Increasing the efficiency of prefabricated drills and the strength of replaceable cutting inserts

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Abstract. The results of calculating the stress-strain state in replaceable cutting inserts of assembly tools are presented, using the finite element method. In the calculation, the mechanical characteristics of the tool hard alloy were specified, the conditions for the interaction of the replaceable cutting inserts with the drill body, the fastener elements, the force loading was replaced by the specification of the boundary conditions. As a result, a number of basic sizes of replaceable cutting inserts were built, with different geometric parameters. A system of equations for the calculation of cutting forces for drilling with prefabricated drills of different types has been developed. To determine the influence of the shape of the plates on the stressed state, replaceable cutting inserts of different shapes were studied: trihedral, rhombic, square. A new form of replaceable high-strength cutting inserts with an enlarged angle has been developed. To improve performance, the auxiliary cutting edge of the replaceable cutting insert is made in the form of an arc inscribed in a quarter of the length of the side of the polyhedron, while the radius of the curved cutting edge is equal to half the length of the side of the polyhedron.

Key words: replaceable cutting inserts, hard alloy, prefabricated tools.

1. Introduction
At present, it is impossible to ensure lower costs and increase the competitiveness of production without using modern technologies, equipment, tools. One of the ways to increase the efficiency of cutting is the transition from the use of a cutting tool to a prefabricated with mechanical fastening of exchangeable polyhedral plates.

Drilling is the most common operation for machining holes [2]. The most effective way of improving performance of hole machining process is the use of modular instrument equipped with plates of hard metal tool that provides high processing and a significant manufacturing cost reduction holes [13-17,25,26]. Therefore, by increasing the productivity of drilling, using a tool equipped with tool hard metal, you can achieve a significant reduction in production costs.

Unlike whole tools of high speed steel and cemented carbide drills and with brazed carbide inserts prefabricated tools for machining holes equipped with cutting elements (plates, heads) of the hard metal tool have the following advantages [1-14]:

1. Increasing the resistance by 25 ... 30%, since in carbide plates there are no thermal stresses (which is characteristic for soldering), which significantly reduce the safety factor and lead to the appearance of cracks, chips and breakages.
2. High cutting speeds and productivity due to the use of hard alloys.
3. A shorter tool setting time due to the simplicity of replacing blunt cutting edges and interchangeability of the plates.
4. No re-sharpening of tools.
5. Constancy of geometric parameters of instruments, which are determined by the performance of plates and nests under them.

6. Saving scarce tungsten due to return to the metallurgical industry about 90% of the plates used, while the return of the solder plates is about 15%.

7. A smaller stock of tools as a whole, since the same drill, countersink or sweep body can be used for tens and even hundreds of cutting inserts.

8. Low processing costs and a significant increase in the economic cutting speed.

9. The possibility of using wear-resistant coatings.

10. The effective use of prefabricated cutting tools on modern machines with numerical control, as it allows for non-debugging.

In addition, the advantage of prefabricated drills with replaceable cutting inserts is the possibility of its non-standard application in comparison with conventional solid drills.

Such a tool should always be considered as the first choice, allowing to reduce the cost of the hole. The design of the drill allows to expand the technological possibilities of using prefabricated drills. This is the most versatile type of drills.

Application features: medium and large diameter holes; average accuracy requirements; blind holes requiring a "flat" bottom; drilling of curved and not flat surfaces, drilling at an angle to the machined surface, drilling intersecting holes, drilling not solid holes, plunger drilling, drilling with the use of helical interpolation and boring.

![Figure 1](image)

**Figure 1.** Technological capabilities of prefabricated drills with replaceable cutting inserts according to Sandvik Coromant and Widia tool companies: a - "Plunger" drilling; b, c - drilling of non-planar and inclined surfaces; d, e - drilling holes on the edges of the workpiece; f - drilling at an angle to the machined plane

However, despite all the advantages of prefabricated drills with replaceable cutting inserts, the practice of their operation showed their insufficient working capacity. Thus, according to the materials
of JSC “Gazturboservis” (the Russian Federation - the city of Tyumen), 65% of replaceable cutting blades of prefabricated drills account for the failure due to shearing, dying and breaking.

**Figure 2.** Destruction of replaceable cutting inserts of prefabricated drills.

The efficiency of the application of the cutting tool can be evaluated in various ways. Usually, the evaluation criteria are the tool costs per part and the total cost of processing one part.

