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THE HEAT CONDITIONS OF THE COLD PILGER ROLLING

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The influence of technological factors and constructive parameters of the cold pilger rolling mill on the warm conditions of deformation is observed. The dependences of the heat conditions of pilger rolling on deformation mode and preheating temperature are shown. There was a conclusion drawn about the expediency of combination of warming and cooling of the metal for keeping the deformation zone temperature within limit, which corresponds to the minimal intensity of the metal strengthening.

Key words: *metal foming, tube, cold pilger rolling, warm deformation*

Toplinski uvjeti hladnog pilger valjanja. Promatra se utjecaj tehnoloških čimbenika i konstruktivnih parametara pilger stana na toplinske uvjete deformacije. Prikazana je ovisnost toplinskih uvjeta pilger stana na način deformiranja i temperaturu predgrijavanja. Donesen je zaključak da se isplati kombinirati zagrijavanje i hlađenje metala da bi se temperatura zone deformiranja držala unutar granica koje odgovaraju minimalnom intenzitetu učvršćivanja metala.

Ključne riječi: *oblikovanje metala, cijev, hladno pilgerovanje*

INTRODUCTION

One of the most important finish metallurgical products are seamless tubes. After the hot rolling a part of these tubes goes to the end-user, the other part serves as a billet to the cold pilger rolling. The tubes, made by the cold pilger rolling, are used by traditional and perspective consumers - machine-building enterprises. At this, a consumer makes the higher demand to the assortment and the product quality. The following factors can be related with such demands: the usage of hardly-deformed materials, which have the high user's quality and the manufacturing of the tubes with the complicated shape of the cross-section - so called hollow profiles. The preciseness of the geometrical dimensions, the surface quality, the structure and mechanical characteristics of the ready tubes require under-recrystallisation temperatures for finish size deformation. One of the wide-using methods of making such tubes is cold pilger rolling (Figure 1.) [1 - 4]. By this method the part of billet (hot-, cold rolled or extruded etc. tube) 1 that equals to feeding volume, gets into moving zone of working cage 2, where rolls 3 with variable dies radius are installed. The variation of dies radius is provided by special calibration of tool. In the rolling process summary deformation zone (working cone) 4 is formed there. Its internal surface is formed by the mandrel 6. The consequent deformation of the parts of billet with the low level of partial strains in working cone is the tube with finish size 5.

At the middle of XX century a considerable progress in the field of technology and pilger rolling equipment for manufacturing of precision tubes was indicated. At that time the concepts such as cold and warm tubes rolling were formed, they had a new sense for technology and equipment improveing.

PARAMETRES OF HEAT CONDITIONS

The metal temperature determines by the equation of thermal balance [5] all conditions of heating and cooling of metal and tool at the pilger tubes rolling

$$N_b + N_f + N_\tau = N_m + N_в + N_o + N_c \qquad (1)$$

where: N_b, N_f, and N_τ, respectively, thermal capacity of incoming components, entering with a billet, from deformation and friction; N_m, $N_в$, N_o, and N_c - respectively, thermal capacities of outgoing components, deflected by the rolled tube through contact surface with the rolls, through the mandrel and out to the environment. Thermal balance (1) allows determining the correlation of the income and outcome of

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heat as for the deformation zone in total (working cone) and for its separate parts. Apart from the technological factors (initial temperature of metal, type of lubrication-cooling liquid (LCL), value of feeding and rolling route) some mill's constructive parameters affect the volumes and ratio of balance components, where it needs to underline the fast motion of the mill (number of double strokes of the cage per minute *n*) and the way of lubrication-cooling liquid is applied to the working cone. Apart from the appointed factors, the metal temperature is affected by the heat, released from the friction, quantity of which depends on difference of natural and forced rolled radius, tool profile and lubricant's effectiveness. In the balance component, reflecting the quantity of heat, released because of the deformation, the character of hardening characteristics of metal right plays the particular role during the deformation process. The length of the working cone determines the duration of the impact of as incoming so and outgoing balance's components and cannot be the independent factor, which determines the heating conditions of rolling.

