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DESIGNING THE STRUCTURES OF DISCRETE SOLID-ALLOY ELEMENTS FOR BROACHING THE HOLES OF SIGNIFICANT DIAMETER BASED ON THE ASSESSMENT OF THEIR STRENGTH

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Розглянуті питання конструювання та оцінки міцності твердосплавних елементів деформуючих протяжок значного діаметра (більше 150 мм) для розробленого процесу дискретного протягування. Граничний стан інструмента оцінювали за двома критеріями міцності: питомої потенційної енергії формозміни і максимальних дотичних напружень. Чисельним моделюванням методом скінченних елементів отримано розподіл еквівалентних напружень в елементах інструмента і контактних напружень по поверхні контакту твердосплавна вставка-корпус, що дозволило проаналізувати міцність інструменту під навантаженням. Моделювання виконувалось при одиничному нормальному навантаженні, що забезпечило універсальність розрахунку для любих значень контактного тиску. Отримані формули для розрахунку допустимого контактного тиску в залежності від одиничного навантаження. Встановлений вплив висоти виступу вставки над поверхнею корпусу на міцність елементів збірного інструменту. Розроблені інженерні залежності, які визначають необхідну величину виступу вставки над корпусом в залежності від граничного навантаження. Розглянуто приклад розрахунку міцності збірного деформуючого елементу при обробці гільзи із сірого модифікованого чавуну твердістю HB230. Виконанні розрахунки показали, що деформуючий елемент, розроблений для нового технологічного процесу дискретного протягування, відповідає умовам міцності при умові дотримання співвідношення $h_1/h=0,15$ (де h_1 – висота вставки над корпусом, h – висота вставки). Отримані результати можна використати в інженерних розрахунках при проектуванні збірного інструменту для дискретного протягування, а також для оцінки міцності збірних інструментів, наприклад фрез, зенкерів, розгорток при уточнені зовнішніх навантажень

Ключові слова: деформуюче протягування, напружений стан, твердий сплав, дискретний деформуючий елемент, міцність елементу

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1. Introduction

One of the main tasks of modern machine building is to devise and implement resource-saving technologies to improve the quality of articles [1]. Deforming broaching (DBR) is a highly efficient and economical operation in the machining of holes [2] and is used both as the draft and finishing operation, including the processes of shape formation and deformation strengthening. Currently, DBR is applied in engineering production when machining precise holes with low roughness and for draft operations to adjust pipe blanks made from various materials before further treatment [3–5]. In this case, both small surface and large deformations can be executed, reaching 20 %, which change the size of a component and the mechanical characteristics of the machined material [6]. Given this, the use of DPR in combination with cutting as advance plastic deformation is a promising direction [7, 8].

Scientists from the Institute of Super-Solid Materials of the Ukraine's National Academy of Sciences devised an effective technological process for machining holes in the sleeves of internal combustion engines (ICE) made from gray modified cast irons [8, 9]. This process is implemented on the basis of a combined broaching operation. In this case, the machining involves a broaching tool, which includes the sequentially placed deforming and cutting elements and a group of deforming elements behind them [8, 9].

The use of such a technological process, when compared to the existing one, which includes boring and honing operations, has made it possible to improve the process efficiency by 3 times and to ensure obtaining the surface of a sleeve with the enhanced mechanical characteristics and the roughness close to equilibrium [9].

However, the widespread adoption of this technological process, especially under conditions of large-scale production, was constrained by the formation, in a confined space in front of the cutting element, of ring shavings, the removal of which was difficult. The shavings compressed in the operation process, the axial force of broaching increased sharply, the quality of the machined surface deteriorated.

Therefore, an effective technique was devised to split the ring shavings into elements [9], which implied designing a structure of the deforming element for the discrete deformation of sections at the sleeve surface. In this case, the element was placed in front of the cutting tooth. When a cutting tooth removes the allowance from a discretely deformed surface, the ring shavings form at first, which, at the moment of cutting, are destroyed into separate elements in the places where the machined area is transitioned into the untreated area. In other words, over areas where there is a preliminary deformation of the surface layer of such a semi-fragile material as cast iron. The devised technique resolved the issue of effective separation of ring shavings. However, to apply this technological process industrially, it is necessary to ensure the operation of the prefabricated deforming element for discrete broaching. This is achieved by devising a scientifically-substantiated methodology for assessing its structural strength.

2. Literature review and problem statement

The efficiency of low-waste DBR-based metal machining technological processes largely depends on the performance of deforming elements (DE) in broaches, which, according to recommendations from [8, 10, 11], are made from a solid alloy of the VK group. When expanding a blank by such elements, the contact area is exposed to high normal (up to $9\sigma_T$ of the machined material) and tangential stresses, leading in some cases to the destruction of the elements. Therefore, assessing the structural strength of DE is necessary in solving any task related to DBR.

