

ELASTOPLASTIC DEFORMATION OF SINTERED POROUS MATERIALS IN PRESSURE WORKING PROCESSES. II. SPECIAL FEATURES OF DEFORMATION OF POROUS BLANKS IN EXTRUSION STAMPING

V. M. Gorokhov, E. A. Doroshkevich, E. V. Zvonarev,
M. B. Shtern and E. V. Shtefan

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The increase of efficiency and widening the regions of application of powder metallurgy processes are not possible without finding and developing a new highly productive technology of producing high-density components for various applications. One of these methods is stamping sintered powder blanks which is based on the application of the processes of shaping and compacting by plastic yielding the material under the effect of applied load. In certain cases this process is similar to the method of final pressing in a closed die (but differs from this method by the presence of wide radial gaps between the blank and walls and of the die, thus ensuring transverse yielding of the material), and in other cases it is similar to processes of stamping – pressing blanks from rolled stock in pressure working.

The main advantages of stamping powder blanks are as follows [1]: it is possible to produce high-density components of complicated form and accurate dimensions; the force of plastic deformation is reduced on average by 20-25% in comparison with a dense material; the number of shaping operations (number of technology comparisons) is reduced; the durability of dies is improved by using initial blanks of optimum form, the stamping processes, including production of initial blanks, can be extensively automated and mechanized; the method is simple and can be used in the conditions of industrial production of components of metallic powders. In addition, cold stamping the powder blanks produces components of complicated form with high parameters of dimensional accuracy and surface quality. With regard to physicomechanical properties, stamped materials are not inferior to compacting materials. The stamping method makes it possible to produce components of small mass (several grammes) with thin walls (to 0.2 mm) and also projecting elements situated in the direction normal to the loading direction. Depending on the initial density and plastic deformation conditions, the strength of sintered material increases several times in comparison with the initial condition.

The highest efficiency of stamping the powder blanks is obtained in producing axisymmetric components with a central cavity, large defenses in the cross section, and complicated external configuration. This large group of components includes sleeves, caps, and vessels with a blind or continuous cavity while are used extensively in various machine components. Cutting these components is associated with a high labor content, a large loss of metal in shavings, and the need to use complicated and expensive tools. Extrusion by stamping blanks from dense materials is also characterized by low durability of pressing tools and a large number of stages in the shaping process. It is most efficient to use cold stamping powder blanks in this case.

In this article, we present the results of theoretical and experimental examination of relationships governing extrusion stamping blanks. Theoretical calculations were carried out on the basis of a program using an elastoplastic model. We examined yielding of sintered copper in extrusion of a blank into an annular gap. The relative initial density of the blank was 94%, the degree of transverse compression varied from 5 to 16. The external diameter of the blank was 63, internal 41 mm, the height of the initial blank 17 mm. The dependence of the elastic properties of sintered copper on porosity is

$$E = E_d(1 - \Theta)^{2.5}, \quad \nu = \nu_d(1 - \Theta), \quad (1)$$

where E , ν and E_d , ν_d is Young's modulus and Poisson's coefficient of porous and dense materials, respectively; Θ is the porosity taken from [2].

