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Development of a New Subermerged Entry Nozzle in Thin Slab Caster

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Abstract: The fluid flow in the mould of the thin slab continuous caster has a large influence on the quality of slabs and its productivity. The fluid flow pattern can be controlled by the SEN (Submerged Entry Nozzle) structure. Traditional SEN can not decrease the surface turbulence and penetration depth at the same time, especially at high casting speed. In order to improve the fluid flow in the mould, a new structure SEN—Dissipation SEN have been invented. The water modeling experiments proved that the dissipation SEN could satisfy the needs of fluid flow condition in the mould at high casting speed.

Key words: thin slab caster mould; dissipation submerged entry nozzle; water-model

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The thin slab continuous casting technology was exploited in 1980s. For the advantages of the faster solidification, the shorter working procedure, the lower cost and the less energy consumption comparing to the traditional caster, the thin slab continuous casting technology was developed all over the world. Many kinds of casting process systems such as CSP (Compact Strip Production) and ISP (In-lined Strip Production) technology were operated.

To satisfy the needs of high casting speed on the thin slab continuous caster, various SEN configurations have been developed [1]. Most of the submerged entry nozzles (SEN) designed for the thin slab continuous castings have two outlets. The stream from the outlets of SEN impinged the solidified shell and surface directly. Thus, the surface wave will increase while decreasing the impingement to the shell, and the impingement to the shell will be stronger while decreasing the surface turbulence. Therefore, the traditional SEN cannot satisfy the needs for the casting technology of high quality thin slabs safely at high casting speed.

To solve the conflict between the surface turbulence and impingement, dissipation principles have been introduced into the design of SEN.

The liquid steel flow from the one side of dissipation SEN was divided into two streams, one is upwards,another downwards. The two streams can impact each other near their outlets in the mould. Therefore, the impingement energy dissipated into all directions and the steel flow impacting the surface and the shell directly has been reduced. The steel exports at least have four outlets, and they can be divided into upward outlets and downward outlets. The range of the upward angle is from −15° to 45°, and the range of the downward angle is from 0° to 45°.

1 Water Model Experiment

In order to study the effect of the dissipation SEN, water-model experiments have been carried out. To compare the dissipation SEN with three practical configurations' SEN (shown in **figure 1**), most parameters were equal, such as the outlet area, the bore configuration, the immersion depth and the casting speed. The cut-open view of the SEN is shown in **figure 2**. The experiment conditions are shown in **table 1**.

Based on the similarity theory, three similarity criteria must be satisfied: geometry, movement, and dynamic similitude. Considering that the fluid flow pattern in the mould are dominated by inertia, gravity and viscosity, the Reynolds number and Frude number have been used in this experiment as similarity criteria. Therefore, a full-scale physical model of the thin slab caster mould was constructed using transparent plexiglas. Water is used as a liquid media similar to the molten steel, thereby both the Froude and Reynolds numbers as similarity criteria are invariant at any given volumetric throughout. The water model system is shown in **figure 3**.

The surface fluctuations and wave impetus depth were measured by using a water experimental system SG200. This system can measure the wave numbers, the wave heights, the maximum wave height and the flow penetration depth. A camera was applied to track

