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Determination of the Interrelation of Technological and Construction Characteristics of Direct Rolling Process

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ABSTRACT. Traditional technology of rolling includes casting of primary billet of large cross-section and then producing thin sheets by hot rolling. Method of direct rolling, in contrast with the traditional technology, allows to obtain thin sheets (0.6-6 mm) by combining processes of continuous casting of liquid metal and rolling.

The method of direct rolling is fairly simple. Liquid metal is passed through a pair of rotating rolls, which are located in horizontal plane at a certain distance from each other equipped with cooling system. By varying rotation velocity of rolls it is possible to regulate metal solidification front which is necessary to establish required conditions for hot rolling process.

In the present paper mechanism of billet formation in the combined crystallizer is considered in detail. Method of theoretical determination of the main technological characteristics of direct rolling for both ferrous and nonferrous metals is conducted. Interrelation of these parameters with construction and energy-power characteristics of the casting-rolling mill is defined.

On the basis of the investigation results a pilot casting-rolling mill was designed and fabricated in metal. *© 2012 Bull. Georg. Natl. Acad. Sci.*

Key words: *crystallizer, billet, front of crystallization, meniscus of liquid metal, arc of deformation zone.*

The challenge of elaboration of new technologies and high effective modular plants for enterprises of low-productivity became topical for steel manufacturing companies of the world. This is partially caused by a sharp decrease of investment due to world economic crisis. To this point of view we developed a method of direct rolling, which means production of thin sheets by means of compact casting-rolling mills.The mentioned method allows to reduce costs of energy resources by 6-7 times and loss of metal by 5-7%; excludes 60-70% of expensive devices (rolling mills) out of technological cycle, which itself stimulates reducing of industrial areas and investment. If one takes into consideration high ecological indices, the actuality and availability of this direction becomes clear.

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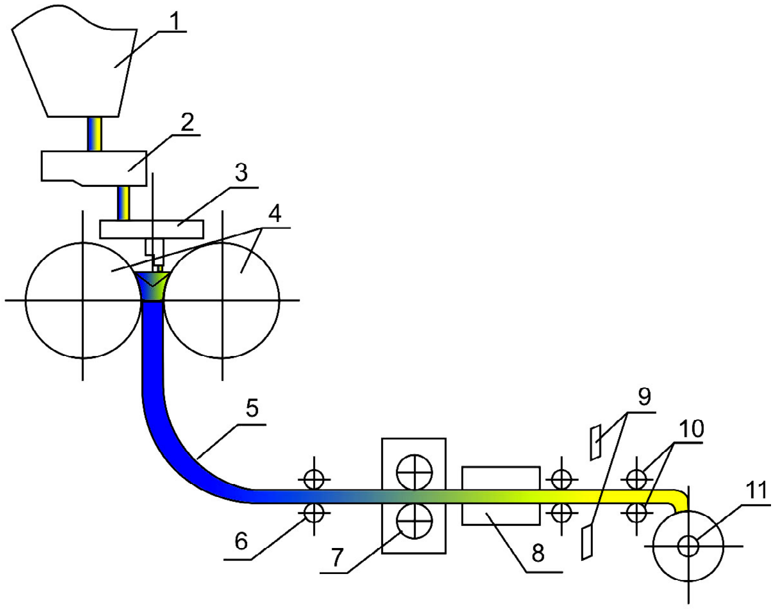

Fig. 1. General technological scheme of direct rolling process.

system. Rotation velocity is chosen in such a way that a billet solidifies after it leaves the rolls. At the same time, it is possible to move a metal solidification front above the interconnecting line of the rolls' centres and in this way regulate the process of hot rolling, which is necessary to produce a dense fine structure. The technological scheme of direct rolling additionally includes standard rolling mills, by means of which the obtained billet is reduced to sheets of needed thickness.

In Fig.1 a general technological scheme of direct rolling process is shown. Liquid metal from the casting ladle 1 goes to the intermediate ladle 2, from where through ladle nozzle 3 it gets to the crystallizer 4 (rotating rolls). After solidification partially rolled billet 5 with the help of guide sheaves 6 gets to the rolling mill 7, where it is rolled to needed thickness. Then, after thermal treatment in special chamber 8 with knives 9 it is cut into sheets of required length.

