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Technical Note

Recycled Hard Metal-Base Wear-Resistant Composite Coatings

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The abrasion-erosion wear resistance of composite coatings from self-fluxing Ni-base alloy and WC-Co hard metal powders is evaluated. The resistance of thermal sprayed and melted NiCrSiB-(WC-Co) coatings was found to be markedly higher than that of NiCrSiB and slightly higher than that of comparative welded coatings. Microstructural and surface analyses were used to describe the coatings and the wear damage. Based on the principles of creating wear-resistant coatings and on experimental studies of wear resistance, high wear-resistant, composite NiCrSiB-(WC-Co) coatings were fabricated. These coatings exhibited 300% higher wear resistance than 0.45% C steel.

Keywords composite powders, reuse of hard metals, selection of coatings, wear resistance

1. Introduction

In terms of product lifetime considerations for industrial materials and parts, the surface is of prime concern. This involves both corrosion behavior and mechanical properties such as material fatigue and wear. Under conditions of impact loading such as wear in a hard particle stream, the materials experience substantial impact, and the stress exceeds the yield stress by one order of magnitude (Ref 1-3).

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Table 1 Chemical composition of self-fluxing alloy powders

Powder codes	Chemical compositions, wt%: Ni	Cr	Si	B
12494	base	8.0-14.0	1.2-2.3	1.7-2.5
12495	base	10.0-16.0	3.0-5.0	2.0-4.0
12496	base	12.0-18.0	3.5-5.5	2.5-4.5

Powders of Castolin SA, Switzerland

Rules of selection have been prescribed by different researchers (Ref 1, 4). In terms of coatings for abrasion erosion and wear resistance, their structure is of primary importance. This includes a structure with maximum hardness and maximum hard phase content at small impact angles and a matrix structure with optimal hardness and hard phase content under straight impact conditions (Ref 2, 5, 6).

According to these principles, new powder composites based on commercially produced Ni-base self-fluxing alloy powders and tungsten carbide-base hard metal powders for wear-resistant coatings were researched. Hard metal powders produced by the milling of recycled hard metals were employed (Ref 7, 8) as the initial materials of composite powders.

2. Experimental Procedure

2.1 Coating Materials

The basic components of the coatings were NiCrSiB alloy powders. Table 1 shows the chemical composition of the self-fluxing alloy powders used for the powder composites. The particle size was +60–160 μm, and their shape was spherical. The technology of producing hard metal powders from used (recycled) hard metals consisted of preliminary cyclic thermal treatment and mechanical refining of hard metal wastes and final milling of pretreated particles by collision. The disintegrator used is one of a few devices for treating materials by a collision process (Ref 9, 10).

Table 2 Main characteristics of hard metal powders

Type of powder	Diameter: Mean d_m, μm	Diameter: Main fraction μm and %	Mean area A_m, μm^2	Roundness(a): Mean	Roundness(a): Interval of main fraction (75%)	Surface in wt unit, m^2/g
+60–125 μm	60	30-60 70%	530	1.43	1.20-1.60	0.0060
+125–250 μm	142	70-230 85%	2 800	1.41	1.20-1.50	0.0030
+250–500 μm	330	270-400 70%	94 000	1.43	1.35-1.60	0.0014

(a) Roundness = $P^2/4\pi \cdot A$, where P = perimeter, A = area

Hard metal particles with a particle size from 60 to 500 μm were used as the hard phase of the composite coatings. Figure 1 illustrates the size (mean diameter) and morphology distribution (roundness) of hard metal particles obtained by using an image analysis system Image-Pro Plus 3.0 (Ref 11, 12). Figure 2 shows the particle shape of powder +125–250 μm. The particles were primarily equiaxed in form. The particle microstructure showed a typical hard metal structure based on tungsten carbide (Fig. 3). Table 2 shows the prime characteristics of the hard metal powders.