The strength of the elements for discrete deformation has not been studied before, although the operational conditions are more severe than those of conventional DEs operating under similar conditions, which is due to a significant decrease in the area of its contact with the machined component compared to a conventional DE. Therefore, assessing the strength of the discrete element and identifying, based on this, its structural elements would ensure the operational efficiency not only of the discrete element but the entire operation of machining the sleeve holes, which takes place over a single run of the tool.

There are several approaches to assessing the structural strength of DE. The most common is the approach described in [10], whereby a DE is treated as a beam on an elastic base. In this case, the criterion for assessing strength is the comparison of the permissible bend stresses $[\sigma_{bend}]$ and the bend stresses that occur in the DE under load. However, a series of assumptions made in calculating stresses and choosing a strength criterion, as well as taking into consideration those stresses that arise only from bending, do not make it possible to objectively assess the strength of the elements. Another approach to assessing the strength of DEs is based on the use of a finite element method (FEM) [12, 13] employing different criteria, such as by Pisarenko-Lebedev. These procedures have enabled a detailed research into the structural strength of whole-made DEs, which has made it possible to widely apply a DBR process in machining a large range of articles made from various structural materials [11, 13].

At discrete deformation, the tool machines sections only at the inner surface of the sleeve. To this end, the samples of the necessary size are fabricated at its outer surface, which make it possible to deform not the entire surface but only some sections.

However, with the large size of the sleeve holes ($d>$ >150 mm), it is not advisable to make DEs completely solid alloy, when each deforming element requires a large amount of acutely deficient solid alloy for its manufacture. This makes the use of the tool made from such elements limited and, in some cases, even impossible. In addition, there are difficulties of a technological nature in the manufacture of molds for such elements, as well as in ensuring the quality of pressing of significant volumes of solid-alloy mixture without the emergence of their discontinuity in the form of pores.

The authors of [14] conducted research on the construction of a structure of steel tools with wear-resistant coatings at their working surface. In most cases, however, the performance of such a tool is much worse than a solid-alloy one. Therefore, the task of creating a solid-alloy DE structure, which minimizes the consumption of scarce solid alloy, is certainly important.

One of the ways to solve this task in the construction of tools for machining the holes with a diameter of more than 150 mm, as the authors of [13] argue, is to design a structure of a prefabricated DE, consisting of a steel base and an external thin-walled solid-alloy ring 1 of height l and a thick wall H. It has a working cone at angle γ_u, a cylindrical ribbon of length b, and a reverse cone with angle γ_{inv}. However, the inaccuracies in a solid-alloy ring hole that occur when it is made represent a significant problem, which can even lead to the destruction of the solid-alloy part of the prefabricated tool. Therefore, the authors of [13] recommend that the steel 3 and solid alloy 1 parts of the tool should be executed with a guaranteed gap of size t, which, after assembling these parts, is simply filled with lightweight metal 2 (Fig. 1).

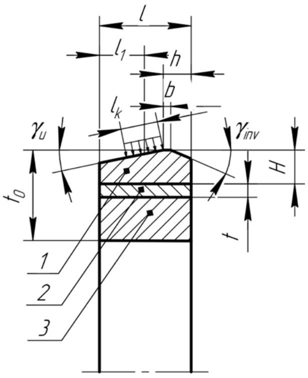


Fig. 1. The structure of a prefabricated deforming element: 1 — solid-alloy ring; 2 — ring made from lightweight material; 3 — steel ring

The existing procedure for calculating the strength of such a solid element [10] is unsuitable for the considered case because of the significant difference between the elastic characteristics of the three materials, which are used in this structure and form a composite wall of thickness t_0. Therefore, the strength of the prefabricated DE was investigated by the authors of work [13] using FEM. Their calculations made it possible to devise recommendations for designing such a tool. Moreover, its development, according to the received recommendations, made it possible to save, only in a single DE with an external diameter of d_4=152 mm, 6 kg of the acutely deficient solid alloy VK15.

However, in some cases involving the machining of holes, one should use the solid alloy DEs, which perform discrete deformation. Such cases include the discrete deformation of cylindrical holes by elements that have an intermittent working surface. As mentioned above, this type of machining is used in the combined broaching of blanks made from the gray modified cast iron SCh20 GOST1412-85 [8, 9]. The DE is placed in front of the cutting element, which has a solid blade and provides, due to the discrete deformation, the separation of ring shavings, cut by the cutting element, into separate segments. This improves the process of machining the openings in such components as, for example, the ICE sleeves, whose hole diameter can reach 300 mm.

However, in order to work effectively, the specified technological process requires that the structural strength of the prefabricated deforming element for discrete broaching should be ensured.

According to the analysis of literary sources [9–13], known methods of calculating the strength of the deforming elements are not acceptable for the considered case. The calculation procedures [10, 12] are devised to assess the strength of whole-made DEs. They are not applicable to calculate the strength of a prefabricated element because of the significant difference in the elastic characteristics of the three materials that make up the prefabricated element wall.

