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Effect of Deformation Conditions on Mechanical Properties of Metal During Tube Cold Pilger Rolling

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Determined quantitative index allows estimating the impact of thermal, kinematic and deformation parameters of a process on the change of mechanical properties of material during tube cold Pilger rolling. The equation of connection of deformation conditions and change of mechanical properties of metal during cold Pilger rolling was obtained.

Keywords: DEFORMATION, PARAMETERS, EFFECT MODE, MECHANICAL PROPERTIES, METAL, COLD PILGER ROLLING, TUBES

Introduction

Both deformation and thermal factors affect the change of mechanical properties of metal through cold Pilger rolling. Final temperature and mechanical properties for each previous control cross-section of working cone become initial for the subsequent cross-section. Moreover, this process is continuous lengthwise working stand. Accordingly, deformation conditions during cold Pilger rolling should change along with the change of characteristic for metal which is in the current cross-section of total deformation zone.

Following methods are currently applied to estimate mechanical properties of metal at cold Pilger rolling:

1. Reference data derived from standard testing on tensile-testing machines. The advantage of this method is the ease of use and a great scope of experimental investigations performed. At the same time, yield strength and ultimate strength, which are fundamental characteristics of metal, and functions presenting their change depending on amount of reduction (hardening curves) do not consider the effect of heat released in the process of treatment and effect of relationship between diameter and wall thickness reductions.
2. Yield stress values obtained by average pressure recalculation when rolling quadrangular pieces [1]. This method considers the effect of heating-up but does not cover the impact of relationship between diameter and wall thickness reductions.
3. Values of ultimate strength and yield strength obtained in the process of testing pieces cut out from the working cones on tensile-testing machines. Application of this estimation method enables deformation conditions to be completely compatible and to consider the impact of relationship between diameter and wall thickness reductions. The disadvantage of the method is an inefficient consideration of heating-up impact. However, this disadvantage can be eliminated by using analytical dependences for determination of current temperature of working cone metal when calculating the deformation conditions [2].

Results and Discussion

Determination of index of metal mechanical properties change through cold Pilger rolling. The ratio of ultimate strength σ_{US} to yield strength σ_{YS} obtained when testing micropieces cut out from a working cone and accomplished according to technology GTI PMB 241-26-02 [3] makes it possible to determine a limit of mechanical properties of metal k_σ and metal recovery S_σ under conditions of cold Pilger rolling by following dependences:

- for stock tube

$$\frac{\sigma_{\text{USst}}}{\sigma_{\text{YSst}}} = k_{\sigma\text{st}} \quad \text{(Eq. 1)}$$

- for finished tube after rolling

$$\frac{\sigma_{\text{USft}}}{\sigma_{\text{YSft}}} = k_{\sigma\text{ft}} \quad \text{(Eq.2)}$$

- for control cross-section x of total deformation zone

$$\frac{\sigma_{USx}}{\sigma_{YSx}} = k_{\sigma x} \quad \text{(Eq.3)}$$

- to estimate the usage of limit of mechanical properties in total deformation zone

$$\frac{k_{\sigma st}}{k_{\sigma ft}} = S_{\sigma\Sigma} \quad \text{(Eq.4)}$$

- to estimate the usage of limit of mechanical properties in the area of total deformation zone before control cross-section *x*

$$\frac{k_{\sigma st}}{k_{\sigma x}} = S_{\sigma x} \quad \text{(Eq.5)}$$

Change of mechanical properties under effect of cold and warm Pilger rolling was estimated for following groups of processing routes:

Group 1 method of tool calculation providing a tapered plug and curve line of pass at cold rolling – 4 routes (1 for a large size mill, 2 for medium and 1 for small);

Group 2 method of tool calculation providing a tapered plug and curve line of pass at warm rolling – 4 routes (3 for a large size mill and 1 for small);

Group 3 method of tool calculation providing a tapered plug and curve line of pass at warm rolling with tube supply increased by 50% – 4 routes (2 for a large size mill, 1 for medium and 1 for small);

Group 4 method of tool calculation based on reduction proportionality principle at cold rolling – 6 routes (3 for a large size mill, 2 for medium and 1 for small).

Mechanical tests were carried out within one batch of tubes made of steels AISI 304, 316 and 31803 for each case of rolling.

As a result, it was determined that limit of mechanical properties for all rolling methods decreases after rolling. For stock tubes, the range of k_σ values was 1.56-2.4, and for tubes after rolling – 1.01-1.5.

Value of mechanical properties usage $S\sigma$ for all methods of calculation and rolling methods is within the interval 1.44-1.98.

Analysis of these results showed that the bigger $S\sigma$ value is, the more intensively the limit of mechanical properties of metal is used, which negatively characterizes the process of deformation and increases the probability of microfractures in metal.

Equation for connection of deformation parameters and mechanical properties of metal at cold Pilger rolling. At cold Pilger rolling, metal is deformed along a working cone, therefore the most widespread coordinate axes for the description of change for the process parameters are ***x/l*** – the ratio of control cross-section place to working cone length and total amount of reduction ε_Σ which is composed of diameter reductions ε_D and wall thickness reductions ε_t. In the investigated rolling routes, the relative engineering strain changed from 28% up to 98%, by diameter from 24% up to 67%, by wall thickness from 21% up to 57%.