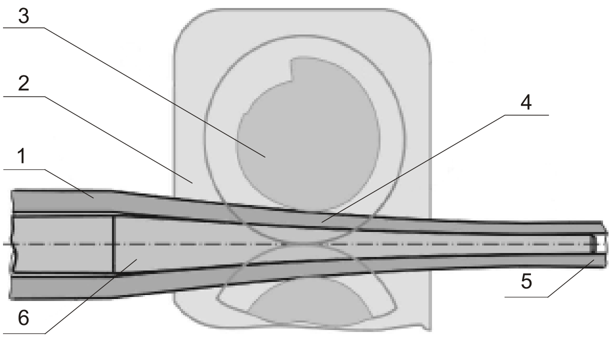

Figure 1. **The scheme of cold pilger rolling**
Slika 1. **Shema hladnog valjanja na pilger stanu**

TYPES OF HEAT CONDITIONS

At the present time some types of the warm rolling modes for cold pilger rolling mills found their application:
- cold rolling - without warming of a billet and with the cooling by lubrication-cooling liquid (LCL);
- warm rolling - warming of a billet, absence of cooling by LCL;
- rolling without any warming and cooling LCL (emulsionless rolling), at that the metal temperature raises at the expanse of warming, appeared as a result of deformation and friction.

It historically developed that under the way of cold rolling of the tubes understood the rolling in the moving rolls' cage, when the process of deformation goes under the following circumstances:
- the billet-tube comes to the rolls at the room temperature;
- working cage with the rolls has relatively low movement *n*, not much than 100 double strokes per minute;
- the length of the part of the tube, rolled per one double stroke of rolls, equals to the product of the drawing out factor μ and the volume of the feeding *m*, does not exceed 15 … 20 mm for the steel tubes;
- the water emulsion, as LCL, is applied on the summary stroke of cage of its length of focus of deformation (working cone) and on the rolls.

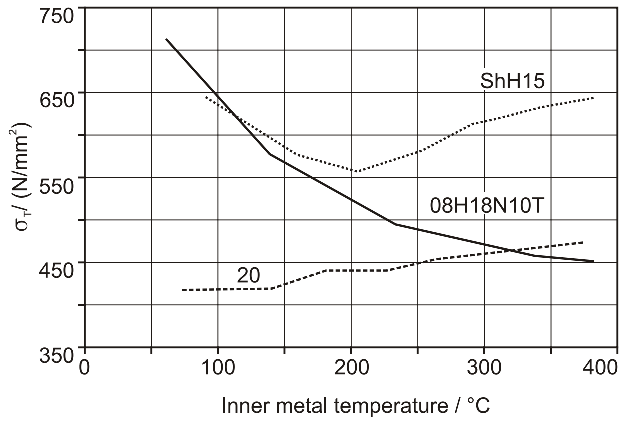

Figure 2. **The dependence of flow stress, calculated by roll pressure [7], on inner temperature of metal deformation zone for steels 20, ShH15 and 08H18N10T (by GOST). Flat rolling, 40 % strain**
Slika 2. **Ovisnost krivulje tečenja, izačunate tlakom valjka [7], na unutarnjoj temperaturi zone deformiranja za čelike 20, ShH15 i 08H18N10T (po GOST-u). Ravno valjanje, 40 % deformiranja**

In such conditions the temperature of the surface of the working cone does not exceed 100 °C - temperature of the water component of emulsion boiling. The emulsion boiling, because of, for instance, the excessive feeding, appears to be a gross violation of the rolling technology. At such temperature the overwhelming majority of the steels and alloys, used for the tubes manufacturing, do not have the activation of the processes, which counteract the strengthening. Thus, we have a "classic" cold deformation.

The lowering of intensity of the metal strengthening, noted during the billet's warming before its feeding to the rolls up to the temperature 150…300 °C and named "the effect of the warm deformation", initiated the way of the warm tubes rolling. This method today is wide used on mills, what rolls tubes from austenite steels.

