Abstract The research work presented in this paper is focused on the influence of coating techniques such as FAD (filtered arc deposition) and VACTEC (straight arc deposition) on the tool life and cutting forces developed in the drilling process. The grain size refinement of the TiAlN coatings (60-80 nm) provides a high wear resistance especially for the oxidation wear. These coatings promote the formation of protective alumina films composed of amorphous-crystalline structures improving the tribological behaviour of the coated tools.

Keywords: PVD coatings, cutting forces, tribological behaviour

1. INTRODUCTION

Recent improvements in the life of cutting tools have been achieved by the development of titanium aluminum nitride TiAlN coatings. Films such as TiAlN display a unique combination of properties, such as a high hardness at elevated temperature together with thermal and chemical stability, as well as low thermal conductivity [1]. The use of PVD coatings such as TiN, TiCN, Ti AlN has increased substantially over the last 20 years. A very important feature of TiAlN coatings consisting in high oxidation stability due to the protective aluminum films, which offer a good oxidation resistance [2,3,4].

The main advantage of the filtered arc deposition (FAD) technique is a significant grain refinement that leads to the formation of nano-crystalline (grain size approx. 60-80 nm) PVD coatings [5]. This technique improves the wear resistance of FAD TiAIN coatings.

The performance and the quality of coatings is dramatically influenced by the quality of cutting tools, i.e. cutting edge preparation, the substrate’s material physical-mechanical properties, residual stress and type of PVD used.

The present research work was focused on developing a feasibility study, which allows assessing the quality of different coatings using the drilling process. There were tested three coatings as follows: VACTEC monolayered TiAlN PVD coating, LAFAD-SR (filtered arc deposited TiAlN PVD coating with single rotation) and LAFAD-DR (filtered arc deposited TiAlN PVD coating with double rotation).

2. EXPERIMENTAL PROCEDURE

The workpiece material used was AISI P20 hardened mold steel with a chemical composition of 0.31%C, 0.40%Si, 0.75%Mn, 1.2%Cr, 0.8%Ni, 0.41%Mo, 0.008%S and Fe balance. The dimension of the workpiece material was 150 mm × 150 mm × 30 mm and the hardness of each block was 35±2 HRC.

The cutting tools used were drills manufactured by Union Butterfield (USA). The quality of edge preparation prior to coating deposition was checked with the
microscope. The microhardness was also checked using a microhardness tester. The drilling tools used throughout the experiments were detailed in Table 1.

### Table 1. Drilling tool characteristics

<table>
<thead>
<tr>
<th>Tool</th>
<th>HSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate</td>
<td>High speed steel grade M2 (M 42)</td>
</tr>
<tr>
<td>Hardness HRC</td>
<td>63-64</td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>10.08 (5/16&quot;)</td>
</tr>
<tr>
<td>Overall length (mm)</td>
<td>130.2</td>
</tr>
<tr>
<td>Flute length (mm)</td>
<td>95.3</td>
</tr>
<tr>
<td>Manufacturer</td>
<td>Union Butterfield (USA)</td>
</tr>
<tr>
<td>Point angle (°)</td>
<td>135</td>
</tr>
<tr>
<td>Ra (μm)</td>
<td>0.2±0.04</td>
</tr>
</tbody>
</table>

All the drills were coated with a TiAlN coating using the PVD method. The coating codes employed in the feasibility studies are detailed in Table 2.

### Table 2. Coating characteristics

<table>
<thead>
<tr>
<th>Coating codes</th>
<th>Substrate</th>
<th>PVD Coating</th>
<th>Thickness (μm)</th>
<th>Hardness HRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>VACTEC</td>
<td>HSS M2</td>
<td>TiAlN-straight</td>
<td>3.0</td>
<td>63</td>
</tr>
<tr>
<td>LAFAD-SR</td>
<td>HSS M2</td>
<td>TiAlN-filtered</td>
<td>3.0</td>
<td>61</td>
</tr>
<tr>
<td>LAFAD-DR</td>
<td>HSS M2</td>
<td>TiAlN-filtered</td>
<td>3.0</td>
<td>62</td>
</tr>
</tbody>
</table>

The tests were performed on an Okuma Cadet Mate CNC vertical milling center and the cutting forces were measured using a dynamometer. It was also used a software for data acquisition Labview. As a wear criterion was chosen the $V_B$ flank wear $V_B=0.3$ mm. The cutting regime employed was as follows:

- Cutting speed $Vc=60$ m/min
- Feed rate $f_n=240$ mm/min
- Feed/tooth=0.05 mm/tooth
- Depth of the hole =15 mm
- RPM=2405 rpm

### 3. RESULTS AND DISCUSSIONS

The cutting forces measured for each type of coating in different stages of wear are presented below. In figures 1, 2, 3 and 4 are presented the average values for $F_x$, $F_y$, $F_z$ and $M_z$ measured when the VACTEC TiAlN coating was employed for a flank wear of $V_B=0.05$ mm.

![Fig. 1 Value for $F_{xmed}=9.2N$, $V_B=0.05$ mm](image1)

![Fig. 2 Value for $F_{ymed}=6.34N$, $V_B=0.05$ mm](image2)
The thrust force (transmitted to the spindle) \( F_z \) was measured vs. cutting time. During the peak cycle, the cutting force decreased to zero and the drill bit was disengaged from the workpiece for chip evacuation.

Fig.3 Value for \( F_{z_{med}} = 670 \) N, \( V_B = 0.05 \) mm

Fig.4 Value for \( M_{z} = 2280 \) Nm, \( V_B = 0.05 \) mm

Figures 5, 6, 7, 8 present the same cutting forces measured when the flank wear has reached the 0.3 mm value.

