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INGRESS OF THE SALT LUBRICANT ON A TUBE-MANDREL CONTACT IN THE STANDS CONTINUOUS MILL OF TUBES

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The mechnism of the salt phosphate lubricant ingress in zone of the tube deformation on a long cylindric mandrel was considered. Suggested mathematical model is based on the points of the hydrodynamic theory of lubrication. Data presented are concerned with a value of a salt lubricant layer thickness and friction factor between metal and mandrel at continuous hot rolling of tubes.

Key words: *continuous hot rolling of tubes, mandrel, lubricant, layer thickness, friction factor*

Prodor slanih maziva u područje kontakta cijevi i trna u stanovima kontinuirane valjaonice cijevi. Razmatran je mehanizam prodiranja soli fosfatnog maziva u zonu deformiranja cijevi valjanih na dugom cilindričnom trnu. Prijedlog matematičkog modela se osniva na hidrodinamičkoj teoriji podmazivanja. Podaci su prikazani vezano za vrijednosti debljine sloja podmazivanja i koeficijenta trenja između metala i trna pri toplom kontinuiranom valjanju cijevi.

Ključne riječi: *kontinuirano toplo valjanje cijevi, trn, mazivo, debljina sloja, faktor trenja*

INTRODUCTION

Continuous longitudinal rolling of tubes on a mandrel is used on a large scale in producing seamless tubes. However, the problem of the tools durability remains actual because of the cyclic deformation-force and temperature conditions on the contact between tube and mandrel while rolling. Looking for solutions of mentioned problem is under way in several directions: use of the modern materials and improvement of technology for manufacture of the tools (different modes of the heat and mechanical hardening treatment); development of new technological lubricants and means of their application on the mandrel surface.

The lubrication on the contact tube-mandrel has an effect on the level of contact friction forces, energy and power parameters of the rolling process. Despite of use of lubricants, the essential friction forces take place in the process of deformation between tube and mandrel, which has a negative effect on the parameters of contact interaction. Decreasing of friction between tube and mandrel reduces the influence of mandrel on all the parameters of rolling in the stands of continuous mill.

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In the world practice the graphite lubricants on the basis of high-dispersed emulsions and high-molecular hydrocarbons are used. A salt phosphate lubricant with addition of inorganic or organic substances is used in continuous mandrel mills in Ukraine. Additives in lubricant ensure the necessary uniformity of lubricant layer, decreasing melting temperature of lubricant composition and other physical properties. Some additives ensure low friction factor on the contact of metal with mandrel that results to reduction of a surface wear of mandrels.

Lubricants operating in special conditions of high-temperature frictional contact which takes place at the temperatures 950...1200 °C (700...1000 °C at the place of contact) are used during hot continuous rolling of tubes. Then the mandrel is exposed to intensive heat action and the rate of metal slipping on the mandrel is great enough, so it is important to have high insulating and antifriction properties of lubricant [1].

The salt lubricants of mineral origin represent viscous fluidic melts at hot rolling. Phosphates from them have a low corrosion effect (phosphates corrosion effect is moderated by selection of appropriate additives) and a high lubricanting ability. The melting temperature of alkaline metals phosphates is 300…960 °C.

The lubricant is applied on the hot mandrel as a water solution polyphosphates having required concentration.

After evaporation of water a dry lubricant layer remains on a mandrel surface. Under effect of hot metal the dried lubricant passes in the fluid melt having a laminar structure as a result of the chain molecules formation [2].

DETERMINATION OF THE LUBRICANT LAYER THICKNESS IN THE ZONE OF DEFORMATION

Thickness of the lubricant layer is one of the most important characteristics of the contact interaction between tube and mandrel. As a salt lubricant is before rolling in the solid state on the mandrel and in the liquid state on the mandrel and in the liquid state in zone of deformation, determination of quantitative correspondence between mass of the dry substance and volume of the latter in the melt is important for determination of the thickness of the lubricant layer on the mandrel. This dependence was investigated experimentally (Figure 1.). A known amount of salt lubricant was placed into the heating furnance with a protective atmosphere. The volume of fluid melt was determined after the complete melting down of the salt.

