A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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FINISHED CROSS-WEDGE ROLLING OF HOLLOWED CUTTERS

WALCOWANIE POPRZECZNO-KLINOWEGO DRĄŻONYCH NOŻY OBROTOWYCH NA GOTOWO

In this work, the results of the process analysis of rotary cutters manufacturing are presented. The possibility of manufacturing of a cutter with hollowed body, formed by means of the cross-wedge rolling method (CWR), was analyzed. In the research thermo-mechanical schema of FEM calculations was used, which was later verified in industrial tests. In this work the design of tools guaranteeing the rolling process, the distribution of wall thickness and distributions of strain in cutters body are presented. On the basis of calculations it was stated that it was possible to form hollowed cutters by means of cross-wedge rolling method. The conception of manufacturing of finished hollowed cutter is demonstrated. In this conception the process of burning on of cutting edge was replaced by its reducing in the body realized during rolling.

Keywords: Cross wedge rolling, rotary cutter, FEM, experiment

W opracowaniu podano rezultaty analizy procesu wytwarzania noży obrotowych. Badano możliwość wytwarzania noża posiadającego korpus drążony, kształtowany metodą walcowania poprzeczno-klinowego (WPK). W badaniach zastosowano termomechaniczny schemat obliczeń MES, który zweryfikowano w próbach przemysłowych. W artykule przedstawiono konstrukcję narzędzi zabezpieczających proces walcowania, podano rozkłady grubości ścianek i rozkłady odkształceń w korpusach noży. Na podstawie obliczeń stwierdzono, że istnieje możliwość kształtowania noży drążonych metodą WPK. Przedstawiono również koncepcję wytwarzania noża na gotowo, w której proces wlutowywania ostrza zastąpiono jego obciskaniem w korpusie realizowanym podczas walcowania.

1. Introduction

Rotary cutters are used mainly in extractive industry for mining coal, salt, metal ore, etc. They can be also used during repairing roads for milling of asphalt or concrete.

The main element of a cutter is a body consisting of mounting part and working (cutting) part. So far, cutters bodies were made by means of machining, casting or die forging. In the working part of the body a conical whole is made in which an edge from sintered carbides and powdered solder is placed. Next, such prepared parts undergo heating in a furnace till solder melts. This solder after cooling connects firmly the edge with the body.

In recent years the Bellarussian company JSC "Beltechnology & M" (the manufacturer of flat wedges rolling mill) has started to produce cutters bodies using the cross-wedge rolling method (CWR). The advantage of cutters formed by means of this technology is obtaining favorable axi – symmetrical macrostructure with continuous metal fibers, condensed at the surface and directed along generating lines. This distribution of fibers allows for rolling more durable bodies than in the case of bodies made by turning, die forging or casting [1].

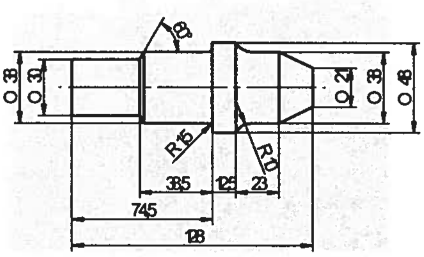

Fig. 1. Cutter body in nr 6000012 in rolled version

In Poland research works dealing with developing of cross-wedge rolling technology are made at Lublin University of Technology at the Department of Computer Modeling and Metal Forming. As the result of these research works the CWR process was implemented in the production of the cutter body with parameters as in Fig 1. Moreover, the conception of finished forming (together with an edge) of cutters with hollowed bodies was

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worked out. In this work the results of numerical analysis of the manufacturing process-according to the proposed technology-of the cutter number 6000012, which body is shown in Fig. 1, are presented.

2. Industrial research of rolling process of cutters hollowed bodies

At Lublin University of Technology wedge tool segments guaranteeing manufacturing of a body of the cutter nr 6000012, rolled from full charge, were designed. The assumed tools designing solution was established during implementation works, described in details in the work [2]. The main parameters of the worked out wedges are shown in Fig. 2. Industrial rolling mill was equipped with these tools. This rolling mill was self-made in cooperation with the manufacturing plant shown in Fig. 3.