To calculate the instrumental costs, it is sufficient to know the cost of the instrument and to calculate or determine experimentally its durability.

Insufficient strength of replaceable cutting inserts - RCI causes an increase in the number of adjustments and an increase in equipment downtime. If selected a very gentle cutting mode, the tool life will increase, but the machining time of the part will increase.

The practice of using replaceable cutting inserts of prefabricated tools has shown that their performance is largely determined by the tool material, the method of basing and fastening, the shape and type of plates used, and the cutting regimes.

In works [1], [3] the results of research of the stress-strain state of RCI are given, and the following formulated requirements for the design of prefabricated tools and RCI of increased strength:

- an increase in the angle at the vertex of the plate ε;
- ensuring, when the plate is fixed to the corner socket of the tool body, with guaranteed pressure against the lateral faces and the supporting surface.

**Figure 3.** Classification of the forms of replaceable cutting inserts by strength, depending on the magnitude of the angle at the vertex ε (* new plate shapes presented in [1], [2])

Schemes of basing and fastening of replaceable cutting inserts of prefabricated drills of the main instrumental firms of the world are presented in Figures 2, 3. The main drawback of all designs of prefabricated drills with cutting inserts is the insufficient reliability of fastening the cutting inserts. The fastening takes place over several stubborn surfaces. The load vector during cutting $R_{xy}$ does not coincide with the vector of the fastening force of the cutting inserts $P$ in the angular groove, which leads to weakening of the fastening, self-loosening of the fastening screw, the occurrence of micro vibrations and to premature wear and destruction of the cutting inserts and drill body, as shown in Figure 4.
Figure 4. Schemes of basing and fixing the central cutting insert of the prefabricated drill of the firm: 1 - Iscar; 2 - according to GOST 27724-88; 3 - Mitsubishi; 4 - Walter; 5 - Sandvic Coromant.

Figure 5. Schemes of the basing and fixing of the peripheral cutting insert of the assembled drill of the firm: 1 - Iscar; 2 - according to GOST 27724-88; 3 - Mitsubishi; 4 - Walter; 5 - Sandvic Coromant.

Figure 6. Results of misuse of prefabricated drills with cutting inserts.

By this way, the task of investigating the influence of forms, schemes of basing and fixing replaceable cutting elements of prefabricated drills on their stress-strain state (SSS) and strength is actual.

2. Building computational models of indexable cutting plates, taking into account the boundary loading conditions

To calculate the SSS cutting inserts of prefabricated drills were created, their three-dimensional volume models were considered in the plane of the plate and in the plane of the chip removal.
Figure 7. Model of trihedral replaceable cutting inserts of the wrong shape of the assembly drill in accordance with GOST 27724 with a grid of pose breakdown and boundary conditions: a) three-dimensional model; b) in the plane of the plate; c) in the cross section of the plane of the chip exit

In the calculations, the mechanical characteristics of the tool hard alloy were set, the conditions of interaction of the replaceable cutting inserts with the drill body, the fastening mechanism elements were taken into account. In addition, the force loading is replaced by the specification of boundary conditions. A number of models of the main standard sizes of replaceable cutting inserts were built, with different geometric parameters used in prefabricated drills with replaceable cutting inserts, from various manufacturers of the assembly tool. The breakdown of the model into finite elements (FE) was carried out both in the automatic mode and with the introduction of the size of the FE. The FE value was taken in accordance with the solution of the test problem, the results of which showed that reliable data can be obtained at a grid step at the vertex of 0.1 mm.

The main problem in the development of models of replaceable cutting inserts is the correct specification of the boundary conditions simulating the interaction of the cutting insert with the body of the assembly drill and the action of cutting forces during drilling.

In the catalogs of tool companies - manufacturers of cutting tools from Garant and Sandvik Coromant, a technique for calculating cutting forces for turning tools, cutters, drills, etc, is given through the specific loads $k_c$ ($N / mm^2$) acting on the cross-sectional area of chips $A$ ($mm^2$).

The main component of cutting force $P_c$ loads the main drive mechanism of the machine and determines the power consumed during the cutting process. The value of the force $P_c$ depends primarily on the properties of the material to be treated and on the cutting parameters (the geometry of the cutting part, the width and thickness of the cut layer, etc.). Therefore, it is determined by taking into account the cross section of chips $A$ for a particular type of treatment.

