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Two-body dry abrasive wear of Cr_3C_2-Ni cermets

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Abstract. The paper considers two-body dry abrasive wear of a series of chromium carbide base cermets with different amounts of Ni binder (10–50 wt%) using a “block on abrasive grinding wheel” test machine. The wear coefficient of the cermets reduces with the increase of Cr_3C_2 content in the composite, which corresponds to an increase in the bulk hardness. The volume wear increases approximately linearly with increasing sliding distance. The wear tracks of the worn blocks after run were analysed using SEM to determine the wear mechanisms. The wear mechanism of Cr_3C_2-Ni cermets depends on the carbide/binder ratio. Material is actually removed by several processes, which include groove formation and the formation of cracks by fatigue under repeated abrasion.

Key words: chromium carbide, cermets, two-body abrasive wear.

1. INTRODUCTION

Cr_3C_2-Ni cermets are perspective materials for operating in corrosive and abrasive environments [1–6]. Main disadvantages of these cermets are relatively low mechanical properties and wear resistance mainly because of their coarse-grained structure (the carbide grain size is usually over 4 μm). At the same time, there is a lack of information about the abrasive wear properties of Cr_3C_2-Ni cermets.

Wear is one of the most common causes for the failure of engineering materials [7]. Abrasive wear is the detachment of the material from surfaces in relative motion, caused by sliding of hard particles between the opposing surfaces; it is the most important wear due to its destructive character [8]. The situation when only two bodies are involved in the interaction is named two-body abrasion. Two-body abrasive wear is a complex process often involving high strain, plastic deformation and microfracture of the material that may be described as the removal of surface particles by a harder substance, which tends to gouge, score or scratch [9].

There have been many attempts to predict the abrasive wear rate of materials. For abrasive wear of bulk materials, the simple Lancaster model [10] can be used:

$$V = ksN,$$

where V is the volume wear, s is the total sliding distance, N is the normal load and k is the wear coefficient or specific wear rate. The wear coefficient k ($\mathrm{mm^3\,N^{-1}\,m^{-1}}$) has proved more useful than volume loss for the comparison of the wear behaviour of different materials.

Multiphase materials are usually used in abrasive conditions. Ceramic-metal composites (cermets) combine extremely hard carbide grains with softer matrix. They are perspective in special applications such as high-temperature or corrosive environments and in situations where high corrosion-abrasion resistance is required [11–13].

There is no single universally accepted view on the mechanisms of abrasive wear of cermets. It has been found that the mechanism of two-body abrasive wear depends on the hardness ratio of the abrasive and the alloy [14–16]. If the hardness of abrasive particles is higher than that of the material, then they can penetrate into the surface and the deformed surface consists of grooves and scratches.

The aim of this work is (1) to study two-body abrasive wear of reactive sintered Cr_3C_2-Ni cermets with different carbide/binder ratio, (2) to compare these alloys with Cr_3C_2-Ni cermets, produced by conventional technology, and (3) to clarify the abrasive wear mechanisms.

2. MATERIALS AND EXPERIMENTAL PROCEDURE

The Cr_3C_2-Ni samples were fabricated at Tallinn University of Technology using a new method of the reactive carburising sintering [17]. Pure chromium, carbon black and nickel powders were used as starting materials. The milling was performed in an attritor, equipped with balls (diameter 6 mm) and vial, reinforced by WC-Co alloy. Cr_3C_2-20%Ni balls were used as the milling media to minimize contamination. The charge ratio (ball to powder mass ratio) employed was 5 : 1. Rotation speed of the impellers was 800 rpm for all the tests. To perform reactive sintering, the as-milled powders were sieved (80 mesh) and pressed at 80 MPa to form compacts with dimensions of $28 \times 18 \times 6$ mm. The optimal carburising sintering parameters were used: sintering temperature 1250 °C, (Cr_3C_2-20, 30 and 50 wt% Ni) sintering time 60 min and 1300 °C (Cr_3C_2-10 wt% Ni) for 60 min.

Reference Cr_3C_2-Ni cermets were produced by conventional PM methods. Chromium carbide powder with an average particle size by FSSS 3.4 μm was received from Tokyo Tungsten Co. It was mixed with nickel and ball-milled during 72 h at a ball-to-powder weight ratio of 5 : 1. The powder was compacted at 80 MPa and sintered at 1250 °C (Cr_3C_2-20, 30 and 50 wt% Ni) and 1300 °C (Cr_3C_2-10 wt% Ni) during 30 min. Optimal sintering parameters for the reference cermets were determined in the previous experiments [18].

