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INFLUENCE OF DRAGGING ON THE PROCESS OF PRESSING THE ROUTINE STRUCTURAL IRON FROM THE SHEET MATERIAL

The paper analyses the influence of dragging parameters on the mathematical model of straining of sheet material during pressing. On the operating surfaces of forcer and female mold there had been suggested to form the increased abrasion in the longitudinal direction of structural iron to reduce the material's state of tension to the gentle type.

Key words: *strain, deformation, sheet material, pressing, gentle stressed state.*

Task setting

Processing by pressure is referred to energy efficient technologies due to low level of production waste. If favors its wide application, which is restricted by gaps in the research of processes of geometry generation. The use of sheet materials for manufacturing the constructions with the increased toughness in the specific direction allows to improve the efficiency in using metal and cheapen the items [1,2].

The simulation of the geometry generation process for routine structural iron oh sheet material on process needs to consider the following stages: 1) working travel of the forcer to the contact with the sheet; 2) from the contact of the forcer with the sheet to the moment of forcer's stop; 3) forcer idle work (sheet tension removal). The possibilities of the process, the construction of the equipment and item characteristics depend on the parameters of the second stage of technological process. During the working travel, in the moment of contact between the surfaces forcer – sheet - sheet – mold – there appear the normal forces between the surfaces and as the thrust to the possible sheet sliding, there appear the friction force. Sheet sliding between the female mold and the forcer requires the difference in tension forces in relation to the forcer's bulge or the mold (fig. 1) to the exceed the static friction force between the elements female mold – sheet and sheet – forcer [3]. If should also be noted that during the simultaneous formation of many crimps, such stretching forces will parcially be balanced relating to the reference axis of the structural iron (fig 1), but the sheet will slide to the center of the stamping tool. Therefore the sizes of the work piece must exceed the sizes of the finished product, and the rest of the sheet must be cut of after pressing. The additional peculiarity in pressing manufacturing the routine structural iron grow sheet material is the ambiguity in frictional influence on the stress-strain state of the work price

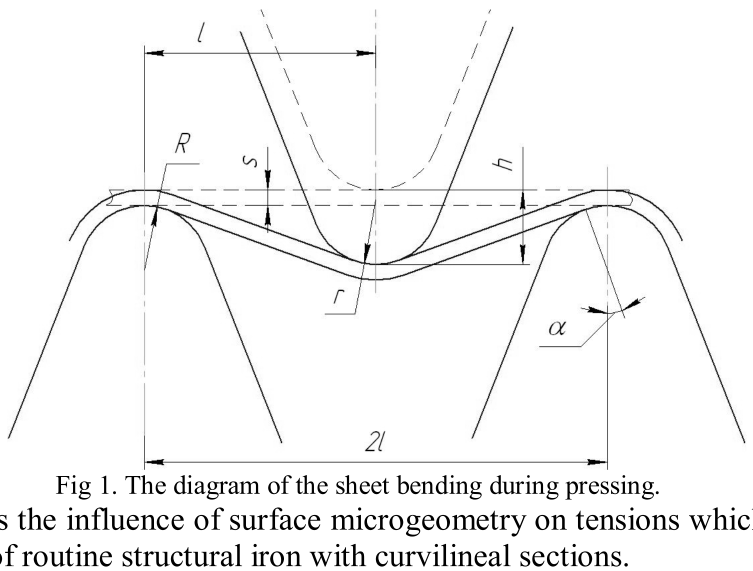

Fig 1. The diagram of the sheet bending during pressing.

This paper analyzes the influence of surface microgeometry on tensions which appear during the geometry generation of routine structural iron with curvilineal sections.

The model of stress-strain state during pressing

In each contact point between the sheet and the forcer, apart from usual responees, there also appear the friction force, directed against the possible sliding of the sheet and alone the z-axis (directed at right angles with the plane of the figure 1) According with the conceptualization of the material form changing during the bend, the inside part of the sheet (with the curve radius less than that of the neutral surface) in the direction of the z-axis increases its length [4] and the friction force resists to this possible deformation. If the sheet has relatively big length, the friction force directed along the z-axis increases ad decreases the stretching strain on the sheet surface in this direction. If the friction factor is big and the static friction force in the direction of z-axis is sufficient to the eliminate the sliding in this direction, then on the inside surface of the sheet the deformation $\varepsilon_z = 0$. That is, the stress state on the inner surface of the work piece change from *biaxial compression – uniaxial tension into the biaxial compression*. The fact, it leads to the decrease in toughness factor of the stress-strain state η and decrease in using the resource of metal ductility[5, 6, 7]. On the other hand the big friction factor between the work piece and the fool leads to the increase in the toughness factor of the stressed state [3].

