Formation of bulges on hollow cylindrical products made of non-ferrous difficult-to-deform alloys

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Abstract. Formation of thickened elements on the edge parts of hollow cylindrical products, which serve as the elements of fuel lines of various power plants, can be applied to ensure a significant quality of their welding connection. The article deals with the formation of such thickening elements on tubes made of special non-ferrous alloys. Due to the mechanical features of these materials, these processes were investigated under narrow temperature and speed conditions causing short-term creep of the material. To analyze these operations, mathematical models have been created that describe power modes. Quantitative rules of the influence of the geometric parameters of the process on the pressure during the upsetting have been obtained. The materials obtained during the analysis can be used to create similar technologies.

1 Introduction

For high-quality welding of hollow cylindrical products, it is necessary to have thickenings on the edge elements [1-4]. The most rational method of their production is plastic forming, that is, upsetting and forging of the workpieces. The upsetting process is accompanied by barrel formation [1, 2, 5, 6]. When it comes to making critical parts from special metal materials using this method, then, when they are deformed, there is a risk to decrease the stability, as well as to significantly increase the loads on the tool [7-11]. Therefore, it is important to implement this process in narrow temperature and speed conditions, under which short-term creep of the material takes place [12-15]. In this case, such factors as the velocity and time of deformation determine the modes of technology application and need to be calculated.

2 Main part

Upsetting of internal thickenings. Fig. 1,a shows the scheme of the upsetting of an internal thickening with a velocity field. The calculations suggest that the heated metal of the workpiece is viscoplastic. For this case, the following expression [1] is true:

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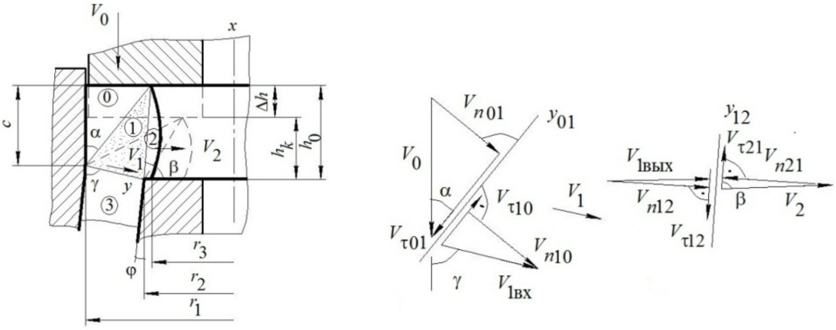
$$\sigma_э = A\cdot\varepsilon_э^m\cdot\xi_э^{\mathrm{n}}, \tag{1}$$

where $\sigma_э, \varepsilon_э, \xi_э$ are respectively the equivalent stress, strain, strain rate; A, m, n are the material constants.

The calculation assumes that the process scheme is axisymmetric. To perform calculations for this operation of modes, we use the power balance [1], and its equation:

$$N = N_1 + N_g + N_{fr}. \tag{2}$$

In expression (2) N is the power of forces on the deforming tool, N_1, N_g, N_{fr} are respectively the powers in block 1, at the boundaries of the gap between the velocity and at the friction areas.



a) b)

Fig. 1. Velocity field for the investigated process (a) and plan of velocities (b).

The powers in block 1, which is also the block of deformations are represented as follows: [1]

$$\mathrm{N}_1 = \int \sigma_э\xi_э \mathrm{dW} = 2\pi A y_{gr.c.}\cdot\left(\frac{\Delta h}{V_0}\right)^m \int_0^h \int_{y12}^{y01} \xi_э^{1+m+n}\cdot dydx. \tag{3}$$

Here $y_{gr.c..}$ is the transverse center of gravity of the sectional area of block “1”.

“01” line power is [1]:

$$\mathrm{N}_{01} == \frac{\pi A\left(r_1^2 - r_3^2\right)}{\sqrt{3}tg^2\alpha}\left(\frac{1}{\Delta h}\right)^n V_0^{1+n}\left[1+\frac{ctg(\alpha+\gamma)}{ctg\alpha}\right]\varepsilon_{э01}^{\mathrm{m+n}}. \tag{4}$$

“12” line power is [1]:

$$\mathrm{N}_{12} = \frac{\pi A\left(r_2^2 - r_3^2\right)\left(r_1^2 - r_3^2\right)}{2r_3h_0\sqrt{3}}\cdot\left(\frac{1}{\Delta h}\right)^n V_0^{1+n}\left[1+\frac{\sin\alpha}{\cos\beta}\cdot\sin(\beta+\gamma)\right]\varepsilon_{э12}^{m+n}. \tag{5}$$

“13” line power is [1]:

$$N_{13} = \frac{\pi A(r_2+r_3)}{(\sqrt{3})^{1+m+n}}\left(\frac{\sin\gamma}{r_1-r_2}\right)^{m+n}\left(\frac{\Delta h}{V_0}\right)^m \int_0^{h-c} V_{1/y=y_{13}}^{m+n}\,dx. \tag{6}$$

