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Design and Manufacture of a Composite Punching Tool

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Abstract—Proposals are made regarding the design and manufacture of a composite rod-type hole-punching tool by plastic deformation.

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Specialized cold-stamping enterprises consume hundreds of thousands of punches, push rods, and other components. Tools account for 20–30% of the costs for automatic upsetting machines. In precise stamping of components from alloys that are difficult to deform, that figure may rise to 50%. The downtime of such machines for tool replacement and adjustment amounts to 30% of their total working time.

Instead of one-piece punches made of expensive tool steel and alloys, bimetallic punches of punches reinforced by hard-alloy inserts may be employed, with significant cost savings and increase in the working life of punches for cold stamping [1]. Such tools may be produced by a new method based on the open broaching of a complex workpiece.

The proposed technology for the assembly of bimetallic punches by broaching consists of four stages. The first (Fig. 1a) is open broaching, with the introduction of rod *1* in workpiece *2* (after heating to forging temperatures). An annular gap *3* appears between the cylindrical rod surface and the cavity in the workpiece. In selecting the complex shape of the workpiece, we take account of the nonuniformity of deformation and upsetting over the height in open broaching, so as to obtain a cylindrical workpiece after open broaching. In other words, the goal is to obtain a lateral surface with minimum barrel-like curvature (without a shrinkage cavity but with an annular gap).

The second stage (Fig. 1b) consists of local heating of the workpiece, followed by upsetting of the rod section by Δl. The system is preliminarily assembled in matrix *4* to permit filling of the annular gap by material from the rod.

The final stage (Fig. 1c) is upsetting of the workpiece (using annular tool *5*) so as to create contact pressure at the adjacent surfaces sufficient for contact welding: the rod and workpiece are fused into a composite tool.

It is difficult to predict the change in shape of the workpiece in producing a bimetallic composite tool by open broaching. Accordingly, we need to develop a design method for the initial complex workpiece.

In Fig. 2, we illustrate the determination of the shape change in open broaching by a tool with diameter $d_b = 0.3–0.7D_0$ (D_0 is the workpiece diameter). We select this range for the following reasons. When $d_b < 0.3D_0$, the deformation of the workpiece is local, since broaching begins to resemble broach insertion in a half-space [2]. When $d_b = 0.7D_0–D_0$, we observe only slight insertion of the broach in the blank [3]. That rules out the production of a permanent joint.

Before broaching, the workpiece is of height H_0 and diameter D_0 (Fig. 2, contour *1*). Broaching results in upsetting of the workpiece; its new height is H_f. The workpiece becomes barrel-shaped (diameter D_{ba}; Fig. 2, contour *2*). The region of hindered deformation (region *3*) moves downward, radially displacing the metal from deformation region *4* into annular region *5*.

Initially, annular region *5* is expanded. That is followed by upsetting, since the metal from the upper part of the sample is entrained by the moving broach.

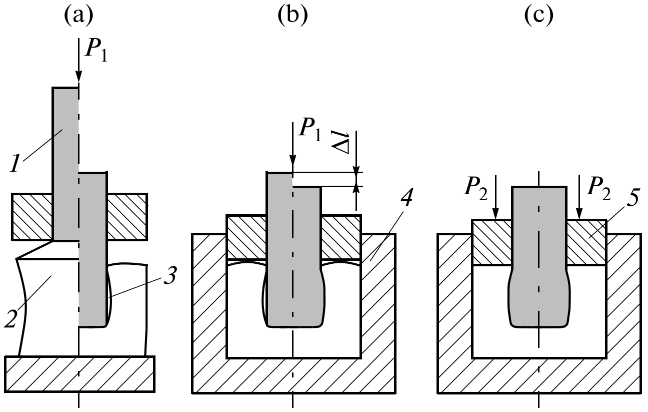

Fig. 1. First (a), second (b), and third (c) stages in the manufacture of a composite tool by broaching.

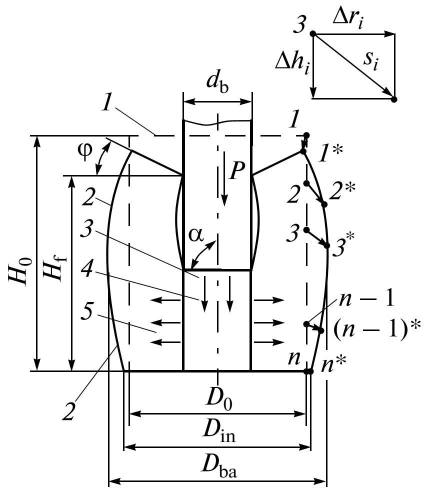

Fig. 2. Determining the shaping parameters for a cylindrical blank in open broaching.

