

# MODIFICATION OF WC-TiC-CO HARD ALLOY SURFACE LAYERS BY COMPRESSIVE PLASMA FLOWS AND LOW-ENERGY HIGH-CURRENT ELECTRON BEAMS ACTION

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## Introduction

As a result of hard alloy structure features such as high residual porosity and large variation in the carbide particles dispersion an actual problem is hard alloy hardening by surface layers additional treatment and formed microstructure changes.

Treatment by pulsed charged particles beams (ions and electrons), plasma flows and laser irradiation with energy density up to tens J/cm<sup>2</sup> is one of the main ways of hard alloys modification. Along with direct action by irradiation of mentioned types combined treatment is also widely used. It consists in irradiation of materials with previously deposited coatings. In addition this treatment allows to alloy materials with other elements. In case of irradiation in gaseous atmosphere (N<sub>2</sub>, H<sub>2</sub>, Ar) precipitation of second phases is possible. These phases are resulted from combination of materials' elements and gases atoms.

In the paper the research's results of direct and combined influence by compressive plasma flows (CPF) on hard alloy consisting of tungsten and titanium carbides. CPF irradiation provides uniform distribution of alloying element throughout melted layer.

## Experimental procedures

The sintered hard alloy T15K6 (WC-15 wt.%TiC - 6 wt.%Co) with the coatings Ti, Mo and Zr deposited by condensation cathodic vacuum arc (CAVD) with bombardment by ions Ti, Mo and Zr appropriately were used as the subject of the study. The corresponding coatings thickness was size of order 2 μm. The conditions of condensation of the coatings were following. The samples' surface was treated by ions within one minute at negative potential of displacement 1 kV and the metal arc current of- 100 A for Ti and Zr and 180 A for Mo coating, the bias voltage of was 120 V and deposition time was 10 minute.

CPF were obtained using a gas-discharge magneto-plasma compressor of compact geometry described in detail earlier [1]. The pressure of the plasma

forming gas was 400 Pa during the discharge. The discharge duration in the MPC amounted to  $\sim 100 \mu\text{s}$ . Treatment of the hard alloy and the formed systems was carried out by five pulses of compression plasma flows to provide homogeneity of the mixed layer. The energy density absorbed by the surface layer changed in the range of  $19\text{-}27 \text{ J/cm}^2$  per pulse.

The phase composition was investigated by the X-ray diffraction analysis (XRD) in Bragg-Brentano geometry and  $\text{CuK}\alpha$  radiation using a DRON 4-13 diffractometer.

Surface morphology as well as samples element composition was analyzed by means of scanning electron microscopy using a LEO1455VP device equipped with an energy-dispersive X-ray Röntec detector.

The microhardness of the samples was tested by means of a Wilson Instruments 402MVD microhardmeter with a Vickers indenter under the load of  $0.25 - 5 \text{ N}$ , loading time was 10 seconds.

## Results and discussion

As it was shown by XRD – analysis as-sintered hard alloy consists of WC and (Ti,W)C carbides and cobalt binding. Formation of coatings is confirmed by appearing of diffraction maxima corresponding to Mo, Ti and Zr for certain coating and decrease of intensities of hard alloy phase's diffraction lines.

CPF treatment with energy density  $19 \text{ J/cm}^2$  in nitrogen atmosphere causes TiN and  $\text{W}_2\text{N}$  phases precipitation (Fig. 1, a). In case of Mo – hard alloy system  $\text{Mo}_2\text{C}$  and  $\text{Mo}_2\text{N}$  are also precipitated (Fig. 1, b).

With increasing of energy density of CPF fully melted layer is formed. It is mainly composed of (Ti, W)C solid solution alloying by Mo and Zr for Mo and Zr (Fig. 2) coatings correspondingly. On our mind high solubility of Mo and Zr carbides in Ti and W carbides is the main reason of (Ti,W)C solid solution alloying by Mo and Zr. The phase composition feature of hard alloy with Ti and Zr coatings is precipitation of WN.