The procedure from [13], used to calculate the strength of the prefabricated solid deforming element, applied to machine the holes of significant diameter (*d*>mm) is also not suitable for calculating the strength of the prefabricated deforming element for discrete broaching due to the difference in their load patterns. In the element considered in [13], the load zone is a ring area, and in a DE for discrete broaching, the load area consists of discrete sites, the number of which corresponds to the number of solid-alloy inserts. This changes the pattern of interaction between the working area of the tool and the machined component, and, therefore, the quality of the external load on the element.

Thus, there is a need to devise a new procedure to assess the strength of a working element for the discrete deformation of holes of significant diameter. The design of the working element should take into consideration the technological conditions of its operation, that is, the actual scheme of contact interaction between the working sites of the tool and the machined part. In addition, the development of the tool structure should take into consideration the possibility of saving an acutely deficient solid alloy, which is especially relevant in the machining of holes of significant diameter (*d*>150 mm). A prerequisite for the effective operation of such a tool is to devise a methodology for calculating it for structural strength and to optimize, on this basis, the structural parameters of the prefabricated tool.

3. The aim and objectives of the study

The aim of this study is to devise a procedure for assessing the strength of a prefabricated DE for discrete deformation, which would make it possible to assess its structural strength and optimize the design of the tool.

To accomplish the aim, the following tasks have been set:

– to investigate the stressed-strained state (SSS) of a prefabricated element when applying unit load and determine the impact of structural parameters on its strength;

– to establish a link between the tool structural parameters and its durability; to optimize, based on this, the structural parameters of solid-alloy deforming inserts;

– to study the impact of the contact load application place on strength of the working element, to devise practical recommendations for the implementation of strength calculations;

– to determine, based on the strength calculation, the structural parameters of the tool for the discrete broaching of a particular component.

4. Research methods and materials

The problem is solved for a prefabricated element, which is an integral part of the composite deforming-cutting broach. The broach (Fig. 2) consists of rod 3, which hosts sleeve 1 with landing surface 2. Landing surface 2 hosts the working elements – cutting 4 and deforming 5, which consists of solid alloy inserts 6, lightweight intermediate layer 7, and steel ring 8. The distance between elements 5 and 4 is adjusted by sleeve 9, which forms a cavity to place the shavings.

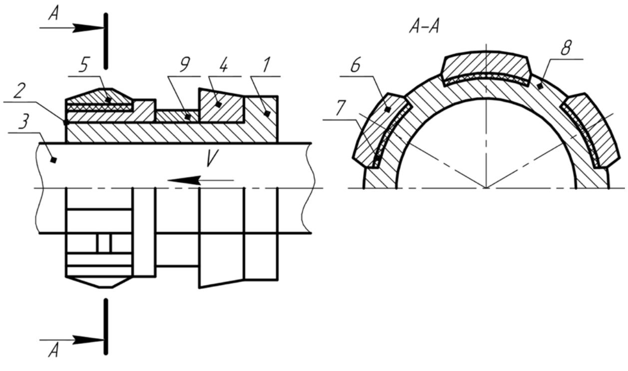


Fig. 2. Prefabricated combined broach

We investigated the structural strength of prefabricated DE 5 under unit contact load, depending on the structural parameters of the individual elements of the tool. The size of the solid-alloy inserts and the corresponding grooves in the body were chosen on the basis of technological requirements. We varied the height of the insert protrusion over the body and the position of the insert contact area with the machined surface.

The prefabricated tool (Fig. 3, *a*) consists of a steel casing and the solid-alloy inserts, fixed in it by soldering. The overall view and the estimated scheme of the broach DE are shown in Fig. 3. Due to the symmetry of the design and DE load conditions, the estimated scheme includes 1/6 of the steel casing and, accordingly, ½ of the solid-alloy insert. The finite-element discretization of the broach DE, shown in Fig. 4, as well as the finite-element form and the number of elements, were chosen according to the recommendations from an estimation complex described in works [15–17].

The following boundary conditions were set:

– at free surfaces, the normal and tangent stresses are zero;

