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Improvement the Round Bloom Continuous Casting Technology at JSC “Ural Steel”

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Abstract. The results of assessment of macrostructure and surface quality of round blooms 455 mm in diameter, cast on 4-strand continuous casting machine (CCM) at JSC “Ural Steel” are presented.
The analysis of technological casting parameters of round blooms 455 mm in diameter (from steel grade “2”) at bloom caster of JSC “Ural Steel” are completed. Violations in casting temperature and rate parameters, which deteriorate thermal conditions of solidification and quality of continuous casting blooms, have been revealed. The main causes of unsatisfactory bloom quality have been determined, which are the increased overheating of cast metal and irrational secondary cooling mode.
The results of the experiment to evaluate the surface temperature dynamics of a round bloom in the secondary cooling zone are presented, which confirmed the inefficiency of the secondary cooling mode for the defect-free bloom formation.
As a result of thermal calculations of round blooms solidification of 455 mm in diameter, rational coolant flow rates by secondary cooling sections for bloom caster of JSC “Ural Steel” have been proposed. Optimized secondary cooling parameters provide a softer secondary cooling of the round bloom, which reduces the probability of the surface and internal defects development.

The Overview of the Problem

Continuous casting is currently the main method for producing steel billets. However, continuous casting technology is associated with increased stresses in the solidifying billet, which can lead to hot cracking [1-5]. A round bloom is particularly susceptible to hot cracking. The main cause of hot cracking of the billet is a drop of metal ductility due to the irrational of temperature and speed parameters of casting and secondary cooling mode.

As you know, the quality of billets is determined by the continuous casting parameters [3-16], liquid steel properties and the design of a continuous casting machine (CCM). Therefore, despite the large number of continuous steel casting studies [2-25], the study of casting technology and bloom quality in specific production conditions allows us to obtain new patterns and improve the production technology.

The Purpose and Object of the Study

The aim of the research is to improve the continuous casting technology of round blooms based on the analysis of production data on the blooms quality and casting parameters. The research was conducted on the basis of data on the operation of 4-strand bloom caster JSC “Ural Steel” curvilinear type. The CCM allows casting of round blooms (diameter 430. 455, 540 and 600 mm) with an annual capacity of up to 900 thousand tons.

Quality Analysis of a Round Bloom

The conditions and results of casting of round blooms 455 mm in diameter of steels for railway wheels (steel grade “2” according to GOST 10791-2011) for the year 2019 were investigated. During the study period, 2 849 steel melts were cast and 4 041 round blooms of 306231 tonnes were produced.

The results of the macrostructure evaluation of a 455 mm diameter round bloom of steel grade "2" are shown in Table 1.

Table 1. Quality of the macrostructure of a round bloom

Macrostructure defects	Range of variation, score	Average value, score	Allowable value of defect development, score	% of templates with exceeding the allowed score*
Central porosity	0.5-4.0	1.19	2.0	15.5
Axial liquation	1.0-2.5	0.99	2.0	0.5
Liquation strips and cross-sectional cracks	0.5-2.0	0.34	1.0	6.9
Liquation strips and axial cracks	0.5-3.0	0.42	1.0	18.5
* of the total number of templates studied - 11968 pcs.				

The average defects values are within the regulated limits. However, proportion of templets exceeding the maximum defect score is as high as 15.5 % for axial porosity and up to 18.5 % for internal hot cracks. While high axial porosity is a consequence of overheated steel casting [18, 25], the significant development of internal hot cracks indicates an irrational secondary cooling regime [3-5, 19-24].

Macrographic examination of the cross-section of round blooms showed the presence of surface and subsurface cracks (crack depths of 2-40 mm) (Figure 1). Crack spreading within the round bloom occurs along the boundaries of the former austenitic grains.

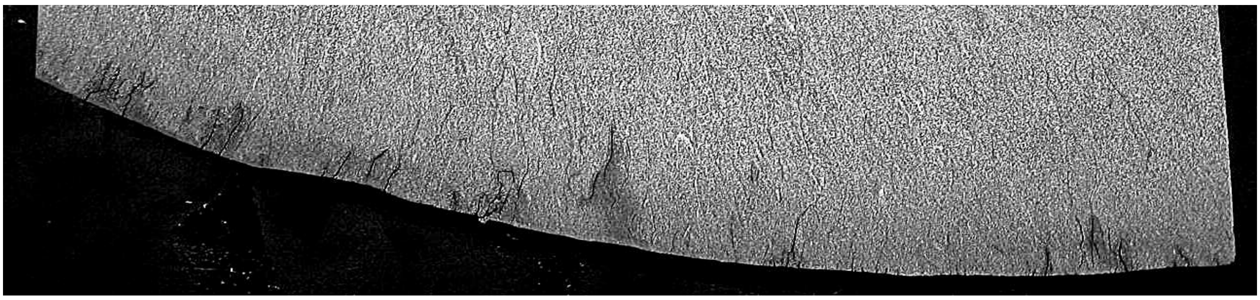

Fig. 1. Surface and internal cracks in the cross-section of the bloom

The surface quality analysis of round blooms has revealed that the most common defects are surface cracks, which can be subdivided into:

- transverse cracks (the main component), usually located at the bottom of the oscillation marks (Figure 2 a) with small longitudinal branches (on 44 of 483 inspected blooms - 9.1 %);
- branched cracks (figure 2 b) - on 40 of 483 inspected blooms (8.3 %).

