RESEARCH ON DURABILITY OF AlCrN COATED TUNGSTEN CARBIDE (WC–Co) CUTTERS DURING OAK WOOD MILLING

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Abstract: the article presents research results on resistance to wear of tungsten carbide (WC–Co) cutters coated and not coated with AlCrN coating and intended to mill oak-wood. The specimens of oakwood milled in three different clamping milling modes were tested. The cutters’ resistance to wear was assessed using the optical method, when radius of the cutting edge was measured. The edge radius and roughness of processed surface were measured in the cutting length up to 9050 m. The received results disclosed that AlCrN-coated cutters are more resistant to wear.

Keywords: tungsten carbide, tool coatings, wear of tools, wood milling, oakwood.

1. INTRODUCTION

Wood cutting tools get worn in the course of cutting process under impact of force, temperature, electric and chemical factors. These factors lead to reduced weight and changed geometrical parameters of the tools. The wearing-out tool gets blunt, the roughness of processed surfaces increases, and such tool becomes unsuitable for work after some time [1]. The tools’ resistance to wear is increased through modification or coating of blades or surfaces in contact with wood by various wear-resistant coatings [2–4].

The coatings of titanium carbide (TiC), titanium nitride (TiN), titanium aluminium nitride (TiAlN), titanium carbon nitride (TiCN), chromium nitride (CrN), chromium carbide (CrC), hafnium nitride (HfN), diamond, and diamond-carbide (DLC) are applied on metal processing tools [5].

The tools from alloy tool steel, high-speed steel (HSS) and tungsten carbide (WC–Co) coated by various coatings are used for wood processing. Tools processing solidwood are coated by chromium-based (Cr) coatings. Cr coatings are inexpensive and effective [4]. The effectiveness of these coatings is determined by Cr amount in the coating. Cr increases coating’s hardness, resistance to heat and resistance to wear [5]. Chromium coatings are applied on the surfaces and blades of tools used to process wet and dry wood. If compared to ordinary uncoated tools, the resistance of Cr-coated tools to wear grows by 2–3 times [6–8]. Chromium nitride (CrN) coatings are applied on tools made from alloy tool steel that are used to cut, shell or mill wet wood. Moisture contained in wood causes tool’s corrosion. Corrosion accelerates significantly wear of the tool’s blade. Cr protects a tool from corrosion and increases its resistance to mechanical wear [9, 10]. HSS tools covered by coatings containing Cr are used to plane and mill wet or dry wood. After having tested various types of dry and wet wood, it was determined that CrN coatings are the most resistant to wear [3, 11]. CrN–coated HSS tools may be used to cut medium- or high-density fibre boards (MDF). The tests revealed that MDF density may be from 740 to 1000 kg/m³. The tools made from WC–Co and PCD (polycrystalline diamond) are used mostly to process wooden materials. PCD tools are the most resistant to wear; however, they are expensive. If blades of WC–Co tools are coated with CrN, their resistance to wear increases [12, 13]. Hardness and wear resistance of CrN coatings were examined using the tribological, corrosion-resistance and machine-processing methods [14].

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2. EXPERIMENTAL

The tests were carried out using the milling tool with a handle and one replaceable cutter. The cutters were made from T06MG-grade hard metal without and with AlCrN coating. The cutters were coated with PVD in the company Oerlikon Balzers Coating Switzerland. The characteristics of the milling tool and hard metal cutter are provided in Table 1 and Figure 1, a. The characteristics of AlCrN coating are provided in Table 2.

Table 1. Characteristics of hard metal and milling tool.

<table>
<thead>
<tr>
<th>Hard metal grade</th>
<th>T06MG</th>
<th>Cutting diameter D</th>
<th>Ø18mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder</td>
<td>6% Co</td>
<td>Cutting edge length l₁</td>
<td>30mm</td>
</tr>
<tr>
<td>Size of WC grains</td>
<td>0.7–1.0 μm</td>
<td>Cutting edge width W</td>
<td>12mm</td>
</tr>
<tr>
<td>Hardness</td>
<td>1800HV10</td>
<td>Cutter’s thickness T</td>
<td>1.5mm</td>
</tr>
<tr>
<td>Bending strength</td>
<td>2700 N/mm²</td>
<td>Length of fixed milling tool l₂</td>
<td>55mm</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>8.2K1C/MPam⁻¹/₂</td>
<td>Rake angle γ</td>
<td>27⁰</td>
</tr>
<tr>
<td>Operating temperature</td>
<td>800–1000°C</td>
<td>Sharpness angle β</td>
<td>53⁰</td>
</tr>
<tr>
<td>Coefficient of friction</td>
<td>0.4–0.6</td>
<td>Clearance angle α</td>
<td>10⁰</td>
</tr>
<tr>
<td>Surface roughnessRa</td>
<td>0.04 μm</td>
<td>Cutting angle λ</td>
<td>87⁰</td>
</tr>
</tbody>
</table>

Table 2. Characteristics of hard alloy and AlCrN coating.