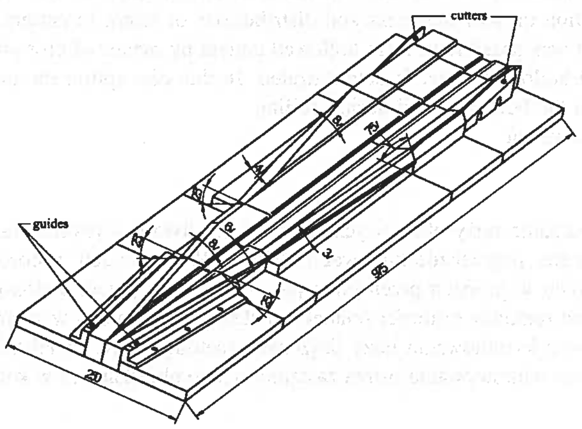


Fig. 2. Schema of a wedge tool guaranteeing CWR body of cutter from full charge

Fig. 3. Flat wedge rolling mill used in industrial tests

The applied unit allows for forming by using rolling with flat wedges; one of these wedges (upper wedge) is moving with the speed of 0.33 m/s. It should be also mentioned that such dimensions of the rolling mill impose limiting of length of the designed wedges, which cannot be larger than 1000 mm. On the basis of rolling tests it was stated that bodies of cutters formed by means of cross-wedge rolling process met all quality requirements, at lower costs of manufacturing. The further lowering of these costs can be expected in the effect of diminution of material consumption of manufacturing technology e.g. by using hollowed charges.

In order to check the possibility of forming of cutters bodies from hollowed charge industrial tests were made in which the same instrumentation (rolling mill and wedges) was used as in the implemented rolling process from full charge. For the research needs hollowed charges (bushes) with external dimensions ∅ 48 × 100 mm were the same as the parameters of full charge, yet, internal diameters d_w were equal ∅ 28.8, ∅ 24.0, ∅ 19.2 and ∅ 14.4 mm. The charges, made from steel of C45 type, were heated in the electric resistance furnace up to the temperature 1150°C. Next, they were placed on guiding tracks of lower (immovable) wedge, from which they were taken by upper tool moving with plane motion. During forming lasting about 6 seconds, the workpiece was rolled on lower wedge – this process is shown in Fig. 4 presenting the CWR process at its final stage (sizing).

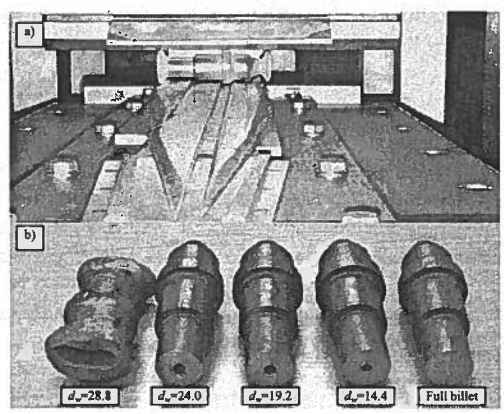


Fig. 4. Workpiece of cutter body during forming from hollowed charge (a) and examples of bodies rolled from bush with internal diameter given in Figure (b)

On the basis of industrial tests it was stated that only in the case of charge with the thinnest wall the product with the desired shape was not obtained. This was because the slide leading to the workpiece squeezing appeared (Fig. 4b). However, in other cases the process was stable. For determining the precision of the workpiece forming, in table 1 the maximal deviations of ovalization for the stages of rolled bodies as well as for the body from full charge are presented. The analysis of deviations values presented in table 1 shows that only the dimensions of full body meet the manufacturing requirements. However, the precision of hollowed bodies manufacturing is not satisfactory, especially in the mounting part of the workpiece symbolized by the letter "C". This observation confirms the fact [3–4] that it is not possible to use wedges designed for rolling of full products in the processes in which hollowed shafts are formed.

Hence, it was decided to design a wedge tool (taking into consideration results of former numerical and experimental research [4]) allowing for rolling of hollowed bodies of required precision. It was assumed that the correctness of that solution would be verified by thermo-mechanical simulations of forming processes, based on the finite element method (FEM). At first, the steps were taken to determine the precision of numerical forming of such complex CWR processes as forming of cutter body in industrial conditions. For that case rolling processes realized earlier in practice were analyzed.