The structure of the cermets is composed of chromium carbide grains in a metal binder with the mean grain size about 2 μm for reactive sintered cermets and about 4 μm for cermets, produced by conventional technology.

The two-body abrasive wear tests were conducted on a modified block-on-ring tester, described in [19]. An abrasive grinding wheel replaced the steel wheel. The abrasive wheel used in this experiment was α-Al_2O_3 (99.9 wt% Al_2O_3). Alumina has Vikers hardness of 1900 [20]. The structure of the vitrified grinding wheel is composed of sharp abrasive grits, a bonding system, and a large number of pores. The mean abrasive grit size was 0.25 mm.

The specimens of different Cr_3C_2-Ni composites with the size of $23 \times 14 \times 5$ mm were clamped in a holder and held rigidly against the rotating abrasive wheel of 250 mm diameter under normal load of 20 N. The rotation speed of the abrasive wheel was 235 rpm (linear speed 2.8 m s^{-1}). Sliding distance was 50 m. Prior to each wear testing, the abrasive wheel was sharpened and the specimen was rubbed on fresh abrasive wheel.

The blocks were finished to a surface roughness of about 1 μm prior to testing. Each specimen was weighed before and after testing with an accuracy of 0.1 mg. Weight loss was converted into the volume loss. The surface of the specimens after the wear tests was observed with scanning electron microscope JEOL JSM 840A.

3. RESULTS AND DISCUSSION

3.1. Volume loss and specific wear rate

Wear behaviour of fine-grained Cr_3C_2-Ni cermets, produced by reactive sintering, has not yet reported in the literature. The effect of the carbide/binder ratio to the wear rate of Cr_3C_2-Ni cermets is shown in Fig. 1. The wear coefficient increased with the increase in Ni volume fraction in the cermets. The wear coefficient increases approximately linearly with increasing of the binder content from 10 to 30 wt% Ni. The wear coefficient of the cermets with 50% Ni is very high. However, the wear coefficient for all alloys is lower for fine-grained reactive-sintered cermets.

Figure 2 shows that the volume loss of Cr_3C_2-Ni cermets increases with the increase of the sliding distance as predicted by the Lancaster equation. The volume of wear varies approximately linearly (after a short run-in period) on the first 150 m sliding distance. After 150 m run the abrasive grains are blunted and the wear rate decreases for Cr_3C_2-10 wt% Ni alloys. The abrasive surface deteriorates during its contact with the specimen and becomes less effective in removing material from the sample. The intensive wear up to 25 m may be caused by high stress, induced by the small contact surface in the beginning of sliding.

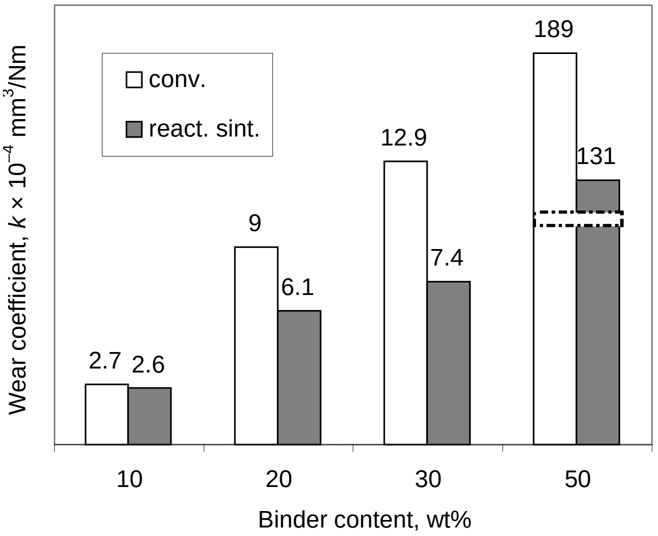


Fig. 1. Wear coefficient of Cr_3C_2-Ni cermets, depending on the binder content and fabrication technology (conventional or reactive sintered cermets).

