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Abrasive Wear and Mechanical Properties of Carbide Composites

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This work focuses on the abrasive wear performance of some carbide composites: WC-hardmetals and TiC-base cermets (in particular, composites prospective for metalforming). Wear tests were performed using the dry rubber-rimmed rotary wheel machine (modified ASTM 65-94 method). The results relate to the mechanical properties and structure. It is shown, that the abrasive wear of a carbide composite is controlled by its rigidity (resistance to elastic and plastic strain) and depends firstly on fraction, grain size and properties of the carbide phase, and secondly, on those of the binder.

Keywords: abrasive wear, cemented carbide, cermet, mechanical property.

1. INTRODUCTION

Tungsten carbide-base hardmetals are the most widely used materials in different wear applications (as working elements of various equipment, machines and tools) owing to their excellent combination of high wear resistance and good strength-toughness [1, 2]. Tungsten-free hardmetals − TiC- base cermets (with a Ni-alloy or steel binder) may be successful in some applications because of their lower friction coefficient, high specific strength (low specific weight) and favourable physical properties (thermal expansion coefficient close to steels, higher corrosion resistance) [3, 4].

It is generally assumed that the performance of a cermet depends both on its wear resistance and resistance to fracture (strength). The optimum durability is obtained when both of these properties are maximized.

Because of lack of information concerning different types and grades of cermets it is important to test the materials and identify their wear behaviour under different working conditions. This is required to choose an optimum carbide composite.

The present study was focused on the abrasive wear behaviour of some carbide composites, in particular composites prospective for metalforming. The wear performance of those composites was studied in relation to their mechanical properties and microstructure.

2. TEST MATERIALS AND EXPERIMENTAL DETAILS

2.1. Materials

Tungsten and titanium carbide-base cemented carbides, in particular, composites prospective for metalforming (carbide fraction 74 – 85 vol %) were under investigation. Additionally, some grades of cermets based on chromium carbide (Cr_3C_2) (approximately at the same carbide fraction) were studied.

TiC-base cermets were cemented with FeNi steels with Ni content of 8 wt % (martensitc structure) or 14 wt % (austenitic structure with traces of martensite) and also with NiMo alloys (Ni:Mo=2:1 or Ni:Mo=4:1).

Porosity was 0.2 vol % and under for all the materials tested (except Cr_3C_2-base composite with porosity 0.4 vol % and under). The average grain size of the carbide phase was 2 – 2.3 μm in the majority of cases (except Cr_3C_2-base composites with grain size ≤ 3.5 μm).

The materials were produced employing the ordinary vacuum sintering technology of pressed powders. In addition some batches were sintered under gas compression (sinterhipping). A review of the composition and mechanical properties of the composites investigated is presented in Table 1.

2.2. Testing procedures

Abrasive wear tests were performed using the rubber-rimmed rotary wheel machine (modified ASTM 65-94 method) (Fig. 2) as follows: abrasive − quartz sand with particle size 0.1 – 0.2 mm (hardness HV = 1100) of amount 3 kg, velocity of wheel 0.24 m/s, wear distance 144 m, testing time 10 min and load 3N (Fig. 1).

A minimum of four tests per composite were performed to ensure the confidence interval of 10% with the probability factor of 95 %.

Transverse rupture strength R_{TZ} was determined by the conventional ISO 332/7 method (using a B-test specimen), and Vickers hardness by EN-ISO6567.

As an additional characteristic the proof stress $R_{co.1}$ featuring the resistance of the material to plastic strain and shear-strength (resistance to micro-cutting) of all composites was determined. The proof stress was determined in a compression test using specimen of diameter 10 and length of 18 mm [2].

3. RESULTS AND DISCUSSIONS

Fig. 2 shows the abrasive wear rates of test materials plotted against their composition (carbide fraction). It can be seen that the increase in the volume fraction of the carbide phase led to a monotonous decrease in wear (increase in wear performance) of all composites unlike the carbide and binder composition.

