Elastoplastic bend of bimetallic steel sheet at edge-bending press

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The increased interest in the production of large-diameter bimetallic thick-walled pipes with an internal coating of anti-corrosion steel makes the problem of studying the deformations of a bimetallic sheet during bending on presses and rollers urgent. A feature of the deformation of such bimetallic sheets is additional bending due to the heterogeneity of the mechanical characteristics of the metal of the sheet wall. The difference in the values of Young's modulus, yield strength and strength, as well as the linear coefficients of thermal expansion of the substrate metal and the coating of the bimetallic sheet, leads to a displacement of the neutral surface of the bimetallic sheet from its median surface. As well to additional bending of the neutral surface of the bimetallic sheet, after its elastic plastic bending. In metallurgy, the elastic-plastic bending of a steel sheet is the basis of the forming process of a pipe billet on step-by-step molding presses, edge bending presses and rollers in the production of large-diameter pipes. In this paper, a mathematical model is constructed for calculating the residual curvature of a bimetallic sheet after elastoplastic bending of its longitudinal edges on an edge bending press.

Key words: bimetallic steel sheet, edge-bending press, elastoplastic bending, large-diameter steel pipe.

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Introduction

Bimetallic pipes (clad pipes) for main gas and oil pipelines have a long service life and are made of bimetallic (clad) sheets and plates. Pipes made of clad materials meet the highest requirements of durability, corrosion resistance and good quality. They are recommended for use in transferable environments, where dynamic stress, high pressure and increased corrosion resistance are increased. The use of clad materials ensures that the superior strength and hardness of steels are combined with the corrosion resistance of high-alloy materials. Clad metallurgical pipes have a lower wall thickness compared to austenitic pipes and pipes made of nickel-based alloys. In addition, they can significantly save weight and reduce material costs. Metallurgically clad pipes are used, for example, as technological pipes, pipelines, pipes for outlets and fittings. Clad plates are used as raw materials for the production of clad metallurgically pipes. The plates consist of a base material and a corrosion-resistant alloy. They are firmly connected to each other by a diffusion.

Bimetallic plates for chemical and petrochemical engineering are intended for the manufacture of elements of heat exchangers and air-cooling devices, reactors, columns and vessels for chemical and petrochemical engineering and shipbuilding parts. Bimetallic plates are manufactured with a base layer of rolled carbon, low-alloy or alloy steel sheets and a cladding layer of rolled corrosion-resistant steels, nickel and copper alloys, manufactured in accordance with Russian and foreign standards. The sizes of rectangular slabs are usually limited to an area of 35–40 m^2 with a different combination of length and width. The thickness of the plates varies from 10 to 320 mm. The thickness of the cladding layer varies from 2 to 12 mm. An important feature of bimetallic plates is the guaranteed increased strength of the joint layers: at least 220 MPa for shear resistance and 220–260 MPa for tear resistance of the cladding layer.

Bimetallic plates "steel-titanium alloys" are designed for the manufacture of elements of heat exchangers and vessels of energy and chemical engineering, electrochemical installations. Bimetallic plates are produced with a base layer of low-alloy carbon steel of Russian and foreign manufacture with a cladding layer of titanium grades VT1-0 and VT1-00. Bimetallic plates are made in the form of rectangular blanks with a thickness from 5 to 300 mm, a width from 300 to 5,000 mm, and a length from 400 to 9,000 mm. The thickness of the titanium cladding layer can range from 2 to 12 mm. The technical specifications provide for improved connection quality relative to other technical specifications and standards, including: shear resistance of at least 200 MPa and tear resistance of at least 180 MPa.

Large-size bimetallic plates (slabs) for the energy and chemical industries with a surface area of 20 to 40 m^2 are manufactured in accordance with current Russian and foreign standards with a number of additional requirements for the base and cladding layers in accordance with their overall dimensions and weight. The main layer of bimetallic coating made of carbon and low-alloy steel of Russian and foreign production is made without welds. The cladding layer made of stainless steels, nickel and titanium alloys of Russian or foreign production can be made by enlarging using argon arc welding with mandatory radiographic control of the weld.