The following conditions define the tubes rolling by that way:
- the billet is heated before the feeding to the rolls up to the temperature 150 … 300 °C;
- mill's high speed *n* does not exceed 100 double strokes per minute;
- the volume of the product of the factor of drawing out μ and the volume of the feeding *m* sums up to 60 mm;

- some salty lubricant is applied on the billet, cooling by the liquid of the focus of deformation and rolls does not exist.

The temperature of the working cone under that condition comes up to 500 °C.

Despite to that lowering of the strengthening intensity [6] were discovered in the major steels as the temperature rises, most expansion the way of the warm rolling has received for austenitic steels. The main reason of that is the continuous nature of lowering of the level of strengthening character with the temperature raising within the interval from 100 up to 500 °C right for that kind of steels. For other materials the nature of changing of the level of strengthening character is not of one single meaning within that temperature interval (Figure 2.).

For example, ball bearing steel ShH 15 (by GOST) in that temperature interval shows change of reducing and increasing of hardening intensity. Steel 20 (by GOST), deformed with 40 % strain shows slow increasing of flow stress for all researched temperatures.

From the Figure 3., it is possible to see the differences in behavior of Steel 20, during the deformation with 10, 20, 40 and 60 % strain. The flow stress is increasing with the level of stain at all temperatures. The reason for is an

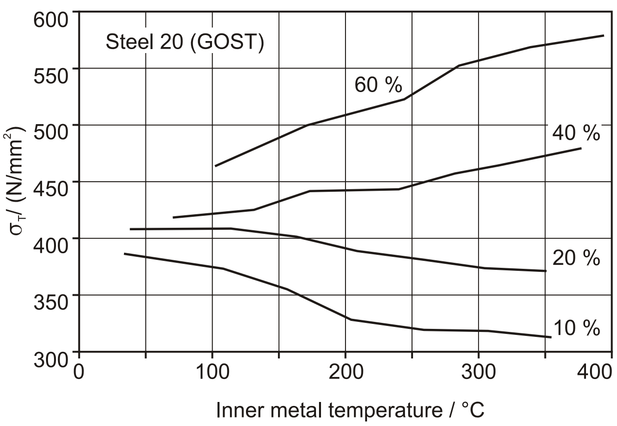

Figure 3. **The dependence of flow stress, calculated by roll pressure [7] during flat rolling with strains 10, 20, 40 and 60 % on inner temperature of metal deformation zone for steels 20**

Slika 3. **Ovisnost krivulje tečenja, izačunate tlakom valjka [7], tijekom ravnog valjanja s deformacijom od 10, 20, 40 i 60 % na unutarnjoj temperaturi zone deformacije za čelike 20**

activity of the dynamic deformation aging process [5, 7]. Increasing of strain moving the starting point of this process to the side of low temperatures. Cold pilger rolling with low partly strains gives a possibility of stopping intensive increasing of flow stress and using the reducing of hardening intensity. Due to low level of partly strains on working cone, in pilger rolling using of "the effect of the warm deformation" for other hard deformed materials is possible. Necessary condition of that is effective common using of temperature increasing and temperature reducing factors.

In order to lower the maximal temperature of the working cone during the steels rolling, which have the range of the lowering of level of the strengthening characteristics lays in the field of lower temperatures, than austenitic steels do, there is a variety of the ways of warm rolling without prior heating of the billet and fluid cooling of the working cone - emulsionless rolling. Emulsionless rolling is characterized by the following conditions:

- tube-billet comes to the rolls at the room temperature;
- mill's high speed n does not exceed 100 double strokes per minute;
- the volume of the product of the factor of drawing out μ and the volume of the feeding m sums up to 25 mm;
- some salty easily melted lubricant is applied on the billet, cooling by the liquid of the focus of deformation and rolls does not exist.

The temperature of the working cone under that conditions comes up to 400 … 450 °C. The experience of use of the emulsionless way of rolling revealed that the achieved increase of the degree of the deformation in this case is accompanied by the major lowering of the tools' resistance and deterioration of the tubes' surface quality.

