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Finite element modeling method of centrifugal rotary processing [*]

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Метод конечных элементов в моделировании центробежно-ротационной обработки[***]

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Introduction. In modern production, when performing finishing operations, centrifugal rotary processing in the medium of abrasive plays an important role. High productivity, low costs and extensive technological capabilities are the main advantages of these cleaning and finishing operations. This paper considers the process of abrasive particle – workpiece surface interaction within the framework of the static contact problem of the elasticity theory. Thus, plastic deformation in the contact area comes into account.

Materials and Methods. The abrasive particle (corundum) is simulated with a linearly elastic body, whose Young's modulus is significantly larger than that of the work material. The process material (steel) is simulated with an elastoplastic bilinear body using the von Mises yield criterion.

Research Results. Finite element modeling of the structures under consideration was performed in the ANSYS CAE package. The process of abrasive particle – workpiece surface interaction was simulated; its stress-strain state was analyzed. The results of numerical experiments are presented. They have determined how equivalent plastic strains are distributed at depths of the cone penetration of 0.01 mm and 0.05 mm. The data obtained, as well as the areas of plastic strain values of more than 1%, are visualized in the ANSYS CAE package.

Discussion and Conclusions. It is established that the equivalent plastic deformation is proportional to the depth of penetration (DP). It reaches a minimum value of 0.158 at DP = 0.01 mm, and a maximum of 0.825 at DP = 0.05 mm. The dependences of the plastic region sizes on DP are determined for cases when the plastic deformation exceeds 1%. At the maximum penetration (0.05 mm), the deformation radius is 1 mm, and the depth is 0.8 mm.

On the basis of the data obtained as a result of the conducted

Введение. В современном производстве при выполнении финишных операций важную роль играет центробежно-ротационная обработка в среде абразива. Основные преимущества этого метода отделочно-зачистной обработки: высокая производительность, низкая себестоимость и широкие технологические возможности. В данном исследовании рассматривается процесс взаимодействия абразивной частицы с поверхностью детали в рамках статической контактной задачи теории упругости. При этом учитывается пластическая деформация в области контакта.

Материалы и методы. Абразивная частица (корунд) моделируется линейно упругим телом, модуль Юнга которого значительно больше, чем у обрабатываемого материала. Обрабатываемый материал (сталь) моделируется упруго пластическим билинейным телом с применением критерия пластичности Мизеса.

Результаты исследования. Выполнено конечноэлементное моделирование рассматриваемых конструкций в CAE-пакете ANSYS. Смоделирован процесс взаимодействия абразивной частицы и поверхности детали, проанализировано ее напряженно-деформированное состояние. Представлены результаты численных экспериментов, которые позволили установить, как распределяются эквивалентные пластические деформации при глубинах внедрения конуса 0,01 мм и 0,05 мм. Полученные данные, а также области значений пластической деформации более 1 % визуализированы в CAE-пакете ANSYS.

Обсуждение и заключения. Установлено, что эквивалентная пластическая деформация пропорциональна глубине внедрения (ГВ). Она достигает минимального значения 0,158 при ГВ = 0,01 мм, максимального 0,825 — при ГВ = 0,05 мм. Определены зависимости размеров области пластической деформации от ГВ для случаев, когда пластическая деформация превышает 1 %. При максимальном внедрении (0,05 мм) радиус деформации составляет 1 мм, глубина — 0,8 мм. На основе данных, полученных в результате проведенного исследования, могут быть выбраны

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research, the parameters of the technological process (rotational speed, size of the abrasive surface, mass of abrasive particles) that affect the workpiece – abrasive particle interaction can be selected. A judicious choice of these parameters will increase the processing efficiency.

параметры технологического процесса (скорость вращения, размер абразивной поверхности, масса абразивных частиц), которые влияют на взаимодействие между деталью и абразивной частицей. Рациональный выбор этих параметров позволит повысить эффективность обработки.

Keywords: centrifugal rotary processing, abrasive treatment, contact problem, plasticity, finite element method.

Ключевые слова: центробежно-ротационной обработки, абразивная обработка, контактная задача, пластичность, метод конечных элементов.

