ABRASIVE WEAR OF Cr$_3$C$_2$ BASE CERMETS

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SUMMARY
Cermets, containing chromium carbide as the major component possess some unique properties, making them useful for certain applications in the tool and chemical industries for producing wear resistance components. At the same time there is shortage of information about wear resistance of such alloys. Present paper studies the abrasive wear resistance and the mechanism of the abrasive wear. A series of cermets on the base of chromium carbide with different amounts of binder phases (10–30 wt %) was investigated using the moderated (utilization of silica sand instead of alumina as an abrasive) procedure of ASTM Standard B611-85. The wear tracks of the worn blocks after 25 m run were analysed using scanning electron microscopy (SEM) to determine the wear mechanisms. It was found, the mechanism of abrasive wear of Cr$_3$C$_2$-Ni cermets depends on the ratio between the hardness of the abrasive and the cermet.

Keywords: Chromium carbide, Cermet, Abrasive Wear, Wear Mechanism

1 INTRODUCTION
Abrasive wear, or abrasion, is caused by the displacement of material from a solid surface due to hard particles sliding along the surface. In three-body abrasion, a loose abrasive particle is trapped between two surfaces of relative motion. Numerous works about abrasive wear of cemented carbides on the base of WC-Co have been published [1-5]. The abrasive wear of chromium carbide base cermets is not studied. One of the reasons is the fact that strength and toughness of such composites compare unfavourably with these characteristics of WC-base hardmetals.

There have been many attempts to develop predict wear models. The most notable one is Archard’s wear law, which has the form[6]:

\[ V = k L P H^{-1}, \]  

where \( V \) is the wear volume, mm$^3$; \( k \) is a dimensionless proportional constant and can be interpreted as the probability of producing a wear particle at each asperity encounter, \( L \) is the sliding distance, m; \( P \) is the normal force, N; and \( H \) is the Vickers hardness of material. Archard’s equation indicates the abrasive wear resistance to be proportional to the specimen’s hardness. Equation assumes that the abrasive particle is harder than the surface and is either rigid.

The wear resistance of materials consisting of several phases can be described in terms of the distribution of the applied load over the individual phases. Various correlations have been attempted to apply between abrasive wear and material properties on a large variety of metals and alloys without much success.

2 MATERIALS AND EXPERIMENTAL CONDITIONS

2.1 Materials
The cermets tested in this study are listed in Table 1, together with their composition, density, hardness, and transverse rupture strength.

<table>
<thead>
<tr>
<th>Cermets</th>
<th>Ni (wt%)</th>
<th>Density (g/cm$^3$)</th>
<th>HV$_5$</th>
<th>TRS (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr$_3$C$_2$</td>
<td>90</td>
<td>7.93</td>
<td>1500</td>
<td>680</td>
</tr>
<tr>
<td></td>
<td>85</td>
<td>7.97</td>
<td>1410</td>
<td>870</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>7.16</td>
<td>1210</td>
<td>1050</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>7.18</td>
<td>1130</td>
<td>1140</td>
</tr>
<tr>
<td></td>
<td>70</td>
<td>7.29</td>
<td>980</td>
<td>1210</td>
</tr>
</tbody>
</table>

Table 1. Composition (wt.%), mechanical properties (density, Vickers hardness HV, transverse rupture strength TRS)

All cermets were produced at the Institute of Materials Technology, TTU with common powder techniques, i.e. form pressing followed by sintering. The system consists of hard chromium carbide grains with an average size 3.8...5.5 \( \mu \)m within a ductile metal binder. Before testing the surfaces of the specimens were carefully ground.

2.2 Abrasion Wear Testing
Abrasive wear rate was measured by means of the moderated procedure of ASTM Standard B611-85 [2]. A steel wheel rotates in a bucket, which was filled with silica sand (HV1150), the most common naturally occurring erodent (not alumina as according to ASTM procedure). The size of silica particles was 0.1...0.3 mm. The samples with dimensions 5 $\times$ 5 $\times$ 25 mm were pressed against the steel wheel of 90 mm in diameter. The rotating speed was 176 rpm, which gives peripheral speed 50 m min$^{-1}$. Pressing force was used as 26 N and sliding distance \( L=25, 50 \) and 100 m. Water was added to the quartz sand abrasive in accordance with the standard – 1,5 cm$^3$ of distilled water per 0.94 g grits. This results in sufficient water to wet the grit with little or no excess water on the surface. The test blocks were weighted before and after the abrasion test.
Abrasive wear rate was determined as volume loss in cubic millimetres per metre of run:

\[ A = G L^{-1} \rho^{-1} \quad (2) \]

where \( G \) is mass loss, \( L \) is the sliding distance in m and \( \rho \) is the density of materials tested. According to ASTM B611-85 only two tests were performed per sample, as they have been found to be quite repeatable.

## 3 RESULTS AND DISCUSSION

### 3.1 Weight loss and wear rate

The wear rate depends on a large number of parameters. These include the worn material properties, particularly the ratio between the carbide phase and metal phase volume. The results are plotted in Figs 1 and 2. Wear loss of all cermets is in proportion to a sliding distance (as predicted from equation (1)). The wear of cermets increases accordingly to the increase of binder content.

In this work, it was found that weight loss and wear rate increases remarkably when the binder content exceeds 20 wt.%. These phenomena, as shown below can be explained by different wear mechanism of abrasive wear cermet with different hardness.

