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THEORETICAL STUDY OF THE SCHEME OF SHAPING FORGINGS BY UPSETTING FROM STEP SHAFTS

Abstract. Experimental studies have shown that shaping forgings by upsetting in closed dies is not possible, since an annular clamp is formed at the junction of steps of larger and smaller diameters. To eliminate the clamp, the upsetting of stepped shafts with a conical cut is proposed and theoretical studies are carried out. Calculations have shown that metal leakage occurs simultaneously with the upsetting of the conical transition and the risk of clamping is small.

Keywords: stepped shaft, ring clamp, conical cut, transition places, plastic deformation, research.

Introduction. Preliminary experimental studies have established that the shaping of forgings by upsetting in closed dies is not possible, since a ring clamp is formed at the conjugation of steps of larger and smaller diameters, which is unacceptable for most shafts due to strength conditions (Fig. 1) [1].
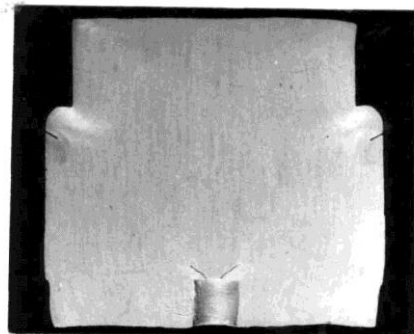

Fig. 1. Macrostructure of a sample with a formed clamp

In connection with the formation of a clamp, we will analyze the version of the workpiece with a conical transition from a larger to a smaller step. Theoretical

analysis should give the optimal value of the cutting angle, at which clamping can be avoided.

Materials and methods. With the selected geometry of the workpiece (Fig. 2), we will determine the dimensions of the compensator required for welding to the end of the smaller step in order to restore the dimensions of the shaft by volumetric deformation.
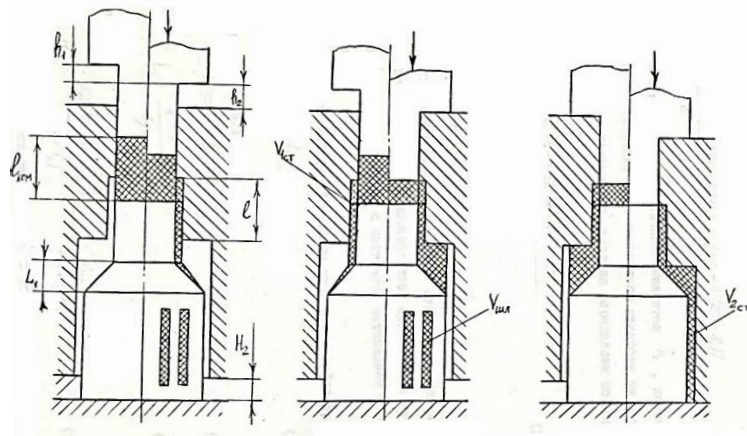

Fig. 2. Scheme of movement of metal of a workpiece with a conical cut

The calculation of the length of the compensator, carried out according to the diagram in Fig. 2, gave the following value

$$l_k = \frac{V_k}{Hr^2} = \frac{\delta_1(2r+\delta_1)l + \delta_2(2R+\delta_2)L}{r^2} + \frac{V_{uu}}{Hr^2} + \frac{L_1()2R^2 - Rr - r^2}{3r^2} \qquad (1)$$

where, L_1 – length of the conical part of the larger step.

The last term of the equation indicates the increase in metal required to compensate for the conical cut, at the transition of the steps.

If we express the length L_1, through the corner α, then the last expression takes the form:

$$l_k = \frac{\delta_1(2r+\delta_1)l + \delta_2(2R+\delta_2)L}{r^2} + \frac{V_{uu}}{Hr^2} + \frac{(2R^2 - Rr - r^2)(R-r)}{3r^2 \lg \alpha} \qquad (2)$$

Let's consider the deformation process step by step, following the rule of displaced volumes. We determine the stroke of the movable punch at stage 1 of deformation:

$$h_1 = \frac{\delta_1(2r+\delta_1)l + \delta_1(2r+\delta_1)H_2}{r^2} + \frac{L[R\delta_1 + \delta_1(2r+\delta_1)]}{3r^2} \qquad (3)$$

In formula (3), the unknown value is H, which is determined below. The value of the stroke of the movable punch at stage II and the total value of the stroke of the movable punch are determined by the formulas:

$$h_2 = \frac{R_1^2(H_2 + L) - r_1^2 \cdot H_2 - 1/3L(R^2 + Rr + r^2)}{r^2}$$

(4)