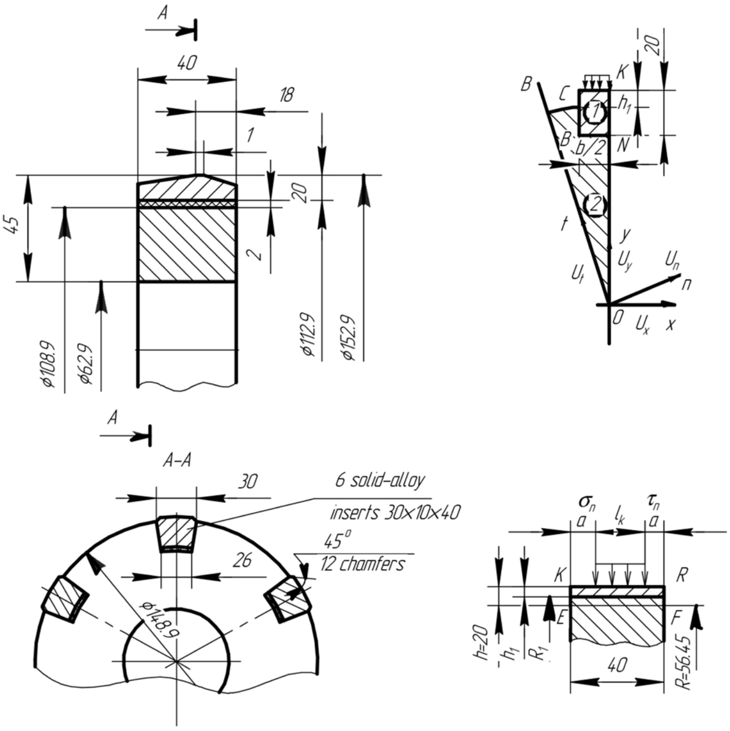
– at surfaces OV and OK, the conditions of symmetry;

– along the boundaries of insert contact with the body of the element – the conditions of absolute adhesion;

– on the working surface *KR*, we set unit normal stresses σ_n=1 MPa and tangent stresses τ_n=0.06 MPa, corresponding to the actual value of the friction factor $f=\tau_n/\sigma_n=0.06$.

In calculations, it was accepted that the body and solid-alloy inserts are deformed elastically, and the insert is aligned with the body without a gap.

Given the linearity of the elastic problem solved, the stressed state calculation was performed for unit contact load.



a *b*

Fig. 3. The broach deforming element: *a* — general view; *b* — estimation scheme; 1 — insert made from the solid alloy VK15; 2 — DE casing made from steel 40KhN

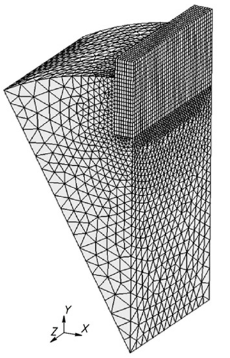


Fig. 4. The finite-element discretization of the broach deforming element

We estimated the effect of the insert protrusion height above the body surface on the equivalent stresses that occur in it and the body under load. To this end, the R_1 and h_1 values were changed accordingly. The variation intervals are given in Table 1.

Table 1

Variable characteristics in calculations

h_1 (mm)	10	5	2
R_1 (mm)	66.45	71.45	74.45

In addition, we considered the effect of the location of the length of a DE contact area with a component relative to the tool edges on the level of equivalent stresses under load. The location parameters of contact zone *a* and its length *l* were set according to Table 2. In this case, the calculations involved the radius R_1=71.45 mm and the protrusion height h_1=5 mm.

Table 2

Variable characteristics in calculations

a (mm)	15	10	5
$l_к$ (mm)	10	20	30

The physical-mechanical properties of the materials used in the calculations are given in Table 3.

Table 3

The physical-mechanical properties of materials used in the calculations

Title	Young modulus, GPa	Poisson coefficient	σ_T=$\sigma_{0,2}$
Solid-alloy VK15 (insert)	554	0.225	3.37
Steel 40KhN (body)	210	0.30	0.60

To study the limit state, the equivalent stresses were calculated based on the strength criteria: the specific potential energy of shape change $\sigma_e^{IV}=\sigma_i$ and the maximum tangent stresses in the form:

$$\sigma_e^{III}=\sigma_1-\sigma_3\leq 2[\tau]=\sigma_{0.2}. \quad (1)$$

The calculations were carried out using the applied software developed at the V. Bakul Institute for

Superhard Materials of the National Academy of Sciences of Ukraine to solve the contact thermoelastic plastic problems at finite deformations applying a finite element method [15–17].

5. Studying the SSS of a prefabricated element under load

The result of numerical modeling is the derived distributions of axial stresses σ_x, σ_y, σ_z, pressure $\sigma_0=(\sigma_x+\sigma_y+\sigma_z)/3$, equivalent stresses σ_e^{III} and σ_e^{IV} contact stresses over the surface of the contact insert-body. The calculation results in the form of the distribution throughout the volume of the prefabricated deforming tool σ_e for the assembled tool and in its various parts are shown in Fig. 5–9.

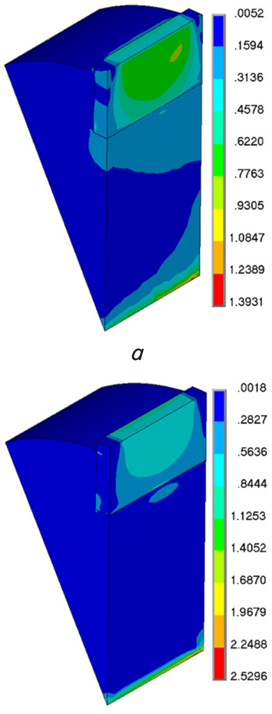


Fig. 5. The distribution of areas of equivalent stresses in DE under load: *a* – σ_e^{III} (MPa); *b* – σ_e^{IV} (MPa): h_1=2 mm, R_1=74.45 mm

Previously, it was established in [13] that the thickness of the plastic layer in a prefabricated ring tool has little or no effect on the magnitude σ_e, that is, the DE strength. This makes it possible to accept that in a given case the layer thickness also does not affect the DE strength. Based on structural considerations, the thickness of this layer is chosen to be up to 2 mm, which is quite realistic to perform the soldering process.

