Chapter

Main Ways to Improve Cutting Tools for Machine Wheel Tread Profile

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Abstract

This chapter considers the methods to increase the performance and reliability of the reprofile machining of the wheel tread profile. Proceeding from the fact that both in milling and turning, the cutting tool is a key element to ensure performance and reliability of the manufacturing process, the study considers the methods to increase the performance properties of cutting tools. In particular, the study includes the investigation of the following ways to improve cutting tools (carbide inserts) to machine wheel tread profile: replacement of traditional grades of WC-TiC-Co carbides with more efficient ones based on WC-TiC-TaC-Co; application of special thermally conductive pads, gaskets, and pastes to improve the distribution of heat flows in the cutting zone; and application of modern nanoscale composite multilayer coatings (NMCC). It is noted that even higher performance can be obtained by combining the above three methods, in particular, by combining application of special thermal pads and NMCC.

Keywords: reprofile machining, wheel tread profile, thermally conductive pads, nanoscale composite multilayer coatings

1. Introduction

In connection with the change in the profile geometry of the wheel tread due to mechanical wear and plastic deformations, as well as appearance of thermomechanical damages, which result from braking of the rolling stock and which occur as flat sections of cold hardening (slides) with the formation of local martensitic structures with hardness of up to 850–900 HV (white spots), there is a need for a regular reprofiling of the wheel treads. Considering the fact that Russia possesses one of the longest rail networks in the world (the second only to the USA), it is clear that the specified challenge is very comprehensive (given more than 6 million wheel sets in operation). There are two main methods of reprofiling: milling and turning. At the same time, the performance and tool life indicators of cutting tools (carbide inserts) are an important and sometimes a critical factor. Milling the profile of wheel treads is the most common process applied to machine wheel sets for locomotives and electric trains.

The existing technology for machining wheel sets on KZH-20 machines is one of the most complex and time-consuming machining operations performed in depot conditions during maintenance and current repairs of locomotives and multiple-unit and subway rolling stocks. KZH-20 is a wheel-milling machine to mill wheel sets without rolling them out from under a locomotive, manufactured at the KZTZ (Kramatorsk Heavy Duty Machine Tool Building Plant, Ukraine, see **Figure 1a**). A similar pattern to restore the profile of wheels with a special shaped milling cutter with replaceable carbide inserts, except for machines of KZH-20 type, is also implemented on machines of Simmons Machine Tool Corporation (USA) and Kawasaki Inc. (Japan). The main advantages of the above method, in comparison with turning, are as follows:

- a possibility of machining with minimum depths of cut in a single pass, which makes it possible to increase the number of possible resharpening of the wheel tread profile and, consequently, to increase the life of wheel sets;

- an increase in the cutting speed and, consequently, an increase in the machining capacity, provided by increasing the rotational speed of the milling cutter and not the wheel set;

- an increase in the tool life of the cutting tool by increasing the active length of the cutting edge in simultaneous cutting with several cutter teeth and reducing the overall heat stress of the cutting process;

- enhancement of the safety of machine tool operators due to safer and more transportable shape of chips in milling.

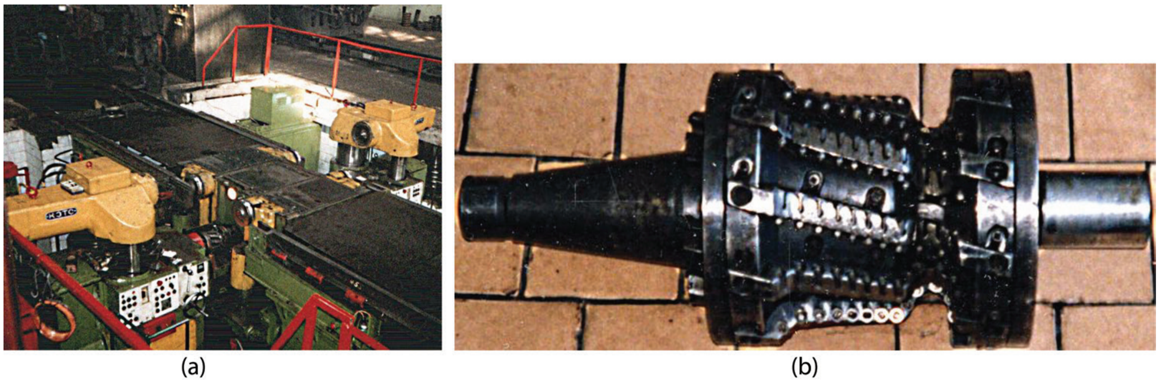
Furthermore, it was found that milling, in contrast to turning, provides practically unimpeded mechanical machining of the wheel tread profile of reinforced tires and tires with increased hardness.

Despite the above advantages, the most widespread pattern for wheel milling with shaped cylindrical cutters (see **Figure 1b**) has the following significant drawbacks:

- poor efficiency in comparison with turning (the main machining time for a single wheel set on a machine of KZH-20 type is 0.6–0.8 h on average);

- roughness of the machined surface and the accuracy of machining the wheel tread profile are related to the accuracy and quality of manufacturing and maintaining shaped milling cutters;

- high complexity of manufacturing and labor-intensive maintenance of special shaped milling cutters (auxiliary time for tool maintenance after machining each wheel set can reach 30–45 min);



(a) (b)

Figure 1.
Process of machining wheel treads on KZH-20 machines (a) and a milling cutter for wheel tread machining (b).

- need to purchase a large number of fairly expensive carbide inserts (123–125 inserts per milling cutter) with substantial consumption; and

- possibility of machining wheel sets under single profile provided by shaped cutting tools (regardless of the wheel wear degree).

The on-the-site studies found that to date, locomotive depots use various replaceable and brazed carbide inserts. The diagram to show ranges for shapes of carbide inserts used in locomotive depots in different regions of Russia is presented in **Figure 2** [1].

As can be seen from the diagram, ISO RNGN 121200 carbide inserts used in shaped milling cutters in machines of KZH-20 type are the most widely used cutting tools for mechanical machining of the wheel tread profile. With the actual distribution of average annual consumption in absolute quantitative terms, i.e., in the weight of the consumable carbide, inserts of the RNGN 121200 type gain 53.9% of the weight of the carbide consumed at locomotive and multiple-unit rolling stock repair enterprises of the JSC Russian Railways. Meanwhile, inserts of the LNMX type are also widely used for turning the railway wheel sets with rolling out from under the rolling stock on wheel-turning machines RAFAMET S.A. (Poland) Model UBB-112, and Hegenscheidt-MFD GmbH (Germany) (Model U2000-400) [1].

The process of manufacturing critical parts of railway rolling stock (turning of wheel sets, boring of wheel bands, turning of axes, etc.) is accompanied by:

- high removal of withdrawn allowance at cutting depth a_p = 5–20 mm, feed f = 0.8–1.5 mm/rev, and cutting speed v_c = 30–50 m/min,

- high variation of cutting allowance (radial runout may reach up to 15 mm),

- inclusion of nonmetallic particles with increased abrasive properties on the machined surface of forged slab [2–4].

