REGULATION OF CUTTING TOOL DURABILITY AND THE QUALITY OF TRANSPORT VEHICLE PARTS MACHINING

[1]Yuriy P. Rakunov, **[2]Valeriy V. Abramov**

[1]Ph.D. of Technical Science, Associate professor, E-mail: Rakunov 1991@mail.ru
[2]Doctor of Technical Science, Professor, E-mail: valabramov @rambler.ru

Federal state budget educational institution of higher education «MOSCOW STATE UNIVERSITY OF CIVIL ENGINEERING (NATIONAL RESEARCH UNIVERSITY)", Yaroslavl highway 26, Moscow, 129337, Russia

The objective of the study is to develop methodology for selecting the criteria of the cutting tool durability and to assign cutting conditions providing information about the dimensional durability and area of typical size surface under machining of the specified quality and accuracy of transport vehicles parts machining. The patented universal cutting tools that allow using the industrial methods for their finishing per their front and rear edges providing the cutting edge necessary corner radius (ρ) of the cutting wedge (CW) have been considered. The literary review has been made and the impact of ρ on cutting tools life up to limiting wear and failure as well as the face mills performance effect in the steel and cast-iron machining is shown. The optimum values of ρ for face mills and cutting tools from different brands of solid alloys were found and provided in the view of tests results of CW and holders various typical sizes of cutting tools. The kinetics change of ρ radius from operation time and its impact on the cutting tools performance has been considered. The dependence of optimal and maximum permissible ρ on cut thickness has been determined and the recommendations for preliminary and finished machining by cutting tools and holders of various typical sizes were formulated.
Keywords: criteria of durability, universal cutting tools, corner radius, cutting tool life, operating capacity of milling cutter, thickness of cut, kinetics change of ρ, performance, technical recommendations

Introduction

According to the results of research and development, the type and design of universal (outside and boring), specialized (grooving and thread turning), as well as special cutting tools with mechanical fixture of cutting tips have been developed. The cutting point geometry has been optimized in order to enhance the tool technological capabilities and implement the principle of multiple resharpening (sharpening and finishing) resulting in reduction 2.5 ÷ 3 times the cost of tool life as the main economic criterion for cutting tool (CT) effectiveness of use. Universal cutting tools (UCT) increases the utilization factor of the solid alloy (up to 80%) for resharpening by reducing its consumption and time of each resharpening under condition of 100% recovery of the original cutting properties of the tool [1, 2, 4, 6]. The universal CT and improvement in the technology of cutter made it possible to develop a technology for their manufacture using a group-based multiposition fittings for general-purpose, tool-grinding, and abrading equipment [4,7].

The basis for automating the machining operation of precision parts of transport vehicles is the consistent quality of their working surfaces and, above all, the accuracy indices of: form deviations in the transverse and longitudinal directions, surfaces roughness and waviness. The task of creating new high-performance, high-speed processes and CNC machines, as well as the operation of existing machines in the context of automated precision transport engineering, requires knowledge of valid patterns of CT's wear and dimensional stability.

In connection with the necessity of production processes automation and the extensive use of new materials being machined and tool materials, the problem of CT study and increase in the dimensional stability become a priority among the most important tasks of modern engineering.

This article contains the methodology how to select criteria of cutting tool durability and to assign cutting conditions providing information about the dimensional stability and area of typical size surfaces under machining with specified quality and accuracy. With decreasing allowance for machining (cut cross-section) at the final stage of processing, when microscopic and micron-accurate is achieved, the cutting force is reduced so that it is possible to expect a non-linear technological system to occur because the organizing effect of the cutting force has already been lost. For example, such state of the system occurs at the beginning and throughout grinding sparkout. The new state of the system is still poorly understood [1, 8, 9]. However, this is the state that determines the quality of the part. The principles of synergetics can be used in full scope to investigate the behaviour of these systems. Synergetics is the science of self-organizing systems.