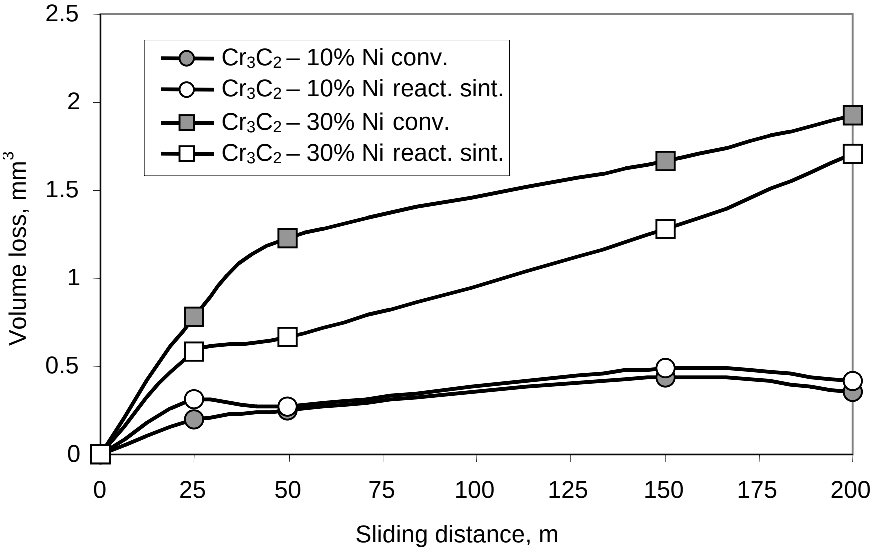


Fig. 2. Volume loss of Cr_3C_2-Ni cermets, depending on the sliding distance and fabrication technology.

As seen in Fig. 3, the volume loss depends on the bulk hardness of the composites. The volume loss decreases with the increase of the bulk hardness of Cr_3C_2-Ni alloys. The depth of indentation into the surface increases as the hardness decreases. Increase in the binder content results in the decrease of the bulk hardness and, consequently, in the wear rate increase.

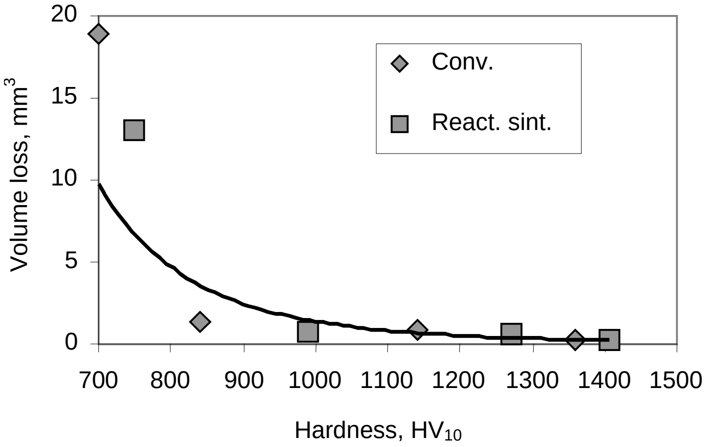


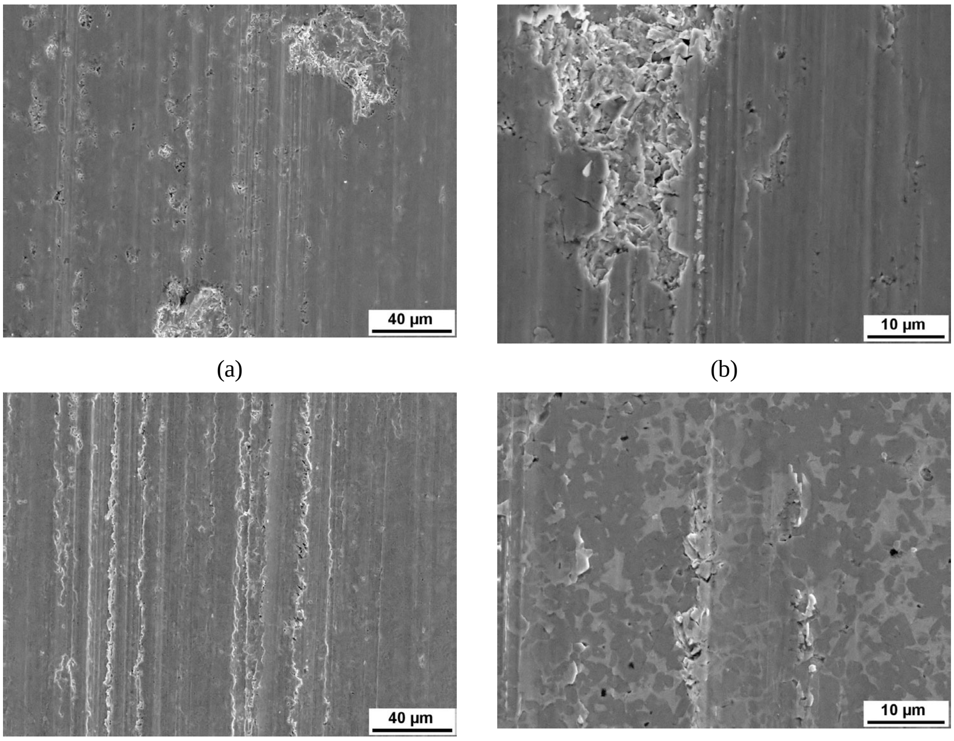
Fig. 3. Volume loss of Cr_3C_2-Ni cermets as a function of hardness.

