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INVESTIGATION OF THE INFLUENCE OF THE METHOD OF FIXING THE CUT-OFF TOOL INSERTS ON ITS STRESS STATE

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Abstract. Cut-off tools equipped with carbide inserts are commonly used in turning operations. Due to the very heavy conditions in which such blades work, they fail, as a rule, not as a result of their operation, but due to the breakage of carbide inserts. This study investigates the causes of such failures and methods to prevent such phenomena. A thorough analysis of the current state and research methods of stress state in cutting tools, including turning cutters, was carried out. Methods of stress reduction in carbide inserts were also analysed. This paper focuses on the study of the stress state in cut-off tools with brazed carbide inserts. The stress state in the carbide inserts and the influence of different fixation methods of carbide insert to the holder were considered. The main approach to stress studies was the photoelasticity method, which allows quickly and clearly obtaining and evaluating the results. Models of carbide inserts were made of optically sensitive material. It as a part of a complex model of a cut-off tool with a carbide insert with three different methods of fixation were loaded with a force by means of a specially designed stand simulating the cutting force. The study was carried out on a PPU-7 polarisation-projection unit. Isochromatic and isocline patterns were obtained. The estimation of the principal stresses was performed by the difference of shearing stresses for three cross sections of the insert: at the surface, in the middle and at the base. It was found that the best result is given by the method in which the insert on the side far from the cutting edge has a bevel made at an angle of 10°

Keywords: tension, cutting tool, photoelasticity, fixation

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INTRODUCTION

When making parts from a bar or a disc, which are fed through the spindle of a lathe, as a rule, the final operation is cutting. This operation is performed by special cut-off tools. Since the cutting operation is the last, the quality of this tool significantly affects the quality of the manufactured part. The work carried out by the cut-off tool takes place in heavy conditions. Cutting takes place over the entire width of the narrow blade, which, moreover, is fixed on three sides by the backing. Such conditions create a high load on the tool, both power and thermal, which, in turn, requires its high strength and durability. Additionally, it is necessary to take into account the difficulty of chip removal in such conditions. Cutters which make grooves in details work in similar conditions. Since modern cut-off tools are equipped with carbide inserts, it is important to fix them, which would provide the lowest stresses in the inserts under loads during operation.

In practice, two basic designs of cut-off tools are used. At some the hard-alloy insert is brazed to a holder by means of a copper-based alloy, and at others it is replaceable and is fixed by the special clamp (Fig. 1).

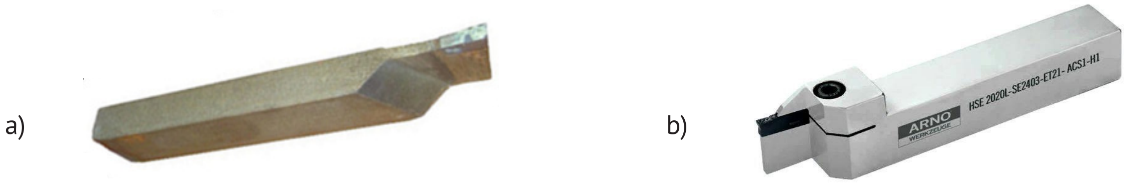

***Figure 1**. Cut-off tools: a) brazed [1]; b) assemblable [2]*

Cutters with brazed inserts are used in single and small-batch production, as well as when working on automatic machines, where high precision machining is required and the tool should not have any gaps. In other cases, prefabricated cutters of various designs are used. Such tool designs make it easy to replace a worn-out carbide insert without the need to sharpen it. In this study, the main attention was paid to cutters with brazed inserts.

The main reasons for failure of cut-off tools with brazed inserts are their breakage due to the appearance of microcracks at the stage of brazing, overloading the cutters in the wrong cutting modes and untimely sharpening of the tool. The study [3] claims that 40-50% of cutters with brazed carbide inserts fail due to breakage of the inserts, and not due to their wear during operation. Because such tools are quite expensive, it leads to significant unproductive material losses.

The *purpose* of the study is to optimise the method of fixing the brazed carbide insert of the cut-off tool through the investigation of the stress state for different fixing options and thus increase the efficiency of the cutters.