3. Numerical analysis of rolling in industrial conditions of cutters hollowed bodies

For the calculation's needs, geometrical models of CWR processes were worked out. One of them is shown in Fig. 5. Wedge parameters were the same as in Fig. 2. As it was in the case of industrial research, it was assumed that the upper wedge moved with the speed of 0.33 m/s and the lower wedge was immovable. Numerical simulations were made using thermo-mechanical schema of FEM calculations. It was assumed that the charge was heated to the temperature 1150°C and tools temperature during the process was constant - 150°C. Material model of C45 steel was taken from the MSC.SuperForm 2004 program library and this program was used in calculations. It was assumed that heat exchange coefficient between material and tools was 10000 W/m^{2}K, and heat exchange coefficient between material and environment was 300 W/m^{2}K. In the calculations constant friction model was assumed which depended on slipping speed, with the limiting value of friction factor m = 1.0.

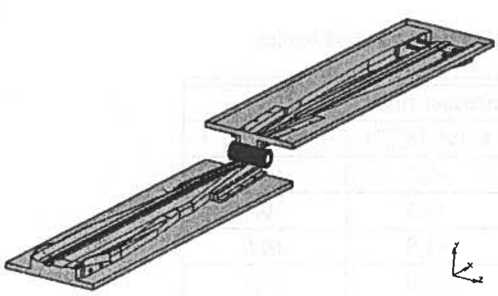


Fig. 5. Geometrical model of CWR of a hollowed cutter body formed by means of wedges

Due to the fact that during industrial tests no measurements were made, the precision of numerical calculations was evaluated basing on comparison between distributions of cutters wall thickness.

In Fig. 6 are shown longitudinal (axial) cuts of bodies rolled in stable CWR processes, compared with cuts of wall thickness calculated by means of FEM. Additionally, on cuts made theoretically distributions were placed which showed how strain intensity was distributed in the cutter body. From these distributions it can be read that the most intensive material flow appears in the cutters mounting part. It was also stated that the calculated changes of wall thickness complied with real changes qualitatively.

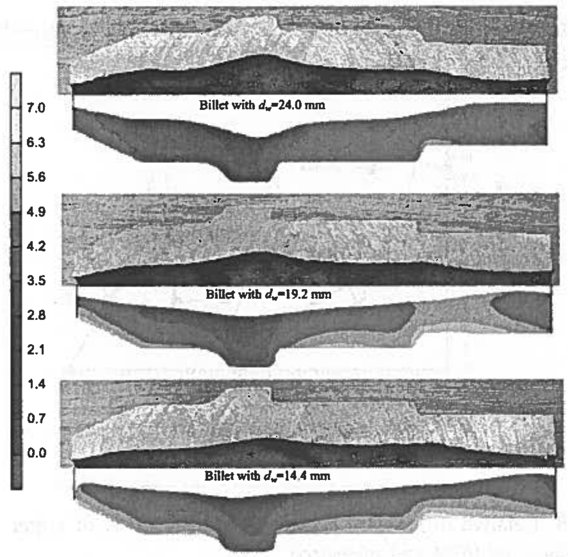


Fig. 6. Walls thickness and strain distributions in the longitudinal cut of a cutter (calculated by FEM method and from experiments)

For quantitative comparison in Fig. 7 are shown numerical values of wall thickness (calculated by FEM and measured) determined in characteristic points of longitudinal cuts. The analysis of data from this Figure shows that the thinnest walls are in the body's working part, however, the thickest walls are in the flange area where the increase of the wall initial thickness can be observed. Moreover, it was observed that rapid changes of wall thickness appeared in places where body's external diameters changed.

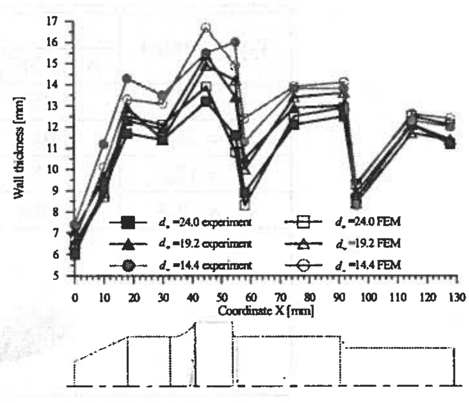


Fig. 7. Comparison of walls thickness of a cutter determined in characteristic points of longitudinal cut

On the basis of data from Fig. 7 additional diagram was made (shown in Fig. 8) which illustrates the precision obtained during the FEM calculations. This diagram shows relative differences Δ_g between the values of walls thickness (calculated and measured), determined in characteristic points of the body's longitudinal cut. These differences were calculated using the equation:

$$\Delta_g = \frac{|g_t - g_e|}{g_e} 100\%, \qquad (1)$$

where: g_t – wall thickness calculated by FEM, g_e – measured wall thickness.