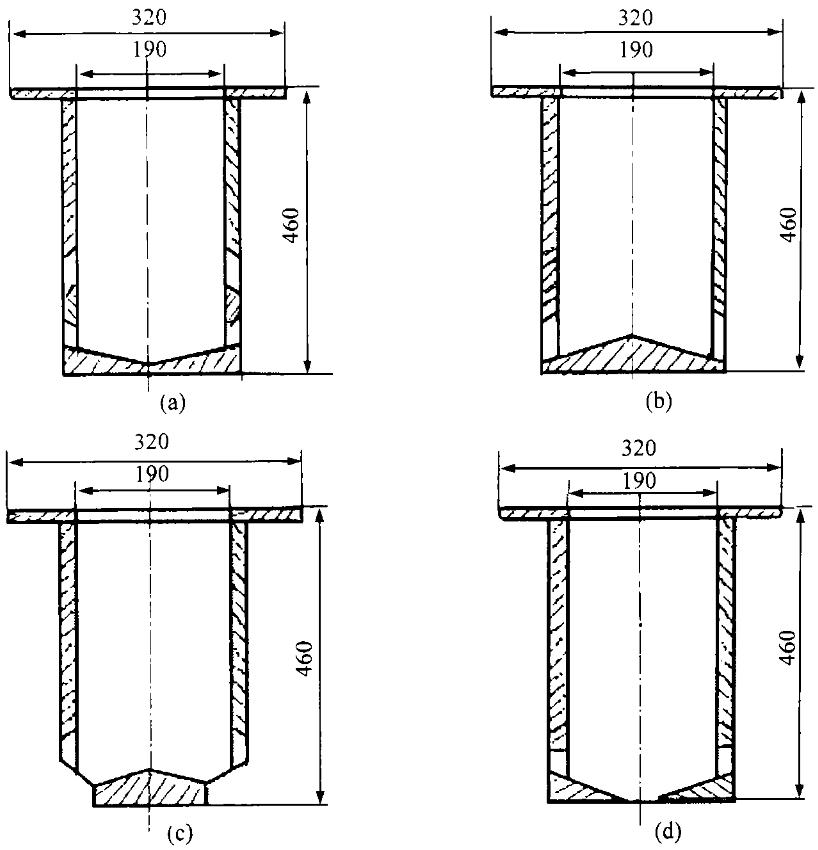

Figure 1 The configurations of SEN for experiment, (a) Dissipation SEN; (b) Ordinary SEN; (c) Reverse V-shape SEN; (d) T-shape SEN; unit: mm.

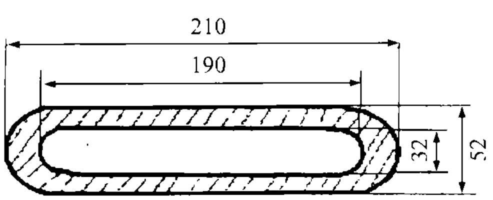

Figure 2 The bore crosses section, unit: mm.

Table 1 Experiment conditions

Mould configuration	Funnel-shape mould
Billet thickness / mm	50
SEN bore area / mm^2	5 860
SEN outlet area / mm^2	5 860
SEN configuration	4
Immersion depth / mm	280
Casting speed / $m \cdot min^{-1}$	6.0

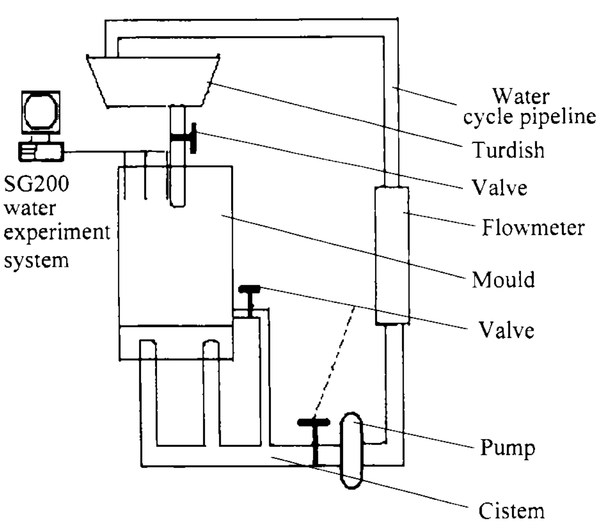

Figure 3 Experiment equipment

record and analyzed the fluid flow pattern.

2 Experiment Results

According to the requirements of steel solidification in the mould, two index of the fluid flow must be considered, one is the surface turbulence, the other is the impingement strength to the solidified shell. The surface turbulence determines the degree of mould flux entrapment and the interior quality of the slab. At the same time, the impingement strength determines the creation of a uniform shell and the surface quality of the strip. Both of them are important to produce the slab of high quality. The higher the surface wave is, the easier the mould powder entraps into the fluid. The deeper the fluid jet penetrates, the worse the uniformity shell is.

To avoid the influence of the incidental factor, the fluctuations at five points (from the mould center being 17, 25cm separately.) had been measured in each experiment conditions. The measurement time is 12 min.

2.1 Surface fluctuations

The mould flux entrapment factors were considered as follows [2].