When turning to determine the cutting force $P_c$, the following formula is valid:

$$P_c = A \cdot k_c = a \cdot b \cdot k_c,$$

where:

- $A$ is the cross-section of the chips ($mm^2$);
- $b$ - width of cut layer (mm);
- $a$ - thickness of the cut layer (mm);
- $k_c$ is the specific cutting force ($N / mm^2$).

According to the materials of Garant, the specific cutting force $k_c$ is affected by the properties of the material being processed. But at the same time, it is a theoretical design value and is not considered as a numerical characteristic of the material. To determine the cutting force $k_c$, the following formula is valid:

$$k_c = \frac{k_{c+1}}{h^m},$$

(2)
Where:
- \( k_{c1} \) is the specific cutting force for a cross section of chips \( A = 1 \text{ mm}^2 \) (\( b = 1 \text{ mm}, a = 1 \text{ mm} \))
- \( m \) - The tangent of an angle \( \alpha \)

To determine the specific cutting force \( k_c \) for different types of drills in the catalogs of the tool company Sandvik Coromant, it is recommended to use the formula:

\[
k_c = k_{c1} \cdot (S_z \cdot \sin \varphi)^m - \left(1 - \frac{\gamma_0}{100}\right),
\]

(3)

![Figure 8. Determination of specific loads by catalogs of the company Sandvik Coromant](image)

As a result of the systematization and generalization of the cutting force formulas for drilling, of the companies Sandvik Coromant and Garant, the author obtained the following system of expressions for calculating the cutting forces when drilling with prefabricated drills of different types:

\[
\begin{align*}
P_{nc} &= 0.5 \cdot k_{c1} \cdot (S_z \cdot \sin \varphi)^m - \left(1 - \frac{\gamma_0}{100}\right) \cdot \frac{D}{2} \cdot s \cdot \sin \varphi \\
P_c &= \frac{D}{2} \cdot s \cdot \left[ k_{c1} \cdot (S_z \cdot \sin \varphi)^m - \left(1 - \frac{\gamma_0}{100}\right) \right] \\
M_{zp} &= \frac{P_z \cdot z \cdot D}{2000}
\end{align*}
\]

(4)

where \( k_{c1} \) is the specific load [N / mm²]; \( z \) - number of teeth (\( z = 2 \) - for solid and prefabricated drills with replaceable cutting heads and \( z = 1 \) for prefabricated drills with replaceable cutting inserts); \( s \) - supply [mm / rev]; \( s_z \) - feed per tooth [mm / rev] (\( S = 2S_z \) - for solid and prefabricated drills with replaceable cutting heads and \( S = S_z \) - for prefabricated drills with replaceable cutting inserts).

To set the boundary conditions, the cutting blades of a single drill and a drill with a replaceable cutting head are divided into \( n \) equal sections, and in a prefabricated drill with replaceable cutting inserts,
the cutting blades of the central and peripheral plates by the number of sections \( n = n_t + n_n \) (\( n_t \) and \( n_n \) number of equal sections on cutting blades of the central and peripheral plates), as shown in Figure 7:

\[
P_{oc} = \sum_{i=1}^{n} P_{oc_i} ; \quad P_{z} = \sum_{i=1}^{n} P_{zi} ; \quad M_{sp} = \sum_{i=1}^{n} M_{spi}
\]

As a result of simulation, the areas of loading of the cutting blades of the central (1-5) and peripheral (6-10) plates along the front \( S_{p.p} \) and rear \( S_{z.p} \) surfaces. In this case, the specific loads, as shown in Figures 10 and 11, are determined on each site from the expressions:

\[
\Delta P_{oc(i=)n} = P_{ocn} - P_{oc(n-1)} ;
\]

\[
\Delta P_{zi(i=)n} = P_{zn} - P_{z(n-1)} ;
\]

Figure 9. Schemes of the cut layer, and geometric parameters of cutting blades of different types of drills (\( \gamma \) is the front angle, \( \alpha \) is the rear angle, \( \varphi \) is the main angle in the plan)

Figure 10. Graphs of the distribution of specific loads (\( \Delta P_{oi}, H/ \text{mm} \) – axial cutting force; \( \Delta P_{z(i), H/ \text{mm}} \) – the main component of the cutting force) на режущие лезвия сверла on cutting blades of drills (\( O25 \text{ mm } \) at the radar \( r, \text{ mm} \)) different types: ○ - one-piece drill; □ - assembly drill with replaceable cutting head; ∆- assembly drill with replaceable cutting inserts
Thus, to study the stress-strain state of replaceable cutting inserts, three-dimensional models have been developed that allow calculating stresses in the plane of the plate, in the main secant plane and in the volume.