<table>
<thead>
<tr>
<th>Coating’s marking, name</th>
<th>Number of layers</th>
<th>Internal stresses, GPa</th>
<th>Cover</th>
<th>Thickness, μm</th>
<th>Coating’s hardness HV, GPa</th>
<th>Max. work temperature, °C</th>
<th>Friction coefficient</th>
<th>Roughness, Ra, μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlCrN, Aluminium chromium nitride</td>
<td>One-layer</td>
<td>–3±1</td>
<td>PVD</td>
<td>2</td>
<td>36±3</td>
<td>1100</td>
<td>0.5</td>
<td>0.09</td>
</tr>
</tbody>
</table>

The wear of the milling tool’s cutters was examined by milling the oak (Quercus robur) wood panel (1000×1000×20 mm) made when oakwood scantlings (1000×67×20 mm) were glued by polyvinyl acetate dispersion (Danafix 437 D3). Average moisture content ω = 8%, average number of annual rings per 1 cm was 4.6 and density ρ = 739 kg/m³. Average temperature in the laboratory where tests were performed was t=19±2°C, and relative air humidity ψ = 60±5%.
The milling tests were carried out in CNC processing center Holzher Pro Master 7123. The specimens were milled in three different milling modes. The climb milling modes’ characteristics are provided in Table 3.

**Table 3. Characteristics of milling modes.**

<table>
<thead>
<tr>
<th>Milling mode</th>
<th>Rotation of spindle, $n$ (min$^{-1}$)</th>
<th>Cutting speed $v$, (m/s$^{-1}$)</th>
<th>Thickness of cut layer, $h$ (mm)</th>
<th>Feed per cutter, $u_z$ (mm)</th>
<th>Length of contact arc, $l$ (mm)</th>
<th>Chip thickness, $a_z$ (mm)</th>
<th>Width of cut layer, $b$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.000</td>
<td>17</td>
<td>1</td>
<td>0.1</td>
<td>4.2</td>
<td>0.024</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>20.500</td>
<td>19.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>23.000</td>
<td>21.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The blade’s wear was assessed through measurement of change in the cutting edge radius $r$ (Fig. 1, b). The values of the edge radius $r$ set in certain points of the cutting length (Table 4) were measured optically, with the help of metallographic microscope Nikon Eclipse MA-100.

**Table 4. Intervals of cutting length $L$.**

<table>
<thead>
<tr>
<th>Milling mode No.</th>
<th>Cutting length $L$, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 2, 3</td>
<td>1, 1050, 2050, 3050, 6050, 9050</td>
</tr>
</tbody>
</table>

The milling scheme of the specimens is illustrated in Fig. 2.

**Figure 2.** Climb milling scheme of the specimens: a – view from the specimen’s end; b – view from the milling tool’s end. (1 – milling tool; 2 – cutter; 3 – wood specimen; 4 – direction of wood fiber; $b$ – width of milled wood layer; $h$ – thickness of cut layer; $u_z$ – feed per cutter; $u$ – feed direction; $n$ – rotation direction of the milling tool).

Parameter of processed surface roughness $R_s$ was measured by contact profilometer Mahr Surf XR 20. Its tip radius was 2 µm, measurement angle 90°, measurement length 5 mm, and measurement speed was 5 mm/s$^{-1}$. Roughness of milled surfaces $R_s$ was measured after the cutter had worked the set cutting length $L$ (table 4). Each point in Fig. 5 is a mean of five measurements. The measurements were carried out along the wood fiber.

### 3. RESULTS AND DISCUSSION

The research helped to determine changes in the rounding radius of cutting edge and roughness of milled oak wood of the milling cutters made from WC–Co and WC–Co coated by AlCrN coating.