The method of "rolling without casting", i.e. direct rolling, combines continuous casting and rolling processes, but continuous casting in the classical sense is not carried out in this case, because we have a combined crystallizer (the space of the crystallizer is closed with rotating rolls and side closing plates). In terms of rolls it is the so-called crystallizer with moving walls, in which the billet and walls move synchronously. On the side closing plates it is slip crystallizer.

Let us consider the process of cast forming in the crystallizer (Fig.2).

By varying the rotating velocity (casting speed) it is possible to move the crystallization front (point C of billet complete solidification) towards the horizontal interconnecting line OO′ of the rolls' centres. It is clear from the scheme of rolling in the Fig. that the rolling process runs when the C point is placed above the line OO′, and the more γ-angle, the more relative stretching.

Intensive work has begun since 2009 at the Institute of Metallurgy and Materials Science on the technology of direct rolling. Following elaboration of detailed analysis of the available literature it was decided to design and construct a pilot casting-rolling mill.

When designing the device special attention is given to the correct determination of energy-power characteristics and interrelation between all main technological and construction characteristics of the process.

As the direct rolling process is a combination of two independent processes (continuous casting and

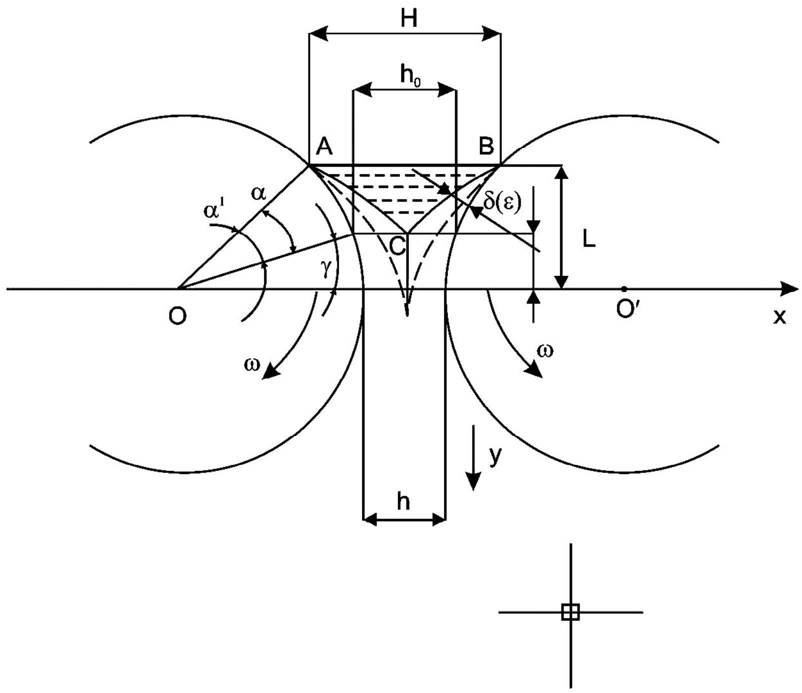

Fig. 2. Schematic view of billet forming in direct rolling process.

rolling), at calculating the driving actuator of an aggregate it is necessary to take into consideration forces taking a billet out of crystallizer and those occurring while rolling.

In the direct rolling process a combined crystallizer with two moving (rolls) and two static walls (side closing plates) are used. So, output of a cast out of crystallizer is impeded by sliding friction only, which occurs due to transverse deformation at casting tension and ferrostatic pressure at the side closing plates.

The ferrostatic pressure $F_f = 0.5\mu\gamma HS_f$ [1-3], where μ is friction coefficient; γ is specific weight of casting metal, kg/mm^3; H – height of liquid metal column, m (from the point C to AB line); S_f – a contact area of both side plates with liquid metal. The value of transversal deformation is calculated with Bakhtinov's formula [4]:

$$\Delta b = 1.15\frac{\Delta h}{2h_o}\left(r\Delta h - \frac{\Delta h}{2\mu}\right),$$

Δb is a linear extension, m; Δh – linear tension, m; h_0 – thickness of the billet at starting deformation, mm (at the point C); μ is friction coefficient; r – radius of rolls, mm. Both values are so small that they can be ignored in calculation of energy-power parameters.

