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Influence of sintering techniques on the performance characteristics of steel-bonded TiC-based cermets

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Abstract. This paper analyses the influence of sintering technology (temperature, gas compression during sintering) and heat treatment on the performance of an advanced TiC-based cermet developed for metalforming. The performance was evaluated by adhesive wear resistance, transverse rupture strength and microstructure studies. Optimal technology and parameters, ensuring maximum wear resistance and strength of the TiC-based (carbide) composite, are determined. The positive effect of gas compression during sintering on the performance of TiC-based cermets was revealed. Heat treatment (tempering) that causes no noticeable changes of strength and hardness results in a remarkable decrease of the adhesive wear resistance.

Key words: sintering techniques, cermet, titanium carbide, wear resistance, adhesive wear.

1. INTRODUCTION

Combinations of desirable material properties are encountered in multiphase material structures, such as ceramic and metal composites. Composites on the basis of tungsten carbide, hardmetals, are a success story in terms of applications, particularly those related to tribology. WC-Co hardmetals are the most widely used materials for different wear applications owing to their excellent combination of high wear resistance and strength [[1]]. Deficiency of some specific properties, particularly corrosion resistance and weldability, leads to some restrictions concerning hardmetals and utilization of alternative ceramic and metal composites, e.g. on the basis of titanium carbide.

TiC-based cermets may be successful in some applications, because of their favourable properties – low friction coefficient, fair weldability (owing to their expansion coefficient close to that of steels), remarkable resistance to oxidation, high specific strength and high adhesive wear resistance.

With respect to abrasive wear resistance and strength, TiC-based cermets are usually outperformed by WC-hardmetals [1,2]. However, recent developments in the technology (HIP, sinter/HIP, etc) have created a renewed interest in TiC-based cermets [3,4]. TiC-based cermets, cemented with Ni-Mo alloys, have proven to be appropriate in cutting operations [5]. Steel-bonded carbides – composites “Ferro-Titanit” – have been used in metalforming and in some other special applications [6,7]. The latter have a marked advantage over ordinary hardmetals – they are machinable by conventional methods and become hard and wear resistant as a result of heat treatment. Unfortunately, the relatively low wear resistance (in particular in adhesion) and the modest strength impose restrictions to wider application of such alloys [7].

A series of TiC-based cermets with a Ni-steel binder have been developed at Tallinn University of Technology [8,9]. Grade T75/14 (75 vol% TiC bonded with 14Ni-Fe alloy) that has proved most successful, has demonstrated its superiority over the ordinary WC-base hardmetal (widely used in metalforming) in the blanking of sheet metals [9].

Focus in this paper is on the influence of advanced sintering techniques (vacuum sintering, sinter/HIP, sintering + HIP) and heat treatment on the performance characteristics of the TiC-cermet (grade T75/14). The performance was evaluated by the transverse rupture strength and the adhesive wear resistance.

2. MATERIALS AND EXPERIMENTAL DETAILS

2.1. Materials and technology

The study covers the TiC-based cermet (grade T75/14), a carbide composite with 75 wt% TiC cemented with Ni-steel (14 wt% Ni) of austenitic microstructure. The grade has proven its reliability in metalforming (blanking) applications [9–11].

The alloy was produced by the two-step sintering techniques – presintering in hydrogen (at 550 °C) and final sintering by three different methods: vacuum sintering, sinter/HIP and vacuum sintering + sinter/HIP. At constant sintering time (60 min) sintering temperature and atmosphere (argon-gas) pressure varied from 1400 to 1460 °C and 30–90 bar, respectively. Additionally, the influence of heat treatment (tempering at 200–500 °C) was studied [12,13].

2.2. Testing procedures

Transverse rupture strength (in accordance with the standard ISO 3327, specimen B) and Vickers hardness (in compliance with EN-ISO 6567-1) were used to estimate the mechanical properties.

The wear behaviour of the alloys was studied under adhesive wear conditions. The adhesive wear is featured as a surface failure of very high structure sensitivity. It controls the wear of cemented carbides used for blanking and metalforming operations [10,11]. Adhesive wear tests were performed by turning mild steel (HV30 ≤ 160) at low speed (v < 18 m·min^{-1}). The adhesive wear resistance L_1 was determined as the length of the cutting path, when the wear land (height h) at the tool (specimen) nose achieved the critical value h = 1 mm (Fig. 1).