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Introduction. In modern production, when performing finishing operations, an important role is played by centrifugal rotary processing (CRP) in an abrasive medium. The primary advantages of this method of finishing – clearing operation are high productivity, low cost and wide technological capabilities. This study discusses the process of interaction of an abrasive particle and a workpiece surface in the framework of the static problem of the elasticity theory. In this case, plastic deformation in the contact area is taken into account. An abrasive grain element in the form of a truncated cone (more precisely: a circle of a minor diameter of this cone) interacts with the workpiece surface. In this case, friction and plastic deformation of this surface should be considered. Kinematic or force boundary conditions are applied to a larger diameter circle. In case of kinematic conditions, normal and tangential displacements of the circle and its rotation are specified. In case of force conditions, force and torque are set. The stress fields and equivalent plastic deformations near the contact area are investigated.

Modeling the geometry of an abrasive particle of a centrifugal rotary processing. The summary of the CRP method is that the abrasive particles 3 and the workpiece 4 (Fig. 1 [1]) are loaded into the working chamber and rotated about the vertical axis so that the entire mass of the load becomes a torus [2, 3] in which particles move along spiral paths.

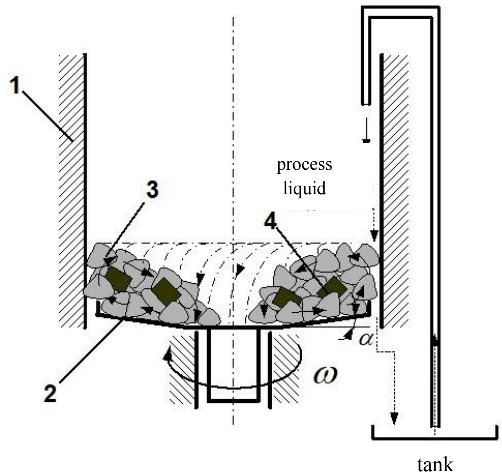


Fig. 1. Centrifugal rotary processing in abrasive medium:
1 is fixed cylindrical ring; 2 is rotor; 3 is abrasive grain; 4 is workpieces

The toroidal helical flow is ensured through the design of the machine working chamber consisting of a fixed cylindrical ring 1 and a rotating bottom (rotor) 2 adjacent to it, having a common plate shape. Workpieces 4 are loaded into the working chamber in bulk together with abrasive particles 3. To reduce wear, the inner surfaces of the bottom and the fixed part of the working chamber are coated with a wear-resistant material. Rubber or polyurethane coatings are most commonly used.

The scheme for constructing an indenter (in the form of a truncated cone) penetration model suggests a spherical shape of an abrasive granule with a set of truncated cones [3]. An approximate idea of the geometry of a spherical abrasive particle is shown in Fig. 2 [4].

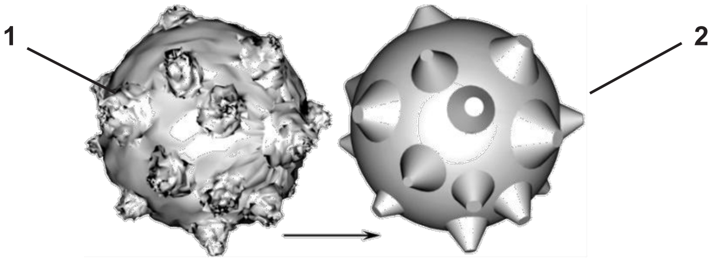


Fig. 2. Geometry of a spherical abrasive granule:
1 is approximate to actual one; 2 is simulated one

According to the model, the abrasive grain has a shape of a truncated cone. This model considers the always occurring blunting of abrasive grains. Fig. 3 presents a diagram of interaction of the abrasive particles and workpieces [5].

