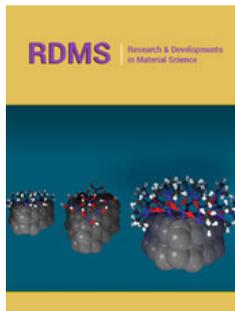


Applications of Electromagnetic Field to Continuous Casting Process of Steel

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Introduction

CC (Continuous Casting) process is regarded as a landmark technology, which had revolutionized steel production along with LD converter process. Toward SDGs, not only the technology which enables higher quality steel products with higher productivity but also the one which enables new steel products with distinctive features and quality, are of demand. Electromagnetic force has an advantage, that can control the fluid velocity field and temperature field without contact with molten metal [1]. Therefore, numerous technologies that apply electromagnetic field to the CC process have been developed and contributed to the marked technological progress of continuous casting process, as shown in Table 1. In this paper, among the main functions of electromagnetic field, the applied technologies to CC mold have been overviewed and new application of electromagnetic field has been proposed with consideration of magnetic property of steel.

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Table 1: Main functions of electromagnetic field and application examples.

Principle	Function	Field	Example
Lorentz Force	Flow Promotion	AC	Electromagnetic Stirring, Electromagnetic Pump
	Flow Suppression	DC/AC	Electromagnetic Brake, Wave Suppression
	Levitation	AC	Electromagnetic Casting, Cold Crucible, Levitation
	Solidification Structure Control	AC	Electromagnetic Stirring, Pulse Current Imposition
Joule Heating	Heating	AC	Induction Heating
		DC	Plasma Heating
Lenz's Law	Detection	AC	Level Sensor, Veocimetry, Slag Flowout Detection

(AC: Alternative Current, DC: Direct Current)

Control of molten steel flow with electromagnetic field

The application of EMS (Electro-Magnetic Stirring) to CC process has comparatively long history and first trial of EMS went back to 1960's [2]. Strand EMS opened the door of real application of EMS to CC machine at the late of 1970's [3,4]. The objective of Strand EMS is to acquire the high equiaxed zone ratio for the purpose of suppression of the center segregation. After that, in-mold EMS had been developed to improve the surface quality of slab by suppression of entrapment of nonmetallic inclusions and Ar bubbles to solidified shell [5].

In 1980's, in order to attain the high productivity of CC process, EMBr (Electro-Magnetic Brake) had been developed to stabilize the molten steel flow in CC mold. The first type of EMBr

is local magnetic field that a pair of DC magnets have been installed at the neighborhood of the SEN (Submerged Entry Nozzle) port and the imposed field brake the discharged flow from SEN directly [6]. The second type of EMBr is level magnetic field that uniform magnetic field in the width direction of mold, develops plug-like flow below magnetic field area [7,8]. One kind of second type of EMBr is FC mold (Flow-Control mold) that the imposition of a pair of level magnetic field at the upper part of CC mold, simultaneously stabilize the meniscus flow and descending flow along the narrow face of mold [9]. At present, the combination of EMS and EMBr have been also developed [10].

Takeuchi et al. [11] developed the continuous casting process for clad steel slabs by suppressing the mixing of molten steels in the strand with electromagnetic brake. In this process, two molten steels of different composition are simultaneously supplied through two submerged entry nozzles into the upper and lower pools in the CC mold to form the outer and inner layers, respectively. The casting principle had been verified by the pilot scale continuous casting experiments and numerical analysis.

Steel transforms magnetically from ferromagnetic to paramagnetic at Curie point and then to nonmagnetic at higher temperature. Noticing that the narrow face of slab has been cooled to around the Curie point at the beneath of CC mold and the deviated flow in CC strand leads to the difference of solidified shell growth, electromagnetic sensor measuring the slab surface temperature have been studied [12]. Plant tests by installing the sensors under the respective narrow face mold, have been performed to clarify that the proposed sensor could measure surface temperature of slab under severe conditions and detect the deviated flow in CC strand by using the estimated temperature difference.

Conclusion

This paper reviews the history of application of electromagnetic field to CC process. Various actuators have been developed to contribute to increase the productivity and improve the quality. As mentioned previously, the electromagnetic sensor can visualize the solidification phenomena in CC mold without any contacts. Further developments of sensors and actuators can control the solidification

phenomena in CC process in the advanced way. Moreover, the combination of numerical calculation and information technologies widen the potential of CC process toward Sustainable Development Goals.

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