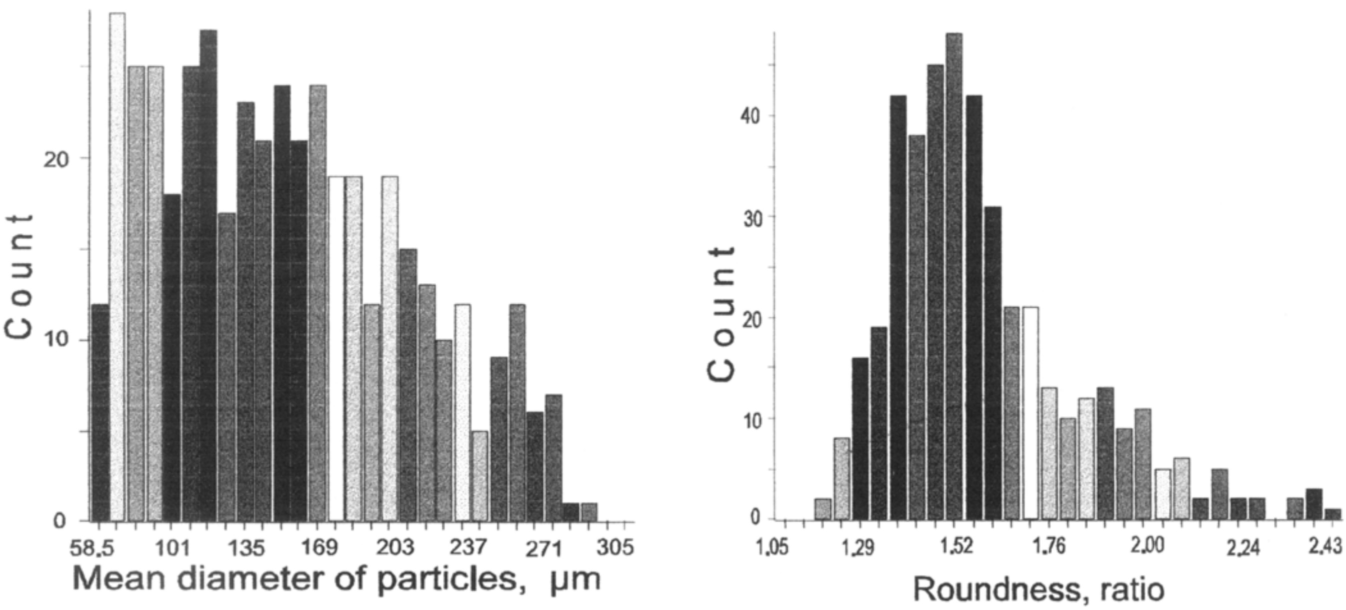
2.2 Coating Technology

Sprayed coatings were deposited by the detonation method under the parameters shown in Table 3. Hard metal powder of below 125 μm was sprayed by means of the Perun-S Detonation Spray System (Institute of Welding, Kiev, Ukraine) with acetylene and oxygen as combustion gases.

The spray and fused coatings based on self-fluxing alloys with WC-Co hard metal particles were deposited by Eutalloy Flame Gun (Castolin SA, Switzerland) on structural steel of 0.45% C content as the substrate material.

2.3 Structure and Hardness of Coatings

The detonation-sprayed coatings were approximately 0.3 mm thick, and the spray and fused coatings were from 0.5 to 1 mm thick. The metallographical investigations showed that the use of fine WC-Co powder (particle size up to 125 μm) by the detonation spray method allowed the formation of a coating from 97 to 98% theoretical density, similar to the spray and fusion method (Ref 6).



(a) (b)

Fig. 1 Size and form distribution of hard metal powder +125–250 μm: (a) mean diameter of powder particles projections and (b) roundness of powder particles in cross-section polish