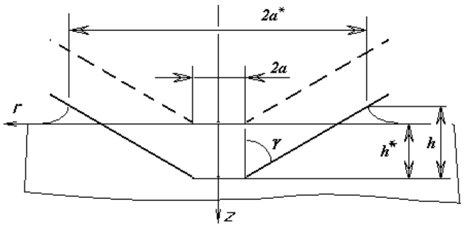


Fig 3. Scheme of conical indenter penetration

In the force acting on the indenter, normal and tangent components are distinguished [2]. According to the work of A. N. Beskopylny [5], a normal component of the cutting force is:

$$P = \begin{cases} 2ah^* E^*, & h^* \le h^*_{cr} \\ \chi \left(\dfrac{h^* + C_1}{C} \right)^2, & h^* > h^*_{cr} \end{cases}$$

where $C = \left(1-\delta^*\right) ctg(\gamma) + \chi \dfrac{(1-2/\pi)}{2E^*}$; $C_1 = a\left(1-\delta^*\right) ctg(\gamma)$; δ^* is the relative height of influx; E^* is the reduced modulus of elasticity; h^* is the depth of grain indentation; $\chi = \dfrac{\pi}{2}\lambda\sigma_T$ is the plasticity parameter.

Mathematical model. Optimization of the abrasion process requires the development of improved models of frictional interaction between abrasive particles and the surface of a metal component. In this model, it is required to require heating and surface wear due to the impact and sliding of an abrasive particle.

Under the abrasive processing, contact interaction occurs, which leads to wear and heating of the workpiece surface. The basic data on the processes of friction and wear are shown in [6]. Processing in a rotation chamber is described by M.A. Tamarkin and his disciples [1–5]. The features of this process are discussed in [7–9].

In the presented paper, the contact interaction of an abrasive particle and the workpiece surface is considered in the framework of axisymmetric deformation of an abrasive particle fragment and the workpiece surface. The abrasive particle fragment is a truncated cone, the smaller base of which interacts with the workpiece surface (Fig. 4).

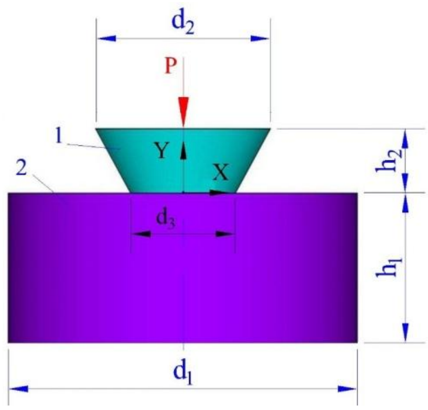


Fig. 4. Particle and workpiece model: 1 is abrasive particle; 2 is workpiece

According to the model, an abrasive particle (corundum) is a linearly elastic body, whose Young's modulus is much larger than that of the processed material. The processed material (steel) is modeled as an elastically plastic bilinear body. The Mises yield criterion [10] is applied.

The abrasive particle and the workpiece are in contact without friction. Contact surfaces are the upper plane of the workpiece, the smaller base and the side surface of the cone. The lower plane and the side surface of the workpiece are fixed normal. On the larger base of the truncated cone, boundary conditions are specified: power (uniformly distributed pressure) or kinematic (vertical displacement). The indentation of a particle into a workpiece is considered, the zone of plastic deformations and their maximum values are investigated.

Solution method. To solve the described boundary-value problems, the finite element method implemented in the ANSYS CAE package is used. Fig. 5 shows the finite element mesh of the first problem.