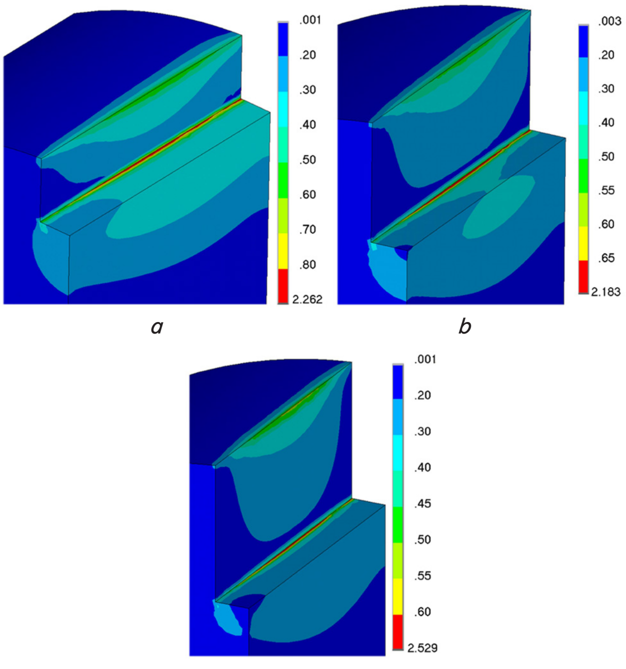


Fig. 7. The distribution of areas of equivalent stresses σ_e^{IV} (MPa) in a DE body under load: *a* – h_1=10 mm, R_1=66.45 mm; *b* – h_1=5 mm, R_1=71.45 mm; *c* – h_1=2 mm, R_1=74.45 mm

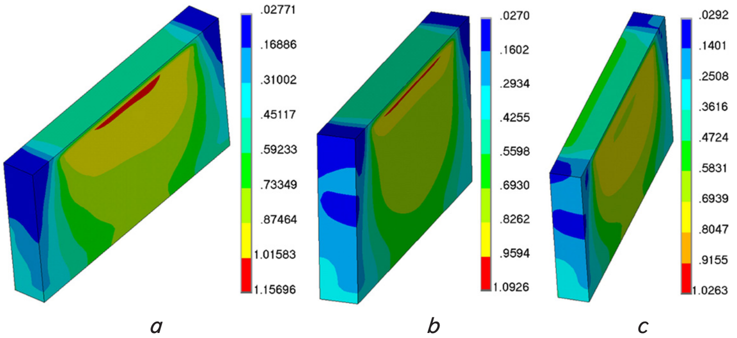


Fig. 8. The distribution of areas of equivalent stresses σ_e^{III} (MPa) in a DE insert under load: *a* – h_1=10 mm, R_1=66.45 mm; *b* – h_1=5 mm, R_1=71.45 mm; *c* – h_1=2 mm, R_1=74.45 mm

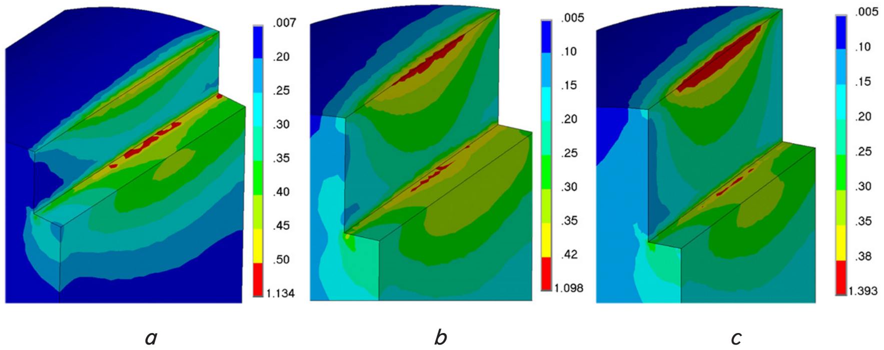


Fig. 6. The distribution of areas of equivalent stresses $\sigma_e^{III/}$ (MPa) in a DE body under load: *a* – h_1=10 mm, R_1=66.45 mm; *b* – h_1=5 mm, R_1=71.45 mm; *c* – h_1=2 mm, R_1=74.45 mm

