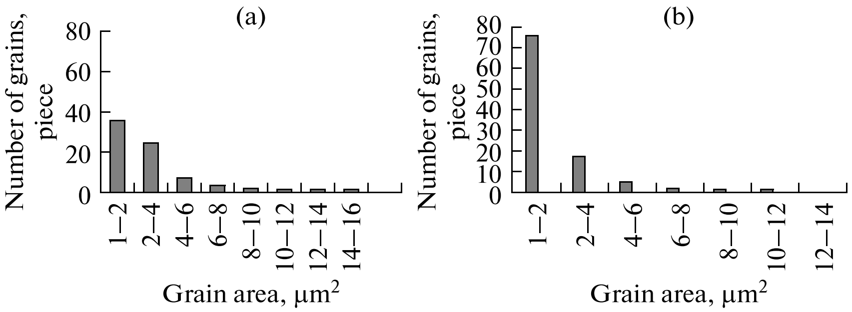

Fig. 4. Histograms for grains distribution over square in the samples: (a) standard and (b) processed.

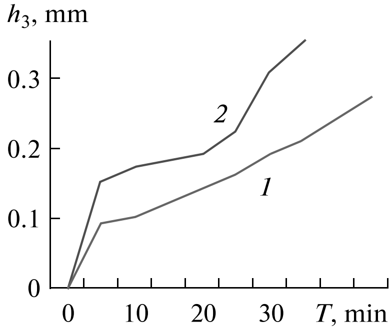

Fig. 5. The relationship between wear on the back surface h_3 of (*1*) standard and (*2*) processed plates made of hard-alloy T15K6 and cutting time T under milling pieces made of 40X steel.

an area of 1–2 µm² is 75–82 pieces and there are no segments with an area of 12–14 µm².

Table 2. Phase line intensity for standard and processed samples made of T15K6 alloy

Line	Phase	Line intensity, mm	Line	Phase	Line intensity, mm
Standard sample					
1	WC	67	8	WC, TiC	45
2	WC, TiC	235	9	WC	20
3	TiC	95	10	TiC	21
4	WC	135	11	WC	30
5	TiC	45	12	WC	20
6	WC	27	13	TiC	6
7	WC	12	14	WC	15
Processed sample					
1	WC	70	8	WC, TiC	30
2	WC, TiC	197	9	WC	14
3	TiC	70	10	TiC	12
4	WC	87	11	WC	17
5	TiC	35	12	WC	15
6	WC	19	13	TiC	6
7	WC	7	14	WC	10

The investigations on the wear resistance of hard-alloy T15K6 plates processed using aerodynamic impact show that the aerodynamic impact decreases the wear rate at the back surface and insignificantly increases (by 15–20%) the wear resistance of a tool made from hard alloys if it operates in the area where adhesion wear is prevalent.

Comparative testing is carried out at the StankoGomel plant (Gomel, Belarus). Workpieces made of 40Kh steel are milled with a GF2122 rotary-table milling machine using a junk bit with a diameter of 200 mm with 12 teeth equipped with PNUM-110408 hard-alloy plates made of T15K6 (intermittent feed milling with varied depth of cut 3.0–5.0 mm, frequency of work spindle is 500 min^{-1}, feed rate is 450 mm/min). It has been determined that the mean time between failures of hard-alloy plates subjected to aerodynamic impact is 1.8–2.2 times higher than it is for the standard sample.

CONCLUSIONS

Under intermittent feed milling, the wear resistance of hard alloy is determined by the impact strength. Therefore, it is necessary to secure the high hardness of surface layers without decreasing the impact strength. The presented procedure that makes possible to increase the impact strength and save the initial high hardness is very efficient with respect to hard-alloy tools that operate under hard conditions.

Production tests of hard-alloy tools processed by aerodynamic impact demonstrate increased wear resistance (by two to three times) under alternating shock loads in the area of brittle fracture and the plastic deformation of contact part of cutting tools.

In the authors' opinions, this effect is achieved by acting on the dislocation structures of the tool's internal layers. For this purpose, we use several cycles of thermal and aerodynamic impacts, i.e., the temperature is varied by 10–30% of the melting temperature and, for aerodynamic impact, we use directed oscillations of acoustic frequency in the range of 160–800 Hz within the predetermined period of time.