The relative hardness of the abrasive to that of the material \((H_A/H_M)\) has considerable influence on the measured wear rate. Experimental results concerning the abrasive wear of heterogeneous materials show that abrasion in the case of \(H_A/H_M < 0.9\) is “mild” while under conditions where \(H_A/H_M > 1.5\) the abrasion is considered “severe” [5]. In between these two values there is a transition from “mild” to “severe”.

In our work it explains the sharp increase in the wear rate when the binder content is changed from 10 wt.% to 30 wt.% Ni (the hardness is changed from HV1500 to HV980 respectively), the wear conditions change from “mild” to “severe”. On the sharp increase in the wear rate (when the hardness is changed) the wear conditions change from “mild” to “severe”.

Various correlations have been attempted to apply between abrasive wear and material properties such as hardness, modulus, hardness-to-modulus, toughness (ductility), and plastic work without much success when large variety of metals and alloys are considered [4].

The results of this investigation imply that the wear rate depends remarkably on the cermets hardness. If the hardness of cermet \((H_C)\) is equal or higher than that of abrasive particles \((H_A)\) a close correlation exists between the wear resistance and the cermets hardness. Under these conditions, fatigue cracks are initiated. The initiation of fatigue cracks in wear regions depends mainly on the stress state in the surface and particularly on the stresses superimposed on the cyclic stress.
Figure 4 shows the wear coefficient \( K \) (eqn. (1)) vs. binder content.

![Figure 4](image)

**Fig. 4. Wear coefficient vs. binder content and sliding distance**

As it can be seen from Fig.4, in practice the wear coefficient \( k \) does not depend on the sliding distance and is different for every material. When \( k \) is known, the wear rate of a certain material may be estimated for contact with equal conditions.

This investigation only deals with one load and one sliding speed, clearly more investigations on the effect of wear from binder content have to be performed before any general description of the performance of chromium carbide cermet’s in abrasive wear resistance can be achieved.

### 3.2 Wear Mechanism

Many works describe typical wear mechanism found for abraded hardmetals [7-10]. Several mechanisms have been proposed to explain how material is removed from a surface during abrasion. The wear mechanism depends on the properties of cermet and abrasives. Abrasive wear, or abrasion, is caused by the displacement of material from a solid surface due to hard particles or protuberances sliding along the surface [9-10]. Abrasive wear involves scratching and gouging of the surface by harder particles, and generation of debris by repeated action. Abrasives wear resistance depending on whether the material is harder or softer than the abrasive.

The SEM morphologies of \( \text{Cr}_3\text{C}_2-\text{Ni} \) worn surfaces are shown in Fig.5. It was found that the mechanism of abrasive wear of \( \text{Cr}_3\text{C}_2-\text{Ni} \) cermet’s depends on the hardness ratio between the abrasive and the alloy.

If cermet’s hardness exceeds that of abrasive particles (\( H_c > H_a \)), then the latter will not be able to penetrate into material and create grooves on the surface (Fig.5a). In this case, the most usual wear mechanisms are contact fatigue, failure of intercarbide boundaries and brittle cracking of large carbide grains. More detailed studies of the worn surfaces show that during abrasion some \( \text{Cr}_3\text{C}_2 \) grains are cracked and pulverized by the high-applied (tensile) stresses of the abrasive particles. It is also shown that part of the carbide grains are pulled out, leaving some pits, as described in [11].

If an abrasive hardness exceeds that of cermet (\( H_a > H_c \)) the abrasive particles are able to penetrate into the surface of the cermet. The deformed surface consists of grooves and scratches (Fig.5b). Splinters of abrasive particles scratch the softer binder phase whereas carbide grains deflect eroding particles thereby protecting the cermet. This phenomenon means, that the maximum length of grooves is limited by the mean free path between carbide grains. The binder extrusion also occurs by the stress of compression of abrasive particles, proposed by Larsen-Basse [8].

Debris may be formed after repeated plastic flow by a fatigue-like mechanism. Material plowed to the side may fracture on the first pass of an abrasive particle or only after deformation by more than one particle.

Sometimes, an abrasive particle moving across a surface under load first indents the surface of steel wheels. Then it either creates a groove as a result of plowing (plastic flow to the sides of the groove) without direct material removal as seen in Fig.5b.

Some types of material removal may occur simultaneously in one test. The loss of material during an abrasive wear process is a complex relation between many interacting variables. Thus the changing of one variable can have important consequences on the behaviour pattern of the total system.
4 CONCLUSIONS

The abrasive wear resistance of Cr₃C₂-Ni cermet depends on the binder content. The most effective technique to increase abrasive wear resistance is to reduce the binder content (increasing hardness of cermets higher that that of abrasive).

The abrasive wear mechanism depends on the ratio \( \frac{H_A}{H_C} \) of hardness of abrasive particles and that of cermets. If the hardness of cermets exceeds that of abrasive particles \( (H_C > H_A) \) the following elementary processes accompany wear:

- binder scratching by the abrasive particles or their splinters (at the first period of abrasion)
- failure caused by the fatigue of the carbide skeleton and by large carbide grains,
- failure of carbide grain-binder and intercarbide boundaries,
- brittle cracking of large carbide grains,
- shifting and separation of small carbide grains without crushing.

If the hardness of cermets is lower than that of an abrasive \( (H_C < H_A) \) the following elementary processes accompany wear:

- penetration of abrasive particles into the cermet surface,
- ploughing without direct material removal,
- grooving with material loss as a result of the fracture,
- brittle cracking of large carbide grains,
- removal a large chips,
- binder extrusion.

5 ACKNOWLEDGEMENTS

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6 REFERENCES