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Research and Application of Tube Mold in Bloom Continuous Casting for Rail Steel

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Abstract. Research on the key parameters of tube mold for rail steel bloom was carried out in this paper, the effects of cooling water on bloom quality was studied, the effects of tube mold on magnetic intensity of electro-magnetic-stirring was analyzed, the shielding effect of tube mold on stirring intensity was represented by comparing solidification structure, suitable stirring parameters was confirmed; the effects of tubular corner size on cooling of bloom corner was analyzed by taken simulate calculate, and explore the effects of taper on the casting amount of steel by carried out experiment, parameters have been worked out and quality of bloom corner have been improved at last, convex hull of corner have been eliminated and zero defect for corner was realized, mean squared error of segregation degree at corner and solidified shell is not more than 0.010, better than combined mold remarkably.

Keywords. Tubular mold, bloom, rail steel, corner convex hull

1. Introduction

Mold is the core component for continuous casting, the performance determine the ability of continuous casting machine and the quality of bloom [1]. It has been distinguished as tub and combined type by the structure of mold, tube mold is mostly used for billets, but blooms and brands casting by use combined mold [2]. Easy to be produced and maintained, and the structure is simple for tub mold, expensive for bloom however. The cooling unit of combined type mold corner is worse by comparing with tube mold, thus some quality detects exists in bloom corner, influence the rolling process, cost of production increased as the result of it. Requirements of bloom need to be further improved with the requirements of rail increased constantly [3], it’s has a significant meaning in the improvement of rail quality.

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2. Key Processes of Tube Mold

2.1. Heat Flux of Tube Mold

Cooling intensity influence the thickness of solidified shell directly, corner crack of bloom would be caused by strong cooling intensity, but enough thickness need to be guaranteed otherwise bleed out would be leaded.

Research shows that the thickness of solidified shell for bloom should be controlled at 12~15mm while bloom have been pulled out from mold, the thickness of shell could resist hydrostatic pressure of melting steel [1]. The safety thickness of solidified shell could be calculated by the empirical formula (1) [4], the value is δmin=1.57cm.

$$\delta\mathrm{min} = 0.154\sqrt[3]{D^2} \tag{1}$$

D is cross section size of bloom, cm.

Calculated the thickness of solidified shell while bloom pulled out mold by numerical simulation software, result shows thickness of solidified shell is 1.67cm, and above δmin, means thickness of solidified shell is safety while the heat flux is 1.17MW/m^2. S and flow of cooling water is 2700L/min, and carried out comparing experiment for the value of cooling water based on the result, programs of cooling water be compared are shown as table 1.

Table 1. Comparing experiment programs of cooling water for tubular mold.

Effective height/mm	Value of flow L/min
750	3300
	3000
	2900
	2700

Make testing for the segregation of bloom by sampling with broach, the size is φ6mm. Testing result shows as table 2, the standard mean square deviation of carbon segregation is 0.013~0.034 which produced by tube mold, and below 0.044 of bloom produced with combined mold, means the homogeneity of bloom has been optimized by use tube mold. Comparing the homogeneity for difference flow of cooling water at the same time, result shows that the homogeneity is the best by cooling with 2700L/min.

Table 2. Statistics result of C segregation for bloom.

Mold	Combined	Tube			
Water flow	3000 L/min	3300 L/min	3000 L/min	2900 L/min	2700 L/min
Max	1.05	1.07	1.06	1.04	1.01
Min	0.95	0.93	0.90	0.96	0.96
Max-Min	0.10	0.14	0.16	0.08	0.05
Stand mean square deviation	0.044	0.030	0.034	0.024	0.013

2.2. Corner Size

The quality of bloom corner has been optimized by use tube mold, ratio of corner convex hull defects have been cleared off completely from 0.25%, soft longitudinal crack was found by corrode with reagent even produce with soft cooling of 2700L/min water flow. The representative crack defects show as figure 1, which was leaded by the strong cooling. Corner size of tube mold was researched based on the safety thickness of solidified shell.

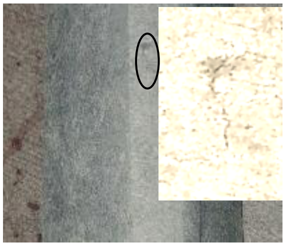


Figure 1. Crack defect of bloom corner for tube mold with 2700L/min water flow.

Simulate calculation result shows as figure 2, and corner size optimized from R10mm to R20mm could realize the cooling intensity close with combined mold.

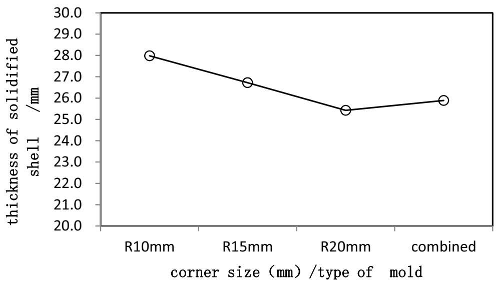
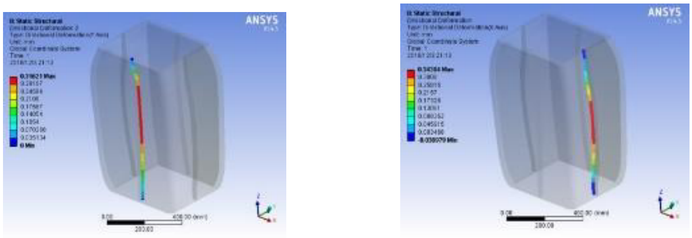


Figure 2. Solidified shell thickness of bloom away mold for difference corner size.

