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INVESTIGATION OF THE TEMPERATURE FACTOR ON THE FORMATION OF A STRIP SURFACE MICRO-RELIEF DURING WARM ROLLING

The temperature is studied as a factor that affects the formation of the micro-relief of the strip, which was rolled with heat. Various schemes for heating the strip to the required temperature are considered. A mathematical model of the temperature distribution over the thickness of the strip and along the length of the deformation zone is obtained. The temperature distribution along the height and length of the deformation zone is not the same. Our studies have shown that the heating scheme is better when the heater is inside the roll. This is better because it gives a smaller temperature spread along the length of the deformation zone. That is, you can better use temperature as a factor. The roughness of the strip during warm rolling is influenced by several factors. If we consider the process with the final tempering, then one of the main factors is temperature. We studied how temperature affects the printability coefficient of the micro-relief from rolls to metal. Experiments were carried out to confirm the results. The experiment consisted in indentation a single indenter into a metal sample. Indenters of various shapes were used, similar to the shape of single micro-protrusions of the real relief of the work rolls. The sample was heated to different temperatures in the drying box, then the depth of its indentation was measured. Experimental studies have shown an almost linear dependence of the penetration depth on temperature, that is, the dependence of the printability coefficient on temperature. This form of dependence was observed for all forms of the indenter, although with different intensity. So, we can confidently say that the temperature factor can be used to control the parameters of the strip roughness that is needed. To do this, at the final stage of the technological chain of rolling, which is temper rolling, you can use the work rolls of the desired micro-relief, and the strip of the desired temperature.

Keywords: rolling, tempering, temperature, micro-relief, printability coefficient, experiment, indenter.

In modern conditions, product quality is extremely important, because it determines the development of production processes and their efficiency. In addition to other factors, the level of quality of rolled products is affected by the state of the surface, because it is the micro-relief that determines the technological features of the following technological operations, as well as the efficiency of the product operation [1]. But the most important influence the quality of the surface has on the presentation of the product [2, 3]. In particular, the micro-geometry of the surface of sheet steel strips greatly affects the quality and durability of paint coatings. It also affects the limiting degree of drawing during stamping, the reflectivity of the metal, etc. [4, 5]. In most technological schemes temper rolling is the final stage of the rolling process. Theoretical and experimental studies have shown that under certain conditions during temper rolling the roughness of the rolls is almost completely transferred to the strip [6]. That is, the micro-relief of the work rolls is printed on the strip (Fig. 1). Recently, this feature has been increasingly used to obtain the desired micro-relief to the strip.

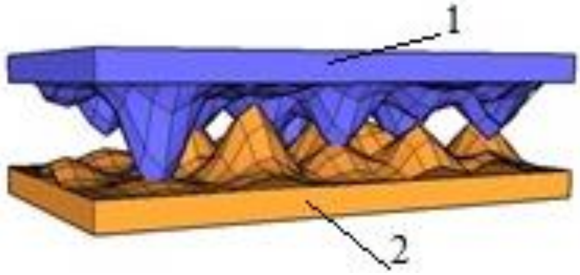


Fig. 1. Model of printability a micro-relief from a roll to a strip

The purpose of this work is to study the temperature factor, since it has a strong influence on the printability coefficient, that is, in the result, the temperature strongly affects the quality of the finished product, product which was obtained by warm rolling.

There are two approaches to implement the warm rolling process. The first involves heating the strip immediately before the deformation zone. Such a scheme is easier to implement and easier to regulate. But the results of mathematical modeling of the temperature field of the strip showed that the temperature in the deformation zone will have a strong spread in this case [7]. The second approach involves additional heating of the metal directly in the deformation zone. This heating occurs due to the contact heat exchange between the strip and the rolls preheated to the desired temperature. This approach often requires renovation of the equipment. But the results of mathematical modeling of the temperature field of the strip show that then the temperature in the deformation zone is uniform. This gives stable mechanical properties of the metal and the possibility of predicting them [7].

When the flow sheet of warm rolling with heating inside is used, an electric heating source is placed, for example, inside the axial channel of the roll (Fig. 2).

