[Research Activities]

KITAMURA Laboratory (2008.4–2009.3)
Base Materials Processing Research Field
Research Center for Sustainable Materials Engineering

The production processes of base materials, such as iron- and steel-making processes, belong to an age of technical innovation toward an eco-friendly society. To support this innovation, fundamental studies are being conducted in our laboratory.

Dr. Farshid Pahlevani joined our laboratory as an Assistant Professor (Research) in April. He is Iranian and employed as a Postdoctoral Fellow to develop a simulation model of hot metal dephosphorization. Further, three new students of the Masters course—Mr. Shinpei Ono, Mr. Akifumi Harada, and Mr. Tetsuro Hotta—joined us. Mr. Kristofer Malmberg stayed with us for 5 months since July 2008 as a visiting researcher. He is Swedish and a student of the Masters course at the Royal Institute of Technology. He has investigated the interaction of inclusion and solidification shell using the confocal scanning laser microscope. Dr. David G.C. Robertson, Professor of Missouri University of Science & Technology, stayed with us for 4 months since September as a Visiting Professor. He is famous as the developer of the coupled reaction model and has provided us with many results through lectures on the modeling of the refining reaction, discussion with staff, and guidance to the students. In October, Ms. Fericia Murai Lazuarudi retired, and on December 17, she gave birth to a cute baby girl. Ms. Megumi Obara was employed from November to support the general affairs of the laboratory. In March this year, four of our students—Mr. Keita Utagawa, Mr. Koichiro Kimura, Mr. Shinji Takeda, and Mr. Toshiaki Maeyama—graduated and started their new careers.

This was the fourth year after the opening of this laboratory, and active research was carried out in this year. The simulation model of hot metal dephosphorization using multiphase slag was adopted as the basic model of the research project of the Iron & Steel Institute of Japan (ISIJ). This project was commenced in April for developing an industry-applicable model. Further, the research project of the ISIJ, entitled “The Structure and Composition Change of Non Metallic Inclusions in Solid Iron” was commenced this year. This project was proposed by our group, and Professor Kitamura was designated as its leader.

The research activities of this year are summarized as follows:

1. Improvement in Reaction Efficiency by use of Multiphase Slag
   
   [Prof. Shibata & Prof. Kitamura]

   This research was aimed at establishing a highly efficient dephosphorization process that can be used to decrease slag generation, by increasing the reaction efficiency to the maximum level. Further, it can
satisfy the requirements of an efficient refining process by using low-quality raw materials in the future.

1.1 Mass Transfer of Impurities between Solid Oxide and Liquid Slag (Mr. Utagawa; M2)

A solid solution of dicalcium silicate (C$_2$S) and tricalcium phosphate (C$_3$P) was prepared by a sintering method. The rod-shaped sintered solid solution was dipped into molten slag saturated with the same solid solution, and the interface was observed. When the activity of P$_2$O$_5$ in liquid is greater than that in the solid solution, the transfer of P$_2$O$_5$ from the liquid slag to the solid solution and the melting of a part of the solid solution were observed. In contrast, when the activity of P$_2$O$_5$ in the liquid slag was lesser, the transfer of P$_2$O$_5$ from the solid solution to the liquid slag was not observed (Figure 1).

1.2 Simulation Model of Hot Metal Dephosphorization by Multiphase Slag (Dr. Pahlevani; PD)

Most of the dephosphorization slag is saturated with the dicalcium silicate (C$_2$S) phase in which P$_2$O$_5$ can be dissolved. A kinetic model of dephosphorization by considering the effect of the solid phase in the slag was developed. The application of this model to the BOF steelmaking process was established. An outline of the model is illustrated in Figure 2. This model was selected as the basic model of the ISIJ Project and rewritten using C++ to shorten the calculation time.

