



## **Advanced Technologies of Production of Cemented Carbides and Composite Materials Based on Them**

Vladimir Bondarenko, Ella Pavlotskaya, Lyudmila Martynova, Irina Epik

V. Bakul Institute for Superhard Materials of the National Academy  
of Sciences of Ukraine, 2, Avtozavodskaya Str., Kiev, Ukraine

### **Summary:**

The paper presents new technological processes of production of W, WC and (Ti, W)C powders, cemented carbides having a controlled carbon content, high-strength nonmagnetic nickel-bonded cemented carbides, cemented carbide-based composites having a wear-resistant antifriction working layer as well as processes of regeneration of cemented carbide waste. It is shown that these technological processes permit radical changes in the production of carbide powders and products of VK, TK, VN and KKhN cemented carbides. The processes of cemented carbide production become ecologically acceptable and free of carbon black, the use of cumbersome mixers is excluded, the power expenditure is reduced and the efficiency of labor increases. It becomes possible to control precisely the carbon content within a two-phase region — carbide-metal. A high wear resistance of parts of friction couples which are lubricated with water, benzine, kerosene, diesel fuel and other low-viscosity liquids, is ensured with increased strength and shock resistance.

### **Keywords:**

W, WC, (Ti, W)C, tungsten hard alloys, titanium-tungsten hard alloys, methane-hydrogen medium, composite materials, sintering, phase composition, properties.

### **1. Introduction:**

Following Schröter and his patent (1) where the basic principles of the technology of production of hard alloys were presented it was shown (2–3)

that properties of hard alloys depend on a great number of factors, and first of all on processes of reduction of  $WO_3$  to tungsten, production of WC and (Ti, W)C and sintering of cemented carbide workpieces. For this reason, it is these technological processes that are given much attention at the Institute for Superhard Materials of the National Academy of Science of Ukraine.

## 2. Production of tungsten powders:

It was shown in (3–5) that properties of tungsten powders essentially depend on temperature, the speed of the boat advance, the oxide layer thickness and the number of the reduction process steps. In addition, we have found (6–8) that the tungsten powder properties depend heavily on the value of free specific surface of compacts of tungsten oxide ( $F_{sp}$ ) which is in contact with hydrogen as well as on the shape of compacts.

In case of making compacts in the form of cylinders or plates, the specific surface ( $S_{sp}$ ) of tungsten powder increases and the mean diameter of particles ( $\bar{d}_w$ ) decreases as  $F_{sp}$  increases. In reduction of compacts in the form of large plates and cylinders the  $F_{sp}$  dependence is described by equations  $S_{sp} = 25.6 F_{sp}^{2.38}$  and  $S_{sp} = 5.04 F_{sp}^{2.38}$ , respectively. In this case, as  $F_{sp}$  of the plates increases from 0.064 to 0.086 1/mm,  $\bar{d}_w$  decreases from 9.2 to 3.6  $\mu\text{m}$ , and as  $F_{sp}$  of the cylinders increases from 0.09 to 0.37 1/mm,  $\bar{d}_w$  decreases from 13.5 to 0.7  $\mu\text{m}$  (Tables 1 and 2).

Table 1. Specific surface and mean diameter of W powder particles as a function of free specific surface of  $WO_3$  plates

Length, width and height of plates $l \times b \times h$ , mm	Specific surface of W powder, $\text{m}^2/\text{g}$	Mean diameter of particles of W powder $\bar{d}_w$ , $\mu\text{m}$	Relative porosity of a compact, %	Free specific surface of $WO_3$ plates $F_{sp} = \frac{1}{h} + 2\left(\frac{1}{l} + \frac{1}{b}\right)$ , 1/mm
200×32×75	0.085	3.65	43.0	0.086
200×39×75	0.051	6.08	42.0	0.075
200×42×75	0.044	7.05	41.0	0.071
200×49×75	0.034	9.12	44.0	0.064

The distribution of tungsten particle sizes in fractions depends heavily on shape and sizes of compacts as well (Fig. 1).