The main feature of all used bimetallic plates for fusion reactor components is their operation in high vacuum conditions. In this regard, all the starting metals included in the base and cladding layers undergo a number of additional tests, including under cryogenic temperatures. Bimetallic plates made of chromium-zirconium bronze and 316L-IG steel are manufactured for the manufacture of heat exchange elements of the reactor divertor. Bimetal has an increased level of adhesive strength of the layers at break (at least 300 MPa at 150 °C) and an absolute level of continuity, confirmed by a special three-dimensional ultrasonic inspection unit and tests for "gel-hermeticity". Structurally, the entire load in the final product is concentrated along the contour of a plate with a bimetallic rib thickness of 5 mm, while on one side there is a reactor working area (high vacuum), and on the other side cooling water circulates at supercritical parameters.

Bimetallic flat plates (sheets) made of aluminum-magnesium alloys and stainless steel are used as blanks for adapters in welded structures in shipbuilding and mechanical engineering, as well as as blanks for parts in the electrical industry and instrument engineering. The total thickness of the plate is 10 mm. The thickness of the layers in bimetal: corrosion-resistant steel 12Kh18N10T – 5 mm, aluminum alloy AMg6UM – 5 mm. The width of the plate is 300–1,500 mm. The length of the plate is 400–3,000 mm. Joint strength of the layers: at least 60 MPa for shear and at least 100 MPa for separation. The dimensions of the initial blank are determined by the size of the aluminum alloy sheet and are limited from above to a size of 1,500×3,000 mm.

In addition to shipbuilding, this type of bimetallic plates is used in the electrical industry and instrument engineering, while providing a compromise combination of low thermal conductivity and corrosion resistance of stainless steel, and high thermal conductivity and electrical conductivity of aluminum alloy, as well as lightweight machining from the aluminum alloy side.

The clad steel sheets (plates) are individually formed on the tube-bending and end-bending presses using the JCOE process into an open-seam pipe and then longitudinal welded through various welding processes [1–3].

In the first stage of the JCOE process, the edge bending of sheet billet on the edge-bending press by means of the step-by-step method is taken place simultaneously from two sides (**Fig. 1–4**). Next the main part of a sheet billet is forming simultaneously by the step-by-step method on the O-forming press along the entire length of the billet from the bent edges to the middle of the billet. Then the assemblage of the pipe by the welding of the pipe's longitudinal seam is taken place.

After welding, the necessary transverse diameter and transverse roundness of the pipe is achieved by using the expander. Thereafter the process of the hydraulic testing of the pipe and the process of applying insulation on the inner and outer surface of the pipe are followed [1, 4–6].

The purpose of this work is to construct the new mathematical model for calculating the residual curvature (and

Fig. 1. Mechanism of feeding a steel sheet into edge-bending press

Fig. 2. Edge-bending press for deformation of steel sheet

Fig. 3. Punch and matrix of edge-bending press

Fig. 4. Edge-bending press (side view)

shape) of the longitudinal edge of a bimetallic sheet after its elastic-plastic bending on an edge bending press.

Calculation of matrix's profile of the edge-bending press

We introduce the rectangular coordinate system *Oxy*, the beginning of which is located at the point of contact of a sheet billet with the matrix (**Fig. 5**).

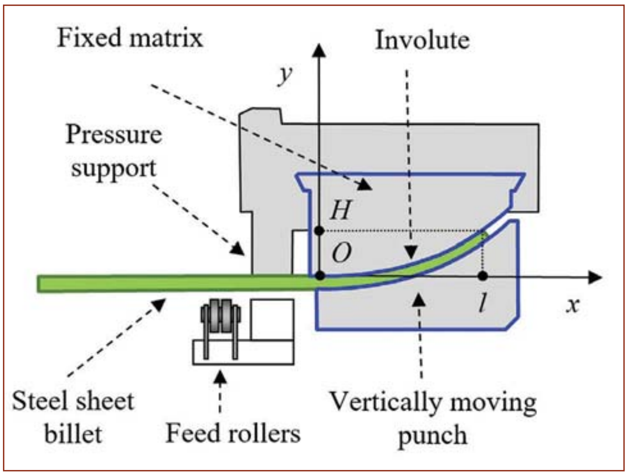

Fig. 5. The coordinate system of working profile of edge-bending press

Let H and l be respectively the height and length of the edge of the deformable parts of the sheet during the forming, H_1 and l_1 – after the springing-back.