THE INFLUENCE OF DEFORMATION PARAMETERS ON HEAT CONDITIONS OF PILGER ROLLING

Let us examine in details the appointed factors, which determine the actual temperature of the working cone's metal. The results, shown below, are based on the experimental research, carried out in the State Tube Institute (Dnepropetrovsk, Ukraine) for rolling tubes made of chrome-

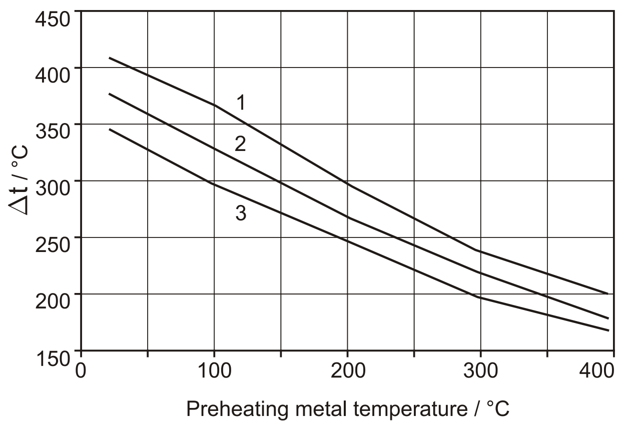

Figure 4. **The dependence of the maximal increase of the temperature of the working cone on the initial temperature of the billet**

Slika 4. **Ovisnost maksimalnog porasta temperature radne zone o početnoj temperaturi gredice** nickel-titanium steel 08-18-10 on the mills "HPT32" (charts № 1 on the drawing 4 - 7), "HPT55" (charts № 2 on the drawing 4 - 7) and "HPT90" (charts № 3 on the drawing 4 - 7). These mills are intended for rolling of billets with external diameter 32, 55 and 90 mm.

The dependences of the maximal increase of the temperature of the working cone (Δt) on the initial temperature of the billet, shown on the Figure 4., have the identical character: at the raising of the initial temperature of metal (t_0), increase of the temperature diminishes.

As it follows from the Figure 5., rising of the number of the double strokes of the cage and the increase of the metal temperature, at the other conditions equal, tighten between each other by the linear dependence.

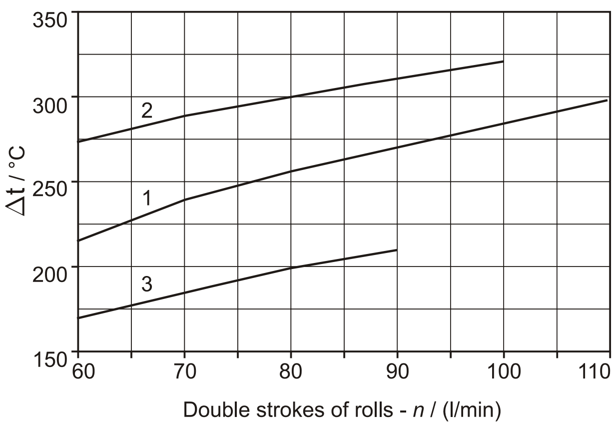

Figure 5. **The dependence of the maximal increase of the temperature of the working cone on the number of the double strokes of the cage per minute, *n***
Slika 5. **Ovisnost maksimalnog porasta temperature radne zone na broj dvostrukih pomaka kaveza u minuti, *n***

The intensity of the volume of feeding dependence on the temperature increase (Figure 6.) depends on the dimension-type of the mill: for the mill of small dimension-type

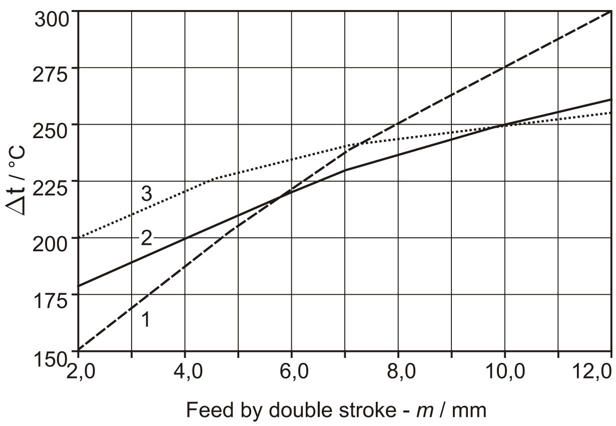

Figure 6. **The dependence of the maximal increase of the temperature of the working cone on the volume of the feeding *m***
Slika 6. **Ovisnost maksimalnog porasta temperature radne zone na istisnuti volumen *m***