LITERATURE REVIEW

To prevent failure of the cutters due to breakage of the inserts, studies of the stress-strain state of the cutter are carried out, in particular, the carbide insert under the load of the forces arising in the cutting process. At the same time, both computational and experimental research methods are applied. Important for both computational and experimental study is the method and location of application of the load acting on the carbide insert. Thus, the study [4] suggests that the most dangerous zone during the loading of the insert is the area of the front surface outside the contact at a distance of 1.5-2.5 contact length. And this allows applying the St. Venant's principle to determine the stresses in this zone, when instead of a distributed load a concentrated force is applied to the top of the wedge. To calculate the stresses that occur in the danger zone of the insert, the study provided special nomograms that allow determining the optimal geometric parameters of the cutting wedge. A more accurate distribution of loads and contact stresses on the front and rear surfaces of the cutter in conditions close to real is provided by the split cutter method. This method was used by a number of researchers, including V.A. Ostafyev [5], M.F. Poletik [6] and others. The disadvantage of this method is the inability to determine the stress distribution in the body of the insert. In addition, the method of a split cutter allows studying the distribution of contact stresses only in the conditions of orthogonal cutting.

The study [7] estimated the magnitude of the loads on the cutter during orthogonal cutting and the cutting process itself in real conditions using a Phantom v7.3 Vision Research high-speed camera. The results of these studies showed that the magnitude of stresses in the cutter blade is influenced not only by the magnitude of the vertical component of the cutting force P_z, but also by the magnitude of the horizontal component P_y. This is confirmed by studies conducted by S.Y. Liang and J.C. Su [8]. That is, when modelling the cutting process, the force acting on the cutting plate must be applied at a certain angle. The magnitude of stresses is also affected by the heat released during the cutting process, but, as stated in [9], during orthogonal cutting, the mechanical effect is the dominant factor. The main tool of analytical studies of the stress-strain state of a metal-cutting tool is the finite element method. The cross section of the body of the tool under study is divided into a finite number of triangular elements with rectilinear sides and the stress state of each of them is calculated. Due to the approach to the blade of the tool to increase the accuracy of calculations, the grid of triangular elements thickens. To model the cutting process by the finite element method, special software products DEFORM, THIRD WAVE ADVANTEDGE (TWA), ABAQUS, LS-DYNA, ANSYS, FORGE and others are used. For example, in [10] the ANSYS programme was used to detect dangerous tensile stresses in carbide inserts in the process of replacing the cutting part from the group of high-speed steels with a carbide cutting part. The same software product was used in [11] to determine the cutting stress during the finishing turning of the hardened alloy AISI H13. Ukrainian scientists have developed the OCFEM model [12], which is used to solve the problem of modelling the process of orthogonal free cutting. Each of these models to some extent takes into account the influence of the magnitude of the cutting forces, cutting parameters, properties of the tool material, temperature, friction and other values. The main question is – how the results correspond to the real picture of the stress-strain state in the body of the tool.

Experimental methods for studying the stress-strain state of a metal-cutting tool include, for example, the holographic method. The study [13] used a holographic interferometry setup based on the HYTEC PRISM deformation and vibration measurement system to determine the deformations of lathes. This allowed combining the results of numerical and experimental studies and obtaining optimal parameters of cutting modes.

The main reason for the breakage of carbide inserts during machining is the occurrence of large tension stresses near the front surface of the insert, exceeding the strength limit of the material. Different studies have suggested different approaches to avoid such tensions. Thus, as a result of [14] it was found that in the process of increasing the thickness of the insert more than 5 mm, there is a significant reduction in tension stresses on the front and bottom surfaces of the insert. The calculation of internal stresses in the insert was performed using the ANSYS14.0 software. The stress in the carbide insert can also be reduced by using an alternative to brazing method of attaching the insert to the holder. The method of diffusion fixing of a hard-alloy insert described in [15] provides, along with stress reduction, also rigid resistance under the cutting plate.

MATERIALS AND METHODS

The photoelasticity method, based on the properties of some transparent materials in which optical anisotropy and associated birefringence occur under the action of applied mechanical loads, can be used to study the stress-strain state of structures. Materials for making models for the study of photoelasticity must meet the following conditions: sufficient optical activity, transparency, isotropy and homogeneity, no initial optical effect, edge effect, linear relationship between stresses and strains and the sequence number, no noticeable creep, the possibility of labour-intensive machining in the process of making models. Although the photoelasticity method due to the development of numerical models is not often used, according to [16] it has great potential, because the information obtained by this method is formed at the micro level. This method is successfully used to study, for example, the stress-strain state of the fixing unit of the carbide cutting tool [17]. New optically sensitive materials with a wide range of optical, mechanical, and rheological properties have been developed, which allow considering a wide range of engineering problems in the study of the stress state [18].

