

Functional parameters of the cutting process of the cutting tool with multilayer coatings after pulsed laser treatment

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Abstract. The paper presents the results of functional parameters of the cutting process using the multilayer coated cutting tool based on nitrides of titanium, zirconium, niobium and aluminum – TiN-TiZrN-TiZrAlN, TiN-TiZrN-TiZrNbAlN before and after the impulse laser processing. It was demonstrated that the impulse laser processing shortens the overall contact length between chips and the front surface, decreases the chips shorting coefficient, cutting force components and the heat flow capacity at the front surface. The shortening of the overall contact length gives some boost to the rate of heat flows along the front and rear surfaces. This fact decreases contact temperatures in comparison with the instrument without the pulsed laser treatment. It was demonstrated that the shortening of the overall contact length between chips and the front surface after the pulsed laser treatment adjusts temperature filed isotherms and stress isobars in the tool cutting wedge to the rear surface and the cutting edge.

1 Introduction

The working capacity improvement of the cutting tool in the modern machinery production can be achieved based on the application of hard wear-resistant coatings [1 – 5]. Whereby the greater effect will be achieved, if contact surfaces of the cutting tool are covered with multilayer coatings [3, 6, 7]. To improve the application efficiency of multilayer coatings it is possible to additionally apply the pulsed laser treatment (PLT) [7-10]. When designing multilayer coatings it is important to evaluate the impact of PLT on changing of the cutting process by the cutting tool. This research is to study functional parameters of the cutting process using the multilayer coated cutting tool after PLT.

2 Methodology of experiment

Multilayer coatings were applied at carbide blades MK8 using the machine «Bulat-6». Contact characteristics of the cutting process were determined according to the working

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procedure [11], the thermal state was evaluated according to the working procedure [12]. The temperature and stress distribution in the cutting wedge of the tool was calculated using the software application package ANSYS. To evaluate coating properties experimental researches of the thermal state of the tool cutting wedge when turning pieces made of 38XГH steel were carried out. Cutting modes: 1 mode: $V=130$ m/min, $S=0,3$ mm/turn, $t=0,75$ mm; 2 mode: $V=170$ m/min, $S=0,15$ mm/turn, $t=0,5$ mm.

3 Research results and discussion

The multilayer coatings architecture was selected taking into account their formation principle suggested in researches [3, 13]. According to this principle in case of continuous turning the coating should provide favorable conditions for the contact interaction of the processed and tooling material at the front surface which can reduce the equivalent stress in the cutting wedge of the tool and improve its shape stability. Simultaneously to keep the process of the cracks formation and their intensity mechanical properties of the coating and the level of proper compressing residual stress shall further the formation of high normal compressing stress in them during the cutting process. As illustrated in researches [5, 13] multiple-element coatings (for example three-element) based on the modified titanium nitride meet these requirements to the fullest extent. Apart from the abovementioned requirements the coating shall provide the high-strength adhesion with the tooling base which is stronger in one-element coating in comparison with multiple-element ones.

Having regard to the above said and taking into consideration the functional purpose of layers of the multiple-element coating we examined coatings TiN, TiN-TiZrN-TiZrAlN, TiN-TiZrN-TiZrNbAlN before and after the pulsed laser treatment. Coatings TiN-TiZrN-TiZrAlN, TiN-TiZrN-TiZrNbAlN were applied using titanium, zirconium, titanium alloys, aluminum and niobium cathodes. The thickness of coatings in all cases was 6 micron.

To calculate the thermal state the overall contact length between chips and the front surface C_γ , the chips shorting coefficient K_L and cutting force components P_x , P_y , P_z were observed. Results are included in the Table 1.

Table 1. The influence of the pulsed laser treatment on contact characteristics of the cutting process when turning pieces made of 38XГH steel

Coating	C_γ , mm	K_L	P_x , N	P_y , N	P_z , N
TiN	0.65/0.47	1.92/1.76	95/68	263/102	491/198
TiN+ PLT	0.58/0.33	1.76/1.55	87/61	243/87	472/183
TiN-TiZrN-TiZrAlN	0.71/0.55	1.98/1.88	101/81	272/119	508/205
TiN-TiZrN-TiZrAlN+ PLT	0.63/0.38	1.80/1.70	93/77	258/100	492/183
TiN-TiZrN-TiZrNbAlN	0.69/0.51	2.09/1.90	112/90	289/115	517/210
TiN-TiZrN-TiZrNbAlN+ PLT	0.61/0.39	1.85/1.78	101/82	277/102	496/194
Note: values of the mode 1 are the numerator and values of the mode 2 are the nominator					