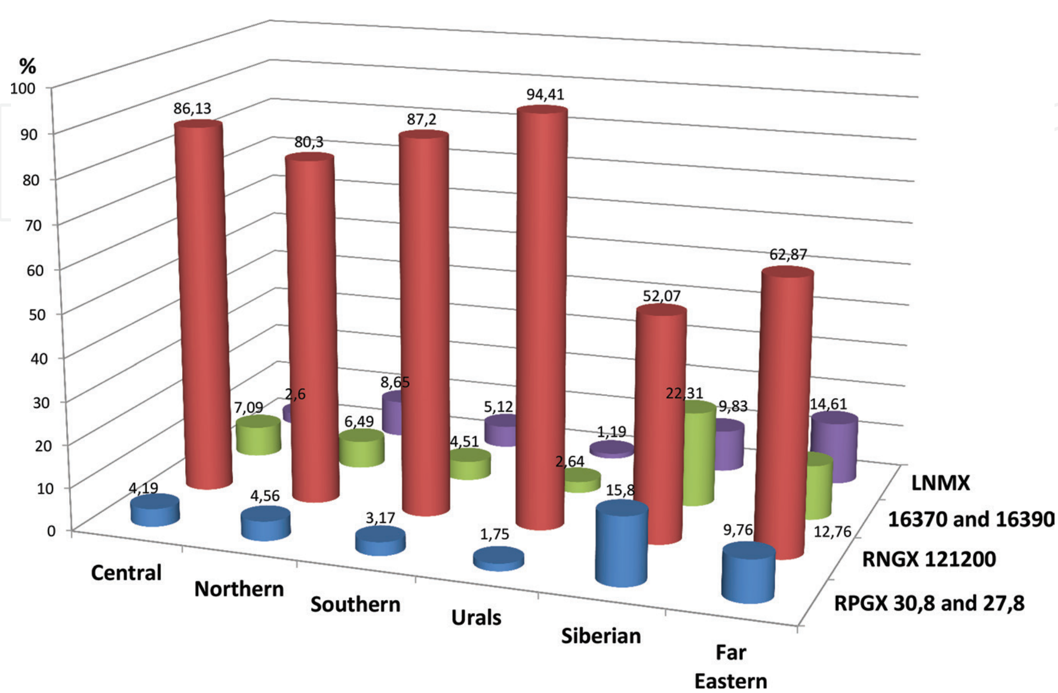


Figure 2.
Percentage distribution of shapes of carbide inserts used in locomotive depots in different regions of Russia [1].

Edge machining of workpieces under the above conditions produces elevated heating of the cutting area (up to 800–1000°C), which results in high concentration of thermal stresses directly at the contact areas of carbide inserts (for example, inserts of LNMX ISO shape) used in this process of manufacturing products for rail transport [2–7]. The studies of wear mechanisms of cutting carbide inserts with coatings of various compositions have shown [3, 9–16] that the process of wear of inserts under conditions of the high thermal stresses is accompanied by thermoplastic deformation of a cutting edge. This in turn is connected with the subsequent intense failure of coating and high adhesion and fatigue wear, which is accompanied by chipping of cutting edges or complete failure of fragile cutting part of a tool [3, 9–11, 14–16].

In this regard, the decrease in thermal stress of the cutting area by the deposition of nanoscale multilayer composite coatings (NMCCs) on the working surfaces of the tool, which reduce friction and capacity of heat sources, as well as the general improvement of the conditions of heat transfer out of the cutting area improves the tool life and the efficiency of the HPC processes. The studies of the effect of wear-resistant coatings on the thermal state of the cutting system under severe cutting conditions [11–13] have shown that they reduce thermal and mechanical loads on the tool and increase its efficiency.

The standard method for reducing thermal stress of the cutting process includes the use of cutting fluids. However, under heavy conditions of machining, the efficiency of cutting fluids decreases significantly. Besides, specialized machine equipment (including wheel turning machines and vertical turning machines), intended for manufacturing of products (wheel sets, wheel bands, axles, etc.) used in rail transport, does not use the systems of supply of liquid fluids because of high probability of their intense damage. Thus, the main objective of this study was to develop a tool system improving the efficiency of the technology of heavy machining of workpieces of rail rolling stock products by reducing the thermal stress of the cutting process and cutting tools.

2. Effect of carbide grade on machining parameters

The study investigated the inserts made of tool carbides of (WC-TiC-Co) and (WC-TiC-TaC-Co) groups (without wear-resistant coatings). The machining was conducted at standard cutting modes typical for locomotive depots: the milling cutter rotational speed was 93 rpm (at the cutting speed of 60 m/min), the working feed rate was 120–160 mm/min, and the allowance was taken in 23 passes (at the depth of cut of 23 mm per pass). Complete failure (blunting) of more permissible value observed on the tested carbide inserts due to macro- and microchipping along the periphery of the rake face was taken as a criterion for blunting of the tested carbide inserts. The tool life indicators for the tested carbide inserts were defined through the ratio between the number of wheel sets machined and a complex set of inserts made of a certain grade of carbide (considering normally worn, broken, inverted, and replaced inserts). The test results are presented in **Figure 3**.

The analysis of the obtained results shows that the modern carbides of the (WC-TiC-TaC-Co) group have wear resistance 1.5–2.0 times higher than the carbides of the (WC-TiC-Co) group. Meanwhile, the change in manufacturing conditions produces less effect on wear resistance of the carbides of the (WC-TiC-TaC-Co) group.

Following the analysis of the external wear pattern and the structure of failures of the cutting edges on the standard RNGX 121200-shaped carbide inserts, it can be noted that in milling tire steel, for the carbide inserts of the (WC-TiC-Co)

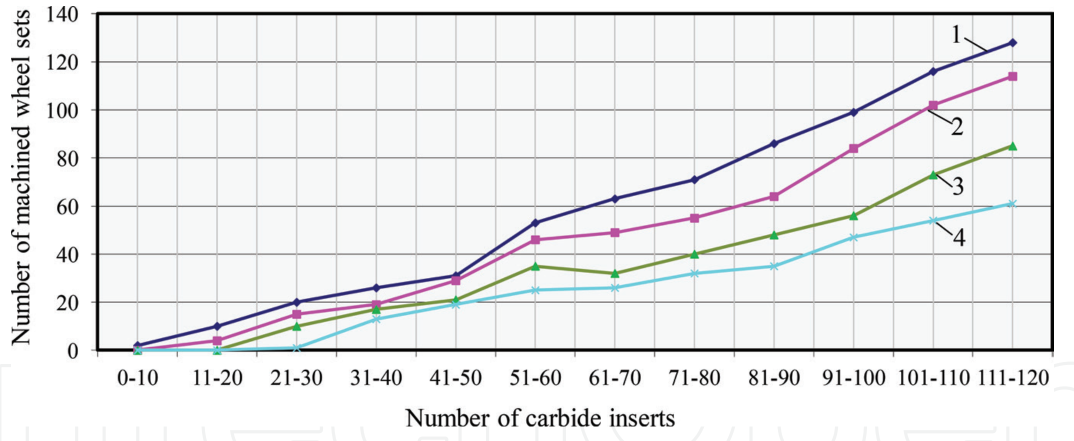


Figure 3.
Results for the tests of RNGX 121200-type carbide inserts made of various carbide grades: 1—WC-15%TiC-6%Co, 2—WC-14%TiC-8%Co, 3—T5 (WC-TiC-TaC-Co), and 4—T1 (WC-TiC-TaC-Co).

