DENSIFICATION AND CHANGE IN THE SHAPE OF A HOLLOW POROUS CYLINDER DURING HOT COMPRESSION IN A CONTAINER

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A nonporous or low-porosity axisymmetric part can be produced from a powder blank by a variant of the hot forging process in which the blank is compressed so that the decrease in its height is accompanied by densification and radial flow of material toward its center [1, 2]. In [3] a method is described for calculating the integral parameters of the process of compression of a hollow cylinder (ring) in a rigid die, in which use is made of the mean porosity, inside diameter, and applied pressure as functions of the degree of axial deformation. The present work was undertaken with the aim of verifying by experiment the theoretical results obtained and examining the possibility of employing this method for calculating the processes of hot forging of porous axisymmetric blanks.

Experiments were carried out with hollow cylindrical blanks of height H_0 = 30 mm, external diameter D_0 = 40 mm, internal diameters d_0 = 9, 14, and 20 mm, and starting porosity $\Theta_0 = 0.36$. The blanks were produced from an atomized L80 (80% Cu–Zn) brass powder by double-ended pressing and 1-h sintering in hydrogen at a temperature of 850°C. The heating of the blanks for forging, to a temperature of 850 ± 10°C, was performed in a tube resistance furnace provided with an argon atmosphere, and compression to various degrees of axial deformation ε_z (Fig. 1) in an F1232 friction press fitted with a die of diameter D_d = 41 mm. The variation of the shape of a blank during forging was assessed by measuring its height H and mean internal diameter d after compression to each desired degree of axial deformation, and its densification by measuring, by the hydrostatic weighing method, its density averaged over its volume after forging.

A numerical analysis of the process of compression of hollow porous cylinders in a closed container for the blank shapes and sizes under consideration was carried out by solving on a computer a system of ordinary differential equations obtained in [3],

$$\frac{\dot{\Theta}}{1-\Theta} = 3e_z \cdot \Theta \cdot \frac{a-b}{2a-(4-3\Theta)b}, \qquad (1)$$

where Θ is the instantaneous relative density; $\dot{\theta}/(1-\theta) = e$, relative rate of densification; v, rate of travel of the pressing punch; $e_z = -v/H$; $a = 2R_e^2 \cdot H \cdot (1-\Theta)$; $b = (R_e^2 - R_{i0}^2) \cdot H_0 \cdot (1-\Theta_0)$; R_e, external blank radius; R_{i0} and R_i, initial and instantaneous internal radii, respectively; and

*Deceased.

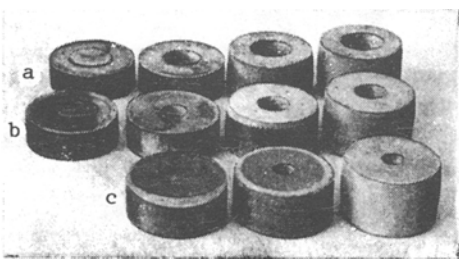

Fig. 1. Blanks compressed to various degrees of axial deformation. Internal diameter d_0: a) 20; b) 14; c) 9 mm.

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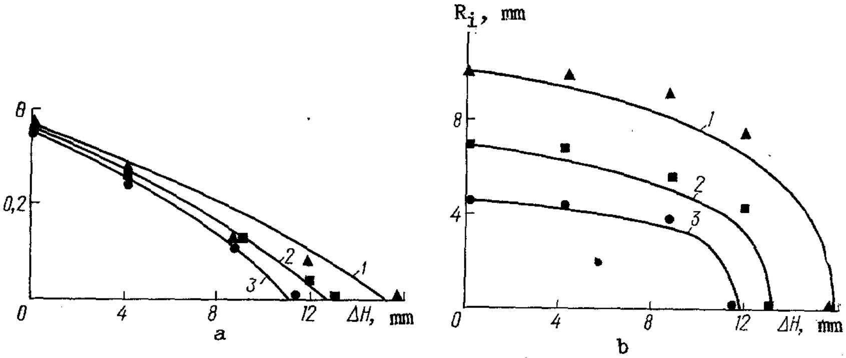

Fig. 2. Variation of blank porosity (a) and internal radius (b) with degree of axial deformation at d_0 = 20 (1), 14 (2), and 9 mm (3). The plot points are experiments data.

$$\dot{R}_i = \frac{(R_i^2 - R_e^2)}{2R_i} \cdot \left(e + \frac{v}{H}\right) \tag{2}$$

($\dot{R}_i$ is the rate of change of the internal radius).

