PROPERTIES OF TUNGSTEN CARBIDE POWDERS PRODUCED BY DIFFERENT TECHNOLOGIES

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Investigation results are presented on properties of powders containing particles of tungsten carbides $WC-W_2C$ and produced by different technologies. Physical characteristics of the above particles were evaluated. Chemical and X-ray analysis of the investigated powders were carried out.

Keywords: *hard-facing powders, tungsten carbides, technologies for production of powders, spherical tungsten carbide, properties of tungsten carbides, wear-resistant composite coatings*

Traditionally, fused tungsten carbides $WC + W_2C$ are produced by crushing of ingots melted in the Tamman furnace at a temperature of 3100 °C. After crushing, a powder is subjected to separation into fractions. Such grains have mostly fragmented, irregular shape (Figure 1, *a*). Mechanical crushing results in formation of lots of cracks in the grains, this decreasing their strength to a considerable degree [1]. Particles of macrocrystalline tungsten carbide (Figure 1, *b*) produced by the WOKA technology have such drawbacks [2].

Irregular shape of the particles causes a substantial decrease in flowability of the powder, thus reducing its technological capabilities in deposition of highly wear-resistant composite coatings, favouring dissolution of tungsten carbide grains (in application of some technologies) and embrittlement of the alloy matrix, and, as a result, leading to decrease in wear resistance of the composite alloy as a whole.

It is a known fact that in the majority of cases the spherical shape of the particles is most optimal for hard-facing powders, as it provides the maximal flowability of materials and stable operation of feeding devices [3]. One of the methods for producing spherical particles of refractory materials is a process of their spheroidisation using the induction-plasma technology [4–7]. The key advantages of the latter include the possibility of preserving chemical composition of the produced particles owing to elimination of decomposition of the material treated. The technology is applied mostly for materials with a high melting temperature.

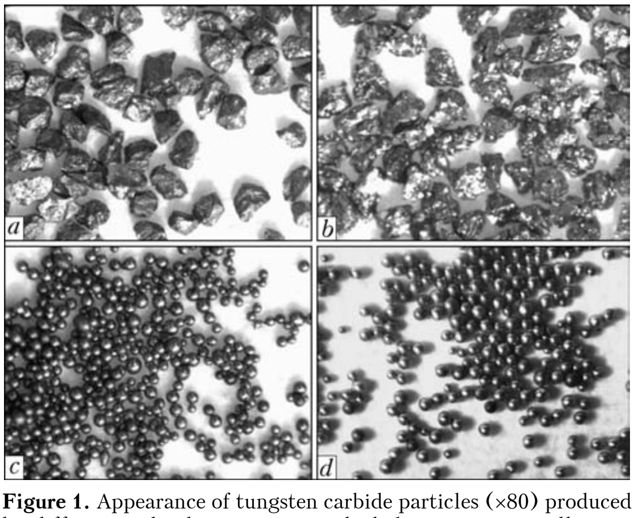

Figure 1. Appearance of tungsten carbide particles (×80) produced by different technologies: *a* — crushed; *b* — macrocrystalline; *c*, *d* — spherical and sprayed, respectively

The spheroidisation method using the induction-plasma technology, in our opinion, has an important drawback. The particles produced by crushing of ingots melted in a resistance or induction furnace are subjected to fusion (Figure 1, *c*). This technology greatly depends upon the skill of operators. The ingots melted are not always homogeneous across their section and along the length. After crushing and fusion, the particles preserve the above inhomogeneity of an ingot, this affecting the quality of a material.

The E.O. Paton Electric Welding Institute developed and uses to advantage the method for thermal centrifugal spraying of cast tungsten carbide ingots [8, 9]. This method of thermal centrifugal spraying (Figure 1, *d*) provides melting of a rotating billet and formation of a thin film of the melt at the billet tip. Under the effect of the centrifugal force, this film moves to the periphery of the tip along the spiral curves. Diameter of the drops is determined by size of the molten film that constantly covers the billet

Table 1. Content of carbon and values of microhardness of tungsten carbide particles produced by different technologies

No.	Type of tungsten carbide particles	C, %	*HV*100
1	Crushed	3.9	1800–2300
2	Macrocrystalline	6.0	1900–2150
3	Spherical (fusion), batch 1	3.9	1950–3000
4	Spherical (fusion), batch 2	3.9	1700–2300
5	Spherical (fusion), batch 2	3.9	1900–2800
6	Spherical (spraying)	4.0	2600–3300

tip. Normally, thickness of this film is less than 150–200 μm. Formation of such microvolumes of molten metal is accompanied by its intensive stirring, this leading to homogenisation of chemical composition of the detaching particles, which determines their high homogeneity and consistency of the stoichiometric composition. The character of melting of the tungsten carbide ingot tip in thermal centrifugal spraying is shown in Figure 2.