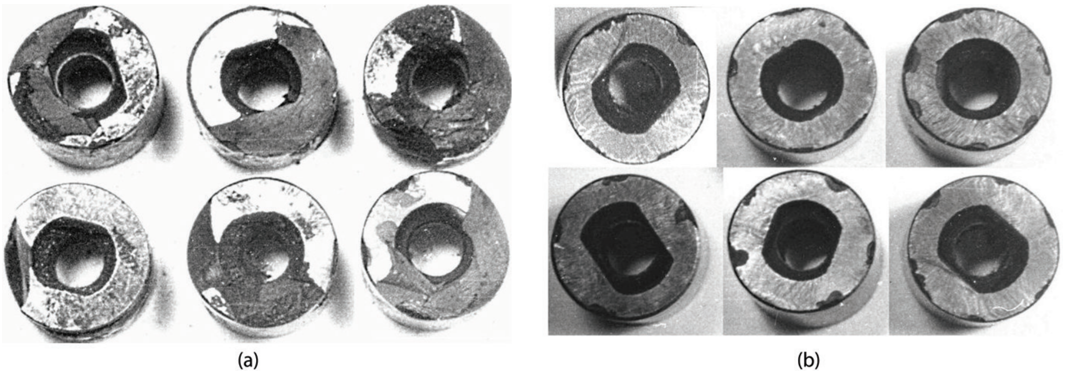


Figure 4.
Failure patterns on (WC-TiC-Co) (a) and (WC-TiC-TaC-Co) carbide inserts (b).

(78.0%WC, 14.0%TiC, 8.0%Co and 79.0%WC, 15.0%TiC, 6.0%Co) grades, currently most widely used for wheel milling, the most typical mechanism of failure is brittle fracture of the cutting edges as macrochipping on the rake and flank faces of the carbide inserts with depth over 3 mm (see **Figure 4a**). Meanwhile, for cutting inserts of the (WC-TiC-TaC-Co) carbides (T1 grade 79%WC, 4.4%TiC, 3.6%TaC, 5.8%Co and T5 grade 78.2%WC, 4.0%TiC, 5.0%TaC, 6.0%Co), failure occurs as blunting of the cutting edges due to wear and microchipping along the periphery of the rake face, due to contact-fatigue chipping with an area of 1.5–2.0 mm^2 and a depth of 0.3–0.5 mm (see **Figure 4b**). The obtained results are in good agreement with the data of production tests of various carbide grades in wheel milling of wheel sets of locomotives, electric, and subway trains on machines of the KZH-20 type [1].

The investigation of the wear rate of the carbide inserts of various carbide grades along the wheel tread profile is shown in **Figure 5**. The analysis of **Figure 4** shows that for the (WC-TiC-Co) and (WC-TiC-TaC-Co) carbides groups, the highest wear rate of the carbide inserts was registered on the area of the wheel tread until the circular cutting of ridge (with the maximum in a plane from the wheel rolling circle), with the presence of thermomechanical defects on the wheel tread (slides, white spots, chipping, etc.).

A slight increase in the wear rate was also registered at the ridge top where pointed rolling appeared. Meanwhile, it should be noted that the wear rate of carbide inserts of the (WC-TiC-TaC-Co) carbide group is more uniform in the wheel tread profile, which makes it possible to significantly reduce the tool costs by installing carbide inserts of various carbide grades in the milling cutters. Thus, the fifth-tenth cutter knife seats on the wheel rolling circle face should

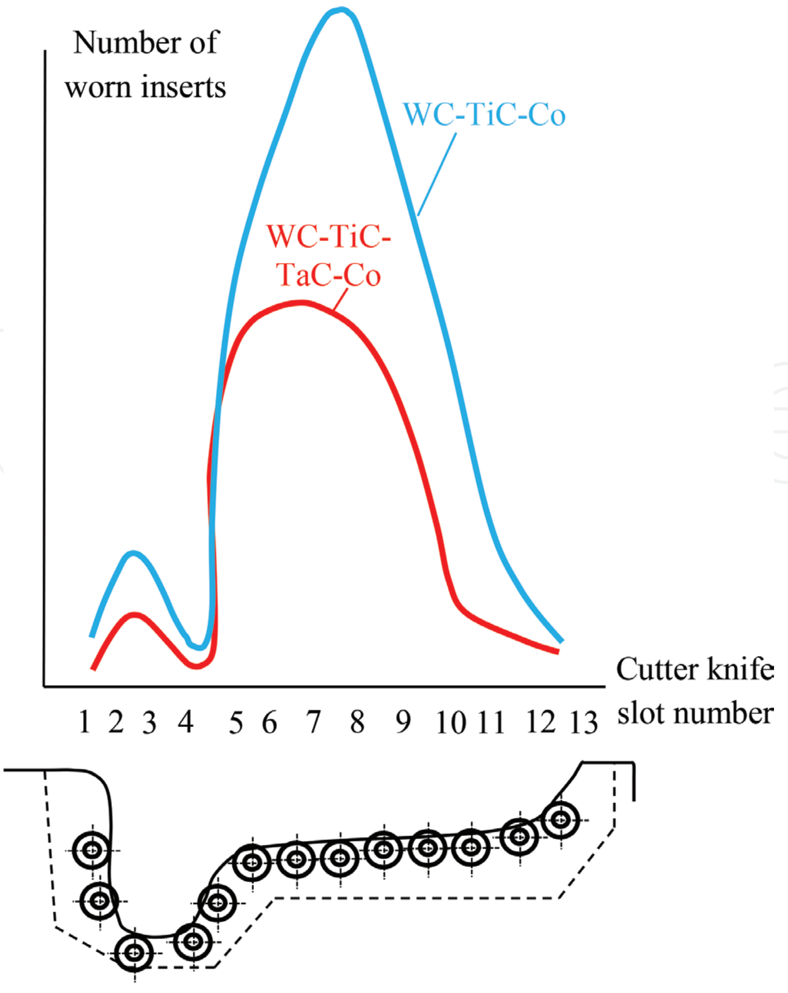


Figure 5.
Wear rates for the carbide inserts of various carbide grades depending on their placement in cutter knife seats.

bear more stable expensive carbides of the (WC-TiC-TaC-Co) group, while cheaper carbides of the (WC-TiC-Co) group can be installed to less critical sections of the profile. This technology provides a decrease in the cutting tool costs by 30% at maximum.

According to the basic principles of the theory of metal cutting, in turning and milling with carbide inserts, the changes in the pattern of the chip formation process and the temperature-stressed state on the tool cutting edges are determined by the geometric parameters of the sharpening of the cutting edges on the carbide inserts. At present, for the modern carbide inserts used to machine wheel sets of locomotives (LNMX 191940, SNMM 190616, RPUX 2709MO, and RNGX 121200 shapes), the geometry of the cutting edge sharpening is determined by two main parameters: the inclination angle of the negative reinforcing wear land (γ_F) on the rake face and the width of the negative reinforcing wear land (f).

In [17, 18], it was found that under conditions of intermittent cutting, the creation of a negative wear land on the rake face of the carbide insert increases the mechanical and heat resistance of the cutting edge. If there is a negative wear land on the cutting edge, the center of chip pressure shifts from the top of the cutting wedge and thereby increases the cutting edge strength. In this case, the angle of sharpening exceeds 90°, and the cutting wedge starts working under the conditions of compression deformation (in contrast to the bending conditions when a sharp tool is used). Moreover, an increase in the angle of sharpening improves the conditions for the heat transfer from the cutting edge to the tool body.