If the changes in the thickness of the work piece shall not be considered, then the deformations conditions are constant along the *z-axis*. The above allows to assume that , deformations ε_z does not depend on z and may me represented as $\varepsilon_z = \varepsilon_z(\rho,\theta)$ with boundary conditions: $\varepsilon_z(r,\theta) = 0$, $\varepsilon_z(\rho_н,\theta) = 0$, $\varepsilon_z(\rho > \rho_н,\theta) < 0$. Since $\dot{\varepsilon}_z = \frac{d\varepsilon_z}{d\tau}$, where τ – time parameter, then $\dot{\varepsilon}_z = \dot{\varepsilon}_z(\rho,\theta)$.

Mathematical model of pressing process is based on the equilibrium equation for the plane stress [4]

$$\begin{cases} \frac{\partial\sigma_\rho}{\partial\rho} + \frac{1}{\rho}\cdot\frac{\partial\tau_{\rho\theta}}{\partial\theta} + \frac{\sigma_\rho - \sigma_\theta}{\rho} = 0; \\ \frac{\partial\sigma_\rho}{\rho\partial\theta} + \frac{\partial\tau_{\rho\theta}}{\partial\rho} + 2\frac{\tau_{\rho\theta}}{\rho} = 0, \end{cases} \tag{1}$$

equations of constraints

$$\begin{cases} \sigma_\rho - \sigma = \frac{2}{3}\sigma_u\frac{\dot{\varepsilon}_\rho}{\dot{\varepsilon}_u}, \\ \sigma_\theta - \sigma = \frac{2}{3}\sigma_u\frac{\dot{\varepsilon}_\rho}{\dot{\varepsilon}_u}, \\ \sigma_z - \sigma = \frac{2}{3}\sigma_u\frac{\dot{\varepsilon}_z}{\dot{\varepsilon}_u}, \\ \tau_{\rho\theta} = \frac{1}{3}\sigma_u\frac{\dot{\gamma}_{\rho\theta}}{\dot{\varepsilon}_u}, \end{cases} \tag{2}$$

and continuity conditions

$$\dot{\varepsilon}_\rho + \dot{\varepsilon}_\theta + \dot{\varepsilon}_z = 0, \tag{3}$$

where $\sigma_\rho, \sigma_\theta, \sigma_z, \tau_{\rho\theta}$ – direct and tangential stresses; $\dot{\varepsilon}_\rho$, $\dot{\varepsilon}_\theta$, $\dot{\varepsilon}_z$ – speeds of relative strain in the corresponding directions; $\dot{\gamma}_{\rho\theta}$ – speed of the relative deformations of the shift; $\sigma = \frac{1}{3}\sigma_{ij}\delta_{ij}$ – average stress (hydrostatical pressure); $\sigma_u = Ae_u^n$ – intensivity of stresses; A and n – parameters of material strengthening curve; $e_u = ln(\rho/\rho_н)$ – deformation degree; $\rho_н$ – the radius of curvature of neutral surface.

For the sheet section which is subject to bend,under condition of material incompressibility (volume stability) and absence of deformation in the neutral level, the curvature radius of neutral surface is determined:

$$\rho_{н} = (r + 0{,}5s')\frac{s'}{s}\cdot\frac{z'}{z}, \tag{4}$$

where s – sheet gauge before deformation; s' – sheet section gauge after deformation; r – inside radius of the work piece curvature (corresponds with the curvature radius of the forcer relief); z – sheet sections length along the *z-axis* before deformation; z' – sheet section length along the *z-axis* after deformation.

Analysis of the expression (4) shows that the decrease in value of the relative lengthening of the sheet in the axial direction *z'/z during deformation decreases the relative thinness of the sheet material (s-s')/s*, which results in stress redistribution on the big square of cross section and in decrease in their efficiency..

