WEAR RESISTANCE AND STRENGTH OF TUNGSTEN CARBIDES $WC-W_2C$ PRODUCED BY DIFFERENT METHODS

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Investigation results are given on wear resistance and strength of particles of fused tungsten carbides $WC-W_2C$ produced by different methods: mechanical crushing of ingots, thermal centrifugal spraying and spheroidisation of powders by using the induction plasma technology.

Keywords: *hard-facing, hard-facing consumables, tungsten carbides, thermal centrifugal spraying, strength, wear resistance, hard-facing composite alloys*

Hard-facing composite alloys consisting of reinforcing particles (fused tungsten carbides) and a matrix are characterised by the maximal wear resistance under conditions of abrasive, gas-abrasive and some other types of wear. A distinctive feature of the process of wearing of such alloys is a stepwise wear of individual components of a composition. This is accompanied by the so-called shadow effect, when the more wear-resistant reinforcing particles take up the main load due to fracture forces, thus protecting the alloy matrix from wear.

Therefore, at an equal wear resistance of the matrix the performance of composite alloys is determined by their chemical composition, concentration, wear resistance and strength of the reinforcing particles. This study gives results of investigations into wear resistance and strength of the particles of fused tungsten carbides $WC-W_2C$ produced by different methods: mechanical crushing of ingots, thermal centrifugal spraying and spheroidisation of powders by using the induction plasma and other technologies [1–4].

It is a known fact that concentration of the reinforcing particles in a composite alloy is determined by their shape. The optimal shape of the particles is spherical, as it provides the maximal concentration of the wear-resistant phase, good flowability and, as a consequence, stable operation of feeding devices of the hard-facing machines [5, 6]. Figure 1 shows the data on apparent density, and Figure 2 — flowability of fused tungsten carbides with particles of the spherical and sharp-angled shapes produced by the conventional procedure [6]. These data prove advantages of the spherical shape of the particles, especially in terms of their flowability. The crushed particles of tungsten carbides do not spill at all via a funnel with a diameter of 2.5 mm.

Also, this conclusion is confirmed by measuring fill factor K_f of a strip tungsten carbide depending on the fractional composition and shape of the reinforcing particles (Figure 3). Filler metal based on the spherical tungsten carbide particles with a size of 0.28–0.45 mm has the maximal value of the fill factor, and that based on the crushed tungsten carbide particles with a size of 0.63–0.90 mm has the minimal value of the fill factor, this being attributable to their shape. The experiments were carried out by pouring of loose reinforcing particles using a strip feeder into a flute formed by the cold-rolled strip 0.3 mm thick and 18 mm wide [7].

Therefore, the spherical shape of the reinforcing particles of composite alloys is best to provide the required concentration of the wear-resistant phase in a hard-facing consumable and wear-resistant layer, as well as the stable operation of the hard-facing equipment.

Fused tungsten carbide particles of both crushed and spherical shape have approximately identical chemical composition. Hence, their wear resistance depends on strength and structure. It should be noted that owing to an increased rate of cooling of the spherical particles the thermal centrifugal spraying process

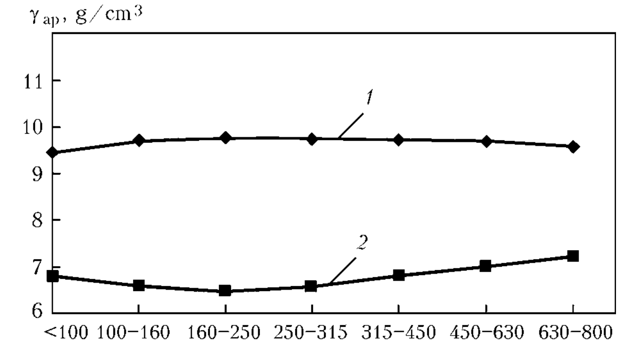

Figure 1. Apparent density γ_{ap} of spherical (*1*) and crushed (*2*) tungsten carbide particles of different size *d*

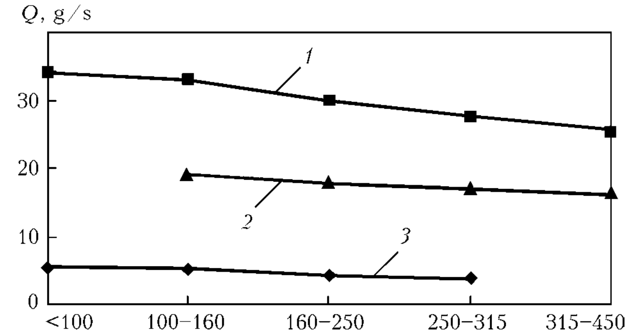

Figure 2. Flowability *Q* of spherical (*d* = 5.0 (*1*) and 2.5 mm (*3*)) and crushed (*d* = 5.0 mm (*2*)) tungsten carbide particles