At XRD-pattern of Ti – hard alloy system in addition to phases mentioned above diffraction line in angle range  $2\Theta=40\text{-}41$  degree is also found. This diffraction maximum can correspond to either Ti or TiN of cubic structure with tritrahedral symmetry type F23 (196). The presence of mentioned line is more detectable after CPF with energy density  $22 \text{ J/cm}^2$  which can be in result of increase of Ti coating evaporation intensity with CPF energy density rise. This assumption is proved by EDX-analysis data according to which titanium concentration is 46 and 30 ( $\pm 3$ ) at.% in case of 22 and  $27 \text{ J/cm}^2$  correspondingly. Formation of nitride phases is suggested to be related to following. It is known, that in irradiation process by intense pulse beams of charged particles driving forces of mass transfer processes in surface melted layers are diffusion, thermal diffusion and mixing of this layer at hydrodynamic regime. Then owing to both

WC lower melting point (3143 K) relative to (Ti,W)C (3337 K) and tungsten higher diffusion mobility in carbides as compared with titanium and partial evaporation of cobalt binder ( $T_{\text{boil}}(\text{Co}) = 3200 \text{ K}$ ), too surface layer is enriched by tungsten causing by melting and decomposition of WC. It should be mentioned that after CPF treatment surface layer is also enriched by nitrogen. So further tungsten combines with nitrogen and WN and  $\text{W}_2\text{N}$  phases are formed. Precipitation of  $\text{Mo}_2\text{N}$  in Mo – hard alloy system’s surface layer occurs as a result nitrogen saturation of mo melted coating.

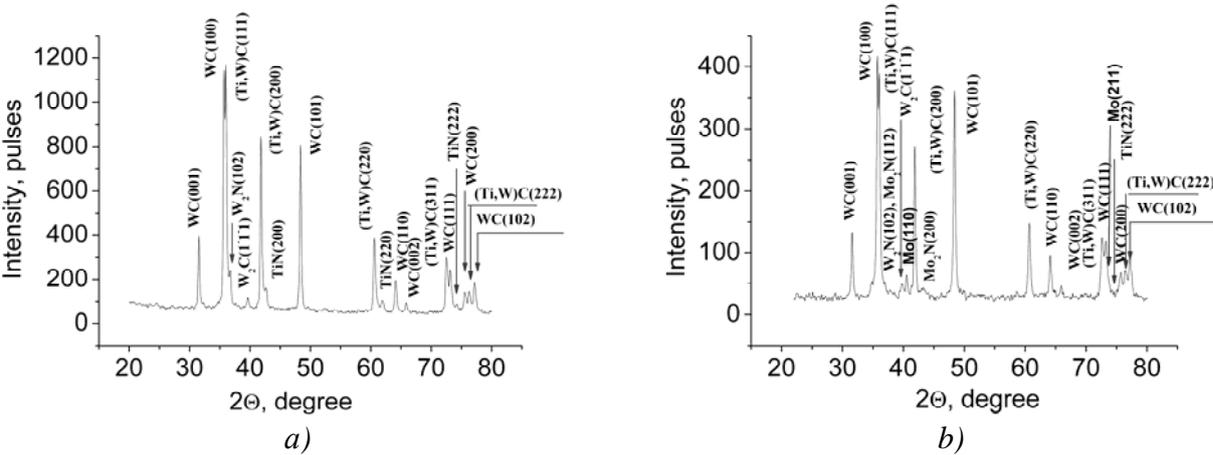


Fig. 1. XRD pattern of T15K6 hard alloy (a) and Mo – hard alloy system (b) after CPF treatment with  $19 \text{ J/cm}^2$