3. Investigation of the influence of the shape and the scheme of the base of replaceable cutting inserts of prefabricated drills on their stressed and deformed state

To determine the influence of the shape of the plates on their stressed state, the investigations were carried out on equilateral replaceable cutting inserts of different shapes: trihedral, rhombic, square. Analysis of the results of a numerical study of the influence of the shape of the replaceable cutting inserts on the stressed state shown in Figure 12 showed that the values of the dangerous tensile stress $\sigma_1$ in the peripheral cutting insert of the assembly drill, in the cutting blade of an equilateral triangular plate ($\varepsilon = 60^\circ$) are greater than in the square $\varepsilon = 90^\circ$) approximately in 3 times.

In the trihedral cutting insert, in contrast to the rhombic ($\varepsilon = 80^\circ$) and square, the stress values $\sigma_1$ are distributed unevenly. The most dangerous area on the main cutting edge is the end zone of the loading section (nodal points 1-8) at the top of the replaceable cutting insert, in another section (node points 9-25), the stress values $\sigma_1$ of the trihedral plate ($\varepsilon = 60^\circ$) are close to the stresses $\sigma_1$ square ($\varepsilon = 90^\circ$) plate. This is due to the fact that in a trihedral plate of the correct form, the scheme of basing the plate in the angular groove of the tool body along the two lateral surfaces of the plates is realized so that one of them falls on the auxiliary cutting edge, which reduces the dangerous tensile stress $\sigma_1$. As shown in Fig. 10, the smaller the angle $\varepsilon$ at the vertex, the greater the stress $\sigma_1$ under the same cutting conditions.

The analysis of the fastening and basing schemes for the central and peripheral plates of prefabricated drills showed that practically in all constructions of prefabricated drills of different firms, the scheme of basing the replaceable cutting inserts in the corner groove of the tool body on the two lateral surfaces of the plates is not realized so that one of them falls on the auxiliary cutting edge.
Figure 12. Pictures of isolines and graphs of stress distribution $\sigma_1$ in cutting blades of equilateral replaceable cutting inserts: 1 - trihedral; 2 - rhombic; 3 - square.

Simulation modeling of the change in the fastening and basing schemes for the central and peripheral plates of prefabricated drills in accordance with GOST 27724-88 (see Figure 13a, b), Mitsubishi (see Figure 13c, d) and Walter (see Fig. 13 e, f) that the realization of the scheme of the base of the replaceable cutting inserts in the angled groove of the tool body along the two side surfaces of the plates so that one of them falls on the auxiliary cutting edge makes it possible to reduce the values of the dangerous tensile stresses $\sigma_1$ in the cutting blades of the plates. However, for the considered forms of cutting inserts it is constructively impossible to provide this requirement.
To increase the efficiency of prefabricated drills, a new form of a replaceable cutting insert with an increased angle $\varepsilon (\varepsilon = 100^\circ)$ made on the basis of an equilateral trihedral plate ($\varepsilon = 60^\circ$) was developed, with the main cutting edge made in the form of a straight line, and the auxiliary cutting edge in the form arc. In the developed design of the assembly drill, as shown in Fig. 14, when fixing a) the peripheral and b) of the central plate, the direction of the cutting force $R_{xz}$ coincides with the direction of the fastening force $P$, and the mounting scheme of the replaceable cutting inserts in the corner groove of the tool body is realized along the two side surfaces of the plates so that one of them falls on the auxiliary cutting edge.
In order to increase the serviceability, reduce the cutting forces and expand the technological capabilities of the drill, the rotation path of the central cutting insert and the peripheral cutting insert is at least partially overlapped to form an overlap region, the cutting edge of the inner cutting insert and the cutting edge of the outer cutting insert inclined to the rotation axis in direction to the part, which provides a step-by-step drilling into the workpiece, as shown in Figure 15 c, d.

