Enhancement of slab internal quality by electromagnetic stirring of molten steel

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Abstract
Internal defects in slab, such as centerline segregation, porosity and micro structure, affect to crack, tearing, surface defect, and mechanical discontinuity in plate. Electromagnetic stirring (EMS) is applied for a long time to achieve better internal quality of slab, especially with regard to the most demanding products. Removing the segregation and the porosity in a centerline of slab is quite difficult even if we apply the EMS and the soft reduction due to mush zone and narrow channel of liquids. Several sets of strand EMS were positioned in the region of bow section to stir liquid, and they were operated to generate several flow patterns. This work carried out optimization of EMS such as system configuration, design of flow patterns, stirrer position configuration, and stirring strength to enhance the internal quality of slab. Strong stirring of the molten steel to the wide range in front of crater end is a quite effective to enhance the internal quality of slab in addition to the reduction technology.

Key words : electromagnetic stirring, slab, solidification, internal quality

Introduction

Centre segregation and centre porosity are usually the main defect in continuously casted slabs, and these can be a major obstacle to produce high strength steel grades with qualified mechanical properties. Many technologies [1], such as a soft reduction and an electromagnetic stirring (EMS), are applied in strand region to overcome the internal quality problem. In spite of applying these technologies, the internal quality cannot be reached to the level of demanded quality. Thus, POSCO developed an innovative heavy strand reduction technology, PosHARP, in several years ago and improved the internal quality dramatically. Strong strand EMS was also adapted on that strand to enhance the internal quality in stable and uniform at the same time. This paper presents the results of installation and application of EMS in POSCO GY32 continuous casing machine.

Installation of heavy strand reduction segment and strand EMS

Soft reduction just avoids the fluid flow of solute-enriched liquid by pressing slightly the continuously cast slab at the end of solidification. On the other hand, PosHARP compresses the slab at high reduction rate in the middle stage of solidification, as shown in Fig. 1, using several rolls equipped on the segment in horizontal region of continuous casting machine. Compressing the slab results to squeeze solute-enriched liquid existing in the mid-thickness region of slab to upstream where a large amount of liquid still exists and homogenized. At the same time, both solidified shells contact each other at the centerline of slab. All these actions result in the negative segregation, which is not harmful for the internal quality of slabs and prevents the formation of shrinkage cavity at the centerline of slab.

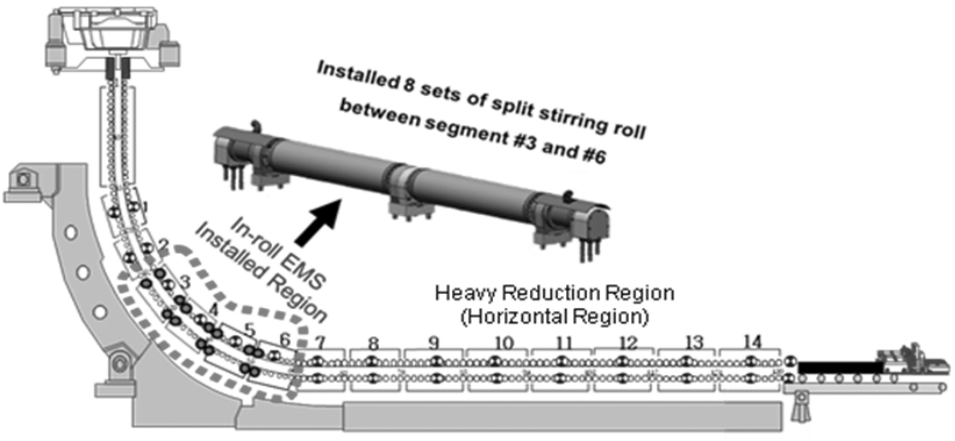

Fig. 1: Installation region of strand EMS and heavy reduction segment

Soft or heavy reduction of slab thickness plays important role to improve the internal quality. But, in some case, the uniformity of segregation distribution along the centre line is poor and the effect of the reduction is unstable even though the reduction technology was applied. Thus, the strand EMS was installed in upstream side segment compare to the reduction segment to enhance distribution uniformity and to achieve stable effect by stirring the squeezed liquid. Fig. 2 is an operation window of strand EMS. Travelling direction and time of magnetic field for each in-roll EMS can be controlled independently to generate various mode of liquid flow in strand.