3.2. The wear mechanism

The detailed mechanism of the material removal in two-body abrasive wear of Cr_3C_2-Ni cermets by Al_2O_3 grits has not been studied yet.

The wear tracks of the worn cemented carbide blocks were analysed using scanning electron microscopy. Contact damage characteristics for conventional and reactive sintered cermets are quite similar. The images of the abraded surfaces showed typical grooves, associated with the two-body abrasion. However, the grooves were relatively shallow for the low-binder alloys (Figs. 4a and c), compared with those seen in the high binder alloys (Figs. 5a and c). The small penetration depth may result in smaller subsurface deformation and therefore in less abrasive wear. Most of the wear surfaces show a significant number of long-length microscratches, suggesting that ploughing also plays a substantial role in wear.

The abraded surface of the low-binder cermets (Cr_3C_2-10Ni) is relatively smooth and featureless, indicating that the binder phase and carbide framework were worn down simultaneously (Fig. 4a). There is no evidence that removal of the binder phase occurs prior to any chromium carbide grain loss. Inside the scratch grooves, extensive fracturing of Cr_3C_2 is not apparent (Fig. 4d). No cracking was evident at the matrix–Cr_3C_2 interface in any of the composites. However, plastic deformation of the matrix was apparent. Plastically deformed shallow grooves in combination with adjacent inter- and transcrystalline surface fracture are dominating. Several pits can be observed on the worn surfaces (Fig. 4c). The size of the pits suggests that they were formed by fracture and delamination of the grains from the surface. Over the first few meters of the contact, the Al_2O_3 abrasive initially makes grooves in the Cr_3C_2-10%Ni surface by plastic deformation. After 150 m run the abrasive becomes blunt by wear and cannot indent into the surface and form any grooves; it can only cause plastic surface deformation (Fig. 3). As the contacting abrasives wear, their average



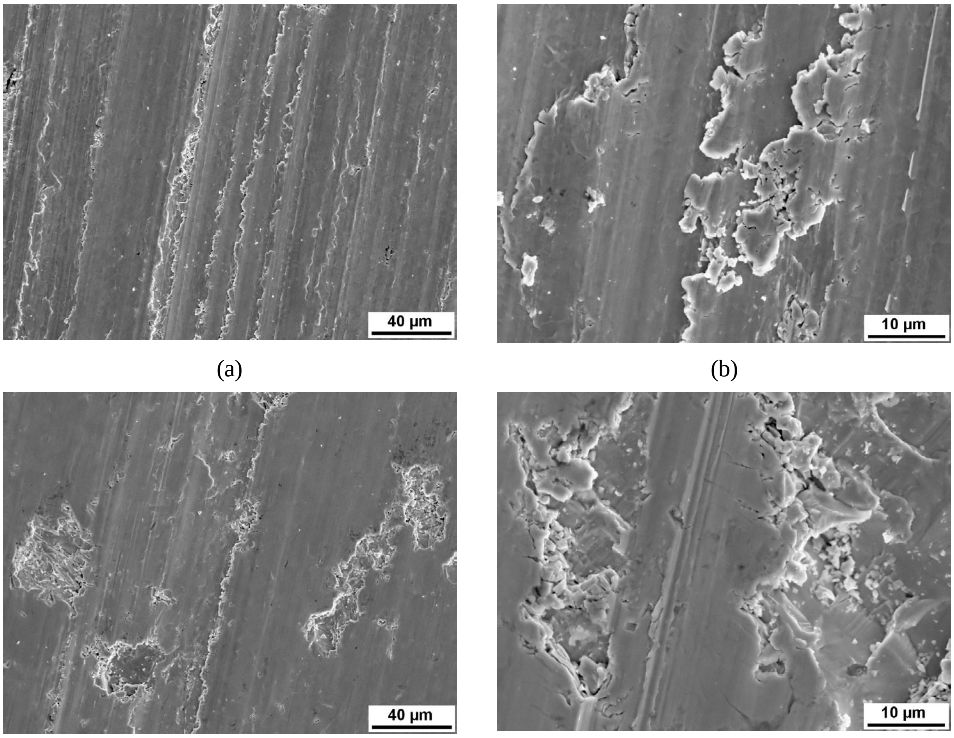
(a) (b)

(c) (d)

Fig. 4. Wear surfaces of Cr_3C_2-10 mass% Ni cermets: a, b – conventional technology; c, d – reactive sintering.

indentations into the surface become increasingly shallow and the deformation pattern goes through a series of changes from plastic to elastic-plastic and finally to elastic wave.