2.3. Taper of Tube Mold

The tube mold is mostly used in the production of billets, blooms are mostly produced with combined type mold, due to the integrated structure characteristics of tube mold, the deformation of mold would be influence the taper of mold directly, and it's an outstanding problems for bloom produced with tube mold. Numerical simulation was carried out to research the deformation of tube mold for continuous casting bloom, result shows as figure 3, it could be found that inward convex deformation occurred with the wide face and out ward for narrow face. And the copperplate of mold mainly deformed as inward to the surface of bloom by taken into consideration the deformation of combined type mold, the wide deformed at first caused by the larger amount of heat flux, and the stress transmit to the corner and narrow lead the narrow face deformed as outward.



(a) Between wide (b) Between narrow

Figure 3. The results of numerical simulation for the deformation of tube.

There were varying degree change for the taper of tube mold during the process of casting, the worst area is 300mm from liquid surface of mold, the curve of cross section along mold height is show as figure 4, the results consistent with the numerical simulation.

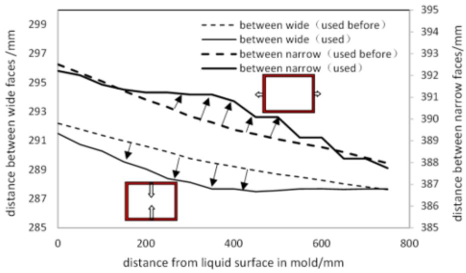


Figure 4. Change of tapper for tubular mold.

Cross section size along mold height between optimized and before is shown as figure 5. The amount of molten steel casted with tube mold before optimized was 6123ton but 14000ton could be reached after optimizing, the consumption of casting powder is 0.32kg/t, the flow is stable improve good lubrication and protection. And the deformation of tube has been controlled effectively by comparing the result shows in table 3.

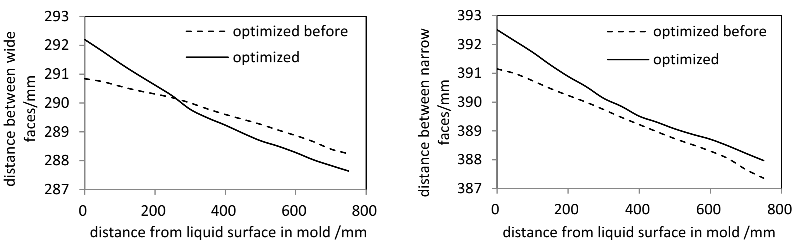


Figure 5. Comparing of section size between optimized and before.

Table 3. The amount of deformation optimized and before.

Projects	Narrow		Wide	
Max value of deformation	before /mm	optimized	before /mm	optimized
	1.77	-28.2%	2.22	-19.4%

2.4. Mold Electro-magnetic Stirring (M-EMS) of Tube Mold

M-EMS have a significant function for optimizing the quality of bloom [5~8], measured the actual intensity of magnetic field on the center line of mold along with the height direction, result shows as figure 6, the strongest position is the point below liquid surface 600mm, the distribution of magnetic intensity along the height of mold central line is same with combined type mold, and the magnetic intensity tend to be stronger with the current intensity increased.

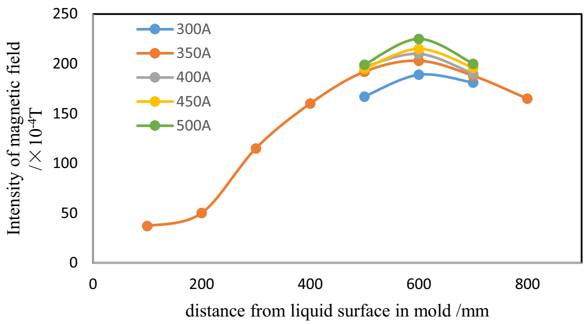


Figure 6. Magnetic intensity at section center-line for difference current intensity for experiment.

Comparing the actual intensity for the same stirring current between tube and combined mold, result shows as figure 7. The intensity of magnetic field is 360×10^{-4}~381×10^{-4}T while the stirring current is 350A for combined mold but 273×10^{-4}T only for tub mold, means magnetic field of tube mold was reduced significantly by comparing with combined mold.

