EFFECT OF ALLOYING ON PHYSICO-MECHANICAL PROPERTIES OF FUSED TUNGSTEN CARBIDES

A.I. BELY[1], **A.P. ZHUDRA**[1], **A.I. ROSLYAKOV**[1], **V.V. PETROV**[1] and **P.I. LOBODA**[2]
[1]E.O. Paton Electric Welding Institute, NASU
11 Bozhenko Str., 03680, Kiev, Ukraine. E-mail: office@paton.kiev.ua
[2]NTUU «Kiev Polytechnic Institute»
37 Pobeda Ave., 03056, Kiev, Ukraine. E-mail: mail@KPI.ua

Studies of fused tungsten carbide alloying by NbC, Cr_3C_2, B_4C, VC, TiB_2, Mo, and of their influence on alloy physico-mechanical properties have been performed. It is shown that the alloy properties largely depend on dimensions and quantity of the reinforcing phase, which can change in a broad range during solidification, depending on melt composition and thermal conditions of solidification. It is established that the high values of physico-mechanical properties of fused carbides are achieved at alloy structures, which are a matrix of one of the refractory compounds, reinforced by fibres of the second refractory compound. Increase of microhardness of the alloy spherical particles by 30–40 %, as well as of strength and wear resistance, particularly at alloying with molybdenum, is found. 6 Ref., 7 Figures.

Keywords: *fused tungsten carbide, alloying, spherical particles, microhardness, microstructure, strength, wear resistance*

Modern level of operation of machines and mechanisms requires continuous improvement of their performance, hence the constant need for development of new, more efficient materials. Considering the need to enhance gas production in the country, we can anticipate a significant increase of the volume of drilling operations that, in its turn, will require large numbers of drilling tools and equipment strengthened by new high-efficient surfacing materials.

The most widely accepted material for strengthening, primarily drilling tools, as well as a whole range of rapidly-wearing parts in mechanical engineering and mining equipment, are materials for deposition of composite alloys based on cast tungsten carbide (relite). Relite is an eutectic alloy of tungsten mono- and semicarbide WC–W_2C (20–22 % WC + 78–80 % W_2C) [1, 2]. Relite melting temperature is 2735 °C, carbon content is 3.6–4.12 %, microhardness $HV100$ is 2200–2400.

Alloy microstructure consists of a matrix of tungsten semicarbide W_2C, pierced by elongated WC tungsten carbide grains, and largely similar in terms of microstructure to quasibinary composite materials with ceramic matrix and single-crystal ceramic fibres [3].

It should be noted that with all the positive properties of fused tungsten carbide, it also has several disadvantages. This, primarily, is the high brittleness inherent to materials of this class.

Fused tungsten carbides have been produced for a long time in Tamman tipping furnaces. The thus obtained ingots are crushed with subsequent sieving into the respective fractions which were applied in the respective surfacing technologies and materials. Powder particles have cracks and preserve the characteristic casting defects: pores, cavities, compositional inhomogeneity, looseness, etc. that adversely affects the alloy wear resistance.

PWI method of thermo-centrifugal atomization of relite ingots allowed producing powder particles of a spherical shape, and, owing to their high cooling rate, greatly increase their quality. Particles acquired a more dispersed structure, higher microhardness and strength. Wear resistance of composite alloys based on spherical relite increased, accordingly (Figure 1). Thus, positive effect of increased rate of relite melt cooling on its service properties was established.

More over, it is shown in [3, 4] that mechanical properties greatly depend on dimensions and quantity of the reinforcing phase, which can vary in a broad range during solidification, depending on the melt chemical composition and thermal conditions of solidification. In this connection, it is proposed to further improve the properties of fused tungsten carbides through formation of solid solutions of other refractory metals by relite alloying with them.