The rectilinear cutting edge of the central cutting insert is inclined to the axis of rotation, and the rectilinear cutting edge of the peripheral cutting insert is inclined from the axis of rotation. The direction of inclination of the central and peripheral cutting inserts coincides with the feeding direction, the inclination angle $\theta_1$ of the central cutting insert being greater than the angle of inclination $\theta_2$ of the peripheral cutting insert, thereby gradually inserting the tool into the material being processed. In the order of insertion of the first I, the curved cutting edge of the central plate cuts into the workpiece. To avoid large radial cutting forces, the curved cutting edge is narrow. Then, in order of insertion of the second II into the material being processed, a straight cutting edge of the peripheral plate enters and
balances the radial cutting forces; the last III cuts the straight cutting edge of the central plate into the workpiece. In addition, the curvilinear cutting edge of the peripheral plate serves as a scraping edge and guide, thereby improving the quality of the treated surface. Such a scheme of gradual, stepwise drilling into the workpiece allows to reduce the cutting forces, increase the efficiency of the cutting inserts and to expand the technological capabilities of the prefabricated drill. To increase the reliability of the fastening of polyhedral cutting inserts, the central and peripheral cutting inserts are made on the basis of an equilateral trihedron. In the proposed design of the prefabricated drill, the misalignment of the cutting central and peripheral plate is eliminated when it is fixed, a power-closing rule is provided, that is, the direction of the cutting force $R_{xy}(H)$ coincides with the direction of the fastening force $P(H)$. Such fastening makes it possible to increase the operability of the cutting inserts and to increase the processing capacity.

The developed form of a cutting insert for a pre-cast drill made on the basis of an equilateral trihedron with cutting edges consisting of a curved and rectilinear portions where the cutting edge of the curved section is made in the form of an arc and inscribed in a quarter of the length of the side of the trihedron, the radius of the curved cutting edge being $1/3$ side length of the polyhedron, it allows to realize the scheme of gradual drilling of the cutting part of the tool into the material being processed, which provides a balance of cutting forces and higher drilling efficiency modular tool.

Figure 16. Sketches of processing by the assembly drill in terms of the number of revolutions and the scheme of incremental drilling of the cutting inserts of the assembly drill in the order of the insertion of I, II, III into the material being processed
To test the increase in the efficiency of the newly developed replaceable cutting insert, the simulation of the turning process with a continuous cutter was performed, as shown in Fig. 17.

Figure 17. Diagram of the simulation of the process of turning through hard cutter equipped with triangular cutting plate: a) standard form (ε=60º); b) developed by the shape (ε=90º)

For the trihedral cutting inserts standard (ε = 60º) and the developed shape (ε = 90º), a comparative stress analysis was carried out by the finite element method when the cutting edge was loaded with the specific load Pi for the following cutting conditions: roughing, the material being processed is stainless steel, the material of the cutting insert - hard alloy grade VK8.

The results of the calculation are shown in Fig. 19 in the form of pictures of isolines of principal stresses σ1 and diagrams of distribution of dangerous tensile stresses σ1 on the main cutting edges of trihedral cutting inserts of different shapes. On the abscissa of L, the digits denote the nodal points on the main cutting edge, including 1-5 the loading site. The ordinate shows the stress distributions σ1 at the cutting edge of the plate, in% of the applied load P_i.

Analysis of the plot of the tension stress distribution diagram σ1 showed that the change in the shape of the auxiliary cutting edge of the plate from rectilinear to curvilinear made it possible to reduce the value of the dangerous tensile stress σ1 on the loaded portion of the main cutting edge by approximately 2 times. The most dangerous area on the main cutting edge is the end zone of the loading site (nodal points 5-6).