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REFERENCES

1. Grigoriev, S.N. and Volosova, M.A., *Nanesenie pokrytii i poverkhnostnaya modifikatsiya instrumenta: Uchebnoe posobie* (Superimposing of Coatings and Surface Modification of Tool: A Tutorial), Moscow: Inform. Tsentr Mos. Gos. Tekhn. Univ. STANKIN, 2007.
2. Sobol, O.V., Andreev, A.A., Grigoriev, S.N., Volosova, M.A., and Gorban', V.F., Vacuum-arc multilayer nanostructured TiN/Ti coatings: Structure, stress state, properties, *Metal Sci. Heat Treat.,* 2012, vol. 54, nos. 1–2, pp. 28–33.
3. Tereshin, M.V., Tumanov, A.A., and Cherkasova, N.Yu., Development of system of cutting process diagnostics, *Vestn Mos. Gos. Tekhn. Univ. STANKIN,* 2012, vol. 23, no. 4, pp. 64–67.
4. Grigoriev, S.N., Mandel, A.M., Oshurko, V.B., Solomakho, G.I., and Veselko, S.G., On the mechanism of friction reduction of nanosize multilayer coatings, *Metallofiz. Nov. Tekhnol.,* 2013, vol. 35, no. 7, pp. 933–942.
5. Grigoriev, S.N., Gurin, V.D., Volosova, M.A., and Cherkasova, N.Y., Development of residual cutting tool life prediction algorithm by processing on CNC machine tool, *Materialwissenschaft und Werkstofftechnik*, 2013, vol. 44, no. 9, pp. 790–796.
6. Grigoriev, S.N. and Maslov, A.R., *Obrabotka rezaniem v avtomatizirovannom proizvodstve (uchebnik dlya VUZov* (Treatment by Cutting in Automated Manufacturing (A Handbook for Inst. High. Educ.)), Moscow: Mashinostroenie, 2008.
7. Andreev, A.A., Volosova, M.A., Gorban, V.F., et al., The use of pulsed ion stimulation to modify the stressed structure state and mechanical properties of vacuum-arc TiN coatings, *Metallofiz. Nov. Tekhnol.,* 2013, no. 7, vol. 35, pp. 953–963.
8. Sobol', O.V., Andreev, A.A., Grigoriev, S.N., Gorban', V.F., Volosova, M.A., Aleshin, S.V., and Stolbovoi, V.A., Effect of high-voltage pulses on the structure and properties of titanium nitride vacuum-arc coatings, *Metal Sci. Heat Treat.,* 2012, vol. 54, nos. 3–4, pp. 195–203.
9. Anisimenko, G.E. and Lopatin, Yu.M., New solid alloys for exchangeable many-sided plates, *Obrabotka Mater.,* 2008, vol. 41, no. 4, pp. 25–33.
10. Adaskin, A.M., Vereshchaka, A.A., and Vereshchaka, A.S., Study of wear mechanism of hard-alloy tools during machining of refractory alloys, *J. Friction Wear,* 2013, vol. 34, pp. 208–213.
11. Fedorov, S.V., Pavlov, M.D., and Okunkova, A.A., Effect of structural and phase transformations in alloyed subsurface layer of hard-alloy tools on their wear resistance during cutting of high-temperature alloys, *J. Friction Wear,* 2013, no. 3, pp. 190–198.
12. Grigoriev, S.N., Fedorov, S.V., Pavlov, M.D., Okun'kova, A.A., and So, Y.M., Complex surface modification of carbide tool by Nb plus Hf plus Ti alloying followed by hardfacing (Ti plus Al)N, *J. Friction Wear,* 2013, vol. 34, no. 1, pp. 14–18.
13. Santhanam, A.T. and Tierney, P., Cemented carbides, in *Metals Handbook,* Metals Park, OH: ASM Int., 1989, vol. 16, pp. 71–89, 9th ed.
14. Sheinman, E., Wear of tungsten-cobalt tool, *Komplekt ITO,* 2009, no. 3, pp. 45–51.
15. Vereschaka, A.A., Vereschaka, A.S., Grigoriev, S.N., et al., Development and research of environmentally friendly dry technological machining system with compensation of physical function of cutting fluids, *Proc. 46th Conf. on Manufacturing Systems (CIRP CMS),* Setubal, Portugal, 2013; Book Series: *Procedia CIRP*, 2013, no. 7, pp. 311–316.

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