To compare properties of tungsten carbide powders produced by different technologies, their microhardness was measured, and their carbon content was determined (Table 1). Particle sizes were within 50–150 μm. Table 1 gives values of the measurements made on twenty particles for each material. To make analysis comprehensive, the list of the investigated powders includes samples of spherical particles produced by fusion by all of the known companies manufacturing this material.

Analysis of the results shows that the most consistent values of microhardness were exhibited by the particles produced by thermal centrifugal spraying of ingots. A wide range of microhardness values of the particles produced by the fusion method proves the above conclusion that the particles preserve heterogeneity of a material made by melting of initial tungsten carbide ingots.

The content of carbon in all the samples (except for macrocrystalline tungsten carbide WC, where the carbon content is 6 %) is 3.9–4.0 wt.%, this corresponding to the content of carbon in tungsten carbide, which is a eutectic mixture consisting of 78–82 wt.% W_2C and 18–22 wt.% WC [10].

Scanning electron microscope CAM SCAN 4 + LINK — system ENERGY 200 (energy-dispersive analyser) was used to study peculiarities of structure of the samples investigated. Analysis of electron microscopy images of the particles (Figure 3) shows that the spherical particles produced by the thermal centrifugal spraying method are characterised by the highest homogeneity of structure.

The investigations revealed the qualitative advantage of the spherical particles produced by the thermal centrifugal spraying method, compared to macrocrystalline tungsten carbide particles and crushed particles of fused carbides, which have a large number of defects in the form of cracks and pores. Moreover, comparing spherical particles produced by different technologies shows the presence of a non-spherical component for the samples produced by the spheroidisation method (up to 15 %), whereas for the particles produced by thermal centrifugal spraying this amount is no more than 5 %.

Comparative characteristics of tungsten carbide particles produced by different methods can be supplemented with X-ray examinations of the samples made by the procedure described in study [11]. Figure 4, *a, b* shows characteristic X-ray patterns of tungsten carbide particles produced by crushing and thermal centrifugal spraying, and Table 2 gives composition of the carbide phase and lattice parameters of carbides produced by the four technologies.

It should be noted that microhardness and properties of the particles of cast tungsten carbides WC–W_2C tend to maximum, providing that each particle

