

STUDY ON STRUCTURAL OPTIMIZATION OF SUBMERGED NOZZLE OF CONTINUOUS CASTING MOLD BY WATER MODEL EXPERIMENT

Received – Priljeno: 2023-1-10

Accepted – Prihvaćeno: 2023-04-15

Original Scientific Paper – Izvorni znanstveni rad

In this paper, by changing the shape of the inner wall of the nozzle, a water model experiment was carried out on the slab with the section of 200 / mm × 1 200 / mm. The results show that under the same immersion depth and the same angle, the improved No.1 nozzle and the improved No.2 nozzle have swirling flow, which reduced the dead region and the internal longitudinal flow velocity, and the swirl ratio generated in improved No. 2 nozzle is more obvious than improved No. 1 nozzle. The impact depth of the velocity at the outlet of the improved No.2 nozzle is obviously lower than that of the original nozzle and the improved No.1 nozzle.

Keywords: steel casting, submerged entry nozzle, mold, water model, velocity model

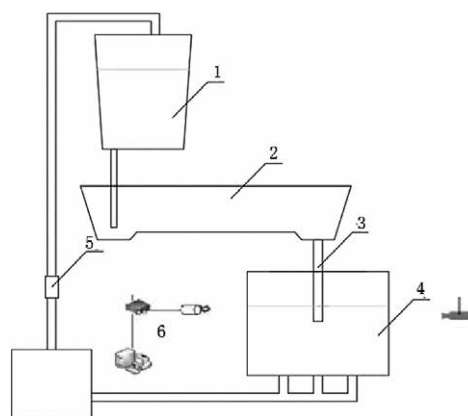
INTRODUCTION

In the process of continuous casting, Al_2O_3 inclusions adhere to the inner wall of submerged nozzle to form nodules, which affects the flow field of the mold, and even leads to broken casting. The submerged entry nozzle, as one of the refractory materials that are in direct contact with molten steel in continuous casting production and one of the important links to protect the casting, the stability of its casting state has a direct impact on the billet quality [1-4]. Some scholars have shown that the rotating flow of molten steel in the submerged entry nozzle during continuous casting can increase the wall velocity and reduce the nodulation, and reducing the outlet velocity is beneficial to increase the casting speed [5,6]. In this paper, the hemispherical crown is projected on the inner wall of the nozzle, so that the swirl can be generated inside the nozzle. The method is simple and the service life of the nozzle can be prolonged. This paper takes slab continuous casting mold as the research object, establishes a 1:1 physical model, and uses particle image velocimetry to measure the speed of the model.

EXPERIMENTAL

The experimental device is based on the submerged entry nozzle and mold of a steel plant, and a 1:1 physical model is established. The tundish, mold and submerged entry nozzle models are all made of transparent plexi-glass. Before the experiment, ensure that the mold is horizontal, fix the nozzle at the same time, and ensure that the nozzle is perpendicular to the mold liquid level. At the

same time, it is required that the two outlet axial surfaces of the mold and the middle axial surface of the mold are in the same horizontal plane. By observing the readings of the rotameter, we control the frequency conversion system to keep the flow of the whole circulation system stable. The PIV particle image velocimetry system of TSI Company of the United States was used for measurement. The experimental device diagram is shown in Figure 1.



1 Steel ladle 2 Tundish 3 Submerged entry nozzle 4 Mold
5 Rotameter 6 PIV Velocity measurement system

Figure 1 Schematic diagram of water model experiment

Water model experiment is to simulate molten steel with water. The physical parameter values of molten steel and water used in the present physical modeling experiment are given in Table 1. When establishing the physical model, it is necessary to ensure the geometric similarity, dynamic similarity and motion similarity between the model and the prototype. The flow of molten steel can be regarded as the flow of viscous incompressible fluid. In the process of flow, it is mainly affected by inertia force and gravity, which must satisfy $(Fr)_p=(Fr)$

C.Y. Cai(ccy@ustl.edu.cn), X. Deng, M.G. Shen, X.Y. Qiao: School of Materials and Metallurgy, University of Science and Technology Liaoning, Anshan

m. The 1:1 model is established, so the formula 1 is obtained. The specific parameters used in the water model are shown in Table 2.

$$\left(\frac{u_{steel}^2}{gL_{steel}}\right)p = \left(\frac{u_{water}^2}{gL_{water}}\right)m \tag{1}$$

Where: p is prototype parameter; m is model parameters, g is the acceleration of gravity, u is fluid velocity, L is characteristic dimensions.

