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DETERMINATION OF TECHNOLOGICAL PARAMETERS FOR CONTINIUOUS CASTING OF A HOLLOW PIPE BILLET

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This article presents a method for calculating the speed of a hollow steel billet continuous casting for the seamless hot-rolled pipes production. As the initial data, used the values of the technological parameters of a round pipe billet production at the Pavlodar branch of LLP "KSP Steel" and physical modeling data of a hollow aluminum billet continuous casting at the laboratory facility of Toraighyrov University. The recalculation of the modeling results into the actual volumes of industrial production was carried out according to the condition of the similarity criterion of Fourier numbers. The casting speed of a steel hollow billet are determined, the increase of which, compared with a solid billet, amounted to 16 %.

Keywords: alloy steel, continuous casting, hollow billet, technological parameters, seamless pipe

INTRODUCTION

Solid cast steel billets with any manufacturing methods are characterized by segregation heterogeneity. The larger the initial cross section of the billet, the greater the degree of chemical heterogeneity over the cross section. The continuous cast billet of large cross section entering the rolling line always has an increased carbon concentration and most impurities in the axial zone. As a result, metal removal of the axial zone of the billet is advisable [1-2].

For the formation of the internal cavity, as a rule, apply the piercing of a solid metal billet. At the same time, on piercing mills, the metal of the axial zone is not removed, but is pushed from the center to the inner surface layer of the sleeve along with defects. In that case, one of the options for improving the technology may be the use of a hollow continuously cast billet as the initial billet. However, there are practically no works on calculating the technological parameters of the hollow steel billets casting process, which is a problem in the design and implementation of proposed production technology developments.As a result, the aim of this work is to develop a methodology for determining the main parameters of casting a hollow pipe billet [3-5].

OBJECT AND RESEARCH METHODS

The object of the research was a billet for the pipe production made of 25CrMnV steel with an outer diameter of 210 mm manufactured by PB LLP "KSP Steel".

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Table 1 **Initialdata**

Parameter	PB LLP "KSP Steel"	Toraighyrov University
Crystallizer diameter/mm	210	50
Crystallizer height/ mm	800	30
Crystallizer material	Copper	Copper
Diameter of crystallizer mandrel/ mm	-	30
Material of billet	25CrMnV (alloy steel)	A5 (primary aluminum)
Thermal diffusivity/ W/m·K	80	230
Density/ t/m³	7,85	2,989
Temperature of material in secondary cooling zone (SCZ)/ °C	950	500
The coefficient of linear expansion/ 1/deg	1,45·10-5	2,22·10-5

For the calculation, used the initial data of the PB LLP "KSP Steel" and Toraighyrov University, according to Table 1.

To determine the optimal parameters of a hollow steel billet casting process was used aluminum casting at the laboratory facility of Toraighyrov University in accordance with the theory of similarity [6].

RESEARCH RESULTS AND DISCUSSION

The casting speed $q_{st.h}$ for a hollow billet with a diameter of 210 mm was determined by the formula [6]:

$$q_{st.h} = \rho_{st} S_{st.h} v_{st.h},$$

where ρ_{st} – hardened steel density/t/m³;
$S_{st.h}$ – cross-sectional area of the hollowbillet/ m²;
$v_{st.h}$ – drawing speed of a steel hollow billet/ m/min.
The density of hardened steel:

$$\rho_{st} = \frac{\rho_{0st}}{1+3\alpha_{st} t_{stSCZ}} = \frac{7,85}{1+3 \cdot 1,45 \cdot 950} = 7,54 \, t/m^3,$$

Table 2 **Experimental data for casting aluminum billets**

Drawing-speed/ m/min	Calculated metal residence time in the crystallizer/ min	Rupture of the metal crust at the exit of the crystallizer		
2,0	125×10^{-4}	no	no	no
2,5	100×10^{-4}	no	no	no
3,0	83×10^{-4}	no	no	no
3,5	71×10^{-4}	no	yes	no
4,0	63×10^{-4}	no	yes	yes
4,5	56×10^{-4}	yes	yes	yes

Table 3 **Technological indicators of the casting process Ø210 mm**

Parameter	Solid billet*	Hollow billet
Drawing speed/ m/min	0,8-0,9	2,01
Casting speed/ t/min	0,235	0,273

*current data of the plant PB LLP "KSP Steel"

where ρ_{0st} – steel density at 0 °C/t/m^3;
α_{st} – linear expansion coefficient of steel/ m^2;
t_{stSCZ} – steel temperature at the end of the SCZ/ °C.