Table 2. Specific surface and mean diameter of W powder particles as a function of free specific surface of WO<sub>3</sub> cylinders

Cylinder diameter D, mm	Cylinder height h, mm	Specific surface of W powder, m <sup>2</sup> /g	Mean diameter of particles of W powder $\bar{d}_w$ , $\mu\text{m}$	Relative porosity of a compact, %	Free specific surface of a WO <sub>3</sub> cylinder $F_{sp} = \frac{1}{h} \left( 1 + 4 \frac{h}{D} \right)$ , 1/mm
12.5	20.1	0.480	0.7	49.0	0.37
15.0	22	0.300	1.0	49.0	0.31
25.0	38	0.086	3.6	48.0	0.19
37.5	38	0.067	4.6	48.0	0.13
50.0	80	0.023	13.5	48.0	0.09

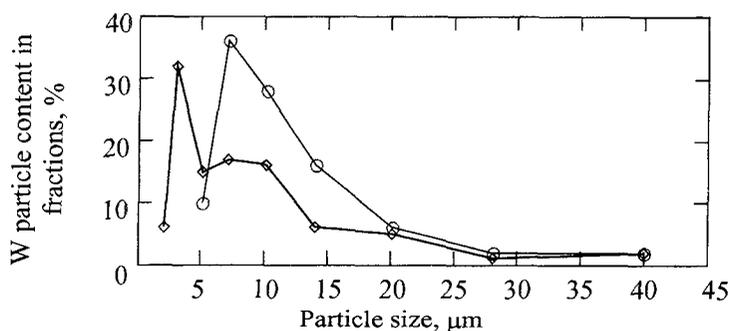


Fig. 1. Differential curves of the distribution of tungsten powder particles reduced from WO<sub>3</sub> cylinders (1) and plates (2).

Our results show that we have found a new factor which strongly affects the tungsten powder quality. Our findings have allowed us to devise processes of production of tungsten powders which differ in  $\bar{d}_w$  and particle-size distribution, the temperature-and-time parameters of the reduction process being unchanged, i.e. there is no need to reset the furnace operation conditions. In this case, a high output of a single-muffle furnace (6–7 kg/h) is ensured.

### 3. Production of high-temperature tungsten carbide:

To transform coarse tungsten powder into tungsten carbide (WC), high temperatures (2000–2300 °C) are needed.

As a rule, to obtain WC, carbon black is used as a carburizer. However, it pollutes production areas, environment and saturates the WC powder with

impurities found in carbon black. For this reason, we have studied the carbidization of tungsten powder in a gas carburizer (methane-hydrogen medium of the equilibrium composition). It was found that when replacing a solid carburizer with a gas carburizer, tungsten carbide sinters into rather strong conglomerates (sintered compacts) to a larger extent. Different tungsten powders (Table 3) when carbidized in the methane-hydrogen medium yielded WC compacts with different values of  $\sigma_{comp}$ .