The values of the forces occurring at billet tension depend on different technological and construction characteristics (tensile strain, cast's geometric dimensions, cross-section, temperature, chemical content, speed of drawing, roll's diameter, etc.).

As seen in the scheme of cast formation, the position of meniscus AB of liquid metal relative to OO′ line defines the angle α. From points A and B on the roll's surface casting process starts with a thickness $\delta(\tau)$, where t is crystallization time. At $\tau = \tau_0$ moment two solid phases will meet at the point C ($y = y_0$). The angle γ concerns complete solidification of the cast section and is defined as follows:

$$[R + \delta(\tau_0)]\cos\gamma = R + 0.5h, \qquad (1)$$

where h is the final thickness of the cast (y=0).

The corresponding crystallization time is

$$\tau_0 = \frac{\alpha - \gamma}{\omega}, \qquad (2)$$

where ω is angular velocity, rad/sec.

From point C the plastic deformation begins. Full length L of contact arc with metal rolls is

$$L = \sqrt{R(H-h)} = R\sqrt{2(1-\cos\alpha)} = 2R\sin\alpha/2, \quad (3)$$

and length of arc of deformation zone $l = \sqrt{R(h_o - h)}$, where $h_0 = 2\delta(\tau_0)$ and is defined from the equation (1), h_0 is billet thickness at point C when $y=y_0$.

Analysis of the literature data showed that the optimal values of α and γ angles are 20-30^0 and 2-5^0, respectively. At that time the value of relative deformation varies within the range 10-30%, which is sufficient enough to get a high grade fine billet. At the same time costs for device exploitation are reduced on account of wear decrease of side closing plates of crystallizer.

As a rule, thickness of the crust formed at continuous casting is defined by the Stephany formula [1-3]:

$$\delta = K\sqrt{\tau}, \quad (4)$$

where K is a crystallization coefficient, mm^2/sec, τ– time of crystallization, sec.

Using this formula at the initial phase of crystallization, especially at casting thin sheets, when duration of the process is a mere 0.5-1 sec, does not give a real picture. In this case using the formula of Brovman and Tsariov is more reasonable [4]:

$$\delta(\tau) = \sqrt{x_0^2 + 2k\tau} - x_0, \quad (5)$$

where k and x_0 are constants for a given metal; k is quantity analogous to the crystallization coefficient, m^2/sec; x_0 denotes the speed of crust thickness growth, m.

Substituting $\delta(\tau)$ in (1) and taking into account expression (2) we obtain

$$\alpha - \gamma = \frac{\omega R^2}{2K\cos^2\gamma}\left[\left(1+\frac{h}{2R}\right)^2 - \right.$$

$$\left. -\cos\gamma\left(2+\frac{h}{R}-\frac{x_o}{R}-\frac{hx_o}{R^2}\right)+\cos^2\gamma\left(1-\frac{x_o}{R}\right)\right], \quad (6)$$

from (6) the angular velocity of rolls' rotation is

$$\omega = \frac{(\alpha-\gamma)2K\cos^2\gamma}{R^2}\left[\left(1+\frac{h}{2R}\right)- \right.$$

$$\left. -\cos\gamma\left(2+\frac{h}{R}-\frac{x_o}{R}-\frac{hx_o}{R^2}\right)+\cos^2\gamma\left(1-\frac{x_o}{R}\right)\right]. \quad (7)$$

Knowing a optimal value of relative stretch allows to define the γ-angle for billets of different thickness. It is known that relative stretch for steels and nonferrous metals is

$$\varepsilon = \ln\frac{n_o}{n} = \ln\left[1+\frac{2R(1-\cos\gamma)}{h}\right]. \quad (8)$$

Theoretical calculation of casting speed was carried out for the values α=20-30°, γ=2-5°, ε=6-33%, $h = 2\div4\cdot10^{-3}$ m using expressions (7),(8) and taking into consideration the diameter of rolls (D=0.42 m) (Figs.3-5).

On the basis of the data obtained power energy parameters of the device were determined.

