Materials Science, Vol. 36, No. 1, 2000

PHASE COMPOSITION OF THE SURFACE LAYERS OF HIGH-SPEED CUTTING STEEL AFTER ELECTROSPARK ALLOYING AND LASER TREATMENT

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UDC 621.9.025.7

Due to the metallurgical processes occurring under the action of laser irradiation, which are accompanied by convectional mass transfer, phase formation, and the interaction of alloying elements with the base material and elements of the environment, tungsten carbide fully dissolves in the steel melt in the case where alloying was carried out with alloys based on this carbide. Moreover, the refractory component of tungsten-free electrode materials stayed completely unaltered, by partially losing a non-metal. These transformations occur under nonequilibrium conditions. To improve the tribotechnical properties and durability of a high-speed cutting steel upon cutting, it is reasonable to alloy its surface layer with elements and compounds which form stable oxides strongly bound to the base.

We study the phase composition of the surface of a cutting tool made of high-speed cutting steels after electrospark alloying (ESA) followed by laser treatment (LT). As electrode materials, we used those based on tungsten carbide with a cobalt binder alloyed with copper, based on tungsten and titanium carbides with a cobalt binder, based on titanium carbide and titanium nitride with a nickel–molybdenum binder, and based on titanium diboride with a nickel binder and Al_2O_3 additions.

Electrospark coatings were applied to specimens made of R6M5 steel (heat treated) on a Elitron-22 apparatus at a working current of 2A and with the specific time of alloying of $1.5\,\mathrm{Ms/m^2}$. Laser treatment was conducted on a Kvant-15 impulse installation. X-ray analysis was carried out on a DRON-3.0 diffractometer in γ-radiation from cobalt, copper, and iron.

The X-ray phase analysis of coatings made of hard alloys of the VK type showed that the main components of applied coatings are the phases present in the electrode material or the products of thermal dissociation of coatings and their chemical interaction with the base material (Table 1). Upon strengthening with alloys of the VK group, we took carbide W_2C as the base of the coating. Moreover, coatings contained carbides WC and Fe_3W_3C and austenite. Coatings applied with hard alloys with a low cobalt content (VK2 and VK4) included a negligible amount of carbide WC, whereas X-ray analysis did not detect carbide WC in alloys with high amounts of cobalt (VK8 and VK15). This can be attributed to the fact that, upon electrospark alloying with alloys VK2 and VK4, the transported products of anode erosion contain more of the solid phase than those with alloys VK8 and VK15. Therefore, in the first case, carbide WC undergoes a smaller thermochemical action due to a more limited contact with the liquid phase. The substitution of cobalt by copper in the electrode binder promotes the activation of liquid-phase erosion upon electrospark alloying, an increase in the amount of tungsten carbides in the strengthened layer, an increase in thickness, and improvement of the tribotechnical characteristics of coatings.

In coatings after electrospark alloying with alloys of the TK group, X-ray analysis revealed the carbide phases TiC, W_2C, and γ-Fe. The phase composition of electrospark coatings obtained by alloying with hard alloys based on TiC (TN 20), TiB_2 (BTNA 20), and TiN (NTNM 20) is represented by a relevant refractory component and the solid solution of a binder material in γ-Fe austenite (Table 1).

After laser treatment, we detected α-Fe in the "white" layer. In this case, the amount of austenite and M_6C increased. Laser treatment implies dissociation and dissolution of carbides WC and W_2C in the metallic melt with formation of M_6C. Upon irradiation of coatings made of alloys of the TK type, the concentration of TiC in the surface layer (up to $50\,\mu m$) does not change (Table 1).

Frantsevich Institute of Problems of Materials Technology, the Ukrainian Academy of Sciences, Kiev. Translated from Fizyko-Khimichna Mekhanika Materialiv, Vol. 36, No. 1, pp. 83–86, January–February, 2000. Original article submitted September 11, 1998.

1068–820X/00/3601–0100 $25.00

Table 1. Phase Composition of Surface Layers Made of R6M5 Steel after Electrospark Alloying and Laser Treatment

Electrode material	ESA	ESA + LT
R6M5 steel – original	α-Fe, M_6C	γ-Fe, α-Fe, M_6C
VK4	W_2C, M_6C, γ-Fe, WC	γ-Fe, M_6C, α-Fe
VK8	W_2C, M_6C, γ-Fe	M_6C, γ-Fe, α-Fe
VK5D3	W_2C, WC, CuO, (Cu_2O), (M_6C)	M_6C, α-Fe, γ-Fe, (W_2C), (CuO)
T5K10	TiC, W_2C, γ-Fe	TiC, γ-Fe, M_6C, α-Fe
T15K6	TiC, W_2C, γ-Fe	TiC, γ-Fe, M_6C, α-Fe, W_2C
TN20	TiC, γ-Fe	α-Fe, γ-Fe, MC, TiC, (TiO_2)
NTNM20	TiC, γ-Fe	α-Fe, MC, γ-Fe, TiN, (TiO_2)
BTNA20	TiB_2, γ-Fe	α-Fe, $M_{23}C_6$, γ-Fe, TiB_2, (TiO_2), (B_2O_3)

The amount of carbide W_2C in the surface layer after treatment of the coating with a laser beam decreases, which testifies to the high level of dissolution of the dissociation products of carbides in the matrix. After a laser-induced remelt of the area of the composition "coating treated by electrospark alloying–steel base," secondary carbides $M_{23}C_6$, M_6C, and MC are separated in the zone of laser action.