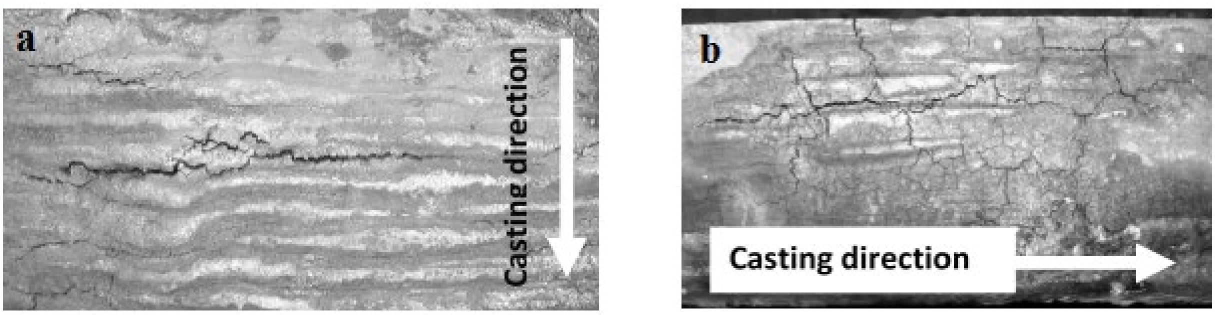

Fig. 2. Example of combined transverse cracks (a) and branched cracks (b)

Thus, based on the results of the study of the macrostructure and surface of round blooms in diameter of 455 mm, it can be concluded that it is necessary to improve the casting technology.

Analysis of Casting Conditions

Bloom quality is influenced by a large number of factors. When analyzing the operation of a particular CCM, the liquid steel properties and casting parameters have a decisive influence on the billets quality [3-16]. The chemical composition of the steel and casting parameters are shown in Table 2.

Table 2. Casting parameters

Parameter	Range of variation	Average value
Number of melts, [pcs.]		2849
Chemical composition, [%]		
carbon	0.6-0.62	0.61
manganese	0.64-0.72	0.67
silicon	0.25-0.33	0.28
sulphur	0.002-0.010	0.003
phosphorus	0.005-0.020	0.010
nitrogen	0.004-0.008	0.072
hydrogen, ppm	0.7-2.0	1.4
Withdrawal speed, [m/min]	0.26-0.44	0.36
Spraying plan, [l/kg]		0.30
Steel temperature in the tundish, [ºC]	1490-1520	1500.5
Steel overheat in the tundish, [ºC]	15.4-45.6	26.7

The chemical composition of the steel meets the modern requirements of continuous casting, so the main problem in producing a quality billet is to maintain rational casting parameters.

Casting temperature and rate parameters (Table 2) vary widely, and the maximum overheating values are beyond the optimal level of 15-30 ºC in more than 10% of melts. Casting with elevated overheating values promotes axial liquation and porosity, and may be cause of internal and surface cracks [3-16].

A Study of the Solidification Thermal Conditions

To assess the temperature conditions of round bloom solidification, measurements were made of the bloom surface temperature at 6 points along the technological length of the CCM. The measurements were made with a Flir T640 thermal imager during casting of 25 melts of “2” grade steel for a round bloom 455 mm in diameter (at normal overheating within 15-30 ºC). The results of the round bloom surface temperature measurements are shown in Table 3.

Table 3. Surface temperature measurement results for a round bloom in 455 mm diameter

Measurement location	Distance from the metal level in the crystalliser, [mm]	Billet surface temperature, ºC		
		Min.	Max.	Average
Exit from the crystalliser	890	1048	1196	1103.2
Exit from segment 1	4970	894	1052	974.3
Exit from segment 2	9420	961	1124	1014.6
Exit from segment 3	16100	881	1015	953.2
Exit from segment 4	25430	839	986	913.1
Exit from the straightening zone	26950	826	971	908.4

The surface temperature dynamics of a round bloom is indicate the ineffective adjustment of the secondary cooling mode, which is the main cause of crack formation [3-6, 13, 14, 19-25]. In addition, billet straightening in the temperature range from 900 to 700 °C (austenite–ferrite transformations interval) is an additional cause of transverse cracks, especially along the oscillation marks.