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Table 1. Structural characteristics and properties (hardness *HV*, transverse rupture strength R_{TZ}), of cemented carbides

Grade	Carbide phase, wt %	Binder, structure	*HV*, GPa	R_{TZ}, GPa
H10	WC, 90	Co(W)	1.35	2.4
H12	WC, 88	Co(W)	1.30	2.8
H15	WC, 85	Co(W)	1.15	2.9
H20	WC, 80	Co(W)	0.98	3.0
T60/8	TiC, 60	FeNi 8, martensite	1.22	2.4/2.7*
T60/14	TiC, 60	FeNi 14, austenite	1.10	2.4
T70/14	TiC, 70	FeNi 14, austenite	1.25	2.3
T80/14	TiC, 80	FeNi 14, austenite	1.44	1.4/3.0*
TN30(2:1)	TiC, 70	NiMo (2:1)	1.40	1.7
TN40(2:1)	TiC, 60	Ni-Mo (2:1)	1.26	1.9
TN40(4:1)	TiC, 60	Ni-Mo (4:1)	1.01	2.2
TN50(2:1)	TiC, 50	NiMo (2:1)	1.00	2.1
C30	Cr_3C_2, 70	NiMo (2:1)	1.15	1.4

* conventional sintering / sinterhipping.

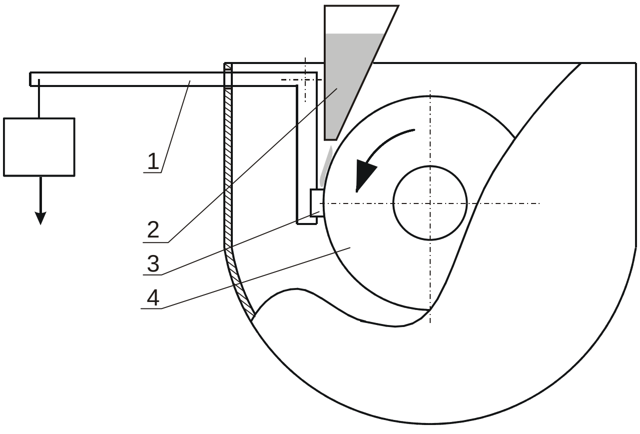

Fig. 1. The scheme of abrasive-wear testing: 1 – loading system, 2 – abrasive-particles, 3 – specimen, 4 – rubber-rimmed rotating steel wheel

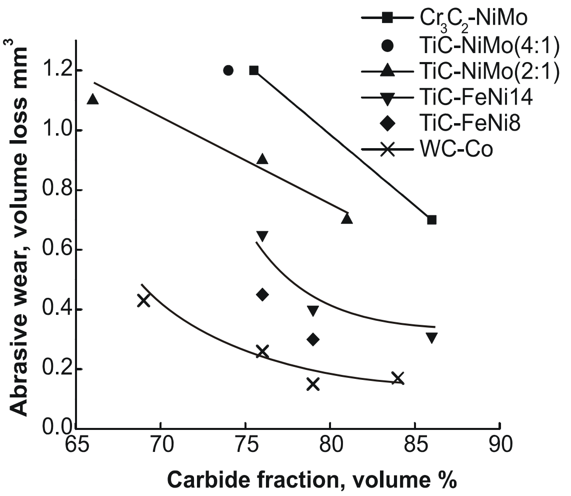

Fig. 2. Abrasive wear of cemented carbides versus carbide volume fraction in an alloy

The results obtained refer to an obvious dependence of the wear performance (wear resistance) of the test material on carbide composition. At an equal carbide volume fraction, tungsten carbide-base composites demonstrate an obvious superiority over TiC-base cermets.The latter, in turn, are at a remarkable advantage over chromium carbide (Cr_3C_2)-base ones.

The wear performance appears to depend on the properties of the carbide phase of the alloy and on those of a binder. TiC-base cermets with a steel binder demonstrate higher wear performance (lower wear rate) as compared to cermets bonded with Ni-alloy.

In terms of abrasive wear performance, TiC-base cermets with a Ni-alloy binder of enhanced alloying degree (Ni : Mo = 2 : 1) and cermets with martensitic steel binder (T70/8, T60/8) are superior over cermets with an ordinary NiMo binder (Ni : Mo = 4 : 1) and austenitic structure (T70/14, T60/14).

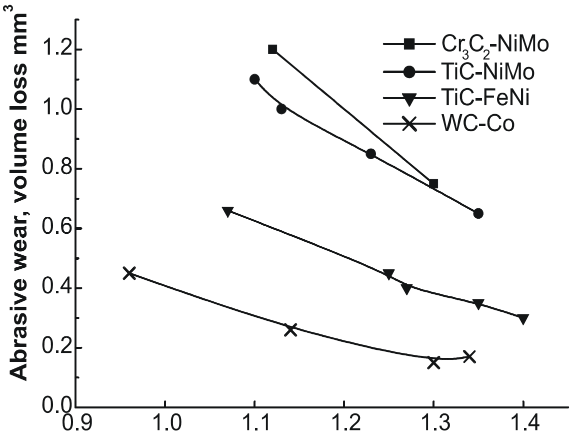

Fig. 3. Abrasive wear of carbide composites versus Vickers hardness

In Fig. 3 the abrasion rates of the test materials are plotted against their hardness (the ordinary measure of material wear resistance). The results confirm the inconclusive influence of hardness on the wear performance of materials revealed for adhesion, erosion and blanking wear conditions [6]. At equal hardness abrasive wear of different carbides differs up to four times.