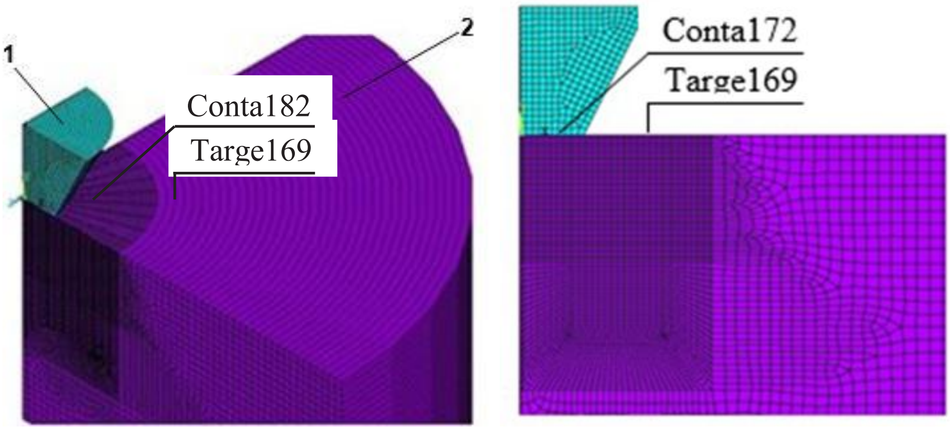
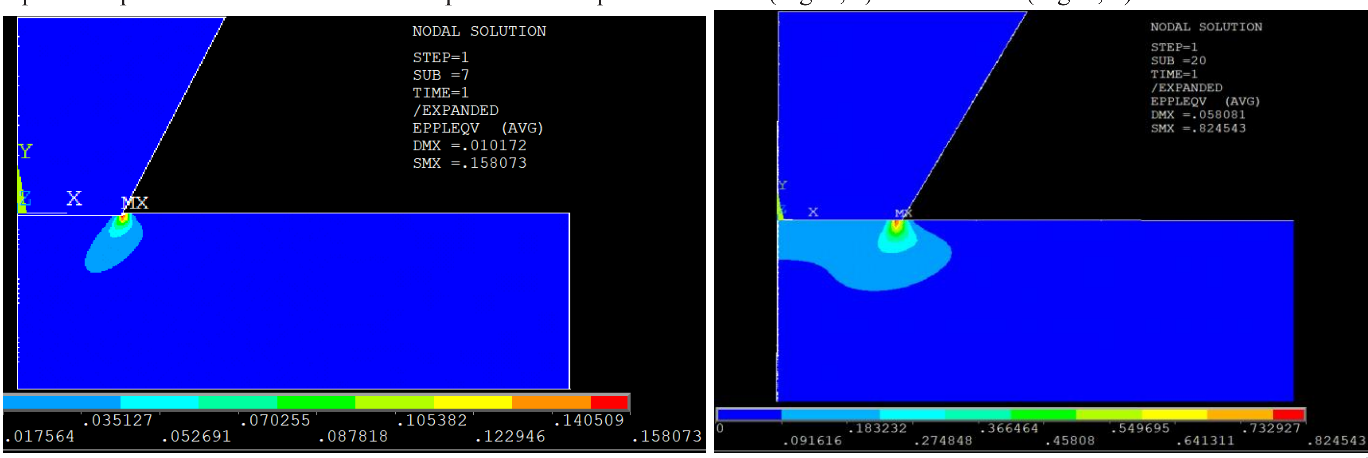


Fig. 5. Finite-element segmentation in the contact problem: 1 is abrasive particle; 2 is workpiece

In the contact area and possible plastic deformation, the grid is condensed. The end elements PLANE183 (material 1), PLANE182 (material 2) and TARGE169, CONTA172 are used for the contact surfaces. The abrasive particle and the workpiece are symmetrical; therefore, half the axial section is considered (see Fig. 5

Results of numerical experiments. In the numerical calculations, the following data were used in the problem: the radii of a truncated cone were 0.5 mm and 1 mm; cone height was 1 mm; part radius was 5 mm; thickness was 3 mm. Young's modulus of the material 1 was equal to 2×10^6 GPa; Poisson's ratio was 0.3. Young's modulus of material 2 was equal to 2×10^2 GPa; Poisson's ratio was 0.28. The yield stress was 0.22 GPa. Fig. 6 shows the distribution of equivalent plastic deformations at a cone penetration depth of 0.01 mm (Fig. 6, a) and 0.05 mm (Fig. 6, b).



a) *b*)

Fig. 6. Distribution of equivalent plastic deformations at cone penetration depth of 0.01 mm *(a)*; 0.05 mm *(b)*

Fig. 7 shows the dependences of the maximum value of equivalent plastic deformation on the depth penetration (DP).