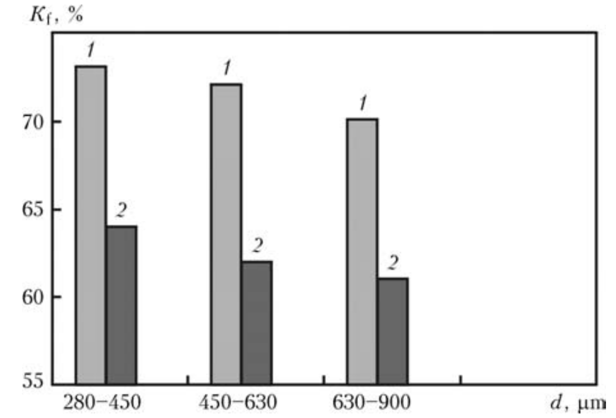

Figure 3. Dependence of fill factor K_f of strip tungsten carbide on fractional composition and shape of reinforcing particles: *1* — spherical; *2* — crushed

has a positive effect on formation of structure of the fused tungsten carbides [8].

Abrasive wear resistance of composite alloys was studied by using the NK-M machine [9, 10]. Quartz sand with a particle size of 0.05–0.50 mm served as an abrasive. The specimens were 10 mm diameter cylinders. They were made as follows. Loose reinforcing crushed or spherical tungsten carbide particles produced by different methods (SPh-1, SPh-2 and SPh-3 grades — by fuse spheroidisation of powder at world leading companies, PWI grade — thermal centrifugal spraying at the E.O. Paton Electric Welding Institute) were poured into the 10 mm diameter graphite mould. A portion of the matrix alloy of copper-nickel-manganese German silver MNMts 60-20-20 was put on top of the particles. The mould was closed by a graphite cover and intensively heated by the plasma arc. The matrix alloy impregnated the reinforcing particles. After cooling, the mould was machined along the diameter and in height. Each of five specimens had the following sizes of the tungsten carbide particles, μm: less than 180, 180–250, 250–450, 450–630 and 630–900. Wear of the specimens was estimated from loss of their weight. Specific load on a specimen was 0.5 Pa, friction rate was 0.58 m/s, and friction path L was $3.5 \cdot 10^3$ m.

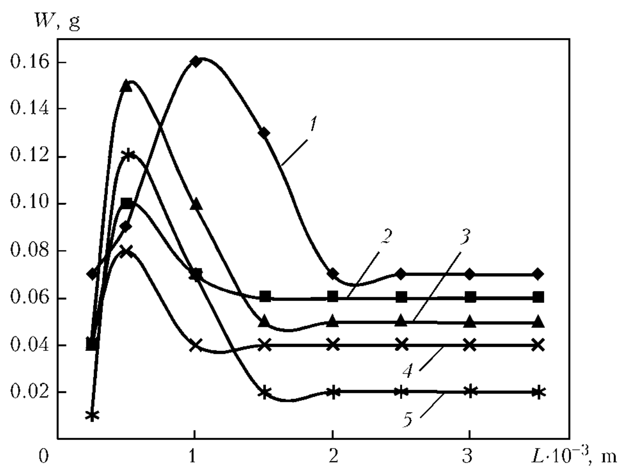

Figure 4. Dependence of wear resistance W of composite alloy with reinforcing crushed tungsten carbide particles of different particle-size compositions on friction path L: *1* — $d < 180$; *2* — 180–250; *3* — 250–450; *4* — 450–630; *5* — 630–900 μm

