ISSN 1392–1320 MATERIALS SCIENCE (MEDŽIAGOTYRA). Vol. 12, No. 2. 2006

Performance of Cemented Carbides in Cyclic Loading Conditions

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Received 20 June 2005; accepted 07 July 2005

This article analyzes the fatigue behaviour of some cemented carbides based on tungsten and titanium carbide. It is shown that the performance of carbides in cyclic loading conditions is controlled by the fatigue sensitivity (slope of Wöhler curve) and plasticity of an alloy. The scanning electron microscopy (SEM) and X-ray diffraction analysis (XRD) studies revealed that the fatigue damage is preceded by the plastic strain taking place in both phases − in the ductile binder and in the brittle carbide (WC, TiC).

Keywords: cemented carbide, cermet, cyclic loading, fatigue.

INTRODUCTION

Cemented carbides (mainly based on tungsten carbide or titanium carbide) are the most widely used ceramic and metal composites because of their excellent strength – wear resistance combination. It is important to note that until now there is no complete understanding of the material behaviour under complex service conditions where cemented carbides with a heterogeneous structure are subjected to various types of loading and wear.

Transverse rupture strength R_{TZ} is an important characteristic of hardmetals for production (as evaluator of quality), application (as an estimate of serviceability), and research (for elaboration of new grades). At the same time, transverse rupture strength, as one of the characteristics used in the evaluation of carbide composite performance in complicated wear condition (wear accompanied by loads of impact and cyclic nature) has been reported to be at a disadvantage [1, 2].

In the present paper the performance of some TiC-base cermets (prospective for metalforming) in cyclic loading conditions – fatigue, blanking of sheet metal – is analyzed and compared with that of an ordinary WC-hardmetal, applicable in metalforming.

The results involve the mechanical properties (strength, plasticity), fatigue sensitivity, blanking performance and microstructure of tested alloys (cemented carbides).

EXPERIMENTAL

Table 1 shows the advanced TiC-base cermets, the performance of which was tested in complicated wear conditions (in relation to ordinary WC-hardmetal H15).

The transverse rupture strength R_{TZ} was determined in accordance with ISO-3327, method using ‘B’ test specimens, while the ultimate plastic strain ε_p was determined in a uniaxial compression test [1]. Fatigue tests resembled those for bending fatigue – fatigue of specimens (5 × 5 × 15) mm under repeated transverse bending load [3]. Frequency of loading was 35 Hz.

Durability tests were performed as functional ones – in the blanking of electrotechnical sheet steel (t = 0.5 mm) in a 3-position (with 3 different alloys) die. In these tests durability was evaluated by the side wear $\Delta D/2$ of the dies after intermediate service time of 0.5×10^6 strokes as N/Δ (strokes per 1 mm of side wear Δ) [4 – 5]. The intermediate service time corresponded to the time between two prophylactic sharpenings used in the exploitation of blanking dies.

The studies were complemented by scanning electron microscope (SEM) and XRD investigations, performed on the instruments JEOL JSM840A and diffractometer Bruker D5005, respectively.

RESULTS AND DISCUSSION

Results of functional tests – wear contours of cutting edges (and side wear Δ) of carbide tools refer to an obvious superiority of a TiC-cermet with Ni-steel binders (grade T70/14) over an ordinary WC-base hardmetal (grade H15) (Fig. 1).

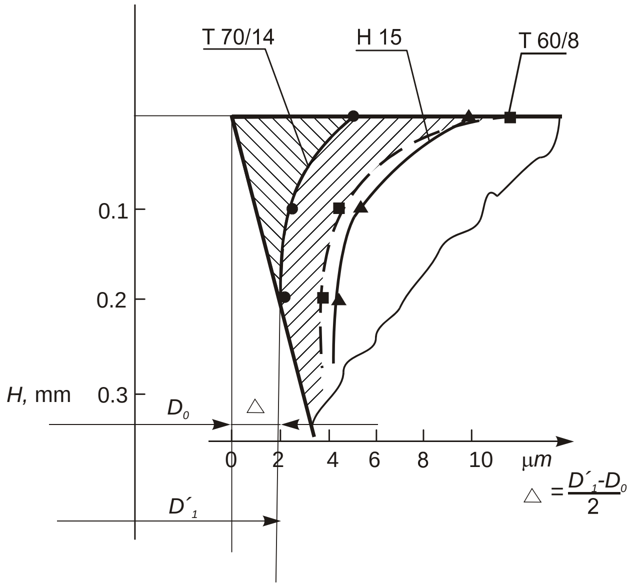

Fig. 1. Wear contours (and side wear Δ) of the tested carbide composites

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Table 1. Structural characteristics and mechanical properties of carbide composites (hardness *HV*, transverse rupture strength R_{TZ}, ultimate plastic strain ε_p, and fatigue limit at 10^7 loading cycles S_7)

