Influence of Thickness of Multilayer Composite Nano-structured Coatings on Tool Life of Metal-Cutting Tool

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Abstract. The paper is focused on turning of structural steels C45. Cutting tools were represented by carbide cutting inserts without coatings, with reference coating TiAlN, as well as with multilayered composite nano-structured coatings Ti-TiN-(TiCrAl)N and Zr-ZrN-(ZrCrNbAl)N (of different thickness of 3-7 μm). The following studies of the properties of coated tools were carried out: measurement of microhardness and strength of adhesion bonds in the "tool-coating" system and investigation of elemental and phase compositions of coatings. The cutting tests were carried out at the following cutting modes: f = 0.2 mm/rev; ap = 1.0 mm; vc = 200, 250, 300, 350 and 400 m/min.

1. Introduction

Wear-resistant coatings are actively and successfully applied to modify superficial layer of tool materials and thus to increase performance properties of cutting tools. On the one side, the use of modifying coatings makes it possible to increase tool life, while on the other side, that can significantly increase cutting modes and, first of all, the cutting speed [1-5]. Coating thickness is an important indicator that significantly affects the performance properties of metal cutting tools. The choice to select the optimum coating thickness f or different machining conditions was studied by a number of researchers. In particular, Klocke et al [6] note that carbide cutting tools with thicker PVD coating are characterized by longer tool life and that contributes to reduction of production costs. Mean while, M essier et al [7] showed that when monolayered coating is deposited, its grains grow with increase in its thickness [6]. It can also be assumed that mechanical strength of thin coatings will be higher than that of thick coatings. It is shown that nominal superficial hardness, superficial yield and maximum superficial strength decrease with increase in coating thickness [6]. Bouzakis et al [7-10] studied the influence of thickness for coating (TiAlN) (coating with thickness of 2-10 μm was studied) on tool life of carbide tools when turning steel at various cutting modes. It is found that tool life improves with increase in coating thickness. Proceeding from the above, it can be noted that there is some kind of "bipolar" opinion on coating thickness. O n the one side, a number of authors argue that tool life improves with increase in coating thickness (up to 10 μm), while other authors note a marked decrease in performance properties of a coating as its thickness increases. Meanwhile, the influence of thickness of a multilayered nano-structured coating on tool life was in fact not studied. The purpose of this study was to investigate the influence of wear-resistant layer thickness and elemental composition of a coating on tool life at various cutting speeds (speeds of 250, 300, 350 and 400 m/min) were considered.

2. Materials and experiments

For the comparative tests, two types of multilayered nano-structured coatings were selected: Ti-TiN-(TiCrAl)N and Zr-ZrN-(ZrCrNbAl)N, each with three different thicknesses (3, 5 and 7 μm). These coatings were selected as the most effective ones in accordance with the results of previous tests [11-15]. The monolayered non-nano-structured coating TiAlN with thickness of 4 μm, as well as carbide uncoated insert were selected as an object of comparison. These coatings were deposited on carbide inserts with square shape (SNUN ISO 1832:2012) and with the following geometric parameters of the cutting part: γ = –8°, α = 8°, K = 45°, λ = 0, and R = 0.8 mm. For deposition of coating, a vacuum-arc VIT-2 unit [11,13] was used, which was equipped with an arc evaporator with filtration of vapor-ion flow, which was named filtered cathodic vacuum-arc deposition (FCVAD) in this study [13]. The monolayered non-nano-structured coating TiAlN with thickness of 4 μm, as well as carbide uncoated insert were selected as an object of comparison. These coatings were deposited on carbide inserts with square shape (SNUN ISO 1832:2012) and with the following geometric parameters of the cutting part: γ = –8°, α = 8°, K = 45°, λ = 0, and R = 0.8 mm. For deposition of coating, a vacuum-arc VIT-2 unit [11,13] was used, which was equipped with an arc evaporator with filtration of vapor-ion flow, which was named filtered cathodic vacuum-arc deposition (FCVAD) in this study [13].
mm; \( v_c = 250, 300, 350 \) and 400 m min\(^{-1}\). Tool failure criterion was flank wear \( l \) and \( V_B = 0.4 \) mm. For microstructural studies of samples of carbide with coatings, a raster electron microscope FEI Quanta 600 FEG was used. To perform X-ray microanalysis, the study used characteristic X-ray emissions resulting from electron bombardment of a sample. The hardness (HV) of coatings was determined by measuring the indentation at low loads according to the method of Oliver and Pharr \([16]\). The adhesion characteristics were studied on a Nanovea scratch tester. The tests were carried out with the load linearly increasing from 0.05 N to 40 N.