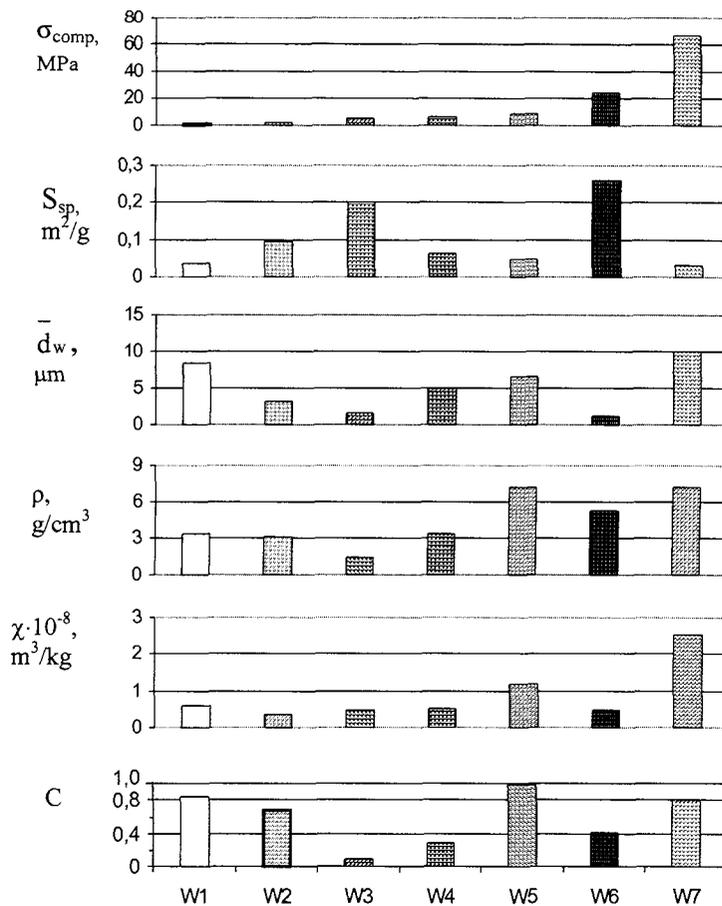


Fig. 2. Compression strength ( $\sigma_{comp}$ ) of WC sintered compacts and properties of W powders of different origins.

Table 3. Grain size of tungsten powders of different origins (-40  $\mu\text{m}$  fraction)

Sample	Particle-size distribution in $\mu\text{m}$ , %											$d_m$ of particles of (-40) $\mu\text{m}$ fraction
	2-3	4-5	6-7	8-10	11-14	15-20	21-28	29-40	41-60	61-80	>80	
W1-one-step W powder (a charge of $\text{WO}_{3\text{init}} = 6000$ g)	-	-	3	8	7	26	22	12	9	5	8	29.0
W2-one-step W powder (a charge of $\text{WO}_{3\text{init}} = 800$ g)	-	-	7	20	58	11	3	1	-	-	-	12.0
W3-one-step W powder from oxidized WC (a charge of $\text{WO}_{3\text{init}} = 800$ g)	26	63	9	2	-	-	-	-	-	-	-	3.88
W4-W powder of KS-type (Russia)	-	3	25	58	6	-	-	-	-	-	-	7.90
W5-W powder of MPGG type ("Stark" firm, Germany)	-	-	-	-	-	-	19	31	29	19	2	44.5
W6-W powder produced by "INMA" firm (Ukraine)	20	29	21	18	6	2	2	1	1	-	-	6.83
W7-one-step W powder reduced from $\text{WO}_3$ compacted plates (a charge = 6000 g)	-	-	-	21	30	17	14	3	12	-	-	21.0

An attempt to use the sinterability criteria suggested by Agte (9) and some geometrical characteristics and physical properties of tungsten powder to explain the dependence of  $\sigma_{\text{comp}}$  of WC sintered compact on W powder type (Fig. 2) failed. It was only simultaneous use of several characteristics of tungsten powder that yielded the equation which adequately described the experimental dependence of  $\sigma_{\text{comp}}$  of a compact on properties of the tungsten powder used

$$\sigma_{\text{comp}} = -35.45 + 104.7S_{\text{sp}} + (4.7 - 4.987S_{\text{sp}}) \cdot \rho + 5.94 \cdot 10^8 \chi + 3.09d_m(1-C), \text{ (MPa)}$$

where  $S_{\text{sp}}$  is the specific surface of the W powder ( $\text{m}^2/\text{g}$ ) measured by the BET method,  $\rho$  is the apparent density of the tungsten powder ( $\text{g}/\text{cm}^3$ ),  $\chi$  is the specific magnetic susceptibility of the tungsten powder ( $\text{m}^3/\text{kg}$ ),  $C$  is the mass fraction of tungsten powder of the +40- $\mu\text{m}$  fraction,  $d_m$  is the mean particle size of tungsten powder of -40- $\mu\text{m}$  fraction measured by the microscopic method

(see Table 3). Powders of (-40  $\mu\text{m}$ ) and (+40  $\mu\text{m}$ ) fractions are obtained by screening tungsten powder on a 40  $\mu\text{m}$ -mesh screen.

The value of  $\sigma_{\text{comp}} \leq 7$  MPa calculated from the above equation suggests that the tungsten powder is not prone to be sintered when carburizing at 2000—2200 °C and it can be used without recourse to additional processes of crushing and milling a sintered compact. Among these powders are W1, W2 and W4 powders (Table 3). Strangely enough, the coarse-grained powders (W6, W7) sintered most strongly. The calculated value of  $\sigma_{\text{comp}}$  for these powders was  $>7$  MPa (Fig. 2). On an industrial scale, the use of the W1 powder is the most efficient, as it is produced at minimum consumption of hydrogen and power expenditure and the highest capacity of a single-muffle furnace (up to 50 t/year).