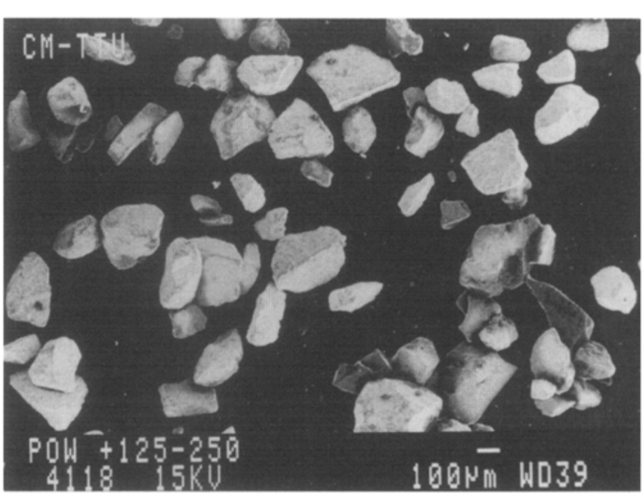


Fig. 2 Micrograph of WC-15% Co powder from +125– 250 μm

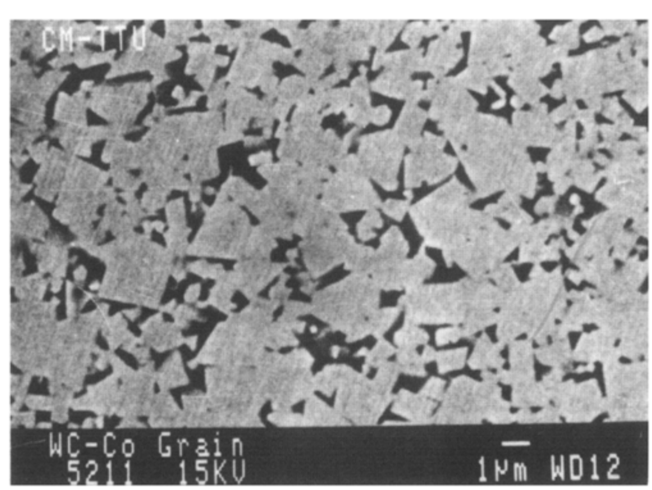


Fig. 3 Scanning electron micrograph of WC-15% Co powder particle

The cross section of the NiCrSiB-25 wt% (WC-15 Co) coating is shown in Fig. 4. NiCrSiB self-fluxing alloy forms a matrix with WC-Co hard particles, which are partially dissolved in the Ni-base matrix. This differs essentially from the structure of coatings from pure self-fluxing alloy powders (Ref 13). This was confirmed by determination of the element distribution in the coating (Fig. 5). The hardness (<50 g load) of the melted coating constituents is indicated in Table 4.

Table 3 Detonation gun spray parameters for WC-Co powder

Parameters	Value
Velocity of spraying, m/s	Up to 800
Detonation frequency, Hz	Up to 5
Spray distance, cm	30
Thickness of layer per shot, μm	20-30
Spot diameter, mm	25
Combustible gases	Acetylene and oxygen

Table 4 Hardness of NiCrSiB-(WC-15 Co) coatings

Type of coating	Hardness HV 0.05
12494	250
12494 + 15 wt% (WC-15 Co)	775/1410 (a)
12494 + 25 wt% (WC-15 Co)	685/1545 (a)
12494 + 50 wt% (WC-15 Co)	735/1465 (a)

(a) Hardness of Ni-base matrix/hardness of hard metal particles

Table 5 Parameters of abrasion-erosion wear

Parameters	Value
Particle size of abrasive, mm	0.1-0.3
Hardness of abrasive, HV	1100-1200
Velocity of abrasive particles, m/s	80
Impact angles of a stream of abrasives, degree	30 and 90

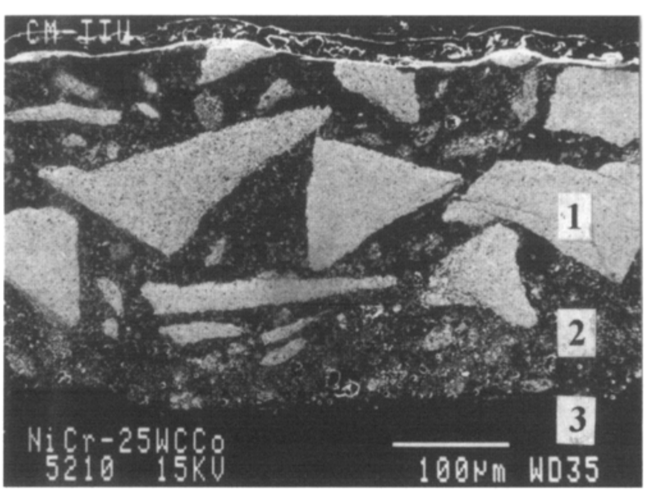
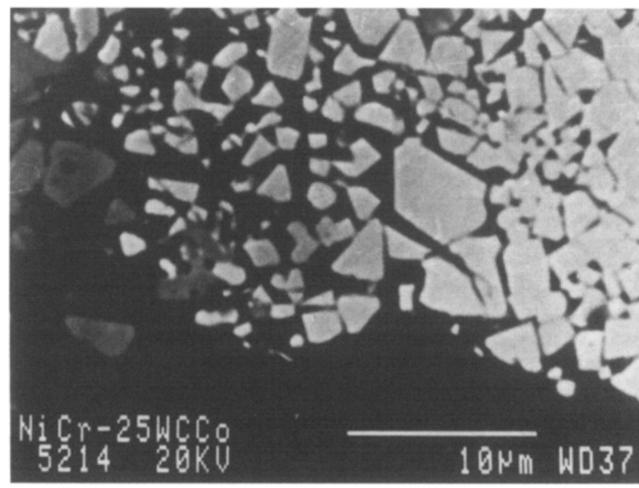