- HPT32, the dependence has a linear character, but coming to the mills of a grater dimension-type - HPT55 and HPT90 the intensity of the temperature increase diminishes.

It is seen from the Figure 7., that the factor of drawing out puts strong influence upon the temperature increase of the metal, at that the intensity of this influence practically does not depend on the mill dimension-type.

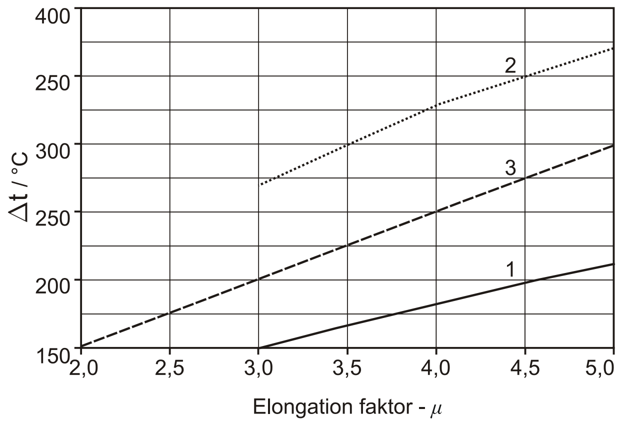

Figure 7. **The dependence of the maximal increase of the temperature of the working cone on the drawing out factor μ**
Slika 7. **Ovisnost maksimalnog porasta temperature radne zone na faktor izvlačenja μ**

Also during the process of the experimental research it was determined that during the rolling without fluid cooling the rolls after 60 … 80 minutes, as the work started, come off to the stable level of the temperature, which corresponds to 220 … 250 °C.

The influence of the heat exchange between the metal and the mandrel, in case last does not cool forcedly, is assumed to be considered as inessential and not to take into account when calculating.

The improvement of the cold pilger rolling mills by the way of usage of the weight balancing of the inertial powers of the moving mass of the working cage and con-rods gave the opportunity to essentially raise the speed of the mills. This brought to that the metal's temperature exceeded 100 °C, and the water emulsion started to boil on the working cone. The emulsion boiling on the working cone brings to the appearance of the steam cover on its surface, which sharply lowers the effectiveness of the heat removal. This circumstance and also a wish of improvement of the quality of the rolling tubes surface stipulated for usage as LCL of the compositions on the basis of mineral or synthetic oils, so called oil LCL. Such LCL, though they lose to the water emulsion intensity of the heat removal at the temperature up to 100 °C, but save their characteristics at the temperature rising.

The method of measurement of working cone temperature [4] allows calculating change of temperature along the length of a cone in different modes of rolling. One of the features of this method is calculating of the increase of the temperature from deformation heat by experimentally confirmed dependency:

$$\Delta t_f = t_0 \, e^{n\varepsilon} - t_0 \qquad (2)$$

where:

t_0 - initial (preheating) temperature for partly deformation on working cone /°C,
n - empirical factor,
ε - strain /%.

Diagrams of rated distribution of temperature along the length of working cone for rolling with emulsion and low-viscosity oil cooling on route 57 × 3,75 ⟶ 35 × 1.5 mm on mill HPT55 with steel 20 (by GOST) and feeding m = 8 mm are shown on Figure 8. The calculations were made with assumption that in this case supply of coolant is made through round nozzles installed on working cage.

