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ISSN 0543-5846
METABK 63(1) 6-8 (2024)
UDC – UDK 669.18:669.163:66.065:532.54:531.52.002.68=111

OPTIMIZATION OF FLOW FIELD AND NUMERICAL SIMULATION OF SLAG ENTRAPMENT BEHAVIOR IN SLAB CRYSTALLIZER

Received – Primljeno: 2023-4-14
Accepted – Prihvaćeno: 2023-07-29
Original Scientific Paper – Izvorni znanstveni rad

At 950 mm × 230 mm slab crystallizer as the prototype, the flow field distribution inside the mold under different conditions was calculated using FLUENT simulation software, and the effects of different casting speeds and nozzle immersion depths on the flow field inside the mold were analyzed. The results show that an increase in casting speed intensifies the fluctuation of the steel slag interface, and as the immersion depth of the nozzle increases, the fluctuation of the steel slag interface gradually stabilizes. Section 950 mm × 230 mm crystallizer with a submerged depth of 120 mm at the nozzle and a casting speed of 1,1 m/min can avoid slag entrapment.

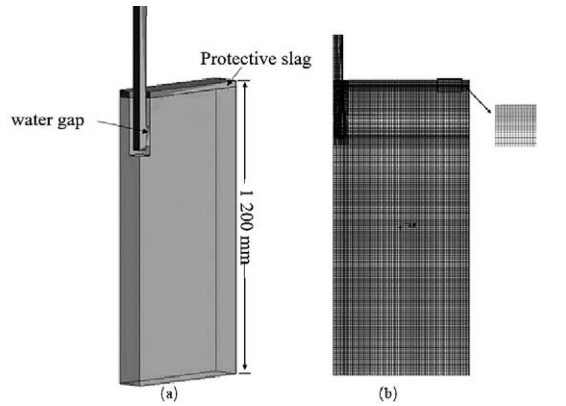
Keywords: steel, casting, crystallizer, pulling speed, slag entrapment

INTRODUCTION

According to statistics, 60 % of defects in the casting production process are caused by slag entrapment in the mold. Therefore, slag rolling is one of the problems that many manufacturers and metallurgical researchers urgently hope to solve[1,2]. Therefore, in order to avoid the quality problems caused by slag entrapment in the mold, optimizing the distribution of flow field in the mold, selecting appropriate process parameters, and reducing the probability of slag entrapment are very important for improving the quality of the casting billet[3].

SOLVING PROCESS

Establish a mathematical model based on the actual size of the crystallizer[4]. Considering the dual symmetric structure of the crystallizer, the 1/4 crystallizer fluid domain is selected as the solution region[5], as shown in Figure 1 (a). During simulation calculation, the length of the crystallizer is 1 200 mm, and the top of the crystallizer includes a 30 mm liquid slag layer. The grid division is shown in Figure 1 (b), with a total number of grids of around 500 000.



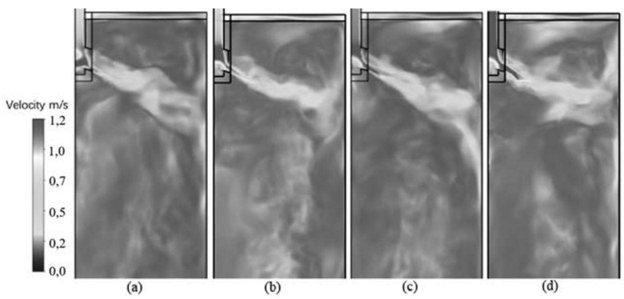
(a) - Model establishment; (b) - Grid partitioning

Figure 1 Crystallizer structure and grid division

DISTRIBUTION RESULTS OF FLOW FIELD IN CRYSTALLIZER UNDER DIFFERENT CASTING SPEEDS

Taking the nozzle immersion depth of 120 mm as an example[6], Figure 2 shows the velocity distribution of molten steel in the mold at different casting speeds at the same time. From the Figure, it can be seen that the molten steel flows out of the nozzle and forms a mainstream stream. After the mainstream stream hits the narrow surface, it forms a typical “double annular flow” mode. At a pulling speed of 1,0 m/min, the speed of the upper and lower reflux zones is relatively small, but as the pulling speed increases, the upper and lower reflux zones become larger. The speed of upward reflux determines the degree of fluctuation at the interface of the crystallizer steel slag and the involvement of the protective slag.

