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# Performance of carbide composites in cyclic loading wear conditions

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ABSTRACT

Performance in cyclic loading wear conditions – results of the functional testing in the blanking of sheet metal and fatigue bending tests – of an advanced TiC-based cermet and that of WC-based hardmetal (used in metalforming) were compared. Additionally adhesive wear resistance was tested, complemented by SEM and XRD studies. Reasonable correlation between the blanking performance of the carbide composite (hardmetal, cermet) and their adhesive wear resistance was found. The superiority of the advanced TiC-based cermet over the hardmetal (at similar volume fraction of carbides) was revealed. The higher blanking performance of the TiC-based cermet results from its higher adhesive wear resistance and its lower fatigue sensitivity.



## 1. Introduction

Cermets are ceramic–metal composites which consist of the ceramic phase and the metal binder. Tungsten carbide (WC) and titanium carbide (TiC) based ceramic and metal composites (carbide composites) are the most known cermets. WC-based cermets–hardmetals are the most widely used composites in different wear applications owing to their excellent combination of high wear resistance and strength, as well as toughness [1,2]. TiC-based cermets (with Ni-alloy or steel binder) have proven successful in some applications because of their high specific strength (low density), high adhesive wear resistance, good weldability and improved resistance to oxidation [3,4].

Application of carbide composites (hardmetals, cermets) enables service life of tools and wearing machine parts to be prolonged. These materials are mainly used in service conditions where high wear resistance either in abrasive conditions or at elevated temperatures (high speed cutting) is required. Carbide composites are not so often used in non-cutting (metalforming) operations owing to complicated service conditions where severe wear (particularly adhesive wear) is accompanied by high mechanical loads of cyclic and dynamic nature. In such conditions primarily special cold or hot working steels or hardmetals with increased binder content have been successfully used [1,5].

Tallinn University of Technology (TUT) has developed a series of TiC-based cermets, particularly tool materials for plastic forming of metals. One of the most successful cermet-grade T70/14 (70 wt% TiC cemented with Ni-steel) – has proven itself as a tool material in blanking of sheet metals [6,7].

The present paper is focused on the study of performance in cyclic loading wear conditions of an advanced (with improved properties) cermet-grade T75/14-H produced by optimized technology (Sinter/HIP, heat treatment) [8,9]. As reference materials, the WC-based hardmetal grade C13 (87 wt% WC) widely used in metalforming and the ordinary TiC-based cermet grade T70/14 (70 wt% TiC) were also under investigation.

## 2. Experimental

### 2.1. Materials

The main microstructural characteristics and mechanical properties of tested carbide composites are presented in Fig. 1 and Table 1. Fig. 1 shows the microstructures of the composites with carbide fraction of ~80 vol.%. The microstructure of WC-composite (grade C13) consists of WC-grains mainly of angular shape embedded in the binder phase. The shape of TiC grains is more rounded.

The alloys were sintered by two techniques: ordinary vacuum sintering (hardmetal grade C13 and cermet T 70/14) and by combined sintering in vacuum + argon gas compression (cermet grade T75/14-H) – developed for TiC-based cermet sinter/HIP technology [8,9].

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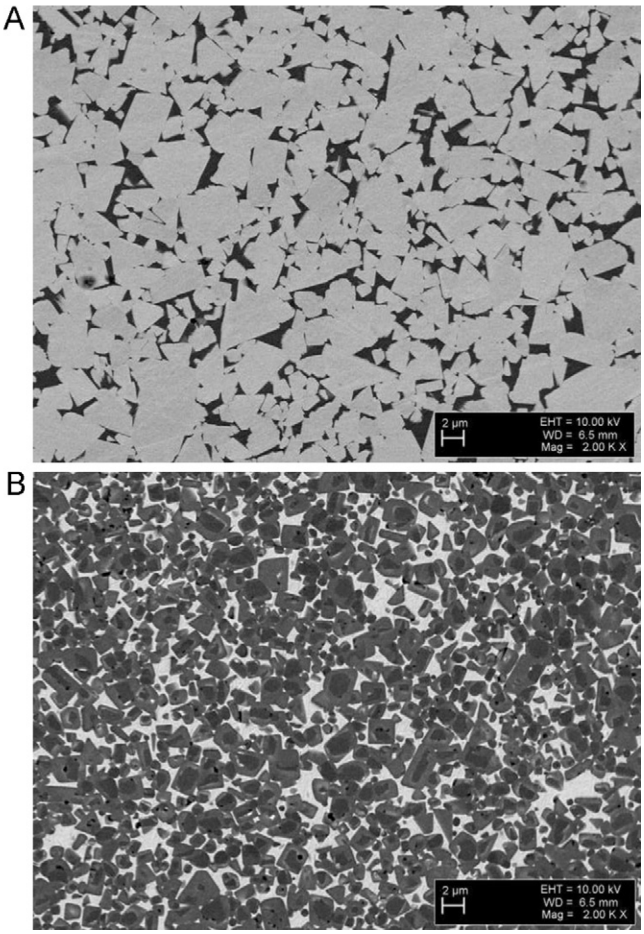


**Fig. 1.** SEM images of investigated carbide composites. (A) WC-based hardmetal (C13), (B) TiC-based cermet (T75/14-H).