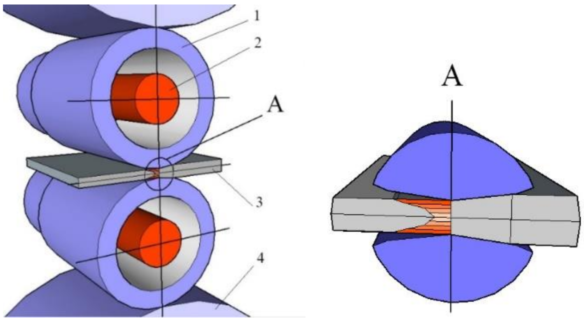


Fig. 2. Model of a roller assembly with an internal heating source

If we do not take into account the length of the arc of contact between the work roll and the strip, that is, the temperature field of the roll will be considered axisymmetric and constant in time. The temperature distribution along the radius in this case must satisfy the following differential equation:

$$\frac{\partial^2 t}{\partial r^2} + \frac{\partial t}{r \cdot \partial r} = 0, \tag{1}$$

where t - the temperature, r - the current work roll radius.

The final solution to this equation, as described in [4], looks like this:

$$t_b(r) = t_{en} + \frac{q_u R_o}{\alpha_b R_b} + \frac{q_u R_o}{\lambda_b} \ln \frac{R_b}{r}, \tag{2}$$

where t_b - the temperature of the roll in the current radius r, t_{en} - the environment temperature, R_b, R_o - the radii of the roll and hole respectively, q_u - the specific power of the heating source, α_b - the thermal conductivity coefficient, λ_b - the heat transfer coefficient.

Rolls and strip are cooled by heat exchange and convection with the environment, as well as by radiation. Heat transfer coefficient by radiation for surface temperature 350…400°C and environment 20°C is 2…3 W/(m^2 deg), that is, it is quite small, so it can be ignored. The proportion of heat that goes to the support rolls is about 5% of all losses. Therefore, it can also disregard separately. Knowing this, as well as the fact that the heat transfer conditions are stationary in time, we can calculate:

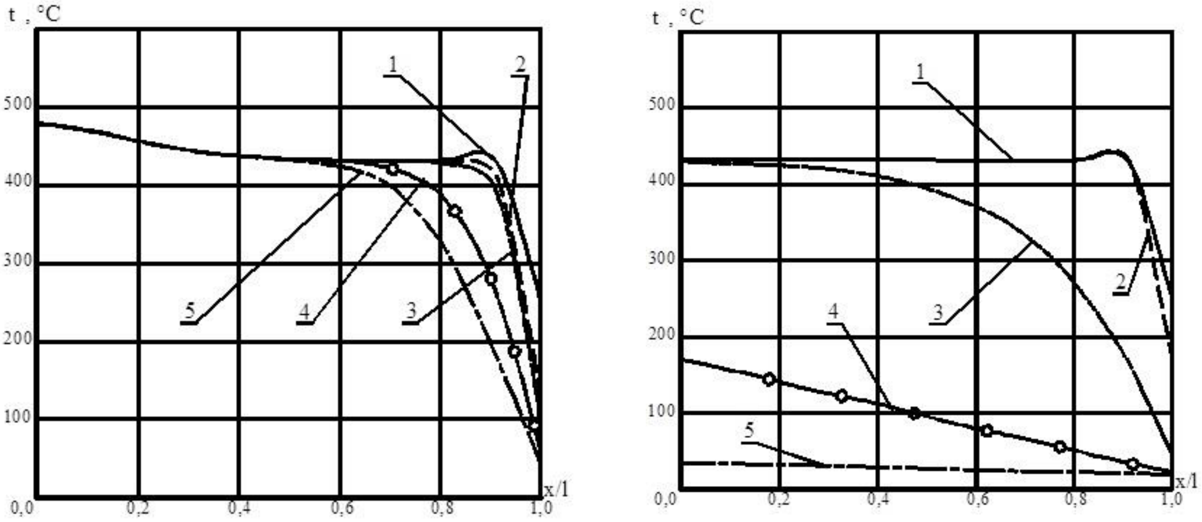
$$t_b(\theta) = t_{en} - t_b \cdot (\theta - \Delta\theta) \cdot e^{-\frac{\alpha_b L_K}{c_b \pi R_b^2 V_b}}, \tag{3}$$

where θ, $\Delta\theta$ - the time and the increase of time, V_b - the circumferential speed of the roll, L_K - the length of the contact.

The analysis of the obtained analytical formulas was carried out on the basis of numerical mathematical models. The resulting graphical illustration of the result of such a model for heating sources, which inside and outside of the work roll, is shown in Fig. 3.

The figures show the temperature distribution of the surface layer (1) along the length of the deformation zone for different schemes. It can be seen that the temperature is more unstable with an outside source and stable with an inside one.