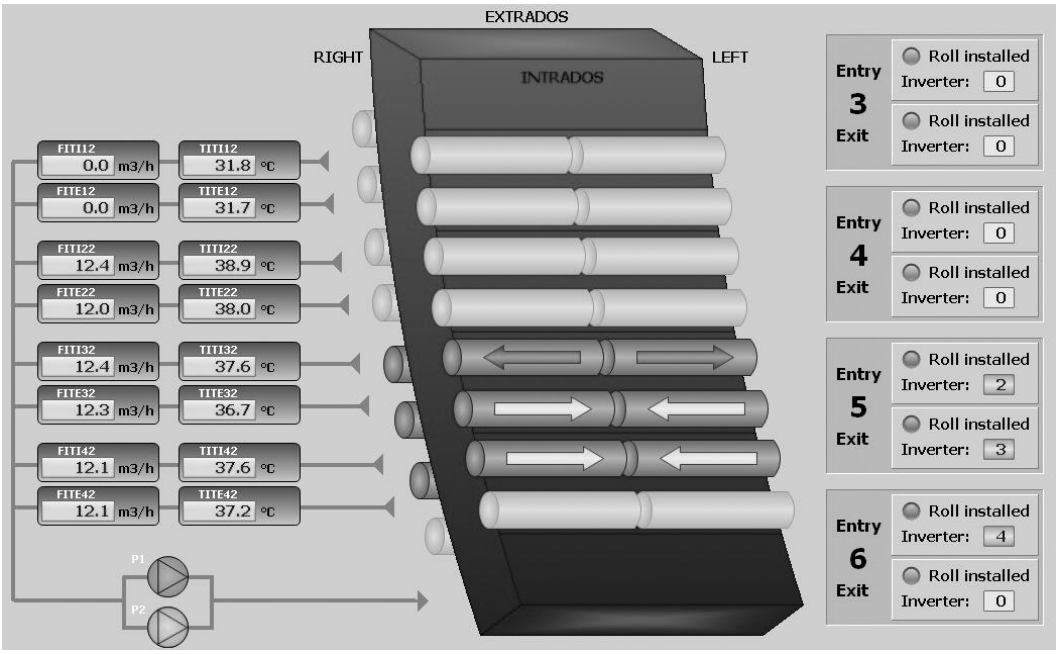

Fig. 2: Operation window of strand electromagnetic stirrer installed in POSCO GY32 continuous casing machine

Flow pattern control

Since divided roll type strand EMS was installed in segments of caster strand, several patterns of flow was designed such as double roll, quadruple roll, and multiple roll. Fig 3 shows one of the simulated flow patterns with strand EMS operation. Alternate operation, forward and reverse, achieved more uniform enhancement of internal quality in direction of slab width compare to continuous operation. Electric current was applied in EMS coil to generate a flow pattern of liquid as shown in right bottom part of Fig. 3, forward during 15 seconds, stop in 2 second, and reverse during 15 seconds. Maximum velocity of melt is 0.053m/s at the left edge of slab in the end of forward current flow with casting speed of 0.8m/min. According to the experimental results, this condition mixed the melt to break a solidification bridge in the center line of slab.