For the case of compression contacting stresses $\sigma_к(\theta)$ influencing the sheet surface, the radius of curvature of the neutral surface may be calculated [4]

$$\rho_{н} = \sqrt{r(r+s)\exp\frac{-\sigma_{к}(\theta)}{\sigma_{и}}}\,. \tag{5}$$

Speeds of deformation shall be determined [4]

$$\begin{cases} \dot{\varepsilon}_{\rho} = \dfrac{\partial \vartheta_{\rho}}{\partial \rho}, \\ \dot{\varepsilon}_{\theta} = \dfrac{\partial \vartheta_{\theta}}{\rho\partial \theta} + \dfrac{\vartheta_{\rho}}{\rho}, \\ \dot{\varepsilon}_{z} = \dfrac{\partial \vartheta_{z}}{\partial z}, \\ \dot{\gamma}_{\rho\theta} = \dfrac{\partial \vartheta_{\theta}}{\partial \rho} + \dfrac{\partial \vartheta_{\rho}}{\rho\partial \theta} - \dfrac{\vartheta_{\theta}}{\rho}. \end{cases} \tag{6}$$

To solve the system of equations (2 – 6) we assume the hypothesis, that the speeds of displacement of the point of the material may be presented [8]

$$\begin{cases} \vartheta_{\theta} = a(\theta)\cdot(\rho - \rho_{н}) = a\cdot(\rho - \rho_{н}), \\ \vartheta_{z} = b(\rho,\theta), \end{cases} \tag{7}$$

where $a(\theta)$ и $b(\rho,\theta)$ – some functions.

Solving (3) considering (6) and (7) we receive:

$$\vartheta_{\rho} = a'\left(\rho_{н} - \frac{\rho}{2}\right) + \frac{c}{\rho}, \tag{8}$$

where $a' = \dfrac{\partial a(\theta)}{\partial \theta} = \dfrac{\partial a}{\partial \theta}$; c – constant.

Substituting (7) and (8) in (6) after simplification we will receive:

$$\begin{cases} \dot{\varepsilon}_{\rho} = -\dfrac{a'}{2} - \dfrac{c}{\rho^2}; \\ \dot{\varepsilon}_{\theta} = \dfrac{a'}{2} + \dfrac{c}{\rho^2}; \\ \dot{\varepsilon}_{z} = 0; \\ \dot{\gamma}_{\rho\theta} = a + \dfrac{a''(2\rho_{н} - \rho)}{2\rho}, \quad a'' = \dfrac{\partial^2 a}{\partial \theta^2}. \end{cases} \tag{9}$$

Function $a(\theta)$ is determined from the system of the equation (9) under condition that the relative deformations $\varepsilon_\rho = 0$, $\varepsilon_\theta = 0, \varepsilon_z = 0, \gamma_{\rho\theta} = 0$ for $\rho = \rho_н$. The relative deformations may be received as an integral of the corresponding speeds of relative deformations as for the time parameter τ. Accepting the speed V and forcer travelling h as know we may write $\tau = \frac{h(s')}{V}$. Then from (9) we get

$$\varepsilon_\rho = \int_0^\tau \dot{\varepsilon}_\rho d\tau = -\int_0^{\frac{h(s')}{V}} \left(\frac{a'}{2} + \frac{c}{\rho^2}\right) d\left(\frac{h(s')}{V}\right) = -\frac{1}{V}\int_0^{\frac{h(s')}{V}} \left(\frac{a'}{2} + \frac{c}{\rho^2}\right) d\left(h(s')\right), \tag{10}$$

Where the function $h(s') = h$ is set in the subtended kind by the system

$$\begin{cases} h(s') = R + r + \cos\alpha \cdot \left(l - (R + r)\cdot(1 + \sin\alpha)\right), \\ tg\alpha = \dfrac{(h(s') + s - s')\cdot l}{l^2 - (h(s') - s')\cdot s}, \end{cases} \tag{11}$$

where α – the angle of sheet bend.

Since $V \neq 0$ and as is seen from (11) and (10), the subintegral function does not depend on the changes in sheet gauge then from (10) on the base of the condition $\varepsilon_\rho = 0$ for $\rho = \rho_н$, we will receive $c = \frac{-a' \cdot \rho_н^2}{2}$. Analogically, for the relative deformation of the shift it is possible to write, that for $\rho = \rho_н$ $\gamma_{\rho\theta} = 0$. On the base of the solution of this condition and (11) we write

$$a(\theta) = k_1 \cdot \sin(\sqrt{2}\theta) + k_2 \cdot \cos(\sqrt{2}\theta), \tag{12}$$

where k_1, k_2 – constants.