The cutting length has the following impact on the wear of tool’s blade expressed by edge radius $r$ (Fig. 3):

- The growing cutting length reduces edge radius $r$ of WC–Co tools’ blades directly.
- WC–Co+ AlCrN tools have arun-in cutting length ($L=1000–2000$ m), after which wear levels out and changes according to the function $\ln(L)$, i.e. slowly.
- Regardless whether the initial cutting edge radius $r$ of WC–Co tool’s blade is equal to the edge radius of WC–Co tool with AlCrN edge (Fig. 3, a), or whether it is twice as big (Fig. 3, b), the edge radiuses become equal because of differences in wear’s intensity along the cutting length.
Therefore, longer cutting length leads to probable crumbling of WC–Co tool’s cutting edge.

\begin{align*}
\dot{r} &= -0.000L + 19.53 \\
R^2 &= 0.854 \\
\dot{r} &= -1.09\ln(L) + 19.11 \\
R^2 &= 0.683
\end{align*}

\begin{align*}
\dot{r} &= -0.001L + 30.73 \\
R^2 &= 0.932 \\
\dot{r} &= -0.7\ln(L) + 14.59 \\
R^2 &= 0.811
\end{align*}

\begin{figure}[h]
\centering
\begin{subfigure}{0.48\textwidth}
\centering
\includegraphics[width=\textwidth]{fig3a}
\caption{Influence of cutting length $L$ on changes in cutting edge radius $r$ while milling at: a – $19.3 \text{ m s}^{-1}$ and b – $21.6 \text{ m s}^{-1}$ speed.}
\end{subfigure}
\begin{subfigure}{0.48\textwidth}
\centering
\includegraphics[width=\textwidth]{fig3b}
\caption{Influence of cutting speed on changes in the cutting edge radius $r$ while milling (cutting length 9050 m).}
\end{subfigure}
\end{figure}

The second factor that affects resistance of tools to wear is cutting speed.

The edge radius $r$ of WC–Cocutter changed the least when cutting speed was $19.3 \text{ m s}^{-1}$. Meanwhile, when cutting speed of WC–Co+ AlCrN tool was growing from 17 to $21.6 \text{ m s}^{-1}$, the edge radius $r$ was only decreasing (Fig. 4).

It was determined that when cutting speeds of 17 and $21.6 \text{ m s}^{-1}$ were used for milling, the edge radius $r$ of AlCrN-coated was changing less than WC–Co cutters. When the cutting speed of $19.3 \text{ m s}^{-1}$ was applied, the edge radius $r$ of AlCrN-coated cutter’s blade was changing more than that of uncoated WC–Co cutter (Fig. 4).
The influence of cutting length \((L=9050 \text{ m})\) on surface roughness processed by WC–Co cutter was determined as follows:

- When WC–Co tool was used for milling, roughness reached minimal value \((3.5–4.8 \mu\text{m})\) when the tool started to work (cutting length of 1 m was reached). The maximal value of processing roughness \((5.5–11 \mu\text{m})\) was achieved when the cutting length reached limit of 9050 m.
- When WC–Co+AlCrN tool started to work (1 m) and came into contact with the processed surface, \(7–7.5 \mu\text{m}\) roughness was formed. The minimal roughness value \((4–4.5 \mu\text{m})\) was reached when the tool made 1000–2000 m of the cutting length (it is probable that the tool was overworked). The maximal value of processing roughness \((9–9.5 \mu\text{m})\) was achieved when the cutting length reached 6050 m. Afterwards roughness started to decrease.
- At 17 m s\(^{-1}\) processing speed, in all the cases, the hard-alloy WC–Co tool processed the surface smoother than the tool WC–Co+AlCrN.
- At 19.3 m s\(^{-1}\) milling speed, roughness of processed surface was almost the same and growing with increase of the cutting length.
Figure 5. Influence of cutting length $L$ and cutting speed $v$ on changes in surface roughness $R_z$ while milling at: a – 17 m s$^{-1}$; b – 19.3 m s$^{-1}$; c – 21.6 m s$^{-1}$.

4. CONCLUSIONS

The cutting edge radius is decreasing (rake $\gamma$ and sharpness $\beta$ angles are changing) with wear of rake surface of cutter’s blade.

Wear of WC–Co cutters is the smallest at 19.3 ms$^{-1}$ speed, while wear of AlCrN-coated WC–Co cutters is decreasing in the interval of tested speeds (17, 19.3 and 21.6 ms$^{-1}$).

With regard to WC–Co tool, the growing cutting speed and increasing cutting length cause increase in roughness of processed surface.

With regard to AlCrN-coated WC–Co tool, the growing cutting length causes increase in roughness of processed surface; however, when cutting speed is growing, roughness of processed surface stays essentially the same.

REFERENCES