Fig. 4 Micrograph of cross section of melted NiCrSiB-25wt% (WC-15Co) coating: 1, hard metal particle, 2, NiCrSiB-matrix, and 3, substrate

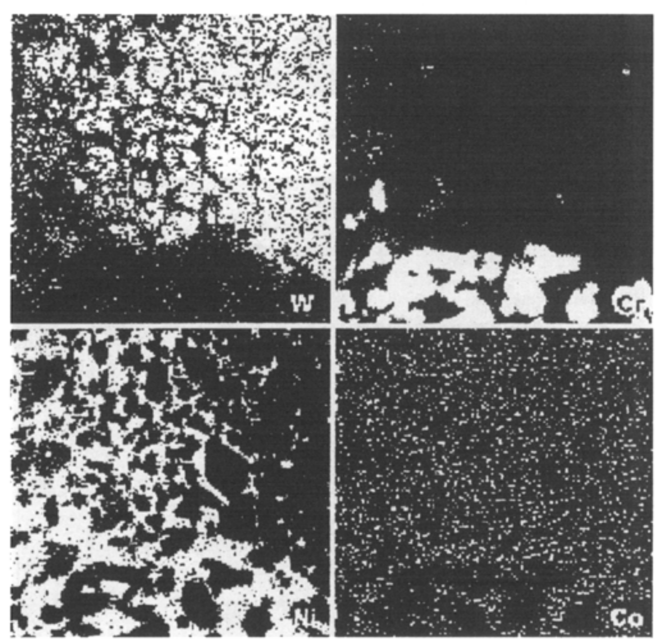
2.4 Abrasion-Erosion Wear Testing

Modeling of wear and the study of wear mechanisms were performed in a centrifugal accelerator as shown in Fig. 6 (Ref 14). The testing method is comprised of abrading the specimens with a stream of abrasive quartz sand particles. The number of replicate tests was six. Table 5 demonstrates the wear parameters.

The measurements permitted calculations for weight and volume losses as a measure for wear intensity; that is, the loss of mass or volume per one kilo of abrading material in mg/kg and mm^3/kg, respectively. The relative wear resistance, E_V, was calculated as the ratio of the volume wear intensities of the studied and the standard material of normalized 0.45 % C steel of hardness 200 HV.



(a)



(b)

Fig. 5 Distribution of elements in melted NiCrSiB-25 wt% (WC-15 Co) coating: (a) micrograph of cross section and (b) distribution of W, Cr, Ni, and Co

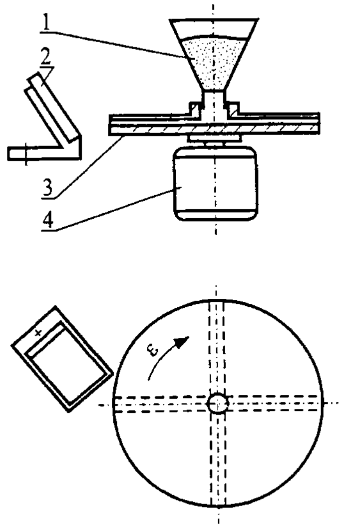
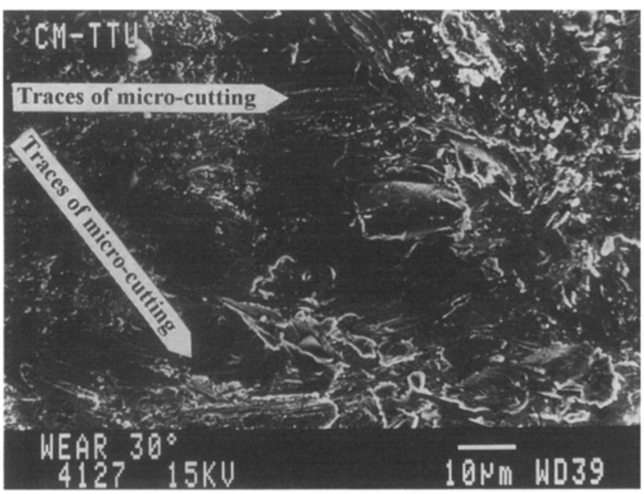
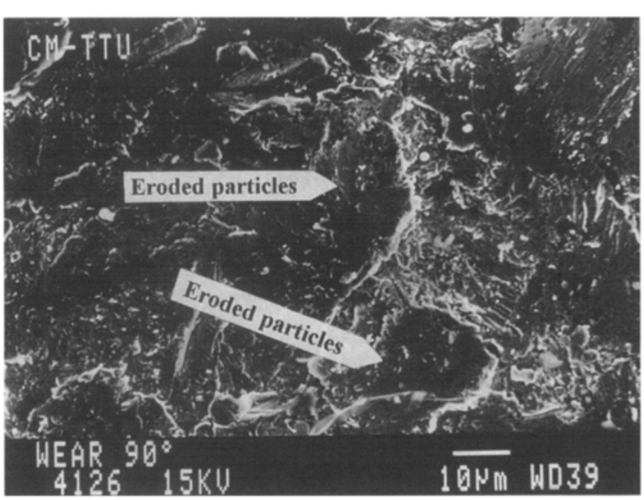