Fig.5 Value for \( F_{x_{med}} = 10 \) N, \( V_B = 0.3 \) mm

Fig.6 Value for \( F_{y_{med}} = 528 \) N, \( V_B = 0.3 \) mm

Fig.7 Value for \( F_{z_{med}} = 1040 \) N, \( V_B = 0.3 \) mm

Fig.8 Value for \( M_{z} = 2290 \) Nm, \( V_B = 0.3 \) mm

The same recordings were made for the other two coatings LAFAD-SR and LAFAD-DR. The results of the cutting forces for \( V_B = 0.05 \) mm are presented in table 3 for all the three types of coatings used during the experiments. Table 4 present the values of the cutting forces when \( V_B = 0.3 \) mm for all the three coatings.
Table 3. Values of the cutting forces when $V_B=0.05$ mm (new tool)

<table>
<thead>
<tr>
<th>Force</th>
<th>Coating</th>
<th>Fx</th>
<th>Fy</th>
<th>Fz</th>
<th>Mz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VACTEC</td>
<td>9.2</td>
<td>6.34</td>
<td>670</td>
<td>2280</td>
</tr>
<tr>
<td></td>
<td>LAFAD-SR</td>
<td>9</td>
<td>6.12</td>
<td>620</td>
<td>2240</td>
</tr>
<tr>
<td></td>
<td>LAFAD-DR</td>
<td>8.5</td>
<td>5.90</td>
<td>605</td>
<td>2160</td>
</tr>
</tbody>
</table>

Table 4. Values of the cutting forces when $V_B=0.3$ mm (worn tool)

<table>
<thead>
<tr>
<th>Force</th>
<th>Coating</th>
<th>Fx</th>
<th>Fy</th>
<th>Fz</th>
<th>Mz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VACTEC</td>
<td>10</td>
<td>5.28</td>
<td>1040</td>
<td>2290</td>
</tr>
<tr>
<td></td>
<td>LAFAD-SR</td>
<td>9.6</td>
<td>6.62</td>
<td>912</td>
<td>2258</td>
</tr>
<tr>
<td></td>
<td>LAFAD-DR</td>
<td>9</td>
<td>6.46</td>
<td>860</td>
<td>2235</td>
</tr>
</tbody>
</table>

The values presented in tables 3 and 4 show that for all coatings an increasing in flank wear lead to an increase of Fz cutting force of about 1.4 to 1.6 times depending of the type of coating. The other components Fx, Fy and Mz have not presented significant differences. Fz is the most important component of the cutting force and is most affected by the flank wear. Anyway the values of the Fz are not so high in case of LAFAD-DR comparing with VACTEC coating. A possible explanation could be the small granulation of the coating (60-80 nm), which improves the tribological behaviour of the cutting tool.

In terms of tool life there were counted the number of holes drilled with each cutting tool (VACTEC, LAFAD-SR, LAFAD-DR) until the $V_B=0.3$ mm flank ear was reached. In this case the tool life of LAFAD-DR was far better than the tool life of the other two coatings. The poorest toll life was reached by the VACTEC coating.

Figures 9, 10 and 11 present the wear patterns for the three coated tools employed when each of them has reached the flank wear threshold $V_B=0.3$ mm.

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**Fig. 9. Wear pattern of VACTEC coated tool, $V_B=0.3$ mm after 30 holes drilled**

The flank wear is irregular and extended along the whole clearance face. The area nearby the tip of the tool is more affected and this can be explained by the high value of the thrust force reached (1040 N) for $V_B=0.3$ mm.

**Fig.10. Wear pattern of LAFAD-SR coated tool, $V_B=0.3$ mm after 42 holes drilled**

The wear pattern is quite regular and it seems that the area close to the drill bit is unaffected by the wear. This can explain the Fz low value comparing with the Fz value recorded when the VACTEC coating has been used.

Finally in figure 11 the wear pattern of the LAFAD-DR coating is showed.
It should be pointed out the number of holes drilled with the LAFAD-DR coating. This was by far the best tool life obtained. The tool life is almost twice the VACTEC tool life and 1.4 times higher than LAFAD-SR coating tool. The wear pattern is quite similar to the wear pattern of the LAFAD-SR coating. The area nearby the drill tip is less worn than the opposite side. The wear displays a regular shape.

4. CONCLUSIONS

The variation of the main component of the cutting force, the thrust force $F_z$, was affected by the tool wear. Increasing the tool wear consisted in increasing of the $F_z$ value by 1.4 to 1.6 factor irrespective of the coating employed. However the other components of the cutting force ($F_x$, $F_y$) did not present a significant variation when the flank wear has increased from $V_B=0.05$ mm to $V_B=0.3$ mm. The wear pattern was different for the VACTEC straight coating and the other two filtered coatings LAFAD-SR and LAFAD-DR. In the first case the wear showed an irregular pattern being localized near the tip of the tool, which confirms the high value of the $F_z$ cutting force component comparing with the $F_z$ cutting force values of the other two coatings.

When LAFAD coatings were employed the wear has been localized along the clearance face and the opposite area of the drill bit.

In terms of tool life, a significant improvement was observed when LAFAD-DR coating has been utilized. This can be explained by the fine granulation of the coating layer (60-80 nm) and to the uniformity of this deposition technique due to the double rotation movement of the tool during the deposition procedure. During the LAFAD-DR procedure the cutting tool has a rotational movement around its center axe and a planetary movement in the same time, which allows a more homogenous deposition of coating layer. The TiAlN offers a high wear resistance especially for the oxidation wear. The TiAlN coating LAFAD-DR has proved to improve the tribological behaviour of the cutting tool taking into account the values of the $F_z$ cutting force.

5. REFERENCES


6. ADDITIONAL DATA ABOUT AUTHORS
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