For carbide inserts used for wheel turning of locomotive tires (LNMX 191940, SNMM 190616, and RPUX 2709MO shapes), the maximum wear land width is limited by the start of the chip-breaking groove and is f = 0.4–0.6 mm on average. The carbide inserts of the RNGX 121200 shape (used for wheel milling) have the reinforcing wear land of f = 0.1–0.2 mm on average. The special study to determine the effect of the width of the reinforcing wear land f on the tool life of cutting tools in machining the tire steel showed (see **Figure 6**) that regardless of the tool material properties, a reduction in the wear land width led to a significant decline in the tool life indicator. For example, for inserts made of the (WC-TiC-TaC-Co) carbides with high hardness of carbide matrix and the (WC-TiC-Co) carbides with high brittleness of carbide matrix, a reduction of the reinforcing wear land by two times led to a decrease in the tool life indicators for the inserts on average by 45–55% and 80–90%, respectively. The analysis of the wear patterns on the inserts showed the presence of considerable plastic deformation of the cutting edge, while for the (WC-TiC-Co) carbides, in the area of maximum wear of the carbide insert cutting edge, there were formation centers of microcracks, chipping, and brittle fracture.

According to the data of [18], finishing-reinforcing machining by the method of cutting edge rounding makes it possible to achieve an increase in the depth of penetration of residual compressive stresses with simultaneous reduction of their gradient in a thin surface layer; i.e., it leads to the creation of a favorable profile of the residual compressive stresses in the near-surface layer of the insert. Meanwhile, during cutting, a tip of the cutting wedge will be under the action of compressive rather than tensile stresses, like in cutting with a sharp cutting edge, and smooth rounding of the edges ensures no voltage concentrators [17]. The production experimental tests conducted in wheel milling of wheel sets of locomotives and subway trains on machines of the KZH-20 type showed that the use of the inserts of the RNGX 121200 shape from the (WC-TiC-Co) and (WC-TiC-TaC-Co) carbide groups with a radius of rounding r = 0.06–0.08 mm increases the tool life indicators by 30 and 25%, respectively, with a general reduction in the number of large chipping and chipping of the cutting edges, as compared to the inserts with the width of the sharpened negative wear land of 0.1–0.2 mm.

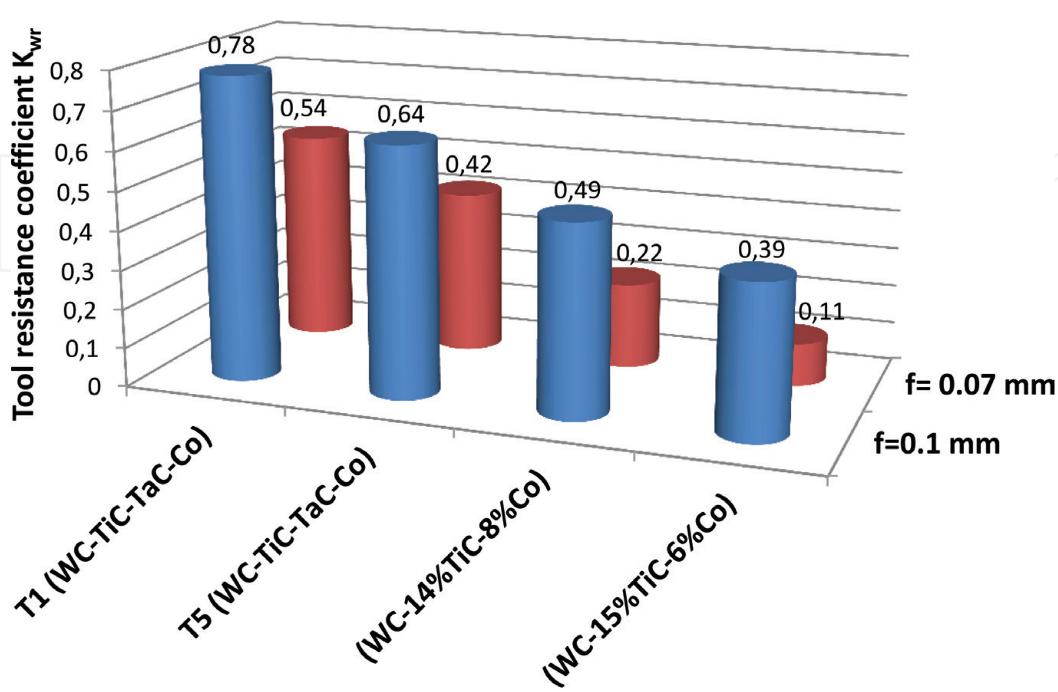


Figure 6.
Relation between the width of the reinforcing wear land f and the tool resistance of the cutting tools made of various carbide grades in machining the tire steel, where K_{wr} is tool resistance coefficient, at f = 0.15 mm, K_{wr} = 1.0.

3. Application of thermal conductive paste and pads in combination with modifying coatings

Along with the inserts of the RNGX 121200 shape, the inserts of the LNMX 301940 shape are also actively used.

The study of the process of wearing of cutting tool equipped with carbide inserts in machining wheel pair contour showed that wearing is accompanied with ductile deformation of cutting wedge of carbide tool followed by brittle fracture (**Figure 7**).

The study mainly focused on testing carbide inserts, which were mounted in tool holders of the cutting tool assemblies. The selection of the shapes of two-way inserts was justified by the extensive use of such inserts in machining rail rolling stock products. Because of large rake angles (γ = 12–15°) and wide chip-breaking grooves, at rake face of carbide inserts (width 2.5–3.5 mm), large air cavities are formed in the contact area of bearing surfaces of the inserts and the tool holder, and the total area of their actual contact can reach up to 50–65% of the total contact area. The above fact results in significant deterioration of heat transfer from carbide insert to holder body, which is a massive heat absorber, since the air thermal conductivity is 3000 times lower than the thermal conductivity of metal of the tool holder (**Figure 8**). With this in mind, during the development of a tool system with improved heat transfer from carbide insert to bearing surface of tool holder, elastic pads of ceramic-polymeric sheet reinforced material with high thermal conductivity were mounted on. In shape and thickness, the above elastic pads corresponded to the sizes of the chip-breaking grooves of carbide inserts [8]. The used ceramic-polymer pads are characterized by high elasticity (at least 50%) and thermal conductivity of about 0.8–1.4 W/(m K), which provided a significant increase in heat transfer along the entire bearing surface of the insert by reducing air gaps between bearing surfaces of the carbide insert and the tool holder (**Figure 8b**). Due to fiber glass reinforcement, ceramic-polymer pads withstand compression of up to 40 MPa, and that guarantees reliable mounting of carbide insert. With the change of bearing surface of carbide insert, when the previous bearing surface of the insert

Figure 7.
Chipping on the cutting insert of LNMX 301940 shape on the rake face of carbide (14%TiC, 78%WC, 8%Co) with nanostructured multilayered composite coating (NMCC) Ti-TiN-TiAlN in machining of running surface of wheel pair with a_p = 6.0 mm, f = 1.2 mm, and v_c = 70 m/min.