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Materials and methods

In order to analyze the tool efficiency in automated production, the dimensional stability is decisive [2, 4, 10-14]. The following dimensional stability characteristics are the most objective: rate of dimensional wear, relative fretting wear and specific dimensional stability. The analytical method shows conclusively that during synergistic approach, h_{op} and T_{yp} are the universal characteristics of dimensional stability, because they allow for objective comparison of the cutting properties of the various tool materials in any combinations of cutting condition (CC): cutting speeds and feeds, and different criteria of CT edges dulling (Table 1).

Table 1

Criteria for CT dimensional stability

Sl. Nos	Criteria	Designation or Formula	Factors limiting the possibility of using the criterion: Cutting speed, V_p, m/min	Feed S_o, mm/rev.	Size of surface under machining	Wear of tool h_r or h_3	The possibility of using for the calculation of machining accuracy
1.	Running time before tool replacement, min.	T	+	+	–	+	No
2.	Number of parts machined, pcs	N	–	–	+	+	No
3.	Cutting path length, m	l = VT	–	+	–	+	No
4.	Area of the machined surface, dm^2	$F = 0{,}1 \cdot V \cdot T \cdot S_o$	–	–	–	+	No
5.	Linear relative wear, μm/km	$h_{lr} = [(h_r - h_H) \cdot 10^3]: :(l - l_H)$	–	+	–	–	No
6.	Dimensional wear rate, μm/min	$V_h = (V \cdot h_{од}): :10^3$	–	–	–	–	Yes
7.	Relative surface wear, $\mu m/dm^2$	$h_{rs} = [(h_r - h_H) \cdot 10]: :(l - l_H) \cdot S_o$	–	–	–	–	Yes
8.	Specific dimensional stability, $dm^2/\mu m$	$T_{sd} = (l - l_H) \cdot S_o : : [(h_r - h_H) \cdot 10]$	–	–	–	–	Yes

Note: The sign (+) means that by comparison of CT or CC versions according to this criterion, the equality of limiting factors must be followed.

Based on the Table 1 analysis, the decision was made to manage the process of finishing turning by means of tool life graphs plotting in coordinates of Δρ [μm]- F [dm^2], i.e. dependence of the dimensional wear $\Delta\rho = f(F)$ on the area of surface machining of the specified quality. Here there is a synergy of cutting conditions effect to wear and the cutting wedge wear in its turn effects to the finish surface quality [1-4].

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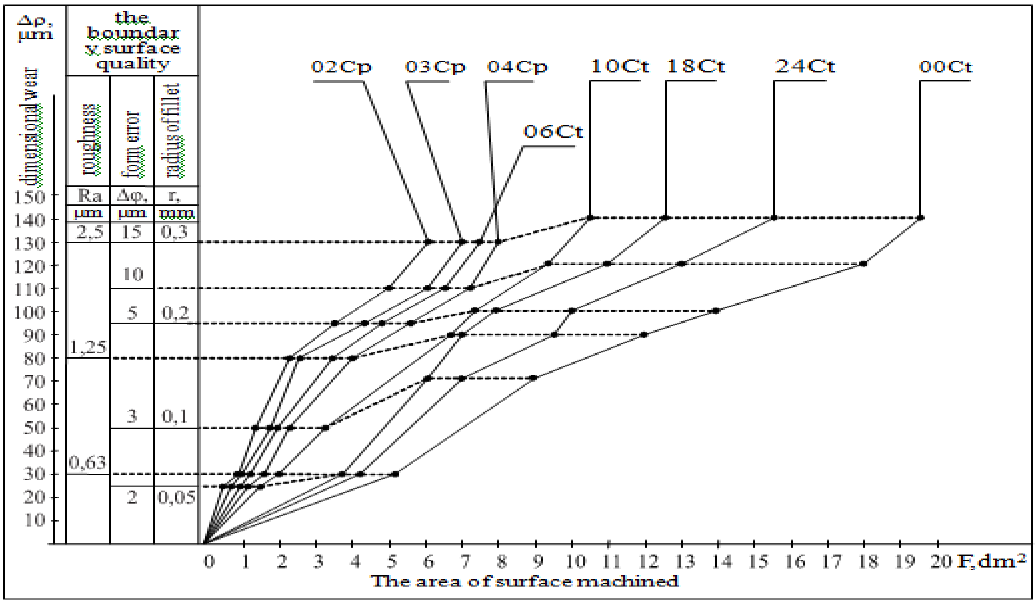

Figure 1. Graphs of the synergistic effects of dimensional wear and its corresponding quality indeces to the area of the machined surface during finishing (fine) lathe machining by means of UCT.