The contact profile of the matrix is set in the edge-bending press by means of the involute equation (**Fig. 6**) [1]:

$$b(\varphi) = r\cos\varphi + r\varphi\sin\varphi, a(\varphi) = r\sin\varphi - r\varphi\cos\varphi, \quad \frac{\mathrm{d}a(b)}{\mathrm{d}b} = \mathrm{tg}\varphi, \tag{1}$$

where φ is the angle of involute, r = const – the radius of involute.

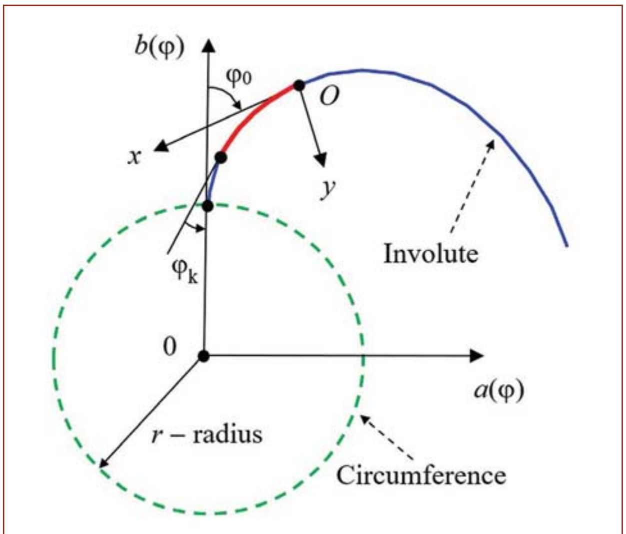

Fig. 6. The coordinate system for matrix's working profile of edge-bending press

The arc length $S_{inv}(\varphi)$ and the curvature radius $\rho_{inv}(\varphi)$ of involute are equal to

$$S_{inv}(\varphi) = \frac{1}{2}r\varphi^2, \quad \rho_{inv}(\varphi) = r\varphi. \tag{2}$$

Denote by φ_0 the angle, corresponding to the beginning of the involute surface of the matrix, and by φ_k the angle, corresponding to the end of this surface.

Then the dependence of the real coordinates $x(\varphi)$ and $y(\varphi)$ of the involute surface of the matrix (the upper surface of the non-spring-back billet) from the coordinates $a(\varphi)$ and $b(\varphi)$ has the form

$$b_0 = r\cos\varphi_0 + r\varphi_0\sin\varphi_0, \quad a_0 = r\sin\varphi_0 - r\varphi_0\cos\varphi_0, \tag{3}$$

$$x(\varphi) = -\left(a(\varphi) - a_0\right)\sin\varphi_0 - \left(b(\varphi) - b_0\right)\cos\varphi_0, \quad x(\varphi_k) = l, \tag{4}$$

$$y(\varphi) = \left(a(\varphi) - a_0\right)\cos\varphi_0 - \left(b(\varphi) - b_0\right)\sin\varphi_0, \quad y(\varphi_k) = H. \tag{5}$$

Mechanical characteristics of bimetallic steel sheet

Consider a bimetallic sheet of rectangular cross-section, which consists of a metal substrate (for example, high-strength K60 grade tubular steel) and a thinner stainless metal coating (for example, stainless steel) [7–10].

Under elastic-plastic stretching of the substrate metal, the dependence of its normal stress σ_s on a relative deformation ε is described by means the direct cubic approximation by Shinkin [2, 3]:

$$\sigma_s(\varepsilon) = \left\{E_s\varepsilon, 0 \le \varepsilon < \varepsilon_{ys} = \frac{\sigma_{ys}}{E_s}; \sigma_{s,plastic}(\varepsilon), \varepsilon_{ys} \le \varepsilon \le \varepsilon_{us}\right\}, \tag{6}$$

$$\begin{aligned}\sigma_{s,plastic}(\varepsilon) &= \sigma_{ys} + P_{ys}\left(\varepsilon - \varepsilon_{ys}\right) - \\ &- \frac{2P_{ys}\left(\varepsilon_{us} - \varepsilon_{ys}\right) - 3\left(\sigma_{us} - \sigma_{ys}\right)}{\left(\varepsilon_{us} - \varepsilon_{ys}\right)^2}\left(\varepsilon - \varepsilon_{ys}\right)^2 + \\ &+ \frac{P_{ys}\left(\varepsilon_{us} - \varepsilon_{ys}\right) - 2\left(\sigma_{us} - \sigma_{ys}\right)}{\left(\varepsilon_{us} - \varepsilon_{ys}\right)^3}\left(\varepsilon - \varepsilon_{ys}\right)^3,\end{aligned} \tag{7}$$