### 2.2. Testing procedures

Durability (blanking performance) trials were carried out as functional ones in blanking on an automatic press of grooves into electrotechnical sheet steel (see Fig. 2) by a 3-position die reinforced with alloys presented in Table 1 [6,7]. Durability was evaluated by the side wear of the die $\Delta D$ (increase in diameter $D$) after an intermediate service time $N = 0.5 \times 10^6$ strokes (as $N/\Delta D$) corresponding to the time between two consecutive prophylactic sharpenings used in the exploitation of blanking dies [7]. The side wear was measured by contact method using the measuring machine STRATO 9–166 in fixed environmental conditions (constant room temperature of $20 \pm 2\,^\circ$C and relative humidity of 50–60%) as an average of five measurements.

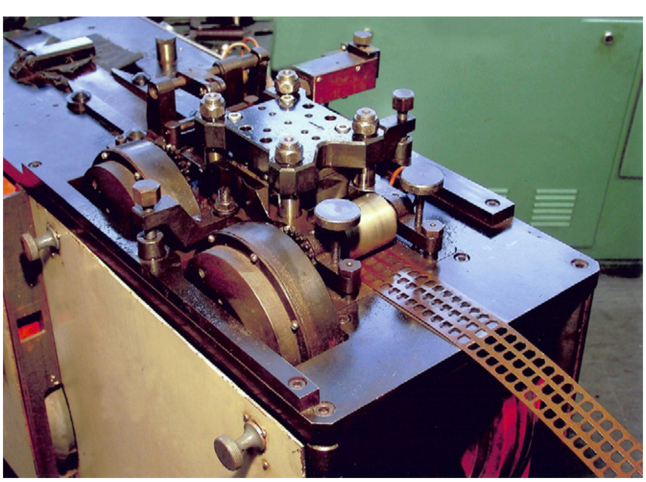

**Fig. 2.** Durability testing of carbide composites in 3-position blanking die, mounted on the automatic press.

**Table 1**
Structural characteristics and properties (hardness *HV*, transverse rupture strength $R_{TZ}$, proof stress $R_{C0.1}$) of carbide composites tested.

| Grade | Carbide (wt%) | Mean grain size (μm) | Binder | *HV* (GPa) | $R_{TZ}$ (GPa) | $R_{C0.1}$ (GPa) |
|---|---|---|---|---|---|---|
| C13 | WC, 87 | 1.8 | Co (W) | 13.0 | 2.9 | 2.8 |
| T70/14 | TiC, 70 | 2.1 | Fe (14Ni) | 12.8 | 2.2 | 2.4 |
| T75/14-H | TiC, 75 | 2.0 | Fe (14Ni) | 13.6 | 2.4 | 2.8 |

The wear was studied in cutting adhesive wear conditions [7]. The wear resistance $L_1$ was determined as the cutting path (by turning mild steel HV = 175) when the track at the nose of a specimen (tool) exceeded 1 mm. Confidence interval of wear resistance did not exceed 10% when the number of test pieces was at least 3.

Fatigue tests resembled those of three point bending fatigue – fatigue of specimen of 5 mm × 5 mm × 17 mm under sinusoidally alternating transverse bending load at the stress ratio $R = 0.1$ and frequency $f = 30$ Hz, up to $10^7$ loading cycles [10–13]. The resistance to fatigue damage was characterized by the factor of fatigue sensitivity – intensity in the decrease of strength with an increase in the loading cycles from $N_3 = 10^3$ to $N_7 = 10^7$ as $\Delta S_{3-7}$.

The mechanical properties of carbide composites were estimated by the Vickers hardness HV (in compliance with EN-ISO6567-1), transverse rupture strength $R_{TZ}$ (in accordance with the ISO 332/7, specimen B) and 0.1% proof stress $R_{C0.1}$. The proof stress was determined in a uniaxial compression test using specimen of a diameter of 10 mm and a length of 17–18 mm. For the probability factor 0,95 the confidence interval of $R_{TZ}$ and $R_{C0.1}$ were 0.07–0.1 GPa and 0.05–0.07 GPa respectively.

Examinations were complemented by SEM and XRD studies of micro- and fine structure, performed on the electron microscope JEOL JSM 840A and diffractometer Bruker D5005, respectively. Changes of line intensities of X-ray reflections from composites phases (line peaks) and their broadening (both characterizing changes in fine structure) were determined in the XRD studies [14,15].

## 3. Results

Results of functional wear tests are shown in Fig. 3 as wear contours $\Delta D - H$ (side wear $\Delta D$ depending on the depth $H$ from the cutting edge of the tool). The wear contours both of the die and punch refer to a superiority of the advanced TiC-based cermet T75/14-H over the hardmetal and cermet T70/14. The blanking performance $N/\Delta D$ ($N = 0.5 \times 10^6$ strokes) of the advanced composite exceeds that of ordinary composites by a factor of 1.5–2.

The results of the adhesive wear test (as wear kinetic curves $h$–$L$) are presented in Fig. 4. The kinetic curves – demonstrating the increase in wear land $h$ at the tool (specimen) nose as a function of wear track – confirm the results of the blanking trials – the superiority of the developed TiC-based cermet (grade T75/14-H) over WC-based hardmetal (grade C13). These results refer to the existence of a correlation between the composite's blanking performance and its adhesive wear resistance.

SEM studies of worn carbide composites surfaces confirm the conclusion stated above (see Fig. 5). They show that surface failure mechanisms occurring during adhesive wear and blanking are similar – in both cases failure (removal of material) appeared first