The following figure shows dependence of the machined surface quality and dimensional wear of various typical sized universal contour tools on their life under the optimal conditions specified in the matrix tables [3]. The procedure for working with graphs (see figure) is shown in work [4].

Correlation between cutting wedge typical size (ρ edge corner radius and angles: front γ and main rear α), and the optimal cross-section of cut (by multiplication of t by S_o, by taking into account the main angle in φ plan), is clear enough [4]. It is this correlation that defines the synergistic influence of the cutter geometrics on the optimal cutting conditions (including V), which together minimize the force of cut, and thus provide the highest accuracy of machining at the maximum possible dimensional stability of the tool. This provision is clearly illustrated by the Table 2 data for various processes of lathe machining [4, 5, 8, 15].

Table 2

Quality indicators for lathe surfaces and
tools geometric parameters and cutting conditions corresponding to them

Quality indicators; geometric parameters of tools; cutting conditions	Tables-matrices of the primary MBT subsystem; carbide UCT	Machining of hardened steel with composites	Diamond turning of non-ferrous metals	Nanocutting of hardened steel ShKh15, HRC 60
Roughness R_a, μm	R_a=0.32÷0.63	R_a =0.1…0.3	R_a < 0.01	R_a < 0.01
Form deviation of cross section, μm	1 ... 3 (15) μm	0.3 ... 0.5 μm	PV < 0.1 μm x ø 100 mm	PV < 0.2 μm x ø 100 mm
Dimensional accuracy	3÷9(50) μm	0.5 … 1.5 μm	< 0.2 μm	< 0.5 μm
Cutting edge corner radius ρ, μm	ρ_{fin} = 5…10 ρ_{pre} =10…15	ρ_{fin} = 5…7 ρ_{pre} = 7…15	ρ = 0.1 ÷ 0.5	ρ < 0.05 (ρ $\leq$ 50 nm)
Front corner γ, ° of the cutting wedge	γ = 13 ... 17 °	γ = (-5)…(-20)°	γ = 0…(-8)°	γ = 0°
Rear corner α, °	α = 10 ... 15	α = 10…18°	α = 8…12°	α = 5°
Radius at the tool point r, mm	0.05…0.2 (0.3)	0.15 $\pm$ 0.05	(0.2$\pm$0.1) 0.2; 0.3	0.25

Main φ and auxiliary $φ_1$	φ = 60; 90; 100° $φ_1$ = 15…20°	φ = 93…95°, $φ_1$ = 5°	φ = 93…95°, $φ_1$ = 5°	φ = 30…45°, $φ_1$ = 0…45°
Cutting conditions: - speed, m/min - feed, mm/rev - depth, mm	Alloy 36NKhTYu (36НХТЮ) V = 40 ... 60 S_o = 0.02 ... 0.1 t = 0.05 ... 0.5	 V = 100 ... 160 S_o = 0.02... 0.04 t = 0.05 ... 0.2	 V = 250 ... 700 S_o = 0.01... 0.05 t = 0.01 ... 0.2	 V = 53 ... 102 S_o = 0.002 t = 0.002

These processes can be considered as attractors (channels of evolution) of the technology systems presented. It is clear that a whole series of imperatives (inhibits) imposed on the manufacturing systems functioning can be used. Moreover, these inhibits imposed on the postbifurcational state of the system, may be of a very different nature. For example, in case of the precision manufacturing system (well-tailored machine model), the speed, temperature, forces, i.e. cutting conditions in optimizing the tool geometric parameters should be simultaneously limited. What kind of imperative to be set, the technologist decides, but to do so, it is necessary to understand the system full range of elements interacting with each other.