$$\sigma(\varepsilon_{ys}) = \sigma_{ys}, \quad \sigma(\varepsilon_{us}) = \sigma_{us}, \quad \frac{d\sigma}{d\varepsilon}(\varepsilon_{ys}) = P_{ys}, \quad \frac{d\sigma}{d\varepsilon}(\varepsilon_{us}) = 0, \tag{8}$$

where E_s is the Young's modulus, σ_{ys} and σ_{us} are the yield and strength limits and P_{ys} is the modulus of hardening at the yield strength of the substrate metal.

Under elastic-plastic stretching of the coating metal, the dependence of its normal stress σ_c on a relative deformation ε is described by means the direct cubic approximation by Shinkin [2, 3]:

$$\sigma_c(\varepsilon) = \left\{E_c\varepsilon, \quad 0 \le \varepsilon < \varepsilon_{yc} = \frac{\sigma_{yc}}{E_c}; \quad \sigma_{c,plastic}(\varepsilon), \quad \varepsilon_{yc} \le \varepsilon \le \varepsilon_{uc}\right\}, \tag{9}$$

$$\begin{aligned}\sigma_{c,plastic}(\varepsilon) &= \sigma_{yc} + P_{yc}\left(\varepsilon - \varepsilon_{yc}\right) - \\ &- \frac{2P_{yc}\left(\varepsilon_{uc} - \varepsilon_{yc}\right) - 3\left(\sigma_{uc} - \sigma_{yc}\right)}{\left(\varepsilon_{uc} - \varepsilon_{yc}\right)^2}\left(\varepsilon - \varepsilon_{yc}\right)^2 + \\ &+ \frac{P_{yc}\left(\varepsilon_{uc} - \varepsilon_{yc}\right) - 2\left(\sigma_{uc} - \sigma_{yc}\right)}{\left(\varepsilon_{uc} - \varepsilon_{yc}\right)^3}\left(\varepsilon - \varepsilon_{yc}\right)^3,\end{aligned} \tag{10}$$

$$\sigma(\varepsilon_{yc})=\sigma_{yc},\quad \sigma(\varepsilon_{uc})=\sigma_{uc},\quad \frac{d\sigma}{d\varepsilon}(\varepsilon_{yc})=P_{yc},\quad \frac{d\sigma}{d\varepsilon}(\varepsilon_{uc})=0, \quad (11)$$

where E_c is the Young's modulus, σ_{yc} and σ_{uc} are the yield and strength limits and P_{yc} is the modulus of hardening at the yield strength of the coating metal.

We remark that for steels, the dependence of the normal stress σ on the relative strain is an antisymmetric function: $\sigma(-\varepsilon)=-\sigma(\varepsilon)$ [11–15].

Bending moment at elastic plastic bending of bimetallic sheet

Let's bending a bimetallic sheet. Let ρ be the radius of curvature of the neutral plane of the bimetallic sheet. In case of elastic bending, the neutral plane of the bimetallic sheet lies at a distance of δ from the surface of contact of the substrate with the coating and is displaced from the plane of their contact towards the substrate, if $E_s h_s^2 > E_c h_c^2$:

$$\delta=\frac{E_s h_s^2-E_c h_c^2}{2\left(E_s h_s+E_c h_c\right)}. \quad (12)$$

Note that the displacement δ does not depend on the radius of curvature of the neutral plane of the bimetallic sheet. In addition, the neutral plane during elastic bending of the sheet does not coincide with the median surface of the sheet.

