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Nanostructured Hardening of Hard Alloys Surface Layers Through Electron Irradiation in Heavy Inert Gas Plasma Conditions

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Abstract. The paper presents research and experimental findings which prove that metal ceramic composite surface layer contains micro constituents' hierarchies in the form of secondary nano sized inclusions inside ceramic phases. These inclusions have typical dimensions from several tens to several hundreds of nano meters. It has been shown that multi level structure-phase condition, developed in a nano sized area, effects physical and tribological properties of a metal ceramic composite surface layer.

1. Introduction

One of the burning issues of material engineering of today is to extend an operational life of metal working tools by means of nanostuctured hardening of industrial hard alloys surface layers, which contain up to 94 mass. % of a ceramic ingredient comprised out of very hard carbides. The method of nanostructured conditions inside a hard alloy surface layer is a promising one [1-9].

The research aimed at comparative evaluation of structure-phase conditions, which appear in a surface layer of a super ceramic hard alloy subjected to electron beam irradiation in the conditions of inert gases gas-discharged plasma with different atomic weight. Another goal of research was to study the way new structure-phase conditions influence a hard alloy cutting resistance.

2. Materials and research methodology

Two kinds of hard alloys were chosen to be evaluated, they are T40 (75%WC + 14% (Ti, Ta, Nb) C)+11%Co) and WC-15 (85%WC+15%Co). The hard alloys were subjected to pulsed electron beam irradiation with ES = (40…90) J/cm^2 electron beam energy density; τ = 150 µs electron beam influence pulse duration; N=15 number of irradiation impulses; and f=0.3 s^{-1} impulse frequency. The hard alloys were irradiated in the conditions of a residual pressure of 0.02 Pa plasma-supporting gas experimental chambers. Table 1 shows specifications of plasma-supporting gases used in the experiment.

Table 1 Specifications of plasma-supporting gases used in the experiment

Plasma-supporting gas	Ionization energy kJ/mol	Atomic weight g/mol
N	1401,5	14,00674
Ar	1519,6	39,948
Xe	1170,0	131,29

To evaluate structure-phase condition of hard alloys surface layers researchers applied methods of optical microscopy (Neofot 32), scanning (Zeiss LEO EVO 50) and transmission diffraction (JEOL JEM-2100) electron microscopy. Electron beam machined cutting plates were full-scale tested via turning a 40X steel up to its cutting edge wear rate came down to its 0.2 mm limit.

3. Results and Discussion

a) T40 hard alloy

Figure 1 shows the original condition of a hard alloy. Carbide particles are non equiaxial with dimensions changing from 0.5 µm to 3 µm.

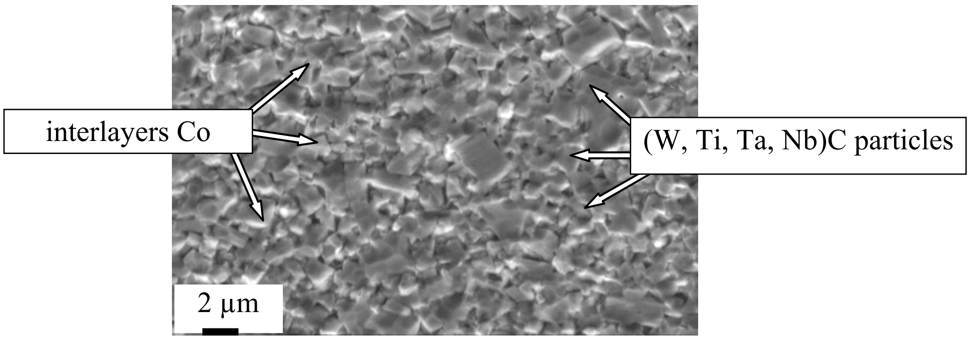

Figure 1. Original T40 hard alloy surface structure.

Impulse electron irradiation of a hard alloy surface layer caused microscopic pores in a surface layer as a result of a carbide phase decomposition and ariel carbon and oxygen compound development, which happen independent from gas-discharged plasma compound. This finding was proved by the evaluation of a hard alloy surface layer structure effected by impulse electron irradiation (Figure 2). It was observed that energy density in electron beam increases in parallel with microscopic pores dimension and number decrease.