In all the attractors under consideration, it is possible and necessary to find optimal combinations of primary technological factors that allow applying the deterministic (dialectic) approach to the task solution of sustainable functioning of the manufacturing systems considered. It is therefore very highly relevant and important task is the development of new methods for investigating the materials machinability that should result in the standards of cutting conditions obtaining having direct connection with the CT dimensional stability and machining accuracy [4, 8, 16-19].

Results

The increase in the cutting edge rounding increases the degree of cold-work and depth of the cold-worked layer under the cutting and machined surface that can increase the tool wear. The increase in the contact area of the tool back surface with the part and cutting forces, while increasing the $ρ_o$, also increases the tool wear rate. In some cases, this may be facilitated by a reduction in build-up. With the increase in the cutting edge corner radius $ρ_o$, the factors that reduce the tool wear also start acting. These include the reduction of the friction factor, the more favourable distribution of contact stresses and their smaller fluctuations, as well as the increased toughness of cutting edges with the reduction in their roughness [4, 20-22]. Cutting temperature is minimal with a certain $ρ_o$ that can be explained by the decrease in tangent forces caused by the reduction of the friction coefficient and chip shrinkage. For example, for roll-end cutters, $ρ_o$= 25 ... 30 μm (Fig. 2).

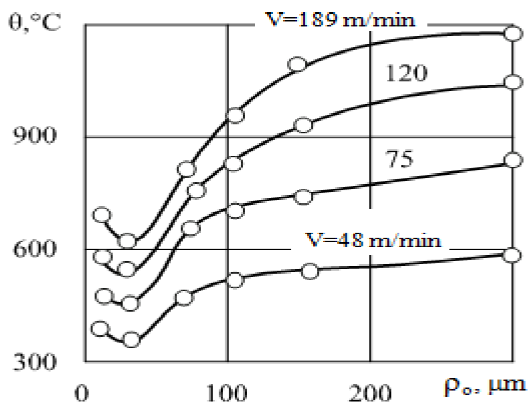

Figure 2. Impact of $ρ_o$ on the cutting temperature when machining steel 45 by roll-end cutter (T5K10;) D_{cutter} = 200 mm; H = 12 mm; *t = 3 mm;* S_z *= 0.2 mm/tooth*

With the increase of ρ, CT durability will initially increase due to the decrease in the friction coefficient, cutting temperature and other changes, and then decrease as a result of the cutting forces, temperature, and the surface material cold-work. The maximum CT durability depending on the working conditions will correspond to the different values of ρ. In the case of laboratory tests, where the criterion of blunting is the wear, in some cases it may be that the optimal radius of $ρ_o$ will not exceed the value obtained as a result of diamond grinding. In the case of production tests, by increasing the durability of tools replaced because of destruction and reduction in percentage of such tools in the lot, the factors role increasing CT mean durability of the whole party is much larger, and the optimal value of $ρ_o$ in this case will be greater.

The wear of tool with a rounded cutting edge develops, within a long period of time, so that between worn areas

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on the back and front surfaces the rounded surface appears, but in the middle or in the end of the durability period, the wear sections on the cutting surfaces are connected (Figure 3), and in this case the rounded surface at the tool top is worn out the last. The new radius (ρ_{eq} = 10 μm) of the tool roundoff is determined by the conditions of wear. The fact that the ρ value of the tools without and with corner radius of cutting edge becomes the same by the end of the durability period (ρ_{eq} = 10 μm - can be called "equilibrium corner radius") does not exclude the effectiveness of roundoff in operation by following reasons: First, a large number of failures take place during works commencement, when the difference in the value of ρ for sharp and rounded tools is significant. Secondly, the roughness of the specially rounded off edge is less than that resulting from wear [7, 22.23].

