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Structure, phase composition and mechanical properties of hard alloy treated by intense pulsed electron beams

V.V. Uglov [a,*], A.K. Kuleshov [a], E.A. Soldatenko [a], N.N. Koval [b,*], Yu.F. Ivanov [b], A.D. Teresov [b]

[a] Belarusian State University, Minsk, Belarus
[b] Institute of High Current Electronics SB RAS, Tomsk, Russia

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ABSTRACT

Phase and structural changes in surface layers of WC–TiC–Co hard alloy treated by intense pulsed electron beams (IPEB) with electron energy of 20 kV are studied. IPEB energy density absorbed by surface layer was 10–80 J/cm^2, pulse duration was 100–200 µs. IPEB action with energy density of 30–80 J/cm^2 results in the formation of tungsten-supersaturated solid solution (Ti,W)C and transformation WC → W_2C caused by melting of surface layers and their subsequent rapid quenching from liquid. Electron beam treatment leads to the formation of layered structure. Changes of structure and phase composition result in the increase of surface microhardness in 1.5–3 times and in the reduction of friction coefficient in 2–3.5 times.

1. Introduction

Microstructure of hard alloys is characterized by high residual porosity and large variation in the carbide particles dispersion. This influences negatively on the performance of the material.

Improvement of efficiency of hard alloy tools by increasing their wear resistance and reliability is a crucial problem of modern industry. Irradiation technology is one of the most promising techniques for surface hardening [1–7]. The effect is provided by the formation of non-equilibrium structures and metastable phases in the surface layer as a result of rapid quenching after the action of particle beams (electrons, ions, lasers) and plasma flows.

The formation of hard alloy with certain phase composition and structure after laser processing is determined by irradiation wavelength, surface reflectivity and scanning velocity [6]. The efficiency of ion beams' heat action is determined by ion kind and ionization loses [7].

Main features of IPEB (~20 kV) treatment of materials are great electron penetrability, high locality of energy distribution in the surface layer of the material and direct energy transfer from electrons to nuclear sublattice [3]. In comparison with other energy influences (ion beams, lasers) irradiation by IPEB with high pulse duration (200 µs) provides higher existence of the surface layer melt. This eventually leads to homogeneous diffusive distribution of the elements over the depth of material. So, this kind of treatment allows to create deep layer (~20 µs) with improved mechanical properties in short period of time that leads to increase of tools' lifetime.

The goal of this paper is to study the influence of pulsed intense pulsed electron beam irradiation with high duration (100, 150, 200 µs) and energy density (up to 80 J/cm^2) on structure, phase composition and mechanical properties of WC–TiC–Co hard alloy.

2. Experimental

The samples of sintered hard alloy T15K6 (WC–15TiC–6Co, wt.%) were tetrahedral plates (10 × 10 × 4 mm size). Elemental composition of the alloy specimens was the following: W — 46, Ti — 12, Co — 5, C — 37 at.%. Phase composition of the alloy included WC, (Ti,W)C and Co. Vickers hardness of the alloy was 13 ± 2 GPa.

Intense pulsed electron beam treatment was carried out on pulse electron beam generator “SOLO” [4] (Institute of High Current Electronics SB RAS, Tomsk, Russia) with 5 pulses. Repetition frequency was 0.3 Hz and electron energy was 20 kV. Absorbed energy density (J_E) and pulse duration (τ) were variable parameters (see Table 1).

Phase composition and lattice parameters of the modified by IPEB alloys were studied by X-ray diffraction (XRD) in Bragg–Brentano geometry with CuK_α radiation (DRON-4 X-ray Diffractometer). Calculated X-ray penetration depth of the alloy was ~0.4 µm for $2\theta = 20–80°$ (assuming the absorption of 75% of X-ray energy). The error of the lattice parameters was less than 0.0003 nm.

Microstructure and elemental composition were analyzed by scanning electron microscopy with the use of the LEO1455VP device

* Corresponding authors.
E-mail addresses: uglov@bsu.by (V.V. Uglov), koval@opee.hcei.tsc.ru (N.N. Koval).

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Table 1
Lattice parameters of (Ti,W)C solid solution in WC–TiC–Co hard alloy treated by intense pulsed electron beam with different regimes.

Pulse duration, μs	–	100			150		200	
Absorbed energy density per pulse, J/cm^2	As-sintered	10	30	50	60	70	60	80
(Ti,W)C lattice parameter, nm	0.4318	0.4319	0.4313	0.4307	0.4308	0.4310	0.4310	0.4311

equipped with an energy-dispersive X-ray Röntec detector. The error of the element's content was less than 1–3 at.%. SEM studies were carried out in element contrast mode (registration of backscattered electrons only).

Microhardness was tested by means of a PMT-3 microhardmeter with a Vickers indenter under the load of 2 N.

Friction coefficient and wear resistance were studied by "pin-on-plane" tests under reciprocating sliding carried out at room temperature (22 ± 10 °C) and relative humidity of 50 ± 5%. The velocity of friction tests was of 4 mm/s, the pin with diameter of 2 mm was made of BK-8 hard alloy (87.5 HRC) and the load was 1 N.