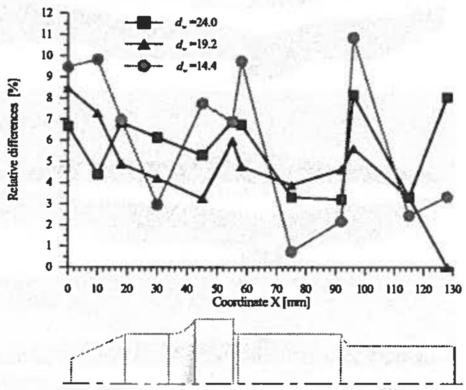


Fig. 8. Relative differences between wall thickness of cutter body calculated by FEM and measured

Analyzing data from Fig. 8 it can be stated that using the FEM method it is possible to forecast the precision of forming of workpieces hollowed by means of the CWR method. This can be confirmed by average values of Δ_g parameter determined for particular bodies which are as follow: 5.74% for charge with d_w = 24.0 mm, 4.68% for charge with d_w =19.2 mm and 6.09% for charge with d_w = 14.4 mm.

4. Modernization of CWR technology taking into consideration the specific of rolling of hollowed parts

Unsatisfactory results of experimental CWR tests of hollowed bodies within the range of the obtained dimension precision (Tab. 1) showed the necessity of making a new design of wedge tools for forming of hollowed bodies. During designing works were taken into consideration the results of research works dealing with the CWR processes of hollowed products made by J. Bartnicki [4].

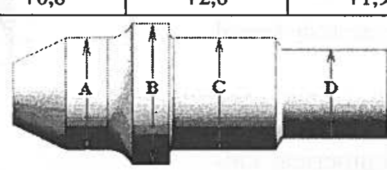
It was assumed that forming angle α (wedge side wall's inclination) is identical for the whole tool and it is 30°. However, because of the differences of length of the working part and mounting part of a body, for forming tools wedges with various spreading angles β (6° for working part, 8° for mounting part) were used. This solution allowed for almost identical length of forming zone for both wedges, which is especially important for the stability of rolling. Moreover, this solution leads to enlarging of the calibration zone to the length of 273.6 mm which guarantees the formed workpiece making two rotations during calibration. Modified wedges are presented in Fig. 9.

Considering the proposed designing solutions for tools, numerical models of the CWR process of hollowed bodies were worked out. The process parameters assumed in calculations were the same as the parameters assumed during thermo-mechanical simulation of the rolling process with tools presented in Fig. 2. Three cases of forming, in which charges with internal diameters 24.0 mm, 19.2 mm and 14.4 mm were used, were based on these calculations.

TABLE 1

Measured maximal dimensional deviations of cutter hollowed bodies

Type of billet	Deviation of dimension [mm]			
	A (Ø $38^{+0,8}_{-0,4}$)	B (Ø $48^{+0,9}_{-0,5}$)	C (Ø $38^{+0,8}_{-0,4}$)	D (Ø $30^{+0,8}_{0,4}$)
full	+0,3	+0,4	+0,2	+0,3
d_w = 24,0	+0,5	+1,1	+1,5	+0,4
d_w = 19,2	+0,9	+1,9	+1,9	+0,6
d_w = 14,4	+0,8	+2,0	+1,9	+1,5