WC produced from the W1 tungsten powder has the following characteristics: the  $C_{\text{total}}$  content = 6.09%, the  $C_{\text{free}}$  content = 0.05%, the apparent density of WC = 3.6 g/cm<sup>3</sup>. This is an easily-grindable carbide. The capacity of a carbide furnace is 4 kg/hour.

The above results show that when using the W1 tungsten powder the method of producing high-temperature powder of tungsten carbide with the use of a methane-hydrogen gas carburizer can be widely used in production of cemented carbides.

#### **4. Production of (Ti, W)C solid solution:**

Our successes achieved using the methane-hydrogen medium for the production of high-temperature WC powder have made us think that the same medium can be efficiently used in the production of the (Ti, W)C solid solution. The complex (Ti, W)C carbide produced by carbonization with carbon black in hydrogen medium, as a rule, is deficient in carbon. The saturation of this solid solution with carbon can be increased by the addition of carbon black to the charge in the amount by several tenths of percent that of the calculated ratio, but in this case the free carbon content increases up to 0.8 wt%.

Our investigations have shown that the optimal carbon content in the solid solution can be provided on condition that a controlled gas medium having an adequate carbon potential is used.

The (Ti, W)C solid solution was synthesized at 2200 °C for 1 hour in a graphite-tube horizontal furnace with a constant passing graphite containers with charges

through it in an equilibrium methane-hydrogen medium which contained 2 vol% methane. It was found that the carbidization in the methane-hydrogen medium yields a high-grade (Ti, W)C solid solution only under the condition that loosening agents are used which inhibit the sintering of the charge into a low-gas-permeable sinter on melting of  $\text{TiO}_2$  (10–13). Powders of titanium and titanium carbide were used as loosening agents. We have prepared the saturated-on-carbon (Ti, W)C solid solution which contained minor amounts of free carbon (no more than 0.08 wt%) by substituting powders of titanium or titanium carbide for 50 wt% and more of  $\text{TiO}_2$  powder (Fig. 3).

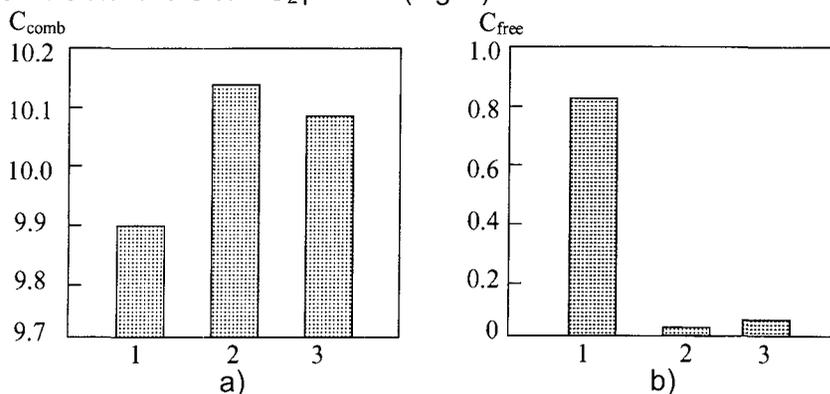


Fig. 3. Combined (a) and free (b) carbon content in the (Ti, W)C solid solution obtained by carbidization using carbon black in a hydrogen medium (1) and by carbidization in methane-hydrogen mixture when adding Ti (2) or TiC (3) to the charge.

The results of X-ray diffraction analysis have shown that this method of the solid solution synthesis makes it possible to obtain consistently the (Ti, W)C solid solution containing particles of homogeneous structure. The properties of hard alloys that contained WC and (Ti, W)C prepared in methane-hydrogen medium corresponded to GOST 3882-74. It should be noted that tensile strength of the alloys was by 5–15% that specified by State Standards (Table 4).

The above data suggest that the use of the methane-hydrogen medium, the proper selection of processes of production of W and WC powders and suitable proportioning of the charge for the production of (Ti, W)C make it possible to change radically the production of carbides for hard alloys of VK and TK groups. The processes of production of hard alloys become ecologically acceptable and free of carbon black, the use of cumbersome

mixers is excluded, the power expenditure is reduced and the efficiency of labor increases.