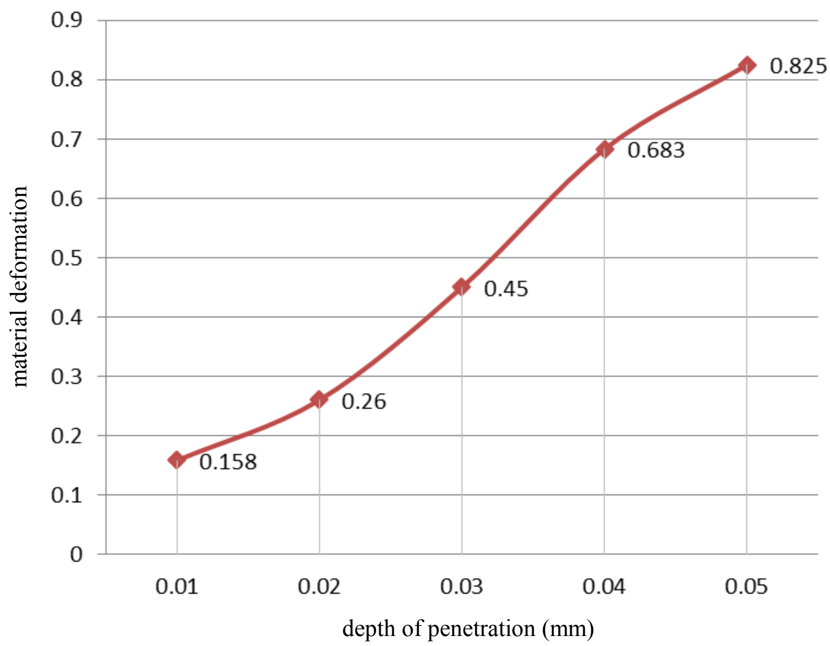


Fig. 7. Peak plastic deformations depending on the depth of penetration

In modeling experiments, the authors have found that equivalent plastic deformation is proportional to the penetration depth. Equivalent plastic deformation reaches a minimum value of 0.158 at a GV = 0.01 mm, a maximum of 0.825 at DP = 0.05 mm. The dependences of the sizes of the plastic deformation region on the penetration depth were determined for the cases when plastic deformation exceeded 1% (Fig. 8–10). Areas of plastic strain greater than 1% are selected using ANSYS software. In this case, the depth (H) and radius (L) of the deformation zone are determined.

