Application of complex niobium nitrides as heat-protective and wear-resistant coating materials for cutting tools

V P Tabakov¹, A V Chikhranov¹,², Y A Dolzhenko² and S N Vlasov³

¹Federal State Budgetary Educational Institution of Higher Education Ulyanovsk Technical State University, Ulyanovsk, 432027, Ulyanovsk, Russia
²Federal State Budgetary Educational Institution of Higher Education Ulyanovsk Institute of Civil Aviation named after Chief Marshal of Aviation B.P. Bugaev, 432071, Ulyanovsk, Russia
³Federal State Autonomous Educational Institution of Higher Education National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, 115409, Russia

E-mail: chihranov@mail.ru

Abstract. The results of investigations of the contact temperatures on the front surface and the thermal state of cutting wedge of carbide tool using coatings based on complex niobium nitrides are presented. The efficiency of using carbide tools with developed wear-resistant coatings is shown. Further use of the developed coating compositions for creating multilayer coatings is proposed.

1. Introduction
Improving the efficiency of cutting tools in blade processing operations is an important task of modern mechanical engineering. Currently, the greatest effect in solving this problem is shown by the use of wear-resistant coatings [1, 2]. In this regard, the development of new compositions of wear-resistant coatings is one of the most effective ways to improve the efficiency of cutting tools [3, 4].

The aim of this work is to study the influence of the composition of complex niobium nitrides on the thermal state and efficiency of a carbide cutting tool.

2. Research results and discussion
Both a simple coating of niobium nitride NbN and complex coatings alloyed with one and two chemical elements NbTiN, NbTiAlN and NbTiZrN were studied. For comparison, a titanium nitride coating was used. Coatings with a thickness of 6 microns were applied on the "Bulat-6" installation on plates made of hard alloy MK8. Cathodes made of titanium, zirconium, niobium, and a cast cathode made of an alloy of titanium and aluminum were used. The chemical composition of the coatings is shown in table 1.

Determination of the contact temperatures on the front and clearance surfaces of the cutting tool was carried out at the longitudinal turning of workpieces made of 30HGSA steel (cutting modes: \( V = 180 \) m/min; \( S = 0.3 \) mm/turn; \( t = 1 \) mm) according to the method described in [5]. The initial data were the chip contact length along the front surface \( C_\gamma \), chip shortening coefficient \( K_\ell \), normal \( \sigma_{\text{max}} \) and
tangential stress $\tau_{\text{max}}$ along the front surface of the cutting tool [6]. The calculation data are presented in table 2 and in figure 1.

**Table 1. Chemical composition of coatings.**

| Coating   | Content of elements (% at) |
|-----------|----------------------------|
|           | Nb | Ti | Al | Zr |
| TiN       | –  | 100| –  | –  |
| NbN       | 100| –  | –  | –  |
| NbTiN     | 55.6| 44.4| –  | –  |
| NbTiAlN   | 49.2| 40.0| 10.8| –  |
| NbTiZrN   | 41.7| 46.5| –  | 11.8|

The use of niobium nitride as a coating material makes it possible to reduce the contact temperatures on the front surface due to the low thermal conductivity. Calculations show that the decrease in temperature $\Delta T$ is 108 °C. When introducing alloying elements into the composition of niobium nitride, the thermal protection effect is significantly reduced, due to an increase in the thermal conductivity coefficient. In comparison with the TiN coating, higher values of the contact length with the front surface and the chip shortening coefficient (which indicates a greater degree of plastic deformation in the cutting zone) lead to a certain increase in contact temperatures (figure 1). However, the stress state for all coatings based on niobium nitride is characterized by lower values of normal and tangential stresses. At the same time, coatings of complex composition are characterized by the greatest stress reduction.

**Table 2. Contact characteristics of coated cutting tools.**

| Coating   | $C_{\text{p}}, \text{ mm}$ | $K_\ell$ | $\sigma_{\text{max}}, \text{ MPa}$ | $\tau_{\text{max}}, \text{ MPa}$ | $\Delta T, ^\circ \text{C}$ | $T_{\text{max}}, ^\circ \text{C}$ |
|-----------|-----------------------------|----------|-------------------------------|----------------|----------------|----------------|
| TiN       | 0.447                       | 1.77     | 1908                          | 559           | 14.4          | 1106          |
| NbN       | 0.517                       | 1.86     | 1847                          | 528           | 108           | 1039          |
| NbTiN     | 0.539                       | 1.91     | 1821                          | 509           | 22.1          | 1120          |
| NbTiAlN   | 0.564                       | 1.95     | 1769                          | 503           | 21.6          | 1126          |
| NbTiZrN   | 0.556                       | 1.97     | 1781                          | 496           | 22.1          | 1132          |

To determine the distribution of temperature fields in the cutting wedge of the tool, a simulation of the heat transfer process in the cutting zone was performed using the Ansys Mechanical APDL program (figure 2).

