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# Development of Pipe Cold Pilger Rolling Mode Computation Method with Account of Metal Properties Change

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The key points of deformation mode calculation at pipe cold pilger rolling are considered taking into account metal speed-torque characteristics. Relations for calculation of accepted diameter and gauge reduction values at austenitic and ferritic steel pipe rolling are defined.

Keywords: DIAMETER REDUCTION, GAUGE REDUCTION, TOTAL DRAWING, CONTRACTION, IMPACT STRENGTH, ROLLING ROUTE

## Introduction

Pipe cold pilger rolling is one of the most complicated technological processes in the field of metal forming. A great number of investigations are devoted to issues of this pipe production method with high quality parameters, at the same time control of cold-rolled pipe metal properties during deformation has not been developed yet. This leads to substantial growth of number of production operations and increased consumption of metal and resources when making pipes with high consumer properties. Decrease of production cycling due to reduction of production operations requires the fullest use of deformation possibilities of the equipment that assumes rolling with the greatest possible amounts of reduction.

The ultimate strain of pipes on cold-rolling mills is determined in a general view by the following conditions:

- base and current level of metal properties along the length of the total deformation zone taking into all thermal and deformation factors affecting this level [1, 2];
- deformation mode, in particular strain distribution along the length of working cone and ratio between diameter and gauge reduction as a parameter ensuring the change of stress sign in the deformation zone [3];
- technological elements of cold pilger rolling which consider the features of equipment, instrument and production technology under conditions of certain production [4].

Determination of specified conditions effect is impeded by metal stress state which is implemented at cold rolling and does not correspond to stress state pattern when standard testing of samples.

## Results and Discussion

In this work we used empirical dependence [6] for practical calculations of maximum-permissible amount of reduction of austenitic corrosion-resistant steel pipes.

$$\varepsilon_{max} \leq 1.24\phi_p, [\quad] \qquad \text{(Eq. 1)}$$

where $\phi_p$ - contraction at tension fracture of unstrained steel samples at temperature corresponding to rolling temperature, %; $\varepsilon_{max}$ - ultimate amount of reduction, %. For ferritic and martensite-ferritic corrosion-resistant steels, except for parameter $\phi_p$, the ultimate amount of reduction depends on impact strength of the metal. Test temperature and grain size have a significant effect on impact strength. Maximum strain of initial hot-deformed blank part with grain size not more than 5 points is possible to define according to empirical dependence:

$$\varepsilon_{max} \le 1{,}24\phi_p - \frac{0{,}62}{a_\kappa^2}, [\quad] \qquad \text{(Eq. 2)}$$

where $a_\kappa$ - impact strength, mJ/m$^2$, at test temperature equal to temperature in the maximum deformation zone at cold pilger rolling [6].

According to (1) the maximum total drawing for austenitic steel can be expressed as follows:

$$\mu_\Sigma \le \frac{1}{1-1{,}24\phi_p} \qquad \text{(Eq. 3)}$$

and for ferritic and martensite-ferritic steels according to (2) as:

$$\mu_\Sigma \le \frac{1}{1-1{,}24\phi_p + \frac{0{,}62}{a_\kappa^2}} \qquad \text{(Eq. 4)}$$

Considering that $\mu_\Sigma = \mu_t \times \mu_D$ (where $\mu_t$, $\mu_D$ - total drawing on wall thickness and diameter in gauge table), we will accept the condition of satisfying the minimum requirements to internal surface quality and limit the total drawing to diameter $\mu_D \le 1{,}25\mu_t$ [7]. Then values $\mu_D$ and $\mu_t$ are as follows:

for austenitic steel

$$\mu_D \le 1{,}11\sqrt{\frac{1}{1-1{,}24\phi_p}}; \qquad \text{(Eq. 5)}$$

$$\mu_t \le 0{,}9\sqrt{\frac{1}{1-1{,}24\phi_p}}; \qquad \text{(Eq. 5a)}$$

for ferritic steel

$$\mu_D \le 1{,}11\sqrt{\frac{1}{1-1{,}24\phi_p + \frac{0{,}62}{a_\kappa^2}}}; \qquad \text{(Eq. 6)}$$

$$\mu_t \le 0{,}9\sqrt{\frac{1}{1-1{,}24\phi_p + \frac{0{,}62}{a_\kappa^2}}} \qquad \text{(Eq. 6a)}$$

Expressions (5) and (6) allow defining the rolling route with minimum production cycling.