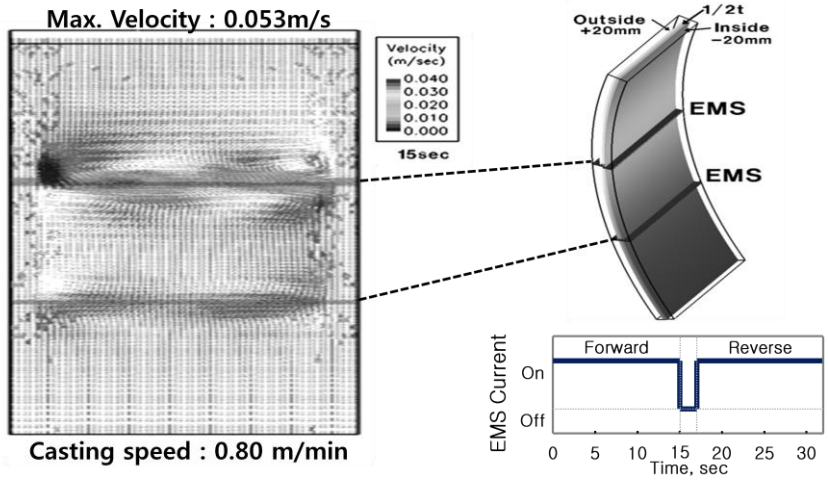

Fig. 3: One of the simulated flow patterns with strand EMS operation

Comparison of internal quality of slabs

Investigation of macrostructure and Mn segregation along a centerline of slab is one of the methods to evaluate the internal quality of slab. Fig. 4 shows the comparison of internal quality of slabs produced by soft reduction and PosHARP with EMS operation, respectively.

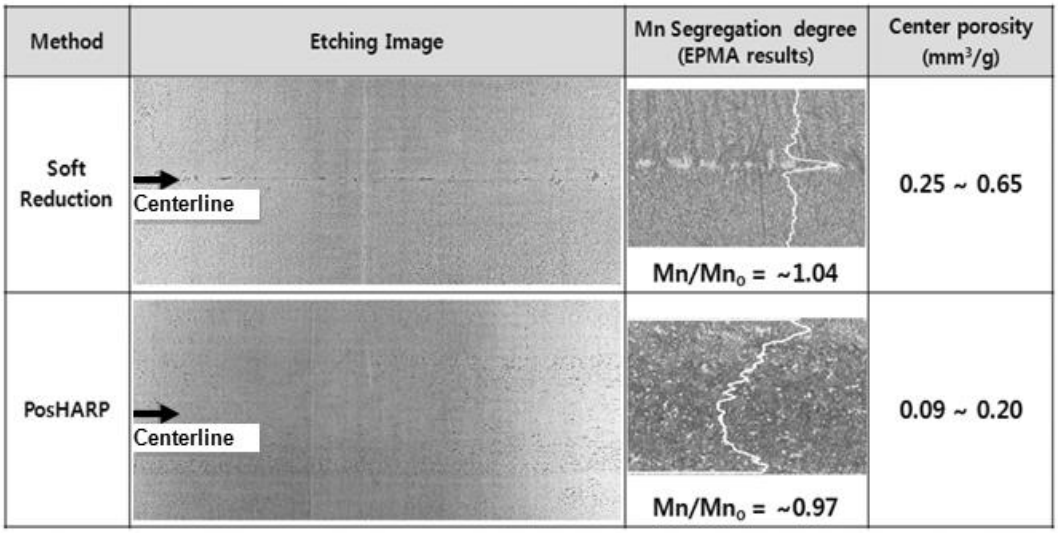

Fig. 4: Comparison of internal quality of slabs produced by soft reduction and PosHARP with EMS operation

As shown in the macrostructure of slab center, thick centerline segregation is observed in slab applied soft reduction only. On the other hand, segregation is hardly observed in slab applied PosHARP and EMS. It was also clearly confirmed in the EPMA results. While soft reduction slab has about 1.04 Mn segregation degree, PosHARP slab shows negative segregation because the solute-enriched liquid was squeezed to upstream. Also, applying POSHARP technology, the solidified shells of slab contact at the centerline and formation of shrinkage cavity reduces remarkably. Thus, center porosity of PosHARP slab is much less than that of Soft reduction slab.

Conclusion

Heavy reduction technology improved internal quality in significant and strand EMS has a role to enhance the uniformity and the stability of centerline quality. Flow patterns in the S-EMS installed region are critical to enhance the internal quality of slab. Optimization of flow pattern, EMS position is needed according to steel grade.

References

[1] The Making, Shaping and Treating of Steel, “Casting Volume”, AISE Steel Foundation, Pittsburgh (2003)