Consider how temperature affects the printability coefficient. The formation of the micro-relief of the strip occurs in three stages: at the previous stages of processing the strip, which form its initial roughness (zones 1-2); in the zone of contact with the work rolls (zone 3), where the formation of the roughness of the strip occurs under the influence of the indentation of the micro-relief of the rolls; in the zone of free exit from the rolls (zones 4-5), there is a slight change in roughness due to contact with the guide rolls and the coiler (Fig. 4).



a) inside b) outside

Fig. 3. Calculated temperature distributions for different flow levels during warm rolling: (*1*- ——— -$y/h_{xi} = 1{,}0$; *2*- — — -$y/h_{xi} = 0{,}75$; *3*- - - - - -$y/h_{xi} = 0{,}5$; *4* - —o— -$y/h_{xi} = 0{,}25$; *5*- — - — -$y/h_{xi} = 0{,}0$)

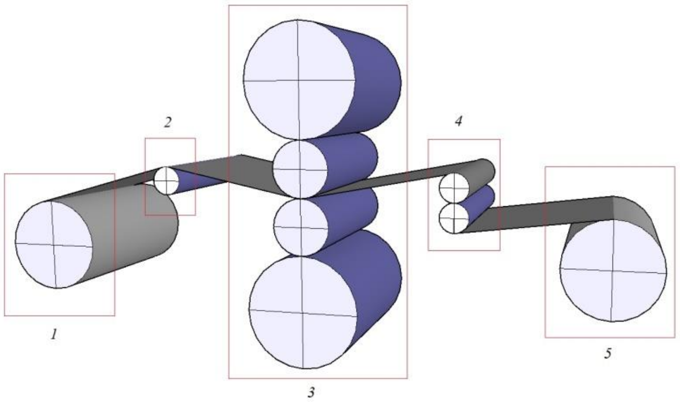


Fig. 4. Zones of surface microrelief formation (1 - decoiler; 2, 4 – zones of free surface micro-relief formation; 3 – zone of micro-relief formation in the deformation zone; 5 – coiler)

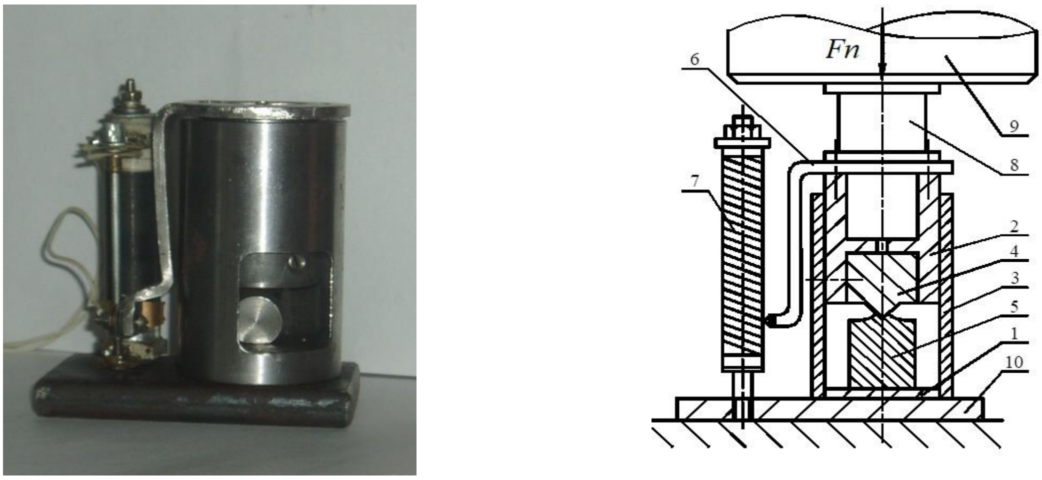
How intensively the roughness is printed from the work rolls to the strip is characterized by the printability coefficient, which is defined as:

$$K_i = \frac{Ra_s}{Ra_r}, \tag{4}$$

where Ra_s - is the strip roughness index Ra, μm; Ra_r - is the roll roughness index Ra, μm.

The value of this coefficient is affected by the following factors: initial strip roughness, roll roughness, compression intensity, strip material and process temperature.

