Influence of coatings based on Zr and Ti on the wear resistance of cemented carbide tools when turning transport machines’ parts from structural steels

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Abstract. The influence of coatings based on titanium carbide and zirconium carbide, obtained by PVD method, on cutting tool wear resistance under conditions of the longitudinal turning of transport machines’ parts of steel 45 and stainless steel 12H18N10T by inserts of hard alloy grade T15K6 was investigated. It has been experimentally established that the presence and composition of the coating on the working surfaces of the tool in most cases contributes to a significant reduction in the intensity of wear of cemented carbide inserts. When turning stainless steel 12H18N10T, the best result was demonstrated by the coating ZrN + (Ti–Zr) N + TiN, which provided not only the minimum intensity of wear, but also the expansion of the range of optimal cutting speeds. When machining structural steel 45, the maximum reduction in the wear intensity of the cutting inserts was observed with the use of a single-layer TiN coating and a (Ti,Zr)N coating.

1 Introduction

A significant number of parts used in modern mechanical engineering consist of metal structural materials, and the technological process of their manufacture contains a high proportion of blade processing operations. Technical progress in metalworking is largely determined by the quality of the cutting tools, which largely depends on the strength and wear resistance of tool materials. At present, when the possibilities of increasing the wear resistance of the tool by creating new materials with improved physical and mechanical properties that provide increased resistance to the processes of volumetric and surface destruction have largely been exhausted, an important reserve for improving the quality of the tool is the use of wear-resistant coatings. Coatings, the material of which in its crystal and chemical structure and physical and mechanical properties is significantly different from the base material, change the surface properties of the tool and actively affect the contact processes when processing materials by cutting. By setting the properties of the coating by varying its chemical composition and structure, it is possible to control the most important output characteristics of the cutting process - tool wear intensity and the quality of the surface

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layer of the work pieces. One of the most common groups of tool cutting materials (TCM) used in modern metalworking production are cemented carbides (CC). Among the main directions for improving the performance characteristics of CC, special mention can be made to the development of new compositions with improved physical and mechanical characteristics [1-4], the choice of the most effective compositions of lubricating media and modes of their supply to the cutting zone, as well as the modification of the working surfaces of the CC tools by deposition of wear-resistant coatings of various compositions [5-10]. Traditionally, a single-layer TiN hard coating has become widespread, especially for modifying surfaces of high-speed steel tools, since this coating has a similar coefficient of thermal expansion with TCM of this group [5]. The disadvantage of this composition is that the TiN coatings are oxidized at a temperature of 500–600 °C, which limits its use at high temperatures in the cutting zone. The next stage in the development of titanium coatings was the use of TiAlN composition. This composition demonstrates the preservation of mechanical properties even at elevated temperatures of about 800 °C [7-10]. A significant effect is observed due to the use of such compositions as carbides, nitrides and carbo nitrides of titanium (TiC, TiN, TiCN) and titanium-boron nitride (TiB2) [11]. Studies have shown a significant improvement in the properties of parts when using these coatings on biomedical implants, aerospace parts and metal-cutting tools. Coatings of these formulations are predominantly applied using one of three methods: chemical vapor deposition (CVD), physical vapor deposition (PVD), and plasma-based chemical vapor deposition (PACVD) [6]. Despite the fact that TiN, TiCN and TiC coatings remain one of the most common and most intensively studied over the past decades, formulations using various zirconium compounds (ZrN, ZrCN, ZrC) also remain a relevant and very promising direction for improving the wear resistance of CC tools [12].

2 Materials and methods

Multilayer wear-resistant coatings of type (Ti-Zr)N, TiN-ZrN, ZrN-(Ti,Zr)N-TiN were obtained by cathode-ion bombardment of CC plates (WC-TiC-Co) using an advanced VU-1 apparatus (Bulat type) with two evaporators. Systematic deposition of layers in a certain order, provided that the TiN layer is always located outside, allows you to create a functionally gradient material that favorably endures the dynamic loads during machining of processed materials. Single-layer coatings were obtained when working with one of the evaporators (TiN, ZrN) or two simultaneously (Ti-Zr) N, two-layer TiN + ZrN – by sequential operation of each evaporator, and three-layer ZrN + (Ti-Zr) N + TiN – by sequential and parallel operation of evaporators. Studies of the cutting process were carried out during longitudinal turning of work pieces made of steel 45 and stainless steel 12H18N10T on a 16K20 lathe, equipped with a system of step less speed control Mitsubishi, which allows you to set the required cutting speed with a high degree of accuracy.

