Metallurgy

Technological Characteristics of Metal Sheet Production in Direct Rolling

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ABSTRACT. For several years Georgian Institute of Metallurgy and Materials Science has been actively working now to develop the technology of direct rolling, where casting and rolling plant was designed and pilot version constructed. The method is a combination of two independent processes (continuous casting, hot rolling). First of all, we assessed the minimum strains providing properties of the rolled metal for the billet produced by the method. Examination of metallographic and mechanic properties of the samples produced with different strains show that the strain of 35-40% is quite sufficient for the billet to gain the properties of rolled metal. Under such strain proper time and velocity necessary for production of the metal sheet of h/2 thickness were theoretically calculated. The values of all parameters and their interdependence are provided in the paper as nomograms. The experiments show that the difference between theoretical computations and experimental data is no more than 5-7%. The mentioned method, i.e., the so-called direct method was used to develop the technology for production of aluminium sheets of 8, 9 and 10mm thickness. *© 2015 Bull. Georg. Natl. Acad. Sci.*

Key words: *crystallizer, roll, billet, crystallization front, meniscus of the liquid metal, deformation.*

Today, the world leading steel manufacturers pay great attention to development of the highly efficient modular equipment and plants for low-productive companies. Against the background of the world energy crisis, great emphasis is placed on significant reduction of energy carriers and capital investments per ton metal production. In that direction the priority is given to metal sheets production using compact casting and rolling plants (so-called direct method). The mentioned method permits 6-7-fold reduction of energy resources, reduction of steel loss by 5-7%, and moreover, it allows to cut out 60-70% of expensive equipment and plants from the technological processes (casting and rolling plants), which, in its part, leads to significant reduction of production space and capital investments. All of these together with the highly ecological factors show clearly why the mentioned method is considered to be the most actual and prospective today.

The method of direct rolling is quite simple. Liquid metal is poured between a pair of rotating rolls equipped with cooling system and placed in a hori-

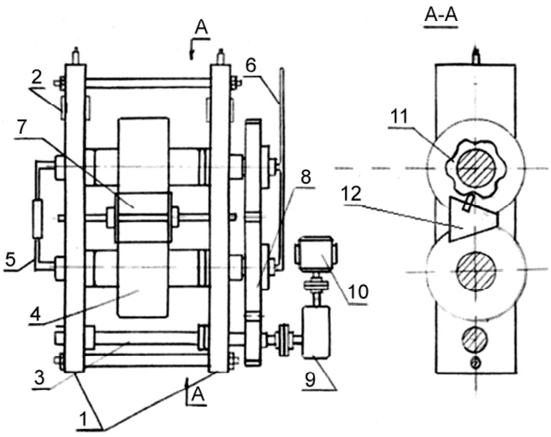

Fig. 1. Schematic representation of the casting and rolling plant construction
1. Lateral supporting plate; 2. Cassette for regulation of the billet thickness; 3. Roll of the driving gear; 4. Pair of roll-crystallizers; 5-6. Water pipes; 7. Groove for pouring the metal; 8.Cylindrical gear rotating the roll; 9. Double-step cylindrical reducer; 10. Direct current generator; 11. Sprocket providing vibration of the closing plate; 12. Lateral closing plate.

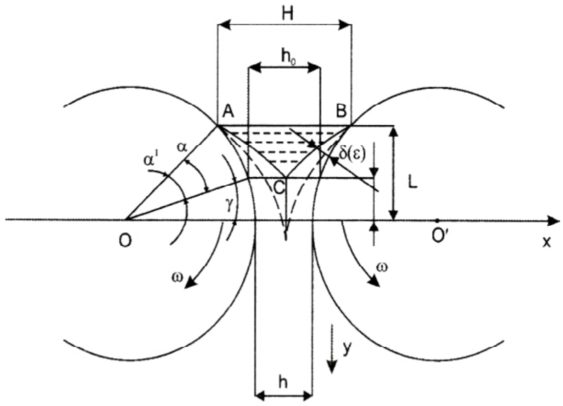

Fig. 2. Scheme of the billet shaping process in direct rolling

zontal plane at a certain distance from each other. Rotation velocity is such that the billet coming out of the rolls has enough time for crystallization. By means of the rolls rotation velocity variation the metal crystallization front can be shifted to the line joining the centers of the rolls to regulate the hot rolling process necessary for producing a strong fine-grained structure.