Table 4. Physico-mechanical properties of titanium-tungsten hard alloys

Alloy grade	Physico-mechanical properties of alloys					
	prepared by a new technology			standard, acc. to GOST 3882-74		
	Density, g/cm <sup>3</sup>	Hardness HRA	Bending strength, MPa	Density, g/cm <sup>3</sup>	Hardness HRA	Bending strength, MPa
T5K10	12.7	89	168	12.5—13.1	88.5	145
T15K6	11.3	90.5	125	11.1—11.6	90.0	120

### 5. Sintering of hard alloys using the methane-hydrogen medium:

To adjust mixtures of various lots and those obtained from various suppliers to the same carbon content, Babich (14) suggested the method of the normalizing solid-phase sintering in graphite grits as a charge. However, in that case, the sintering process duration more than doubled which resulted in higher consumption of hydrogen, power expenditure, and graphite containers. In addition, the working conditions become worse because of graphite grits. To eliminate this disadvantage, we have suggested to replace graphite grits with a methane-hydrogen mixture of the equilibrium (at a given temperature) composition (15) and to combine the normalizing sintering with final sintering. Scientific principles of a new process are described in (16–17).

By virtue of the fact that in sintering of hard-alloy compacts a wide temperature variation across the length of a continuous furnace was observed it was necessary to ensure a variable-composition gas medium in different temperature zones of the furnace in order to eliminate the alloy decarbonization or the graphite liberation in it. We have managed to solve this problem by a substantial change in the distribution curve of the temperature across the furnace length and by feeding a gas medium of various compositions into different zones of the furnace (Fig. 4). In this case, one furnace successfully combined the processes of normalizing and final sintering, the disadvantages of normalizing sintering were eliminated and a high homogeneity of final products was ensured. The coercive force of the commercially produced hard alloy varied within  $\pm 0.4$  kA/m. This in turn ensured a high degree of consistency of performance characteristics of the alloy. At present the "Alkon-Tverdosplav" enterprise at the Institute for Superhard Materials sinters hard alloy workpieces only with the use of the methane-hydrogen medium.

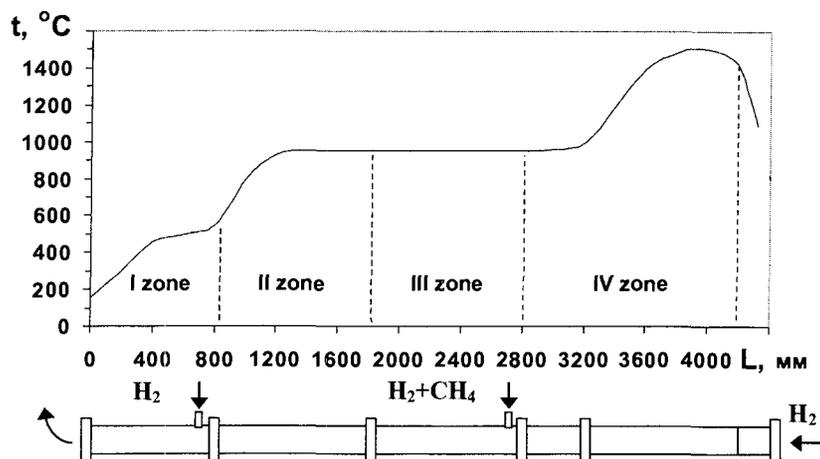


Fig. 4. Distribution of temperature across the furnace length and the scheme of feeding gases into different zones.

When vacuum furnaces are employed, combined gas-vacuum sintering is used, i.e. the solid-phase sintering is carried out in the methane-hydrogen medium, while the final (liquid-phase) sintering in vacuum.

It should be noted that the use of the methane-hydrogen medium at the stage of the solid-phase sintering and the precision control ( $\pm 0.1$  vol%) of the medium composition make it possible to use industrial furnaces for the production of alloys with various carbon contents within two-phase regions WC-Co or WC-Ni. In this case, particular values of properties of hard alloys are attained (Table 5).

