Study of the additional strengthening treatment impact on structural parameters and mechanical properties of coatings based on nitrides of niobium, titanium, zirconium and aluminum

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Abstract. In this paper results of the impulse laser processing impact on structural parameters and mechanical properties of coatings based on nitrides of niobium, titanium, zirconium and aluminum are set out. Structures of multilayer coatings are suggested and the utilization efficiency of carbide-tipped tools with engineered coatings is shown.

1. Introduction
Application of abrasion-resistant coatings is an efficient method for material improving the operating capacity of cutting tools [1, 2]. Notwithstanding significant advances in this sphere, in some cases the operating capacity of cutting tools with coatings is not high. This fact urges to search for new coating compositions or to engineer technological methods for improving the efficiency of the known coatings. One of such lines is the additional strengthening treatment, for example, the impulse laser processing [3–6].

The objective of this paper is to study the additional strengthening treatment impact on the operating capacity of carbide-tipped tools with the multilayer coating.

2. Research results and discussion
We studied coatings NbTiAlN and NbTiZrAlN which were applied using the apparatus «Bulat-6» on carbide-tipped blades MK8. We used cathodes made of niobium, titanium, zirconium and aluminum. Chemical composition of coatings is presented in table 1.

To determine the value of the laser radiation energy we modelled the impact process of the impulse laser processing (ILP) on the composition «coating–tool base» using the program Ansys Mechanical APDL. The value of the laser radiation energy was calculated taking into consideration stresses...
generated under the impact of ILP. Exceeding of these stress values led to the crack formation in the composition «coating-tool base» and the further destruction of the coating. Subject to the aforesaid, we modelled the impact of ILP power density on stresses generated at the surface of the carbide-tipped base without coating and on the boundary of the abrasion-resistant coating with the carbide-tipped base. Modelling of ILP impact process on the composition «coating–tool base» gave an opportunity to calculate the power density value of ILP for the carbide-tipped base MK8 which amounted 5100 W/cm². Study results of ILP impact on structural parameters and mechanical properties of coatings are presented in table 2.

### Table 1. Chemical composition of coatings.

| Coating     | Content of elements (% at) |
|-------------|----------------------------|
| NbTiZrAlN   | 10.4 48.6 40.6 0.4         |
| NbTiAlN     | 14.5 83.4 – 2.1            |

It has been established that ILP impact causes the half-width escalation of the X-ray line $\beta_{111}$ by 11…32 %, the reduction of compressive residual stresses $\sigma_0$ by 28.8…31.1 % depending on the coating composition. Reduction of stresses is explained by their relaxation on the boundary of the coating with the carbide-tipped base as the result of the high-speed laser heating and cooling.

### Table 2. Structural parameters and mechanical properties of coatings.

| Coating     | $\beta_{111}$ (grade) | $\sigma_0$ (MPa) | $H_p$ (GPa) | $E$ (GPa) | $K_{IC}$ (MPa·m$^{1/2}$) | $K_a$ |
|-------------|------------------------|-----------------|------------|----------|--------------------------|--------|
| NbTiAlN     | 0.53                   | -1438±158       | 30.6       | 416      | 12.34                    | 0.17   |
|             | 0.70                   | -1023±84        | 32.8       | 442      | 12.04                    | 0.07   |
| NbTiZrAlN   | 0.75                   | -1376±19        | 32.2       | 438      | 13.16                    | 0.34   |
|             | 0.86                   | -948±193        | 36.7       | 487      | 13.73                    | 0.21   |

*Data in the numerator and the nominator are before and after ILP as relevant

Impact of ILP causes the increase of the coating micro-hardness $H_p$ by 7.2…13.9 %, the elasticity modulus $E$ by 6.2…11.2 % which is due to the half-width escalation of the X-ray line $\beta_{111}$ which certifies the crystalline lattice micro-deformation of the coating material. ILP leads to the reduction of the delamination coefficient $K_a$ by 38…40 % which certifies the improvement of the coating adhesion strength with the carbide-tipped base. Impact of ILP almost does not change the critical stress intensity coefficient $K_{IC}$.

Multilayer coating architecture working under uninterrupted cutting conditions were selected taking into consideration recommendations from works [1, 7]. Authors [7] demonstrate that the upper layer of the multilayer coating designed and suitable for the turning processing simultaneously implements two requirements: provides favorable conditions for the contact interaction at the front surface of the cutting tool and suppresses crack formation processes in the coating during cutting. As can be seen from the above, the structure of multilayer coatings designed and suitable for the turning processing and providing the high resistivity to crack formation processes, can have two layers minimum. Having regard to the above, bilayer coatings were engineered. Studied coatings: TiN–NbTiAlN and TiZrN–NbTiZrAlN were used as upper layers. Mechanical properties of bilayer coatings after ILP are presented in table 3.

Study results show that ILP of bilayer coatings causes similar changes of mechanical properties which were true for one-layer coatings. The greatest impact ILP has on the adhesion strength which is certified with the reduction of the delamination coefficient by 2.7…3.5 times depending on the coating construction.
### Table 3. Mechanical properties of bilayer coatings after the impulse laser processing.a.

| Coating          | $H_p$ (GPa) | $E$ (GPa) | $K_{IC}$ (MPa m$^{1/2}$) | $K_o$  |
|------------------|-------------|-----------|--------------------------|--------|
| TiN–NbTiAlN      | 31.8/33.2   | 421/445   | 12.45/12.84              | 0.42/0.12 |
| TiZrN–NbTiZrAlN  | 33.4/35.9   | 432/483   | 13.00/13.21              | 0.58/0.21 |

*a data in the numerator are for coatings without ILP and data in the nominator are after ILP

Operating capacity of carbide-tipped cutting tools with coatings was studied when turning processing of workpieces made of steel 38XTH. The following modes were used: cutting speed $V = 180$ m/min and $V = 140$ m/min, supply $S = 0.15$ mm/turn and $S = 0.3$ mm/turn, cutting depth $t = 0.5$ mm.

### Table 4. Operating capacity of carbide-tipped blades with multilayer coatings.a.

| Coating          | Durability $T$ (min) |
|------------------|----------------------|
|                  | $V = 180$ m/min, $S = 0.15$ mm/turn | $V = 140$ m/min, $S = 0.3$ mm/turn |
| TiN–NbTiAlN      | 45/63                | 46.5/75            |
| TiZrN–NbTiZrAlN  | 49/74                | 59/98.5            |

*a data in the numerator are for coatings without ILP and data in the nominator are after ILP

Study results show that the application of ILP leads to the prolongation of the durability of carbide-tipped blades with bilayer coatings by 1.4…1.7 times depending on the coating construction and the processing mode. As can be seen from data in the table 4 the greater effect in the prolongation of the durability of carbide-tipped blades is achieved when reducing the cutting speed and increasing the supply by the turn. In addition to the above, the greater efficiency has the coating TiZrN–NbTiZrAlN functional layers of which have the superior mechanical properties.

### 3. Conclusions

Study results showed the opportunity to apply ILP for improving the operating capacity of cutting tools with multilayer coatings.

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