The application of niobium nitride coatings changes the thermal state of the cutting wedge of the tool. An increase in the contact length of the chips with the front surface, which is typical for both NbN coating and coatings based on complex niobium nitrides, contributes to the displacement of the isotherms of the temperature fields in the direction from the clearance surface and the cutting edge of the tool. At the same time, when using a niobium nitride coating, as compared to a titanium nitride coating, a slightly less heating of the cutting wedge of the tool in the direction from the front surface is observed. For coatings of complex composition based on niobium nitride, the isotherms, on the contrary, are shifted deep into the cutting wedge of the tool.

The efficiency of a cutting tool with wear-resistant coatings was evaluated by the amount of wear intensity on the clearance surface (figure 3). The use of a cutting tool with both a niobium nitride coating and a complex coating based on niobium nitride leads to a decrease in the wear intensity by 1.2...2 times compared to a tool with a TiN coating. At the same time, a greater reduction in the intensity of wear is provided by the application of NbTiAlN and NbTiZrN coatings. As shown by the
data of previous studies [7], coatings of complex composition have higher values of mechanical properties and better resist the processes of cracking and destruction.

![Graph showing contact temperatures on the front surface of cutting tool with wear-resistant coatings.](image)

**Figure 1.** Contact temperatures on the front surface of cutting tool with wear-resistant coatings.

![Temperature distribution images with different coatings.](image)

**Figure 2.** Temperature distribution $T$ (°C) in the cutting wedge of carbide tools with coatings: a – TiN, b – NbN, c – NbTiN, d – NbTiAlN.

### 3. Conclusions

The conducted studies have shown the possibility of using wear-resistant coatings based on niobium nitride both for creating heat-protective coatings and for improving the efficiency of cutting tools. Analyzing the results obtained, it can be noted that niobium nitride as a coating material is able to significantly reduce the temperature in the cutting zone due to low thermal conductivity. At the same time, coatings based on complex niobium nitrides can further reduce the wear rate of the cutting tool,
both due to changes in the contact characteristics in the cutting zone, and due to higher mechanical properties. As a result, it can be recommended to use the compositions of such coatings to create multilayer coatings, where niobium nitrides alloyed with titanium, aluminum and zirconium can be used as the material of the upper coating layer, and niobium nitride can be used as the material of the lower layer. In this case, the upper layer of the coating will provide the maximum reduction in contact stresses with increased wear resistance, and the lower layer will perform heat-protective functions that allow the maximum temperature reduction on the front surface of the carbide tool.

**Figure 3.** Influence of the coating composition on the wear intensity \( J \) of the cutting tool with the wear-resistant coating (a: \( V = 130 \) m/min; \( S = 0.3 \) mm/turn; \( t = 0.5 \) mm; b: \( V = 180 \) m/min; \( S = 0.15 \) mm/turn; \( t = 0.5 \) mm).

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**References**

[1] Mokritskiy B Y 2010 Controlling the efficiency of tools by means of coating application *STIN* 11 11–5

[2] Volosova M A and Gurin V D 2013 *Journal of Friction and Wear* 34 183–9

[3] Vereshchaka A A and Grigoriev S N 2020 *Theoretical justification of the choice of rational architecture and element composition of multilayer composite wear-resistant coatings* (Moscow: STANKIN) p 141

[4] Oskolkova T N and Glezer A M 2017 *Steel in Translation* 47 788–96

[5] Reznikov A N 1981 *Thermophysics of processes of mechanical processing of metals* (Moscow: Mashinostroenie) p 279

[6] Tabakov V P, Chikhranov A V and Dolzhenko Y A 2019 *University science in modern conditions: collection of materials of the 53rd scientific and technical conference* 77–80

[7] Tabakov V P, Chikhranov A V and Dolzhenko Y A 2020 *IOP Conf. Series: Materials Science and Engineering* 709 033096