Georgian Institute of Metallurgy and Materials has been actively working for several years now to develop the technology of “direct rolling” process. According to the detailed analysis of the available sources a pilot casting and rolling plant construction was developed and fabricated in metal. During the experimental researches the construction was permanently refined. Fig. 1 shows the scheme of the final version of a pilot casting and rolling plant.Since the process is so complex and there is not much experience in that direction we decided to study and develop the technology for production of thin sheets of non ferrous metals at the first stage.

As it was mentioned above, by means of the rolls rotation velocity variation the liquid metal crystallization front (point C, Fig. 2) can be shifted to the line OO' joining the centers of the rolls. The higher the point the more is the billet strain in hot rolling, and consequently, the greater are the forces generated on the rolls. These are the forces regulating the process of casting. Theoretical calculation estimates the force to be maintained throughout the process of casting in order to avoid the metal crack (due to insufficient cooling) and the billet jam between the rolls due to the greater strain than admissible. At the first stage it was necessary to estimate the minimum strain providing the billet with the mechanic and structural properties peculiar to the rolled metal. To this end some aluminium billets of ∅ 16mm (chemical composition of the metal is given in Table 1) were casted.

They were processed in hot rolling (500-550^{0}C) at different strains ε 20-60%. It was estimated that at 35-40% strain the samples completely satisfy mechanical properties of the rolled metal. The results of the

Table 1. Chemical composition %

Si-%	MMg-%	Ca-%	Fe-%	Mn-%	Ni-%	Ti-%	Cu-%	Pb-%	Al-%
0.1	0.08	0.2	0.8	0.02	0.02	-	0.005	0.1	98

Table 2. Mechanical properties (on strain)

	rolled		before rolling ε 35%	
#	δ%	$\sigma б_{n/mm^2}$	δ%	$\sigma б_{n/mm^2}$
1	33	73	26.6	107.5
2	17	69	30.0	107.8
3	23	73	30.0	107.4
4	13	68	30.0	110.0
5	33	75	28.7	127.5

mechanical properties tests (on strain) of the samples before and after rolling are given in Table 2.

The forces generated on the rolls at 15-50% strain were theoretically calculated (with account of the billet size, the temperature and chemical composition of the metal, the diameter and rotation velocity of the rolls). Relation between the forces generated on the rolls for producing the aluminium sheets of $8 \div 10$mm thickness and 240 mm width with respect to the position of point C and the strain percentage in the process of rolling are given in Tables 3, 4 and 5.

The direct rolling process of billet shaping in the crystallizer is given by a diagram in Fig. 3 (A, B, C) illustrating the relation between the forces generated on the rolls at different strains (0-50%) and position of C to the axial line OO', time of complete crystallization and the casting velocities necessary for such a mode.

Since the process of direct rolling involves a com-

Table 3. Theoretically calculated energy-power parameters in casting process h - 10 mm

	h, mm	h_0, mm	ℓ, mm	ε, %	P, kn	τwm	Vm/wT
C_0	10	10	0	0	0	2.0	2,5
C	10	12	20.6	16.6	166	2.9	1.7
C_1	10	14	29.0	28.0	280	4.1	1.12
C_2	10	16	35.4	37.0	390	5.4	0.80
C_3	10	18	40.8	44.0	500	6.2	0.60
C_4	10	20	45.4	50.0	620	8.2	0.44

bined crystallizer, a pair of rotating (rolls) and a pair of stationary (lateral plates) walls, in hot rolling the billets coming out of the crystallizer meet some resistance from the forces generated on the rolls as well as from the forces acting on the lateral plates. On the lateral plates the forces are generated due to the ferrostatic strain of the liquid metal, on the one hand, and on the other hand, due to the sliding friction caused by lateral deformation derived in the process of hot rolling of the billet.

In the first case:

$$Fpl = 0.5\, \mu\gamma\ HS\ [1.2.3.],$$

where μ is the friction coefficient; γ – specific weight of the casting metal, kg/m^3; H – height of the liquid pole (up to point C), m; S – contact area for both lateral plates and the liquid metal, m^2;

The value of lateral deformation can be calculated according to Bakhtinov's formula [4]

$$\Delta b = 1.15\frac{\Delta h}{2h_0}\left(r\Delta h - \frac{\Delta h}{2\mu}\right),$$

where Δb is a linear expansion, m; Δh – linear strain, m; h_0 – the billet thickness at the beginning of deformation, m (at point C); μ – friction coefficient; r – radius of the rolls, m.

However, both values are so small that in calculations of the parameters of energy and power, they can be neglected.