In Figs. 4 – 5 abrasive wear rates of the test materials are opposed to their mechanical properties – modulus of elasticity E and proof stress $R_{co.1}$. While E – an $R_{co.1}$ features material resistance to the elastic and plastic strain, respectively, R_{TZ} does it to brittle fracture.

The results refer to an obvious dependence of wear performance on the modulus of elasticity and proof stress of the composites. The increase of the modulus of elasticity or proof stress of a composite decreases monotonously its wear rate. In essence, the relationships obtained (Fig. 2 – 5) repeat those revealed for erosive wear. It was shown that the erosion of cermets, hardmetals and metals may be adequately evaluated by the product $E^n \cdot R_{co.1}$ (where $1 < n < 2$) [5].

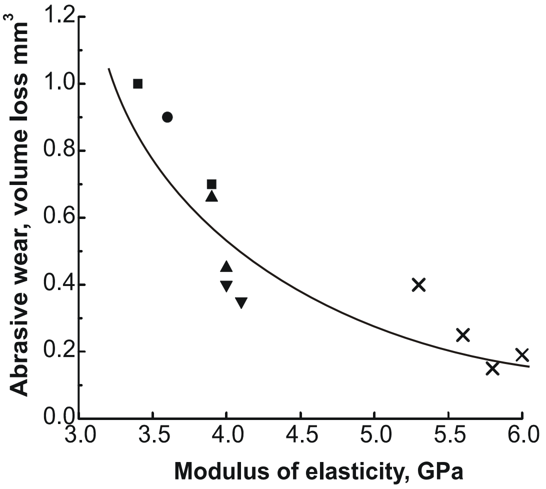

Fig. 4. Abrasive wear of cemented carbides versus modulus of elasticity

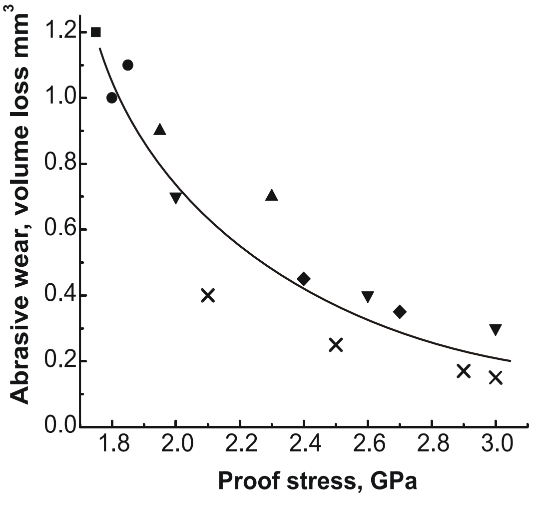

Fig. 5. Abrasive wear of cemented carbides versus proof stress

In general, these results accord with the physical model of abrasive-erosive wear reported in several studies [5 – 8]. Material removal starts in the binder, takes place by extrusion microcutting and continues by transgranular cracking of the subsurface of carbides. Therefore, the resistance to wear depends primarily on the elastic strain (compression) controlling the extrusion of the binder and the cracking of carbides (as a result of accumulation of elastic strain energy). These processes depend on the modulus of elasticity of the cermet carbide particles. Secondly, the wear depends on the resistance of the binder to the plastic flow (extrusion) and microcutting (shear-fracture). These processes are controlled by the proof stress (in particular, the proof stress of the binder).

4. CONCLUSIONS

1. At equal carbide volume fraction, tungsten carbide-base composites (WC-hardmetals) have advantage over tungsten-free cermets in abrasive wear conditions.
2. In terms of abrasive wear performance, TiC-base cermets with a steel binder are superior over TiC-cermets with Ni-alloy.
3. Prognosis of abrasive wear performance on the basis of hardness can lead to pronounced mistakes, when carbide composites of different composition are considered.
4. The performance of carbide composites in abrasive wear conditions is controlled by the stiffness of the alloy – its resistance to elastic (measured by the modulus of elasticity) and plastic (measured by the proof stress) strains and depends primarily on the properties of the carbide phase, its amount and grain size and secondly, on the properties and the composition of the binder.

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