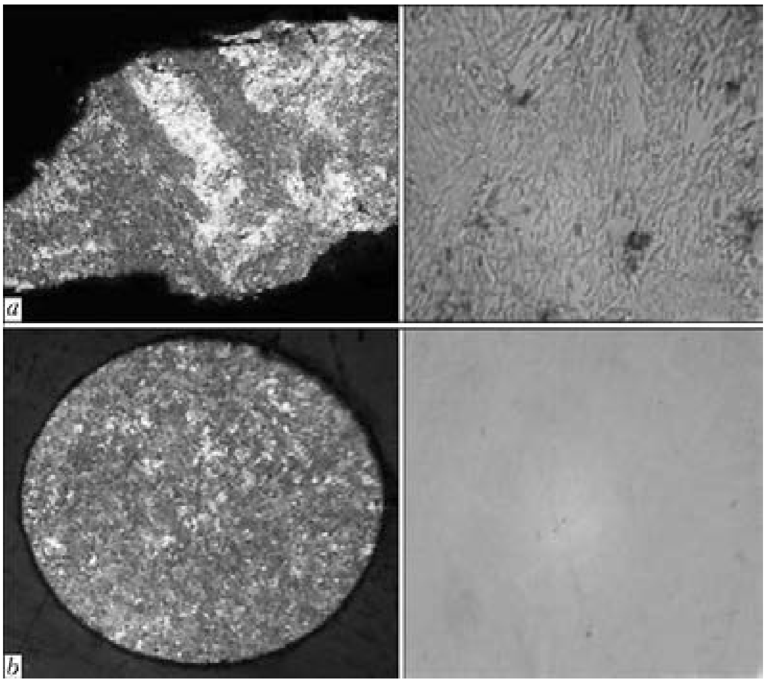

Figure 1. Macro- and microstructure (×100) of crushed (*a*) and spherical (*b*) relite particles

Performed experimental work on producing test alloys doped with NbC, Cr_3C_2, B_4C, VC, TiB_2 showed that the degree of alloying of the above material is limited to 5–7 wt.%, depending on the kind of added element. Exceeding the above limits leads to disturbance of melting process, intensive melt boiling, and material splashing, right up to interruption of melting. Considering these technological features, alloy doping was limited to 5 wt.% of alloying component.

Obtained samples were subjected to mechanical crushing and thermo-centrifugal atomization for producing spherical particles, filling and preparation of microsections for metallographic analysis and determination of microhardness as one of the main quality indices.

Analysis of composite alloy structures obtained at different cooling rates shows that fragmented particle structure is more defective. Alloying by Cr_3C_2 and Mo leads to the most considerable refinement of relite phase components and prevailing dissolution of alloying component in semicarbide phase. By the nature of microstructure, spherical particles produced as a result