It is possible to recommend directions for improvement of round bloom casting technology at blooming caster of JSC "Ural Steel":

- maintaining optimal steel overheat in the tundish (15-30 ºC);
- optimisation of the secondary cooling of the round bloom.

Calculation of a Rational Secondary Cooling Mode

In order to improve secondary cooling the calculation of coolant consumption by secondary cooling sections for casting steel grade "2" for a round bloom 455 mm in diameter was carried out. The calculation of secondary cooling modes was made for the conditions of steel casting at normal (15-30 °C) overheating with a withdrawal speed w = 0.44 m / min and at increased overheating (more than 30 °C) with a withdrawal speed w = 0.36 m / min. The round bloom surface temperature before the straightening zone was taken constant – 950 °C. The water flow rates used (according to the process instruction) and the optimum water flow rates for the secondary cooling sections are shown in Table 4.

Table 4. Used and optimum water flow rates by secondary cooling sections

Sections of the secondary cooling zone	Length of secondary cooling sections, [mm]	Cooling mode	Water flow rates, l/min at different metal superheats			
			Normal overheating (15-30 ºC) at w = 0.44 [m/min]		Elevated overheating (over 30 ºC) at w = 0.36 [m/min]	
			actual	optimum	actual	optimum
Zone 1	240	Jetting (water jet)	33.2	10.76	28.4	9.41
Segment 1	4080	Water-air	81.2	34.66	66.8	26.39
Segment 2	4450		35.2	29.58	29.2	21.20
Segment 3	6680		22	20.01	18	11.78
Segment 4	9330		0	5.91	0	0

From the results of the thermal calculations (Table 4) it follows that in order to optimise the thermal conditions for solidification of a 455 mm diameter round bloom of steel grade "2", a significant reduction in water consumption by section of the secondary cooling zone is necessary.

Calculated data on the surface temperature dynamics of a 455 mm diameter round bloom within the secondary cooling zone at current and optimum coolant flow rates (at normal overheating) are shown in figure 3.

The data in Fig. 3 confirms that under the current secondary cooling and casting temperature-rate regimes, overcooling of the round bloom surface occurs in the first two segments of secondary cooling, which leads to additional thermal and phase stresses. In the third segment of the secondary cooling zone, the bloom surface warms up due to the heat of the central part. Under optimised secondary cooling modes, a more favourable smooth decrease in the temperature of the bloom surface is ensured, and the temperature is in the zone of the plastic state of the metal, which minimises the probability of cracking.

Conclusion

The analysis of production data on casting of round blooms 455 mm in diameter (from steel grade “2”) at blooming caster of JSC “Ural Steel” has allowed to establish the main reasons for unsatisfactory quality of billet, which consist of increased steel overheat in the tundish and irrational of secondary cooling mode.

Rational coolant consumption by sections of secondary cooling for casting of round blooms 455 mm in diameter at bloom caster of JSC “Ural Steel” are proposed as a result of the conducted thermal calculations.

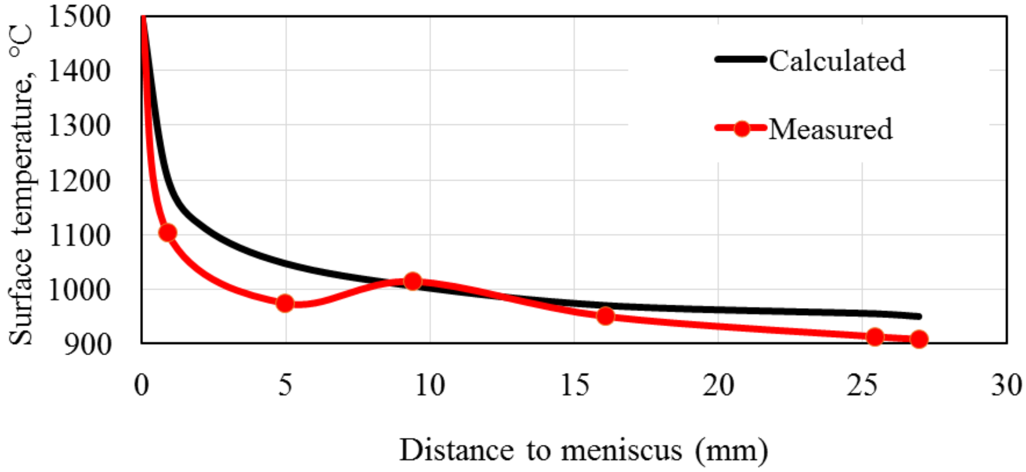

Fig. 3. Dynamics of the surface temperature of a 455 mm diameter bloom at actual and optimum coolant flow rate in a secondary cooling zone

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