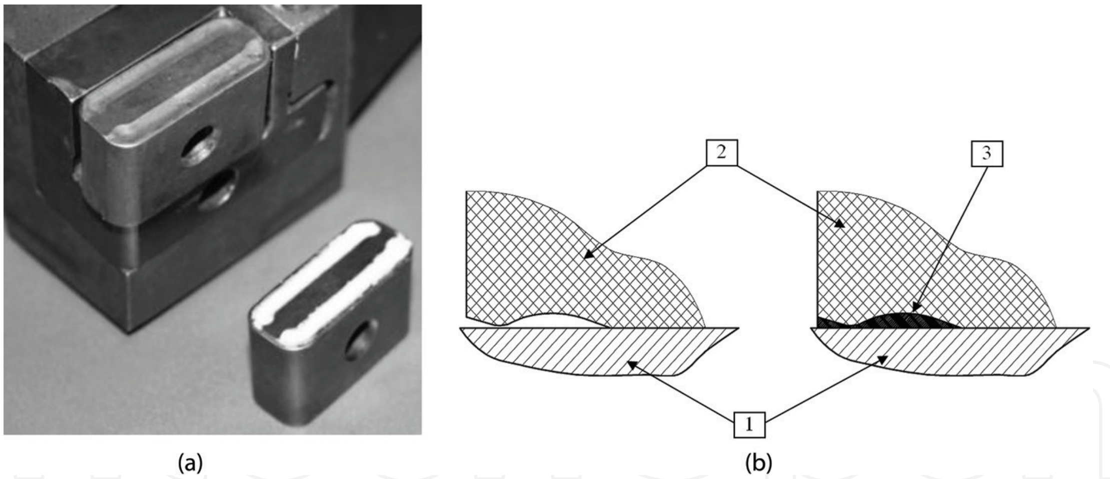


Figure 8.
(a) General view of the insert, and (b) contact of bearing surfaces of holder and cutting insert: 1—holder, 2—carbide insert, and 3—thermal pad.

became the rake face, the remains of the pads appearing in the cutting area were easily removed by chips cutoff.

4. Development of the system of increasing thermal conductivity of cemented carbide

It is known that the contact area in all friction pairs is determined not by the nominal and by the actual contact area, which is the total area of the contacting asperities of microroughness of friction pair and which comprises some percentages of the nominal contact area [8]. The air areas (pockets) are formed in places with absence of contact. The thermal conductivity of air is 3500 times lower than that of metals used in composite cutters. Therefore, the border between the contact surfaces of cutting insert and tool holder has high thermal resistance, and that greatly deteriorates the conditions of heat transfer into the tool.

Reduction of the thermal resistance in the narrow area of contact supporting surfaces is proposed by use of thermally-conductive interface with increased thermal conductivity. The specified interface formed by special thermally-conductive paste which thin layer is located between the contacting surfaces of tool holder and carbide cutting insert (**Figure 9**). Paste AlSink-3 on the basis of a mixture of oxides of aluminum and zinc together with a silicon organic solvent.

To ensure normal heat transfer, all air should be eliminated from gaps by special elastic thermally conductive composition with much higher thermal conductivity. However, in any case, the thermal properties of the best thermally conductive

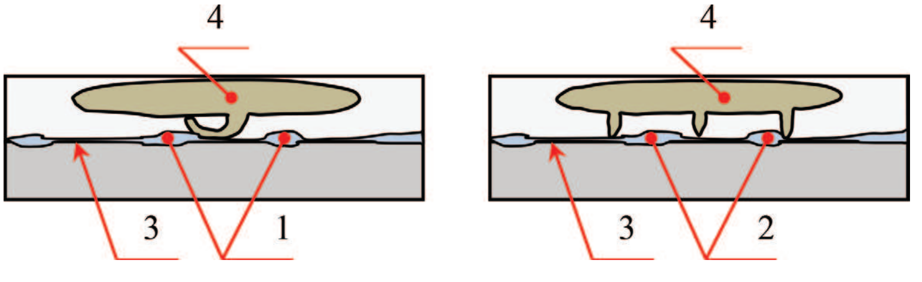


Figure 9.
Example of supporting surfaces of the cutting insert and tool holder [2]: 1—air gap clearance, 2—thermally conductive paste, 3—supporting surfaces of the carbide inserts and tool holder, and 4—heat flow.

pastes are lower than that of metals, and therefore, the quality of the mating surfaces and the thickness of the layer of thermally conductive paste are critical.

The thickness of paste at the point of contact shall not exceed the value of roughness on the mating components; and the paste should be applied with even layer to the degreased surface and smeared for guaranteed filling of all surface irregularities.

One of the main advantages of the presented method to reduce thermal stress in the cutting zone through removing heat from the cutting insert to the tool holder is its low cost and no need to use complicated equipment. In the process of the tool operation, the thermally conductive interface does not require frequent replacement, since it is sufficient to form it for the whole lifetime of cutting insert, and it should be replaced only with the dismantling and replacement of worn-out cutting insert. However, prior to the formation of a new layer of thermally conductive interface, the old paste should be removed with a detergent, and the surfaces should be completely degreased and dried. The above shows the great technological effectiveness of use of thermally conductive paste in production environment [2]. The studies have shown that the use of thermally conductive paste in composite cutter improves heat transfer from the cutting zone and reduces the thermal stress of tool cutting wedge. This greatly increases the efficiency of the cutting tool during wheel turning.

5. Deposition of nanoscale composite multilayer coatings (NMCC)

Nanoscale composite multilayer coatings were deposited on carbide inserts using filtered cathodic vacuum arc deposition (FCVAD) with the vacuum-arc unit VIT-2 [9, 10, 12, 13, 19]. The study used a three-component nanoscale composite multilayer coatings (NMCC) system, comprising outer (wear-resistant) layer, intermediate layer, and adhesive layer. The developed three-component NMCCs meet at best the dual nature of coatings as an intermediate process medium between the tool material and the material being machined. The coating should at the same time increase the physical and mechanical properties of the cutting tool (hardness, heat resistance, wear resistance) and reduce thermal and mechanical effect on the contact pads, resulting in their wear. The analysis of the influence of the synthesis process parameters on various properties of composite coatings (e.g., Ti-TiN-TiCrAlN) has shown that the most important parameters are as follows: current of titanium cathode arc I_{Ti}., nitrogen pressure in vacuum chamber p_N, and bias potential on the substrate (tool) during condensation of wear-resistant layer U_k. These parameters were taken as major ones for the deposition of NMCCs.

The investigation into the microstructure of NMCCs was carried out on a Jeol electron scanning microscope JSM-6480LV. The macroscopic properties of NMCCs, such as thickness, hardness, friction coefficient, and strength of coating adhesion to substrate, were determined by standard methods.

Using a portable computer tomography UPUC-2000, the temperature gradient of the developed tool system was obtained as shown in **Figure 10**. Here, a reduction in the intensity of the heat source in the NMCC can be seen with a better heat dissipation through the thermal pad.

The certification (industrial confirmation) tests of the developed tool system were carried out in turning of running surfaces of wheel sets. The tests were conducted with carbide inserts (14% TiC, 8% Co, 78% WC) without coatings, and with inserts coated with the developed Ti-TiN-TiCrAlN NMCCs. Tests were performed on the heavy machines of Rafamet UCB-125 bUBB112, the criterion of insert failure was flank wear VB_{max} = 0.5 mm.