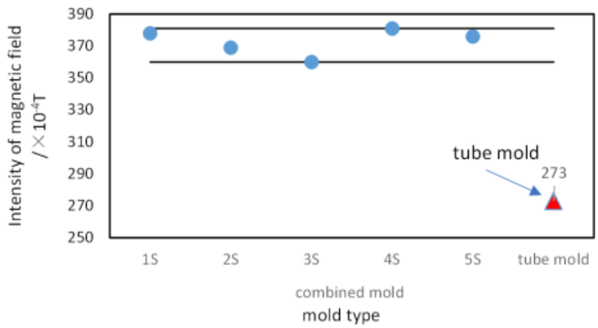
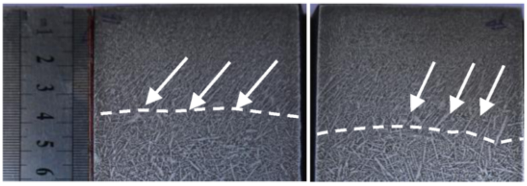


Figure 7. Magnetic intensity among difference strands while current intensity is 350A.

Solidification structure in the representative area of bloom for combined type and tube mold is shown as figure 8. The deflection angle of columnar crystal was measured, the result is 20.56°~22.33° for the bloom which produced by tub mold, and it's below the result of combined type mold for 23.20°~26.04°, means the actual stirring intensity of electromagnetic stirring for tube mold is more soft than combined type mold.



(a) Combined type mold (b) Tube mold

Figure 8. Solidification structure in the representative area of bloom.

Induced current would be generated in the smelting steel by the spinning magnetic field, the galvanic smelting steel would be driven by electro-magnetic force to realize stirring, and the induced current would be generated in the copper pipe of mold, the current would generate an induced magnetic field to reduce the spinning magnetic field, the more current induced at copper pipe the stronger reduce would be. The copper pipe of tub mold has a smaller resistance and induced current intensity would be stronger than combined mold by analyze the characteristic of copper pipe for tube mold and compare with combined mold, the effective magnetic field for driving smelting steel is lower intensity as the result of it. The magnetic field intensity should be set to 360×10^{-4} ~ 380×10^{-4}T while produce with tube mold.

3. Experimental Results

3.1. Quality of Bloom Surface

The key process parameters of tube mold including the value of cooling water, magnetic field intensity of mold electromagnetic stirring, size of tube corner, and the taper of tube were specified. The value of cooling water for mold set as 2700L/min, corner size should be produced to be R20mm (circular arc radius of tube corner), and the magnetic field intensity of mold electromagnetic stirring should be set as 360×10^{-4}T. Based on the above all process parameters operate stably, the amount of molten steel casting by tube mold could be reached 14000 ton each, key quality index of bloom were accounted and the result shows as table 4, the quality of rail bloom was dramatic optimized by comparing with the combined mold, all of the corner crack of bloom were eliminated.

Table 4. The quality of bloom surface for the difference mold type.

Projects		Convex hall	groove	Uneven chamfer	Total /%
Crack ratio/%	Tube mold	0.00	0.00	0.00	0.00
	Combined mold	0.25	0.07	0.17	0.49

3.2. Homogeneity of Solidified Shell

Comparing test for the homogeneity of solidified shell was carried out, and the sampling position distribute on bloom section was shown as figure 9, testing result shows as table 5. The value of stand mean square deviation decreased from above

0.015 to be below 0.010, and means the homogeneity of solidified shell has been optimized obviously.

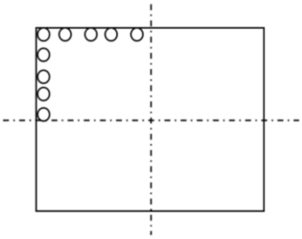


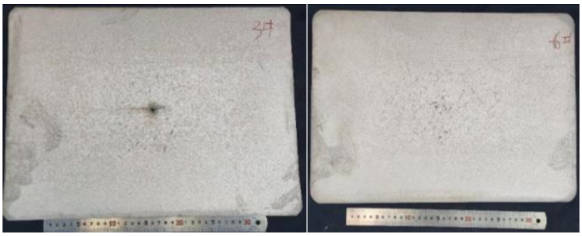
Figure 9. Schematic program of sampling position for homogenity testing of solidified shell.

Table 5. Statistics results of C segregation for solidified shell.

Projects	Mold type (n=15)	
	Tube mold	Combined mold
Max	1.01~1.02	1.02~1.03
Min	0.98~0.99	0.98~0.99
Value of stand mean square deviation	≤0.010	≥0.015

3.3. *Macro-quality of Bloom (After the Corrosion)*

The macro-photograph of blooms produced with difference mold were shown as figure 10, bloom produced with the tube mold is better, but bloom which produce with the combined type mold is exist obvious central segregation.



(a) Combined mold (b) Tube mold

Figure 10. The macro-photograph of bloom (cross section and after the corrosion).

4. Conclusions

(1) The suitable process parameters of tube mold for continuous casting rail steel bloom was determined as: The value of cooling water is 2700L/min, corner size of tube is R20mm (circular arc radius of tube corner), and the magnetic field intensity of mold electromagnetic stirring should is 360×10^{-4}T.

(2) The taper of tube would be change, the deformation of tube could be optimized by advance taper, magnetic field intensity of electro-magnetic stirring is weaker by comparing with the combined type mold.

(3) The blooms produced with tube mold would be better for the quality such as surface quality, homogeneity of solidified shell and the macro-quality of bloom, the value of stand mean square deviation could be controlled as ≤0.010.

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