Cross sectional area of a hollow billet:

$$S_{st.h} = \pi(R_{st}^2 - r_{st}^2) = 3,14(0,105^2 – 0,0722) = 183,4 \cdot 10^{-4}\, m^2$$

where R_{st} and r_{st} – external and internal radius of a steel hollow billet/m.

The internal radius of the hollow billet corresponds to the internal radius of the sleeve obtained on the piercing mill.

As a result, the casting speed is:

$$q_{st.h} = 7,54 \cdot 183,4 \cdot 10^{-4} v_{st.h} = 0,136 v_{st.h}.$$

The speed of drawing a hollow billet at a continuous casting machine was determined from the condition of equality of the Fourier numbers [6], based on experiments on casting an aluminum hollow billet.

The optimal drawing speed of an aluminum billet with a diameter of 50 mm depends on the thickness of the crust formed in the crystallizer, which must withstand the static pressure of the metal and friction against the walls of the crystallizer. The growth of the metal crustτ_{Al}, in turn, depends on the residence time of the metal in the crystallizer:

$$\tau_{Al} = \frac{h_{Al}}{v_{Al}}$$

where h_{Al} – working height of the crystallizer equal to the difference between the total height of the crystallizer and underfilling/ m;
v_{Al} – drawing speed of aluminumbillet/ m/min.

The drawing speed of a hollow aluminum billet was determined empirically in a laboratory facility for continuous casting of Toraighyrov University (Figure 1). To do this, increasing the drawing speed at a laboratory facility for billet continuous casting fixed the maximum value of time from the condition of integrity maintaining the metal crust when leaving the crystallizer. The casting of the aluminum billet was carried out three times at each drawing speed. The average results are shown in Table 2.

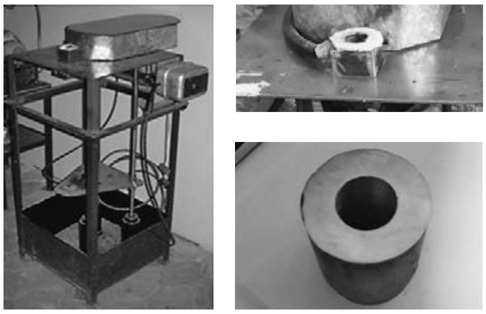

Figure 1 Facility for continuous casting of billets at the laboratory of Toraighyrov University and hollow aluminum billet

Analyzing the results of the experiment, determined that the maximum drawing speed of the aluminum billet, provided the metal crust was not broken, was 3,0 m/min.

From the equality condition of the Fourier numbers, determine the optimal residence time of a steel billet with a diameter of 210 mm in a crystallizer with a working height of h_{st}= 700 mm:

$$\tau_{st.h} = \tau_{Al} \cdot \frac{\beta_{Al} \cdot S_{st.h}}{\beta_{st} \cdot S_{Al}}$$

where τ_{Al} – optimal residence time of aluminum in the crystallizer/ min;
β_{Al}, β_{st} – thermal diffusivity of aluminum and steel, respectively/ W/m·K;
S_{Al} – cross-sectional area of aluminum billet/ m^2;
$S_{st.h}$ – cross-sectional area of steel hollow billet/ m^2.

Sectional area of aluminum billet:

$$S_{Al} = \pi\left(R_{Al}^2 - r_{Al}^2\right) = 3,14(0,025^2 - 0,015^2) = 12,56 \cdot 10^{-4}\ \mathrm{m}^2;$$

where R_{Al} and r_{Al} – external and internal radius of aluminum hollow billet/m.