The power on friction areas is [1]:

$$N_{fr.} = \pi\mu q V_0 \frac{\left(r_1^2 - r_3^2\right)\left(r_2^2 - r_3^2\right)}{2r_3h_0}. \tag{7}$$

The pressure for the formation of the internal thickening by upsetting is determined by the equation (2) by substituting the expressions (8), (13), (18), (21), (22) [1]

$$q \le \frac{N_1 + N_{01} + N_{12} + N_{13}}{\pi\left(r_1^2 - r_3^2\right)\left(1 - \mu\frac{r_2^2 - r_3^2}{2r_3h_0}\right)}. \tag{8}$$

Once the calculations have been performed, we can analyze the effect of various values on the upsetting pressure of the internal bulges. The calculations are made for the upsetting of internal thickenings on a hollow workpiece made of deformable aluminum alloy AA5086 at 420 $°C$ and alloy 304 L at 900 $°C$. The constants of the alloys are given in [1]. For calculations and analysis, the following geometry values were taken: $r_1 = 75mm$, $r_2 = 70mm$, $r_3 = 65mm$, $h_k = 15mm$, $\varphi = 10^0$.

Fig. 2 shows the dependence of the change in the upsetting force on the relative size of the flange for the metals under study.

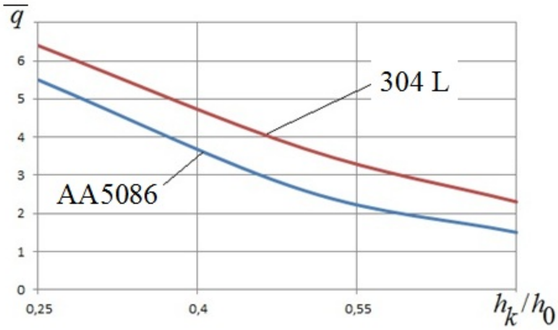


Fig. 2. Dependences of the change in the upsetting force on the relative size of the flange for the studied metals

The analysis of this graphical dependence showed that with a decrease in the relative size of the flange (with an increase in the relative punch stroke), the upsetting pressure increases by 1.8 times for the materials under study. In general, the dependences of change for both studied alloys are identical.

Fig. 3 shows the dependence of the change in the upsetting force on the relative value of the flange radius.

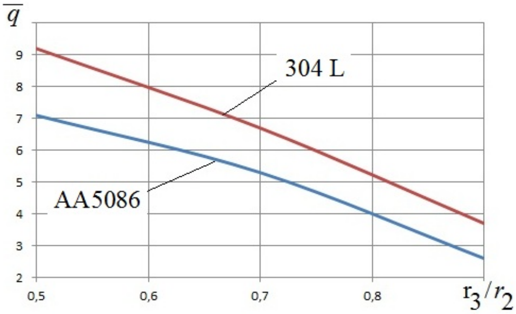


Fig. 3. Dependences of the change in the upsetting force on the relative value of the flange radius

The analysis of this graphical dependence showed that with a decrease in the relative value of the flange radius from 0.5 to 0.9, the pressure decreases by 2.3 times for a chromium-nickel alloy and by 2.8 times for AA586 aluminum.

Figure 4 shows the dependence of the change in the upsetting force on the velocity of the tool movement.

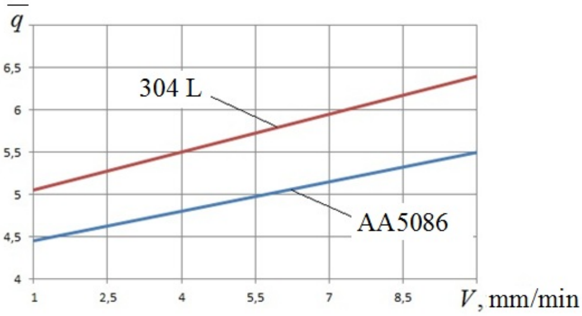


Fig. 4. Dependences of the change in the upsetting force on the velocity of the tool movement

The analysis of this graphical dependence showed that with an increase in the velocity of the tool movement, the pressure increases by 20% for material AA5086 and by 28% for 304 L. Having analyzed the obtained dependences, it can be said that the intensity of pressure growth during the upsetting for a chromium-nickel alloy is greater than for alloy AA5086.

Upsetting of external thickenings. The upsetting scheme for making external thickenings is shown in Fig. 5. The equation of state of the material in the deformation zone is described by the following expression [2]:

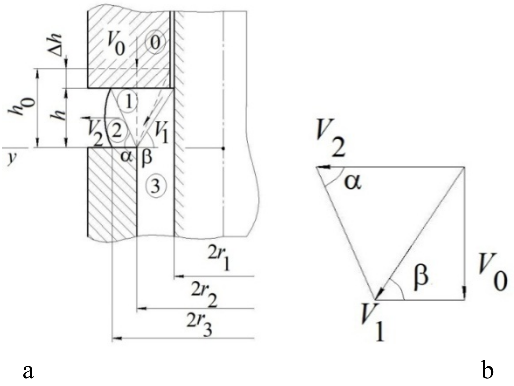
$$\sigma_e = A\left(\int d\varepsilon_e\right)^m \xi_e^n . \tag{9}$$

Here σ_e, ε_e, ξ_e are the equivalent stress, strain, strain rate; A, m, n are the constants of hardening and creep of the material.