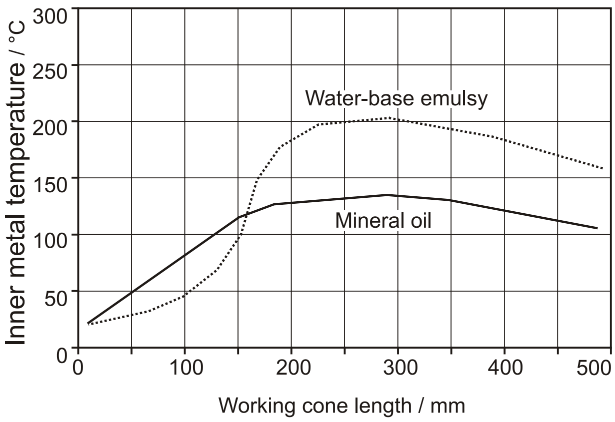

Figure 8. **The calculated change of the temperature of the metal through the working cone's length [8]**
Slika 8. **Izračunata promjena temperature metala po dužini radne zone [8]**

However, even with application of progressive methods of supply of coolant to working cone on rolling mill KPW 25 VMR, temperature of metal is exceeding 100 °C. So, for example, at rolling of stainless austenite steel pipes without preheating with $m\mu$ = 25 mm and n = 200 min^{-1}, temperature of metal runs up to 220 °C. At this temperature, the same as in case of emulsionless rolling, there can be an effect of warm deformation, which decreases power of rolling, or activation of deformation aging process, which impedes deformation.

The different types of steel show different reaction on common influence of preheating and strain during pilger rolling. On the Figures 9. and 10. experimental dependences of vertical component of rolling force (VRF) and working cone temperature (WKT) on preheating temperature are presented. Experiment were carried out without liquid cooling of working cone and rolls. The measurements of temperature of working cone were performed on the start - charts *a*, middle - charts *b* and finish of working cone - *c*.

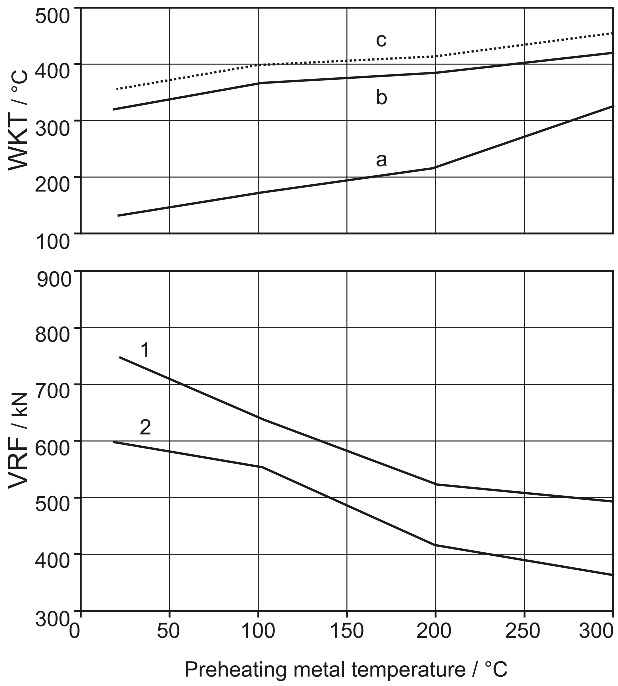

Figure 9. **The dependence of vertical component of rolling force (VRF) and working cone temperature (WKT) on preheating temperature. Steel 08H18N10T (by GOST). Mill HPT 55. Rolling route 45 × 4,3 - 25 × 2,0 mm. μ = 3,8. 1- feeding 14 mm. 2- feeding 9 mm. Temperature values received with feeding 14 mm**
Slika 9. **Ovisnost okomite komponente sile valjanja i temperature radne zone o temperaturi predgrijavanja. Čelik 08H18N10T (po GOST-u). Stan HPT 55. Linija valjanja 45 × 4,3 - 25 × 2,0 mm. μ = 3,8. 1- pomak 14 mm. 2- pomak 9 mm. Vrijednost temperature dobivene pomakom 14 mm**

As it can be seen from Figures 9. and 10., the temperature of working cone reaches to the level of 300 … 600 °C. It renders a negative influence on stability and lifetime of rolls, mandrels and technological grease, though reducing of vertical component of rolling force (VRF) and absence of destruction of metal gives possibility to intensification of process.