Full stroke of the movable punch

$$h_{nyaн} = h_1 + h_2$$

(5)

Research results and discussion. At stage III of deformation, the movable punch moves together with the movable matrix and the metal moves along the surface of the larger step with partial flow of metal into the grooves of the splines. We determine the stroke of the movable matrix at stage III of deformation.

$$H_2 = \frac{(R_1^2 - R^2)(L - L_1)}{R_1^2} + \frac{V_{ш}}{HR_1^2}$$

(6)

If in formula (2) we replace

$$R_1 = R + \delta_2$$

(7)

$$L_1 = \frac{R - r}{\lg \alpha}$$

(8)

Then we get

$$H_2 = \frac{\alpha_2(2R + \delta_2)\left(L - \frac{R - r}{\lg \alpha}\right)}{(R + \delta_2)^2} + \frac{V_{ш}}{H(R + \delta_2)^2}$$

(9)

After substituting the value of H into the formulas for determining the stroke of the movable punch (3, 4, 5), we obtain

$$h_{nyya} = l_{kom} - H_2$$

(10)

After determining the necessary data for the design of die tooling, we will analyze the possibility of forming a clamp when using a blank with a conical cut. A number of works on the upsetting of blanks in the idea of a truncated cone have been published in technical literature. We will note the most significant works of the authors [2,3,4,5], in which the analysis of the deformation process of conical blanks is carried out using the slip line method. The results of the listed works can be used by us in full, since they were carried out for upsetting "high blanks" with a height greater than the diameter of the small base $(L/d\rangle1)$. In this case, the field of slip lines looks like this (Fig. 3).
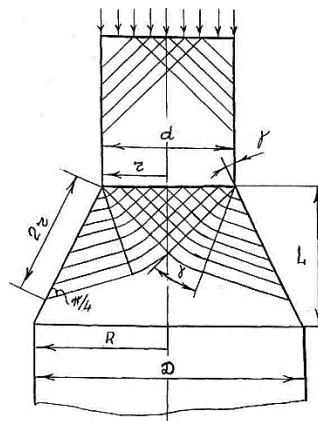
Fig. 3. Field of sliding lines during upsetting of a "high" cone

Using such a "long" cut on blanks would lead to excessive metal consumption and increased labor intensity of mechanical processing. In addition, as shown by in-depth studies conducted by Zhuravlev A.Z. [5], during upsetting of a high cone, defects in the form of folds (clamps) may appear. Based on the theoretical and experimental studies conducted, Zhuravlev A.Z. determined the limits of possible fold formation depending on the ratio at D/d the cone angle $\alpha = 0^0 - 10^0$.

During upsetting of stepped blanks, the clamp is formed together with the transition of the steps. Therefore, the works of Zhuravlev A.Z. are valuable in that they indicate the lower limit of the cone angle with a value of , above which the appearance of folds and clamps on the conical surface is excluded. Our task includes determining the optimal value of the cutting angle of a larger step, at which the clamp would be excluded or its value would be reduced to a minimum.

From the adopted clamping scheme, it is possible at the II stage of deformation, when the upsetting of the diameter of the small step ends and the metal begins to flow into the cavity (receiver) for its further movement along the outer surface of the diameter of the larger step. For analysis, we use the slip line method.

Let us consider the flow of metal at the moment the metal begins to flow out in the diametrical direction into the cavity-receiver.

With a "short" length of the conical transition ($h/d\langle 1$) the possible field of slip lines will look like this (Fig. 4).

From the diagram of the field of slip lines (Fig. 4) it is clear that we have two centers of plastic deformation at the exit of the metal into the cylindrical belt and on the free surface of the conical transition between the steps.

The first field of slip lines (AFS) corresponds to the typical field of slip when displacing metal into a burr groove during hot stamping.

The second slip line field (VO, D) corresponds to the typical slip line field during closed stamping, when the die corners are filled.

Based on the rigid-plastic body hypothesis, it can be said that plastic deformation occurs in the zone outlined by the slip line field. The rest of the body is conditionally rigid. Thus, the deforming force is necessary to displace the metal into the cylindrical belt through the rigid zone O VO acts on the conical transition, forcing the metal of the conical transition to move in the radial direction.