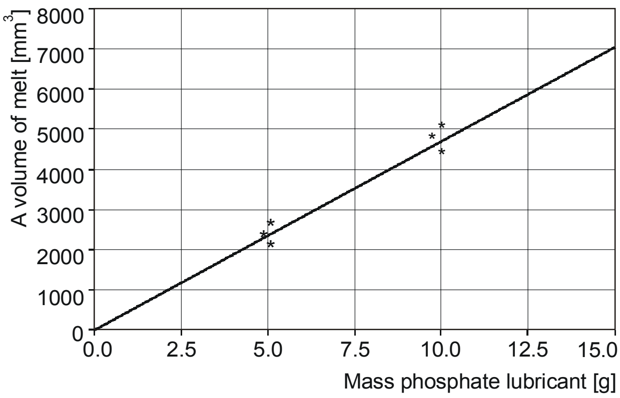

Figure1. **A value of melts volume from dried phosphate lubricant (*- an experimental dates)**

Slika 1. **Količina suhog fosfatnog maziva u otopljenom dijelu materijala (* - postotak dobiven pokusom)**

It is assumed that products of phosphates interaction with metal and metal oxides at high temperature don't differ essentially from the melt and act as good lubrication. So the effect of phosphate lubricant unlike other salt lubricants is spreaded on the wide temperature range. The interaction of lubricant, scale and metal components on the contact surface change initial physico-chemical properties of lubricant. It proves to be true by the mutual dissolution of lubricant and scale, by the change of the melting temperature and lubricant viscosity [2]. The mechanism of phosphate lubricant effect can be explained by the transformation of the scale on metal surface while interacting with melt into a substance having the same structure as polymers. The stable feeding of technological lubricant over all the time of a tube rolling ensures the stationarity of the process, improves the quality of tubes, reduces the wear of tool.

The modern tube-rolling units with continuous mill incorporate a section of mandrel circulation [1]. After being extracted from the tube, the mandrel is cooled and introduced into special device, for application of the lubricant on the mandrel. A strongly adhesire lubricant layer is formed on the surface of mandrel, the thickness of this layer depends on the physico-chemical properties of lubricating solution and temperature of the mandrel surface.

In hydrodynamical models the mechanism of lubricating effect consists in developing hydrodynamic effect in zone placed ahead of zone of deformation, involving of lubricants in contact zone by microhills of surfaces and formating an interlayer reducing the effective area of contact. One of the basic values to be calculated in such models, is the thickness of a lubricating layer which is function of the rheologic properties of lubricating medium and metal to be strained, parameters of rolling (speed, temperature, contact stresses), roughness on contact surfaces. The determination of lubricant amount, entering in zone of deformation is important because of the influence lubricating layer thickness on the value of friction forces. The determination of a minimum necessary and rational amount of feeded lubricant is of an essential impotance from the point of view of stable course and expenditure of lubricant. These questions are slightly studied for salt lubricants.

Depending on presence and thickness of lubrication layer on the contact tube - mandrel, the force of friction varies theoretically from zero up to the value of shearing stresses in metal. The direction of friction forces on the mandrel coincides with direction of tube movement while rolling or is opposite to it. Therefore the mandrel exerts essential effect on the process of tube rolling in continuous mill through the friction forces on its surface.

The known theoretical studies in determination of the thickness of lubricant layer have been carried out for cold and hot sheet rolling [3], as well as for hot continuous rollin of tubes on a long mandrel [4, 5].

The theoretical determination of the thickness of lubricant layer is based on the solution of Navier-Stokes differential equations for movement of viscous liquid. The thickness of lubricant layer h_o at the entrance in a zone of the tube wall thickness reducing by the top of the groove is defined according to [5]:

$$h_o = \frac{6(V_t + V_o)\eta_o\theta}{2m(1-e^{-\theta P_o})\delta + 12(V_t + V_o)\eta_o\theta}, \qquad (1)$$

where

$$m = \frac{R_g - r_o - S_g}{\sqrt{R_b \Delta D} - \sqrt{(S_g - S_t)(2R_b + S_g + S_t)}};$$

V_t, V_o - are the rates speed of tube and mandrel; R_g, r_o, R_b - are the radius of shell, mandrel and roll by the top of groove; S_g, S_t - are the thickness of the shelll and tube wall; ΔD- is a reduction of the tube diameter; η_o, θ - are the dynamic viscosity and piezofactor of lubricant melt viscosity; δ - is an initial thickness of a fluid lubricant layer on the mandrel; at the exit of the tube out of zone of deformation of any filled stands the thickness of the lubricant layer h_1 is:

$$h_1 = -r_o + \sqrt{r_o^2 + k_o \cdot (2r_o + h_o) \cdot h_o}\ , \tag{2}$$

where

$$k_o = \frac{\mu_i^{x_o^{\acute{\imath}}/l_{d,k}} + 1}{\mu_i^{x_o^{\acute{\imath}}/l_{d,k}} + \mu_i}\ ;$$

$x_o^{\acute{\imath}}$ - is a location of the neutral (zero) section on a mandrel; $l_{d,i}$ - is a length of zone of deformation by the groove top of the *i-th* stands; μ_i - extension factor in the *i-th* stands.