Thus, knowing the position of the liquid metal meniscus aganst the axial line OO' (angle α is taken according to the recommendation given in [4]) and position C at $35 \div 40$% we can use formula of Brovman and Tselikov [5] to compute the time necessary for receiving the thickness of 1/2h and the rolls rotation velocity, which is equal to:

$$w = \frac{(\alpha-\gamma)2k\cos^2\gamma}{R^2} \times$$
$$\times\left[(1+\frac{h}{2R}) - \cos\gamma\left(2+\frac{h}{R}-\frac{x_0}{R}-\frac{bx_0}{R^2}\right)+\cos^2\gamma(1-\frac{x_0}{R})\right]$$

where w – is the rolls rotation velocity; α – value of the angle at point A; γ – value of the angle at point C; R – radius, m; h – billet thickness, m; k – value analo-

Table 4. Theoretically calculated energy-power parameters in casting process h - 10 mm

	h, mm	h_0, mm	ℓ, mm	ε, %	P, kn	τwm	Vm/wT
C_0	9	9	0	0	0	1.7	2.8
C	9	10	20.5	10	9.6	2.16	2.2
C_1	9	12	25	25	23.2	2.9	1.65
C_2	9	14	29.2	35	35.2	4.1	1.1
C_3	9	16	38.2	43.7	45.7	5.4	0.73
C_4	9	18	43.3	50	60	6.2	0.6

gous to crystallization coefficient in m^2/sec; x_0 – constant (velocity of the skin expansion at the initial stage of crystallization), m.

On the basis of the method described above the optimal velocity for the rolls with 420mm diameter was established to be 0.7rot/min (V=0.92 m/min) for casting an aluminium sheet of 10mm thickness and 240mm width at 35-40% strain. Certainly, in real process of casting the crystallization front is not uniformly distributed throughout the cross section, which is due to the method of liquid metal delivery to the crystallizer. The metal flows derived at that moment break the integrity of the crystallization front. Therefore, in real casting the forces derived on rolls are admissible to be 5-10% more compared to the optimal one, the more so if the forces of friction coefficient on the lateral closing plates are neglected.

As our experiment shows, during casting the forces change to 35-65t in great interval, but it is well regulated by means of the rolls rotation velocity providing a stable process. Such a change of forces is caused by fluctuation of the level of liquid metal in crystalizer because casting from the intermediate ladle is manually done.In conditions of 420 mm diameter crystallizer when $\alpha=30^0$ the height of the metal pole in the crystallizer is just 110 -115mm, while 10-20mm variation of the metal has a great influence on crystallization process. Experimental casting proceeds in quite a short period (3) and since the velocity variation process is easily regulated this is not a great problem. However, in conditions of manufacture the all-around automation of the process will be necessary.

The same method was used for estimating the velocity for aluminium sheets of 8-9 mm thick.

As the experiments showed, technological parameters computed theoretically do not greatly differ from the parameters estimated experimentally.

Table 5. Theoretically calculated energy-power parameters in casting process h - 10 mm

	h, mm	h_0, mm	ℓ, mm	ε, %	P, kn	τwm	Vm/wT
C_0	8	8	0	0	0	3.1	1.7
C	8	19.0	14.6	11	110	2.56	2.1
C_1	8	10	20.5	25	179	2.16	2.3
C_2	8	12	32.7	33	306	2.9	1.5
C_3	8	14	35.4	43	421	4.1	1.02
C_4	8	16	40.8	50	544	5.4	0.66