Experimental studies of the mechanism of formation of surface roughness and the factors that affect it were carried out using a special device (Fig. 5), which provides physical modeling of the process of indentation of a complex-profile indenter into a workpiece under warm rolling temperature [8].



a) b)

Fig. 5. External view (a) and principle scheme (b) of the device for experimental study of the process of warm indentation of a complex-profile indenter into a workpiece

Structurally, this installation included a lower fixed 1 and an upper movable 2 punches, interconnected by a guide bush 3. In the upper movable punch 2, a complex-profile indenter 4 was placed, which was indentation into the workpiece 5. While a total of 12 indenters of different sizes and shapes were making (Fig. 6) with different configurations of the deforming surface. Using lever 6, the upper movable punch 2 was connected to a linear displacement sensor 7 of a rheostat type.

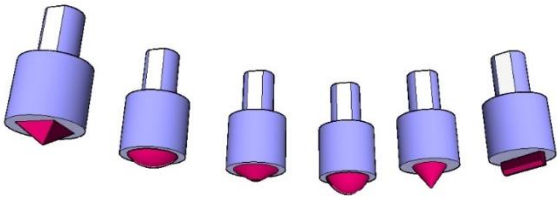


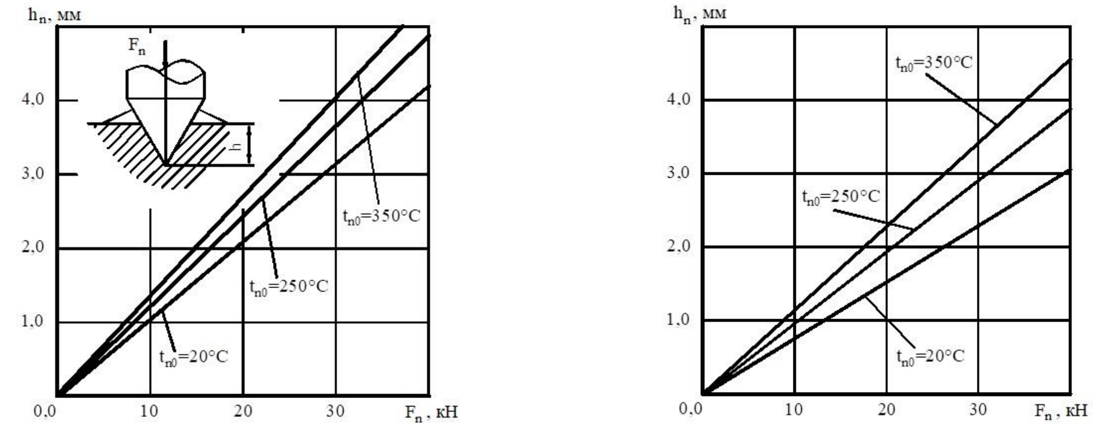
Fig. 6. Appearance and model of indenters of various types

The indentation force F_n was fixed with the help of a pressure capsule 8, connected by the end surfaces of its annular element with the upper movable punch 2 of the considered device and the power punch 9 of the hydraulic press GP 70-5278, which ensured the movement of the upper punch 2 and the creation of this force.

The entire equipment was placed on a single stand 10, which during the experiment was installed in the working space of the aforementioned hydraulic press. The sample 5 were heated to the required temperatures in a drying box immediately before their warm plastic deformation. The results obtained for sample made of steel 20 and steel 45 are shown in fig. 7.

In this case, the force of the indentation process $\boldsymbol{F_n}$, which hydraulic press was created a through a power punch 9, is considered as an argument, and the indentation depth $\boldsymbol{h_n}$, which was measured by a linear displacement sensor 7 of a rheostatic type, was taken as a function.

The results showed that with increasing force, the indentation depth of the indenter increases almost linearly. An increase, ceteris paribus, takes place in the case of an increase in the heating temperatures of the initial sample. In particular, with a force of $\boldsymbol{F_n}$ = 30 kN and an increase in temperatures from 20°C to 350°C, the indentation depth of the conical indenter increases from 3.13 mm to 4.05 mm, that is, by 29% for samples made of steel 20 and from 2.26 mm to 3.48 mm, i.e. by 54%, for steel 45.



a) steel 20 b) steel 45

Fig. 7. Empirical depth distributions $\boldsymbol{h_n}$ depending on the indentation force $\boldsymbol{F_n}$ of a pyramidal indenter into a flat sample made of steel 20 (a) and steel 45 (b), preheated to a temperature $\boldsymbol{t_{n0}}$

CONCLUSION

When using the inside heating of the work rolls, the surface of the strip is evenly heated, this shows the presented mathematical model. Several factors influence the formation of the strip micro-relief at the final stage of the technological rolling line, the main ones being temperature. An installation for investigating the effect of temperature on the printability coefficient is presented. The indentation of a single micro-roughness of the work roll into the strip was physically simulated. In the course of the experiment, the samples were heated in a drying box and indenters of various shapes were dented into them. The results showed that with increasing temperature, the indentation depth of the indenter increases almost linearly. This confirms the possibility of using temperature as a factor influencing the printability coefficient of the roughness of the work rolls. That is, the temperature makes it possible to control the surface micro-geometry parameters during warm rolling.