It is found that when cutting under lower cutting speeds and greater feed and the cutting depth, PLT of abrasion-resistant coatings when turning pieces made of 38XГH steel shortens the contact length between chips and the front surface C_γ by 10.7-11.6%, decreases the chips shorting coefficient K_L by 8.3-11.6% and cutting force components P_x , P_y , P_z by 2.6-8.9% depending on the composition and the structure of coatings. The shortening of the overall contact length C_γ after PLT increases average normal and tangential stresses at the front surface of the cutting tool by 11.1-11.8% and by 5.7-7.7% depending on the cutting mode. When cutting at higher cutting speeds and lesser feeds and cutting depths the same changing regularities of contact characteristics of the cutting process when using PLT are observed.

To measure contact temperatures at the front and the rear surface of the tool we used the analytical solution of A.N. Reznikov. Findings of the thermal state of the tool cutting wedge are included in the Table 2.

Table 2. The influence of the pulsed laser treatment on the thermal state of the cutting tool

Coating	Q_f, W	Q_r, W	$q_f, MW/m^2$	$q_r, MW/m^2$	$T_{fm}, ^\circ C$	$T_{rm}, ^\circ C$
TiN	16.7/10.7	-2.2/-1.9	23.8/32.2	-40.9/-53.5	887/821	436/414
TiN+ PLT	15.8/10.2	-2.3/-2.3	25.7/43.3	-43.5/-64.4	875/814	407/376
TiN-TiZrN-TiZrAlN	17.3/12.2	-2.2/-2.2	23.0/31.2	-41.6/-60.8	913/885	455/425
TiN-TiZrN-TiZrAlN+ PLT	16.6/11.2	-2.3/-2.4	24.8/41.5	-43.9/-68.2	901/879	421/380
TiN-TiZrN-TiZrNbAlN	18.3/12.5	-2.4/-2.3	25.0/34.5	-45.3/-64.6	971/925	473/436
TiN-TiZrN-TiZrNbAlN+ PLT	17.6/11.6	-2.6/-2.4	27.3/41.9	-49.4/-68.8	962/911	426/405

Note: values of the mode 1 are the numerator and values of the mode 2 are the nominator

After finishing the analysis of data included in the Table 2 we can reach the conclusion that the application of PLT reduces the heat flow capacity at the front surface Q_f by 3.8-5.4% and insignificantly increases at the rear surface Q_r by 4.5-8.3%. The shortening of the contact length C_γ after PLT slightly increases the rate of heat flows along the front surface q_f and the rear surface q_r by 9.2-12.7% and by 6.4-9.1% in comparison with the tool without PLT. Changing of the heat flows capacity at the front surface Q_f and the rear surface Q_r and their rates q_f and q_r leads to changing of contact temperatures. The application of ILP leads to the decrease of contact temperatures at the front surface T_{fm} and the rear surface T_{rm} of the cutting tool by 0.9-1.4% and 6.7-9.9% in comparison with the tool without PLT. The application of coatings TiN decreases contact temperatures at the front surface T_{fm} and the rear surface T_{rm} . The application of multi-element coatings in comparison with the coating TiN increases them.

PLT of the cutting tool with coatings has an impact on temperature fields in its cutting wedge. As can be seen in Figure 1 the shortening of the overall contact length between chips and the front surface after PLT of the cutting tool with the coating TiN leads to the adjustment of temperature field isotherms to the rear surface and the decrease of the temperature flow along the front surface leads to their adjustment to the front surface.