3. Results and discussion

Phase composition of the hard alloy before and after intense pulsed electron beam treatment is presented in Fig. 1 and Fig. 2. XRD pattern of the untreated sample contains maxima corresponding to (Ti,W)C and WC carbides (Fig. 1). The analysis of WC and (Ti,W)C diffraction lines showed the formation of tungsten-supersaturated solid solution (Ti,W)C. It is a result of extra dissolution of WC in (Ti,W)C after intense pulsed electron beam action as it was also shown in Ref. [8]. Irradiation results in abrupt decrease of WC lines intensities (30 J/cm^2, 100 μs) and their complete disappearance (50 J/cm^2, 100 μs; 60–70 J/cm^2, 150 μs; 60–80 J/cm^2, 200 μs). The formation of W_2C carbide and precipitation of graphite (C), double- (Co_2C, Co_2Ti) and triple-base ($Co_3W_9C_4$) phases is observed.

Detailed XRD studies showed that (Ti,W)C lattice parameter decreases from 0.4318 to 0.4307 nm after intense pulsed electron beam action (Table 1). It is mainly caused by smaller tungsten atomic radius (0.141 nm) in comparison with titanium one (0.149 nm) and correlated with continuous increase of tungsten content in this solid solution [9].

Phase transformations are caused by the pulsed thermal action of IPEB. In order to find temperature profiles and temperature evolution after intense pulsed electron beam irradiation we solved one-dimensional heat equation

$$\frac{\partial}{\partial x}\left(k(x)\frac{\partial T(x,t)}{\partial x}\right) - \rho(x)c(x)\frac{\partial T(x,t)}{\partial t} = 0 \qquad (1)$$

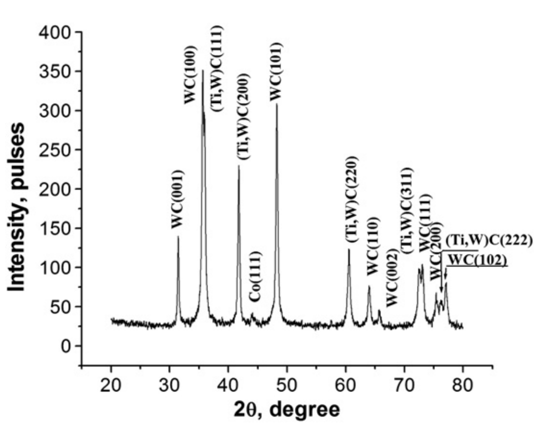

Fig. 1. XRD pattern of as-sintered hard alloy.

where $k(x)$, $\rho(x)$ and $c(x)$ are heat conductivity, density and heat capacity of the alloy, respectively. In the present study hard alloy was supposed to be isotropic.

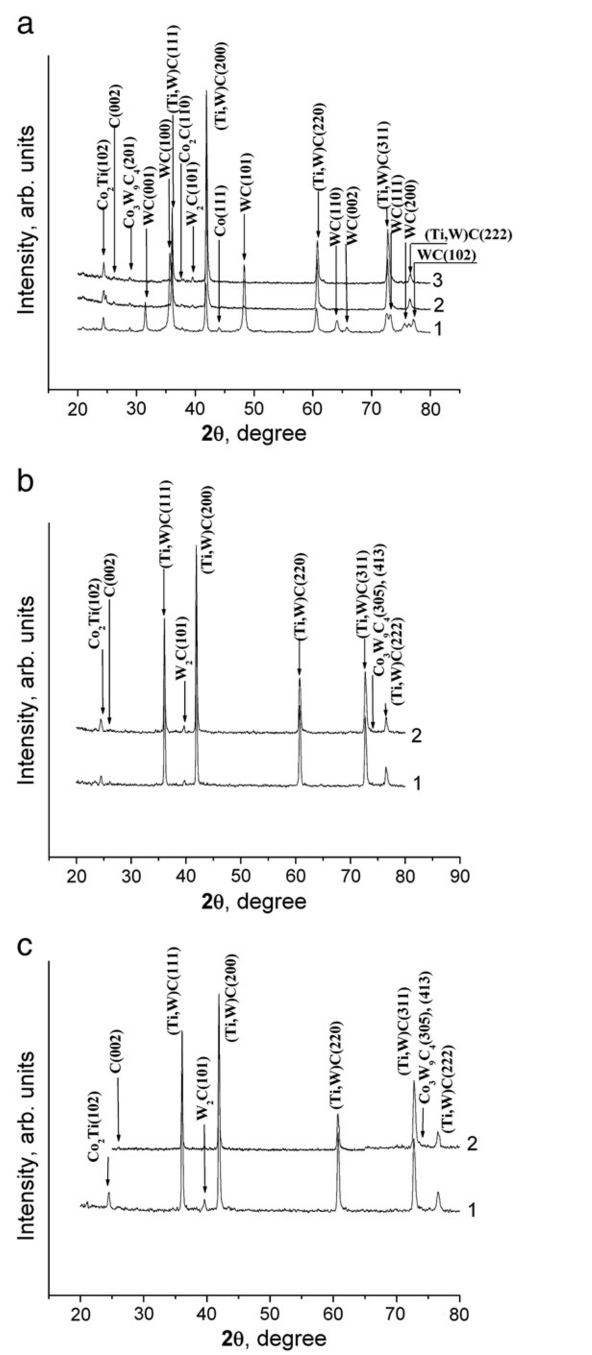

Fig. 2. XRD patterns of the hard alloy after intense pulsed electron beam treatment: *a* — τ = 100 μs, J_E = 10 (1), 30 (2), 50 (3) J/cm^2; *b* — τ = 150 μs, J_E = 60 (1), 70 (2) J/cm^2; *c* — τ = 200 μs, J_E = 60 (1), 80 (2) J/cm^2.