Radiation causes melt development. Cristallyzation of the melt, in its turn, causes formation of a mesostructured level of a surface layer of electron irradiated hard alloy (Figure 3). It was found that mesolevel structure formation depends sufficiently on the kind of a plasma-supporting gas – in movingt from nitrogen to argon and then to xenon we observe a hard alloy ceramic ingredient particle size enlargement. Particle size grows in parallel with electron beam energy density increase. For

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example, if particle size changes within (4…10) μm when E_S = 40 J/cm^2, it changes within (2…5) μm when E_S = 70 J/cm^2.

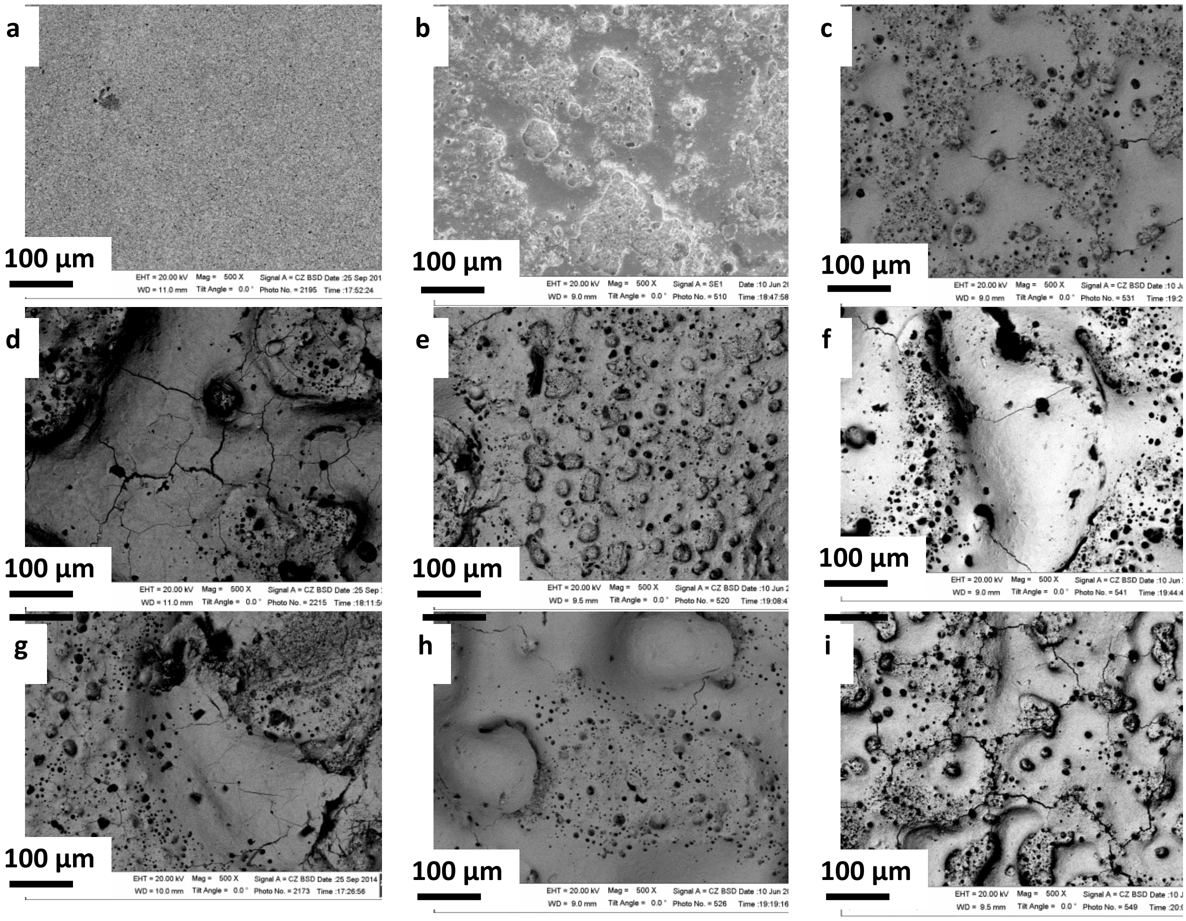

Figure 2. Hard alloy surface microstructure being subjected to impulse electron-ion-plasma irradiation (irradiation impulse duration – 150 ms, 15 impulses) in:
40 J/cm^2 in N (a), in Ar (b), and Xe (c) plasma;
60 J/cm^2 in N (d), in Ar (e), and in Xe (f) plasma;
70 J/cm^2 in N (g), in Ar (h), and in Xe (i) plasma.