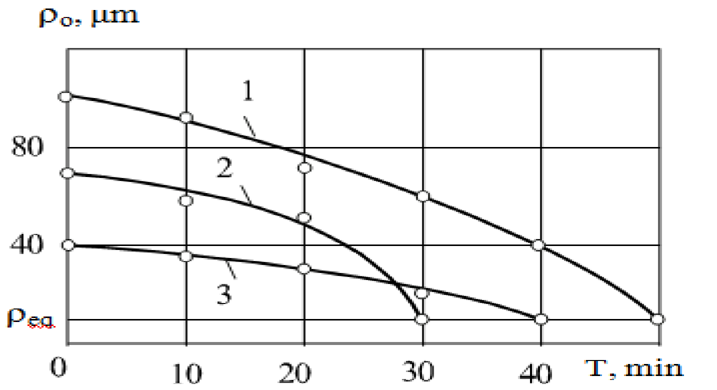

Figure 3. The dependence of ρ_o radius on
operating time of the roll-end cutter
(t= 2 mm): 1 and 2 - steel 9XΦ (9KhF)
S_z = *0.185 mm/tooth; V = 59 m/min,*
ρ_o, 100 and 70 μm, respectively;
3 - Steel 20XH (20KhN), S_z = *0.27 mm/tooth;*
V = 147 m/min, ρ_o = 40 μm.

Discussions

In all cases, the increased corner radius reduces the breakdown rate, increases the mean durability till destruction and mean number of periods of tools life. For sharp tools, the increased number of cutters failure is observed at the beginning of operation and to the first resharpening as well. The wearing-in area is almost absent in cutters with rounded-off cutting edges, because in the process of rounding the defective layer [7, 8, 24, 25] is removed in different ways.

The results of the laboratory and operational tests of tools made of alloy T5K10 in the process of carbon steel parts machining are shown in Figure 4, a. The laboratory tests for ρ_o to 70 μm and operational tests within the entire range of verified rounding radius showed that the durability depends little on ρ_o. The greatest strength and largest volume of metal cut in course of laboratory tests was observed for cutters with ρ_o 100 and 75 μm respectively, and in course of operational tests - for tools with ρ_o = 60 μm. Therefore, the rounding radius preset in the lab conditions should be reduced slightly.The smallest coefficient of durability variation, the biggest durability with a specified probability and total durability are obtained at the same ρ_o (60 μm) as the biggest strength (the biggest *K*) and metal removal (Figure 4, b). With this radius, the total time cycle t_{total} is minimal and the cost of products produced by one tool during lathe machining *A* is maximum. When working with fine shavings (diamond turning, stretching, etc.), in contrast to the cases under consideration, it is reasonable to reduce the rounding radius proportionally to the cross-section of cut. The rounding radius ρ_{str} providing strength, and the radius ρ_t providing the greatest durability, increases along with the cut thickness.