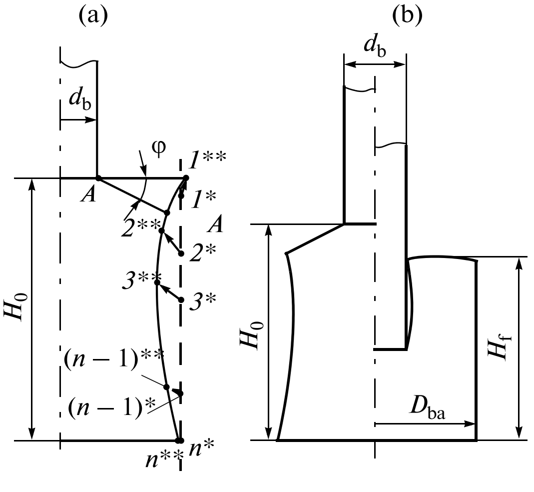

Fig. 3. Design of the generatrix of a complex workpiece (a) and contours of the designed workpiece (b).

As the tool moves downward, the height of region *4* is reduced. Metal is primarily displaced into the lower part of annular region *5*, which is enlarged. That leads to flexure of the sample's lateral surface and the formation of a gap (volume V_g) between the broach and the workpiece. An annular frictional zone is formed at the cylindrical part of the tool.

Since an annular gap is formed, the cavity formed in broaching becomes barrel-shaped. The relative volume of the annular gap is $\theta_g = (V_g/V_{int}) \times 100\%$, where V_g is the volume of the annular gap, mm^3; and V_{int} is the volume of the cylindrical broach introduced, mm^3. The contour of the upper end surface is rotated by φ, forming a shrinkage cavity.

When $\alpha < 90°$, the region of hindered deformation is somewhat differently shaped. The metal flow is perpendicular to a conical surface, but the overall character of the flow is the same. Only the direction of metal flow changes. That reduces the upsetting of the workpiece. The shape of the sample has little influence on the direction of metal flow. These findings provide the basis for the design of the complex workpiece.

The figures 1, 2, ..., *n* in Fig. 2 denote the initial positions of equidistant points on the lateral surface (*n* is the total number of points). The figures 1*, 2*, ..., *n** denote the final positions of the points after broaching. The motion from the initial position is characterized by the vector $\vec{s}_i(\Delta r_i, \Delta h_i)$, where Δr_i and Δh_i are, respectively, the radial and axial displacements of point *i*. Hence, on the basis of those displacements of the points from the required shaping contour, we may obtain the contour of the complex workpiece at points 1**, 2**, ..., *n*** (Fig. 3a).

However, this method does not permit compensation of the shrinkage cavity formed at the upper end of the workpiece. Therefore, the intended contour of the complex workpiece must be corrected by an angle φ in the direction of shrinkage-cavity formation. To this end, we pass secant plane *AA* through the point with coordinates ($d_b/2$; H_0) at an angle φ to the end surface (Fig. 3a).

In Fig. 3b, we show the contours of the complex workpiece before (to the left) and after (to the right) broaching; after broaching, it is represented by a cylinder of diameter D_{ba} and height H_f.

The experimental results are entered in a knowledge base regarding the geometric parameters of final workpiece shaping in open broaching. This knowledge base rests on mathematical models expressing the final shaping dimensions of the workpiece Δr_i, Δh_i, D_{ba}, D_{in}, H_f, φ, θ_g. The experimental data may be expressed as a function of the relative rod diameter d_b/D_0, the relative workpiece height H_0/D_0, and the punch's base angle α

$$\left.\begin{aligned}\Delta r_i &= f_1(d_b/D_0;\ H_0/D_0;\ \alpha);\\ \Delta h_i &= f_2(d_b/D_0;\ H_0/D_0;\ \alpha);\\ D_{ba} &= f_3(d_b/D_0;\ H_0/D_0;\ \alpha);\\ H_f &= f_5(d_b/D_0;\ H_0/D_0;\ \alpha);\\ \varphi &= f_6(d_b/D_0;\ H_0/D_0;\ \alpha);\\ \theta_g &= f_7(d_b/D_0;\ H_0/D_0;\ \alpha).\end{aligned}\right\}$$

We now consider the following parameter values: broach diameter $d_b/D_0 = 0.3–0.7$; workpiece height $H_0/D_0 = 0.5–1.5$ (at large H_0/D_0, it is difficult to ensure stability of the punch); base angle of punch $\alpha = 45°–90°$. The depth of punch introduction is $0.8H_0$. (Greater depth leads to the formation of a removable flap and is used mainly to punch holes through workpieces.)