The bending moment during the elastic plastic bending of bimetallic sheet is equal to

$$M_{bend,plastic}(\rho)=bN_{bend,plastic}(\rho), \quad (13)$$

$$\begin{aligned}
N_{bend,plastic}(\rho)&=\frac{1}{2}\rho^2\sigma_{ys}\left[\left(\frac{\delta}{\rho}\right)^2+\left(\frac{h_s-\delta}{\rho}\right)^2-\frac{2}{3}\varepsilon_{ys}^2\right]+\\
&+\frac{1}{2}\rho^2P_{ys}\varepsilon_{ys}\left[\left(\frac{\delta}{\rho}-\varepsilon_{ys}\right)^2+\left(\frac{h_s-\delta}{\rho}-\varepsilon_{ys}\right)^2\right]+\\
&+\frac{1}{3}\rho^2\left[P_{ys}-\frac{\left(2P_{ys}\left(\varepsilon_{us}-\varepsilon_{ys}\right)-3\left(\sigma_{us}-\sigma_{ys}\right)\right)\varepsilon_{ys}}{\left(\varepsilon_{us}-\varepsilon_{ys}\right)^2}\right]\times\\
&\times\left[\left(\frac{h_s-\delta}{\rho}-\varepsilon_{ys}\right)^3+\left(\frac{\delta}{\rho}-\varepsilon_{ys}\right)^3\right]-\\
&-\frac{1}{4}\rho^2\left[\frac{2P_{ys}\left(\varepsilon_{us}-\varepsilon_{ys}\right)-3\left(\sigma_{us}-\sigma_{ys}\right)}{\left(\varepsilon_{us}-\varepsilon_{ys}\right)^2}-\frac{\left(P_{ys}\left(\varepsilon_{us}-\varepsilon_{ys}\right)-2\left(\sigma_{us}-\sigma_{ys}\right)\right)\varepsilon_{ys}}{\left(\varepsilon_{us}-\varepsilon_{ys}\right)^3}\right]\times\\
&\times\left[\left(\frac{h_s-\delta}{\rho}-\varepsilon_{ys}\right)^4+\left(\frac{\delta}{\rho}-\varepsilon_{ys}\right)^4\right]+\\
&+\frac{1}{5}\rho^2\left[\frac{P_{ys}\left(\varepsilon_{us}-\varepsilon_{ys}\right)-2\left(\sigma_{us}-\sigma_{ys}\right)}{\left(\varepsilon_{us}-\varepsilon_{ys}\right)^3}\right]\left[\left(\frac{h_s-\delta}{\rho}-\varepsilon_{ys}\right)^5+\left(\frac{\delta}{\rho}-\varepsilon_{ys}\right)^5\right]+\\
&+\frac{1}{2}\rho^2\sigma_{yc}\left[\left(\frac{h_c+\delta}{\rho}\right)^2-\left(\frac{\delta}{\rho}\right)^2\right]+\\
&+\frac{1}{2}\rho^2P_{yc}\varepsilon_{yc}\left[\left(\frac{h_c+\delta}{\rho}-\varepsilon_{yc}\right)^2-\left(\frac{\delta}{\rho}-\varepsilon_{yc}\right)^2\right]+\\
&+\frac{1}{3}\rho^2\left[P_{yc}-\frac{\left(2P_{yc}\left(\varepsilon_{uc}-\varepsilon_{yc}\right)-3\left(\sigma_{uc}-\sigma_{yc}\right)\right)\varepsilon_{yc}}{\left(\varepsilon_{uc}-\varepsilon_{yc}\right)^2}\right]\times\\
&\times\left[\left(\frac{h_c+\delta}{\rho}-\varepsilon_{yc}\right)^3-\left(\frac{\delta}{\rho}-\varepsilon_{yc}\right)^3\right]- \quad (14)\\
&-\frac{1}{4}\rho^2\left[\frac{2P_{yc}\left(\varepsilon_{uc}-\varepsilon_{yc}\right)-3\left(\sigma_{uc}-\sigma_{yc}\right)}{\left(\varepsilon_{uc}-\varepsilon_{yc}\right)^2}-\frac{\left(P_{yc}\left(\varepsilon_{uc}-\varepsilon_{yc}\right)-2\left(\sigma_{uc}-\sigma_{yc}\right)\right)\varepsilon_{yc}}{\left(\varepsilon_{uc}-\varepsilon_{yc}\right)^3}\right]\times\\
&\times\left[\left(\frac{h_c+\delta}{\rho}-\varepsilon_{yc}\right)^4-\left(\frac{\delta}{\rho}-\varepsilon_{yc}\right)^4\right]+\\
&+\frac{1}{5}\rho^2\left[\frac{P_{yc}\left(\varepsilon_{uc}-\varepsilon_{yc}\right)-2\left(\sigma_{uc}-\sigma_{yc}\right)}{\left(\varepsilon_{uc}-\varepsilon_{yc}\right)^3}\right]\left[\left(\frac{h_c+\delta}{\rho}-\varepsilon_{yc}\right)^5-\left(\frac{\delta}{\rho}-\varepsilon_{yc}\right)^5\right].
\end{aligned}$$