No of grade	Grade	Carbide, wt%	Binder composition, structure	*HV*, GPa	R_{TZ}, GPa	ε_p, %	S_7, GPa
1	H15	85	Co(W)	1.15	2.8	1.5	1.35
2	T70/14	70	Fe+15Ni steel, austenite	1.25	2.3	1.8	1.30
3	T60/8	60	Fe+8Ni steel, martensite	1.22	2.4	1.4	–

Table 2. Decrease in intensity ΔI (measure of local plastic strain) of X-ray reflections from carbide WC and TiC of carbide composites tested in cyclic loading conditions (fatigue)

No	Grade	Carbide, line	Intensity, Lin(cps)		Decrease ΔI, Lin (cps)
			Before testing I_0	After testing I_c	$\Delta I = I_0 - I_c$
1	70/14	TiC, [200]	76	58	18
2	H15	WC, [001]	52	37	15

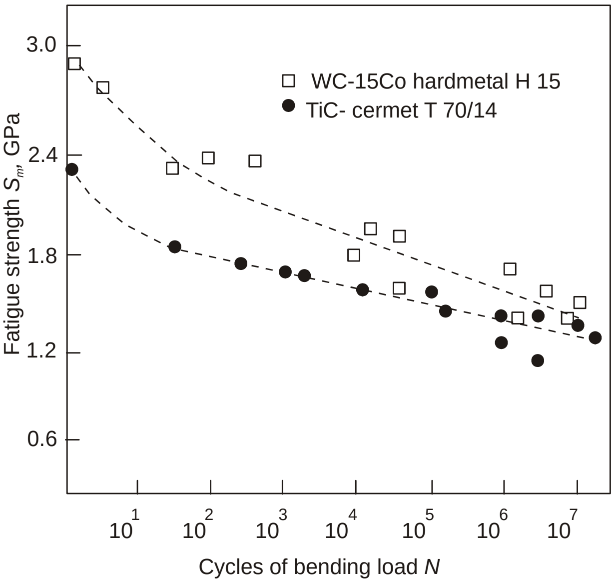

Fig. 2. Wöhler curves of carbide composites: 1 – ordinary hardmetal H15; 2 – TiC-cermet T70/14

The results of fatigue tests, i.e., Wöhler curves of these grades revealed an important peculiarity (in relation to H15) in the behaviour of grade T70/14 – its lower fatigue sensitivity (Fig. 2). The fatigue sensitivity of an alloy is featured by the slope of its Wöhler curve – by the intensity in the strength decrease ΔS with an increase of loading cycles *N*. ΔS characterizes material resistance to fatigue damage (Fig. 3).

The global presentation shown in Fig. 4 refers to the existence of a good correlation between cemented carbide blanking performance on the one hand and its fatigue sensitivity (factor $\Delta S = S_7 - S_3$) and plasticity ε_p on the other hand.

Results show that both fatigue sensitivity (resistance to fatigue damage) and blanking performance may be related, to great extent, to the ability of an alloy to absorb fracture energy (elastic strain energy stored at crack tips during cyclic loading) by means of local plastic strain.

It has been shown by SEM that the local plastic strain (onset of failure) of cemented carbides in case of static and cyclic starts and takes place mainly in the ductile binder [2, 3].