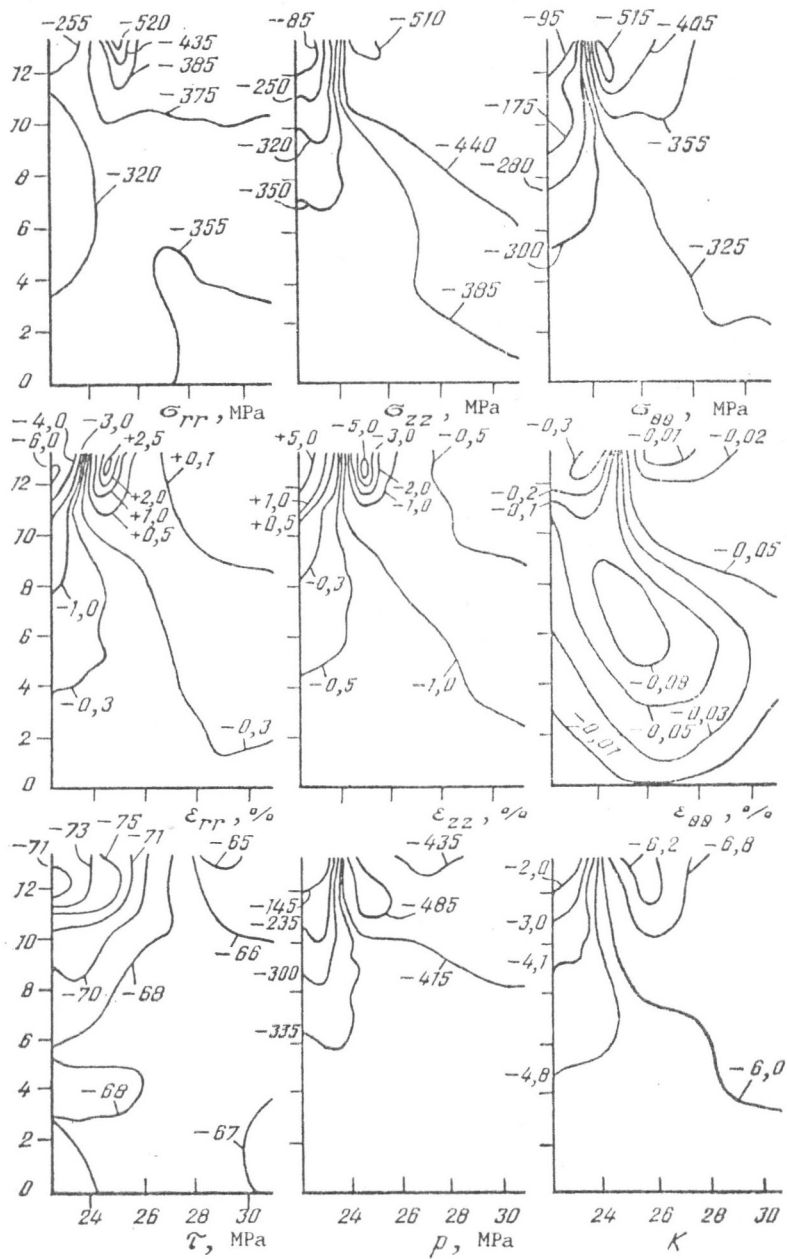


Fig. 1. Main stress σ_{rr} , σ_{zz} , $\sigma_{\theta\theta}$, main strains, ϵ_{rr} , ϵ_{zz} , $\epsilon_{\theta\theta}$, intensity of tangential stresses τ , mean stress p , and the stiffness coefficient K of a porous blank.

Hardening the sintered material in extrusion was determined taking into account corrections for cumulated plastic strain of powder copper taken from the experiments with uniaxial testing specimens [3]:

$$\sigma_T = \sigma_{T0} + 280\epsilon^{0.5}, \quad (2)$$

where σ_{T0} and σ_T are the initial and actual yield limit of the material of the base; ϵ is cumulated strain.

Mathematical simulation was carried out using a "Uprugoplastichnost" a system with programs for inputting and outputting information. To input initial information into the loading system, we calculated programs of generating a net of triangular elements on an arbitrary coupling region. The simulation results were displayed using a special package of graphic programs based on the Grafor package which makes it possible to use an ES-7051 N graph plotter to show the process parameters. The plotter was used to construct isolines of fields of total stresses and strains, isolines of mean stress, intensity of tangential stresses, intensity of shear strains, and determine the stiffness factor. A pattern of transition of material points of a solid