Based on condition of the best internal surface quality it is necessary to accept:

$$\mu_D \le (0{,}85 \div 1)\mu_t$$

We set $\mu_D = \mu_t$, and:

for austenitic steel

$$\mu_D = \mu_t = \sqrt{\frac{1}{1-1{,}24\phi_p}};$$

for ferritic steel

$$\mu_D = \mu_t = \sqrt{\frac{1}{1-1{,}24\phi_p + \frac{0{,}62}{a_\kappa^2}}}.$$

Further we consider rolling with the maximum permissible deformation on diameter (i.e. condition $\mu_D \le 1{,}25\mu_t$). In this case value $\mu_t$ is defined as $\mu_t = \frac{\mu_\Sigma}{\mu_D}$ and should correlate with permissible rolling force for given standard mill size.

Value $\mu_D$ is

$$\mu_D = \frac{D_0 - t_0}{D_{0\kappa} - \Delta D_\Sigma - t}, \qquad \text{(Eq. 7)}$$

where $D_0$ - outside diameter of blank part, mm; $\Delta D_\Sigma$ - total strain on diameter, mm; $t_0$; $t_\kappa$ - initial and final wall thickness, mm.

In this case, neglecting effect of wall thickness $t_0$ и $t_\kappa$, equation (7) can be written as follows:

$$\mu_D = \frac{D_0}{D_0 - \Delta D_\Sigma} \qquad \text{(Eq. 8)}$$

Taking into account expression (1) and (8), the dependence for definition of maximum permissible diameter reduction is:

for austenitic steel

$$\Delta D_{\Sigma} \le D_0 \left(1 - \frac{0,9}{\sqrt{\frac{1}{1 - 1,24\phi_p}}}\right); \quad \text{(Eq. 9)}$$

for ferritic steel (taking into account (2) и (8))

$$\Delta D_{\Sigma} \le D_0 \left(1 - \frac{0,9}{\sqrt{\frac{1}{1 - 1,24\phi_p + \frac{0,62}{a_к^2}}}}\right) \quad \text{(Eq. 10)}$$

Except for material properties under conditions of reduction, deformation mode can limit the value $\Delta D_{\Sigma}$ depending on applied mandrels (variable or constant conicity) and reducing zone length.

If the maximum strain on outer diameter is $\Delta D_{\Sigma_1}$, then

$$\Delta D_{\Sigma_1} = \Delta D_{ред} + 2tg\alpha_{cp} L_{обж} + 2\Delta t_{\Sigma} \quad \text{(Eq. 11)}$$

where $\Delta D_{ред}$ - permissible decrease of outer diameter in the free reduction zone, mm; $\Delta t_{\Sigma}$ - total decrease of wall thickness, mm; $L_{обж}$ - reducing zone length, mm; $\alpha_{cp}$ - average tilt angle of curvilinear mandrel generatix to rolling axis, degree (for curvilinear mandrel $\alpha_{cp}$ is considerably more than the maximum value $\alpha$ for rectilineal ones, therefore we consider these gages).

Value $2tg\alpha_{cp}$ for mandrels with a wide-spread profile of parabola of the second order

$$2tg\alpha_{cp} = tg\alpha_0 + tg\alpha_к,$$

where $tg\alpha_0; tg\alpha_к$ - initial and final conicity of parabolical mandrel.

We accept $\Delta D_{ред} \le (0,07 \div 0,09) D_0$ which ensures the satisfactory quality of pipe internal surface.

Angle $\alpha_0$ can be determined from condition of permissible axial force acting in the direction of blank part. This force usually reaches the maximum level at stand backward running in the beginning of reducing zone. Usually axial force in the direction of blank part is restricted to value:

$$Q \le (0,15 \div 0,16)P, \quad \text{(Eq. 12)}$$

where $Q$ - axial force, kN, in the beginning of reducing zone at stand backward running; $P$ - vertical component of rolling force in the beginning of reducing zone at stand backward running, kN.