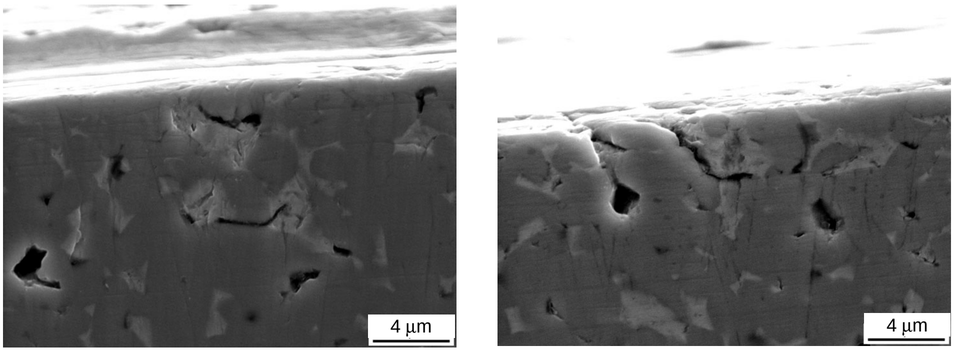
Figure 5 shows the worn surface of Cr_3C_2-30 wt% Ni cermets filled with deep grooves and lateral ridges parallel to the sliding direction. The passage of the abrasive causes plastic deformation of the surface, which results in the formation of grooves with materials pile-up at the groove edges. The worn surface is characterized by long and deep parallel grooves, which are formed as the abrasive particles plough across the surface and eventually remove or push the material into ridges along sides of the grooves. In the case of Cr_3C_2-30Ni cermets with high binder content, crushing of the weak carbide framework takes place in the beginning of wear. After crushing of the framework, their fragments are pressed into the binder and some of the binder is squeezed out onto the surface, from which it is wiped off. Direct fracture and fragmentation of Cr_3C_2 grains was not observed. The formation of some sub-surface lateral cracks and cracking interfacial boundaries are seen in Fig. 6.



(a) (b)

(c) (d)

Fig. 5. Wear surfaces of Cr_3C_2-30 mass% Ni cermets: a, b – conventional technology; c, d – reactive sintering.



(a) (b)

Fig. 6. Cross-section of the worn surface of Cr_3C_2-30 wt% Ni cermets: a – lateral cracks, b – grain shifting.

4. CONCLUSIONS

1. Cermets, produced by reactive sintering are more wear-resistant than those produced by conventional technology.
2. The specific wear rate of Cr_3C_2-10%Ni cermets is low (~10^{-4} mm^3/Nm). Wear coefficient increases with an increase in the binder content, which corresponds to a decrease in the bulk hardness. Reactive sintered cermets with higher hardness exhibited lower wear rate. There was a critical volume fraction of carbide, lower of which the wear rate increased abruptly.
3. The volume wear of Cr_3C_2-Ni cermets varied linearly with the sliding distance up to 150 m as predicted by the Lancaster equation. After that the wear of abrasive wheel reaches a certain degree and the sharpness of alumina grits will become blunt.
4. The wear of material occurs through surface plastic deformation of the bulk solid (plowing) to the lateral ridges, followed by fracture and loss of small volumes of Cr_3C_2-Ni composites. There are no significant differences in wear mechanisms of cermets produced by conventional and reactive sintering.

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Cr_3C_2-Ni kermiste kuiv abrasiivkulumine

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On uuritud Cr_3C_2-Ni kermiste abrasiivkulumist kahe keha meetodil. Kermised on valmistatud tava- ja uudse tehnoloogia – reaktsioonpaagutuse – abil. On näidatud, et sideaine sisalduse kasvades väheneb kermiste kõvadus ja sellest tulenevalt suureneb nende kulumine. Kulumine on väiksem reaktsioonpaagutuse teel valmistatud kermistel. Kermiste mahuline kulumine kasvab lineaarselt teepikkuse suurenedes. Materjali eemaldumise põhjuseks on vagude tekkimine pinnale ja materjali väsimuslik eemaldumine.