(1) The entrance of powder at the negative pressure region as the result of asymmetry flow near the SEN. Therefore, the higher the surface wave is, the easier the mould fluxes entrap into the fluid flow.

(2) The immixture of powder near the meniscus is due to the unstable surface flow. So the higher the standing wave near the meniscus, the easier the mould fluxes entrap into the fluid flow.

Figure 4 shows the typical surface wave curve of each SEN, from this figure it can be seen that the surface turbulence of dissipation SEN is weaker than ordinary SEN, more suitable for casting.

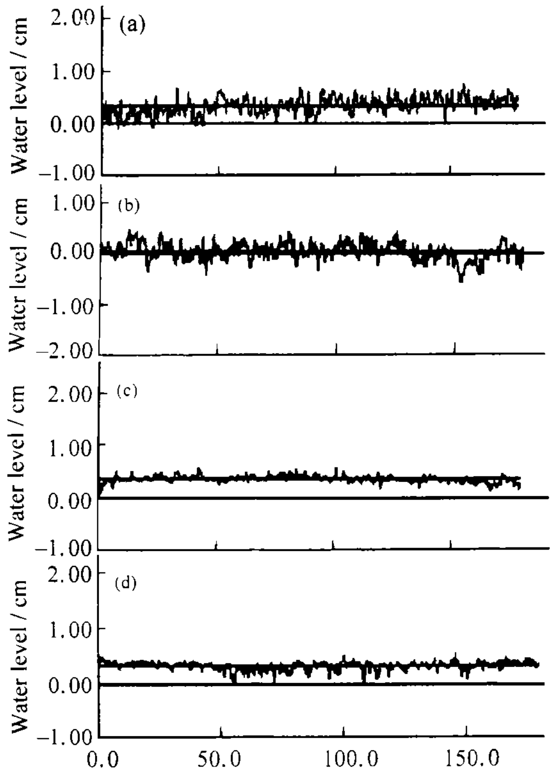

Figure 4 Typical wave curve of each SEN, (a) Dissipation SEN; (b) Ordinary SEN; (c) Reverse V-shape SEN; (d) T-shape SEN.

The average surface wave height and standing wave height were regarded as the surface fluctuation index. The value of surface fluctuation index can be seen in **figure 5** and **figure 6**.

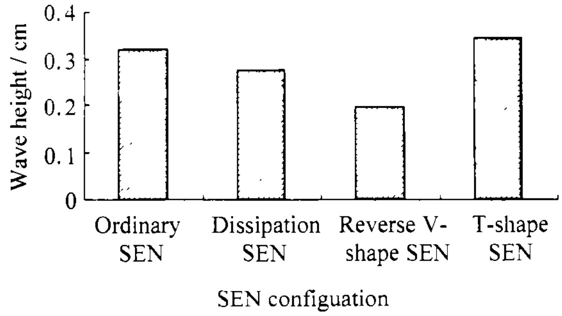

Figure 5 Average surface wave height of each SEN.

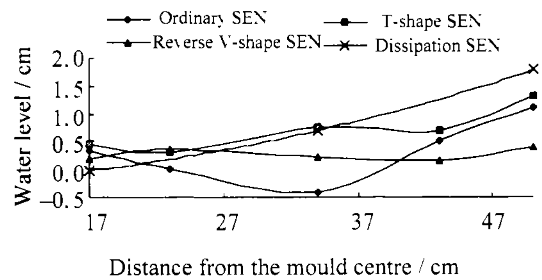

Figure 6 Average water level at each point

The higher the surface waves, the stronger the kinetic energy distributes on the surface, and the easier the powder entries the liquid steel flows due to the vortex formed by the negative pressure. However, in order to provide the heat to melt the mould powder, a little surface wave height is also needed. Figure 5 shows that the surface of Reverse V-shape SEN is much calmer and the T-shape SEN and ordinary SEN are much stronger.

The curve of average water level shown in figure 6 represents the standing wave of each fluid flow surface. The more smooth the curve, the calmer the surface turbulence. The higher the standing wave, the more surface kinetic energy, the easier the mould powder entries into the steel flow by the form of vortex. Figure 6 shows that the standing wave of the ordinary SEN is higher than other SEN. Combine with the result of surface wave height, it can be concluded that the ordinary SEN is easy to involve the powder.