Figure 3 shows the slag entrapment behavior in the mold at different casting speeds of 40 s, 45 s, and 50 s. At a pulling speed of 1,0 m/min, the interface between the



(a)-1,0 m/min; (b)-1,1 m/min; (c)-1,2 m/min; (d)-1,3 m/min

Figure 2 Velocity Distribution of molten steel in mold

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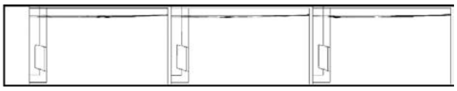
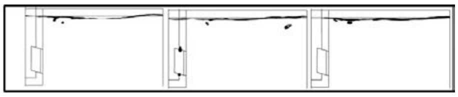


(a) - Pulling speed 1,0 m/min

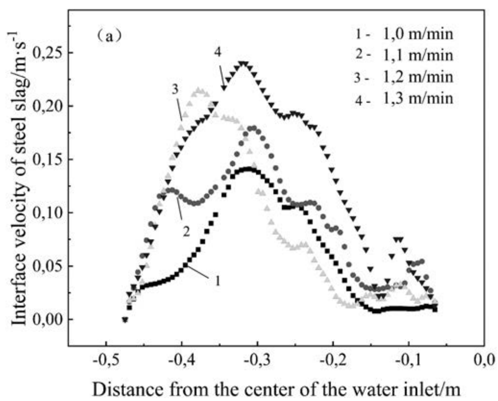
(b) - Pulling speed 1,1 m/min

(c) - Pulling speed 1,2 m/min

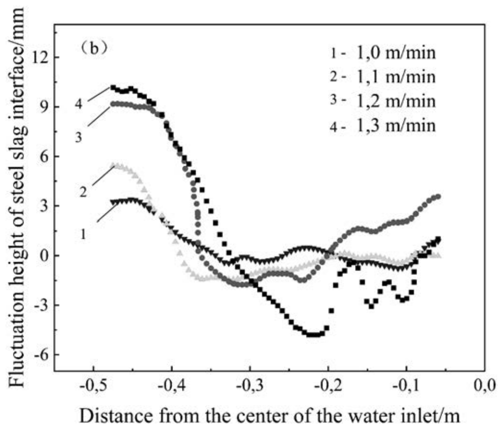


(d) - Pulling speed 1,3 m/min

Figure 3 Slag entrapment phenomenon in the crystallizer at different casting speeds



(a) - velocity distribution of steel slag interface



(b) - The fluctuation height of the steel slag interface.

Figure 4 Velocity Distribution and Fluctuation Height of Steel Slag Interface

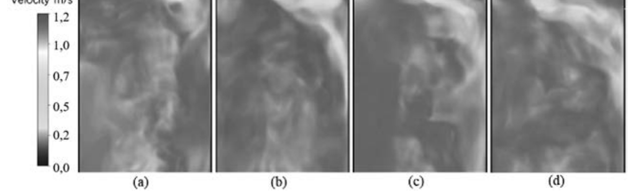
crystallizer steel slag is relatively stable and there is no slag curling phenomenon. When the casting speed increases to 1,1 m/min, there is a certain amplitude of fluctuation at the steel slag interface near the water inlet, but no protective slag is drawn into the molten pool. At a pulling speed of 1,2 m/min, a large vortex appeared near the water inlet of the crystallizer, and at the same time, there was a large fluctuation at the narrow surface of the crystallizer, resulting in vortex and liquid level fluctuations. When the casting speed increases to 1,3 m/min, the amount of protective slag entangled near the mold nozzle significantly increases. The part of the entangled protective slag floats up to the protective slag layer with the flow of the steel liquid, and some is brought into the interior of the mold. Therefore, to avoid slag rolling, the maximum pulling speed should be less than 1,2 m/min.

Figure 4 shows the velocity and fluctuation height on the centerline of the crystallizer steel slag interface at different pulling speeds, it can be seen that when the pulling speed increases from 1,0 m/min to 1,1 m/min, the maximum surface velocity also increases from 0,141 m/s to 0,178 m/s, the maximum fluctuation height increases from 3,38 m/s to 5,42 m/s, the maximum surface velocity increases by 0,037 m/s, and the fluctuation height increases by 2,04 mm. At a pulling speed of 1,2 m/min, slag curling phenomenon begins to occur, with a maximum surface flow rate of 0,214 m/s and a maximum fluctuation height of 9,19 mm. Therefore, at a immersion depth of 120 mm, the casting speed of the mold should not exceed 1,2 m/min, and the maximum flow velocity and fluctuation height at the steel slag interface should not exceed 0,214 m/s and 9,19 mm.

DISTRIBUTION OF FLOW FIELD IN CRYSTALLIZER UNDER DIFFERENT IMMERSION DEPTHS

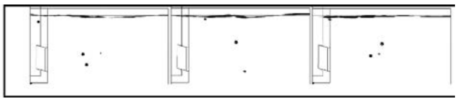
The distribution of the flow field in the mold at the same casting speed of 1,2 m/min at different water inlet immersion depths is shown in Figure 5. From the figure, it can be seen that the velocity of the main stream formed by the steel liquid flowing out of the nozzle is similar. As the immersion depth of the nozzle increases, the impact point of the main stream of the steel liquid flowing out of the nozzle significantly moves downwards on the narrow surface, and the disturbance to the steel slag interface also decreases. The downward movement of the impact point causes the main stream of molten steel to impact the narrow surface, resulting in less upward reversal of the molten steel. The flow velocity of the molten steel in the lower reflux zone is very high, while the velocity in the upper reflux zone decreases.