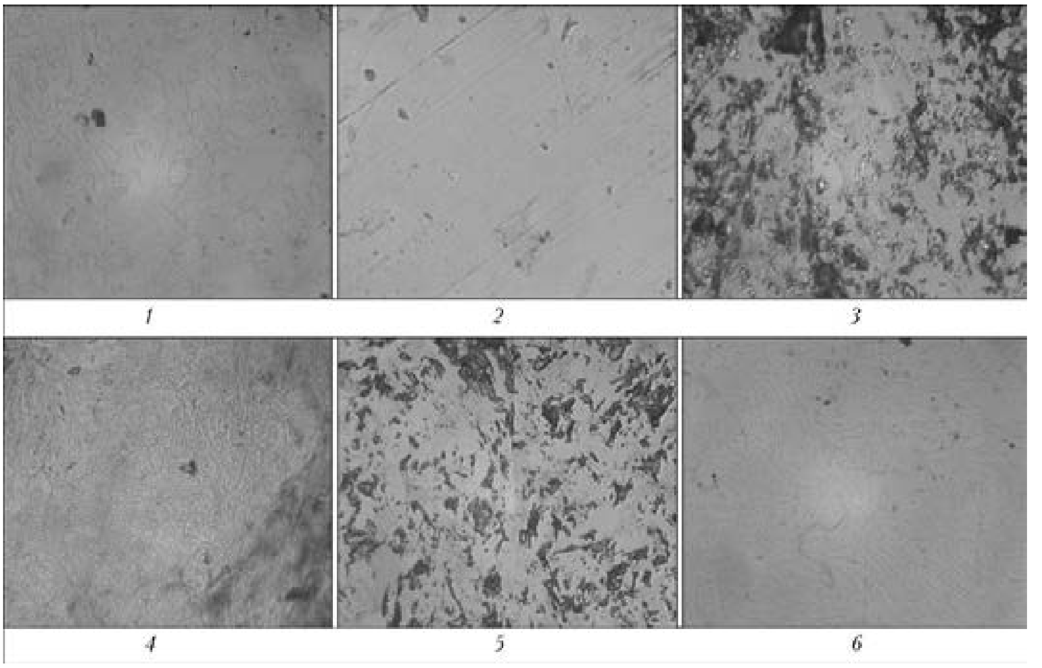

Figure 2. Microstructure (×100) of alloyed crushed particles: *1* — 5NbC + WC–W_2C; *2* — 5Cr_3C_2 + WC–W_2C; *3* — 3B_4C + WC–W_2C; *4* — 5VC + WC–W_2C; *5* — 5TiB_2 + WC–W_2C; *6* — 5Mo + WC–W_2C

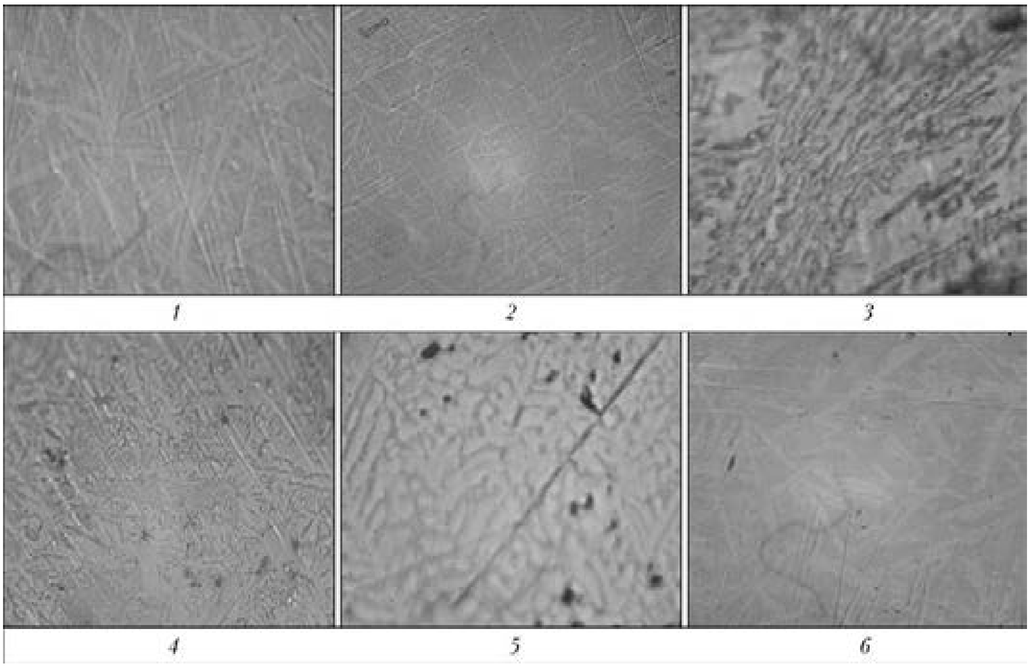

Figure 3. Microstructure (×100) of alloyed spherical particles: *1* — $5NbC + WC{-}W_2C$; *2* — $5Cr_3C_2 + WC{-}W_2C$; *3* — $3B_4C + WC{-}W_2C$; *4* — $5VC + WC{-}W_2C$; *5* — $5TiB_2 + WC{-}W_2C$; *6* — $5Mo + WC{-}W_2C$

of thermo-centrifugal atomization, consist of a matrix of tungsten semicarbide, alloyed by additive component. Microstructure of promising alloyed crushed and spherical particles is given in Figures 2 and 3.

Results of microhardness studies are given in Figure 4.