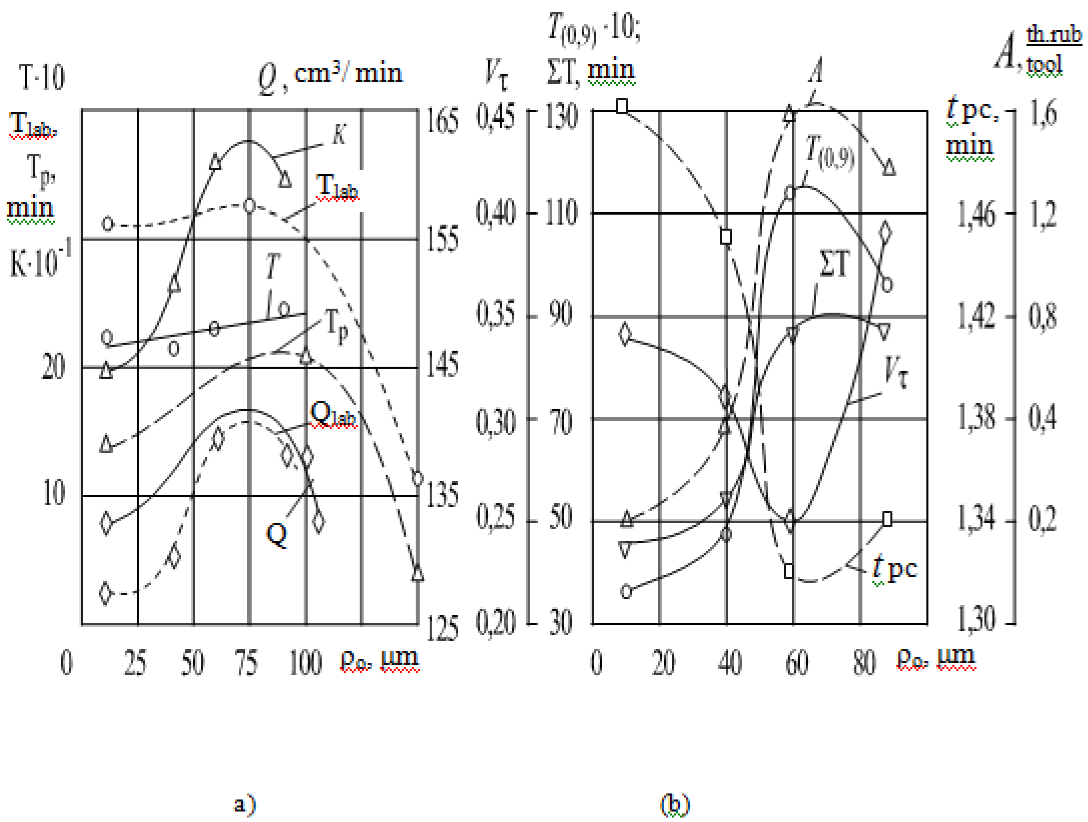

Figure 4. ρ_o impact of cutters cutting edges of alloy T5K10, with cross-section 16x16 mm to their performance: T_p at $t = 4$ mm; $S_o = 0.63$ mm/rev; T_{lab} at $t = 2$ mm; $S_o = 0.53$ mm/rev; $V = 95$ m/min; K and T at $t = 1.25$ mm; $S_o = 0.76$ mm/rev $V = 44$ m/min.

Paired of correlation dependences between these parameters are shown in Figure 5. They may be expressed by the following equations:

$$\rho_{str} = 160 \bullet \boldsymbol{\alpha}^{0.5};$$
$$\rho_T = 110 \bullet \boldsymbol{\alpha}. \qquad (2)$$

These graphs are drawn closer in the area of large thickness of cut, when the durability dependence on the tool contact strength increases.

When machining the improved and high alloyed steel and using the tools from the alloys T15K6 or BK6M, as well as with reduced stiffness of the WTDM system (workpiece-tool-device-machine), the recommended values of ρ should be increased by about 25%, and during sharpening, for example, low carbon steel it should be decreased by the same value. The tool materials and the materials under machining, the stiffness of WTDM system, and other factors other than the cut thickness, have insignificant impact on the rounding radius. This is because when conditions are less favourable from the point of view of failure probability, it is required to increase ρ_o but in these cases, less feeds are usually applied which requires ρ_o to be reduced.