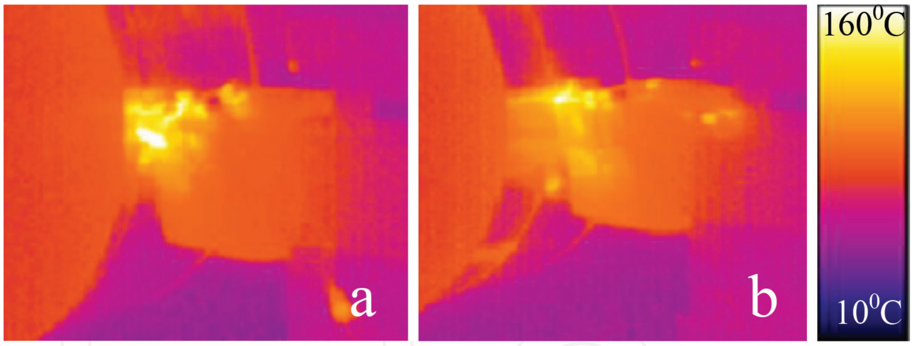


Figure 10.
A general view of heat distribution in the cutting zone at cutting speed v_c = 40 m/min, a_p = 3 mm, f = 1.0 mm/rev [19]; a—commercial carbide inserts with multilayer coatings of modern generation and b—newly developed tool system.

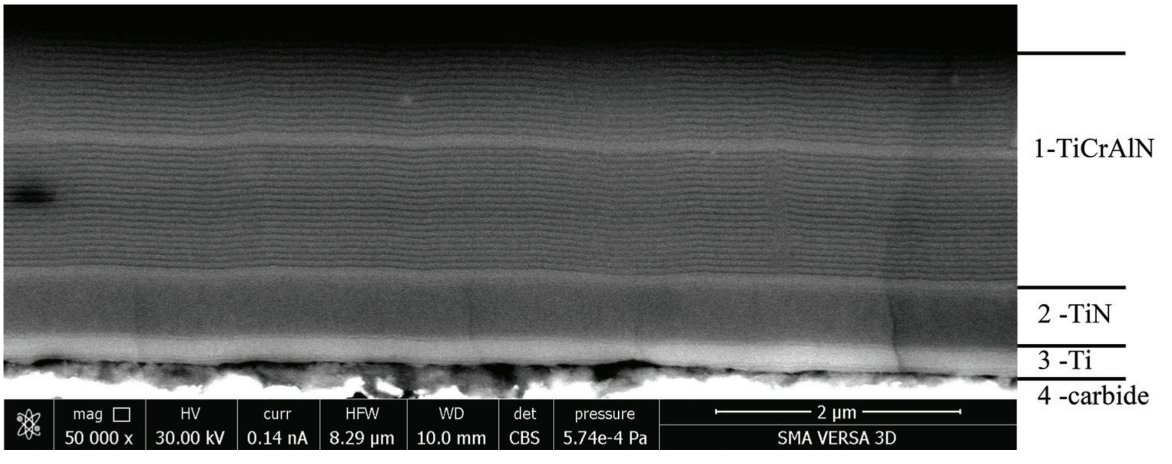


Figure 11.
SEM section image of (WC-TiC-Co) carbide insert with NMCC based on Ti-TiN-TiCrAlN [19]: 1—TiCrAlN wear-resistant layer, 2—TiN intermediate (transition) layer, 3—Ti adhesive sublayer, and 4—carbide substrate (14% TiC, 8% Co, and 78% WC).

The properties of NMCCs base on the Ti-TiN-TiCrAlN system are illustrated in **Figure 11** and in **Table 1**.

The Ti-TiN-TiCrAlN multilayer composite coating was deposited with the following process parameters: I_{Ti} = 104 A, p_N = 0.24 Pa, U_C = 42 V, and deposition time = 45 min. The analysis of the data presented in **Table 1** shows the following.

Wear-resistant layer of TiCrAlN of the tested NMCC based on the Ti-TiN-TiCrAlN system has a super multilayer architecture with sublayer thicknesses of about 15–25 nm, a columnar grain structure oriented perpendicular to the plane of TiN underlayer, in which grain sizes do not exceed 5–15 nm. The thicknesses of the sublayers of the intermediate TiN layer were also about 15–25 nm, and the sizes of its grains, as well as of grains of adhesion sublayers, did not exceed 5–15 nm. The results obtained allow classifying the multilayer composite coating of Ti-TiN-TiCrAlN as a nanocoating. The use of a vacuum arc system with filtration of vapor-ion flow FCVAD provided a significant increase in the quality of the surface of NMCC and almost a complete absence of droplets (which are dangerous defects) on the surface of the coating. This study revealed a high efficiency of the developed tool system based on double-sided (WC-TiC-Co) carbide inserts (see **Figure 8a**), with dense contact with tool holder, provided by elastic pads of reinforced ceramic-polymer material with high thermal conductivity. Tool life and coefficient of tool life variation for the developed tool system were compared with commercial tool equipped with carbide inserts with multilayer coating of the modern generation. The tool life coefficient TTL (**Figure 12**) was determined as the ratio of tool life

Material	Phase composition	Grain size, [nm]	Thickness of coating h_c, layers h_L, sublayers h_{sl} [nm]	HV, [GPa]	F_m^*, [N]	ΔP, [mg/cm^2]
NMCC	Ti-TiN-TiCrAlN	5–15	h_C = 4000	25.0–35.0	120–130	14.7
Layer (1)	$Ti_{0.45}Cr_{0.35}Al_{0.2}N$	5–15	h_l = 2000; h_{sl} = 15–25	35.0–40.0	—	—
Layer (2)	TiN	5–15	$h_{l,}$ = 1500 h_{sl}, = 15–25	23.0–30.0	—	—
Layer (3)	Ti	5–15	h_l = 500	—	—	—

Table 1.
Test results of NMCC parameters (on the example of Ti-TiN-TiCrAlN system).

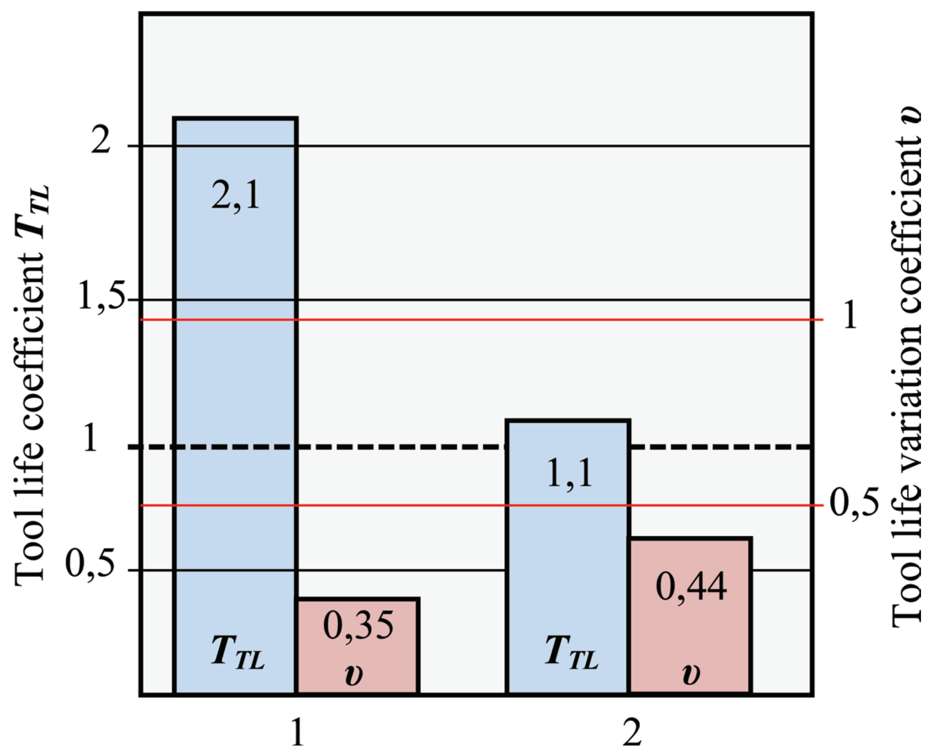


Figure 12.
Results of comparison of tool life coefficient TTL and tool life variation υ of the developed tool system with commercial carbide inserts with coatings in rough turning of wheel sets [19]; process parameters: v_c = 50 m/min, f = 1.2 mm/rev, and a_p = 6.0 mm. 1—developed tool system and 2—commercial carbide inserts with modern multilayer coatings.