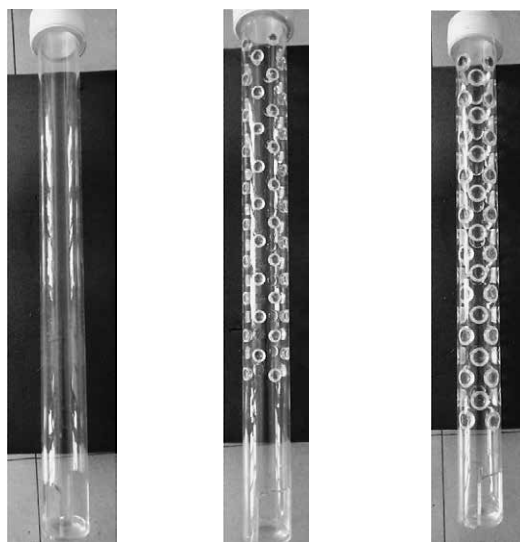
Table 1 Physical properties of molten steel and water

Medium	Density / kg/m ³	Dynamic viscosity / kg/(m·s)	Kinematic viscosity / m ² /s
Molten steel	7 020	6,2×10 ⁻³	0,95×10 ⁻⁶
Water	1 000	1×10 ⁻³	1×10 ⁻⁶

Table 2 Crystallizer Model and Prototype Parameters

Parameter	Model	Prototype
Mold length / mm	1 800	1 800
Mold width / mm	1 200	1 200
Mold thickness / mm	200	200
Liquid flowrate / m ³ /h	18,72	18,72

The original nozzle and optimized nozzle are shown in Figure 2. (1) The original nozzle, the size of which is 780 / mm (length) × 75 / mm (outer diameter) × 70 / mm (inner diameter), and the side hole inclination angle of the nozzle is 15°. The nozzle is composed of the nozzle inlet, outer wall, inner wall and the nozzle outlet with two side holes. (2) The improved No. 1 nozzle, with four rows of hemispheres protruding from the inner wall of the original nozzle, the radius of the hemispheres being 10 / mm, the longitudinal spacing being 10 / mm, and eight hemispheric crowns in each row, which are symmetrical and staggered. (3) The improved No. 2 nozzle, with four rows of hemispheres protruding from the inner wall of the original nozzle, each of which has a radius of 15 / mm, and each row has eight hemi-



The original nozzle The improved No. 1 nozzle The improved No. 2 nozzle

Figure 2 Real nozzle model

spheres with the longitudinal spacing of 10 / mm. The water model experiment was carried out on the above nozzle, tracer particles were added, and PIV testing device was used to capture the flow state in the nozzle.

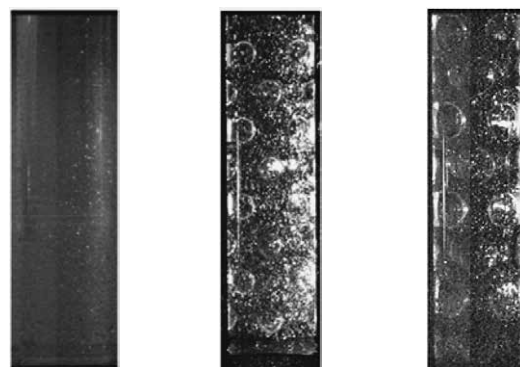
RESULTS AND DISCUSSION

When the water level of tundish and mold reaches the required level, the liquid level in tundish is stable and no swirling flow occurs. After keeping the water circulation running stably for 10 minutes, tracer particles are added, and PIV device is used to capture the flow state in the nozzle. The captured image is shown in Figure 3.