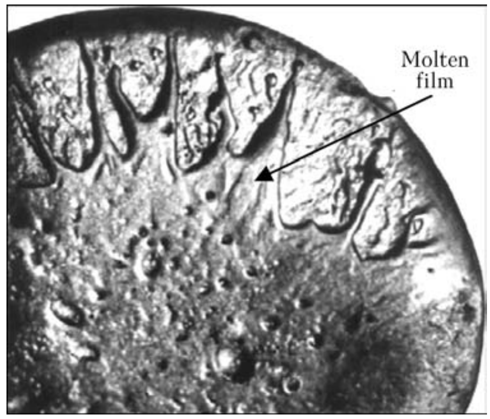

Figure 2. Character of melting of ingot tip in thermal centrifugal spraying

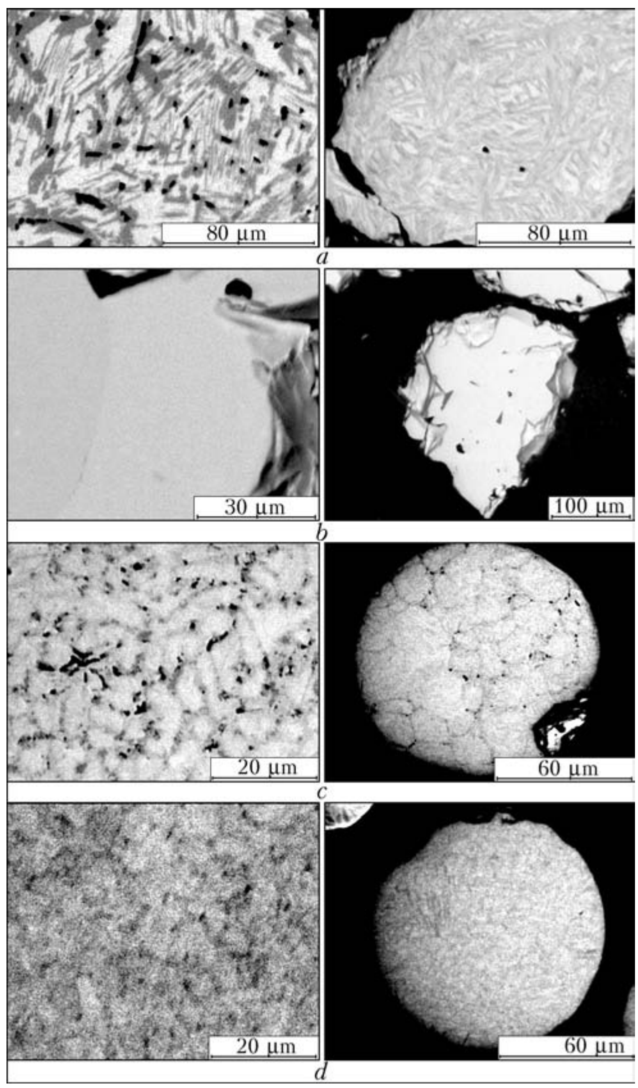

Figure 3. Electron microscopy view of tungsten carbide particles produced by different technologies: *a* — crushed; *b* — macrocrystalline; *c* — spherical (fused); *d* — spherical (sprayed)

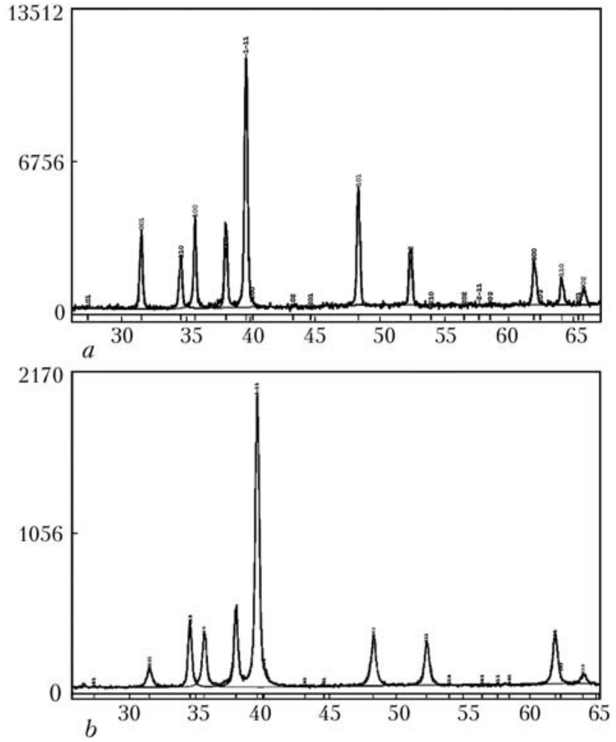

Figure 4. X-ray patterns of tungsten carbide particles produced by different technologies: *a* — crushed; *b* — spherical (spraying)

has a stoichiometric composition, which is a eutectic alloy consisting of 78–82 % W_2C and 18–22 % WC. It can be seen by comparing X-ray patterns of the examined samples that particles of the powder produced by the thermal centrifugal spraying technology developed by the E.O. Paton Electric Welding Institute have practically a eutectic composition. Two phases W_2C and WC in a proportion of 77.34 and 22.66 wt.%, respectively, were detected in the powder (Table 2, Figure 4, *b*).

To compare, the spherical tungsten carbide particles produced by the fusion spheroidisation method contain lines of free tungsten, as well as phases of free tungsten and carbon (see Table 2). Composition of spherical particles of batch 1 is closest to eutectic. However, proportion between the W_2C and WC phases is violated and equals 62.67 and 37.33 wt.%.

Table 2. Phase composition of powders and their lattice parameters

Type of particles	Phase	Phase content, wt.%	Lattice parameters, nm	
Crushed	WC	36.20	2.9048	0. 28368
	W_2C	63.80	5.1861	0.47237
	W	–	–	–
Macrocrystalline	WC	95.42	2.9063	0.28398
	W_2C	4.08	5.1868	0.47163
	W	–	–	–
Spherical (fusion), batch 1	WC	37.33	2.9067	0.28364
	W_2C	62.67	5.1909	4.73830
	W	–	–	–
Spherical (fusion), batch 2	WC	26.32	2.9056	0.28375
	W_2C	69.42	5.1850	0.47286
	W	4.26	3.1645	–
Spherical (fusion), batch 3	WC	31.12	2.9063	0.28370
	W_2C	57.20	5.1855	0.47298
	W	11.41	3.1645	–
	C	0.27	2.4612	0.67163
Spherical (spraying)	WC	22.66	2.9056	0.28368
	W_2C	77.34	5.1893	0.47333
	W	Traces	–	–

CONCLUSIONS

1. The technology for plasma thermal centrifugal spraying of refractory materials, developed by the E.O. Paton Electric Welding Institute, allows producing spherical tungsten carbide particles, which are closest in their stoichiometric composition to the eutectic one.

2. The cast tungsten carbides particles produced by spraying are characterised by high microhardness *HV* 26,000–33,000 MPa and stable homogeneous structure, and are superior in their properties to particles produced by other technologies.

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