Load was applied in stages, and values of changes in specimen height ΔH in an arbitrary unit of time were substituted for v in these equations. The increases in relative density $\Delta\Theta/(1 - \Theta)$ and internal radius ΔR/R in the same period of time were expressed in terms of ΔH. With ΔΘ and ΔR known, the expressions

$$\Theta_j = \Theta_{j-1} + \Delta\Theta; \qquad (R_i)_j = (R_i)_{j-1} + \Delta R_i \tag{3}$$

were used for finding after each j-th loading step mean values of porosity and internal raidus, which served as starting data for the following, (j + 1) step of deformation.

Figure 2 shows calculated curves of instantaneous mean porosity and mean internal radius of a blank being pressed, plotted against axial deformation $\Delta H = H_0 - H$. The plot points in the graphs are corresponding experimental data.

Analysis of the results obtained shows (Fig. 2a) that the process of compression of a porous ring in a die can be arbitrarily divided into two stages. In the first stage, when the porosity of the blank being compressed is still relatively high, densification predominates over shape change, which manifests itself in a high intensity of densification with only a slight decrease in the internal diameter of the ring. Under these conditions the rate of densification is greater, and the change in the diameter of the internal cavity smaller, when the ratio R_e/R_i is large, i.e., with rings of large wall thickness. In the second stage of compression, when the mean ring porosity falls to 3-6%, the rate of radial deformation sharply increases (the internal ring diameter decreases), and at $\Theta \approx 1\%$ the internal ring cavity disappears (Fig. 1). With rings of large wall thickness (large values of R_e/R_i), the disappearance of the internal cavities takes place at smaller degrees of vertical deformation $\varepsilon_z = \Delta H/H_0$. At the same time, in the second stage of deformation the intensity of deformation slightly grows owing to the fact that with decreasing diameter of the internal cavity the stressed state becomes more severe. Similar results are reported in [4], where it is shown that with increase in severity of loading the intensity of densification grows.

Comparison of results of theoretical and experimental investigations of the process under consideration revealed that on practically the whole path of deformation calculated values of the cavity radius R_i were 5-15% smaller than those found in experiments. By contrast, at any given degree of axial deformation ε_z the calculated porosity of compressed rings slightly exceeded the experimental value of Θ. The discrepancy between the theoretical and experimental data can be attributed to the fact that in the theoretical model [3] no allowance is made for the effect of the friction forces between the blank being compressed and the elements of the container. Bearing in mind that during the compression of a blank in a container the axial stress σ_z exceeds the radial stress σ_r [5] and that consequently the tangential stress is higher on the end faces of the blank than on its side surface, we can assume that the effect of the friction forces will manifest itself more strongly on the end contact faces than on the side surface. Slower radial flow of material is apparently also due to more intense cooling of the end faces of the heated blank in the initial stage of deformation, before its side surface comes into contact with the die walls (in our work blanks were placed in the die cavity with a clearance of about 0.5 mm on each side).

CONCLUSIONS

The compression of a porous ring in a container can be arbitrarily divided into two stages: Initially, densification predominates over shape change, but, when the porosity decreases to 3-6%, the rate of radial deformation sharply rises, and at $\Theta \approx 1\%$ the cavity closes up. With increasing value of R_e/R_i at any given porosity the intensity of densification grows and the rate of radial deformation falls. There is a discrepancy of not more than 15% between experimental and theoretical data, which means that the theoretical model adopted is sufficiently accurate and can be employed for calculating the process of hot compression of a porous ring in a container.

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