Influence of electro-discharge machining on wear and friction behaviour of hardmetals

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Abstract – There is an enormous industrial demand for wear resistant materials. Hardmetals are ceramic materials that could meet this need, as they exhibit an extremely high degree of hardness, stiffness and wear resistance. Moreover, their electrical conductivity allows them to be manufactured by electro-discharge machining (EDM), a thermal process with material removal occurring via the discharge of energy between a work piece and a tool electrode. A number of hardmetal grades, EDM’ed with several finishing regimes, corresponding with different surface roughnesses, were subjected to dry friction experiments using a small-scale pin-on-plate test rig. The influence of varying EDM regimes, sliding velocities and contact pressures on their tribological behaviour was investigated. The observed wear was qualified by scanning electron microscopy (SEM) and quantified by surface scanning topography.

Keywords – hardmetal, wear, friction, reciprocate sliding, electro-discharge machining (EDM)

I. INTRODUCTION

Electro-discharge machining (EDM) [1,2,3] is a manufacturing process that allows to create shapes in materials irrespective of their mechanical properties, provided they are electrically conductive. Hardmetals are wear resistant ceramic materials that satisfy this condition. Moreover, these ceramics display an excellent hardness, stiffness, wear resistance and chemical inertness. As a result, they are extremely appropriate to be used for applications such as machining tools, metal forming dies, bearings and gears, which are exposed to a considerable friction.

The influence of several EDM-regimes on the wear behaviour of a number of tungsten carbide based hardmetal grades was investigated.

II. EXPERIMENTAL

A. Test Materials

The investigated hardmetal grades consist of a tungsten carbide matrix, with cobalt or nickel as binder element and chromium and/or vanadium as grain growth inhibitor. Their chemical, microstructural and mechanical properties are summarized in TABLE 1.

B. Test Rig

Hardmetal pins were reciprocally slid against hardmetal counter plates using a high frequency pin-on-plate test rig, in accordance with the ASTM G133 wear test principle.

TABLE 1: Hardmetal grades: composition, inhibitor, average grain size, compressive strength, Vickers hardness, indentation fracture toughness, Young's modulus.

<table>
<thead>
<tr>
<th>Hardmetal grade</th>
<th>GC32</th>
<th>GC20</th>
<th>MG12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt %</td>
<td>WC-10% Co</td>
<td>WC-12% Co</td>
<td>WC-6% Co</td>
</tr>
<tr>
<td>Inhibitor</td>
<td>none</td>
<td>V</td>
<td>Cr/V</td>
</tr>
<tr>
<td>A.G.S. [µm]</td>
<td>2.165</td>
<td>0.849</td>
<td>0.548</td>
</tr>
<tr>
<td>C.S. [GPa]</td>
<td>4.2</td>
<td>4.9</td>
<td>7.2</td>
</tr>
<tr>
<td>HV10</td>
<td>1149 ±10</td>
<td>1286 ±8</td>
<td>1913 ±13</td>
</tr>
<tr>
<td>$K_{IC}^{10/2}$ [MPa√m]</td>
<td>&gt; 20</td>
<td>&gt; 20</td>
<td>10.3 ±0.3</td>
</tr>
<tr>
<td>E [MPa]</td>
<td>578 ±6</td>
<td>563 ±2</td>
<td>609 ±4</td>
</tr>
</tbody>
</table>

The hardest hardmetal grade (MG12) was used as pin material. The friction force between the moving pin and the counter plate is measured online by a piezo-electrical transducer and can be divided in a static and dynamic component ($F_{\text{stat}}$ and $F_{\text{dyn}}$). The friction coefficient $\mu$ is defined as the ratio of the friction force ($F$) and the applied normal force ($N$), Fig. 1.

\[
F_{\text{stat}} = \frac{|F_{\text{max}}| + |F_{\text{min}}|}{2}
\]

\[
F_{\text{dyn}} = \frac{1}{T} \int_0^T F(t) \, dt
\]

Fig. 1. Static and dynamic friction force $F$ and friction coefficient $\mu$

C. Test Conditions

The wear tests were performed in an airconditioned atmosphere of 23 °C and a relative humidity of 60 %. Normal loads were varied up to 50 N, based on the laws of Hertz [4], which allow a maximum admissible normal load calculation between two sliding surfaces depending on their compressive strength. The stroke length of the reciprocating motion was 15 mm. A frequency of 15 Hz, i.e. 0.45 m/s, was applied. The test duration was associated with a sliding distance of 10 km, allowing wear amounts of hardmetals to be compared.

III. RESULTS

A. Friction and wear

The hardmetal-hardmetal combinations exhibit a typical wear behaviour: initially a high friction coefficient and wear rate, as the contact surface between pin and plate is very
limited, followed by a decreasing friction coefficient and wear rate, as the contact surface increases while the pin penetrates into the plate, and eventually a regime situation where friction coefficient and wear rate are almost constant.

Several influences on the wear behaviour were investigated, as summarized in Fig. 2 and TABLE 2. Similar curves were recorded for the static and dynamic friction coefficient, but the static friction coefficient exhibited slightly higher values. It should be taken into account that a relatively large scatter up to 30% occurred between the experiments because of the powerful influence of minor factors on the type of predominating wear mechanism.

Friction force and wear were noticed to increase for an increasing normal load (contact pressure), which can be attributed to a stronger adhesion of the two sliding surfaces. The presence of a lubricant seemed to decrease friction and wear drastically. Moreover, friction coefficient and wear were found to decrease and increase respectively with increasing EDM finishing treatment, i.e. a decreasing surface roughness (Ra-value). When wear debris on the wear track was constantly removed by blowing pressurized air on the contact surface, the wear rate was noticed to decrease slightly, whereas the friction coefficient exhibited a small increase. This behaviour can be explained by the wear particles on the wear track serving as micro-bearings. These observations were made for both EDM-ed hardmetals GC32 and GC20.

**B. Post-mortem analysis**

The generated wear of hardmetal plates and pins were measured by surface scanning topography, TABLE 2, and examined by SEM. Scanning electron micrographs showed how the hardmetals were affected after wear testing, Fig. 3. Amongst the observed wear phenomena were: polishing of the surface of the wear track, formation of wear debris especially in the outer extensions of the wear track but occasionally also present along the complete track, pull-out of individual tungsten carbide grains as well as larger chunks, and the formation of an adhering layer in the wear track [5].

![Fig. 3: Wear track of an EDM-ed hardmetal plate (SEM, 2000x)](image)

**IV. CONCLUSIONS AND FURTHER RESEARCH**

Comparative wear tests on EDM-ed tungsten carbide based hardmetals revealed that their friction and wear increased for a rising normal load, but reduced drastically when lubrication was used. Friction coefficient and wear were found to decrease and increase respectively with a decreasing roughness. Wear debris formation on the wear track seems to cause a slight raise of wear rate and a slight reduction of friction.

Wear testing of hardmetal-hardmetal combinations will be continued in order to investigate the influence of the EDM-regime on the friction and wear behaviour. In-depth SEM-analysis of the wear tracks will be performed, in order to clarify the influence of the recast layer generated by EDM on wear behaviour of the tribocouples. Wear patterns of both hardmetal plates and pins will be quantified by means of surface topography, in order to determine wear ratios of plate and pin and to develop wear models.

**REFERENCES**