Fig. 6 Principal scheme of abrasion-erosion tester: 1, abrasive bunker, 2, specimen holder with specimen, 3, rotor, and 4, electromotor



(a)



(b)

Fig. 7 Worn surfaces. Topographical image of a composite NiCrSiB-25 wt% (WC-15%Co) coating at impact angles (a) 30° and (b) 90°

3. Results and Discussion

3.1 Wear Resistance of Sprayed Coatings

The abrasion-erosion wear resistance of detonation-sprayed WC-Co hard metal coatings at small impact angles is ~3× higher than that of the 0.45% C steel (Table 6). As shown in Ref 15, the wear resistance of sprayed WC-Co hard metal coatings exceeds that of coatings made from a WC-Co mechanical mixture powder by up to 10×. At the same time, the wear resistance of coatings under straight impact is approximately the same as that of steel.

3.2 Wear Resistance of Sprayed and Fused Coatings

Table 7 shows the relative wear resistance of conventional melted NiCrSiB (12494) coatings and that of the coating reinforced with hard metal particles. For comparison, the wear resistance of analogous welded coatings (Castonlin SA, Switzerland) is provided. As shown, the wear resistance of the composite coatings exceeds that of conventional NiCrSiB coatings by approximately 1.5× and is similar to the coatings formed from the commercially produced welding electrodes.

Depending on the hard metal particle content, coatings with 15 to 50 wt% (WC-15 Co) hard metal particles showed a relative volume wear resistance exceeding 1.3 to 2.1× that of pure NiCrSiB coatings (Tables 7 and 8). Based on wear intensity and wear mechanism study of the coatings, the wear of coatings at a

Table 6 Relative abrasion-erosion wear resistance of detonation-sprayed WC-Co coatings

Composition of coatings	Hardness HV 0.1	Relative volume wear resistance, E_V $\alpha = 30°$	$\alpha = 90°$
WC-9 Co(a)	1310	3.1	1.1
WC-15 Co	1410	2.8	1.1

(a) Powder was produced by sintering.

Table 7 Relative abrasion-erosion wear resistance of sprayed and fused composite NiCrSiB-(WC-15 Co) coatings

Composition of coatings	Relative volume wear resistance, E_V $\alpha = 30°$	$\alpha = 90°$
NiCrSiB(a)	1.3	0.8
NiCrSiB-15 wt% WC-Co	1.5	0.7
NiCrSiB-25 wt% WC-Co	1.9	0.6
NiCrSiB-50 wt% WC-Co	2.0	0.6
8811(a)	2.1	0.7

(a) Coatings from Castolin SA, Switzerland

Table 8 Relative abrasion-erosion wear resistance of unreinforced coatings

Coating code	Hardness HV	Relative volume wear resistance, E_V $\alpha = 30°$	$\alpha = 90°$
12494	430	1.3	0.8
12495	560	1.3	0.6
12496	930	1.6	0.4

straight impact angle (α = 90°) results from the direct fracture of hard metal particles and low cyclic fatigue of matrix metal (Fig. 7a). At smaller impact angles (α = 30° and less), microcutting of the metallic matrix is dominant as indicated by wear cracks of the abraded coatings (Fig. 7b). It is similar to the wear mechanism of hard metals by abrasion erosion (Ref 3).