Through the method of transmission diffraction electron microscopy a modified layer was evaluated to study the dependencies of a hard alloy surface layer micro level phase compound and defect substructure from impulse electron-ion-plasma irradiation modes.

Experience has shown that irradiation in nitrogen and argon gas-discharged plasma conditions results in ceramic particles fragmentation within a hard alloy surface layer. Sub grain structure with small angles of disorientation is formed inside sub micro sized (≈500 nm) ceramic particles (Figure 4 a, b). At that a xenon plasma irradiation causes appearance of a metal ceramic structure with nano- and sub micro particles with large angles of disorientation inside the surface layer (Figure 5 a); and gives rise to micro twins of deformation origin (Figure 5 b, plate like shape formation).

Nanostructured ceramic ingredients as well as twin structures in ceramic particles after impulse electron-ion-plasma irradiation are the attributes of ceramic materials crack resistance and their strength capacity enhancement in the conditions of shock loading [10-13]. Figure 6 presents experimental details of hard alloy plate's metal cutting ability examination held after impulse electron-ion-plasma irradiation in N, Ar and Xe plasmas in correlation with energy density in an electron beam. Experiments have allowed to establish that irradiation in N and Ar plasmas reduces a hard alloy surface layer resistance in the process of cutting metals, whilst irradiation in Xe plasma with electron beam energy density equal to 70 J/cm^2 increases a surface layer resistance capacity by 1.5 times [14].