As is known, in the rolling process the value of full load force is $P=pF$, where p is specific pressure on the roll's surface, kg/cm^2; F – contact area of the deformation site. In its turn $p = \gamma n'n''n''' n_c\,\sigma$, where in our case, which presents a plate problem, $n''' = 1$; $n_c = 1$;

$$n'' = 1;\ \gamma = 1.15;\ n' = 2, 3.$$

In its turn $\sigma = \sigma_0 K_1 K_n K_\varepsilon$, where for hot metal basis σ_0=30 mPa; values of other coefficients depend on technological characteristics of the process and are defined with consideration of certain conditions [5, 6].

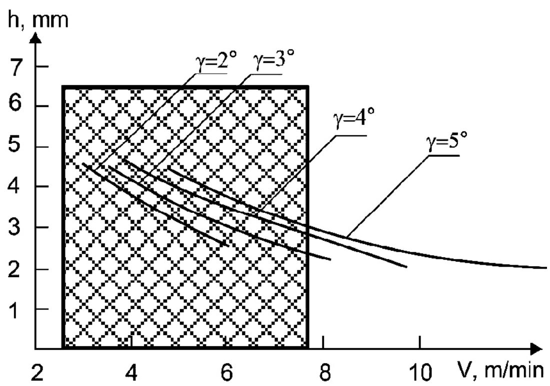

Fig. 3. Dependence of drawing velocity of a steel billet on its cross-section and γ-angle (for steel 45 α=30°, K = $0.8\cdot10^{-5}$; $x_o = 3\cdot10^{3}$; R = 0.21 m)

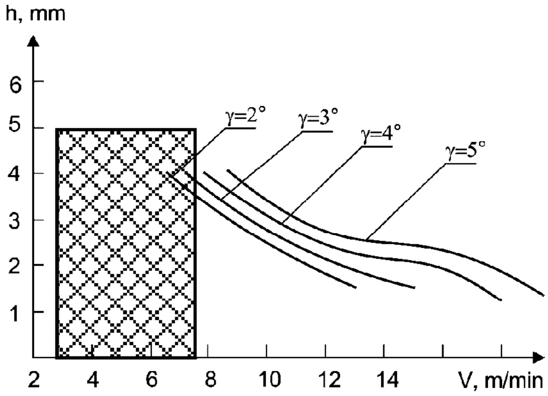

Fig. 4. Dependence of drawing velocity of a copper billet on its cross-section and γ-angle (α = 30°, K = 2.6·10^{-5}; x_o = 7·10^3; R = 0.21 m)

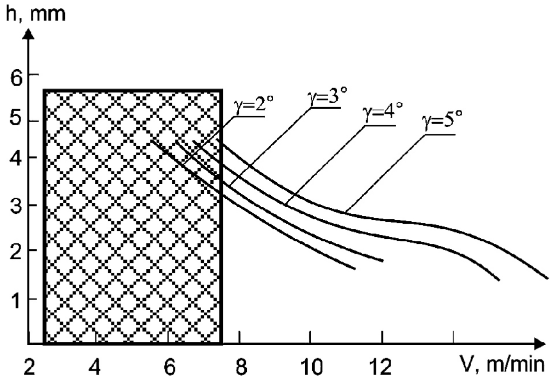

Fig. 5. Dependence of drawing velocity of an aluminium billet on its cross-section and γ-angle (α=30°, K = 2.8·10^{-5}; x_o = 9·10^3; R = 0.21 m)

In our case K_1=const=0.5, values of K_n and K_a are given in Table 1. A contact area $F=Bl$, where B is roll's length (250 mm), l –length of deformation zone $(l=\sqrt{R(h_o-h)})$.

The calculated magnitudes of F are shown in Table. On their basis diagrams are constructed (Figs.3-5), where the shaded areas correspond to the optimum regime of the process.

The torsion moment on the motor shaft

$$M_{\text{mid}}=2P\Psi l.$$

In our case the coefficient of rolling moment arm Ψ=0.5, l is the length of deformation zone, mm.

A moment occurring due to torsion in roll neck and sliding bearing $M_{\text{tor.1}}=pd\mu$, where d is the diameter of the roll neck and equals 0.1 mm; torsion moment in the gear system driver-rolls (reduction gear, gear box) is equal to $M_{\text{tor.2}}=0.01$ tm $=10$ kgm.

$$M_{\text{dr}}=M_{\text{midl}}+M_{\text{tor.1}}+M_{\text{tor.2}}.$$

Finally, power of the engine

$$N_{\text{dr}}=M_{\text{dr}}\omega kW.$$

The angular velocity of the rolls' rotation $\omega=\frac{2v}{D}$, where v is linear velocity of billet drawing, m/sec., D – diameter of rolls.