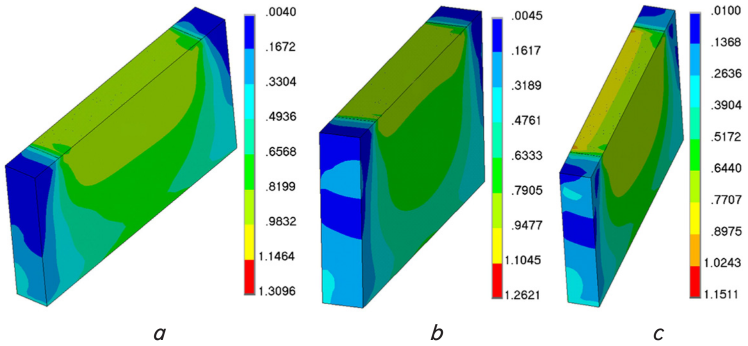


Fig. 9. The distribution of areas of equivalent stresses σ_e^{IV} (MPa) in a DE insert under load: *a* – h_1=10 mm, R_1=66.45 mm; *b* – h_1=5 mm, R_1=71.45 mm; *c* – h_1=2 mm, R_1=74.45 mm

We investigated by calculation the effect exerted on the amount of equivalent stresses by such a structural parameter as the insert protrusion height above the body surface. To this end, we calculated the equivalent stresses by varying the insert protrusion height above the body. It is governed by two values: the protrusion height h_1/h and the body radius R_1 (Fig. 3). The range of variations of these parameters is given in Table 1.

Changes in σ_e depending on the height of the protrusion are shown in Fig. 10 (curve 1), where the dots show the estimated results of the values of equivalent stresses for a specific protrusion height.

It follows from Fig. 10 that a decrease in the h_1/h value, that is the height of the protrusion, reduces the acting σ_e in proportion to this parameter. The results of the calculation of the values of equivalent stresses, depending on the height of the proposition, obtained using conditions III and IV from strength theories, are almost identical. The approximation of graphic dependence 1 (Fig. 10) produced formula (2), convenient for engineering calculations and making it possible to determine the σ_e value corresponding to the specific size of the insert protrusion.

$$\sigma_e = 0.5 + 1.25\frac{h_1}{h}. \tag{2}$$

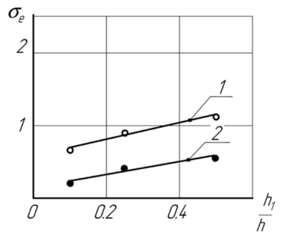


Fig. 10. The dependence of σ_e on the size of the insert protrusion at insert size $h \times b \times l$=20×30×40 at l_k/l=0.5, σ_e: 1 – for an insert; 2 – for a body

A change in the σ_e value in a body depending on the protrusion height (Fig. 10, curve 2) is also derived from the estimated modeling; the dots show the value of equivalent stresses for a specific size of the insert protrusion over the body.

Depending on the h_1/h parameter, the σ_e value for a body is described by formula (3), obtained from the approximation of graphic dependence 2 (Fig. 10). It should be noted that the character of dependences (2) and (3) is similar. However, the estimated value of σ_e for the body is slightly lower.

$$\sigma_e = 0.125 + 0.94\frac{h_1}{h}. \tag{3}$$

The effect of the contact length for a prefabricated tool is almost invisible if the length of the contact is symmetrical to the edges of the insert, which follows from Fig. 11, curve 1.

The points along this curve are the results of the calculation of σ_e for different values of the l_k/l parameter.

Shifting the beginning of a contact length towards the insert edge, that is, the asymmetrical load application, increases σ_e. The calculations have shown that the increase in σ_e, when replacing the symmetrical load with the asymmetrical one (a=0, a=l–2*a*, Fig. 3, *b*), reaches up to 30 %.

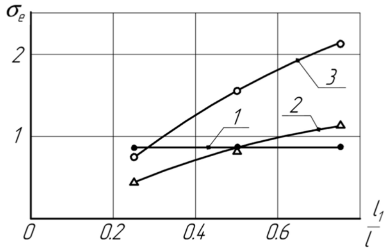


Fig. 11. The dependence of σ_e on the contact length location at insert size $h \times b \times l$=20×30×40, σ_e: 1 – for an insert; 2 and 3 – for a body, based on strength theories III and IV, respectively

When calculating the equivalent stresses in the tool body, the points on curves 2 and 3 correspond to the specific values of the l_k/l parameter. An increase in this parameter leads to an increase in σ_e (curves 2 and 3). Similar results were obtained in [13] in the calculation of a solid prefabricated element of the ring form. Therefore, when designing a tool, it is necessary to take into consideration that the optimal option is the symmetrical location of the contact area relative to the ends of the tool.

When calculating the equivalent stresses for a body, the zone of maximum equivalent stresses (Fig. 6, *b*) is located at the intersection of the body with a solid-alloy insert. Moreover, there is a difference between σ_e, calculated based on strength theory III, and the values calculated based on strength theory IV (Fig. 11, curves 2 and 3). This difference increases with an increase in the length of the contact area.