3.3 *Effect of Matrix Hardness*

The difference in wear resistance of coatings from self-fluxing Ni-base alloys of different hardness was up to 2× as shown in Table 8 (Ref 4). The effect of the NiCrSiB matrix hardness on the wear resistance of composite coatings is insignificant (Fig. 8). Depending on the hardness of the matrix metal, WC-15Co coatings exhibited a volume wear intensity, which differed from 30 to 40% because the matrix phase hardness is higher than that of a matrix without hard metal particles (coatings base of 12494 and 12495 alloys). The higher hardness is attributed to dissolved hard metal particles within the Ni-base matrix. In practice, microhardness (number of measurements was from 12 to 15) of different Ni-base matrices with dissolved hard metal micro-sized particles varied slightly (Table 4).

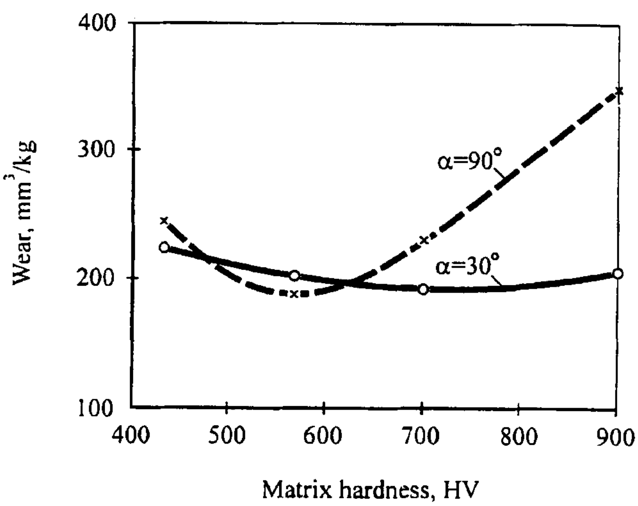


Fig. 8 Dependence of wear intensity on the initial hardness of the coating matrix