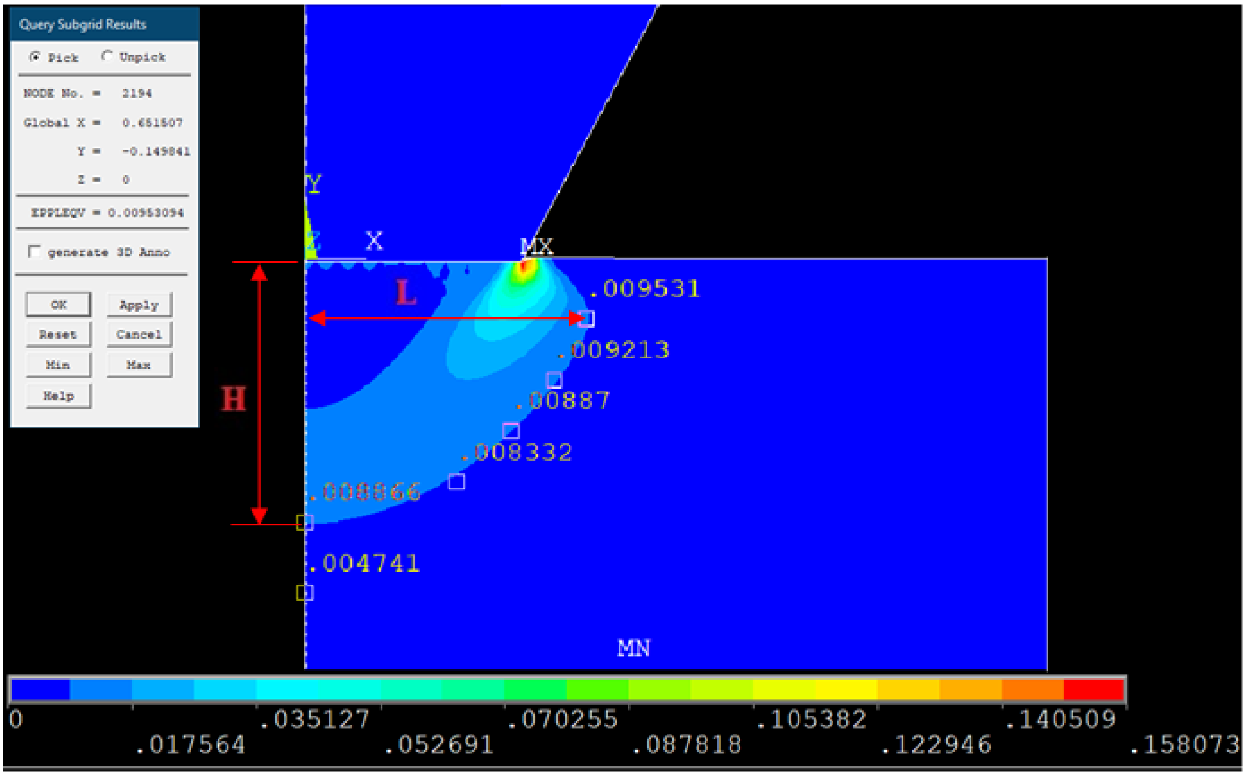


Fig. 8. Sizes of the plastic deformation region

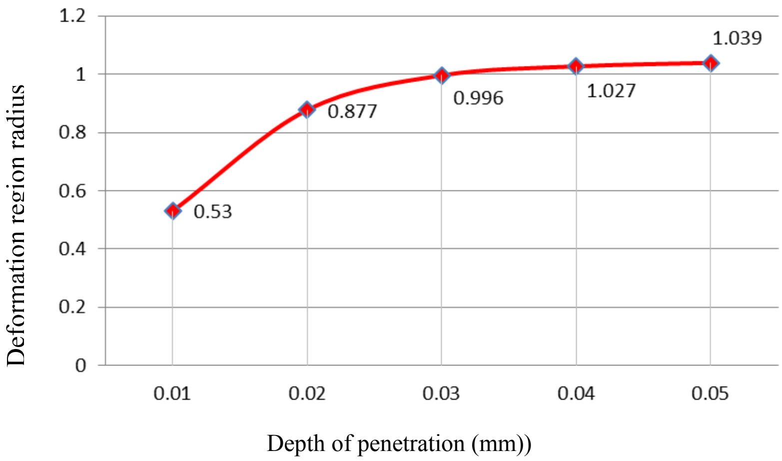


Fig. 9. Dependence of radius of plastic deformation region on penetration depth

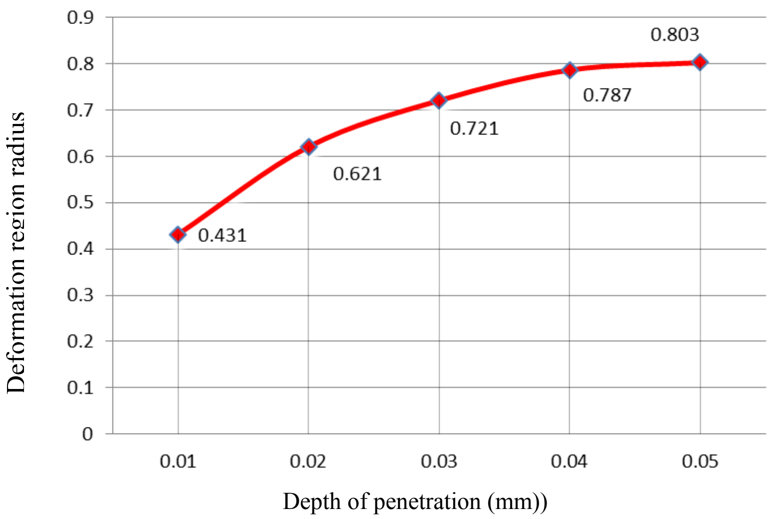


Fig. 10. Dependence of depth of plastic deformation region on penetration depth

The dependence of the cone penetration depth on the uniform pressure acting on its larger base is determined. This dependence is presented in Table 1.