Twenty tests per composite (produced by different techniques) were performed for mechanical properties and a minimum of three tests for adhesive wear resistance to ensure confidence interval of 10% with probability factor of 95%.

Examinations were complemented by microstructure investigations performed on the scanning electron microscope (SEM) Zeiss EVO MA15. Carbide grain size and binder content were determined by the digital image analysis (Image Pro Plus).

3. RESULTS AND DISCUSSION

3.1. Sintering parameters

The results of mechanical and wear tests presented in Figs. 2 and 3 demonstrate that the properties (performance characteristics) of TiC-based cermets are essentially influenced by sintering parameters. Both, the transverse rupture strength R_{TZ} and adhesive wear resistance, vary approximately 20%,

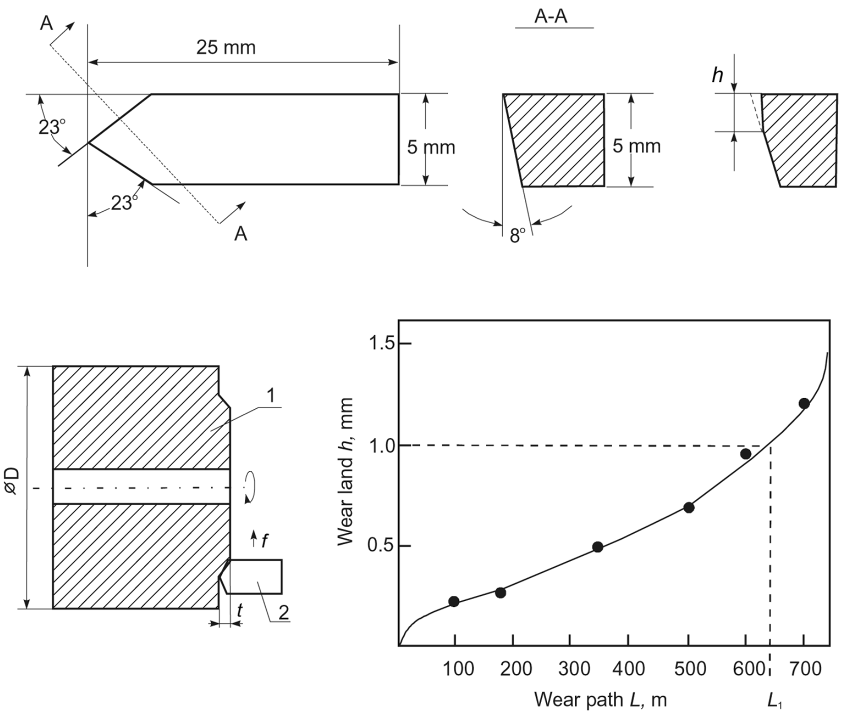

Fig. 1. The scheme of adhesive wear testing: 1 – mild steel to be turned; 2 – specimen; h – height of wear land; L_1 – adhesive wear resistance, L – wear path.

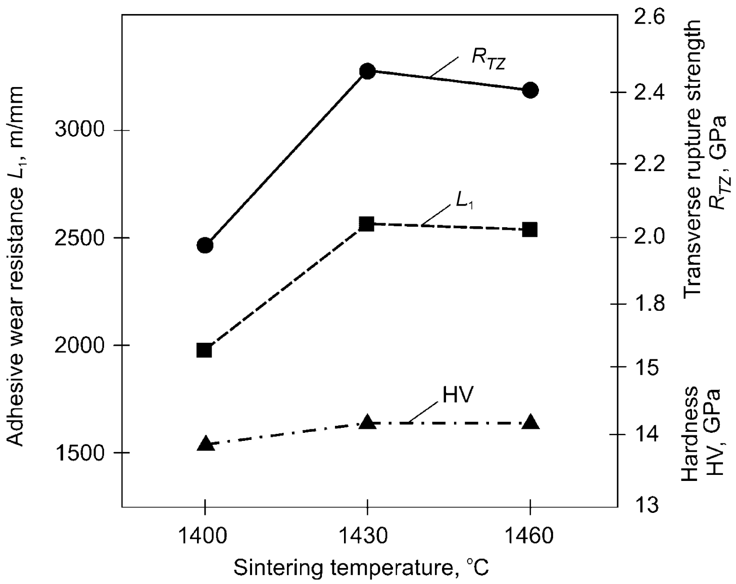

Fig. 2. Influence of the sintering temperature on the performance characteristics of TiC-based cermet T75/14 (compression sintering at p = 60 bar).