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Кулик Т. А. Исследование температурного фактора формирования микро-рельефа поверхности полосы при теплой прокатке

Исследован температурный фактор формирования микрорельефа полосы, полученной в результате реализации процесса теплой прокатки. Проанализированы разные схемы нагрева полосы до нужной температуры на основе полученной математической модели распределения температуры как по толщине полосы, так и по длине очага деформации. Показано, что распределение температуры по высоте и длине очага деформации неоднородно. Причем, исследования показали, что предпочтительней схема нагрева с внутренним нагревом рабочего валка, поскольку в таком случае имеет место меньший разброс температуры по длине очага деформации, что, в свою очередь, позволяет использовать температуру как элемент влияния. Рассмотрены факторы, которые влияют на шероховатость полосы при теплой прокатке. Если рассматривать процесс с дрессировкой на финальной стадии, то одним из главных факторов является температура. Исследовано влияние температуры на коэффициент отпечатываемости микрорельефа валков на металле. Для подтверждения результатов были проведены эксперимент, который заключался в внедрении единичного индентора в образец металла. При этом использовали инденторы разной формы, имитирующие типичные формы одиночных микровыступов реального рельефа рабочих валков. В ходе эксперимента образец нагревали до различных температур в сушильном шкафу, затем измеряли глубину его внедрения. Экспериментальные исследования показали почти линейную зависимость глубины внедрения от температуры, то есть линейную зависимость коэффициента отпечатываемости от температуры. Такая зависимость наблюдалась при всех формах индентора, хотя и показана различная её интенсивность. Результаты исследований показывают возможность использования температурного фактора для получения требуемых параметров шероховатости полосы. Для этих целей финальном этапе технологической цепочки процесса прокатки, которым является дрессировка, необходимо использовать валки нужного микро-рельефа, а полосу нужной температуры.

Ключевые слова: прокатка, дрессировка, температура, микрорельеф, коэффициент отпечатываемости, эксперимент, индентор.

Кулік Т. О. Дослідження температурного фактора формування мікро-рельєфу поверхні смуги при теплій прокатці

Досліджено температурний фактор формування мікро-рельєфу смуги, отриману в результаті реалізації процеса теплої прокатки. Проаналізовано різні схеми нагрівання смуги до потрібної температури на основі отриманої математичної моделі розподілу температури як за товщиною смуги, так і за довжиною осередку деформації. Показано, що розподіл температури за висотою та довжиною осередку деформації неоднорідний. Причому дослідження показали, що краще схема нагріву з внутрішнім нагріванням робочого валка, оскільки в такому випадку має місце менший розбіг температури по довжині осередку деформації, що, у свою чергу, дозволяє використовувати температуру як фактор впливу. Розглянуто фактори, що впливають на шорсткість смуги при теплій прокатці. Якщо розглядати процес із дресируванням на фінальній стадії, то одним із головних факторів є температура. Досліджено вплив температури на коефіцієнт віддруковуваності мікрорельєфу валків на металі. Для підтвердження результатів було проведено експеримент, який полягав у впровадженні одиничного індентора у зразок металу. При цьому використовували індентори різної форми, що імітують типові форми одиночних мікровиступів реального рельєфу робочих валків. В ході експерименту зразок нагрівали до різних температур у сушильній шафі, потім вимірювали глибину його впровадження. Експериментальні дослідження показали майже лінійну залежність глибини впровадження від температури, тобто лінійну залежність коефіцієнта віддруковуваності від температури. Така залежність спостерігалася при всіх формах індентора, хоча й показана різна її інтенсивність. Результати досліджень показують можливість використання температурного фактору для отримання необхідних параметрів шорсткості смуги. Для цього на фінальному етапі технологічного ланцюга процесу прокатки, яким є дресирування, необхідно використовувати валки потрібного мікро-рельєфу, а смугу потрібної температури.

Ключові слова: *прокатка, дресирування, температура, мікрорельєф, коефіцієнт друку, експеримент, індентор.*

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