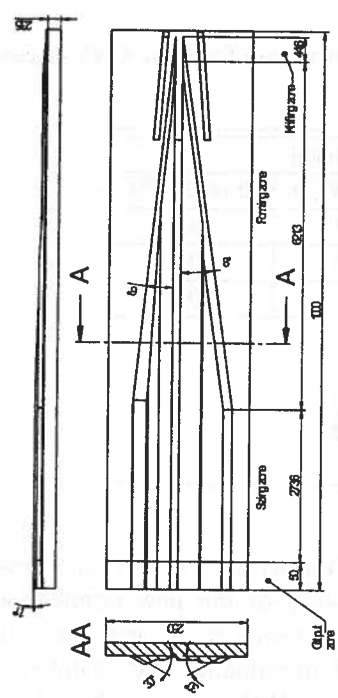


Fig. 9. Schema of modified wedge tool for the CWR process of hollowed cutter

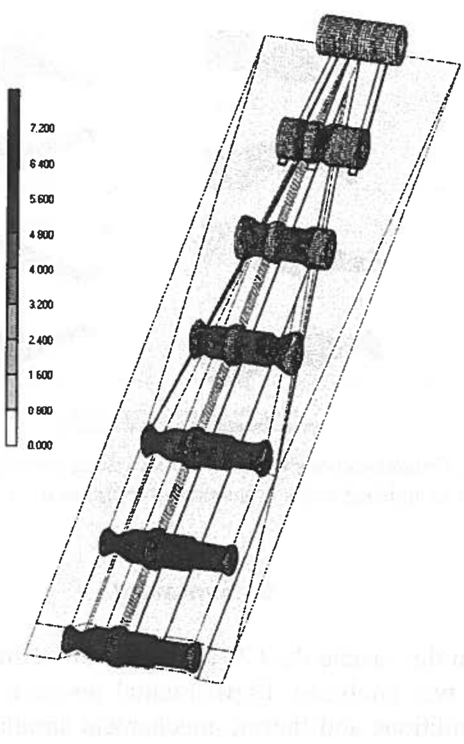


Fig. 10. Progression of shape and strain distributions of hollowed workpiece (d_w 24 mm) rolled with tools from Figure 9

On the basis of calculations it was stated that the analyzed cases of CWR were realized in a stable way. In Fig. 10 the changes of the hollowed workpiece external shape during CWR process, rolled from a bush of d_w = 24.0 mm are presented (in calculations was omitted very complicated numerically process of cutting the final discard). From Fig. 10 results that wedges cut into the material at both sides of the charge, reducing the workpiece diameter to the required value of ⌀38 mm. Moreover, at the beginning of the process, the workpiece position is stabilized by guiding belts. Next, the reduction of the cut is developed in the forming zone, at the required lengths of the body's working and mounting parts. However, there are no undesired movements of the workpiece in the axial directions caused by differences in angle β values assumed for particular wedges. During elongated calibration the ovalization of cross cut is present. This ovalization is the biggest in the area of changing the mounting part diameter from ⌀38 mm to ⌀30 mm (Fig. 1).

As the result of introduced designing changes of the wedge a considerable improvement of precision of hollowed body's workpiece forming was obtained. This is confirmed by a comparison shown in Fig. 11, in which cross cuts of bodies particular steps calculated for the CWR processes with the use of typical tools (Fig. 2) and modified ones (Fig. 9) are presented. This comparison deals with the workpiece rolled from the charge with internal diameter d_w = 24.0 mm. This type of charge is the most interesting for the manufacturer because of the possibility of material savings.

The analysis of data from Fig. 11 shows that taking into consideration the specificity of CWR of hollowed workpieces, wedge tools can be designed in such a way that the precision of tools making will be the same as the precision obtained during rolling of workpieces from full charge.

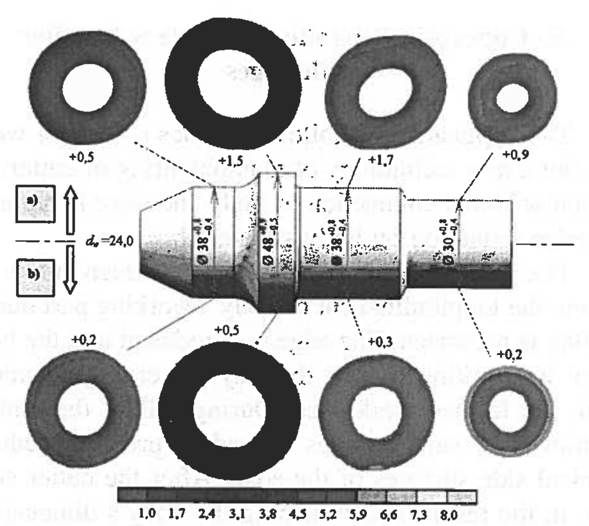
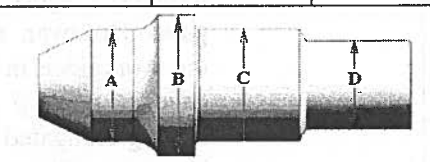