Value $Q$ can be expressed [2]

$$Q \le 2\sin\gamma_0 P \pm p_{уд} f (F_{отс} - F_{оп}), \quad \text{(Eq. 13)}$$

where $\gamma_0$ - tilt angle of groove to rolling axis in the beginning of reducing zone, degree; $p_{уд}$ - average specific pressure, MPa; $F_{отс}; F_{оп}$ - square of backward slip and forward slip zones, mm$^2$.

At correct selection of leading roll gears it is possible to accept that in the beginning of reducing zone $F_{отс} = F_{оп}$.

Then taking into account (12) and (13), we obtain

$$Q = 2P\sin\gamma_0 \le (0,15 \div 0,16)P$$
$$2\sin\gamma_0 \le 0,15 \div 0,16$$

It is possible to define angle $\alpha_0$ approximately knowing value $\gamma_0$ and considering that the difference $\sin\gamma_0$ and $\sin\alpha_0$ in the current gages is

$$\sin\gamma_0 - \sin\alpha_0 \le 0,015$$

Therefore it is true

$$2\sin\alpha_0 \le 0,12 \div 0,13$$

Values $\sin\alpha_0$ and $tg\alpha_0$ at angle $\alpha_0 \le 8^0$ differ not more than by 3 %. Having accepted $tg\alpha_0 = 0,065$, and $tg\alpha_к = 0,005$, expression (11) is as follows:

$$\Delta D_{\Sigma_1} = 0,08 \times D_0 + 0,07 \times L_{обж} + 2\Delta t_{\Sigma} \quad \text{(Eq. 14)}$$

Obtained dependences (9) and (10) as well as dependence (14) considering the deformation mode allow defining rolling routes with the maximum strain on diameter. Thus it is necessary to accept smaller value from $\Delta D_{\Sigma}$ and $\Delta D_{\Sigma 1}$.

We define permissible strain at rolling on cold-rolling mills on the instance of austenitic steel 08X18H10T and martensite-ferritic steel 12X13 pipes. Thus the total ultimate strain is defined according to formulas (1) and (2), and permissible relationship of strains on wall thickness and diameter equal to $\mu_D \le 1,25\mu_t$. Value $\Delta D_{\Sigma 1}$ is defined from dependences (14), and value $\Delta D_{\Sigma}$ - from dependences (9) and (10).

If $\Delta D_{\Sigma 1} < \Delta D_{\Sigma}$, set marginal ratio of strains $\mu_D \le 1,25\mu_t$ is not observed at total strain invariance.

Value $\Delta D_{\Sigma 1}$ according to equation (14) includes unknown value $\Delta t_{\Sigma}$. Analytical definition of $\Delta t_{\Sigma}$ is difficult. Value $\Delta t_{\Sigma}$ is reasonable to define by iteration method. In the beginning we determine $\Delta t_{\Sigma}$ proceeding from dependences (5a) and (6a) (we call it $\Delta t_{\Sigma 1}$). Having substituted $\Delta t_{\Sigma 1}$ в in the formula (14), we define value $\Delta D_{\Sigma 1}$ and $\mu_{t_1} = \frac{\mu_{\Sigma}}{\mu_{D1}}$; further it is possible to define new value $\Delta t_{\Sigma}$ ($\Delta t_{\Sigma 2}$)

$$\Delta t_{\Sigma 2} = \frac{t_0(\mu_{t_1} - 1)}{\mu_{t_1}}.$$

For practical calculations it is enough to define value $\Delta t_{\Sigma 2}$ and corresponding value $\Delta D_{\Sigma 2}$.

**Conclusions**

Developed method for strain mode calculation at pipe cold pilger rolling considers the change of metal properties. Dependences for calculation of rolling routes of austenitic and ferritic steel pipes based on the known data about connection of metal properties and strain mode parameters are obtained. The dependences consider both change of metal properties under conditions of cold pilger rolling and strain mode parameters, in particular, strain distribution along the length of working cone and diameter and gauge reduction. The account of ultimate pipe strain at strain mode calculation will allow raising stability of the process and lowering crack formation.

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**Развитие метода расчета режимов холодной пильгерной прокатки труб с учетом изменения свойств металла**

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Рассмотрены основные положения расчета режимов деформации при холодной пильгерной прокатке труб с учетом механических характеристик металла. Определены зависимости для расчета допустимых значений обжатий по диаметру и толщине стенки при прокатке труб из аустенитных и ферритных марок сталей.