To test the developed replaceable cutting insert, experimental studies were carried out when turning steel 12X18H10T. Two cutting end cutters with interchangeable cutting inserts made of VK8 were used as a cutting tool, with the first cutter equipped with a standard trihedral cutting insert with geometry: the front angle γ = 5 °; the rear angle α = 5 °; angle of inclination of the cutting edge λ = 10 °; the main angle in the plan is φ = 90 °; the auxiliary angle in the plan is φ1 = 30 ° and the angle at the vertex ε = 60 °. The second cutter, as shown in Figure 17, was equipped with a developed replaceable carbide cutting insert with an auxiliary cutting edge made in the form of an arc with geometry: the front angle γ = 5 °; the rear angle α = 5 °; angle of inclination of the cutting edge λ = 10 °; the main angle in the plan is φ = 90 °; an auxiliary angle in the plan φ1 ≈ 0 ° and an angle at the vertex ε = 90 °. Investigations were carried out under cutting conditions: feeding s = 0.4 mm / rev, cutting depth mm and different cutting speeds (in the interval 13 - 84 m / min).
Figure 18. Results of the study of the influence of the shape of the cutting insert on the distribution of dangerous tensile stresses $\sigma_1$ on the main cutting edges: a) the loading scheme of plates of different shapes; b) the distribution of the stresses of tensile stress $\sigma_1$ on the main cutting edges of three-edged cutting inserts of different shapes (▲ - $\varepsilon = 60^\circ$ and ● - $\varepsilon = 90^\circ$)

Figure 19. Photo of the cutter with a developed cutting plate of increased performance

The results of experimental verification of the developed replaceable cutting insert, as shown in Figure 20, showed that the new shape of the replaceable cutting insert allowed to increase the strength and operability of the cutting tool. Analysis of the results of the experiment made it possible to establish that for the developed cutting insert the change in the shape of the auxiliary cutting edge, from rectilinear to curvilinear, made it possible to increase the serviceability of the plate, measured approximately twice by cutting, as shown in Figure 18. The results of the theoretical calculations correlate well with the experimental data.

Thus, it is proved that an increase in the angle at the vertex $\varepsilon$ allows to reduce the value of dangerous stresses of tensile $\sigma_1$ and, accordingly, to increase the strength of cutting inserts and the efficiency of assembly tools.
Figure 20. Results of experimental verification of the developed replaceable cutting insert:
a) chipping and b) chipping the cutting blade of the trihedral cutting insert with the developed $\varepsilon = 90^\circ$
and the standard shape $\varepsilon = 60^\circ$;
c) wear and d) increased wear of the cutting blade of the trihedral cutting insert developed by $\varepsilon = 90^\circ$
and the standard shape $\varepsilon = 60^\circ$;
e) wear and f) shearing of the cutting blade of the trihedral cutting insert developed by $\varepsilon = 90^\circ$ and
standard shape $\varepsilon = 60^\circ$. 
Figure 21. The length of the cutting path of the standard and developed cutting inserts (▲ - ε = 60º and ● - ε = 90º)

Figures 22 and 23 show isoline patterns, and in Figure 24, stress strain diagrams σ₁ for peripheral and central replaceable cutting inserts (RCI) of various shapes, basing and fastening schemes offered by major instrumental firms. Three-sided: RCI 1 - firm Iscar with ε₁ = 60 º and ε₂ = 120 º; RCI 2 of the assembly drill - according to GOST 27724-88 with ε = 80 º; rhombic RCI 3 - firms Mitsubishi with ε₁ = 50 º and ε₂ = 100 º).

Analysis of the stressed-deformed state of replaceable cutting inserts of drills showed that the zone of the greatest dangerous stresses of stretching σ₁ is located in the cutting blade along the main cutting edge of the peripheral and central plates and depends on the shape, the baselines and the attachment of the replaceable cutting inserts.

Also on the value of dangerous tensile stresses σ₁ in replaceable cutting of the plates of prefabricated drills is influenced by the scheme of basing and fastening of cutting inserts in the tool body.

In the orthorhombic PSA 3 of Mitsubishi, as well as in the square RCI of the 4- firm Walter with ε = 90 º and the RCI 5- of Sandvik Coromant (peripheral RCI with ε = 90 º and central with ε = 110 º), the direction of the cutting force vector R does not coincide with the direction of the binding force vector P of the replaceable cutting inserts in the corner groove.