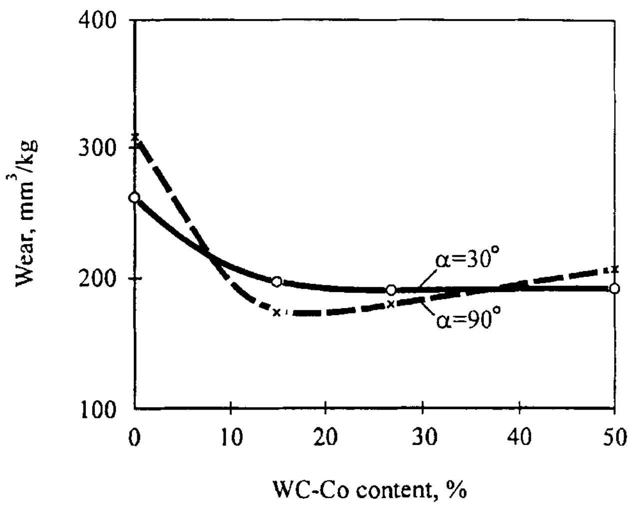


Fig. 9 Dependence of wear intensity on the hard phase content

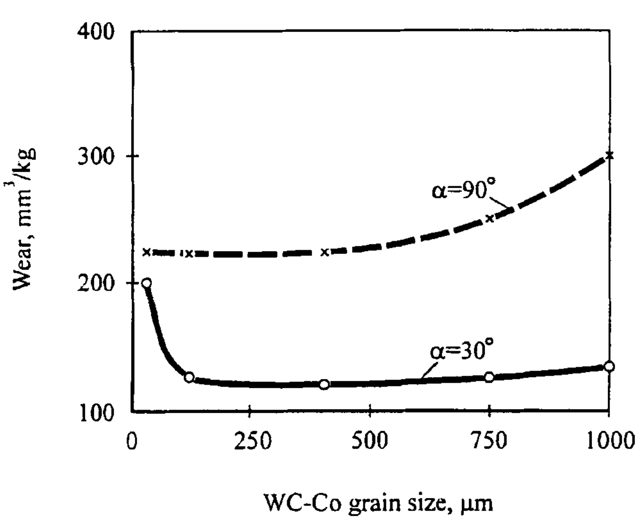


Fig. 10 Dependence of wear intensity on hard metal particle size

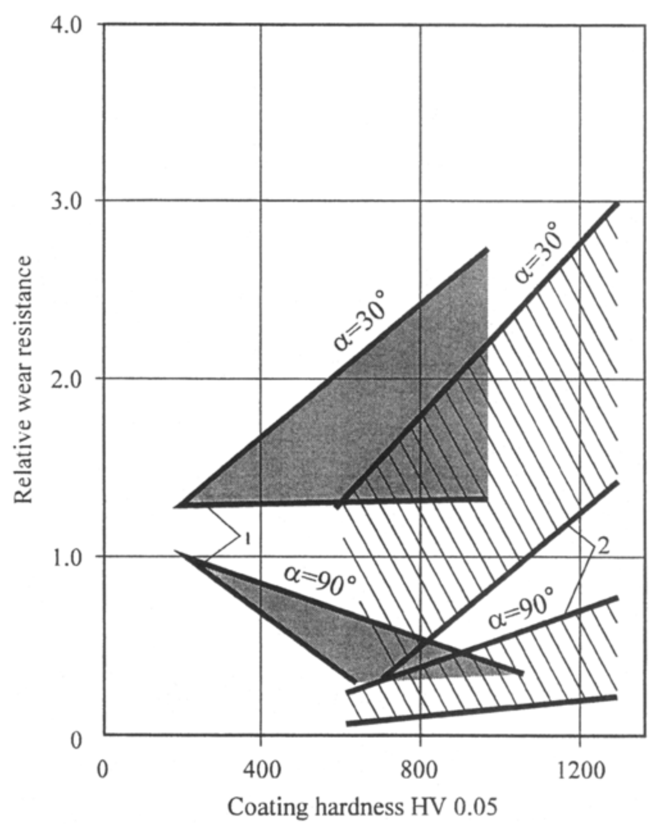


Fig. 11 Effect of coating hardness on the relative volume of wear resistance of sprayed and melted composite coatings at impact angles 30° and 90°

3.4 *Effect of Hard Phase Content and Particle Size*

Figure 9 shows the effect of the amount of hard phase, hard metal particles (from 15 to 50 wt%), on the wear resistance of composite coatings. According to the principles of the creation of abrasion-erosion resistant coatings, an increase in the amount of hard metal particles of composite coatings led to an increase in the wear resistance under wear conditions similar to sliding wear (at small impact angles). Under operating conditions at straight impact, as a result of an increase in the hard phase content, the wear resistance of the coatings decreased.

The influence of hard phase particle size on the wear resistance of a coating (Fig. 10) in the range of the studied hard metal particle size (+60–500 μm) is insignificant.

3.5 *Rules of Powder Coating Selection*

The powder coatings of the same hardness deposited by different methods may differ by one order of magnitude in their wear resistance under analogous wear conditions. In the case of small and medium impact angles (Fig. 11), the wear resistance of melted coatings increases as coating hardness is enhanced (in this case, $E_V > 1$). When great attack angles are applied, an increase in coating hardness causes a decrease in its wear resistance ($E_V < 1$)(Ref 15).

With sprayed coatings an increase in detonation coatings hardness, wear resistance is enhanced both at small and great impact angles (Fig. 11). This is different from the trends observed under other abrasive wear conditions (Ref 1, 3, 16).

4. Conclusions

New NiCrSiB self-fluxing alloy-base composite powders, containing WC-Co hard metal powders (from 15 to 50 wt%), can be produced from used (recycled) hard metals. A technology of producing hard metal powders with a predicted particle size by collision in the disintegrator equipment has been employed. The physical and technological properties of powders have been analyzed.

The wear resistance of the detonation-sprayed hard metal coatings and the flame-melted composite coatings was examined under conditions of abrasion-erosion wear. It was found that the wear resistance of sprayed coatings is high. The wear resistance of melted NiCrSiB-(WC-Co) coatings on the composition of coatings and the wear conditions. The wear resistance of coatings increased with an increase in matrix phase hardness as well as with an increase in hard phase content in the composite at small impact angles of abrasive particles. The wear resistance of the coatings reinforced with hard metal particles is low at straight impact.

In addition to high wear resistance, NiCrSiB-(WC-Co) composite powder implies costs lower than with analogous welding electrodes. This is due to the presence of WC-Co hard metal powder produced from used (recycled) hard metal from a grinding process.

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