6. Assessing the structural strength of a prefabricated tool

The results of the mathematical modeling of DE behavior under load were used to devise a technique for assessing its strength required for practical use.

Denote an equivalent stress, for example, based on strength theory III, calculated for unit contact load $\bar{\sigma}_n = 1$ through $\bar{\sigma}_e^{III}$. Then, based on the linearity of the elastic problem, the actual value $\bar{\sigma}_e^{III}$ is equal to:

$$\sigma_e^{III} = \bar{\sigma}_e^{III} \cdot \sigma_n. \tag{4}$$

The strength condition for a solid-alloy insert takes the following form:

$$\sigma_e^{III} \le [\sigma], \tag{5}$$

where the permissible stress is:

$$[\sigma] = \frac{\sigma_{res}}{n}, \tag{6}$$

n is the strength margin factor.

Then, from (4), taking into consideration (5) and (6), we obtain a dependence to determine the acceptable contact load:

$$\sigma_n = [\sigma]/\sigma_e^{III}. \tag{7}$$

For the solid alloy VK15, σ_{res}=3,370 MPa. The strength margin factor n, taking into consideration the cyclical nature of the load action, n=1.5 [18]. For a solid-alloy insert, as it follows from dependence (2), the maximum strength is ensured by the ratio $h_1/h\approx0.1$; in this case, $\overline{\sigma}_e^{III} = 0.63$.

Then, from (4), taking into consideration (5) and (6), we obtain σ_n=3,566 MPa ≈3.6 GPa. This is the permissible contact pressure on the tool.

The amount of acting contact pressures, when using solid DEs in the form of round rings, is determined, taking into consideration a procedure from [10], based on the known axial strength of broaching, the area of the contact, the geometry of the tool, and the corresponding value of the friction factor.

For a body, the minimum value of equivalent stresses, depending on the size of the insert protrusion above the body, is determined based on dependence (3) and corresponds to the value $h_1/h\approx0.1$. In this case, σ_e=0.22. We shall determine the maximum value of contact pressure, which is accepted based on the conditions of body strength. A steel body is made from the thermally treated steel 40KhN, for which σ_{res}=1,400 MPa, the strength margin factor is adjusted for the cyclical nature of the load n=1.5. Then, from dependence (7), taking into consideration (5) and (6), we obtain σ_n=4.2 GPa. The comparison of current and acceptable contact pressures showed that the strength of the steel body is ensured.

It should be noted that the analysis of dependences (2) and (3) reveals that the maximum strength of the tool corresponds to the value $h_1/h\approx0$. However, for technological reasons, it is not always possible to implement the condition $h_1/h=0$. Otherwise, one should evaluate the effect of this parameter on the structural strength based on dependences (2) and (3), obtained when varying the values of the insert protrusion size over the body.

Thus, dependences (2) and (3) resulting from simulations make it possible to select the necessary structural parameter – the height of the solid-alloy insert protrusion over the body, based on determining the acceptable contact pressure from dependence (7).

7. An example of practical calculation

As an example, we consider the calculation of strength of the deforming element, which is part of the deforming broach shown in Fig. 2. This tool machines a sleeve made from grey modified cast iron of hardness HB230. The machining (Fig. 12) involves a unit containing the deforming 2 and cutting 3 elements. To improve the separation of the ring shavings cut by the solid blade of cutting element 3, deforming element 2 performs discrete deformation using solid-alloy inserts 4. When the discrete deformed layer is cut by cutting element 3, the ring shavings, due to the presence of pre-deformed areas, are destroyed into elements 5 and are easily removed from the cavity of the sleeve.

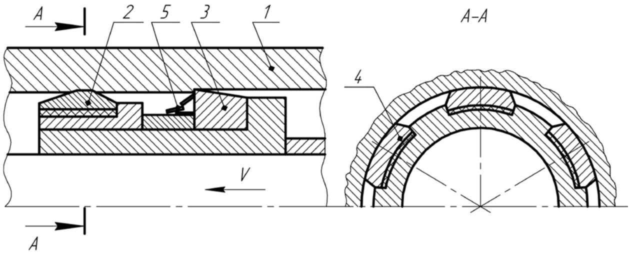


Fig. 12. Machining a cast-iron sleeve using a deforming-cutting broach

When machining the considered component, we have the following data. The sleeve is made from grey modified cast iron; its dimensions, $d_0=152.7^{+0{,}1}$ mm, t_0=10 mm. The diameter of the prefabricated element for discrete broaching is 152.9 mm. The number of inserts made from the solid alloy VK15 is 6; the insert dimensions are 40×20×40. The tension on DE is a=0.15 mm. The area of the contact, taking into consideration the area of the inserts, S=196 mm^2. The axial force of DE broaching is equal to Q=45 kN, the acting contact pressure q=1.35 GPa.

