Forming of curvilinear metal billets

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Forming of curvilinear metal billets

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Abstract. Elastic-plastic bending of sheet billets is considered. The values of deformation, at which it is possible to reduce residual stresses in the metal after deformation, this has a positive effect on the durability of products.

1. Introduction

Actuality and practical importance of processes of processing of metals by pressure with the use of local plastic deformation when the plastic flow takes place only in part of the volume of a deformable workpiece and in the rest of the volume occurs only elastic deformation. The local location of the plastic deformation zones can have a negative impact on the accuracy of the resulting products, but it can also be useful in the preparation of blanks with local thickenings.

There are differences between the processes in which plastic deformation is realized in the entire volume of the deformable body and those in which plastic deformation occurs only in part of its volume.

The first includes various types of forging, stamping, as well as basic rolling operations. When rolling in each moment of time is subjected to a plastic deformation of the small volume of the workpiece, but is being consistently implemented such a deformation along its entire length.

In contrast to these processes, the deformation of pipe end sections is an example of local deformation. For example, if a compressive strain on the pipe lengths 2...4 m form the plot of increased thickness with a length of 0.1...0.2 m, the zone of plastic deformation is 0.025...0.1 of the total length of the workpiece, i.e., is a local deformation.

When deformation of the end sections of long pipes can be loss of stability and violation of the shape of the workpiece, its curvature. Instability of plastic deformation processes contribute to the inevitable changes in the conditions of their implementation: uneven heating of billets and fluctuations in the friction coefficient, the spread of the yield point within ±(0.10 ... 0.15) σ.

Pipes from 1.5 to 6 meters long with thickened length of 100-120 mm are often used in the construction and operation of mines.

Figure 1. Deformation of end sections of blanks variable section: a-straight; b-curved.
2. The dependence of the deformation of the deflection from bending moment

For bending pipe blanks used methods of stamping curved dies, figure 2. The accuracy of the size is low. For the choice of technological modes the formulas taking into account residual deformations are necessary. Experimental data on the influence of deformation intensity in dies and residual deformations on the accuracy of the part can confirm the proposed theoretical dependence of the bending deformation on the deformation forces. According to the bending scheme of the workpiece in figure 2 using a pressure roller (figure 1a) or punch (figure 1b) on the section length L width b and thickness h the force P we use the model of an ideal elastoplastic body with constant yield strength $\sigma_T$ and modulus of elasticity E. Introduced two dimensionless parameter, where the first describes the balance of forces.

When bending the workpiece on two pillars force p, applied in the middle of its length, bending moment $M(x) = 0.5P x$, where $x$ is the coordinate, the distance from the left support a and the Stress in the supports A and B is equal to 0.5 P, and the stress $\sigma = \frac{3P}{bh^2}$ for the workpiece rectangular cross section b x h. When $\sigma = \sigma_t$ - plastic deformation zone begins ($\sigma_t$ - yield strength of the workpiece material), $l_1$ determined by the equation:

$$l_1 = \frac{\sigma_T bh^2}{3P}$$

But there is a limit value of the moment $M_{max} = 0.25\sigma_T bh^2$ and a limit value of the size $l_1$. In section $x = 0.5l$ plastic deformation zone covers the entire section of the workpiece and the maximum force is

$$P_m = \frac{\sigma_T bh^2}{l},$$

and $l_1 = \frac{\sigma_T bh^2 l}{3\sigma_T bh^2} = \frac{l}{3}$.

Upon receipt of the blanks to a deformation of the bending parts near the supports of lengths $\frac{l}{3}$ and remain elastic after unloading is straightforward.

$$m = \frac{Pl}{4\sigma_T bh^2}, n = \frac{\sigma_T l}{Eh}$$

![Figure 2](image_url)

**Figure 2.** Scheme of deformation and bending a - of the pressing roller; b-sequential step-by-step bending punch; c-distribution of bending moment.
Figure 2.c shows a bending moment diagram $M(x)$, where $x$ is a longwise coordinate of a stock. Maximum bending moment $0.25P\ell$ acts in the middle of the stock length where force $P$ is applied. Maximum deflection in the cross section $x = 0.5\ell$ is calculated by the standard method [1, 2]. It is equal to

$$\frac{V_m}{a\ell} = 0.024\left[0.96 - (1 + 2m)\sqrt{1 - 4m}\right] \tag{1}$$

If, for example, a metal sheet with yield point $\sigma_T = 300\text{MH/m}^2$, modulus of elasticity $E = 2 \cdot 10^5\text{MH/m}^2$, length $l = 1\text{m}$ and thickness $h = 4 \cdot 10^{-2}\text{m}$, then value $\frac{V_m}{a\ell} = 0.2$ under the load defined by parameter $m = 0.2$.