Fig. 11. Shapes of cross cut (with maximal ovalization deviations) together with strains distributions, calculated for the CWR processes realized with tools for forming a) full products b) hollowed products (d_w = 24 mm)

TABLE 2

Calculated FEM maximal dimensional deviations of cutter hollowed bodies formed by means of tools for CWR process of hollowed products

Type of billet	Deviation of dimension [mm]			
	A (Ø $38^{-0,4}_{+0,8}$)	B (Ø $48^{+0,9}_{-0,5}$)	C (Ø $38^{+0,8}_{-0,4}$)	D (Ø $30^{+0,8}_{-0,4}$)
d_w = 24,0	+0,2	+0,5	+0,3	+0,2
d_w = 19,2	+0,6	+1,1	+0,6	+0,4
d_w = 14,4	+0,6	+0,9	+0,7	+0,5



In table 2 maximal values of dimensional deviations calculated by means of FEM method and present during rolling of cutters bodies from charges of various internal diameters are shown. From the data from table 2 it results that increasing the charge wall thickness is connected with lowering the precision of workpiece manufacturing. This observation is also confirmed by comparison of precisions obtained in industrial tests presented in table 1. However, as it was mentioned earlier, due to economical reasons more interesting seems to be rolling from a charge with a thinner wall. Additionally, the bush manufacturing is easier when the wall is thin. Hence, from the economical reasons, in further industrial tests only rolling of workpieces bodies from hollowed charge with the internal diameter Ø24 mm (for which the best results were obtained) should be taken into consideration.

5. Conception of rolling of cutters together with edges

The application of hollowed bodies allows for working out a new technology of manufacturing of cutters, in which soldered connection of body and edge is replaced by edge reduction by body's material.

The process of edge reduction can be seen in Fig. 12, where the longitudinal cut of body's working part during rolling is presented. The edge is introduced into the body from its working part in the way preserving coaxiality with the formed workpiece. During rolling the material moved by side surfaces of wedges precisely reduces conical side surfaces of the edge. After the cutter cooling, in the result of diminishing the body's dimensions, the force clamping the edge increases. The material allowance from the cutter side can be removed by cutting knives placed at the end of wedge tool segment.

The implementation of the proposed conception of manufacturing of finished cutters has to be, of course, preceded by numerous experimental research, during which the quality of the new connection between the edge and body needs to be verified. Additionally, the technology of introducing and maintaining (at the beginning of the CWR process) the edge in the proper position should be worked out. This technology should also allow for the proper reduction of the edge by the body's material.

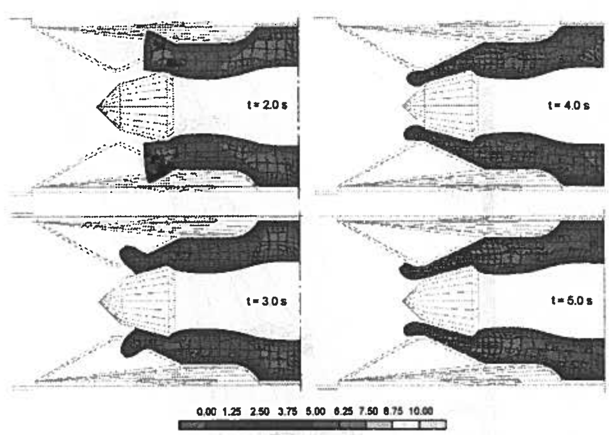


Fig. 12. Progression of shape of body's working part during the CWR process of finished cutter together with edge, at d_w = 24 mm

6. Summary

In this article the CWR process of a cutter hollowed body was analyzed. Experimental research in industrial conditions and thermo-mechanical simulations based on the FEM method were made. It was stated that using tools segments designed for a full charged body it was impossible to roll products from hollowed charges. This was because of the large ovalization present in the body's mounting part. The introduction of changes into the wedges design (resulting from research made within the confines of work [4]) causes that the rolled hollowed bodies meet the dimensional requirements. In this paper the results of numerical simulation of the new CWR process of finished cutter are also presented. In this process the edge from sintered carbides is mounted on the body by reduction realized during rolling. The results of calculations confirmed the rightness of assumptions of the new technology of cutters manufacturing.

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