Then, the optimal residence time of the steel in the crystallizer:

$$\tau_{st.h} = 83 \cdot 10^{-4} \cdot \frac{230 \cdot 183,4 \cdot 10^{-4}}{80 \cdot 12,56 \cdot 10^{-4}} = 0,348\ \text{min}$$

The speed of drawing a steel hollow billet:

$$v_{st.h} = {h_{st}}/{\tau_{st.h}} = {0,7}/{0,348} = 2,01\text{m / min.}$$

As a result, the speed of casting a hollow steel billet:

$$q_{st.h} = 0,136 \cdot 2,01 = 0,273\,\text{t / min},$$

where t – ton.

Comparing the values of the casting parameters of solid billet cast on a PB LLP "KSP Steel" and a hollow steel billet (Table 3), it is seen that the speeds of drawing and casting of the hollow billet ishigher.

The productivity of PB LLP "KSP Steel" today is 350 thousand tons of round solid billets per year. Thus, in the case of a hollow billet use, the excess in tonnage compared to the solid will be at least 16 % or 56 thousand tons.

In addition, from the point of economic feasibility view, the use of a hollow cast billet as the initial one eliminates the need for a piercing process, which in turn eliminates the excessive consumption of expensive tools from piercing mills, such as rolls, mandrels, guiding rulers and auxiliary tools, not counting labor. When casting a hollow billet, the technological parameters of cooling in the secondary cooling zone will differ from the parameters when cooling a solid billet, due to the difference in the geometry of the cross section. Because of this, in order to ensure a homogeneous structure and uniform mechanical properties over the cross section, it is necessary to determine the optimal cooling conditions for the hollow billet.

In [7] proposed the use of an improved device for casting a hollow billet. However, a disadvantage of the device is the lack of cooling of the internal cavity of the hardened billet. In this regard, to ensure uniform cooling of the hollow billet both from the inside and from the outside, it is necessary to determine the optimal ratio of the flow of the air-water mixture inside and outside the billet, respectively.

According to the source [8], water flow is defined as:

$$G = gS,$$

where g – irrigation density/ m^3/(m^2·h);
S – irrigated surface area/ m^2.

The irrigation density of the surface of the billet depends on the heat fluxes of the liquid core through the layer of hardened metal, radiation and convection from the surface of the billet. In turn, the heat flux depends only on the temperature of the metal and the environment, which are identical both outside and inside the billet. In this regard, the changing parameter is the area of the cooled surface of the billet.

In [9], it was proved that the cooling uniformity depends on geometric parameters and provides more uniform mechanical properties over the cross section of the product. Thus, the flow rate of the cooler should correspond to the area of the cooled surface:

$$\frac{G_o}{S_o} = \frac{G_i}{S_i}$$

where G_o, G_i – cooler consumption, respectively, on the external and internal surfaces of the billet/ m^3/(m^2·h);
S_o, S_i – the area of the cooled surface outside and inside, respectively/ m^2.

$$\frac{G_o}{2\pi Rh} = \frac{G_i}{2\pi rh}$$

where R, r – external and internal radius of the billet/ m;
h – length of the cooled surface/ m.

Thus, in order to ensure uniform cooling of the work piece and, accordingly, the growth of the metal crust with the same thickness during solidification, the ratio of the flow to the external and internalsurfaces should be:

$$G_o = \frac{R}{r} \cdot G_i$$

According to the calculation results for a hollow billet with a diameter of 210 mm and an inner diameter of 144 mm, the flow rate of the cooler to the outer surface should be 1,46 times greater than with the inner.

Subject to this cooling condition, the initial quality of the billet will improve the final properties of the finished pipe, and will facilitate the production of high-strength pipes using appropriate heat treatment modes [10].

CONCLUSION

To calculate the technological parameters of casting a hollow steel billet, physical modeling of the casting process of a hollow aluminum billet is applicable based on similarity criteria.

The use of a hollow original billet will increase the productivity of the production line by 16 %.

The metal structure of the billet which is to improved due to uniform cooling in the secondary cooling zone from the external and internal sides of the billet, keeping the ratio of the refrigerant flow rate of 1,46 for a billet with an outer diameter of 210 mm.

The main technological parameters of continuous casting of steel hollow billets with a diameter of 210 mm have been determined: drawing speed 2,01 m/min, casting speed 0,273 t/min.

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Note: The responsible for English translate is Almaz Kuandykov, Pavlodar, Kazakhstan