Figure 4 shows the normal stress distribution diagrams constructed on the basis of slip line fields.
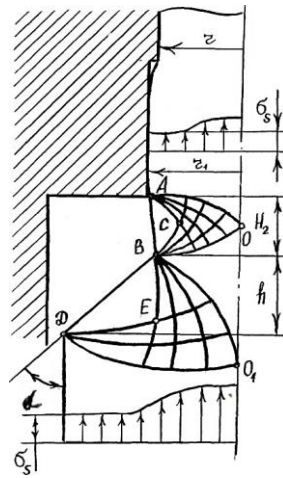

Fig. 4. Slip line field at the moment of metal flow into the diametric receiver

The author [6] proposed the following analytical dependencies for determining the magnitude of the deformation force, taking into account the nature of the normal stress distribution in the section of the deformed part.

Cylindrical belt (after slip lines AOB):

$$P_{\ddot{o}} = \delta_s \left(1.2 \ln \lambda_n + \frac{1.2}{\lambda_n} - 0.2 \right) H r^2$$

$$\lambda_n = \frac{F}{f} = \frac{H r_1^2}{2 H r_1 \dfrac{H_2}{2}} = \frac{r_1}{H_2}$$

where: – degree of deformation; F – cross-sectional area of a deformable body; f – area of the free surface of the metal flow.

After substituting the values λ_n formula (10) will take the form:

$$P_{u} = \delta_s (1.2 \ln \frac{r_1}{H_2} + \frac{1.2 H_2}{r_1} - 0.2) H r_1^2 \tag{11}$$

Mathematical processing of the field of slip lines of the VO D allows us to write the following analytical expression for determining the force required to deform the conical transition:

$$P_{k} = \delta_s (1.85 \ln \frac{R^2}{r^2} + \cos^2 \alpha \frac{r^2}{R^2}) H r^2 \tag{12}$$

where r – radius of the minor section of the cone; R – radius of the base of the cone; α – angle of inclination of the cone generatrix.

From the condition of metal flow towards the minimum resistance, we need the resistance to deformation in the annular part and in the conical transition to be

the same. In this case, uniform metal flow in the annular and conical parts of the part is ensured.

From the condition of equality of deforming forces $P_ц = P_к$ you can find the value of the conical cut angle α for the original workpiece. Let's make an equation from formulas (11 and 12).

$$\delta_S\left(1,2\ln\frac{r_1}{H_2}+\frac{1,2H_2}{r_1}-0,2\right)Hr_1^2 = \delta_S\left(1,85\ln\frac{R^2}{r^2}+\cos^2\alpha\frac{r^2}{R^2}\right)Hr^2 \tag{13}$$

From the resulting equation we find:

$$\cos\alpha = \frac{R}{r}\sqrt{\frac{r_1^2}{r^2}\left(1,2\ln\frac{r_1}{H_2}+\frac{1,2H_2}{r_1}-0,2\right)-1,85\ln\frac{R^2}{r^2}} \tag{14}$$

The obtained expression (14) shows that the magnitude of the angle depends on the ratio $\frac{R}{r}$ and heights H_2, which in turn is determined by the volume of metal moved to restore the second stage of the product.

In the analysis, the assumption used in their works by the authors [5,6] is that the cone generatrix retains a rectilinear shape during upsetting. Then, in the intermediate position, it can be represented by the diagram (Fig. 5).

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As the forming punch moves, the conical transition is upset from the initial height to some intermediate height, and, taking into account the above assumption, the angle of inclination of the generatrix decreases from the value α to α_i. At the same time, the metal flows into the diametric receiver. The initial height H_2 increases to H_{2i} due to the cone's settlement.
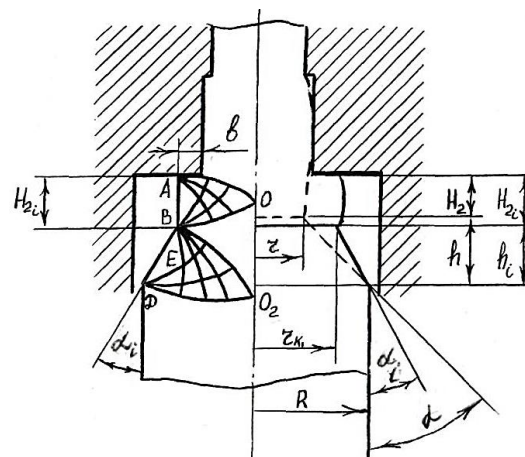
a) field of sliding lines; b) change in product shape.