Compounds of titanium with oxygen and nitrogen, which are formed on the surface as a result of a high-energy action of laser radiation on coatings after electrospark alloying in air, have a higher melting temperature, adhesion to the base, and stability on the surface as compared with the similar compounds of tungsten which volatilize from the surface due to sublimation [1, 2]. The former compounds are more stable on the alloy surface and protect it against decarburization due to the interaction with atmospheric oxygen. Alloying with the electrode material based on TiB_2 (BTNA 20) facilitates the formation of carbide $M_{23}C_6$, characteristic of the system M-B-C (Table 1). Upon laser treatment of coatings based on the refractory compounds of titanium, a partial loss of a nonmetal from the refractory compound occurs, and the interaction of the products of dissociation of the refractory compound with the base material is observed [2–4].

In all layers strengthened by the combined treatment, the amount of residual austenite increases by causing a negligible decrease in hardness. High-alloyed austenite shows an enhanced stability [5]. Heated to high temperatures, the solid solution in surface layers is saturated with alloying elements keeping a fine-grained structure, which provides an increase in the heat resistance of a strengthened tool. One cannot obtain this effect by the methods of conventional heat treatment, since austenite grains become significantly larger due to overheating, which increases the embrittlement of steel. Austenite promotes the formation of tensile stresses in surface layers due to its denser lattice and a larger coefficient of thermal expansion as compared with alpha-iron. After electrospark alloying, diffraction maxima become wider, demonstrating the increase in the number of defects of the crystalline structure in the strengthened "white" layer, formation of solid solutions, and growth of stresses in microvolumes. After laser treatment, diffraction maxima become narrower by 5–10%. These facts can be explained by a decrease in microdeformations in the crystal lattice and stresses in microvolumes due to laser annealing.

In the surface layers obtained by a treatment of hard-alloy coatings with laser impulses in the helium jet, a smaller amount of austenite and carbide Fe_3W_3C is produced than in air. This effect can be attributed to an increase in heat withdrawal by the helium jet and a decrease in the number of exothermic reactions of oxidation of the surface by oxygen. In this case, the width of diffraction maxima is less due to a weaker dissolution of alloying elements in the solid solution and, therefore, due to lower stresses in the surface layer.

Table 2. Crystal Lattice Parameters of Refractory Compounds WC, TiC, and TiN after Electrospark Alloying and Laser Treatment

Phase	Lattice constant, Å		
	original	after ESA	after ESA and LT
WC	a: 2.909	a: 2.894	a: 2.8983
	c: 2.837	c: 2.828	c: 2.8318
TiC	4.328	4.315	4.317
TiN	4.240	4.230	4.243

The thermal action of electrospark alloying and laser treatment favor both an increase in the level of hexagonality of the crystal lattice of carbide WC (the ratio c/a) from 0.975 to 0.977 and a decrease in the lattice constants due to a partial loss of carbon (Table 2).

The decrease in the lattice parameters of carbides TiC and TiN after electrospark alloying testifies to the decrease in the contents of carbon and nitrogen, respectively. The subsequent laser treatment increases the contents of carbon and nitrogen owing to the formation of solid solutions.

Analysis of the intensity of diffraction maxima after electrospark alloying has shown that the intensities of the basic peak of the refractory component exceed that of α-Fe by a factor of 5–6. The subsequent laser treatment leads to a drop in the peak intensity of the refractory component and to a growth in the intensity of the peaks of phases in the matrix (Fe, M_6C). At a power density of $500\,MW/m^2$, the intensity of the lines of components of the matrix exceeds the intensity of the strongest line of the refractory component by a factor of 5–6. This confirms the decrease in the concentration of the refractory component in the surface layer ($50\,\mu m$) as a result of a convectional mixing of the refractory compound in the melt bath and the active dissolution of alloying components of the coating treated by electrospark alloying in the base material. The zone of thermal influence and the original thermally treated R6M5 steel are composed of martensite, carbides of the Me_6C type, and a negligible amount of austenite.

Upon work of a frictional pair [6] of surfaces strengthened by electrospark alloying with electrode materials based on refractory titanium compounds, the formed dense films of oxides act as a solid lubricant. Unlike films based on tungsten oxides, they demonstrate the capacity for sublimation when heated to 850-1000°C and a lower density [1]. The phases TiC, TiO, and TiN are isomorphic compounds [2] which produce a continuous series of solid solutions with a broad region of homogeneity.

In the presence of copper in a strengthened layer based on tungsten carbide, oxide films are formed on the conjugate surfaces (secondary structures). These films possess certain protective properties and the ability to decrease the work of friction [6].

In a micrometallurgical bath with a melt, certain metallurgical processes occur under the action of laser irradiation, which are accompanied by convectional mass transfer, formation of phases, and interaction of alloying elements with the base material and elements of the environment. As a result of these processes, we observe the complete dissolution of tungsten carbide in steel in the case where alloying was carried out with alloys based on this carbide. At the same time, the refractory component of tungsten-free hard alloys is kept practically unaltered with a partial loss of a nonmetal.

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