of coated insert to tool life of an uncoated insert; and the tool life variation υ was determined as the ratio of standard deviation of tool life to its arithmetic mean value. The study showed that the developed tool system based on inserts of carbide (WC-TiC-Co) with Ti-TiN-TiCrAlN NMCCs outperformed the commercial version of carbide insert with coating of the modern generation during hard reconstruction turning of running surfaces of wheel sets (**Figure 12**). In particular, the study has shown not only the higher average tool life value (88.1 min) and tool life coefficient TTL (2.1), but also the decrease in the coefficient of tool life variation (υ = 0.355). The latter indicates the significant increase in the reliability of the developed tool system for rough turning of wheel sets.

The results of production tests of carbide cutting tools with the use of thermal pads made of NOMAKON KPTD-2 are shown in **Table 2**. The analysis of the results of the production tests also shows the increase in tool life in the developed tool system.

Part to machine	Machining type	Insert shape	Cutting parameters			Tool life improvement (%)
			a_p, mm	f, mm/rev	v_c, m/min	
New shaft of freight cars	*A*	SNMG 250724	5–15	0.9–1.1	80–100	20
Wheel sets with new wheel bands	*B*	LNMX 301940	6–8	1.1–1.3	40–50	16

A—turning-and-contouring machining of surface of neck, wheel seat and middle part of axes and B—turning-and-contouring machining along outer diameter.

Table 2.
Results of industrial tests of 14% TiC; 8% Co; 78% WC carbide inserts with NMCC and thermal pad.

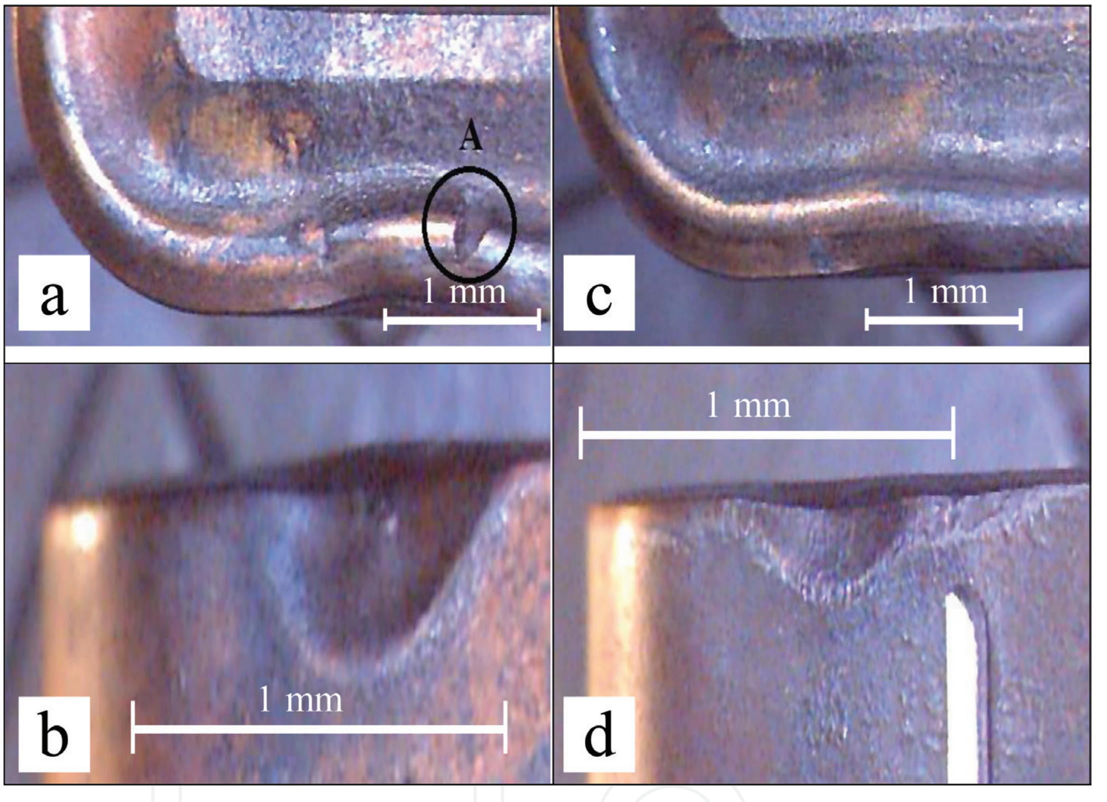


Figure 13.
Wear of carbide insert LNUX 301940 [19]: (a, c) rake, (b, d) flank, (a, b) without thermal pad, intensive plastic deformation of cutting edge, leading to cracking and brittle fracture—(zone A). (c, d) with thermal pad, less pronounced plastic deformation, mainly flank wear [2].

The effect of applied thermal pad on the nature of the wear of rake and flank faces is illustrated in **Figure 13**.

Additional tests were done with inserts AT15S carbide type LNUX 301940. These carbides were composed of 86.5% WC, 2.5% TiC, 3.6% TaC, 1.5% NbC, 5.5% Co. These tests showed a significant effect of the applied thermal pad, and the NMCC in turning of wheel sets. This is depicted in **Figure 14**.

1—uncoated inserts without thermal pad, 2—uncoated inserts with thermal pad, 3—inserts with TiN (PVD) coating, without thermal pad, 4—inserts with TiN (PVD) coating, with thermal pad, 5—inserts with Ti-TiN-TiCrAlN NMCC, without thermal pad, and 6—inserts with Ti-TiN-TiCrAlN NMCC, with thermal pad.

The studies were carried out under turning of running surface of wheel pair with v_c = 50 m/min, f = 1.2 mm/rev, and a_p = 6.0 mm (presented in **Figure 15**).