As shown in Figure 4, the results of the captured particles processed by PIVview. The flow field in the original nozzle is stable from top to bottom, and the flow state in the nozzle is not change; In the improved No.1 nozzle and the improved No.2 nozzle, after the water collides with the protruding hemisphere on the inner wall of the nozzle, the flow direction in the nozzle changes, and the flow state trend of water is obviously different from that of the original nozzle, resulting in obvious swirling flow.

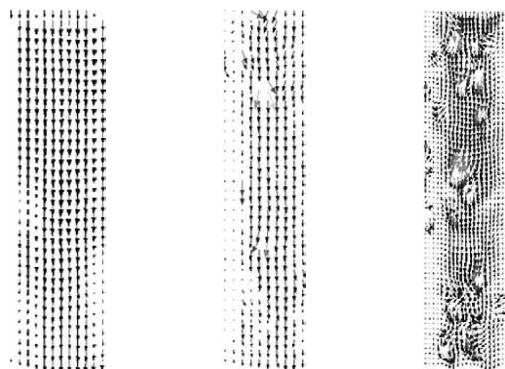
The result of image processing by Tecplot is shown in Figure 5. It is obvious that the wall in Figure 5(c) shows a horizontal amount and a downward spiral trend.

By comparing and analyzing the flow state of the improved No.1 nozzle with that of the improved No.2 nozzle, it is found that the trend of the flow state in the im-



The original nozzle The improved No. 1 nozzle The improved No. 2 nozzle

Figure 3 The captured actual nozzle flow field



The original nozzle The improved No. 1 nozzle The improved No. 2 nozzle

Figure 4 Flow field after PIVview processing

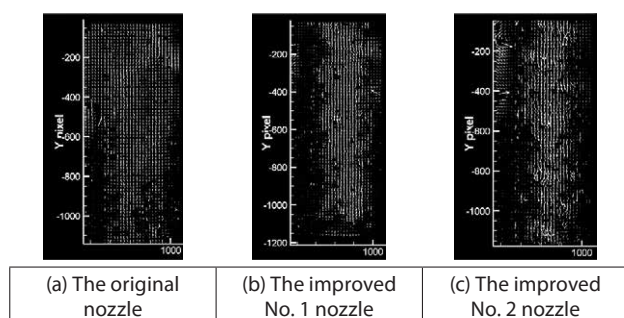


Figure 5 Flow field after Tecplot processing

proved No.1 nozzle and the improved No.2 nozzle produces swirling flow, and the swirling flow of the water around the hemisphere in the improved No.2 nozzle is more obvious than that in the improved No.1 nozzle, because the water in the nozzle collides with the hemisphere on the inner wall of the nozzle, which changes the direction and speed of the water flow. Because the hemisphere embedded in the inner wall of the improved No.2 nozzle is larger, the collision between the water flow and the hemisphere is more intense, and the swirl is more obvious.

When three different nozzles are used to ensure that the liquid level in tundish is at the same level (± 5 / mm) after the system meets the experimental requirements, it can be regarded that the average inlet speed is the same when three different nozzles are used, but the liquid level height in the mold is not the same at this time. In order to ensure the same casting speed of the mold during the use of three nozzles, it is necessary to inject water into the mold during the use of improved No.1 and improved No.2 nozzles, but this part of water added separately needs to be subtracted when calculating the outlet speed. The average velocity of inlet and outlet obtained by calculation is shown in Table 3.