Form (12) and (9) we will get

$$\begin{cases} \dot{\varepsilon}_\rho = -\dfrac{1}{\sqrt{2}}\left(1 - \dfrac{\rho_н^2}{\rho^2}\right)\left(-k_1 \sin\left(\sqrt{2}\theta\right) + k_2 \cos\left(\sqrt{2}\theta\right)\right), \\ \dot{\varepsilon}_\theta = \dfrac{1}{\sqrt{2}}\left(1 - \dfrac{\rho_н^2}{\rho^2}\right)\left(-k_1 \sin\left(\sqrt{2}\theta\right) + k_2 \cos\left(\sqrt{2}\theta\right)\right), \\ \dot{\varepsilon}_z = 0, \\ \dot{\gamma}_{\rho\theta} = \left(1 - \dfrac{\rho_н}{\rho}\right)\left(k_1 \cos\left(\sqrt{2}\theta\right) + k_2 \sin\left(\sqrt{2}\theta\right)\right). \end{cases} \tag{13}$$

For the plane stress state

$$\dot{\varepsilon}_u = \frac{1}{\sqrt{3}}\sqrt{\begin{gathered} 2\left(1 - \frac{\rho_н^2}{\rho^2}\right)^2 \left(-k_1 \sin\left(\sqrt{2}\theta\right) + k_2 \cos\left(\sqrt{2}\theta\right)\right)^2 + \\ + \left(1 - \frac{\rho_н}{\rho}\right)^2 \left(k_1 \cos\left(\sqrt{2}\theta\right) + k_2 \sin\left(\sqrt{2}\theta\right)\right)^2 \end{gathered}}. \tag{14}$$

The [3] considers the interaction of the die tooling and the sheet during deformation and formulates the condition of work piece sliding between the surfaces of female mold and forcer. The value of such sliding or its absence is determined on the base of friction factor f. This enables to specify the value of the contacting stresses $\sigma_\rho(r,\theta)=\sigma_к(\theta)$ и $\tau_{\rho\theta}(r,\theta)=\sigma_к(\theta)\cdot f$ on the inside surface of the sheet (under condition of sliding absence), conduct calculations of the used plasticity resource and stress- strain state of the material during pressing and determine the factors k_1 and k_2 for specific conditions of deformation. The change of friction factor in different directions is ensured due to design features of the die tooling.

Substituting (2), (13), (14) into (1) we receive

$$\begin{cases} \dfrac{\partial\sigma_\rho}{\partial\rho} = -\dfrac{1}{\rho}\dfrac{\partial\tau_{\rho\theta}}{\partial\theta} - \dfrac{2}{3}\sigma_u \dfrac{\dot{\varepsilon}_\rho - \dot{\varepsilon}_\theta}{\rho\dot{\varepsilon}_u}, \\ \dfrac{\partial\sigma_\rho}{\partial\theta} = \dfrac{\partial\sigma_\theta}{\partial\theta} + \dfrac{2}{3}\dfrac{\partial}{\partial\theta}\left(\sigma_u \dfrac{\dot{\varepsilon}_\rho - \dot{\varepsilon}_\theta}{\dot{\varepsilon}_u}\right), \end{cases} \tag{15}$$

whre

$$\tau_{\rho\theta} = \frac{\sigma_u\left(1-\dfrac{\rho_н}{\rho}\right)\left(k_1\cos\left(\sqrt{2}\theta\right)+k_2\sin\left(\sqrt{2}\theta\right)\right)}{\sqrt{6\left(1-\dfrac{\rho_н^2}{\rho^2}\right)^2\left(-k_1\sin\left(\sqrt{2}\theta\right)+k_2\cos\left(\sqrt{2}\theta\right)\right)^2+2\left(1-\dfrac{\rho_н}{\rho}\right)^2\left(k_1\cos\left(\sqrt{2}\theta\right)+k_2\sin\left(\sqrt{2}\theta\right)\right)^2}} \tag{16}$$

Since in the end point of the contact between the sheet and the forcer with coordinates $\theta=\alpha$ and $\rho=r$ the shear equals zero, and strain intensity does not equal zero, then $k_1 = -k_2 \cdot tg(\sqrt{2}\alpha)$. Thus, the equations (12), (13), (14) and (16) will look as

$$a(\theta) = k_2 \cdot \frac{\cos(\sqrt{2}\alpha + \sqrt{2}\theta)}{\cos\left(\sqrt{2}\alpha\right)}; \tag{17}$$