Because of non-uniformity of the tube deformation the thickness of the lubricant layer is different longitudinally on the sections of zone of deformation. Therefore, it is necessary to take into account the distribution of the lubricant along periphery of the contact zone of the tube with mandrel.

The amount of lubricant involved into zone of deformation depends on the hydrodynamic factors at the entrance in mentioned zone as well as on random components attributed to the roughness of contacting surfaces. The use of the random function theory for description of the surface roughness is the most justified for evaluating of the friction and lubricating phenomena on the contact. The simulation of the surfaces microgeometry by means of the random function of the normal distribution law allows to obtain convenient and simple relations for the lubricant layer thickness in analyzing with allowance for roughness. The summed up roughness on contact of tube and mandrel is specified by means of parameter $R_{q,i}$. It is assumed that the hydrodynamic condition of friction takes place in all stands of continuous mill. The evidence for this are values of friction factors on the mandrel order of 0.05…0.08, obtained by computation and checked experimentally.

At an one-dimensional cross roughness the lubricant layer thickness h_r is defined by means of equation:

$$h_r = h_g\left[1 + 2(R_{q,i} / h_g)^2\right], \tag{3}$$

and at an one-dimensional lengthwise and uniform isotropic roughness - h_r is defined by means of equation:

$$h_r = h_g\left[1 - 0.5 \cdot (R_{q,i} / h_g)^2\right], \tag{4}$$

where h_g - is a hydrodynamical component of the lubricant layer thickness average over periphery.

The lubricant layer thickness on the contact between tube and mandrel in the stands of continuous mill can be defined theoretically by means of procedure described in [5] the thickness of initial layer of dry lubricant ensuring on the contact of liquid or close to it friction can be calculated as well.

The thickness of the salt phosphate lubricant layer is defined experimentally as follows. The cylindrical samples of lubricant having the minimum thickness have been drawn and carefully weighed on analytical balance. The strips from the steel Sт10 having dimensions 5x50x150 mm were heated to the temperature 1150 °C in electrical heating furnace. A pellit of the lubricant was placed on the metal strip (mandrel) measuring 10x80x250 mm, preheated to 250...300 °C, covered from above with a heated sample and rolled together in laboratory mill “duo 200”. In the process of deformation lubricant melt interacts with the hot scale on the sample surface, spreads and forms a spot with the rests of lubricant. The boundaries of spreading of a fluid lubricant over sample surface are clearly discernible after cooling. The average lubricant layer thickness has been determined as in the droplet method [6]. The experimental and calculated values of thickness of the salt phosphate lubricant layer are shown in the Figure 2..

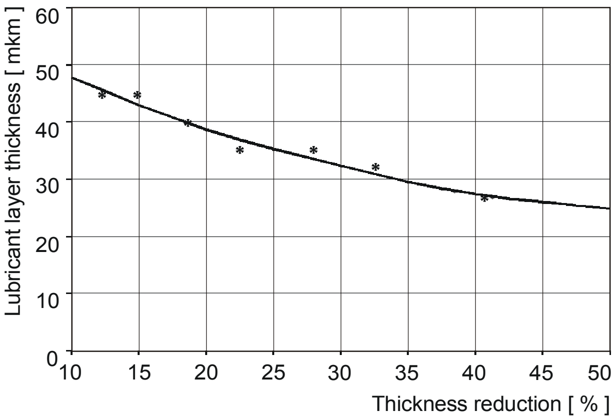

Figure 2. **A dependence of lubricant layer thickness from the relative strain over the the tube wall (*-an experimental dates)**
Slika 2. **Ovisnost debljine sloja maziva o relativnoj deformaciji duž stijenke cijevi (* - podatak dobiven pokusom)**

The important rheologic characteristics of a fluid lubricant are viscosity and piezofactor of viscosity. An increase of temperature reduces viscosity of liquid medium and increase of presure increases it. The dynamic viscosity η_p of a liquid at the pressure P is defined by expression:

$$\eta_p = \eta_o \exp(\theta P)\ , \tag{5}$$

where η_o - is viscosity at atmospheric pressure and θ - is piezofactor of viscosity.

The piezofactor phosphate lubricant viscosity has been determined by the way of calculation from a known expression for the lubricant layer thickness at the hot strip rolling [2].

Having expanded in McLoren series the expression $\exp(\theta P)$ by the powers of θ and using only the first three terms of series we shall receive an equation for finding:

$$\theta = \left[\frac{2}{P} - \frac{6\eta_o V_b (1+\mu)}{\alpha h_s P^2} \right], \qquad (6)$$

where α - is the angle bite; V_b - is the roll lineary speed; μ - is a factor of extension; h_s - is the lubricant layer thickness with allowance for roughness of rolls and strip.