## 6. Thermochemical regeneration of cemented carbides:

The formation of loose oxidation products when oxidizing hard alloys in air, high rates of reduction of oxides of tungsten and cobalt by hydrogen and the possibility to after-carbonize mixtures of VK hard alloys up to the stoichiometric composition in the methane-hydrogen medium have made us think that by using the methane-hydrogen medium we can prepare mixtures of hard alloys from oxidation products of hard alloy waste.

Our investigations of processes of hard alloy oxidation (18) and the combined process of reduction and carbidization of the oxidation products (19) have allowed us to devise a technique to regenerate hard alloys of the VK and TK groups. Physico-mechanical properties of the regenerated hard alloys meet

the requirements of the State Standards (Table 6), performance characteristics of these alloys are highly competitive with those of alloys produced from commercial mixtures. In 2000 the "Alkon-Tverdosplav" produced 15 t of hard alloy articles following our technology. For 2001 our plan is to produce more than 20 t of regenerated hard alloys which are very efficient in high pressure apparatuses for diamond synthesis, cutting and mining tools, dies, press molds, friction units, etc.

Table 5. Properties of hard alloys prepared by sintering in the methane-hydrogen gas medium having a precision composition

Hard alloy grade	C <sub>total</sub> content, wt%	Lattice constant of the binder phase, Å	Phase composition	Physico-mechanical properties			Specific characteristics		
				Density $\rho$ , g/cm <sup>3</sup>	Hardness HRA	Bending strength, MPa	K <sub>res</sub>	K <sub>str</sub>	Magnetic property
VK6	5.76	3.552	WC+ $\gamma$	15.01	90.5	1920	1.53	0.95	magn.
VN10	5.55	3.555	WC+ $\gamma^1$	14.75	89.0	2120	-	-	magn.
VN10	5.39	3.565	WC+ $\gamma^1$	14.76	89.2	2100	-	-	non-magn.

Notes:  $\gamma$  and  $\gamma^1$  are, respectively, cobalt and nickel binding phases;

K<sub>res</sub> and K<sub>str</sub> are, respectively, the coefficient of resistance in cutting and the coefficient of strength in tests by the single-cutter method in comparison to standard VK8 hard alloy;

magnetic properties were tested by a permanent magnet from the YuNDK 3515 alloy with magnetic energy of  $7.5 \times 10^6$  Gs·Oe.

It should be noted that the regeneration of hard alloys by our technique is performed with no acids, carbon black and graphite grits. This makes our technique ecologically acceptable. Combination of some operations in one process considerably reduces costs of the production of hard alloys and makes them competitive in the world market.

## 7. Production of highly efficient WC-Ni and Cr<sub>3</sub>C<sub>2</sub>-Ni hard alloys:

Our investigations have shown that the refining of WC grains in WC-Ni alloys has a greater effect on an increase of their hardness than on a decrease of their strength. For this reason, in the majority of cases medium-grained alloys of the VK group can be replaced with fine-grained WC-Ni alloys. We have developed a process of production of medium- and fine-grained WC-Ni alloys (Table 7), which are used successfully in friction units, press molds, mining tools, high pressure apparatuses.