$$\begin{cases} \dot{\varepsilon}_\rho = -\dfrac{1}{\sqrt{2}}\left(1-\dfrac{\rho_н^2}{\rho^2}\right)k_2\dfrac{\cos(\sqrt{2}\alpha - \sqrt{2}\theta)}{\cos\left(\sqrt{2}\alpha\right)}, \\ \dot{\varepsilon}_\theta = \dfrac{1}{\sqrt{2}}\left(1-\dfrac{\rho_н^2}{\rho^2}\right)k_2\dfrac{\cos(\sqrt{2}\alpha - \sqrt{2}\theta)}{\cos\left(\sqrt{2}\alpha\right)}, \\ \dot{\varepsilon}_z = 0, \\ \dot{\gamma}_{\rho\theta} = \left(1-\dfrac{\rho_н}{\rho}\right)k_2\dfrac{\sin(\sqrt{2}\theta - \sqrt{2}\alpha)}{\cos\left(\sqrt{2}\alpha\right)}; \end{cases} \tag{18}$$

$$\dot{\varepsilon}_u = \frac{k_2}{\sqrt{3}\cos(\sqrt{2}\alpha)}\sqrt{2\left(1-\frac{\rho_н^2}{\rho^2}\right)^2\left(\cos\left(\sqrt{2}\alpha-\sqrt{2}\theta\right)\right)^2+\left(1-\frac{\rho_н}{\rho}\right)^2\left(\sin\left(\sqrt{2}\alpha-\sqrt{2}\theta\right)\right)^2}; \tag{19}$$

$$\tau_{\rho\theta} = \frac{-\sigma_u}{\sqrt{3}}\frac{\left(1-\dfrac{\rho_н}{\rho}\right)\sin(\sqrt{2}\alpha-\sqrt{2}\theta)}{\sqrt{2\left(1-\dfrac{\rho_н^2}{\rho^2}\right)^2\left(\cos\left(\sqrt{2}\alpha-\sqrt{2}\theta\right)\right)^2+\left(1-\dfrac{\rho_н}{\rho}\right)^2\left(\sin\left(\sqrt{2}\alpha-\sqrt{2}\theta\right)\right)^2}}. \tag{20}$$

From (20) it follows that the surface tangential stresses depend on the friction factor, and normal – inversely related. Thus, the increase in friction factor f causes the decrease in surface deformation along z – axis, decrease in compressing stresses and toughness of the stress conditions of the inside in the friction factor f softens the stress condition of the inside part of the sheet and increases deformation along z - axis, which leads to the decrease in radius of curvature in the neutral surface(for sheet material with large width). Therefore the change in friction factor f causes two opposite processes, which change the toughness of the stressed state. Controlling over the value of the friction factor in each of the directions allows to find the most favorable conditions for deformation.

Conclusions

1. The suggested mathematical model for formation of work pieces from the material allows to calculate the stress strain state in the bending zone of the sheet.

2. The analysis showed the expediency in formation of the friction force of different values in different directions relative to the female mold axis and the forcer. For the direction along the axis of the routine structural iron it is appropriate to increase the friction factor, and in the tangential direction – the factor has to be minimal.

СПИСОК ЛИТЕРАТУРЫ

1. Тришевский О. И. Снижение металлоёмкости гнутых профилей за счёт деформационного упрочнения / О. И. Тришевский, Е. Г. Полстянкин, Р. Ю. Дебердеев // Сталь. – 1988. – № 8. – С. 36 – 37.
2. Стеблюк В. И. Разработка теории и методов интенсификации формоизменяющих операций листовой штамповки: дис... д-ра техн. наук : 05.03.05 / Стеблюк Владимир Иванович. – К., 1998. – 340 с.
3. Savuliak V. Modelling of the process of regular profiles stamping from sheet materials / V. Savuliak // Buletinul institutului politehnic din Iasi. – 2011. – Tomul LVII (LXI). Fasc. 4. – P. 199 – 208.
4. Попов Е. А. Основы теории листовой штамповки / Е. А. Попов. – М.: Машиностроение, 1977. – 278 с.
5. Сивак И. О. Получение гофрированних заготовок методами локальной пластической деформации / И. О. Сивак, В. В. Савуляк // Удосконалення процесів та обладнання обробки тиском в металургії і машинобудуванні. – 2003. – С. 392 – 394.
6. Огородников В. А. Оценка деформируемости металлов при обработке давленим / В. А. Огородников. – К.: Вища школа, 1983. – 175 с.
7. Сивак І. О. Штампування гофрованих заготовок з використанням гідростатичного підпору / І. О. Сивак, В. В. Савуляк // Удосконалення процесів та обладнання обробки тиском в металургії і машинобудуванні. – 2004. – С. 331 – 335.
8. Сивак І. О. Дослідження процесу виготовлення гофрованих заготовок / І. О. Сивак, В. В. Савуляк // Удосконалення процесів та обладнання обробки тиском в металургії і машинобудуванні. – 2005. – С. 287 – 290.

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