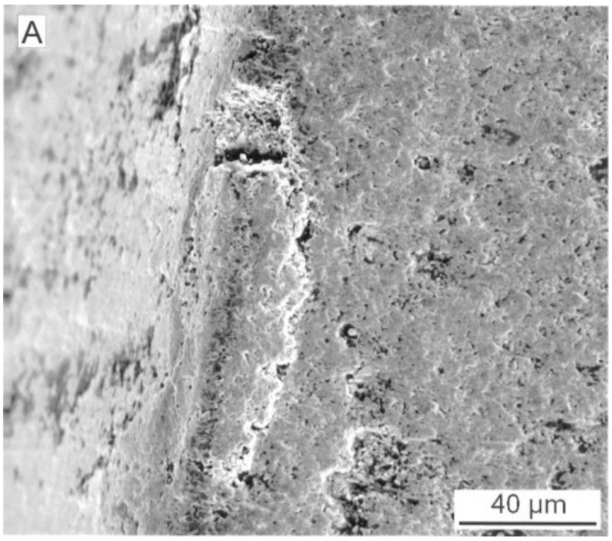

Fig. 3. SEM image of hardmetal H15 worn surface, representing origin of fatigue microcracks (after $N = 3 \cdot 10^5$ loading cycles)

Results of XRD investigations (Table 2), i.e., decrease in the intensity ΔI of X-ray reflection lines from carbides TiC and WC allow us to conclude that the fracture of carbide composites during cyclic loading propagates in their carbide phase and is preceded by local plastic strain. It means that the ability of a cemented carbide to absorb fracture energy by plastic strain depends on the plasticity of its both phases − the ductile binder and the brittle carbide.

CONCLUSIONS

1. The superiority of an advanced TiC-base cermet (cemented with 14 % Ni-steel) over an ordinary WC-hardmetal used in metalforming in cyclic loading conditions (blanking of sheet metal, fatigue) was revealed.
2. The higher blanking performance of the TiC-base cermet in relation to WC hardmetal may be related to its lower fatigue sensitivity.

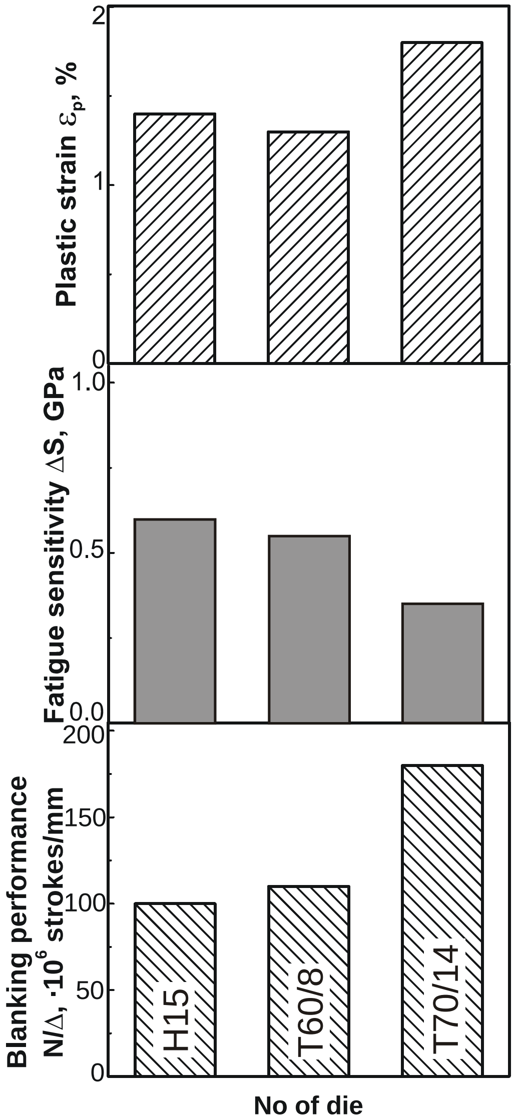

Fig. 4. Blanking performance, fatigue sensitivity factor $\Delta S = S_7 - S_3$ (S_7 and S_3 − cyclic strength at $N = 10^7$ and $N = 10^3$ loading cycles respectively) and ultimate plastic strain ε_p of carbide composites

3. The fatigue sensitivity characterized by the slope of Wöhler-curve (intensity in the decrease of strength with the increase of loading cycles) is controlled, to a great extent, by the ability of the composite to undergo plastic strain.
4. The fracture of a carbide composite in cyclic loading conditions starts in the binder, propagates in the carbide phase and is preceded by local plastic strain taking place in both phases – in the ductile binder and in the brittle carbide.

Acknowledgments

This work was supported by the Estonian Science Foundation grant G-5882.

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DOI: 10.5755/j02.ms.26420