At the same time, the collected data are processed to obtain the cloud picture of the flow velocity inside the nozzle, and the image is imported into Insight3G for processing, the cloud picture of the velocity obtained is

Table 3 The inlet and outlet speed of the nozzle

Nozzle number	Entrance velocity / m/s	Export velocity / m/s
original nozzle	2,5	2,75
improved No.1 nozzle	2,5	2,6
improved No.2 nozzle	2,5	2,45

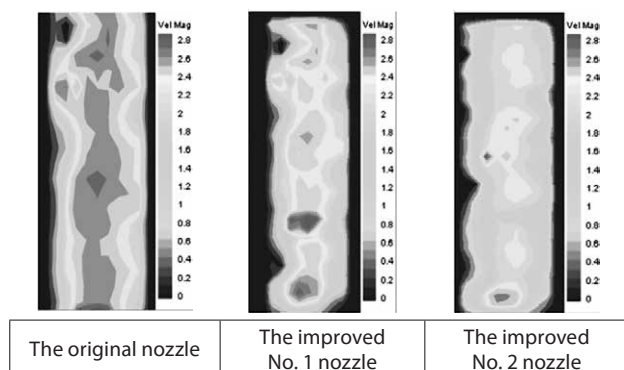


Figure 6 Velocity cloud image of the nozzle cross-section

shown in Figure 6. After comparison, it is obvious that the velocity in the improved No.2 nozzle decreases, which is consistent with the calculated results, and the outlet velocity decreases.

CONCLUSIONS

Due to the action of the hemisphere, the improved No.1 nozzle and the improved No.2 nozzle have the effect of slowing down the liquid flow in the nozzle, and the outlet velocity decreases with the increase of the convex height of the hemispherical crown.

The flow state in the original nozzle is relatively stable, and there is basically no swirl in it. Improve the No.1 nozzle, because the protruding hemisphere on the inner wall is small, which makes some swirling flow in the nozzle; The improved No.2 nozzle, due to the large hemisphere protruding from the inner wall, has a strong collision with the water flow in the nozzle, and there is obvious swirl in the nozzle, especially in the area near the hemisphere; The swirl produced in the improved No.2 nozzle is more obvious than that in the improved No.1 nozzle.

Acknowledgements

Authors are thankful to the supported by Liaoning Provincial Department of Education support (LJKZ0276).

REFERENCES

- [1] B.G. Thomas, Continuous Casting [J]. Yearbook of Science and Technology, (2004)1-6.
- [2] C.Y. Cai, et al. Research on the Influence of the Inner Wall Structure of the Continuous Casting Submerged Nozzle on the Stream of Molten Steel[J].Transactions of the Indian Institute of Metals, 75(2022)3, 613-624.
- [3] Z.F. Tong, F.P. Wang, J.L. Qiao, et al. Continuous casting tundish nozzle clogging mechanism and preventive measures[J]. Nonferrous Metal Science and Engineering, 7(2016)5.
- [4] Nobuyoshi Hiroki, et al. Development and application of annular step submerged entry nozzle[J]. Shinagawa Technical Report, 36(1993)75-88.
- [5] Tsukaguchi Y, Hayashi H Yuichi, Tsukaguchi, Hiroshi, et al. Development of Swirling-flow Submerged Entry Nozzles for Slab Casting[J]. ISIJ International, 50(2010)5, 721-729.
- [6] D.W. Li, Z.J. Su, Marukawa Yujo, et al. A new swirl continuous casting technology—electromagnetic swirl nozzle [J]. Continuous Casting, (2013)4, 18-21.
- [7] D.W. Li et al. Effects of Electromagnetic Swirling Flow in Submerged Entry Nozzle on Square Billet Continuous Casting of Steel Process[J]. ISIJ International, 53(2013)7, 1187-1194.
- [8] Y.L. Jin, Z.J. Gong, B. Wang, et al. Experimental study of PIV used in slab continuous casting mold flow field [J]. The Chinese Journal of Process Engineering, (2009) 9S1, 193-196.
- [9] H.Q. Yu Engineering Fluid Mechanics: Hydraulics-Second Edition [M]. Southwest Jiaotong University Press, 2007.
- [10] Z.Z. Han, J. Wang, X.P. Lan. FLUENT: Fluid Engineering Simulation Calculation Examples and Applications [M]. Beijing Institute of Technology Press, 2004, 4-10.

Note: The responsible translator for English is Zuoxun Hou, University of Science and Technology Liaoning, Anshan, China