Table 6. Properties of regenerated hard alloys

Hard alloy grade	Application	Chemical composition of the mixture, %			Physico-mechanical properties			Structure			
		Co	C <sub>total</sub>	C <sub>free</sub>	Density, g/cm <sup>3</sup>	HRA	$\sigma_{\text{bend}}$ (TRS), MPa	Porosity, %	$\eta_1$ phase content	Graphite content, %	$\bar{d}_{\text{wc}}$ , $\mu\text{m}$
VK6	Metal cutting	5.7	5.8	0.03	14.8	89.6	1780	0.2	not present	not present	2.1
		5.7–6.2	$\geq 5.4$	$\leq 0.10$	14.6–15.0	$\geq 88.5$	$\geq 1519$	$\leq 0.2$	impermissible	$\leq 0.2$	2.0–2.5
VK6	HPA	5.8	5.8	0.05	14.7	89.0	1890	0.2	not present	not present	2.5
		5.7–6.2	$\geq 5.4$	$\leq 0.10$	14.6–15.0	$\geq 88.5$	$\geq 1519$	$\leq 0.2$	impermissible	$\leq 0.2$	2.0–3.0
VK8	Metal cutting	7.8	5.6	0.02	14.6	89.3	2000	0.1	not present	not present	2.0
		7.5–8.0	$\geq 5.4$	$\leq 0.10$	14.5–14.8	$\geq 88.0$	$\geq 1666$	$\leq 0.2$	impermissible	$\leq 0.2$	2.0–2.5
VK8V	Coal mining	7.5	5.7	0.05	14.5	86.6	2068	0.2	not present	not present	3.0
		7.5–8.0	$\geq 5.4$	$\leq 0.10$	14.4–14.8	$\geq 86.5$	$\geq 1813$	$\leq 0.2$	impermissible	$\leq 0.4$	2.0–5.0
VK15	HPA	13.8	5.3	0.05	14.0	86.5	2300	0.2	not present	not present	2.2
		13.9–15.0	$\geq 5.0$	$\leq 0.10$	13.9–14.1	$\geq 86.0$	$\geq 1862$	$\leq 0.2$	impermissible	$\leq 0.5$	2.0–3.0
VK15S	Dies	13.8	5.3	0.03	14.0	86.0	2300	0.1	not present	not present	2.5
		13.9–15.0	$\geq 5.0$	$\leq 0.10$	13.9–14.1	$\geq 86.0$	$\geq 1862$	$\leq 0.2$	impermissible	$\leq 0.5$	2.0–3.0
VK20	Dies	18.0	4.8	0.02	13.6	85.0	2510	NA	not present	not present	2.2
		18.0–19.5	$\geq 4.7$	$\leq 0.10$	13.4–13.7	$\geq 84.0$	$\geq 2058$	$\leq 0.2$	impermissible	$\leq 0.5$	2.0–3.0
T5K10	Metal cutting	8.6	6.4	0.03	12.6	89.6	1500	0.1	not present	not present	2.0
		8.5–9.0	$\geq 6.1$	$\leq 0.10$	12.5–13.1	$\geq 88.5$	$\geq 1421$	$\leq 0.2$	impermissible	$\leq 0.3$	2.0–3.0

Note: Lower lines for each hard alloy grade give values according to Technical Specifications and GOST (State Standards).

Table 7. Properties of tungsten-nickel hard alloys

Hard alloy grade	$\bar{d}_{WC}$ , $\mu\text{m}$	Density, $\text{g/cm}^3$	Hardness HRA	Bending strength, MPa
VN8	2.1	14.70	87.5	2070
VN15	2.4	14.00	84.5	2490
VN15M	1.8	14.00	86.5	2530
VN20	2.3	13.60	83.0	2460

$\text{Cr}_3\text{C}_2$ -Ni hard alloys are characterized by higher corrosive and heat resistances but they have lower strength and higher brittleness. We have shown in (20, 21) that the basic reason for this is due to a high rate of the  $\text{Cr}_3\text{C}_2$  grain growth at temperatures needed for more complete densification of these alloys. The mean grain size in the alloys was about  $12 \mu\text{m}$ . To increase strength and hardness of the alloys, the size of a chromium carbide grain should be considerably decreased. To do this, we alloyed the binder with boron and phosphorus (22). We have managed to decrease the mean size of a  $\text{Cr}_3\text{C}_2$  grain to  $4 \mu\text{m}$ . In this case both strength and hardness of the alloys have increased considerably (Fig. 5). These hard alloys can be successfully used to make rings and bushes of friction couples that are lubricated with aggressive liquids, 400 mm in diameter and 500 mm in height.