We now consider the basic stages in the design of the complex workpiece. The first stage is the input of

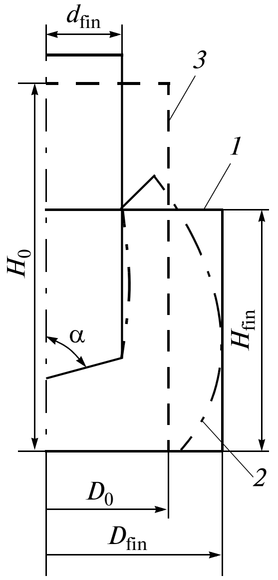

Fig. 4. Design of a complex workpiece on the basis of the part to be produced.

the initial data in the form of a CAD model of the final bimetallic part to be made from the complex workpiece (Fig. 4).

We must solve the equations

$$\begin{cases} D_{\text{ba}} = f_3(d_{\text{b}}/D_0;\ H_0/D_0;\ \alpha); \\ H_{\text{f}} = f_5(d_{\text{b}}/D_0;\ H_0/D_0;\ \alpha); \\ \theta_{\text{g}} = f_7(d_{\text{b}}/D_0;\ H_0/D_0;\ \alpha). \end{cases}$$

Next, the dimensions D_0 and H_0 of cylindrical workpiece *3*, the annular gap θ_{g}, and the rod's taper angle α are calculated. The contour of this cylindrical workpiece *2* after broaching must be inscribed in the contour of the final composite tool *1*. In other words, the following condition must be satisfied

$$\left.\begin{aligned} d_{\text{b}} &= d_{\text{fin}}; \\ H_{\text{f}} &= k_V H_{\text{fin}}; \\ D_{\text{ba}} &= D_{\text{fin}}, \end{aligned}\right\} \tag{1}$$

where H_{fin} and D_{fin} are the housing height and diameter; d_{fin} is the rod diameter of the final bimetallic part (forging); H_{f} and D_{ba} are the dimensions of the cylindrical workpiece after broaching (contour *2*); k_V is a correction factor introduced to ensure constancy of the volume. (In the first calculation cycle, $k_V = 1$.)

Since there are many such contours (four unknowns in three equations), we select the contour with the maximum possible annular gap $\theta_{\text{g}} = \theta_{\text{g max}}$.

After determining the dimensions of the cylindrical workpiece, the radial and axial displacements Δr_i and Δh_i of points on its lateral surface are calculated, as well as the shrinkage angle φ of the upper end surface, by substituting the values of D_0, H_0, and α obtained in the previous stage into the following equations

$$\Delta r_i = f_1(d_{\text{b}}/D_0; H_0/D_0;\ \alpha);$$

$$\Delta h_i = f_1(d_{\text{b}}/D_0; H_0/D_0;\ \alpha);$$

$$\varphi = f_1(d_{\text{b}}/D_0;\ H_0/D_0;\ \alpha).$$

The results are used to plot the contour of the convex workpiece (Fig. 3a). To fill the annular gap with the rod as a result of upsetting in the course of assembly, the rod must be elongated by Δl:

$$\Delta l = (\theta_{\text{g}} l_{\text{int}}/100),$$

where l_{int} is the length of the rod introduced in the workpiece.

In the final stage, the constant-volume condition is verified by calculating the actual value of the correction coefficient k_V:

$$k_V = \frac{V_{\text{fin}}}{V_{\text{com}} + V_{\text{g}} + V_{\text{int}}}, \tag{2}$$

where V_{fin} is the volume of the final composite tool, mm^3; V_{com} is the volume of the complex workpiece, mm^3.

If $k_V = 1$, the calculation stops and the result is recorded. If the total volume of the complex workpiece, the part of the rod introduced in the workpiece, and the angular gap is less than the required housing volume of the bimetallic part, then the calculation is repeated with the value k_V in Eq. (1). The calculation continues until Eq. (2) is satisfied. The final geometric parameters of the complex workpiece and the rod take the form of CAD models of the complex workpiece and the rod workpiece.

We verify the proposed geometric design method for the complex workpiece by manufacturing an experimental batch of bimetallic punches. The results show that the proposed method expands the scope for the production of bimetallic parts by plastic deformation, with high assembly quality.

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