At present value $a = \frac{300 \cdot 1}{2 \cdot 10^5 \cdot 4 \cdot 10^{-2}} = 3.75 \cdot 10^{-2}$ deflection at the midpoint of a stock is equal to $V_m = 7.5 \cdot 10^{-3}\text{m}$.

Formula (1) is used only in the range of $\frac{1}{6} \leq m \leq \frac{1}{4}$, if $m = \frac{1}{6}$, then $V_m = 0.167a\ell$ (but if $m < \frac{1}{6}$, linear dependence $\frac{V_m}{a\ell} = m$ is valid).

In the course of bending the value of maximum flexure is attained if $x = 0.5\ell$ (figure 1)

$$K_m = \frac{2a}{\ell} \left(\frac{1}{\sqrt{3\sqrt{1 - 4m}}}\right) \tag{2}$$

However, after off-loading which occurs under elastic deformation, the residual flexure of a stock is equal to

$$K_0 = \frac{2a}{\ell} \left(\frac{1}{\sqrt{3\sqrt{1 - 4m}}} - 6m\right) \tag{3}$$

If $a = 3.75 \cdot 10^{-2}$ and $m = 0.2$

$$K_m = \frac{2 \cdot 3.75 \cdot 10^{-2}}{1\sqrt{3}} \cdot \frac{1}{\sqrt{0.2}} = 9.7 \cdot 10^{-2}\text{m}^{-1},$$

$$K_0 = \frac{2 \cdot 3.75 \cdot 10^{-2}}{1} \left(\frac{1}{\sqrt{3\sqrt{0.2}}} - 1.2\right) = 0.68 \cdot 10^{-2}\text{m}$$

It is seen that value $K_0$ is much less than $K_m$. With increase of $m = 0.24$, $K_0 = 1.45m^{-1}$ i.e. the flexure increases 2.1 times (compared to the load when $m = 0.2$). If $m \leq \frac{1}{6}$, only elastic deformations are true. So if $m = \frac{1}{6}$, $K_0 = 0$ and the residual flexure is equal to zero (value $K_m = \frac{2a}{\ell}$ when $m = \frac{1}{6}$). If bending moment tends to limiting value $m = \frac{1}{4}$, $K_m \to \infty$ and $K_0 \to \infty$.

Function graph $\frac{V_m}{a\ell}$ from load parameter $m$ is given in figure 2. It is seen that the rate of deflection rise increases when $m \to 0.25$. 

\[3\]
Since a limiting value of non-dimensional load parameter $\frac{1}{4}$, minimum length $l_1 = \frac{l}{3}$. This means that plastic bending deformation under the diagram of figure 1 can be performed only along the length equal to one-third of the total stock length, i.e. the distance between bearers.

According to the bending diagram of figure 2a, two-thirds of a stock length remains straight. According to the step-by-step bending diagram of figure 2b, a stock is gradually moved then brought to stop in order to be bent and it again keeps approaching as shown by the arrow [3, 4]. Each approach step should not be greater than value $\frac{l}{5}$, it is better to take it equal to $l$ (not exceeding 0.15-0.20). The lower the value of a step motion, the higher the dimensional accuracy of a molded pipe (or a bent billet).

The main drawback of the bending deformation schemes is that the stresses vary along the length of the deformable workpiece and there are zones where the deformations remain elastic near the supports of the deformable billets, in which the curvature change of the workpiece axis is zero. To improve the bending process developed machine, figure 4, in which the deformable workpiece -1; 2 and 3 – support, 4 and 5 – bending rollers are mounted on the beam 6 and hinge 7, vertical movement – from the hydraulic cylinder 8 on the frame 9, sleeve 10 limits the angle of rotation of the beam 6.