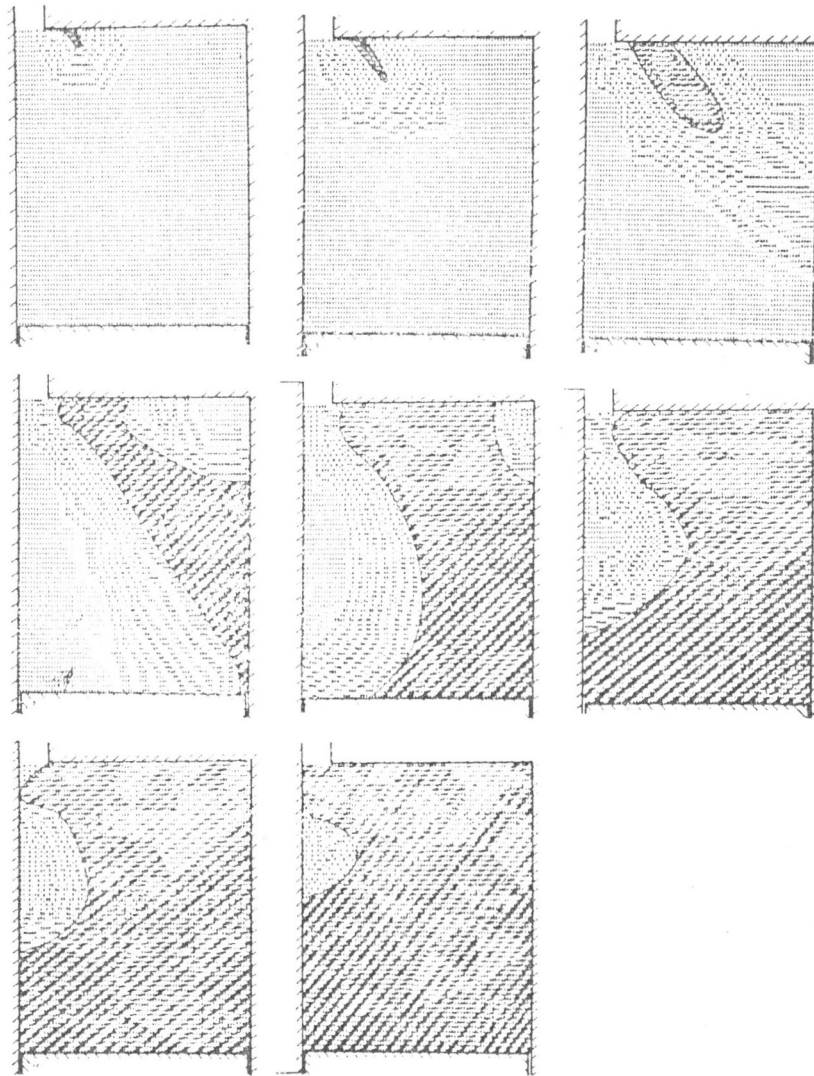


Fig. 2. Development of the region of plastic deformation in a cross section of a powder blank in different loading stages.

from elastic to a developed plastic state was constructed separately. The developed program package made it possible to process efficiently information and greatly facilitate its analysis. The data and distribution of the stress – strength state in the cross section of a deformed porous blank (Fig. 1) showed the following main relationships.

The stress–strain state of the extruded blank is characterized by a highly nonuniform distribution of the properties throughout the cross section. The distribution becomes even more heterogeneous with increasing strain. The concentration of the isolines of the stresses and strains at the point of transition of the flange to the tubular part increases, whereas in the regions with a free boundary and in elastic zones it decreases. The zone of developed plastic yielding propagates from the deformation region at an angle of 45° and gradually embraces the entire cross section of the deformed blank. The transition to the stationary yielding condition of the material (the zone of developed plastic yielding) is accompanied by stabilization of the extrusion force (Fig. 2).

Comparison of the patterns of the isolines in the cross sections of the deformed high-density ($\rho = 94\%$) powder and compact blanks shows that there are no large differences in their stress–strain state. The distribution (Fig. 3) of densities characterized by the following special features. The tubular part of the blank has a high density because the porous material during flow into the cavity of the die passes through the deformation region in which it is additionally compacted under the effect of a high level of tangential stresses. High porosity in the vicinity of the free boundaries is explained by the fact that the porous material of this zone in the initial condition is outside the limits of the lower boundary of the plastic deformation region

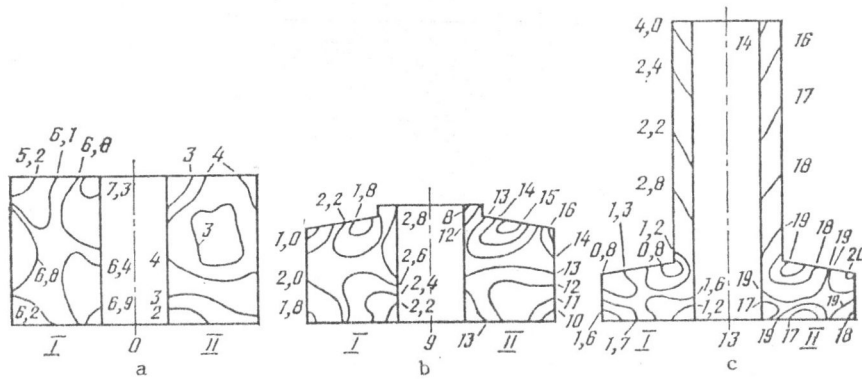


Fig. 3. Lines of equal level of porosity (I) and Vickers microhardness and (II) in the cross section of initial (a) and deformed (b, c) porous copper blanks of annular form and the displacement of the deforming punch of 9 (b) and 13 mm (c). Initial porosity 6%.