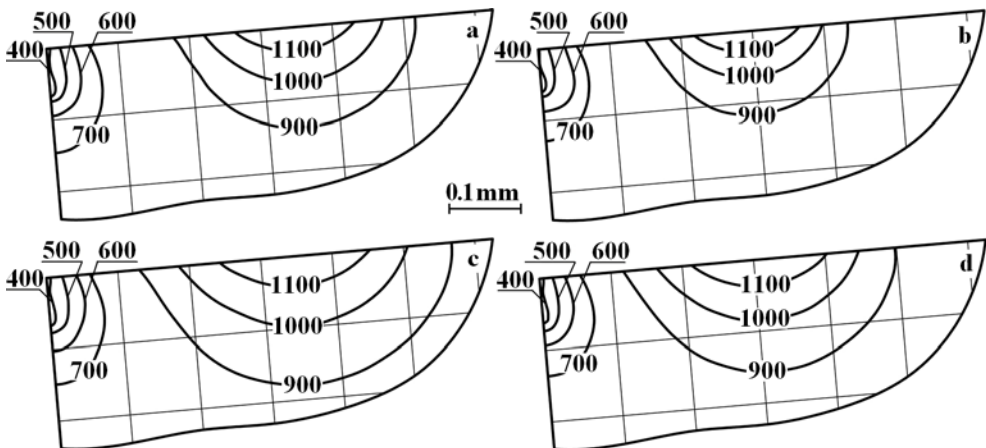


Fig. 1. The stress distribution σ_x (MPa) in the cutting wedge of the carbide tool with coatings: a – TiN; b – TiN+PLT; c – TiN-TiZrN-TiZrNbAlN; d – TiN-TiZrN-TiZrNbAlN+PLT ($V=130$ m/min, $S=0,3$ mm/turn, $t=0,75$ mm)

The extension of the overall contact length between chips and the front surface typical for the multi-element coating TiN-TiZrN-TiZrNbAlN in comparison with the coating TiN apart from the increase in capacity of the thermal source leads to the adjustment of temperature filed isotherms in the cutting wedge of the tool to the rear surface, cutting edges of the tool and in depth of the tooling base.

The stressed state of the tool cutting wedge was estimated under normal and tangential stresses at the front surface and stresses σ_x at the tool cutting wedge along the front surface.

It is found that the pulsed laser treatment leads to some increase in normal stresses. Results of stress calculations at the cutting wedge showed that stress isobars σ_x as the result of the overall contact length shortening between chips and the front surface in case of using the pulsed laser treatment are adjusted to the rear surface of the tool and their occurrence depth is decreased (Figure 2).

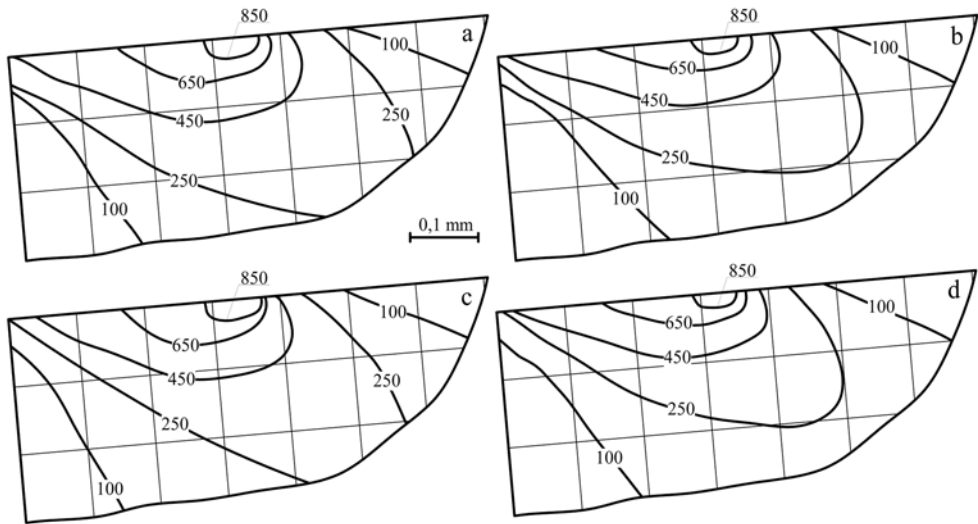


Fig. 2. The stress distribution σ_x (MPa) in the cutting wedge of the carbide tool with coatings: a – TiN; b – TiN+PLT; c – TiN-TiZrN-TiZrNbAlN; d – TiN-TiZrN-TiZrNbAlN+PLT ($V=130$ m/min, $S=0,3$ mm/turn, $t=0,75$ mm)

4 Conclusion

It is found that the application of the pulsed laser treatment changes functional parameters of the cutting process using the cutting tool with coatings. The impulse laser processing leads to the shortening of the overall contact length between chips and the front surface, the chips shortening coefficient, cutting force components and contact temperatures. The shortening of the contact length between chips and the front surface is the reason for some increase in normal and tangential stresses at the front surface and the adjustment of temperature isotherms and stress isobars at the cutting wedge to the rear surface. The analysis of research results of cutting contact characteristics and the thermal state is the basis to conclude that changing of functional parameters of the cutting process using the cutting tool with coatings after the pulsed laser treatment shall lead to the improvement of its efficiency.

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