OBSERVATION OF BUBBLE BEHAVIOR AFFECTED BY LORENTZ FORCE

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Introduction. Control of second phases in molten steel such as argon bubbles and inclusions is important for production of high quality steel. Water model experiments and numerical simulations have been used for investigating the behavior of the second phases in steelmaking processes. In continuous casting, electromagnetic brake (EMBr) has been used to control the molten steel flow in the mold. Hence, it is necessary to clarify the behavior of argon bubbles and inclusions in the molten steel under a magnetic field produced by the electromagnetic brake. Their behavior also has not yet clarified experimentally. Because there have been troubles to set up the experimental system to observe the second phase behavior affected by the Lorenz force except the successful result of Dresden group [1], it is required to develop a new experimental system in which one can observe the second phases directly by using an electrically conductive transparent fluid. In this system, Lorentz force does act on the fluid under a magnetic field. On the other hand, water model experiments have been used for investigating the behavior of argon bubbles in molten steel. In these experiments, however, the effect of Lorentz force is negligible. Here, we propose use of a transparent strong electrolyte solution. Imposition of a static high magnetic field on the solution produces Lorentz force, which affects the behavior of argon bubbles. The present study gives new knowledge about the effect of Lorentz force on the bubble behavior.

1. Experimental setup. A rectangular acrylic vessel was filled with saturated sodium chloride aqueous solution and was set in the bore of a superconducting magnet generating a horizontal static magnetic flux density. An argon gas bubble was injected from the bottom of the vessel through a copper nozzle. The bubble motion was recorded by a high-speed camera to evaluate the bubble passing time of a certain distance in both the cases with and without the magnetic field. The effect of the magnetization force on the bubble motion is negligible in this experiment because the ratio of the magnetization force to the Lorentz force acting on the bubble is 0.05 in this experimental condition. The 3mm bubble diameter in this experiment corresponds to the 2mm diameter in the continuous casting process from the viewpoint of the similarity of the Froude number, and it corresponds to the 0.3mm diameter from the viewpoint of the similarity of the ratio of the Lorentz force to the buoyancy force, and it corresponds to the 0.6mm diameter from the viewpoint of the similarity of the Hartmann number, respectively.

2. Experimental result. Table 1 shows averaged passing times and standard deviations of bubble passing time of 30 mm. Under the imposition of the 7 T magnetic field on the sodium chloride aqueous solution, the averaged passing time of the bubbles is 0.1310 s, while it is 0.1265 s under the imposition of the 0 T magnetic field. The standard deviation of bubble passing time without the magnetic field is 0.0034, while it is 0.0060 with the magnetic field.

Table 1. Averaged passing time and standard deviation of bubble passing time.

Bubble diameter $2r$, mm		Without magnetic field (0 T)	With magnetic field (7 T)
3	Averaged passing time t/s	0.1265	0.1310
	Standard deviation of bubble passing time s/s	0.0034	0.0060

The difference of the averaged passing time between with the magnetic field and without the magnetic field is 0.0045s. This value is larger than the time interval of each picture recorded by the high-speed camera, $1/240\,\mathrm{s} = 0.00416\,\mathrm{s}$. Thus, it is concluded that the averaged passing time becomes longer by imposing a magnetic field. This might be the result that the liquid motion surrounding the bubble is suppressed by the Lorentz force.

3. Conclusion. To clarify the gas bubble behavior in a liquid metal submerged in a magnetic field, we used the model experimental system in which a high magnetic field is imposed on a saturated sodium chloride aqueous solution. In the model experiment, the rising velocity of an argon gas bubble in a saturated sodium chloride solution is suppressed by imposing a horizontal high magnetic field.

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