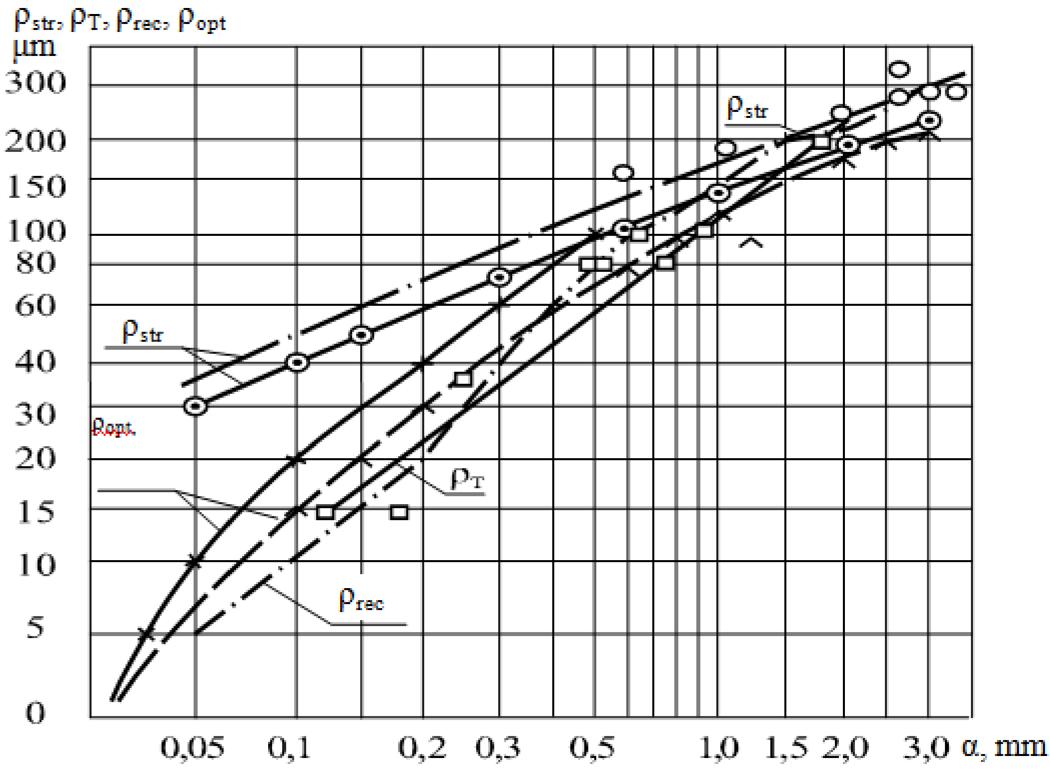

Figure 5. The dependence of rounding radii of the CT cutting edge from the actual cut thickness a; ρ_{opt} -optimal rounding radius, ρ_{rec} – recommended one [2, 8, 11, 12].

An efficient industrial way to obtain the rounding radius of the tool is the electrolytic processing (ELP)-electrolytic polishing that takes place when the process is directed to the top of the cutting tip. The tool cutting edges when sharpening and milling the parts made of dispersion-hardening, heat-resistant steel and other high-ductile, difficult-to-machine materials ρ_o should not be specifically rounded.

Conclusion

Optimization criteria found are as follows: the specific dimensional stability and the surface relative wear are universal - they are not restricted by the cutting speed, feed per revolution, tool wear criteria and so on. Therefore, these criteria of optimization should be used for: comparative assessment of CT dimensional stability, analysis of accuracy and quality of machining, synthesis of machining and cutting conditions, economic options for manufacturing activity, as well as for development and designing the automatic control system of flexible production.

In conditions of favourable distribution of stresses resulting from the cutting process, and reduced oscillations of cutting forces when operating tools with rounded cutting edges, the impact of large pores in solid alloy on the tool strength, the residual tensile stresses obtained during soldering and sharpening, as well as other defects are reduced, that is why the rounding is particularly important for the new tool. The wear resistance of the tools under study characterized by mean durability up to wear T_{and}, differs slightly. For the same conditions, the mean durability T_{chip} before chipping and T_{fail} before the insert damage increased significantly. Mean durability of all tools, i.e. the working time before any of the failures, is in all cases higher for tools with rounded cutting edges, which, together with the increased K led to a steep increase in total durability (1.8 - 2.05 times). In most cases, ρ_o providing the fewest number of failures corresponds to a smaller coefficient of durability variation that indicates the cutting properties stability of the tools with rounded edges. Durability with probability of 0.9 increases (1.4 ... 3) times.