In this study, the photoelasticity method was used to investigate the stress-strain state of a carbide insert during various methods of its fixation. The PPU-7 polarisation-projection unit was used in the study. Models of carbide inserts were made of optically sensitive material based on ED-6 epoxy resin cured with methyltetrahydrophthalic anhydride with an optical constant $\sigma_0^{1.0} = 1.88$ MPa. The geometric dimensions of the models are presented in Fig. 2.

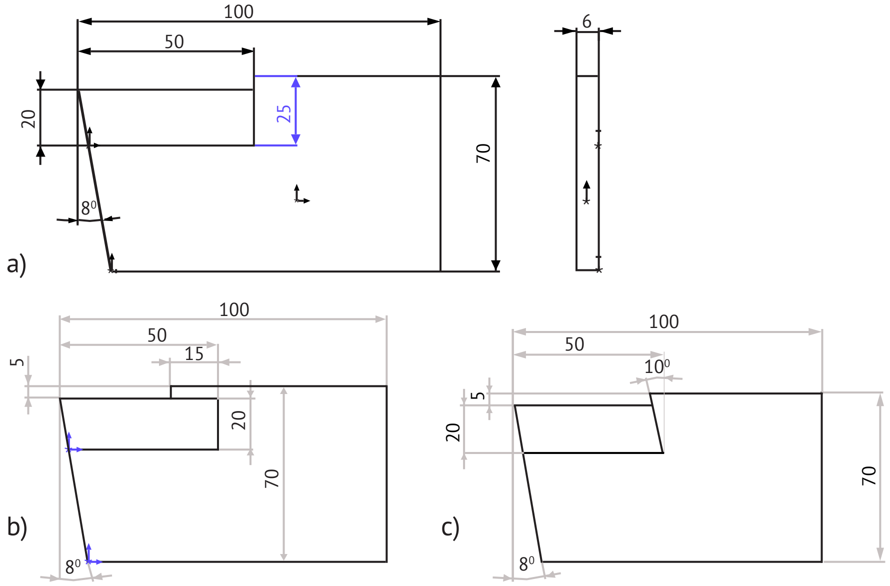

***Figure 2**. Geometrical dimensions of models of cut-off tools: a) standard variant; b) with additional fixation from above; c) with a bevelled back of the insert*

The geometric parameters of the model are selected based on the geometric scale of the simulation (1):

$$\alpha = \frac{l_p}{l_m} = const, \qquad (1)$$

where l_p i l_m – the lengths of any corresponding segments in kind and on a model.

The power scale can be selected arbitrarily (2):

$$\beta = \frac{P_p}{P_m} = const. \qquad (2)$$

The scale of similarity of stresses will be related to the force scale β through the geometric scale α (3):

$$\delta = \frac{\sigma_p}{\sigma_m} = \frac{\beta}{\alpha^2} = const. \qquad (3)$$

In accordance with the general principles of the similarity theory, the modulus of elasticity of a model having the dimension of stresses should be modelled on the same scale as stresses б (4):

$$\frac{E_p}{E_m} = \delta = const, \qquad (4)$$

where E_p i E_m – elastic moduli at the corresponding points in kind and on a model.

Poisson's ratios of materials in kind μ_p and materials on a model μ_m as dimensionless quantities should be equal to each other (5):

$$\mu_k = \mu_{m.} \qquad (5)$$

The fulfilment of these similarity conditions is sufficient for the internal (which are investigated) stresses in the model to have a scale δ, a displacement scale α, and the deformations of the model and in kind coincide. This allows, based on the findings, evaluating the real state of the stressed state of a cutter with a carbide insert.

RESULTS AND DISCUSSION

In the course of the study, models of cutters were installed in a special stand and loaded with a force that mimics the cutting force (Fig. 3). The magnitude of the applied force was measured using a LMF universal dynamometer.