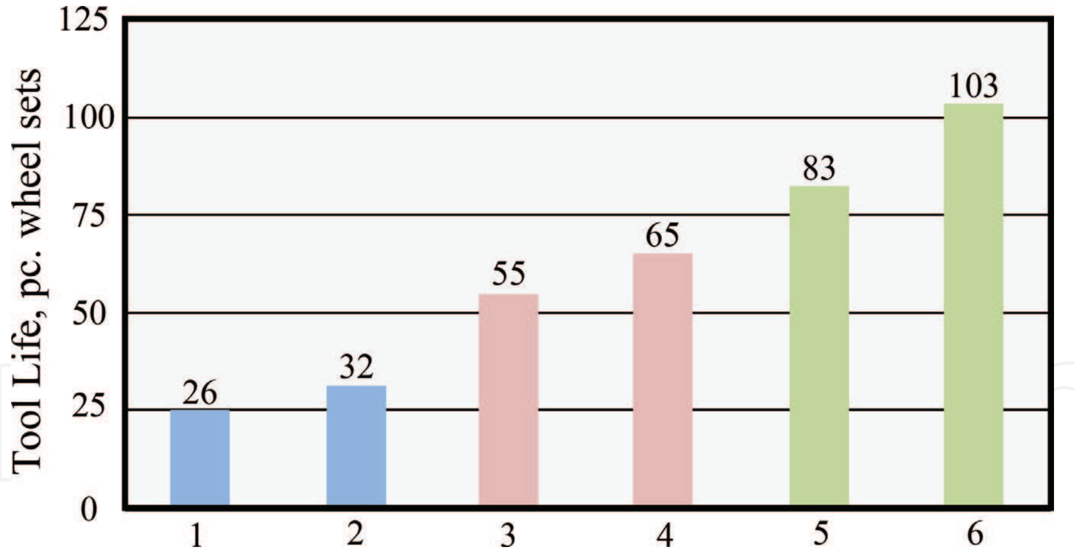


Figure 14.
Average tool life of one insert with eight cutting edges for carbide inserts type LNUX 301940, carbide AT15S [19] (process parameters: v = 50 m/min, f and = 1.2 mm/rev, and ap = 6.0 mm) [2].

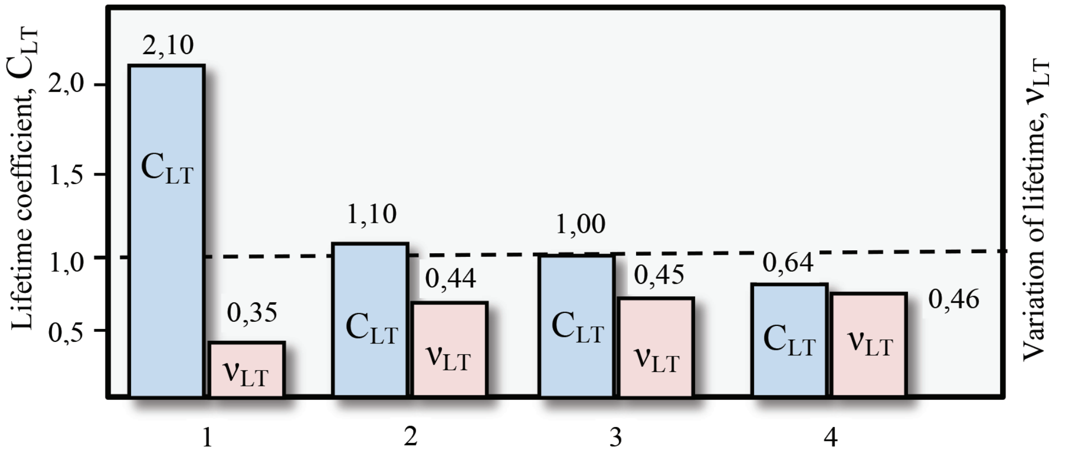


Figure 15.
Results of comparative tool life tests CLT and variations of tool life υ_{LT} of the carbide inserts with standard coating of leading manufacturers (2–4) and the inserts made of carbide WC-TiC-Co with high thermal conductivity and developed NMCC (1) under rough turning of railway wheel sets [19]. 1—inserts with high thermal conductivity and developed Ti-TiN-TiAlN (technology FCVAD), 2—inserts with standard multilayered composite coating TiN-TiCN-TiN (CVD, manufacture 2), 3—inserts with standard coating TiCN-Al_2O_3-TiN (HT-CVD, manufacture 3), and 4—inserts with standard coating TiC-TiCN-TiN (HT-CVD, manufacture 4).

Evaluation of the working efficiency of cutting inserts was performed by the coefficient of wear resistance relative to the reference inserts of WC-TiC-Co without coating, in which wear resistance was taken as a unit under tests with the specified machining modes with limited flank wear land HV = 0.5 mm. The comparison was made with carbide inserts of best manufacturers with standard coatings and inserts with generated interface improving the thermal conductivity of the cemented carbide and developed NMCC.

The analysis of the studies presented in **Figure 15** allows noting the following. The analysis proved high efficiency of carbide cutting inserts in the form LNMX made of carbide grade WC-TiC-Co with thermally conductive interface and developed NMCC on the basis of a three-layer system of Ti-TiN-(Ti,Al)N in comparison with standard analogues under severe reductive turning of running surface of wheel pairs. In particular, the analysis notes not only the higher average value of lifetime of carbide tool (88.1 min) and the lifetime coefficient CLT(2.10), but also reduction of the factor of a variation of lifetime (υ_{LT} = 0.35). This indicates the significant increase in working efficiency and reliability of the tool equipped with tangential carbide inserts LNMX made of WC-TiC-Co with enhanced thermal conductivity of carbide with elaborated NMCC on the basis of the system Ti-TiN-TiAlN developed for reductive turning (roughing) of hardened (hard-drawn) surface of wheel pairs [2].

6. Conclusion

Reprofiling of the wheel tread profile is an important and large-scale manufacturing challenge. Both in milling and turning, the cutting tool is a key element ensuring efficiency and reliability of manufacturing process. The improvement of the metal cutting tools can be carried out in several directions at once, as follows:

- replacement of traditional grades of WC-TiC-Co carbides with more efficient ones based on WC-TiC-TaC-Co,
- application of special thermally conductive pads, gaskets and pastes to improve the distribution of heat flows in the cutting zone, and
- application of modern nanoscale composite multilayer coatings (NMCC).

Even higher performance can be obtained by combining the above three methods, in particular, by combining application of special thermal pads and NMCC.

The analysis of the results of laboratory and industrial tests has shown that the use of the developed tool system, including carbide inserts with NMCCs and set of structures for mounting the insert on the tool holder, including high heat-conducting ceramic-polymer pads with high thermal conductivity increased the actual contact bearing surface between the carbide insert and the holder intensifies the effective heat transfer along bearing surface of the insert. The combined effect of the increase in heat transfer and reduction of frictional heat sources due to application of the developed NMCCs showed a significant reduction of the thermal stress of the cutting system during roughing of rolling stock products. This new approach has positively transformed the character of the tool wear, and brought in an improvement of the tool life up to four times by increasing the reliability of the tool due to reduction of the coefficient of tool life variation.

The technology of modifying treatment of carbide tools was developed, which increases wear resistance of tools to high-temperature creep and tool failure because of ductile fracture of its cutting part. That is achieved by introducing between the supporting surfaces of tool holder and cutting carbide inserts a special paste (AlSink-3) on the basis of a mixture of oxides of aluminum and zinc with an silicon organic solvent that improves thermal conductivity of cemented carbide by filling air gaps between the supporting surfaces and by application of nanodispersed multilayered composite coatings, which reduce contact stresses and power of friction heat sources under severe reprofiling machining of hardened running surface of rail wheel pairs. It was found out that wear resistance of tools made of carbide grade (WC-TiC-Co) with thermally conductive interface and nanodispersed multilayered composite coating on the basis of Ti-TiN-TiAlN was up to two times higher than wear resistance of the inserts with standard coatings.

Acknowledgements

This research was financed by the Ministry of Education and Science of the Russian Federation (Leading researchers, project 16.9575.2017/6.7).

Conflict of interest

The authors declare no conflict of interest.

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