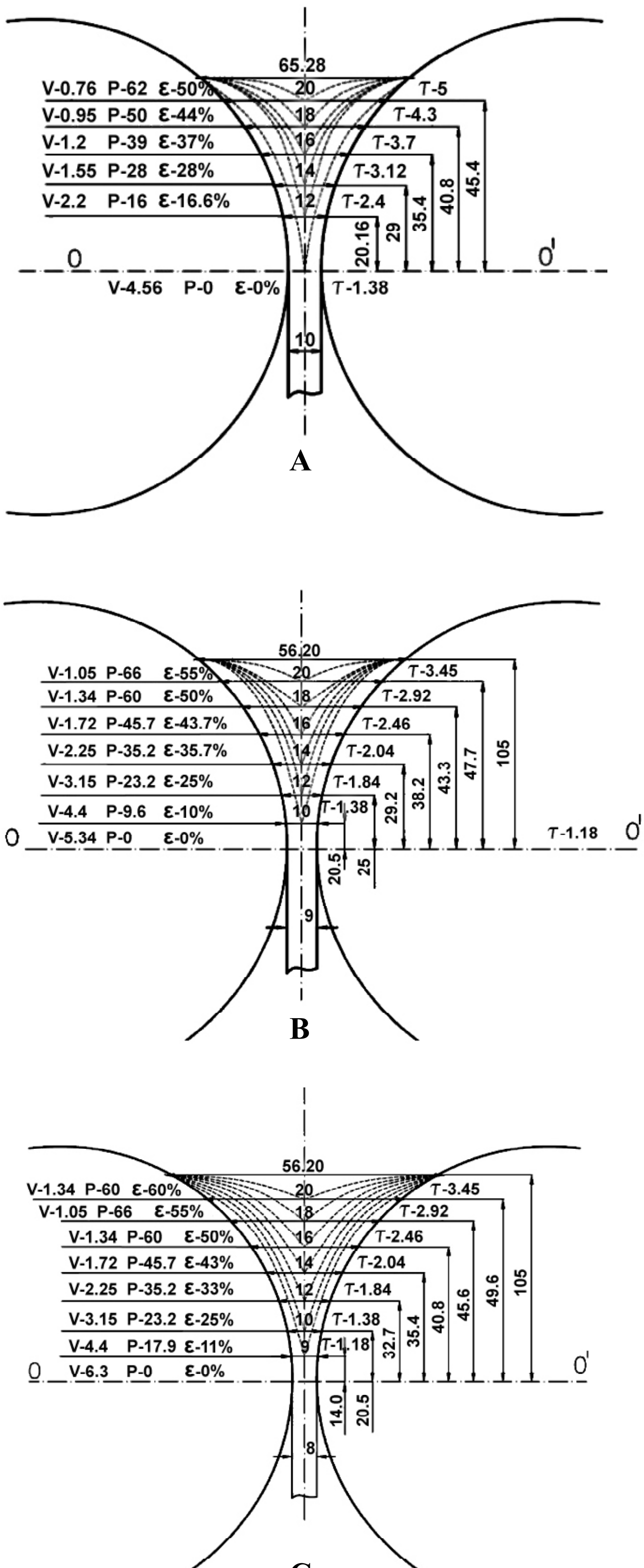

Fig. 3. Nomogram of relation between the billet crystallization velocity and the forces generated on the rolls in the process of direct rolling. A) h=10mm; B) h=9mm; C) h=8mm.

მეტალურგია

უსხმულო გლინვის მეთოდით თხელი ლითონური ფურცლების წარმოების ტექნოლოგიური პარამეტრების განსაზღვრა

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***აკადემიის წევრი, საქართველოს მეცნიერებათა ეროვნული აკადემია, თბილისი*

რამდენიმე წელია საქართველოს მეტალურგიისა და მასალათმცოდნეობის ინსტიტუტში მიმდინარეობს აქტიური მუშაობა "უსხმულო გლინვის" პროცესის ტექნოლოგიის ათვისებასთან დაკავშირებით. დამუშავდა საჩამოსხმო-საგლინავი დანადგარის კონსტრუქცია და დამზადდა ლითონში მისი საცდელი ვარიანტი. წარმოდგენილი მეთოდი ორი, ერთმანეთისაგან დამოუკიდებელი პროცესის (უწყვეტი ჩამოსხმა, ცხლად გლინვა) ერთობლიობას წარმოადგენს. პირველ რიგში დადგინდა ის მინიმალური მოჭიმვები, რაც ამ მეთოდით მიღებულ ნამზადს ნაგლინი ფურცლის დამახასიათებელ თვისებებს შესძენდა. როგორც სხვადასხვა მოჭიმვებით მიღებული ნიმუშების მეტალოგრაფიულმა და მექანიკური თვისებების გამოცდამ გვიჩვენა, 35-40%-იანი მოჭიმვა სავსებით საკმარისია, რომ ნამზადის ლითონმა ნაგლინისათვის დამახასიათებელი თვისებები შეიძინოს. დადგენილი იყო (თეორიული გათვლებით) ამ დონის მოჭიმვებისას გლინებზე წარმოქმნილი ღერძულა ხაზის მიმართ, h/2 სისქის ქერქის ფორმირების დრო და შესაბამისი ჩამოსხმის სიჩქარე. ყველა ამ პარამეტრის მნიშვნელობა და ურთიერთკავშირი მოყვანილია სურ. 3-ზე წარმოდგენილი ნომოგრამების სახით. როგორც ექსპერიმენტული კვლევების შედეგად გამოჩნდა, განსხვავება თეორიულ გათვლებსა და ექსპერიმენტულ მონაცემებს შორის ცდომილებების ფარგლებშია და 5-7% არ აღემატება. აღნიშნული მეთოდიკით არის ათვისებული 8, 9 და 10 მმ სისქის ალუმინის ფურცლების წარმოების ტექნოლოგია ე. წ. "უსხმულო გლინვის" მეთოდით.

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