Most effective way of overcoming this contradiction is precision cooling of working cone and rolls.

Taking the above-mentioned examples into account, there is a doubt about appropriateness of term "cold rolling" to intensive modes of deformation. It concerns, particularly, rolling at long-range high-speed rolling mills on which the process of non-stop rolling is realized (KPW HMRK). The process of rolling without shutdown of the mill and switching-off the feeding at recharging of another billet favours to stabilization of temperature on higher level at the expense of elimination of temperature losses during shutdown of the mill for recharging. Thus, modern modes of squeezing characterized by capacity of mills about 200 - 1600 mph, practically, leave no chance to “classical cold rolling”.

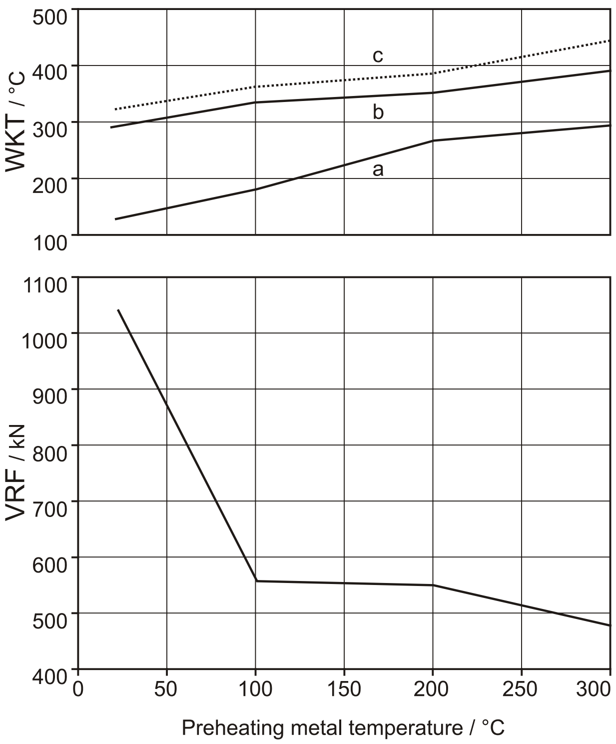

Figure 10. **The dependence of vertical component of rolling force (VRF) and working cone temperature (WKT) on preheating temperature. Steel H25T (by GOST). Mill HPT 75. Rolling route 89 × 8,0 - 56 × 4,0 mm. μ = 3,12. Feeding 10 mm**

Slika 10. **Ovisnost okomite komponente sile valjanja i temperature radne zone o temperaturi predgrijavanja. Čelik H25T (po GOST-u). Stan HPT 75. Linija valjanja 89 × 8,0 - 56 × 4,0 mm. μ = 3,12. Pomak 10 mm**

Moreover, there is growing actuality of usage of warm deformation effect not only for austenite steels, but for other steels and alloys as well. Effectiveness of deformation modes during periodical rolling of pipes can be increased by methods of retention of working cone temperature in narrow (up to ±30 °C) temperature interval, where durability characteristics of metal are on the lowest level and rolls and mandrel has satisfactory lifetime.

These methods are: preliminary heating of billets and usage of heat from deformation and contact friction, together with fluid cooling of working cone and rolls.

CONCLUSIONS

1. The intensive modes of the deformation of the precision pipes rolling with the modern pilger rolling mills do not appear as cold rolling, even if prior heating, before the billet comes to the rolls, does not exist. At such modes of deformation the achievement of the “warm deformation” temperatures happens at the expense of the heat of forming and friction without prior billet warming.
2. The cold pilger rolling in condition of combination of metal preheating with using of effective lubrication-cooling liquid and methods of cooling gives possibility to hold working cone temperature at narrow interval, where intensity of hardening is lowest.

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