Based on the analysis of the stress state results in RCI, RCI 6 was developed - a new form of increased strength for prefabricated drills. A study of the stress state of the new RCI showed a significant reduction, up to 60%, of the dangerous tensile stresses σ₁ in the cutting blade along the main cutting edge of the peripheral plate, and a decrease in the stress σ₁ in the cutting blade along the main cutting edge of the central plate to a negative state (stress state) with a trihedral plate of irregular shape for prefabricated drills in accordance with GOST 27724-88.
Figure 22. Pictures of isolines of distribution of tensile stress $\sigma_1$ in cutting blades of peripheral RCI prefabricated drills of different firms:
1 - RCI of firm Iscar; 2 - RCI in accordance with GOST 27724-88; 3 - RCI - of firm Mitsubishi; 4 - firms Walter and Sandvik Coromant; 5 - new RCI form of increased strength developed by the author.
Figure 23. Pictures of isolines of stress distribution of tension $\sigma_1$ in the cutting blades of central RCI prefabricated drills of different firms
6 - RCI firm Iscar; 7 - RCI according to GOST 27724-88; 8 - RCI – firm Mitsubishi; 9 - firms Walter; 10 - firms Sandvik Coromant; 10 - a new RCI form of increased strength developed by the author
The main criterion for assessing the brittle strength of replaceable cutting hard-alloy plates of prefabricated drills is the safety factor for normal stresses $K$. The minimum value of the safety factor for carbide cutting elements of assembly tools must be at least $K = 1.5$.

Verification calculation of strength for peripheral replaceable cutting inserts of the assembly drill in accordance with GOST 27724-88 showed that the most dangerous zone is the top of the cutting blade. In this case, we are interested in the bands in which $K$ approaches critical values ($K < 1.5$).

**Figure 24.** Graphs of stress distribution of tension $\sigma_1$ in cutting blades RCI:

a) peripheral; b) central prefabricated drills of different firms

(1 – RCI firm Iscar, 2 – RCI in accordance with GOST 27724-88, 3 – RCI-firms Mitsubishi, 4 – firm Walter; 5 – firm Sandvik Coromant; 6 – the new RCI form of increased strength developed by the author)
Figure 25. The boundaries of the ultimate fracture surfaces of the replaceable carbide cutting insert of the assembly drill in accordance with GOST 27724-88

Investigation of the strength of the new replaceable cutting insert showed that an increase in the angle at the vertex $\epsilon$ and a baseline and fastening of the plate into the angled groove of the tool body along the two lateral surfaces of the plates so that one of them falls on the auxiliary cutting edge allows to reduce the dangerous zone of probable failure, the safety factor is less than the limit value in comparison with a trihedral plate of irregular shape for prefabricated drills in accordance with GOST 27724-88.

Figure 26. The boundaries of the ultimate fracture surfaces of the replaceable carbide cutting insert of the assembly drill in accordance with GOST 27724-88 in the cutting plane of the plate

Figure 27. The boundaries of ultimate fracture surfaces by a new form developed by the author of a replaceable cutting insert of increased strength

Modeling of the loading of replaceable cutting inserts of prefabricated drills in accordance with GOST 27724 for high loads under conditions of cutting conditions typical for prefabricated drills with replaceable cutting heads (when processing stainless steel for prefabricated drills with replaceable cutting heads, cutting modes are typical:
V = 70 m / min, S = 0.25 mm / rev, for prefabricated drills with replaceable cutting inserts: V = 150 m / min, S = 0.10 mm / rev) showed that for replaceable cutting inserts operating at increased feeds, the zone of dangerous tensile stress $\sigma_1$, as represented in Figure 25, and also, the zone of possible fracture is represented in the figure as 2-4 times larger than for replaceable cutting inserts of prefabricated drills operating at the recommended cutting conditions, which causes the use of prefabricated drills with replaceable cutting inserts at low feed rates, and also confirms the correctness of the author's proposed method for studying the stress state and the strength of replaceable cutting carbide elements of prefabricated drills.

**Figure 28.** Insulation patterns of tension distribution $\sigma_1$ in the cutting blades of the peripheral replaceable cutting insert of the assembly drill in accordance with GOST 27724 operating: a) in the range of recommended cutting conditions (V = 150 m / min; S = 0.10 mm / rev); b) with increased feed rate (V = 70 m / min, S = 0.25 mm / rev)

**Figure 29.** The boundaries of the ultimate destruction surfaces of the replaceable carbide cutting insert of the assembly drill in accordance with GOST 27724 operating with increased feed
Figure 30. The boundaries of the ultimate fracture surfaces in the cutting plane of the replaceable carbide cutting insert of the assembly drill in accordance with GOST 27724 operating with increased feed

Thus, in the replaceable cutting hard-alloy plates of prefabricated drills, an increase in the angle at the vertex $\varepsilon$ and the base and fixing of the plate into the angled groove of the tool body along the two lateral surfaces of the plates, so that one of them falls on the auxiliary cutting edge, reduces the dangerous tensile stress $\sigma_1$.