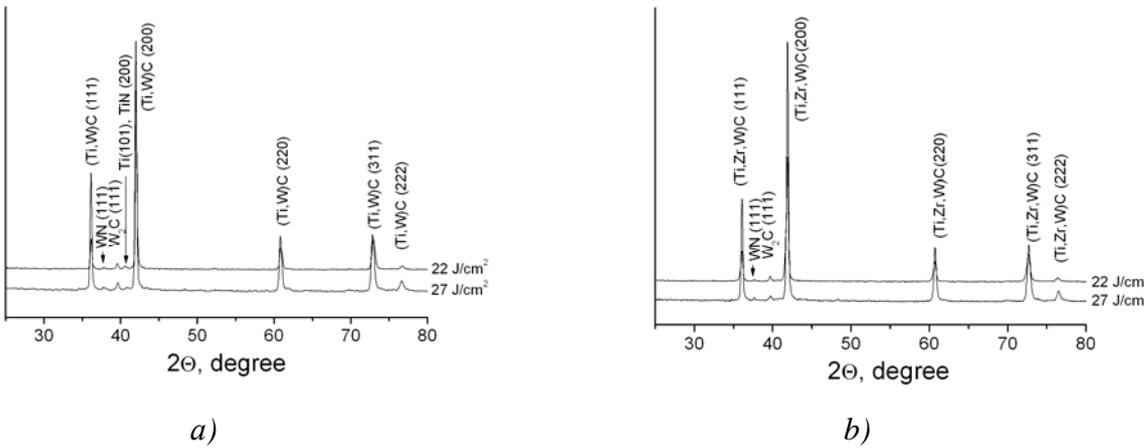


Fig. 2. XRD pattern of T15K6 hard alloy with Ti (a) and Zr (b) after CPF treatment with  $22 \text{ J/cm}^2$  and  $27 \text{ J/cm}^2$

According to SEM data direct CPF impact with energy density  $19 \text{ and } 27 \text{ J/cm}^2$  leads to partial and full melting of investigated systems’ surface layer with formation at subsequent crystallization process of either cell or cell and dendrite structures simultaneous.

The feature of hard alloy with Ti and Zr coating surface structure is presence of two morphology types differing in number of microcraters and voids per unit area. It is the reason of visible contrast on SEM – image (Fig. 3). As we can suggest formation of several morphology types occurs due to filamentation of plasma flow [2] and as a consequence difference in magnitude of thermoelastic stress at different surface regions.

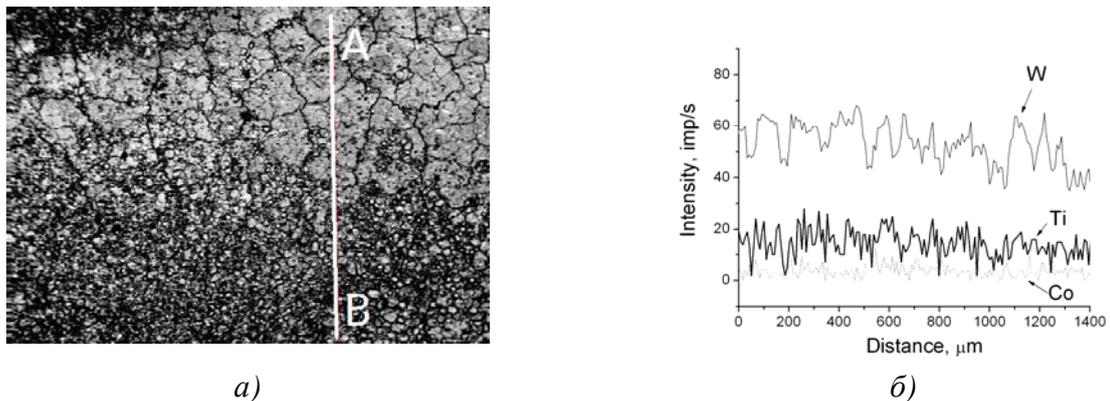


Fig. 3. SEM-image ( $\times 100$ ) (a) and distribution of characteristic X-ray of tungsten, titanium and cobalt along AB line at Ti – hard alloy system (b) after CPF treatment with energy density  $27 \text{ J/cm}^2$

Tests of surface layers microhardness measuring showed that it becomes variable along the depth and in the surface layer ( $\sim 0.4 \mu\text{m}$ ) increases more than twice as compared to as-sintered hard alloy microhardness.

Comparing of hard alloy's physical-mechanical properties after modification by CPF and low-energy high-current electron beams (LEHCEB) was also drawn.

## Conclusions

It was found that influence by five pulses of CPF with duration of  $100 \mu\text{s}$  and energy density of  $19\text{-}27 \text{ J/cm}^2$  on T15K6 hard alloy both without and with Mo, Ti and Zr coatings leads to formation of (Ti,W)C solid solution, saturated by tungsten and alloying by Mo and Zr for Mo and Zr coatings correspondingly, carbide ( $\text{W}_2\text{C}$ ,  $\text{Mo}_2\text{C}$ ) and nitride (WN, TiN,  $\text{W}_2\text{N}$ ,  $\text{Mo}_2\text{N}$ ) phases in the surface layers, melted dispersed layer with variable microhardness throughout depth magnitude of which increases more than twice at depth of  $0.4 \mu\text{m}$ .

## References

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