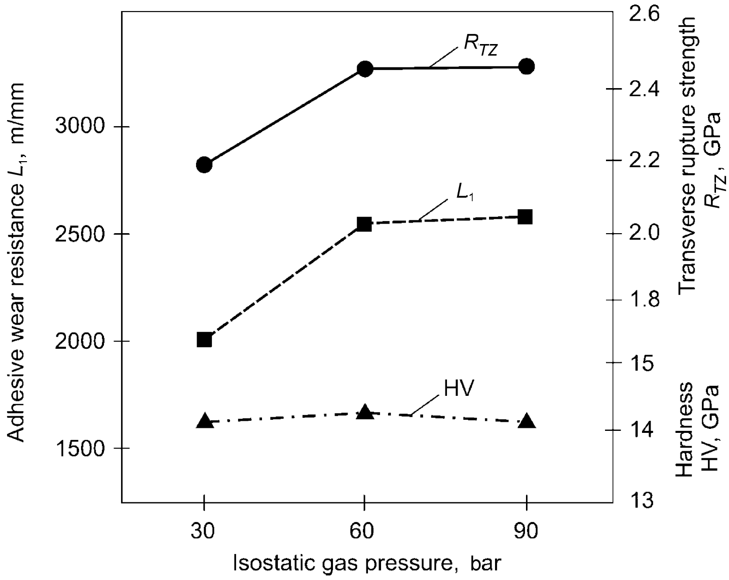

Fig. 3. Influence of the isostatic gas pressure (compression) on the performance characteristics R_{TZ}, and L_1 of TiC-based cermet T75/14 (sintering temperature 1430 °C, sintering time 60 min).

depending on the sintering temperature and gas compression. The relationship refers to the presence of slight maximums (at 1430 °C and 50 bar, respectively).

Results indicate that in contrast to adhesive wear resistance and transverse rupture strength, the hardness (ordinary characteristic of wear resistance) exhibits a low sensitivity to sintering parameters. Such difference in the behaviour of different properties of alloys may be related to differences in their structural sensitivity and stress states (during testing and failure).

3.2. Sintering modes

Figure 4 demonstrates the performance characteristics of the TiC-cermet (grade T75/14), sintered by three different modes: ordinary vacuum sintering, sinter/HIP (SH) and sintering + sinter/HIP (S + SH). Vacuum sintering was performed by optimal parameters – sintering temperature $T = 1430$ °C and vacuum $p < 13$ Pa (10^{-1} mm/Hg) [3,11]. Sinter/HIP was performed in a combined atmosphere – vacuum sintering followed by gas compression at the sintering temperature.

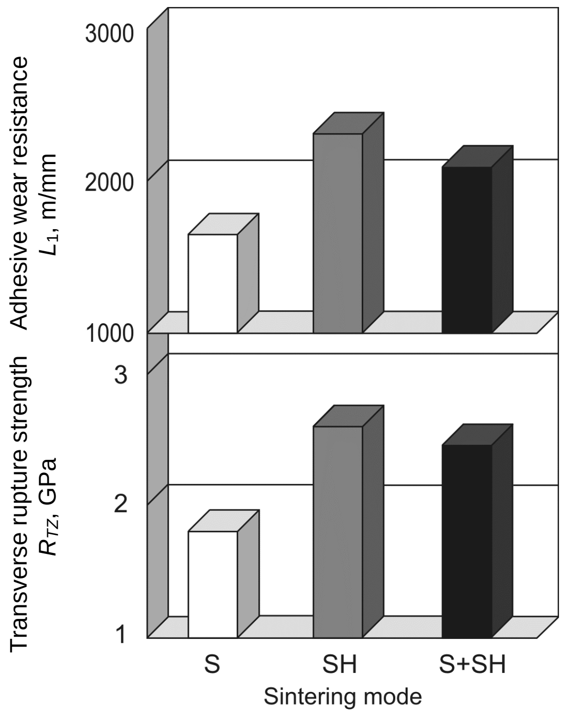

Fig. 4. Performance characteristics of cermet T75/14 sintered by different modes (S – ordinary vacuum sintering, SH – sinter/HIP, S + SH – sintering + sinter/HIP).