References

[1]. Suslov A.G., Dalsky A.M. Science of Engineering. -M.: Engineering, 2002. - 684 p.
[2]. Makarov A.D. Optimization of the cutting processs. -M.: Engineering, 1976. - 278 p.
[3]. Rakunov Yu.P Development of multi-level basic technology system//High technologies in Engineering. 2012. No. 1. - p. 40-46.
[4]. Rakunov Yu.P Primary subsystem of multi-level basic technology//High technologies in Engineering. 2012. -No. 3. - p. 23-31.

[5]. Zakharevich E.M. Nanocutting of hardened steel. The book of abstracts at the exhibition Metalloobrabotka – Technoforum 2009. M.: CEC Expocentr, 25-29. 05.2009.
[6]. Tool: RF Patent No. 2170160/Kalmykov V.I., Rakunov Yu.P, Khrulkov V.A., Petrovskaya T.M., Zolotova N.A., Borisenko N.N. - Newsletter. No. 19, 2001.
[7]. Multiple Repeated cutter: Patent. No. 2226453/Rakunov Yu.P, Khrulkov V.A., Zolotova N. A. Tikhonov N.A. Newsletter. No. 10, 2004.
[8]. Rykunov A.N Increase In Efficiency of Fine Sharpening Based on Achievable Quality of Parts And Processing Capabilities: Author's abstract.... D. Eng. Sc.-M: -MSTU STANKIN, 1999.-30 p.
[9]. Billington I.E., Crane L.W. PM Research in academic institutions. University of Action in Birmingham//Powder Met. 1983. -N 26-P. 45-54.
[10]. Rakunov Yu.P., Abramov V.V. Comparison of the optimization methods for cutting modes for machining machine parts // Mechanization of construction, - 2015. - № 11, p. 22-26.
[11]. Rakunov Yu.P., Abramov V.V. Optimization of process control and cutting modes for turning processing of structural materials // Mechanization of construction, - 2015 - № 11, p. 40-45.
[12]. Fine-grain carbide finally cuts it. Machine and Tool Blue Book. 1988. Vol. 83.-N 2 – P. 57-58.
[13]. Kaiser M.M. Scheidstoffuntersuchungen im Analogic Versuch zum Schaiwaizfrasen/Ind.-Anz. 1988. -Vol. 110. -N 99.-p. 40-41.
[14]. Karapantev P. Investigation on wear parameters of CVD layers on carbides by a scanning electron Microscope Annals of CIRP, 1978 Nip. - P. 79-85.
[15]. Kolaska H., Dreyer K. Immer feiner Verbesserte Hartmetalsorten als Schnenmarkt, 1988. -Vol. 94. – N42, - P. 44-46, 48, 50.
[16]. Kolaska H., Dreyer K. Entwicklungsstand keramischen schneidstoffe. Werkzeuge fur die spanende fertigung, sept. 1989, - P. 4-13.
[17]. Neuartiger Schneidstoff fur Hartwerkstoffe. Maschine -werkzeug. – 1988. – Vol.59. -N10. - P. 44-46.
[18]. New carbide tools on show of EMO (Milan). = Intern. Journal of Refractory and hard metals. 1987. -Vol. 6-N4. - P. 180-183.
[19]. Pastor H. Present status and development of the tool materials: Part 1. Cutting Tools//Intern. Journal of Refractory and hard metals. 1987. -Vol. 6-N4. -P. 196-209.
[20]. Sandvik Coromant. Lathe tools. Catalog C-1000: RUS, 2014.
[21]. Yamomoto T. Developing coated tungsten carbide inserts. Austral. Mech 1980. -Vol. 33. -N13.-P. 17-18.
[22]. Sandvik Coromant. Recommendations on Cutting Conditions. Lathe Machining. Http://www.coroguide.com/CuttingDataModule/CDMTurning.asp. (date od access 24.12.2015).
[23]. Klocke F. Manufacturing Processes. Cutting. Springer, 2011. 500 p.
[24]. Machining: Fundamentals and Recent advances/Ed. J. Paulo Davim. Springer, 2008. 361 p.
[25]. Trent E.M., Wright P.K. Metal Cutting, Butterworth – Heinemann, 2000. 446 p.