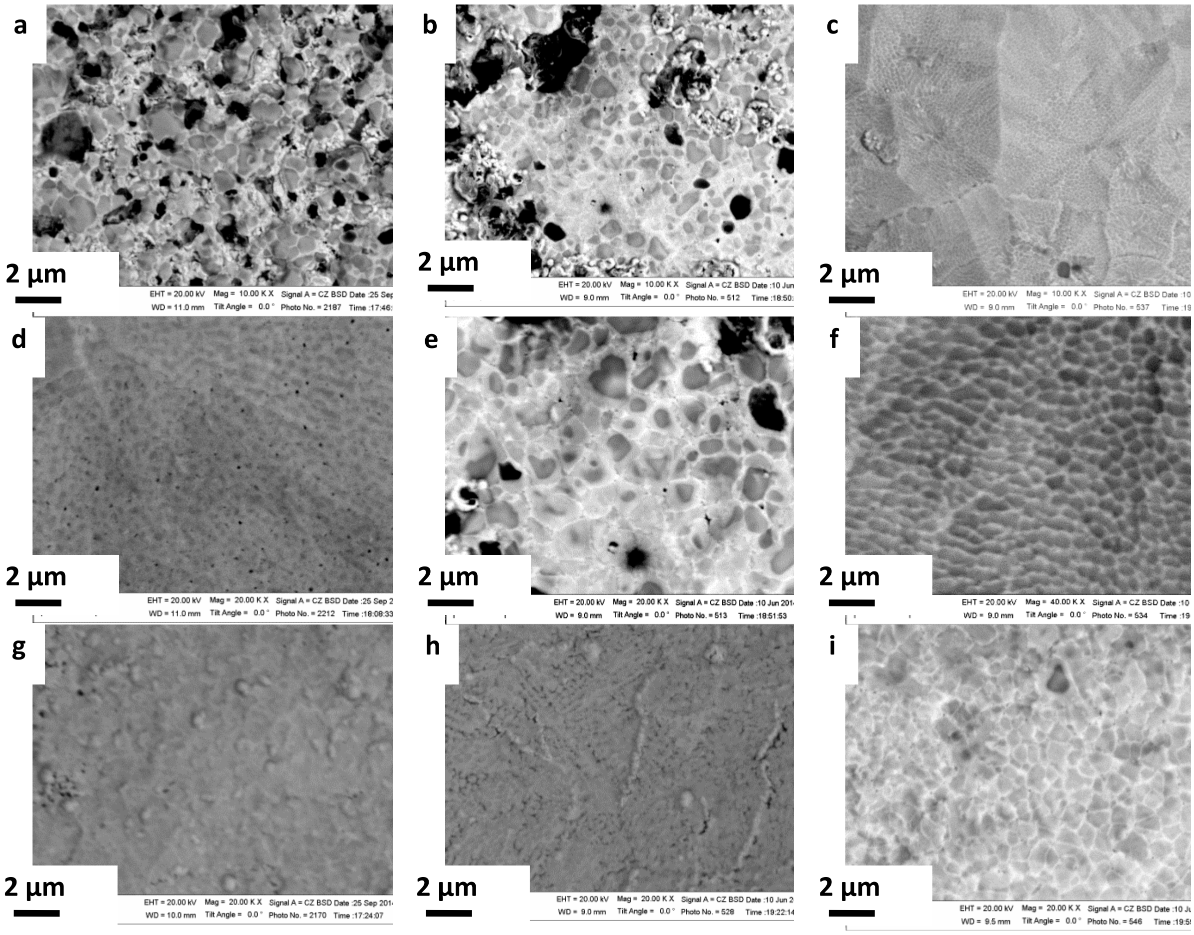

Figure 3. Mesostructured level of a hard alloy surface being subjected to impulse electron-ion-plasma irradiation (irradiation impulse duration – 150 ms, 15 impulses) in:
40 J/cm^2 in N (a), in Ar (b), and in Xe (c) plasma;
60 J/cm^2 in N (d), in Ar (e), and in Xe (f) plasma;
70 J/cm^2 in N (g), in Ar (h), and in Xe (i) plasma.

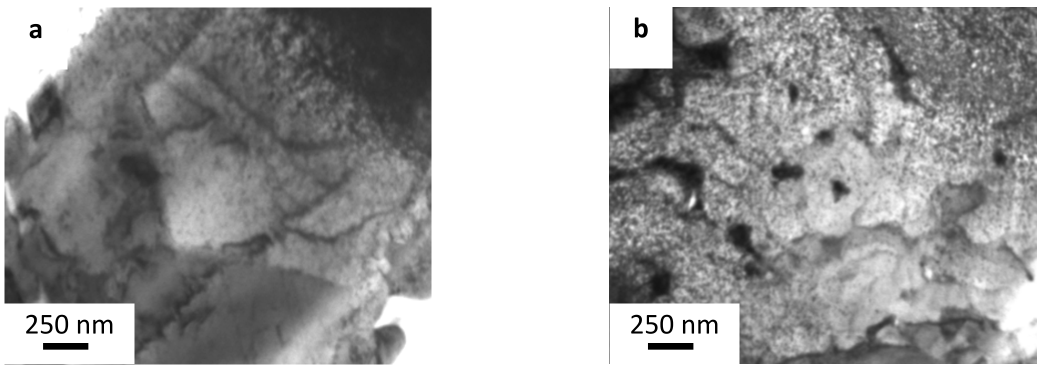

Figure 4. Microstructure of a surface layer of a hard alloy being subjected to impulse electron-ion-plasma irradiation in nitrogen (a), argon (b) and xenon (c) gas-discharged plasmas.

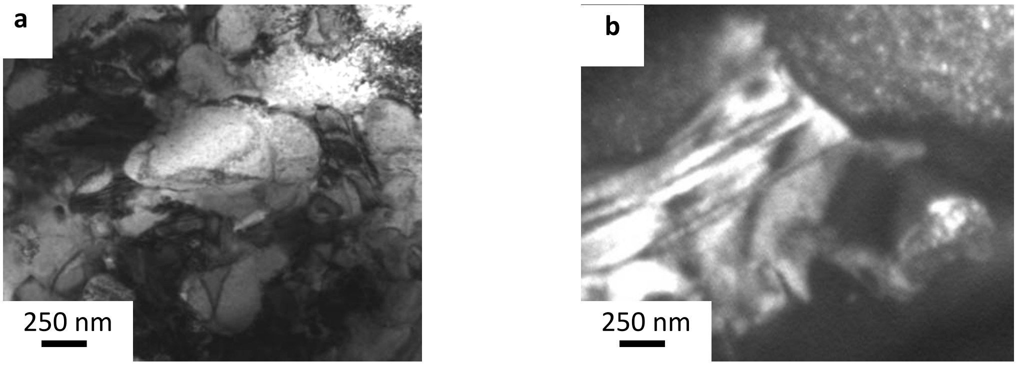

Figure 5. Microstructure of a surface layer of a hard alloy being subjected to impulse electron-ion-plasma irradiation in xenon gas-discharged plasma.