The results refer to an obvious positive effect of gas compression during sintering (sinter/HIP) on the performance characteristics of the cermet T75/14 and confirm the results of previous studies concerning the effect of sinter/HIP onto TiC-based cermets [3]. Results also show that the two-cycle sintering mode – vacuum sintering + sinter/HIP-process – is less effective than the one-cycle sinter/HIP process [4,14–19].

3.3. Heat treatment

Ordinarily TiC-based cermets, cemented with Ni-steel, consisting of Ni > 4 wt% possess a stable microstructure (a binder with a stable austenitic structure occasionally including traces of bainite) resulting from sintering. Such composites are not usually subjected to any heat treatment (tempering or normalizing), because heat treatment provides no noticeable improvement in the strength or in the hardness [8,12,20].

This study analysed the effect of tempering at 300–500 °C on such a specific tribological property as adhesive wear resistance. The adhesive wear resistance is a characteristic, relevant in the evaluation of wear performance of alloys applied in metalforming operations [11]. This characteristic is featured by a high structure sensitivity. It means that small changes in the microstructure and stress state of phases result in a remarkable alteration of wear performance [12].

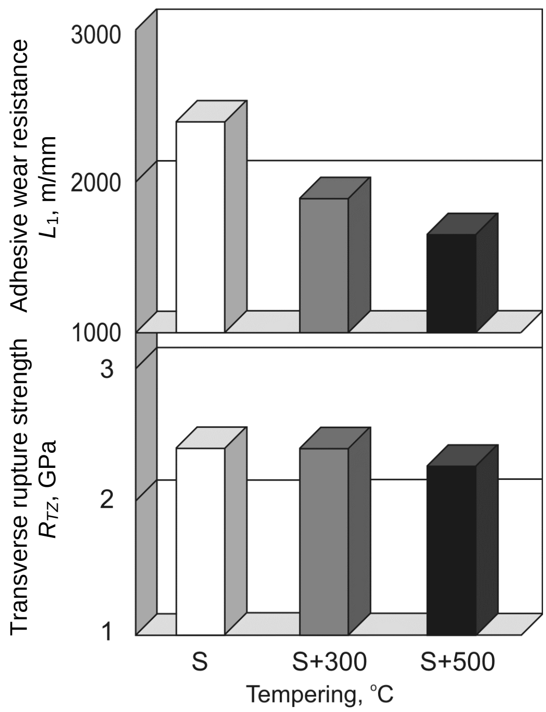

Fig. 5. Performance characteristics of cermet T75/14, tempered at different temperatures.

As seen in Fig. 5, tempering of cermet T75/14 at 300–500 °C does not practically influence the strength, but results in a remarkable decrease (up to 30%) of the adhesive wear resistance.

3.4. Microstructure

The results of SEM studies, presented in Fig. 6, refer to a remarkable influence of sintering techniques on the microstructure of the TiC-based cermet. The microstructure of an alloy, sintered by optimal Sinter/HIP technology (ensuring maximized performance characteristics – strength and wear resistance), is featured by a high homogeneity: uniform distribution of phases, decreased and uniform grain size, reduced contiguity and porosity.