Note the high nonuniformity of classical composition particles and those alloyed, for instance, by 5 % TiB_2, in terms of microhardness, and high stability of microhardness of particles alloyed with 5 wt.% Mo (Figure 5). This, in our opinion, is due to volume ratio of system components, as grains of refractory compounds present in eutectic melt are separated by grains of different nature.

The process of thermo-centrifugal atomization improves the uniformity of structure of fused tungsten carbide particles, that has a positive effect on their strength. The force required for destruction of grains was determined in MP machine. The particles were placed between two polishing plates and were statically loaded. Testing was performed on forty particles of 100–250 μm size of each composition (Figure 6).

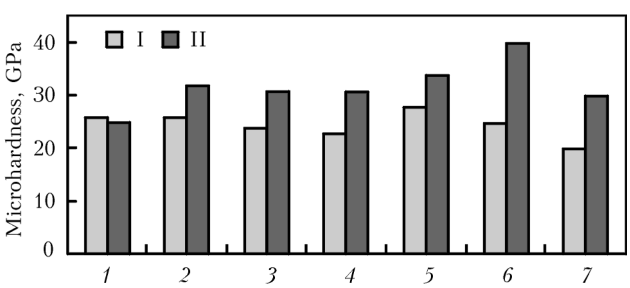

Figure 4. Microhardness of crushed I and spherical II particles: *1* — $5NbC + WC{-}W_2C$; *2* — $5Cr_3C_2 + WC{-}W_2C$; *3* — $3B_4C + WC{-}W_2C$; *4* — $5VC + WC{-}W_2C$; *5* — $5TiB_2 + WC{-}W_2C$; *6* — $5Mo + WC{-}W_2C$; *7* — $WC{-}W_2C$

Thus, investigation of spherical particle strength also showed the good prospects for tungsten carbide alloying by molybdenum.

Studies of microstructure of fused tungsten carbides of classical composition, compared to microstructure of alloys doped by molybdenum, revealed that classical relite has a fine-grained

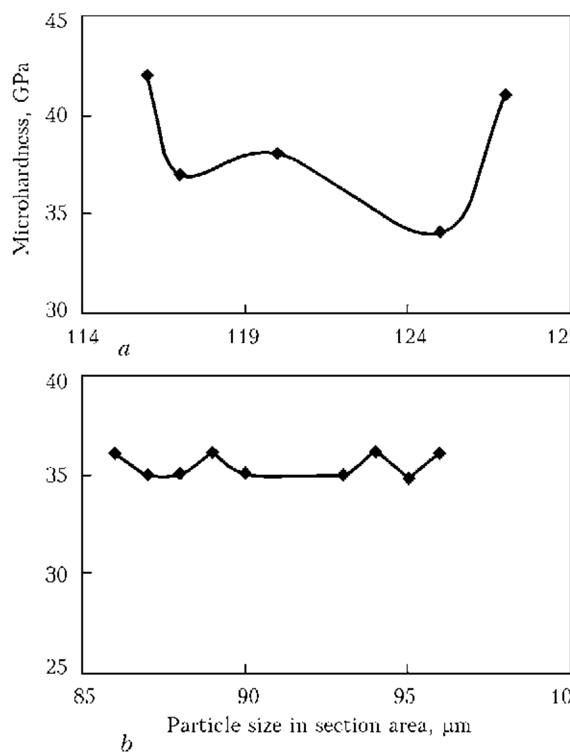

Figure 5. Microhardness of spherical alloyed relite particles of 100–250 μm size: *a* — $5TiB_2$; *b* — 5Mo