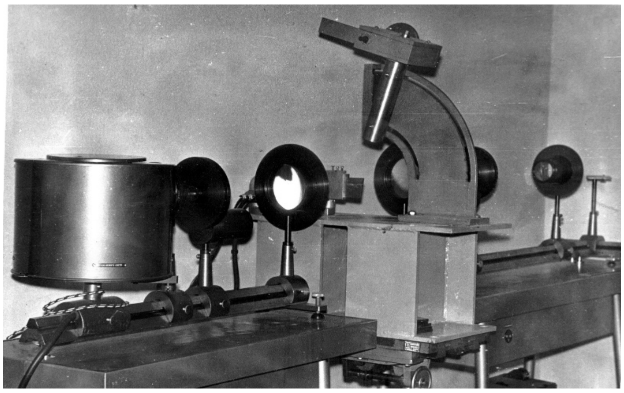

***Figure 3**. PPU-7 polarisation-projection unit with the stand for loading*

For each method of fixing at the same loads P_z=1000H, isochromatic patterns (strips of the same colour connecting the points with the same difference of the main stresses) (Fig. 4) and isoclinal patterns (dark lines connecting the points with the same direction of the main stresses) were obtained. To determine the stresses along arbitrary lines, two parallel auxiliary sections were drawn on different sides of these lines at a sufficiently close distance from the main ones. The values of tangential stresses τ'_{xy} and τ''_{xy}, were determined along these sections, as well as the differences of these stresses $\Delta\tau_{xy}=\tau'_{xy} - \tau''_{xy}$ between the auxiliary sections.

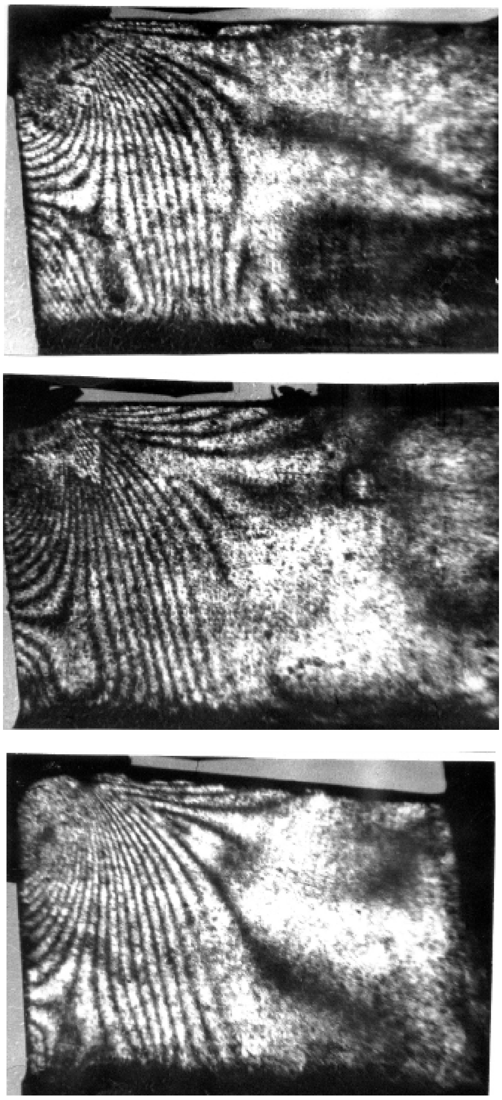

***Figure 4**. Isochromatic and isoclinal patterns with different fixation of the insert*

The values of normal stresses σ_x and σ_y were determined using formulas (6-7):

$$\sigma_{xn} = \sigma_{x0} - \sum_{i=1}^{n}(\Delta\tau_{xy})_i \frac{\Delta x_i}{\Delta y}; \qquad (6)$$

$$\sigma_{yk} = \sigma_{y0} - \sum_{r=1}^{k}(\Delta\tau_{xy})_r \frac{\Delta y_r}{\Delta x} + \gamma \sum_{r=1}^{k} \Delta y_r, \qquad (7)$$

where n and k – the number of measured points along the x and y axes, respectively; σ_{x0} and σ_{y0} are known values of σ_x and σ_y at the starting point of integration; Δx_i and Δy_r – intervals along the x and y axes, through which measurements were performed; Δx and Δy – the distances between the parallel auxiliary sections along the x and y axes; $\gamma\sum_{r=1}^{k}\Delta y_r$ – the product of volume weight by the length of the integration segment (taken into account if the model operates under its own weight).

Knowing the values σ_x,σ_y and τ_{max} for each section, the values of the principal stresses σ_1 and σ_2 were determined. The calculation of the dangerous section of the hard-alloy insert was carried out according to maximum-strain of failure. The equivalent stress σ_{eq} was determined for the case of a plane stress state (8):

$$\sigma_{eq} = \sigma_1 - \mu\sigma_2 \tag{8}$$

The calculation was performed for eight points for each of the three longitudinal sections of the insert: at the surface, in the middle, and at the base for all three methods of fixing the insert. According to the values of σ_{eq} the dependences of the location of dangerous sections and the value of σ_{eq} on the method of fixing the carbide insert were obtained. Figures 5-7 show graphs of the distribution of σ_{eq} (values are presented in bands) along the front surface of the inserts, along the middle section of the inserts, and along the base of the inserts for all three samples with different fixation of the carbide insert.