Figure 6 shows the slag entrapment situation in the crystallizer at three times of 40 s, 45 s, and 50 s under different water inlet immersion depths at a casting speed of 1,2 m/min. From the figure, it can be seen that when the immersion depth is 110 mm, a relatively large amount of protective slag liquid in the mold separates from the slag layer and enters the mold. At 1/4 of the width of the crystallizer, the upward reflux has a significant shear effect on the protective slag, forming



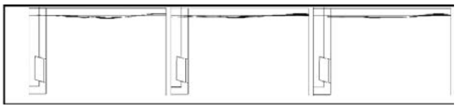
(a)-110 mm; (b)- 120 mm; (c)-130 mm; (d)-150 mm

Figure 5 Velocity Distribution of molten steel in mold

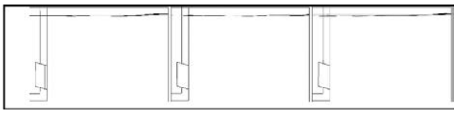


(a) Immersion length 110 mm

(b) Immersion length 120 mm

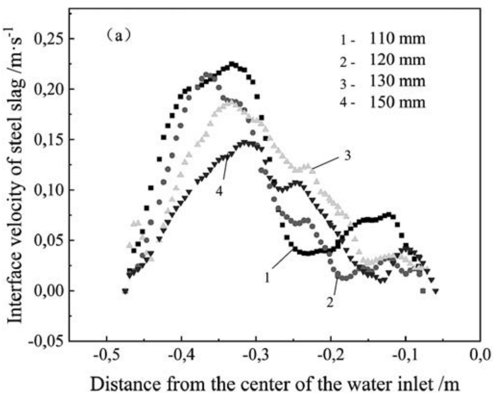


(c) Immersion length 130 mm

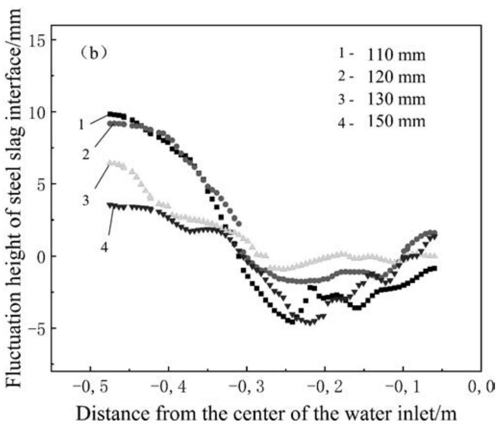


(d) Immersion length 150 mm

Figure 6 Slag entrapment phenomenon in crystallizer under different water inlet immersion depths



(a) - velocity distribution of steel slag interface



(b) - The fluctuation height of the steel slag interface

Figure 7 Velocity distribution and fluctuation height of steel slag interface

shear rolled slag. When the immersion depth of the nozzle increases from 110 mm to 120 mm, the amount of protective slag drawn into the mold decreases. When the immersion depth of the water inlet is 130 mm, there is a certain fluctuation at the steel slag interface, but there is no slag curling phenomenon. Therefore, at a pulling speed of 1,2 m/min, the appropriate immersion depth of the nozzle is 130 mm. When the immersion depth of the water inlet is 150 mm, the interface between the steel slag becomes very stable and the fluctuation is very small. If the nozzle is immersed too deeply, it will cause non-metallic inclusions in the mold to float up to a longer distance, making it difficult to remove the inclusions and ultimately affecting the quality of the casting billet.

Figure 7 shows the speed distribution and fluctuation height on the centerline of the steel slag interface at the same time when the casting speed is 1,2 m/min and the nozzle is immersed in the mold at different depths. From Figure 7, it can be seen that the fluctuation height and surface velocity of the large steel slag interface are inversely proportional to the immersion depth of the nozzle. When the immersion depth is 110 mm and 120 mm, the maximum flow velocity on the mold surface is 0,225 m/s and 0,214 m/s, and the maximum fluctuation height is 9,85 mm and 9,19 mm. At this time, the flow velocity at the steel slag interface is too large, and the fluctuation is severe, which is prone to slag entrapment. As the immersion depth increases, the maximum surface velocity and fluctuation height of the steel slag interface decrease until 130 mm, and no slag curling occurs at a pulling speed of 1,2 m/min. At this time, the maximum surface velocity of the steel slag interface is 0,188 m/s, and the maximum fluctuation height is 6,42 mm.

CONCLUSION

(1) The main ways of slag entrapment in the mold are vortex slag entrapment caused by a large velocity difference at the steel slag interface near the water inlet, and fluctuation slag entrapment caused by severe fluctuations in the narrow surface of the mold.

(2) When slag rolling occurs in the mold, the maximum flow velocity at the steel slag interface is above 0,2 m/s, and the maximum fluctuation height is above 9 mm.

(3) To reduce the probability of slag entrapment, the maximum casting speed of the 930 mm x 230 mm mold with a cross-section is 1,1 m/min when the immersion depth of the nozzle is 120 mm.

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Note: The responsible translator for English language is S. WANG -Hebei Normal University, China.