The curvature of bimetallic sheet after springing-back

According to Hencky's theorem, the springing-back of bimetallic sheet will be occurred according to the elastic law [1, 6, 13].

The curvature krest of the neutral line of the bimetallic sheet after springing-back is equal to

$$k_{rest}(\rho)=\frac{1}{\rho}-\frac{12\left(E_s h_s+E_c h_c\right)N_{bend,plastic}(\rho)}{E_s^2h_s^4+4E_sh_s^3E_ch_c+6E_sh_s^2E_ch_c^2+4E_sh_sE_ch_c^3+E_c^2h_c^4}, \quad (15)$$

$$\rho_{rest}(\rho)=\frac{1}{k_{rest}(\rho)}, \quad (16)$$

where $\rho_{rest}(\rho)$ is the curvature's radius of the neutral line after springing-back of the bimetallic sheet.

Numerical multi-radius scheme of calculation of the form of spring-back steel sheet

At bending of the edges of sheet, the value of the involute radius r and the involute angle φ_0 is always set.

Let ΔL_{fp} be the width of the bent edge on one side of the steel sheet, then the involute angle φ_k^{end}, corresponding to the boundary of the bent edge of steel sheet, is equal to

$$\varphi_k^{end}=-\frac{h_c+\delta}{r}+\sqrt{\left(\frac{h_c+\delta}{r}\right)^2+\varphi_0^2+\frac{2\left(h_c+\delta\right)}{r}\varphi_0-2\frac{\Delta L_{fp}}{r}}. \quad (17)$$

To obtain the exact value of the profile of the billet's neutral plane (x_{rest}, y_{rest}), the values H_1 and l_1 after the springback of the steel sheet billet, we can by means of the *numerical multi-radius scheme by Shinkin* [1] of the calculation for the edge-bending press (**Fig. 7**):

$$j = 1 \ldots N \ (N = 10^4), \quad \varphi_0 = \varphi_0, \quad \varphi_j = \varphi_0 - \frac{\left(\varphi_0 - \varphi_k^{end}\right) j}{N}, \tag{18}$$

$$\begin{gathered} \rho_0 = r\varphi_0 + h_c + \delta, \quad \rho_j = r\varphi_j + h_c + \delta, \\ \rho_{rest,0} = \rho_{rest}(\rho_0), \quad \rho_{rest,j} = \rho_{rest}(\rho_j), \end{gathered} \tag{19}$$

$$\Delta S_0 = 0, \quad \Delta S_j = \frac{1}{2}\left(\varphi_{j-1}{}^2 - \varphi_j{}^2\right)\left(\frac{r\varphi_{j-1} + h_c + \delta}{\varphi_{j-1}}\right), \tag{20}$$

$$\psi_0 = 0, \quad \Delta\psi_0 = 0, \quad \Delta\psi_j = \frac{\Delta S_j}{\rho_{rest,j-1}}, \quad \psi_j = \psi_{j-1} + \Delta\psi_j, \tag{21}$$

$$x_{rest,0} = 0, \quad x_{rest,j} = x_{rest,j-1} + \rho_{rest,j-1}\left(\sin\psi_j - \sin\psi_{j-1}\right), \tag{22}$$

$$y_{rest,0} = 0, \quad y_{rest,j} = y_{rest,j-1} + \rho_{rest,j-1}\left(\cos\psi_{j-1} - \cos\psi_j\right), \tag{23}$$

$$l_1 = x_{rest,N} - \left(h_c + \delta\right)\sin\psi_N, \quad H_1 = y_{rest,N} + \left(h_c + \delta\right)\cos\psi_N. \tag{24}$$