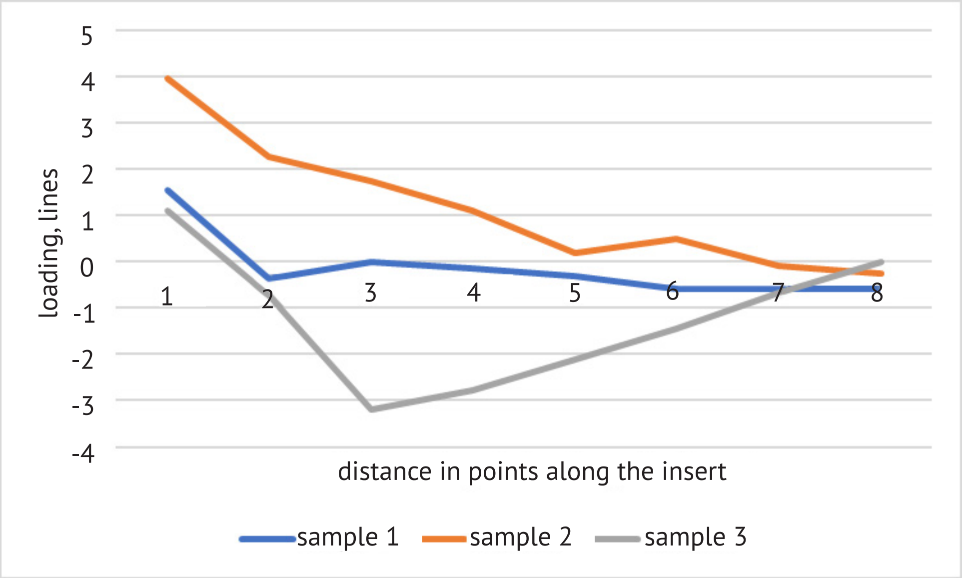

***Figure 5**. Distribution of σ_{eq} along the front surface of the inserts*

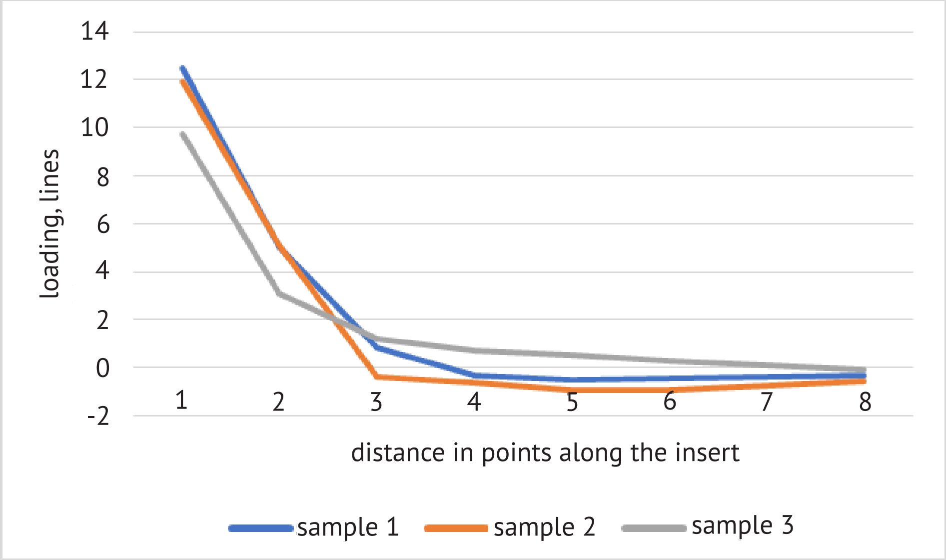

***Figure 6**. Distribution of σ_{eq} along the middle section of the inserts*

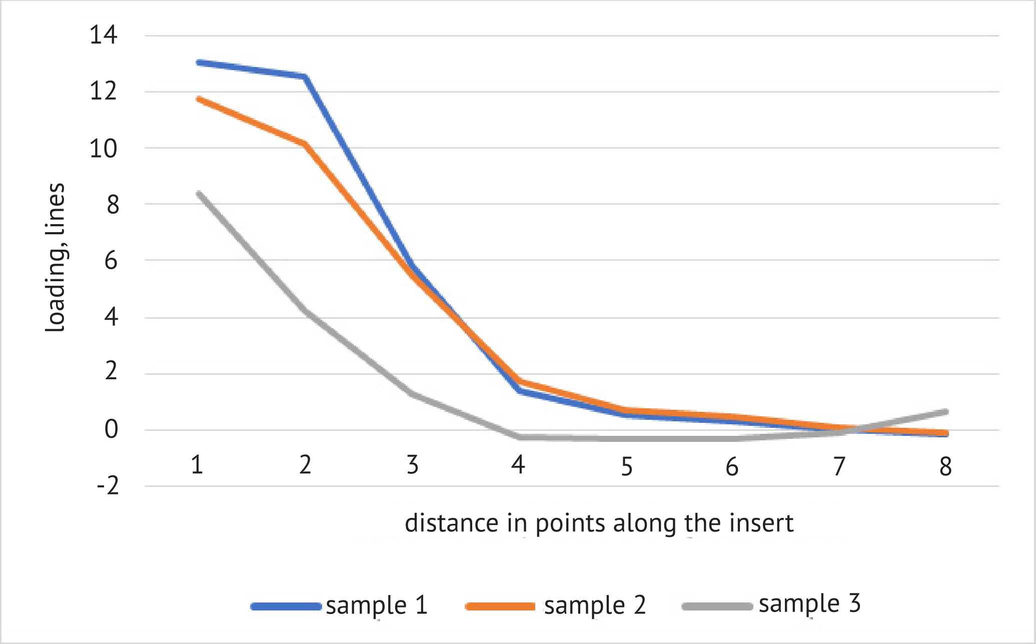

Figure 7. *Distribution of σ_{eq} along the base of the inserts*

Admittedly, the stresses according to the fixation method No. 3 are the smallest in all three sections. Therefore, it is proved that the method of fixing the carbide insert to the cutter holder affects the stress distribution in the tool. It allows choosing an optimum way of fixation due to which the stress will be the smallest and at the same time reduce probability of breakage of hard-alloy inserts during their operation.

CONCLUSIONS

Studies of the influence of the method of fixing the cutting carbide insert on the stress distribution allows for the conclusion on the most appropriate fixation method in terms of strength. The results obtained show that the stress distributions for all three methods of fixing the carbide insert are similar. The greatest stresses occur near the blade of the cutting edge, they gradually decrease moving away from the blade. The location of the dangerous sections for all three types of fixation is approximately the same, but the values of stresses in them with different fixation can differ. The most expedient, from this point, is the third method of fixing, in which the amount of stress is the smallest.

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ДОСЛІДЖЕННЯ ВПЛИВУ СПОСОБУ ЗАКРІПЛЕННЯ ПЛАСТИНКИ ВІДРІЗНОГО РІЗЦЯ НА ЇЇ НАПРУЖЕНИЙ СТАН