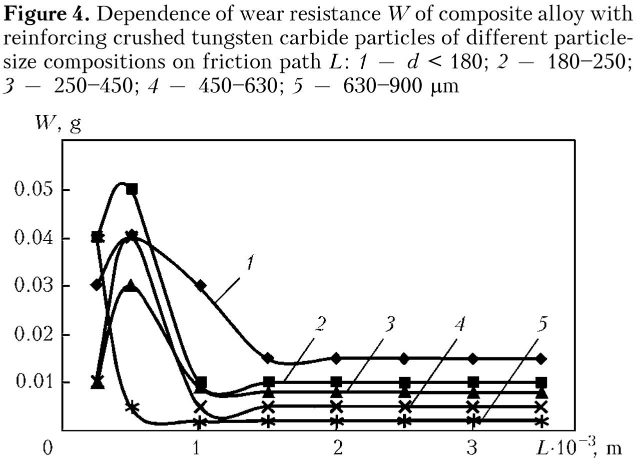

Figure 5. Dependence of wear resistance W of composite alloy with reinforcing spherical tungsten carbide particles of different particle-size compositions, produced by thermal centrifugal spraying, on friction path L: *1*–*5* — see Figure 4

The investigations conducted showed dependence of wear resistance of a composite alloy with the reinforcing crushed (Figure 4) and spherical (Figures 5 and 6) particles produced by different methods upon the friction path. The data presented indicate that wear resistance of the composite alloy with the spherical particles of the identical particle size composition is 3 or more times higher than that of the crushed tungsten carbide (see Figures 4 and 5).

Among composite alloys with the reinforcing spherical particles produced by different methods the lowest wear was exhibited by an alloy comprising the reinforcing spherical tungsten carbide particles produced by thermal centrifugal spraying (see Figure 6).

Also, it was found that run-in of the specimen wearing surfaces takes place at the initial period of the tests. For a composite alloy with the spherical particles this run-in occurs on abrasive friction path $L \approx 1 \cdot 10^3$ m, and for a composite alloy with the crushed particles — on $L \approx 2 \cdot 10^3$ m. This can be explained by an irregular shape and inconsistent strength of the crushed tungsten carbide particles, as wear, destruction and spalling of sharp angles of these particles take a longer period of run-in of the specimen surfaces.

Stabilisation of wear of specimens after run-in is a characteristic feature of the process of wear of composite alloys. Wear of specimens with the crushed tungsten carbide particles is less stable. Wear resistance of the composite alloys was found to decrease with increase in size of the particles (Figure 7). It is this fact that seems to confirm the shadow effect.

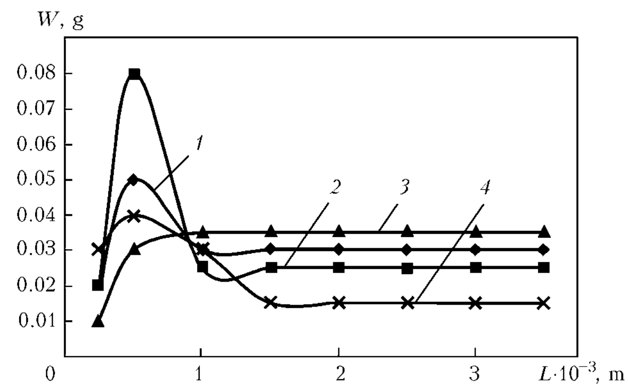

Figure 6. Dependence of wear resistance W of composite alloy with reinforcing spherical tungsten carbide particles, produced by fuse spheroidisation (*1* — SPh-1; *2* — SPh-2; *3* — SPh-3) and thermal centrifugal spraying (*4* — PWI), on friction path

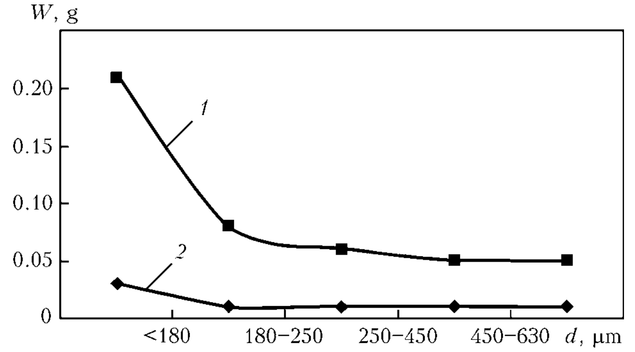

Figure 7. Dependence of wear resistance W of fused tungsten carbides on size d of reinforcing crushed (*1*) and spherical (*2*) particles at $L = 2 \cdot 10^3$ m