The range of cutting speeds during the study varied within \( V = 0.8 \ldots 5.0 \, \text{m/s} \), with a constant cross-section of the cut layer. The feed rate was \( S = 0.39 \, \text{mm/rev} \), cutting depth \( t = 0.5; 1.0 \, \text{mm} \), cutting path \( L = 200..800 \, \text{m} \). The turning process was carried out without the use of lubricant, wear on the flank surface of the insert \( h_f \) and the length of the contact of the chips with the rake surface of the insert \( l_c \) were determined by optical microscopy. Each experiment was repeated at least 5 times, and the results obtained were processed in the MathCAD software environment using the methods of reliability theory according to the methodology [19].
3 Results and discussion

Analysis of experimental results showed that both the very presence of a wear-resistant coating on the working surfaces of the cutting tool, and its composition, significantly affect the characteristics of the cutting process. The results of comparative studies of the intensity of wear with a variation in the composition of the coating during the processing of stainless steel 12H18N10T are given in Table 1.

### Table 1. Influence of coating composition on the performance of the cutting process when turning steel 12H18N10T with CC grade T15K6 ($V = 2.5 \text{ m/s}, t = 0.5 \text{ mm}, L = 600 \text{ m}$).

<table>
<thead>
<tr>
<th>Coating</th>
<th>Coating thickness $H_i$, µm</th>
<th>Flank wear $h_f$, mm</th>
<th>Wear intensity $I_x \times 10^8$</th>
<th>Contact length $l_k$, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without coating</td>
<td>–</td>
<td>0.34</td>
<td>5.60</td>
<td>1.69</td>
</tr>
<tr>
<td>TiN</td>
<td>5–8</td>
<td>0.10</td>
<td>1.66</td>
<td>0.84</td>
</tr>
<tr>
<td>TiN+ZrN</td>
<td>9–12</td>
<td>0.20</td>
<td>3.33</td>
<td>0.72</td>
</tr>
<tr>
<td>ZrN</td>
<td>6–8</td>
<td>0.16</td>
<td>2.66</td>
<td>1.43</td>
</tr>
<tr>
<td>(Ti–Zr)N</td>
<td>6–9</td>
<td>0.21</td>
<td>3.50</td>
<td>0.92</td>
</tr>
<tr>
<td>ZrN+(Ti-Zr)N+TiN</td>
<td>10–15</td>
<td>0.08</td>
<td>1.30</td>
<td>0.56</td>
</tr>
</tbody>
</table>

As can be seen from Table 1, when turning stainless steel 12H18N10T, the use of two- and three-layer (combined) coatings reduces the wear intensity of the T15K6 alloy compared to cutting without coating by 2 or more times. The lowest values of linear wear on the flank surface and, consequently, wear intensities are demonstrated by the multilayer coating of the composition (ZrN + (Ti–Zr) N + TiN). The length of the chip contact with the rake surface for this composition is also significantly lower than when cutting with T15K6 alloy. The presence of a coating on the working surfaces of the tool also affected the deformation indicators of the turning process, which was reflected, in particular, in the decrease in the angle of shear in the zone of primary plastic deformations.

The parameters characterizing the effect of coatings on tool wear during the processing of steel 45 are shown in Table 2.

### Table 2. Influence of coating composition on the performance of the cutting process when turning steel 45 with CC grade T15K6 ($V = 5.3 \text{ m/s}, t = 1 \text{ mm}, L = 600 \text{ m}$).