The required power of the engine is chosen for maximum values of pressures on the rolls at γ= 5° and α=30° (Table).

Table. Interrelation of energy-power parameters of the casting-rolling mill and technological characteristics of the billet (steel 45).

NN	Thickness of the billet before rolling, h_o, mm	Deformation value, Δh, mm	Thickness of the billet after rolling, h, mm	Relative stretch, ε, %	Specific pressure on the rolls' surface, p, kg/mm^2	Force of full load, P, t.f.	Length of the deformation arc, l, mm	Power necessary to motor, N, kW	Angular velocity of rolls' rotation, ω, rad/min	Angle corresponding to the metal solidification, γ^o	Linear velocity of the billet drawing, V, m/hr
1	2.26	0.26	2	11.5	12.4	22.543	7.27	1.9	0.97	2	12.280
2	3.26	0.26	3	8.0	9.68	17.634	7.27	0.96	0.62	2	7.812
3	4.26	0.26	4	6.1	8.8	15.998	7.27	0.6	0.49	2	6.159
4	2.58	0.58	2	22.5	15.07	41.670	11.11	4.3	0.84	3	10.628
5	3.58	0.58	3	16.2	12.43	34.447	11.11	2.3	0.55	3	6.935
6	4.58	0.58	4	12.7	10.84	30.002	11.11	1.5	0.4	3	5.004
7	3.02	1.02	2	33.8	15.6	56.737	14.54	6.2	0.7	4	8.870
8	4.02	1.02	3	25.4	13.2	48.008	14.54	3.5	0.473	4	5.973
9	5.02	1.02	4	20.3	11.9	43.280	14.54	2.4	0.347	4	4.388
10	3.60	1.60	2	44.4	15.6	71.385	18.3	7.9	0.57	5	7.185
11	4.60	1.60	3	34.8	13.7	62.691	18.3	3.9	0.4	5	5.009
12	5.60	1.60	4	28.6	12.4	56.742	18.3	3.1	0.35	5	3.758

მეტალურგია

უსხმულო გლინვის პროცესის ტექნოლოგიური და კონსტრუქციული პარამეტრების ურთიერთკავშირის განსაზღვრა

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უსხმულო გლინვის მეთოდი განსხვავებით ტრადიციული ტექნოლოგიისა, რაც ითვალისწინებს დიდი კვეთის პირველადი ნამზადის ჩამოსხმას და შემდგომში მისი ეტაპობრივი ცხლად გლინვის ტექნოლოგიის ხარჯზე თხელი ფურცლების წარმოებას, საშუალებას იძლევა თხიერი ლითონიდან უწყვეტი ჩამოსხმისა და გლინვის პროცესის შერწყმის გზით თხელი ფურცლების (0,6-6) მმ-ის მიღებას.

მეთოდის არსი საკმაოდ მარტივია. ჰორიზონტალურ სიბრტყეში განლაგებულ, გარკვეული მანძილით დაცილებულ ორ მბრუნავ გლინს შორის მიეწოდება თხიერი ლითონი. გლინების ბრუნვის სიჩქარის ვარირებით შესაძლებელია თხევადი ლითონის გამყარების ფრონტის რეგულირება, რაც აუცილებელი პირობაა ცხლად გლინვის პროცესის სასურველი რეჟიმის დასამყარებლად.

ნაშრომში დეტალურად არის განხილული კომბინირებულ კრისტალიზატორში ნამზადის ფორმირების მექანიზმი. შემუშავებულია მეთოდიკა ჩამოსხმის ძირითადი ტექნოლოგიური პარამეტრების თეორიულად განსაზღვრისათვის და ამ პარამეტრების დამოკიდებულება როგორც ფერადი ასევე შავი ლითონებისათვის საჩამოსხმო საგლინავი დანადგარის კონსტრუქციულ და ენერგოძალოვან პარამეტრებთან.

კვლევების შედეგად მიღებული მონაცემები საფუძვლად დაედო საცდელი ტიპის საჩამოსხმო-საგლინავი დანადგარის დაპროექტებასა და ლითონში დამზადებას.

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