The pressure during the upsetting of the external thickenings is estimated by the following inequation [2]:

$$q \le \frac{1}{(r_3 - r_1)V_0} \Sigma\left(\frac{1}{\sqrt{3}}\sigma_{ep} V_\tau l_p + \tau_{mp.} V_k l_k\right). \tag{10}$$

Here q is the pressure on the punch; σ_{ep} is the value of the equivalent stress at the boundaries of the velocity gap; V_0, V_τ, V_k are the velocities of movement of the deforming element, at the boundaries of the gap and surfaces of contact friction areas; τ_{fr} - shear stress on the contact friction areas.



a b

Fig. 5. Scheme of the upsetting process, field (a) and hodograph (b) of the movement velocity

The final form of the equation for the upsetting pressure of the external bulges is presented as follows [2]:

$$q \le \frac{\dfrac{A}{(\sqrt{3})^{1+m+n}}\left(\dfrac{V_0}{\Delta h}\right)^{n}\left[1-\mu\left(tg\beta+\dfrac{r_3-r_2}{h}\right)\right]}{\left[\left(\dfrac{r_3-r_2}{(r_3-r_1)\cos\alpha}\right)k_1^{m+n}\left(\dfrac{1}{\sin\alpha}\right)^{1+m+n}+\left(\dfrac{r_2-r_1}{(r_3-r_1)\sin\beta}\right)k_2^{m+n}\left(\dfrac{1}{\cos\beta}\right)^{1+m+n}\right]}. \qquad (11)$$

Expression (11) makes it possible to set the upsetting pressure for making external thickenings on tubes made of aluminum alloy AA5086 and alloy based on titanium 6Al-4V when heated to temperatures $450°C$ and $930°C$ respectively. The following dimensional ratios were taken for substitution in formula (11): $r_1 = 25$ mm, $r_2 = 30$ mm, $h = 10$ mm, $\Delta h = 3$ mm. The constants of equations (9), (11) for AA5086: $A = 55\ MPa \cdot c^n$; $m = 0{,}1$; $n = 0{,}025$; $A_{np.} = 540$ MPa. For alloy 6Al-4V $A = 67\ MPa \cdot c^n$; $m = 0{,}03$; $n = 0{,}06$; $\varepsilon_{np.} = 0{,}8$.

After the substitution of these constants and dimensional ratios into formula (11), we obtained the dependences of the pressures on the deforming tool on its velocity $q(V_0)$ (Fig. 6) and those of the pressures on the deforming tool on the relative thickness of the workpiece $q(r_1 / r_2)$ (Fig. 7).

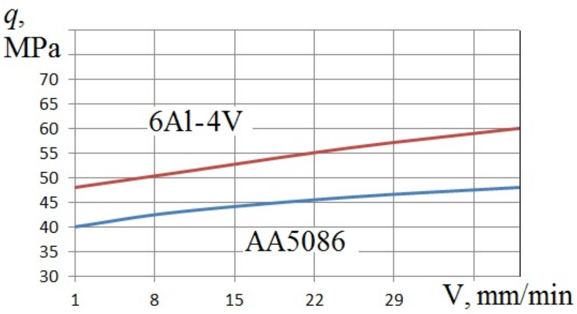


Fig. 6. Dependences of the pressures on the deforming tool on his velocity $q(V_0)$

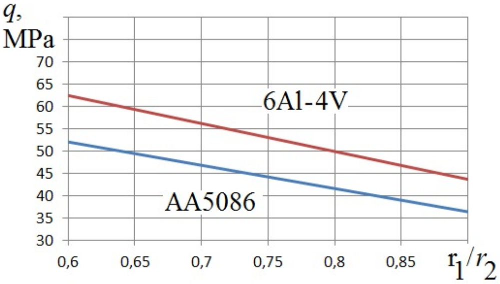


Fig. 7. Dependences of the pressures on the deforming tool on the relative thickness of the workpiece $q(r_1/r_2)$

The analysis of the results of the dependences shown in Fig. 6 and 7 suggest that increasing the pressure tool velocity for alloy AA5086 results in a 20% increase in the upsetting pressure. For a titanium-containing alloy, the intensity of the pressure growth in the same velocity range is 28%. Increasing the relative thickness of the workpiece from 0.6 to 0.9 leads to a 44% decrease in pressure for AA5086. For the 6Al-4V alloy in the same range, changes in the relative pressure thickness are reduced by 40%.

3 Conclusion

Thus, after the analysis of the research results concerning the upsetting of external and internal thickenings, it can be said that compliance with high-speed deformation modes has a positive effect on reducing power loads. Dependences between the degrees of deformations during the upsetting and the force of the process have been established. The results can be used as recommendations for the manufacture of thickened tube elements.

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