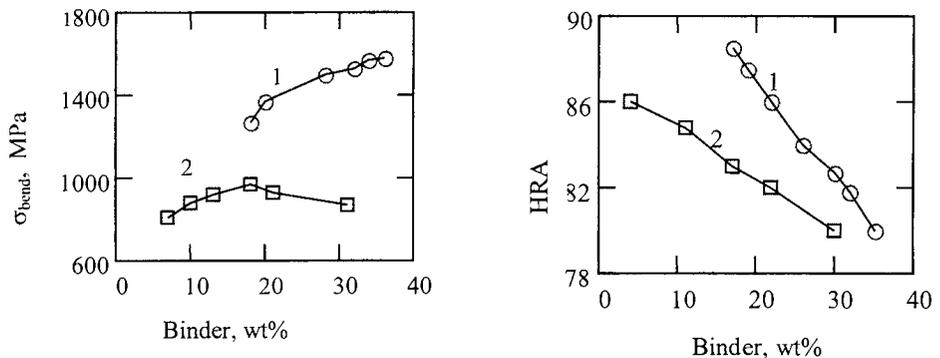


Fig. 5. Properties of  $\text{Cr}_3\text{C}_2$ -Ni-based composites as a function of the content of a binder alloyed with phosphorus and boron (KKhNPR) and phosphorus (KKhNF): 1 – KKhNPR,  $\bar{d}_{\text{Cr}_3\text{C}_2} = 4.85 \mu\text{m}$ ; 2 — KKhNF,  $\bar{d}_{\text{Cr}_3\text{C}_2} = 7.5 \mu\text{m}$ .

To further increase strength and hardness of  $\text{Cr}_3\text{C}_2$ -based hard alloys, techniques should be devised which would allow one to decrease  $\text{Cr}_3\text{C}_2$  grain size to  $1.5\text{--}2.0 \mu\text{m}$ . It is likely that with  $\text{Cr}_3\text{C}_2$  grain sizes below  $1.5 \mu\text{m}$  the

hardness will increase and the strength will decrease as an increased brittleness of thin nickel interlayers will have an effect on it.

### 8. Composites based on hard alloys:

Multicomponent materials which consist of hard alloys in whose composition particles are added which differ substantially from a high-melting constituent in their properties (chemical composition, crystal lattice, hardness, strength, coefficient of friction, etc.) are classed by us with composites based on hard alloys. We have devised technologies of preparing graphite-containing composites based on WC-Ni hard alloys as well as CBN-containing composites based on Cr<sub>3</sub>C<sub>2</sub>-Ni hard alloys (23, 24). Both the composites were used for making friction units which are lubricated with low-viscosity liquids (water, benzine, kerosene, diesel fuel, etc.) In both the cases, charges were prepared in a similar manner: the constituents in a given proportion were mixed in drums in rolling mills. The WC-Ni-graphite charges (VN15Gr2, VN15Gr4, VN20Gr2, VN20Gr4 grades) were pressed in ordinary press molds and the resulting compacts were sintered following the procedure of sintering of WC-Ni hard alloys (25). Properties of sintered composites are listed in Table 8. These composites feature high wear resistance, the absence of seizure even in case of a short-duration (up to 3 min) dry friction, the absence of sparking, an adequate running-in, much higher strength and impact resistance as compared to siliconized graphite which is usually used in these friction units.

Table 8. Properties of graphite-containing composites based on tungsten-nickel hard alloys

Material grade	Mass fraction of the basic constituents			Physico-mechanical properties		
	Tungsten carbide	Nickel	Graphite	Bending strength, MPa	Density, g/cm <sup>3</sup>	Hardness HRA
VN15Gr2	83	15	2	980	11.5	70
VN15Gr4	81	15	4	230	10.2	45
VN20Gr2	78	20	2	1078	11.7	70
VN20Gr4	76	20	4	294	10.3	40

A kubonit (CBN)-containing charge was hot-pressed on steel substrates, i.e. the Cr<sub>3</sub>C<sub>2</sub>-Ni-kubonit composite is far more brittle than the WC-Ni-graphite composite. In addition, kubonit is a very expensive material. For this reason, it is a good practice to use this composite as a coating on a steel substrate. Kubonit which is the second hardest material (next to diamond) makes this composite very wear-resistant. In units of face sealings with drop lubrication

with industrial water, the serviceability of components of a friction couple made of this composite is retained during 40,000 hours. Following our procedure we can make rings for face sealings up to 350 mm in diameter.

## 9. Conclusions:

The above presentation of a great number of new technologies shows that the use of only some technological approaches (shape and size variation of  $WO_3$  compacts, application of a methane-hydrogen medium of an equilibrium composition and the addition of particles of antifriction or superhard materials to hard alloys) have allowed us to devise a wide range of advanced processes of production of hard alloys and composites based on them. It is evident that the potentialities to devise new advanced technologies have not yet been exhausted. We are working now on the development of new technologies and have already obtained promising results.

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