Table 1

Dependence of cone depth penetration on pressure

Voltage (N/mm^2)	100	150	200	250	300
Displacement (mm)	–0.059	–0.119	–0.237	–0.354	–0.530

The results of numerical experiments make it possible to determine the regions of plastic deformations and their magnitude depending on the penetration depth. The data in Table 1 relate them to the force that should be applied to the abrasive particle. This effort can be determined through the parameters of the process.

Discussion and Conclusions. In this work, we have performed:

- finite element modeling of the interaction of an abrasive particle and the workpiece surface;
- analysis of the stress-strain state of the surface.

The dependence of the peak plastic deformation on the cone penetration depth (0.01 mm - 0.05 mm) is determined. It is found that this value varies from 0.158 to 0.825.

The dependences of the sizes of the plastic deformation region on the penetration depth are determined for the cases when the plastic deformation exceeds 1%. At maximum penetration (0.05 mm), the deformation radius is 1 mm and the depth is 0.8 mm.

Based on these data, the process parameters (rotation speed, abrasive surface size, mass of abrasive particles) that affect the interaction between the workpiece and the abrasive particle can be selected. The rational choice of these parameters will improve the processing efficiency.

References

1. Tamarkin, M.A., Tishchenko, E.E., Druppov, V.V. Issledovanie udaleniya metalla pri tsentrobezhno-rotornoy obrabotke v abrazivnoy srede. [Study on metal removal during centrifugal rotor treatment in an abrasive medium.] Vestnik of P.A. Solovyov Rybinsk State Aviation Technical University, 2007, no. 1 (11), pp. 169–186 (in Russian).

2. Tamarkin, M.A, et al. Teoreticheskie i eksperimental'nye issledovaniya protsessov obrabotki fasonnykh poverkhnostey detaley svobodnym abrazivom. [Theoretical and experimental study of process of shaped parts surfaces loose abrasive.] Strengthening Technologies and Coatings, 2011, no. 11, pp. 27– 31 (in Russian).

3. Tamarkin, M.A., Tishchenko, E.E., Druppov, V.V. Formirovanie parametrov kachestva poverkhnosti dlya tsentrobezhno-rotornoy obrabotki v abrazivnoy srede. [Formation of parameters of quality of surface at centrifugal-rotational processing in the environment of the abrasive.] Strengthening Technologies and Coatings, 2007, no. 10, pp. 19–23 (in Russian).

4. Korolkov, Yu.V. Obespechenie nadezhnosti tekhnologicheskikh protsessov tsentrobezhno-rotatsionnoy obrabotki svobodnym abrazivom. [Reliability control of production processes of centrifugal-rotary treatment by loose abrasive.] Vestnik of DSTU, 2011, 8, pp. 1247–1254 (in Russian).

5. Shvedova, A.S., Kazakov, D.V. Obespechenie nadezhnosti tekhnologicheskogo protsessa tsentrobezhno-rotatsionnoy otdelochno-uprochnyayushchey obrabotki. [Software of reliability technology process of centrifugal rotary finishing-hardening treatment.] Vestnik of DSTU, 2014, no. 4, pp. 69–83 (in Russian).

6. Kragelskiy, I.V. Trenie i iznos. [Friction and wear.] Moscow: Mashinostroenie, 1968, 480 p. (in Russian).

7. Grützmacher, Ph.G. The influence of centrifugal forces on friction and wear in rotational sliding. Tribology International, 2017, no. 116, pp. 256–263. DOI: org/10.1016/j.triboint.2017.07.021.

8. Wenhui Li, et al. Theoretical and Simulation Analysis of Abrasive Particles in Centrifugal Barrel Finishing: Kinematics Mechanism and Distribution Characteristics. Powder Technology, 2017, no. 318, pp. 518–527. DOI:10.1016/j.powtec.2017.06.033.

9. Aurich, J.C., Hauschild, M., Carrella, M. Sustainability of abrasive processes. CIRP Annals. Manufacturing Technology, 2013, no. 62, pp. 653–672.

10. Silori, P., et al. Finite Element Analysis of Traction Gear Using ANSYS. Materialstoday Proceedings, 2015, vol. 2, pp. 2236–2245. DOI. org/10.1016/j.matpr.2015.07.243

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