Based on the design calculations, we take h_1/h=0.15. Then, based on dependence (2), σ_e=0.69. For the solid alloy VK15, [σ]=2.25 GPa. According to formula (7), the permissible contact load is σ_n=[σ]/0,69=3.2 GPa.

Based on the calculations, an algorithm has been developed to sequence the calculation of a prefabricated DE for discrete broaching (Fig. 13).

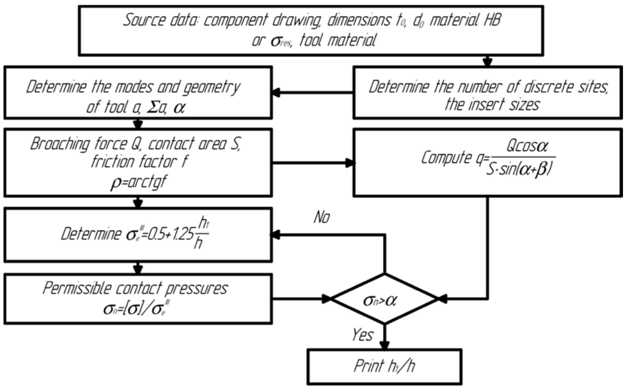


Fig. 13. The calculation sequence algorithm for a prefabricated DE

8. Discussion of research results on the development of a methodology for assessing the strength of a prefabricated working element for discrete broaching

The estimation dependences (2) and (3), obtained from modeling the DE behavior under load, show the effect of the h_1/h parameter on the structural strength of the element and allow the tool design to be optimized according to this parameter. The increase in the strength of a solid-alloy element as the protrusion height decreases is due to bringing its operational conditions to the conditions of comprehensive compression. This is confirmed by the fact that under the conditions corresponding to h_1=0 the values of equivalent stresses become minimal.

As for the location of the contact area along the length of the working cone of the solid-alloy insert, then it follows from Fig. 11 that it must be positioned symmetrically to the insert distanced from the edges. That is, along the axis of its symmetry. This option is implemented by shifting the beginning of the cylindrical ribbon (Fig. 3, *a*) from the axis of the insert symmetry to the size of half the length of the contact. This shift depends on the length of the contact area and the prerequisite for this will be the coincidence of the axis of symmetry of the contact area with the axis of the symmetry of the insert. Then the insert design will be symmetrically loaded.

Our study has made it possible to analyze the tool behavior in a wide range of changes in external loads. The calculation was carried out under unit normal load σ_n=1 MPa. To use the obtained results under other loads, it is necessary to use dependence (4), derived from the condition of the elastic problem linearity, and the strength conditions of the elements of the prefabricated tool, which are expressed by dependence (5). The value of the permissible contact pressure is estimated by dependence (7).

The use of the prefabricated design of the working element could solve not only the task of discrete deformation and facilitate the process of shaving formation by forcibly separating the ring shavings but also reduce the consumption of acutely deficient solid alloy compared to a whole-made solid-alloy element of similar size by 6 kg.

The reported procedure for modeling the working conditions of the tool under load could be used to assess the strength and to optimize the structural parameters of prefabricated tools used in the machining of holes by cutting, namely: cutters, drills, reamers. To this end, it is necessary, in each case, to clarify the external loads acting on the tool's tooth, choose the estimation scheme and boundary conditions.

Our study implied assessing strength when a single deforming element was used for discrete broaching. With two discrete elements involved in deformation at the same time, that is, a group of discrete elements, the current research does not take into consideration the mutual influence of the deforming elements in a group, which, according to data from [10], can be very significant. This issue, therefore, requires further investigation.

9. Conclusions

1. Our study into the SSS of a prefabricated DE for discrete broaching when applying unit load provides the versatility of strength calculation for any values of contact loads, including for articles made from different machined materials. The versatility of the calculation is implemented by the product of the values of equivalent stresses obtained under unit load and the actual value of contact pressure corresponding to a particular case and calculated using an algorithm.
2. We have derived the engineering dependences that make it possible to establish a relation between the values of equivalent stresses and the protrusion height of solid-alloy inserts above the body and ensure choosing the required insert height above the body based on the condition of tool strength.
3. Studying the effect of the location of the contact area relative to the insert ends has made it possible to establish the optimal variant for the considered prefabricated tool the symmetrical position of the contact load relative to the ends of the insert, which is achieved by the axial shift of the beginning of the cylindrical ribbon of the solid-alloy insert relative to its axis of symmetry at a magnitude equal to half the length of the contact.
4. Based on the performed strength calculation of the prefabricated DE for the discrete broaching of a hole in the ICE sleeve made from the modified grey cast iron, it has been established that the required relative height of insert protrusion above the body, corresponding to the conditions of strength, is h_1/h=0.15, which corresponds to 3 mm for the case in question. The developed algorithm of the sequence of calculation of a prefabricated DE for discrete broaching makes it possible to choose the technological and structural parameters of the tool.

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