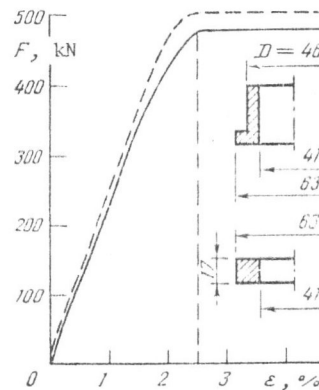


Fig. 4. Dependence of the total deformation force on the displacement of the deforming tool. Here and in Fig. 5, the broken line indicates theoretical calculations.

and traveled through the output cross section having the initial density. The maximum density is obtained in the vicinity of the point at which the stress gradient is the steepest.

The total deformation force is greatly affected by certain factors such as the initial porosity of the blank prior to extrusion, the drawing degree, the friction coefficient, the conicity angle, the radius of curvature of the lower side edge of the punch. The effect of the initial porosity of the blank starts to operate after reaching a certain threshold density at which the metal is discharged into the annular gap. In the final deformation stage the variation of the initial density by 1% changes the total force by approximately 4-5%. The total deformation force is greatly affected by the drawing degree. For example, when the degree of transverse deformation is increased from 4 to 10, the deformation force for the selected geometry of the blank prior to extrusion increases from 500-1000 kN. An increase of the friction coefficient by 0.1 increases the deformation force by 15-20%. The optimum conicity angle, ensuring the minimum extrusion force, is in the range 25-30%. The radius of curvature of the edge of the punch, ensuring the required minimum of intensity of the tangential stresses and durability of the two, is in the range 2-3 mm.

Experimental examination of force and kinematic characteristics of the extrusion process was carried out using a KB 8342 mechanical press with a force of 4000 kN using a specially designed die. Force transducers were represented by wire strain gage transducers connected into a bridge circuit which was also used to measure the kinematic parameters of extrusion: the displacement of the shaping die and discharge of the metal of the blank into the gap between the matrix and rod. Displacement transducers were in the form of rheostat transducers. Misbalance signals from the bridge circuits were amplified using UT-4B strain gage four channel amplifier. The measured parameters were recorded using a N115 light beam oscilloscope.

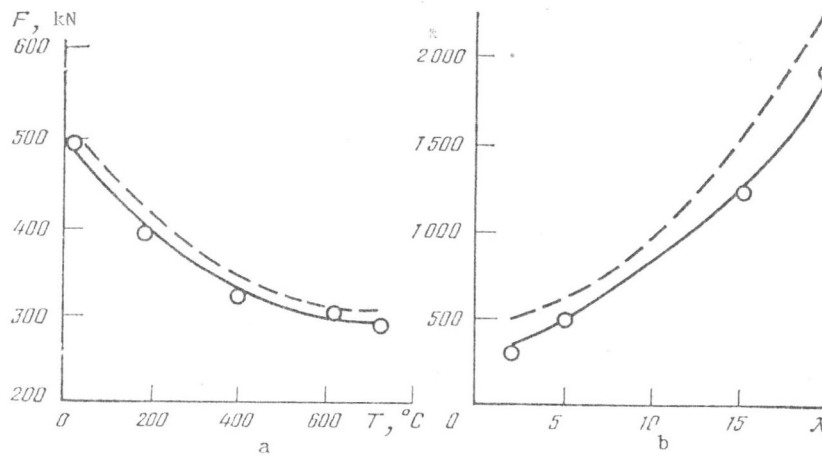


Fig. 5. Effect of temperature (a) and drawing degree (b) on total deformation force. $\rho_0 = 94\%$; $\lambda = 5$ (a); $T = 20$ C (b).

The force transducers was calibrated in a P500 test machine with a maximum force of 5000 kN, and displacement transducers were calibrated using a micrometer with a step of 0.5 mm in the ranges 0-45 mm for the metal discharge sensor and 0-35 mm for the die displacement sensor.

The theoretical and experimental dependences of the total deformation force on the displacement of the deforming tool, shown in Fig. 4, indicate that the extrusion force rapidly increases in the elastic region during a small displacement of the punch. Formation of the deformation zone in the volume of the extruded blank stabilizes the force (irrespective of the displacement of the deforming tool). The difference in the values of the total extrusion force, obtained by calculations and as a result of experiments, is 5-7% which can be regarded as satisfactory.

Thus, the tests show that the deformation force decreases relatively rapidly in heating the blank to 700°C (Fig. 5). An increase of the drawing degree in extrusion results in a rapid increase of the total force, and in high loads on the internal rod and the deforming punch.

LITERATURE CITED

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