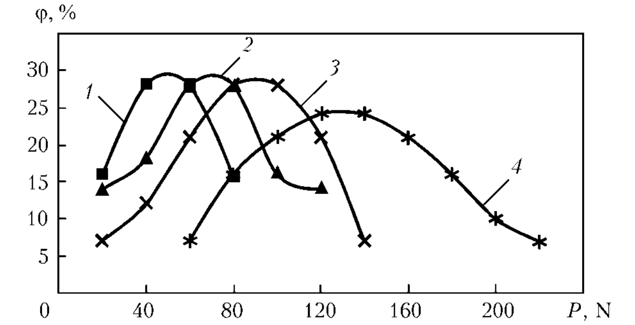

Figure 8. Strength φ of particles of crushed tungsten carbide with different particle size composition: φ — repetition frequency; P — load; *1* — d = 180–250; *2* — 250–450; *3* — 450–630; *4* — 630–900 μm

As indicated above, the process of thermal centrifugal spraying improves homogeneity of structure of the fused tungsten carbide particles, which has a positive effect on their strength. The force required to destroy them was determined by using a special device. The particles were placed between two abrasive plates and statically loaded. 40 particles of each fraction (d < 180, 180–250, 250–450, 450–630, and 630–900 μm) were subjected to the tests. It was impossible to measure strength of the less 180 μm fraction of the crushed particles because of their small size and difficulty to determine load.

Figures 8 and 9 show of the distribution of strength of the crushed and spherical tungsten carbide particles produced by thermal centrifugal spraying, having different particle size compositions. Also, strength of the spherical tungsten carbide particles with size d < < 180 μm, produced by different methods, was compared (Figure 10). As seen from the Figure, the PWI particles produced by the E.O. Paton Electric Welding Institute by the thermal centrifugal spraying method had the highest strength.

CONCLUSIONS

1. Spherical shape of the reinforcing particles of composite alloys is optimal for achieving a high concentration of the wear-resistant phase in hard-facing consumables and in a wear-resistant layer, as well as for providing stable operation of the hard-facing equipment.

2. As seen from the results of investigation of abrasive wear resistance of the MNMts 60-20-20 + tungsten carbide composite alloy produced by different methods, the alloy with the spherical tungsten carbide particles of the PWI grade, produced by thermal centrifugal spraying of ingots by using the E.O. Paton Electric Welding Institute technology, exhibited the lowest wear. Increase in size of the reinforcing particles increases wear resistance of the composite alloy.

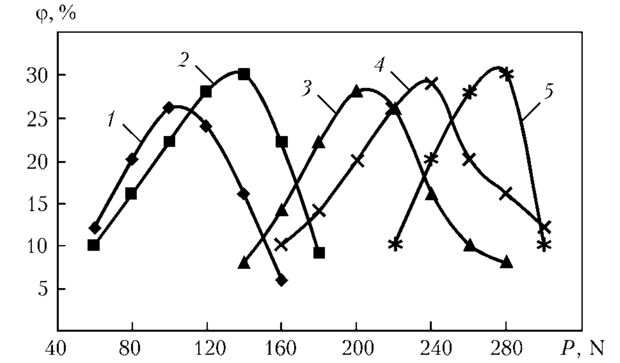

Figure 9. Strength φ of particles of spherical tungsten carbide with different particle size composition produced by thermal centrifugal spraying: *1* — d < 180; *2* — 180–250; *3* — 250–450; *4* — 450–630; *5* — 630–900 μm

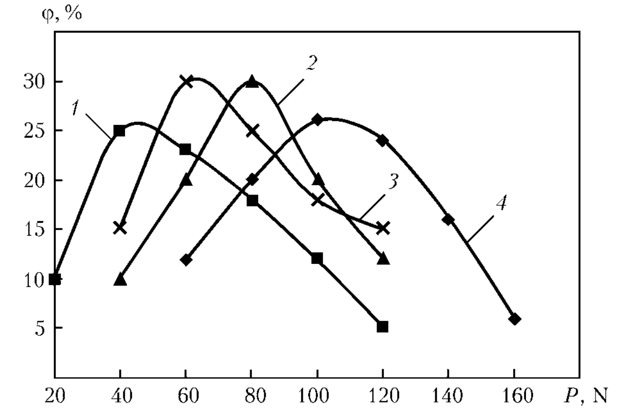

Figure 10. Strength φ of particles of spherical tungsten carbide produced by fuse spheroidisation (*1* — SPh-1; *2* — SPh-2; *3* — SPh-3) and thermal centrifugal spraying (*4* — PWI)

3. Investigations of strength of the tungsten carbide particles produced by different methods show that the PWI particles produced by thermal centrifugal spraying have the highest strength.

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