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Анотація. Оснащені твердосплавними пластинками відрізні різці є дуже поширеним інструментом, який використовується в токарних операціях. Через дуже важкі умови, у яких працюють такі різці, вони виходять з ладу, як правило, не в результаті їх спрацювання, а внаслідок поломок твердосплавних пластин. У даній роботі досліджувалися причини таких поломок і методи для запобігання таким явищам. Проведений ґрунтовний аналіз сучасного стану та методів досліджень напруженого стану в ріжучих інструментах, зокрема токарних різців. Аналізувалися також методи зменшення напружень у твердосплавних пластинках. Дана робота зосереджена на вивченні напруженого стану у відрізних різцях з напайними твердосплавними пластинками. Водночас вивчався напружений стан у твердосплавних пластинках і вплив на нього різних способів закріплення твердосплавної пластинки до державки. Основним методом досліджень напруженого стану був метод фотопружності, який дозволяє досить швидко та наочно отримати й оцінити результати. Були виготовлені з оптично-чутливого матеріалу моделі твердосплавних пластинок, які у складі складної моделі відрізного різця з твердосплавною пластинкою з трьома різними способами закріплення, за допомогою спеціально розробленого стенду, навантажувалися силою, що моделювала силу різання. Дослідження проводилися на поляризаційно-проекційній установці ППУ-7. Були отримані картини ізохром та ізоклин. Розрахунок головних напружень виконувався методом різниці дотичних напружень для трьох перерізів пластинки: біля поверхні, посередині і біля основи. Встановлено, що найкращий результат дає спосіб, за якого пластинка на віддаленій від ріжучої кромки стороні має скіс, зроблений під кутом 10°

Ключові слова: напруження, різець, фотопружність, закріплення