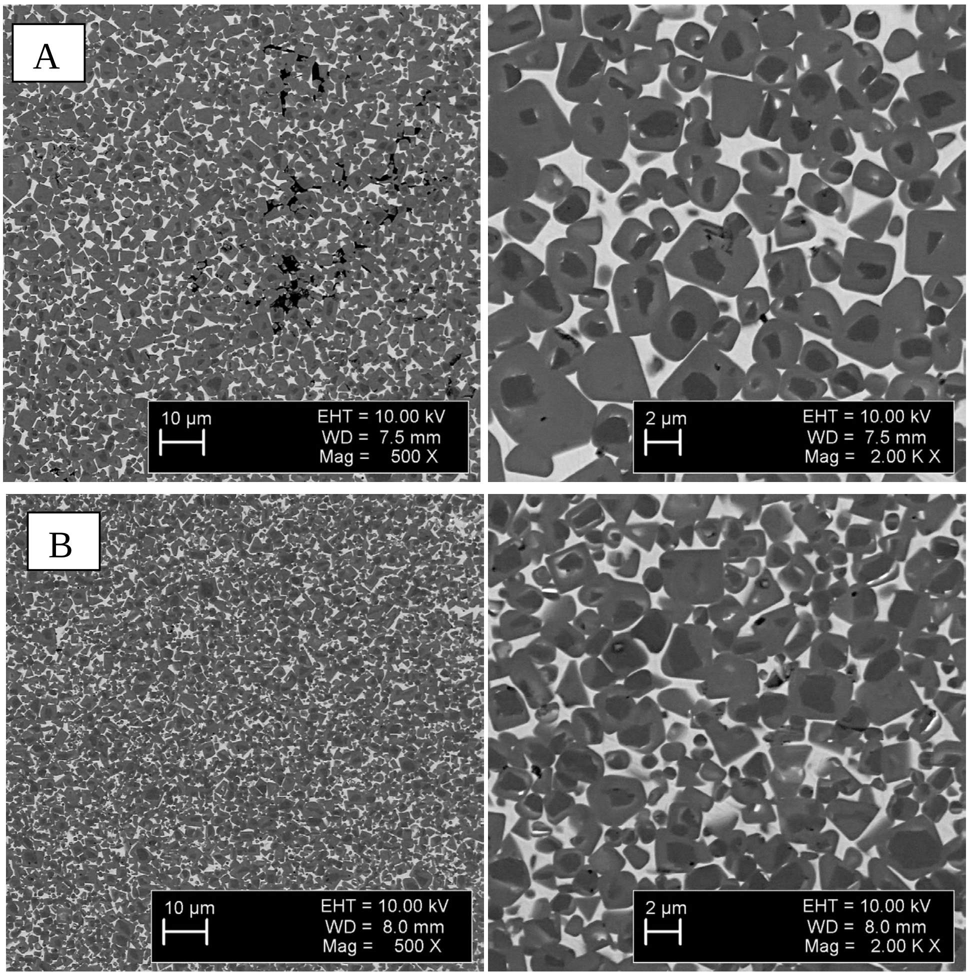

Fig. 6. SEM micrographs of cermet T75/14, sintered by different techniques and differing in the performance characteristics: A – ordinary vacuum sintering technology (R_{TZ} = 1.8 Pa, L_1 = 1600 m/mm); B – optimal technology (R_{TZ} = 2.5 GPa, L_1 = 2300 m/mm).

Heat treatment – tempering at 300–500 °C – induces decrease in the performance characteristics that is remarkable (up to 30%) in the adhesive wear resistance and imperceptible (less than 10%) in the transverse rupture strength. Such kind of behaviour of alloy properties during tempering refer to unnoticeable changes in the structure of the binder or its stress state (decay of the non-uniform austenite binder, relaxation of internal stresses) that influence the characteristics of very high structural sensitivity.

4. CONCLUSIONS

- Focus of the investigation was on the influence of sintering technology (sintering modes, sintering parameters) and heat treatment on the performance characteristics – transverse rupture strength, hardness, adhesive wear resistance – of an advanced TiC-based cermet grade T75/14, developed for metalforming (blanking) applications.
- It was found that gas compression (isostatical gas pressure) during sintering (sinter/HIP-process) has a positive effect on the performance of cermet T75/14.
- Optimal sintering parameters (sintering temperature, gas compression), ensuring maximized performance characteristics (transverse rupture strength and adhesive wear resistance) have been determined.
- Heat treatment of the TiC-cermet T75/14, inducing unnoticeable changes in its binder structure, has a major influence on the properties of high structure sensitivity, particularly on the adhesive wear resistance.
- TiC-based cermets, sintered by the optimal technology that ensures maximized performance characteristics, is characterized by a microstructure of high homogeneity and low porosity.

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Paagutustehnoloogia mõju terassideainega TiC-kermise T75/14 töökindlusele

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On analüüsitud paagutustehnoloogia (temperatuur, gaasi surve) ja termilise töötlemise mõju terassideainega TiC-kermise T75/14, mis töötati välja TTÜ-s survetöötlemise tööriistade tarvis, töökindluse näitajatele – paindetugevusele, kõvadusele ning adhesioonkulumiskindlusele.

On välja selgitatud optimaalne tehnoloogia, tagamaks materjali maksimaalseid mehaanilisi omadusi ja adhesioonkulumiskindlust. On näidatud, et survepaagutamine võimaldab oluliselt (kuni 25%) tõsta komposiidi T75/14 töökindluse näitajaid – paindetugevust ja adhesioonkulumiskindlust.

Termiline töötlemine ei põhjusta märgatavaid muutusi kermise struktuuris ega mehaanilistes omadustes (kõvadus ja paindetugevus), küll aga halvendab märgatavalt adhesioonkulumiskindlust.