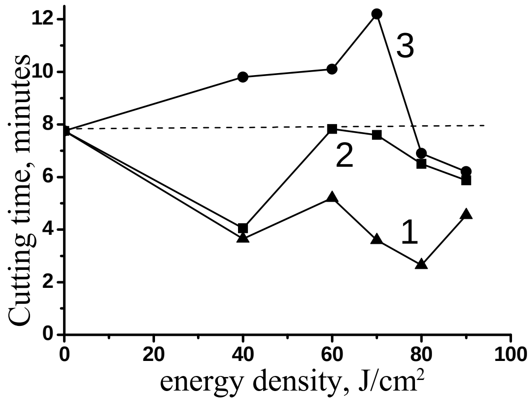

Figure 6. (75%WC+14%(Ti,Ta,Nb)C)-11%Co hard alloy surface layer resistance capacity during the process of metal (40X steel) cutting dependence from electron beam energy density during impulse electron-ion-plasma irradiation (150ms, 15 impulses) in N (1), Ar (2) и Xe (3) gas-discharged plasmas.

b) WC-15 hard alloy

Figure 7 presents an image of a hard alloy surface layer microstructure in its original condition and after it had been subjected to electron irradiation in Ar and Xe plasmas.

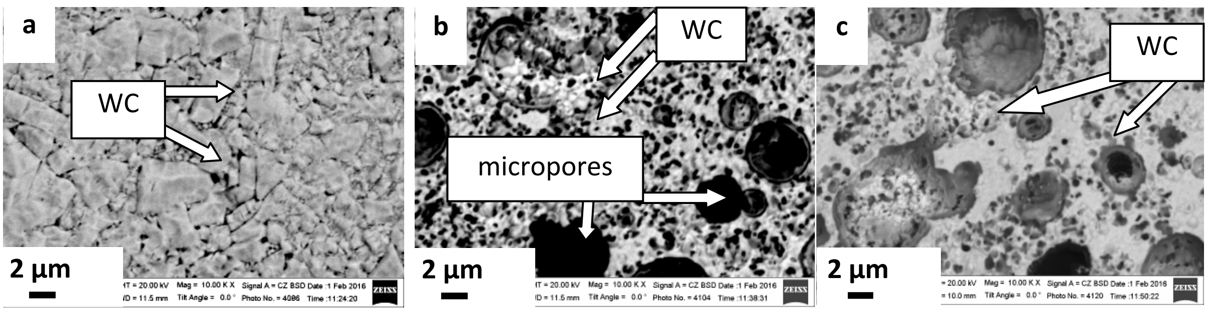

Figure 7. Microstructure of an original WC-15 hard alloy surface layer (a); and after electron irradiation in Ar (b) and Xe (c) gas-discharged plasmas (with electron beam energy density equal to 40 J/cm^2).

It is important to note that a hard alloy surface layer microstructure does not contain micro pores after Xe plasma irradiation. That is the critical distinction of a hard alloy surface layer microstructure in moving from Ar irradiation to Xe gas-discharged plasma irradiation.

A hard alloy surface layer wear resistance was evaluated during the process of cutting metals by measuring the wear rate of the back cutting plate′s edge, which was made of a hard alloy. The experiment has shown that electron-ion-plasma irradiation of a WC-15 hard alloy in Ar plasma decreases a surface layer wear resistance, whilst Xe plasma irradiation increases a surface layer wear resistance two times compared to that of the original hard alloy (Figure 8) [14].

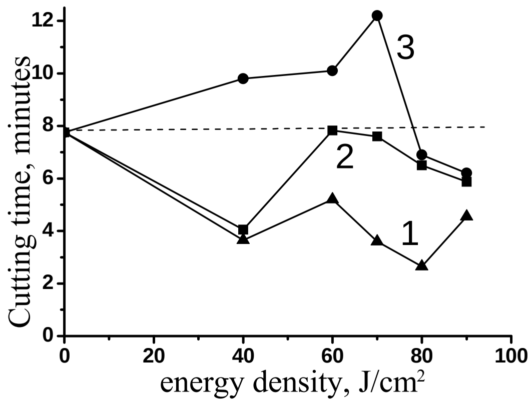

Figure 8. Dependence of the back hard alloy cutting plate′s edge wear rate from energy density in an electron beam when irradiated in Ar (1) and Xe (2) gas-discharged plasmas.

3. Conclusions

When super ceramic hard alloys are being subjected to impulse electron-ion-plasma irradiation in Xe heavy inert gas plasma condition, ceramic particles in a hard alloy surface layer change their dimensions up to nano size level, and form nanostructured structure-phase conditions, which are specified by their high wear-resistance during the process of cutting metals. This modification of a structure-phase condition of a surface layer results in 1.5-2 time increase in hard alloy plates resistance capacity.

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