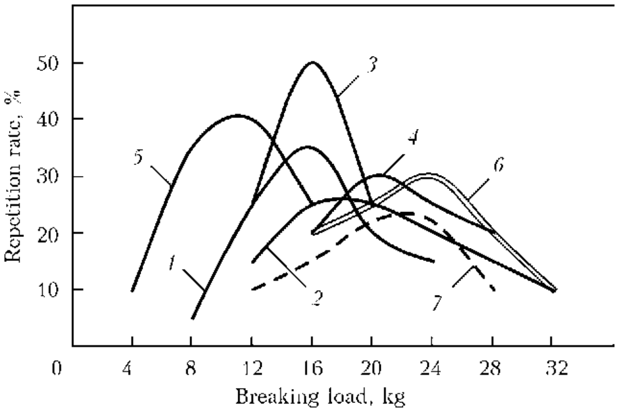

Figure 6. Strength of 100–250 μm spherical particles of alloyed tungsten carbides: *1* — 5 % NbC; *2* — 5 % TiB_2; *3* — 5 % VC; *4* — 3 % B_4C; *5* — 5 % Cr_3C_2; *6* — 5 % Mo; *7* — $WC{-}W_2C$

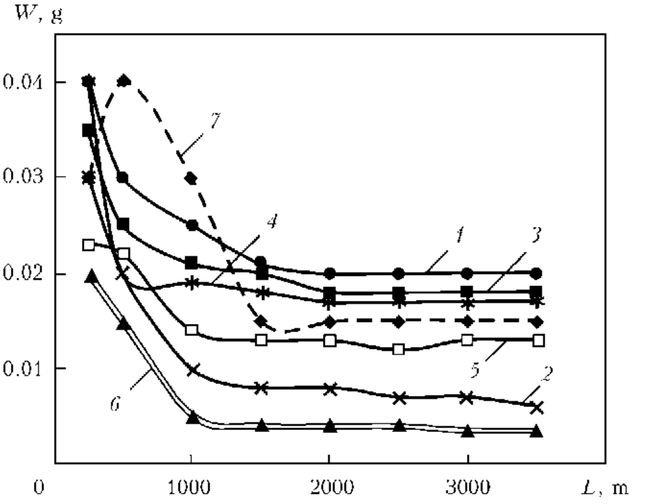

Figure 7. Wear resistance of spherical particles of alloyed tungsten carbides of less than 180 μm size compared to unalloyed particles of similar size (same designations as in Figure 6)

structure, while relite alloyed by molybdenum, has a plate-like structure. The high values of physico-mechanical properties of fused carbides are achieved at alloy structures, which consist of a matrix of one refractory compound, which is reinforced by fibres of the second refractory compound. Analysis of tungsten carbide microstructures, alloyed by molybdenum, confirms formation of a reinforcing lattice, which consists of complex W–Mo carbide.

Wear resistance of alloyed spherical particles was studied by testing for abrasive wear in NK-M machine [5, 6]. Abrasive was quartz sand of 0.05–0.50 mm granulation. Used as samples were cylinders of 10 mm diameter, which were made as follows. Reinforcing grains of crushed or spherical tungsten carbides were loosely charged into a graphite mould of 10 mm diameter. A portion of matrix alloy from MNMts 60-20-20 was placed on top of the grains. The mould was closed by a graphite lid and intensively heated by plasma arc. The matrix alloy impregnated the reinforcing grains and after cooling it was subjected to machining by diameter and height. Wear was evaluated by mass loss. Sample area was equal to 78.5 mm^2, specific load was 0.5 Pa, friction speed was 0.58 m/s. Friction path was 3500 m.

It was found that fused tungsten carbide alloying by niobium, vanadium and molybdenum improves wear resistance of spherical particles produced by thermo-centrifugal atomization. Alloying with molybdenum in the amount of 5 % is the most effective (Figure 7).

Conclusions

1. Studies showed the good prospects for and rationality of alloying fused tungsten carbides by refractory metals, that provides 30 to 40 % increase of microhardness. Alloying is particularly effective when producing spherical relite by centrifugal atomization that ensures higher rates of alloy solidification.

2. Studying the strength of tungsten carbide particles produced by different methods showed that spherical tungsten carbides alloyed with molybdenum have the highest strength.

3. Fused tungsten carbides alloying with niobium, tungsten and molybdenum improves wear resistance of spherical particles produced by thermo-centrifugal atomization. Alloying with molybdenum in the amount of 5 % is the most effective.

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