The slab has more specific surface area in the thin slab continuous casting. For the characteristic of TSCC (thin slab continuous casting), the specific surface of billet was increased, then more mould powder were needed to melt for lubricate the slab surface. Moreover, the spaces that provide for the powder melting was decreased comparatively, therefore the upward circumfluence flow that can provide heat to melt powder was needed. If the fluid flow is too calm to provide liquid powder adequately, the accident of steel leak is easy to occur. Therefore, from the demands of powder melting the Reverse V-shape SEN is unfit for thin slab caster.

Figure 7 shows that the average surface wave height has increased with the casting speed increase. However, compare the curve position and slope, it can be seen that the surface waves of dissipation SEN are lower than those of ordinary SEN, and have a smaller slope with the casting speed increase. Thus, it can be concluded that the dissipation SEN is more suit for high casting speed and has more potential development than ordinary SEN.

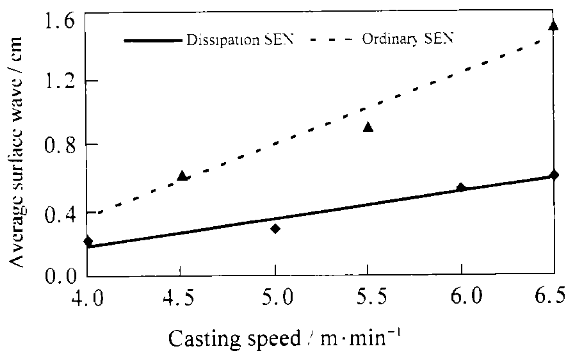

Figure 7 Relationship between surface wave height and casting speed

2.2 Impingement depth

The appropriate location of the steel flow impacts into the mould narrow-side is important. The penetration depth is the distance from the impact point to the fluid flow surface. The location of high-temperature region in mould will be lower with the penetration depth increase. For the impact of high-temperature steel from the SEN, the solidified shell will re-melt and weaken, therefore result in those problems such as steel-leaking in caster, inefficient of the billet cooling, spotty production and so on. Therefore, to prevent the weak surface fluctuation, a shallower penetration depth is benefit for production.

Particle tracer was applied in this experiment for the visualization of the fluid flow, thus the penetration depth could be measured quantitatively. The measured values are shown in **figure 8**.

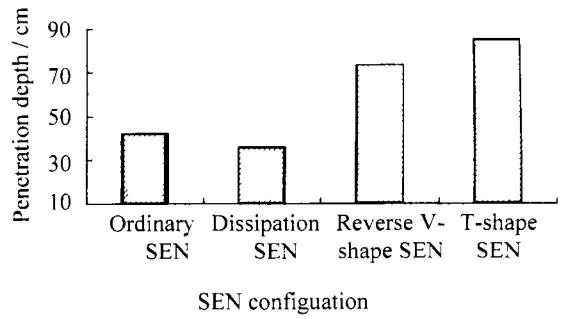

Figure 8 Penetration depth of each SEN

Figure 8 shows that the impingement depth of dissipation SEN is much less than that of T-shape SEN and Reverse V-shape SEN. The outflow from the T-shape SEN and Reverse V-shape SEN impacts the solidfied shell directly, thus these two types of SEN are unfit to thin slab caster.

3 Conclusions

(1) Traditional SEN has the limitation of impossible to decrease the surface turbulence and penetration depth at the same time, especially at high casting speed.

(2) The water experiments proved that the dissipation SEN not only decreased the surface turbulence but also reduced the penetration depth. This is a promising new structure SEN for thin slab caster at high casting speed.

References

[1] N. Y. Tian: *Thin Slab Continuous Cast*, Metallurgic industry press, Beijing, 1998, p1.

[2] J. Herbertson, Q. L. He, P. J. Flint, R. B. Mahapatra: [In:] *Steelmaking Conference Proceedings*, 1991, p. 171.

[3] Y. P. Bao, J. Q. Zhu, *et al.*: *Journal of University of Science & Technology Beijing*, 6 (1999), p. 15.