学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Solidification and Segregation in Continuously Cast Steel

(鋼の連続鋳造における凝固と偏析に関する研究)

In this study, the approximate analytical solutions for the solidus temperature which strongly depends on the steel composition were sought as the part of the solutions of the nonlinear heat- and solutes- transfer equations in the mushy zone of the continuously cast steel. Because the conventional theories of the solidification of the multicomponent steel were not well grounded due to the highly nonlinear phenomenon complicated by the time depending phase change interface. Neither analytic nor approximate solutions existed that describe the relation between the size of the mushy zone (the solid-liquid coexisting zone) and the volumetric energy generation. In addition, owing to the lack of the reliable measurements in the real casting process due to the difficulties of measurements, the significant discrepancies exist between the estimates of the solidus temperature and the thermo-analytical measurements by the small specimens of the various grades steel. This may cause the considerable errors in the accuracy of the numerical heat analysis to estimate the shell thickness and the solid fraction at the target point in the mushy zone of the continuously cast steel.

The simultaneous solutions of the non-linear heat- and solute- transfer equations were difficult to obtain at once, therefore, the problems were resolved step by step through the three models, assuming the linear relation between solid fraction and temperature in the mushy zone.

(1) Model Ⅰ: Develop the mathematical treatment to simultaneously solve the heat- and solutes- transfer equations, with the simple boundary conditions (Dirichlet conditions), adopting the measured solidification constants which represent the boundary positions with respect to time. (2) Model Ⅱ: Incorporate the Neumann's boundary conditions (i.e., equal derivative values at the boundary front and back) which are generally used in the numerical analysis for the solid- liquid zone in the model. The solidification of the Fe-C binary steel was investi-

gated to make the model as simple as possible. The model predictions were in good agreement with the numerical heat analysis and were also consistent with Neumann's solution in the low carbon range. (3) Model Ⅲ: Obtain the solidus temperature of the multicomponent general steel by expanding the Model Ⅱ to the multicomponent steel. The predicted solidus temperatures of the various grades steel were in reasonable agreement with the measured zero ductility temperature of the high manganese steel and the thermo- analytical measurements. It was shown that the conventional numerical heat analysis, such as the equivalent specific heat method, adopting the solidus temperature predicted by the model, was in good agreement with Model Ⅲ. The model can reduce the extensive numerical computational load to seek the solidus temperature.

The models and the predicted solidus temperature were, subsequently, used in the numerical heat analyses to estimate the solid fraction at which the electro magnetic stirring was applied in the continuously cast steel slabs. The industrial findings with these numerical heat analyses and the analog study with Pb-Sn alloy showed that the stirring at the low fraction solid was important to refine crystals and to improve the macro-segregations, in the continuously cast steel.