### 3. Results and discussions

The results of the main parameters of coatings are shown in Table 1.

<table>
<thead>
<tr>
<th>Type of coating</th>
<th>Coating thickness</th>
<th>Hardness</th>
<th>Strength of adhesion bond to substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiAlN</td>
<td>4 (±0.8)µm</td>
<td>30.3 GPa</td>
<td>30.1 N</td>
</tr>
<tr>
<td>Ti-TiN-(TiCrAl)N</td>
<td>3 (±0.7)µm</td>
<td>32.7 GPa</td>
<td>34.2 N</td>
</tr>
<tr>
<td>Ti-TiN-(TiCrAl)N</td>
<td>5 (±0.6)µm</td>
<td>32.2 GPa</td>
<td>35.0 N</td>
</tr>
<tr>
<td>Ti-TiN-(TiCrAl)N</td>
<td>7 (±0.6)µm</td>
<td>33.5 GPa</td>
<td>34.8 N</td>
</tr>
<tr>
<td>Zr-ZrN-(ZrCrNbAl)N</td>
<td>3 (±0.6)µm</td>
<td>29.4 GPa</td>
<td>32.6 N</td>
</tr>
<tr>
<td>Zr-ZrN-(ZrCrNbAl)N</td>
<td>5 (±0.5)µm</td>
<td>30.1 GPa</td>
<td>33.1 N</td>
</tr>
<tr>
<td>Zr-ZrN-(ZrCrNbAl)N</td>
<td>7 (±0.5)µm</td>
<td>30.2 GPa</td>
<td>33.2 N</td>
</tr>
</tbody>
</table>

From the data provided, it can be seen that all the coatings under study are characterized by sufficient adhesion to substrate and microhardness, corresponding to the usual values for these coatings. Meanwhile, adhesion of multilayered coatings under study is slightly higher than that of monolayered coating TiAlN, and that can be explained by the presence of a specific adhesive layer in the structure of multilayered coatings \([13]\). The structures of coatings on cross-section are shown in Figures 1-2.

It can be seen that monolayered coating TiAlN has no nano-structure, while coatings Zr-ZrN-(ZrCrNbAl)N and Ti-TiN-(TiCrAl)N show a clear nano-structure of wear-resistant layer, and a transition layer without nano-structure can also be clearly seen. An adhesive layer cannot be determined on Figure due to its small thickness (about 20 nm).

![Fig. 1. Structure on cross-section of coating TiAlN, with thickness 4 (±0.8) µm.](image)

![Fig. 2. Structure on cross-section of coatings Zr-ZrN-(ZrCrNbAl)N (a) and Ti-TiN-(TiCrAl)N (b) with thickness of about 5 µm.](image)
The results of cutting tests for uncoated tool and tools with coatings under study are shown in Figure 3. On the basis of the results obtained, it can be noted that:

- At cutting speed of \( v_c = 400 \text{ m min}^{-1} \), an uncoated insert shows excess flank wear after the very first minute of cutting, which indicates uncoated tools cannot be used under these cutting modes.

4. Conclusions

The use of multilayered nano-structured coatings (in particular, coatings \( Zr-ZrN-(ZrCrNbAl)N \) and \( Ti-TiN-(TiCrAl)N \)) makes it possible to increase cutting speed in turning of structural steels. Advantages of cutting tools with these coatings are especially obvious at high cutting speeds (in particular, \( v_c = 400 \text{ m min}^{-1} \)). The phenomenon can be explained by more significant growth of internal stresses in thick coatings with an increase in cutting speed. High internal stresses result in formation of internal cracks and interlayer delamination that ultimately lead to destruction of coating.

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