<table>
<thead>
<tr>
<th>Coating</th>
<th>Flank wear $h_f$, mm</th>
<th>Wear intensity $I_x \times 10^7$</th>
<th>Contact length $l_k$, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without coating</td>
<td>0.42</td>
<td>5.25</td>
<td>1.05</td>
</tr>
<tr>
<td>TiN</td>
<td>0.13</td>
<td>1.62</td>
<td>0.56</td>
</tr>
<tr>
<td>TiN+ZrN</td>
<td>0.18</td>
<td>2.25</td>
<td>0.68</td>
</tr>
<tr>
<td>ZrN</td>
<td>0.23</td>
<td>2.87</td>
<td>1.10</td>
</tr>
<tr>
<td>ZrN+(Ti,Zr)N+TiN</td>
<td>0.18</td>
<td>2.25</td>
<td>0.45</td>
</tr>
<tr>
<td>(Ti,Zr)N</td>
<td>0.12</td>
<td>1.50</td>
<td>0.60</td>
</tr>
</tbody>
</table>

In this case, the greatest increase in wear resistance (almost 3 times compared to T15K6 without coating) was observed for coatings TiN and (Ti,Zr)N. The results of comparative studies of wear intensity depending on the cutting speed for some coating compositions are shown in Fig. 1-4. When machining various materials, the intensities of wear of CC inserts, depending on the cutting speed and composition of the coating, at constant cross-sectional values of the cut layer and the cutting path, are of extreme character, which allows us to assess the ranges of optimal speeds at which the maximum wear resistance of the cutting tool is observed.
Fig. 1. Dependence of wear intensity on cutting speed at turning steel 45 ($S = 0.39 \text{ mm}/v, t = 1 \text{ mm}$): 1 - T15K6 without coating; 2 - TiN coating; 3 - ZrN coating.

When cutting steel 45, multilayer coatings reduce the intensity of wear compared to uncoated inserts in the speed range from 0.8 to 5 m/s. With an increase in the cutting speed, the degree of influence of the coatings increases and the optimal speed range is $1.57 \ldots 4.5 \text{ m/s}$. Of the single-layer coatings, the TiN composition demonstrates the best wear resistance at all the studied speeds.

Fig. 2. Dependence of wear intensity on cutting speed at turning steel 45 ($S = 0.39 \text{ mm}/v, t = 1 \text{ mm}$): 1 - T15K6 without coating; 2 - coating ZrN+(Ti, Zr)N+TiN; 3 - coating (Ti, Zr)N.

When turning stainless steel 12H18N10T, the use of two- and three-layer (combined) coatings reduces the wear intensity of the T15K6 grade compared to uncoated insert by about 2 or more times and increases the productivity of machining. The optimal speed range, at which wear is minimal, corresponds to $1.23 - 3.89 \text{ m/s}$. At the same time, the coating ZrN + (Ti, Zr)N + TiN showed the lowest value of wear and significantly expands the optimal area of use in terms of speed from 1.2 to 4.94 m/s. The wear of the coated insert (Ti, Zr)N is much lesser than for the same uncoated tool.
Fig. 3. Dependence of wear intensity on cutting speed at turning steel 12H18N10T: 1 - T15K6 without coating; 2 - TiN coating; 3 - TiN+ZrN coating.

Fig. 4. Dependence of wear intensity on cutting speed at turning steel 12H18N10T: 1 - T15K6 without coating; 2 - coating ZrN+(Ti, Zr)N+TiN; 3 - coating (Ti, Zr)N.

For the composition ZrN + (Ti–Zr) N + TiN, an expansion of the upper limit of the speed interval with the lowest values of the wear intensity to 4.9 m / s was recorded. If when cutting hard-to-machine steel 12H18N10T there is a significant difference in the levels of wear intensity of the cutting tool with combined coatings, then when turning structural carbon steel 45 in the region of optimal cutting speeds, the differences in the values of the wear intensity are small, but there is a shift in the optimal cutting speeds towards higher values when using more efficient coatings.

5 Conclusion

As a result of the study of the longitudinal turning of work pieces made of structural carbon steel 45 and stainless steel 12H18N10T with tools equipped by CC inserts having single- and multi-layer coatings deposited by the PVD method, a significant reduction in the wear intensity of the cutting tool was found in comparison with the inserts without coating. When turning stainless steel 12H18N10T, the best result is demonstrated by the coating ZrN + (Ti–Zr) N + TiN, which provided not only the minimum intensity of wear, but also the expansion of the range of optimal cutting speeds. The presence of the same coating of the composition...
(Ti, Zr) N in this case contributed to a decrease in the wear resistance of the tool in comparison with T15K6 grade without coating. When processing structural steel 45, the maximum reduction in the intensity of wear was observed when using a single-layer coating TiN and a coating (Ti, Zr) N. In experiments with these compositions, the least wear on the flank surface and the length of the chip contact with the rake surface were recorded among all the options studied.

References

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