For above-specified rolling cases, the dependences for the change of mechanical properties usage on total deformation $S_{\sigma\Sigma}=f(\varepsilon_\Sigma)$, ratio of diameter reductions and wall thickness reductions $S_{\sigma\Sigma}=f(\varepsilon_D/\varepsilon_t)$, amount of diameter reduction $S_{\sigma\Sigma}=f(\varepsilon_D/\varepsilon_\Sigma)$, and wall thickness reduction in total deformation $S_{\sigma\Sigma}=f(\varepsilon_t/\varepsilon_\Sigma)$ were constructed.

An increase in amount of diameter reduction $\varepsilon_D/\varepsilon_\Sigma$ in the rolling route is determined to cause a stable growth of $S_{\sigma\Sigma}$ values with various intensity for all cases of rolling (**Figure 1**).

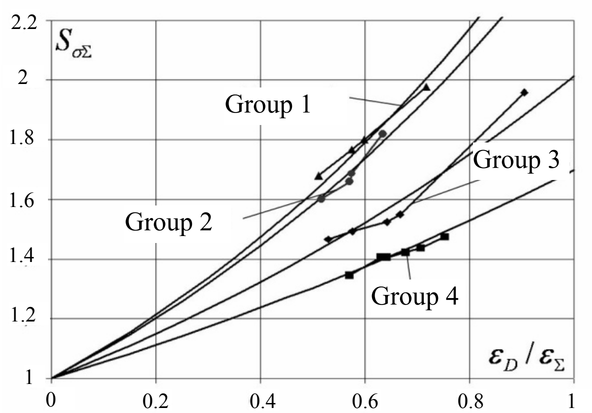

Figure 1. Interrelation of usage for mechanical properties of metal on amount of diameter reduction in total deformation

Determination of boundary data for dependence $S_{\sigma\Sigma}=f(\varepsilon_D/\varepsilon_\Sigma)$ showed that at $\varepsilon_D/\varepsilon_\Sigma=0$ Pilger rolling process was impossible from the kinematic point of view, and accordingly the limit of tube mechanical properties was equal to the limit of billet mechanical properties. At $\varepsilon_D/\varepsilon_\Sigma=1$, there is no wall thickness deformation which provides the maximum values of usage for mechanical properties. This conclusion corresponds to known literature data about negative impact of free reduction on mechanical properties of tubes.

Analysis of observed dependences revealed the fact that change of usage for mechanical properties $S_{\sigma\Sigma}$ on the amount of diameter reduction in total deformation $\varepsilon_D/\varepsilon_\Sigma$ could be presented as follows:

$$S_{\sigma\Sigma} = e^{b_D(\varepsilon_D/\varepsilon_\Sigma)}$$ (Eq. 6)

where b_D – factor of mechanical properties usage (for route group 1 it equals to 0.97, for route group 2 – 0.92, for route group 3 – 0.7, and for route group 4 – 0.53). Rearrangement of dependence (6) enables to obtain the equation of connection for deformation parameters and mechanical properties of metal at cold and warm Pilger rolling

$$\varepsilon_D/\varepsilon_\Sigma = \frac{\ln(\frac{\sigma_{\mathrm{USst}}\sigma_{\mathrm{YSft}}}{\sigma_{\mathrm{YSst}}\sigma_{\mathrm{USft}}})}{b_D}$$ (Eq. 7)

Values of factor b_D allow comparing the methods of tool calculation in view of impact of thermal, kinematic and deformation parameters of the process on change of mechanical properties of metal during Pilger rolling. Values of factor are in the range from 0, which corresponds to conditions of "ideal" process (mechanical properties do not change), to 1, which is a sign of irrational process (the limit of mechanical properties is used with maximum intensity). Tool shape, stage-by-stage deformation and thermal mode of rolling have the main impact on intensity of usage of mechanical properties.

Dependence of factor b_D on the specified parameters for investigated rolling routes is described by the following expression:

$$b_D = \frac{m}{k_b n_\sigma}\mu_\Sigma^{1-k_{\sigma 3}}$$ (Eq. 8)

where m – supply (6-9 mm); μ_Σ – cumulative elongation ratio (1.7-7.6); k_b – factor considering the cross-section form of working cone (0.2-0.27); n_σ – factor of stage-by-stage deformation (9.48-39.8) which depends on the length of total deformation zone determined by tool shape; $k_{\sigma 3}$ – limit of mechanical properties of stock tube which, in this case, allows considering the change of mechanical properties depending on warm deformation effect. When comparing the values of factor b_D obtained under dependence (6) for route groups and for each route (8), it is clear that for great values of cumulative elongation ratio it is necessary to use great values of factor k_b considering the form of cross profile of working cone.

Conclusions

1. Increase of reduction amount in total deformation reduces the difference between ultimate strength and yield strength of metal for all methods and modes of cold Pilger rolling.

2. The quantitative index for estimation of the effect of thermal, kinematic and deformation parameters of the process on change of mechanical properties of material during tube cold Pilger rolling is obtained.

3. The equation of connection of deformation conditions and change of mechanical properties of metal at cold Pilger rolling is deduced.

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Влияние параметров режима деформации на механические свойства металла при холодной пильгерной прокатке труб

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Получен количественный показатель, позволяющий в одних координатах оценить влияние тепловых, кинематических и деформационных параметров процесса на изменение механических свойств материала при холодной пильгерной прокатке труб. Получено уравнение связи режима деформации и изменения механических свойств металла при холодной пильгерной прокатке.