When the distances from the hinge axis 7 to the axes of the bending rollers 4 and 5 are equal: the forces on the rollers 4 and 5 are equal $P_1 = P_2 = P$ regardless of fluctuations in the thickness of the workpiece 1, its mechanical properties and the initial curvature. The device with diameters of rollers 50 mm and bending rollers 40 mm at $l_1 = 0.5$ m and $l = 10$ m (and $l_1 = 0.05$ m, and $l = 0.10$ m) was manufactured by NIIPTMASH. A press with a force of 0.5 MN was used as a loading device. The hydraulic drive with a working fluid pressure of 50 MPa and a cylinder diameter of 0.1 m provided a force of 400 kN for bending both steel and aluminum sheets up to 10 mm thick and up to 500 mm wide. In this design, figure 4, the forces on rollers 4 and 5 are always equal, ensuring the constancy of the bending moment (and bending stresses) along the entire length in the area between rollers 4 and 5. The constancy of the bending moment also means the constancy of the curvature, i.e. the increase of its accuracy. The proposed design (RF patent No. 2561937) provides a reduction in the degree of "locality" of deformation – the zone of plastic deformation increases. Elastic zones at the edges of the workpiece remain, but their length is reduced.

![Figure 3. Function graph $V_m/a_l$ from load parameter $m$.](image)
The design principles of forging machines in which to reduce the loss of thermal energy is carried out local heating of the end sections of the blanks in the working position before the deformation. To improve the accuracy and prevent distortion of the configuration of deformable workpieces, figure 4, the end section length of 120-150 mm is clamped in matrices 2 and 3, introduced into the inner cavity of the workpiece centering rod 4. Moving the punch 5 realizes plastic deformation of the pipe section at a temperature of 1100-1130°C. When forming the flange, figure 5, at the end of the pipe 1 outer diameter \( d \) and wall thickness \( h \) is heated by the inductor, its end portion with a length of 70 - 80 mm, clamp in matrices 2 and 3 on a length of 120-200 mm. The Punch 4 with the internal guide rod 5 forms a flange 6 with a diameter \( d_0 \) and a thickness \( h_0 \), which forms with the tube 1 a single product.

According to the scheme of local deformation with the formation of the flange on the edge of the hollow billet, figure 5c to determine the deformation forces, we use the method of upper estimates with the construction of kinematically acceptable velocity fields.

For example, when \( \frac{d_0}{h_0} = 12 \), value \( \frac{P}{\sigma_T} = 4.5 \). If \( \frac{d_0}{h_0} = 8 \), we get: \( \frac{P}{\sigma_T} = 1 - \frac{2\pi n 1.25}{0.5625} + \frac{3.8 \cdot 1.25}{3\sqrt{3} 2.25} \cdot 8 = 2.8 \). According to these calculations, the force required to deform the flange when using a velocity field with a rigid zone is less than for a field without a rigid zone. For the formation of the pipe outer diameter \( d = 60 \) mm and inner flange \( d_1 = 50 \) mm thickness \( h_0 = 15 \) mm, take the length of the protruding part of the pipe matrix \( l = 20 \) mm. Examples of effort oscillograms, figure 6 a, b, the local
deformation of workpieces made of steel 36G2S at \( t = 900-9300 \text{C} \), \( d_0 = 70 \text{ mm}, d = 60 \text{ mm}, d_1 = 50 \text{ mm}, \sigma_T = 100 \frac{M_H}{m^2} \), the force reaches \( 0.33 - 0.35 \text{ MN} \).

![Graphs of efforts of deformation of pipes with diameter 50 mm](image)

**Figure 6.** Study the landing end sections of the hollow billet (the graphs of the efforts of the deformation of pipes with diameter 50 mm): a – St3; b – steel 36G2S.

On the basis of experimental studies, it is shown that for the formation of areas increased to 10-12 mm thickness on blanks with diameters up to 50-65 mm thicknesses up to 5 mm from carbon steels and steels of type 36G2S, forging machines with forces up to 0.85-0.90 MN are required. The obtained data were used in the design of new forging machines. For the possibility of local deformation of curved hollow billets (with axes in the form of circular arcs), a forging machine was proposed (RF patent No. 2561937), figure 7.

![New forging machine for deformation of end sections of billets](image)

**Figure 7.** The construction of a new forging machine for the deformation of the end sections of billets of variable cross-section: 1 – deformable part; 2, 3-half-matrix; 4, 5-punch; 6-guide rod; 7-adjusting rod; 8, 9-hydraulic cylinder; 10-hinge; 11, 12-thrusters; 13-drive.

**3. Conclusions**

1. Based on the research of advanced modern methods of OMD at the local plastic deformation on stability of the processes of bending and precipitation of the blanks.
2. Theoretical studies of the processes of local deformation of hollow billets are carried out, energy-power parameters are determined.
3. The influence of technological parameters of bending deformation on the dimensional accuracy and curvature of the workpiece is estimated, the optimal, in terms of increasing the accuracy of the workpiece size, the interval of effort is determined.

4. Theoretical positions are realized at creation and industrial development of the new equipment.

4. References

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