When designing, creating and developing new designs of cutting tools, the problem of strength calculation is the key.

4. The developed design of the assembly drill with replaceable cutting inserts of increased strength

Based on the above studies, the design of a prefabricated drill with interchangeable cutting inserts of increased strength was developed and patented.

The invention relates to the field of material processing by cutting, assembled cutting bit with mechanical fastening of polyhedral cutting inserts.

Figure 31. Prefabricated drill with replaceable cutting inserts of increased strength [3]

The drill comprises a Case, a central cutting insert mounted adjacent to the axis of rotation and a peripheral cutting insert identical to the central cutting insert. The peripheral cutting insert is further away from the axis of rotation than the central cutting insert. In order to increase the efficiency, reduce cutting forces and expand the technological capabilities of the drill, the rotation path of the central cutting insert and the peripheral cutting insert at least partially overlap to form an overlap region, the cutting edge of the inner cutting insert and the cutting edge of the outer cutting insert inclined toward the axis of rotation in the direction towards details, which provides a step-by-step drilling into the workpiece. To improve the reliability of the fastening of polyhedral cutting inserts, the central and peripheral cutting inserts are made on the basis of an equilateral trihedron with the main and minor cutting edges formed by the intersection of the front surface with the side surfaces. In prefabricated drills of this design, the misalignment of the cutting inserts is eliminated when the screw is tightened, the force closure rule is ensured, that is, the direction of the cutting force coincides with the direction of the fastening force. The results of production tests at the JSC "Gazturboservis" (Russian Federation –
Tyumen city) of prefabricated drills with the developed replaceable cutting carbide elements while drilling parts from steel 12X18H10T on the recommended cutting conditions, which showed an increase in the working capacity of the prefabricated units with replaceable cutting inserts by 1.7 times.

Figure 32. Production tests of a tool equipped with a replaceable high-strength cutting insert and a drill bit [4] with replaceable cutting inserts [3]

5. Conclusions

Based on the results of stress-strain analysis and the strength of replaceable cutting inserts of prefabricated drills, qualitative and quantitative analyzes of the influence of loading conditions, design parameters of replaceable cutting inserts, and the basis and fixing schemes on the stressed state and strength were carried out. In addition, based on all of the above, the following conclusions were formulated:

1. A new form of replaceable cutting inserts of increased strength with an increased angle at the vertex $\varepsilon$ is developed. To improve performance, the auxiliary cutting edge of the replaceable cutting insert is formed as an arc of a quarter-long side of the polyhedron $L$, where the radius $R$ of the curved cutting edge is equal to half the length of the side of the polyhedron.

2. With the use of the finite element method, deformation and stress diagrams were first obtained in cutting carbide plates of prefabricated drills of various shapes, the results of which formulated the following requirements for the design parameters of prefabricated drills of increased serviceability:
   - an increase in the angle $\varepsilon$ at the vertex RCI;
   - the scheme of basing and fixing the plate in the angular groove of the tool body along the two lateral surfaces of the plates so that one of them falls on the auxiliary cutting edge.

3. Investigations of the stressed state of replaceable cutting inserts of prefabricated drills have shown that the use of a new designed replaceable cutting insert with an increased angle at the vertex $\varepsilon$ allows to significantly reduce the value of the dangerous tensile stress $\sigma_1$ on the main cutting edge of the peripheral plate and to reduce stress values $\sigma_1$ on the main cutting edge of the central plates up to a negative value (compressive stress) as compared to a trihedral plate of irregular shape for prefabricated drills in accordance with GOST 27724.

4. An increase in the angle at the vertex $\varepsilon$ and a scheme of basing and fixing the central and peripheral plates in the angled groove of the tool body along the two lateral surfaces of the plates so that one of them falls on the auxiliary cutting edge allows to significantly reduce the dangerous zone of dangerous tensile stress $\sigma_1$.

5. In accordance with the formulated requirements for the construction of prefabricated drills of increased serviceability, the design of a prefabricated drill with replaceable cutting inserts of increased strength and a scheme for their fixing and basing into the corner groove was developed.
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