The calculations of piezofactor viscosity θ were carried out according to expression (6). The average value of θ for phosphate lubricant is equal to $\theta = 1.19 \cdot 10^{-8} \frac{sq.m}{N \cdot s}$.

The contact interaction of a tube and mandrel at continuous rolling is often described with conventional friction factor on the mandrel f_c. In the general case f_c is a function of parameters of deformation ε, rolling temperature T, speed of metal relative slipping on the mandrel ΔV, lubricant layer thickness h_r on the contact etc.

A relation allowing to define conventional friction factor on the mandrel f_{ci} in any stand continuous mill has been obtained from experimental data [1]:

$$f_{ci} = 0.0057 + 0.000762\varepsilon_i + 8.553 \cdot \frac{1}{1400 - T_i} - -0.00582 \cdot \Delta V_i - 0.0755 \cdot \sqrt{\overline{h}_{ri}} \qquad (7)$$

where i is the number of continuous mill stand; T_i is metal temperature of the *i-th* stand of the mill; ε_i is a relative strain over the tube wall in the *i-th* stand of the mill; $\overline{h}_{ri}$ is an average lubricant layer thickness with allowance for roughness of the tube and mandrel in the *i-th* stand of the mill; ΔV_i is a rate of speed of metal relative slipping on the mandrel in the *i-th* stand of the mill.

Thus, taking into account the above mentioned points we shall define the lubricant layer thickness in the stands of continuous mill by means of the the following algorithm:

1. Determination of geometrical parameters, speed parameters of the mandrel movement and metal under deformation in zone of deformation of continuous mill stands.
2. Determination of a hydrodynamic component of the lubricant layer thickness at the entrance h_{oi} and the exit h_{1i} out of zone of the *i-th* stand.
3. Determination of an average lubricant layer thickness $\overline{h}_{gi}$ in zone of deformation of the *i-th* stand (hydrodynamic component of the lubricant layer thickness).
4. Determination of the lubricant layer thickness $\overline{h}_{ri}$ in the *i-th* stand with allowance for roughness of the mandrel and inside surface of the tube.

Calculation of the friction conditions on the contact between tube and mandrel in stands of continuous mill was carried out on PC according to the specially developed program allowing to calculate convenient friction factor on the mandrel in the stands of continuous mill in different periods of the one tube rolling as well as for processes of continuous rolling with different schemes of mandrel movement.

The results of calculation convenient friction factor f_{ci} on the mandrel in the stands of continuous mill in the steady period of rolling at the of the rough tubes rolling 120x4.0 mm is shown in Figure 3..

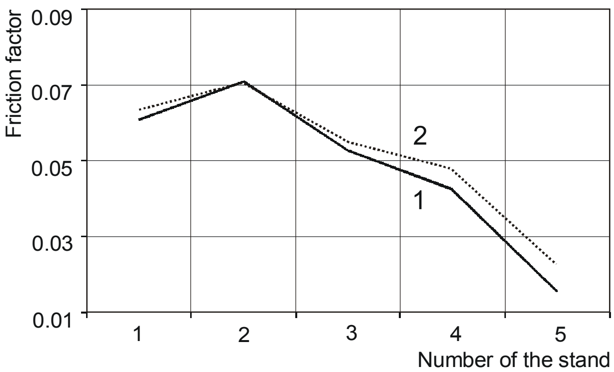

Figure 3. **Convenient friction factor on a free mandrel at the rolling of tubes in continuos mill:**
1 - rate of the tube exit out of the mill is equal to 6 m/s;
2 - rate of the tube exit out of the mill is equal to 4 m/s

Slika 3. **Prikladan faktor trenja na slobodnom trnu pri valjanju cijevi u kontinuiranoj valjaonici:**
1 - brzina izlaženja cijevi iz valjaonice jednaka je 6 m/s
2 - brzina izlaženja cijevi iz valjaonice jednaka je 4 m/s

CONCLUSIONS

1. A salt phosphate lubricant provides in the best way a necessary complex of the antifrictional and thermal insulating properties during the continuous rolling on the mandrel.

2. The most impotent characteristic of the contact interaction between metal under deformation and instrument is the lubricant layer thickness.

3. The ingress of the lubricant in the zone of deformation is connected with hydrodynamic phenomena in the

entrace contact zone and roughness of the metal and instrument surfaces.

4. A mathematical model was developed for determination on the lubricant layer thickness and the friction factor on the tube-mandrel contact during the continuous rolling. Results of calculations carried out according to the model correspond well with experimental data.

5. A suggested mathematical model can be used for characteristic of conditions on the contact interaction between metal and instrument during the continuous rolling of the tubes with different models of the mandrel motion in process of the rolling.

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