Fig. 5. Intermediate stage of metal displacement into the diametric receiver and cone upsetting

From the condition of constant volume for the conical transition, we can write:

$$\frac{1}{3}Hh\left(r^2 + Rr + R^2\right) = \frac{1}{3}Hh_i\left(r_{ki}^2 + Rr_{ki} + R^2\right),$$

(15)

where, given the value h_i, you can find the radius of the upper base of the cone:

$$r_{ki} = -\frac{R}{2} + \sqrt{\frac{R^2}{4} + \left[\frac{h}{h_i}\left(r^2 + Rr + R^2\right) - R^2\right]}$$

(16)

Size h_i we select based on the condition that the deformation at each deformation interval is approximately 10%, and we find the magnitude of the deformation from the ratio:

$$\Sigma = \frac{h - h_i}{h} \cdot 100\%$$

(17)

From the diagram in Fig. 5 it is evident that the metal will flow out in the cylindrical receiver by some amount, and the shape of the field of slip lines will change. Mathematical processing according to the method of Shofman [7], in this case gives the following analytical expression for calculating the deformation force:

$$P_\text{ц} = \delta_s\left(1.2\ln\frac{r}{H_2} + \frac{1.2H_2}{r_i} - 0.2 + \frac{2MB}{H_{2i}}\right)Hr_1^2$$

(18)

where μ – coefficient of friction in hot stamping.

Equation (18) differs from equation (11) only by the term $\frac{2MB}{H_2}$ taking into account the friction forces when displacing the metal into the ring receiver.

Given the value h_i, we determine the dimensions of the upper base of the cone r_{ki} by formula (16). Then we determine the required deformation force for a given period of deformation of the conical transition by formula (12). In this case, in formula (12) instead of the value, a specific value found by formula (16) is put.

Next, it is necessary to determine the amount of metal movement into the annular diametric receiver under the action of the technological force that was necessary for the deformation of the conical transition.

The amount of metal movement in is found from equation (18) by the given value $P_{\text{ц}i} = P_{ki}$

$$B = \frac{H_{2i}}{2M}\left(\frac{P_{ki}}{\delta_s Hr_1^2} - 1.2\ln\frac{r_i}{H_{2i}} - 1.2\frac{H_{2i}}{r_i} + 0.2\right)$$

(19)

In this way, it is possible to determine step-by-step the metal movements in the cylindrical belt and conical transition for the entire process of filling the receiver with metal. It should be noted that formula (12) shows the maximum force required at the end of the cone upsetting, when $r_{ki} = R$.

In this case
$$\ln \frac{R^2}{r_{ki}^2} = 0, \alpha = 0, \cos \alpha = 1$$

$$P_k = H\delta_s R^2 \tag{20}$$

At each interval we compare the magnitude of the radial displacement of the metal in the conical transition (r_{ki}) and in the cylindrical belt ($r_{ц} = r_1 + B$).

The difference between them determines the magnitude of the resulting clamp.

$$B_{заж} = \pm\left[(r_i + B) - r_{ki}\right] \tag{21}$$

Conclusion. Calculations have shown that metal leakage occurs simultaneously with the conical transition settling. The risk of clamping is small within 0.5 mm.

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САТЫЛЫ БІЛІКТЕРДЕН ТҰНДЫРУ АРҚЫЛЫ СОҒУДЫҢ ҚАЛЫПТАСУ СХЕМАСЫН ТЕОРИЯЛЫҚ ЗЕРТТЕУ

Аңдатпа. Эксперименттік зерттеулер жабық штамптарда тұндыру арқылы соғулардың пайда болуы мүмкін емес екенін анықтады, өйткені үлкен және кіші диаметрлі қадамдардың конъюгациясында сақиналы қысқыш пайда болады. Қысқышты жою үшін конустық кесіндісі бар сатылы біліктердің шөгінділері ұсынылды және теориялық зерттеулер жүргізілді. Есептеулер көрсеткендей, металдың ағуы конустық түйісу шөгіндісімен бір мезгілде жүреді және қысқыштың пайда болу қаупі аз.

Тірек сөздер: сатылы білік, сақиналы қысқыш, конустық кесу, өтпелі орындар, пластикалық деформация, зерттеу.

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ТЕОРЕТИЧЕСКОЕ ИССЛЕДОВАНИЯ СХЕМЫ ФОРМООБРАЗОВАНИЯ ПОКОВОК ОСАЖИВАНИЕМ ИЗ СТУПЕНЧАТЫХ ВАЛОВ

Аннотация. Экспериментальными исследованиями установлено, что формообразование поковок осаживанием в закрытых штампах не представляется возможным, так как в сопряжении ступеней большего и меньшего диаметров образуется кольцевой зажим. Для устранения зажима предложены осадка ступенчатых валов с конусным срезом и проведены теоретические исследования. Расчеты показали, что вытекание металла происходит одновременно с осадкой конического перехода и опасность образования зажима небольшая.

Ключевые слова: ступенчатый вал, кольцевой зажим, конусный срез, переходные места, пластическая деформация, исследование.