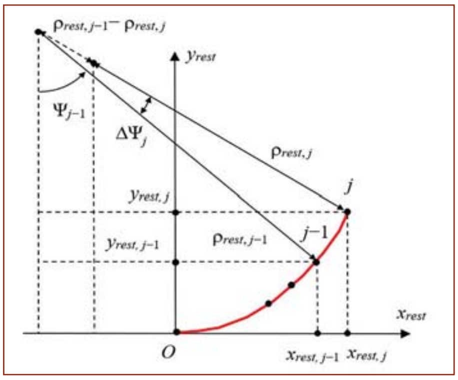

Fig. 7. Multi-radius scheme of calculation of profile of billet's neutral plane after spring-back

Numerical calculation of bimetallic steel sheet's shape after forming in edge-bending press

Let's consider the bimetallic steel sheet for large-diameter pipe with the width of 1,420 mm, the length of 12 m, the wall thickness of 18 mm and the width of 4,405 mm, consisting of the substrate (pipe steel of strength class K60) and the coating (stainless steel 08Kh18N10T – structural corrosion-resistant heat-resistant austenitic steel).

Then for the coating: $E_c = 1.96{\cdot}10^{11}$ Pa, $\sigma_{yc} = 195$ MPa, $\sigma_{uc} = 490$ MPa, $\delta_c = 0.35$, $\psi_c = 0.40$, $\varepsilon_{yc} = \sigma_{yc}/E_c = 0.00099$, $\varepsilon_{uc} \approx \delta_c(1-\psi_c) = 0.21$, $P_{ys} \approx 2(\sigma_{uc}-\sigma_{yc})/(\varepsilon_{uc}-\varepsilon_{yc}) = 2.8229{\cdot}10^9$ Pa; and for the substrate: $E_s = 2.10{\cdot}10^{11}$ Pa, $\sigma_{ys} = 500$ MPa, $\sigma_{us} = 600$ MPa, $\delta_s = 0.35$, $\psi_s = 0.40$, $\varepsilon_{ys} = \sigma_{ys}/E_s = 0.00238$, $\varepsilon_{us} \approx \delta_s(1-\psi_s) = 0.21$, $P_{ys} \approx 2(\sigma_{us}-\sigma_{ys})/(\varepsilon_{us}-\varepsilon_{ys}) = 0.963{\cdot}10^9$ Pa.

Let the coating thickness $h_c = 3$ mm, the substrate thickness $h_s = 15$ mm, and the width of the edge, bent on one side of the sheet, be $\Delta L_{fp} = 0.433$ m. Let the profile of the edge-bending press's matrix be given by the involute with the radius $r = 0.561$ m and the angles $\varphi_0 = 88°$ and $\varphi_k = 43°$.

Then $\varphi_k^{end} = 52.86°$, $\delta = 6.08$ mm, $l = 400.16$ mm, $H = 124.59$ mm, $l_1 = 411.39$ mm, $H_1 = 96.23$ mm. The shape of steel sheet's edge during forming in the edge-bending press and after its springing is shown in **Fig. 8**.

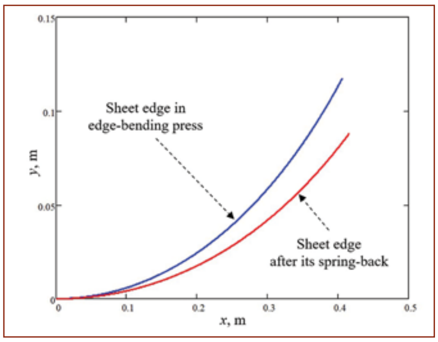

Fig. 8. Numerical calculation of shape of steel sheet's edge during forming in edge-bending press and after its spring-back

Conclusions

The new mathematical model for calculating the residual curvature of a bimetallic sheet after its elastoplastic bending on an edge-bending press has been constructed.

Under bending a bimetallic sheet, the new expression for the bending moment is obtained, depending on the basic mechanical characteristics of the coating metal and the substrate metal, as well as the radius of curvature of the neutral plane of the bimetallic sheet.

The obtained results can be used in metallurgy, for example, at "Vyksa Steel Works", "Chelyabinsk Tube Rolling Plant" and "Izhora Pipe Plant" for forming bimetallic sheet on an edge-bending press at the production of the large-diameter bimetallic pipes for the main gas and oil pipelines. CIS

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