1.3 Distribution of P$_2$O$_5$ between Solid Solution and Liquid Slag (Dr. Pahlevani; PD)

When the solid solution was precipitated from the liquid slag by the decrease in temperature, P$_2$O$_5$ was distributed between the solid solution and the liquid slag. The distribution ratio was already measured in the slag of a CaO-SiO$_2$-P$_2$O$_5$-Fe$_2$O$_3$ system, and a good relation of the distribution ratio with (T.Fe) in the slag was observed (Figure 3). The measurement of the system in which FeO was used as an iron oxide was performed.
2. Separation and Recovery of Rare Metals from By-product of Steelmaking Process

[Prof. Shibata & Prof. Kitamura]

2.1 Recovery of Manganese from Steelmaking Slag using Sulfuration [Mr. Hotta (M1)]

Steelmaking slag contains many valuable elements such as manganese and chromium. The purpose of this research was to investigate the possibility of recovering these elements using pyrometallurgical technologies. As phosphorus is distributed in the metal phase by a simple reduction technology, it is difficult to use the recovered metal. To separate phosphorus from manganese, the technique of sulfurating the slag and forming a FeS-MnS matte was proposed. The experimental equipment to measure the distribution of manganese between the slag and the matte was installed.

3. Process Design of Highly Efficient Reactors by Enlargement of Reaction Interface

[Prof. Maruoka & Prof. Kitamura]

An improvement in the reaction rate can cause an increase in the productivity of high-grade steel and a decrease in heat loss during the treatment. The rate-controlling step of the reaction is different in each treatment. In this research, technologies for increasing the interfacial area of the reaction and the dissolution rate of lumpy materials in slag were investigated.

3.1 Evaluation of Reaction Rate at Bath Surface in Gas-liquid Reaction System [Ms. Razuarudi-Murai]

The influence of bottom bubbling on the surface reaction rate was evaluated by the measurement of the oxygen removal rate in a water model. As illustrated in Figure 4, it was found that the measured volumetric rate constants of the surface reaction were closely related to the plume eye area. To evaluate the surface reaction rate at the plume eye area to that at another area separately, the entire surface except for the plume eye region was covered by styrene and the reaction rate was measured. The thickness of styrene on the surface was changed to evaluate the reaction rate at the plume eye.

3.2 Condition for Forming Metal Emulsion by Bottom Bubbling [Mr. Maeyama(M2)]

To increase the interfacial area by the formation of metal particles suspended in the slag phase (called metal emulsion), the influence of the bubbling gas flow rate and the physical and chemical properties of the metal and slag phases on the emulsion formation behavior were investigated. An experimental method using lead as the metal phase and slat as the slag phase was established. As salt can be dissolved in water,
suspended lead particles can be separated in this system. By applying a special method for suppressing the formation of hydrate, many lead particles were observed, as shown in Figure 5.

3.3 Dissolution Rate of Lumpy Oxide in Molten Slag [Prof. Maruoka]

To determine the dissolution rate of fluxes such as lime, dolomite, and silica in molten slag, lumpy fluxes used in industry were added to the molten slag. The dissolution rate was evaluated on the basis of the composition change in the slag. The experimental procedure was established.

4. Effect of Non-metallic Inclusions on Kinetics of Solidification, Phase Transformation, and Precipitation in Steel [Prof. Shibata & Prof. Kitamura]

4.1 Change in Oxide & Sulfide Composition by Heat Treatment [Mr. Kimura (M2) & Mr. Harada (M1)]

Recently, it has been reported that both the composition and the distribution of oxides change during annealing of austenitic stainless steel. This research was aimed at elucidating the possibility of applying this phenomenon to material design. The change in oxide composition by the heat treatment of a Fe-Cr alloy and the influence of Cr, Si, and Mn contents on this behavior were observed. From the observation carried out using a field-emission-type scanning electron microscope, the precipitation of the MnO-Cr₂O₃ phase from the MnO-SiO₂ inclusion phase by the heat treatment was observed as shown in Figure 6. Rods of MnO-SiO₂ oxide and steel were contacted at 1673 K for 2 h under high compression pressure. At the interface, the composition gradient was observed in steel and in the MnO-Cr₂O₃ phase formed in the oxide phase.

The influence of the composition change on the precipitation behavior of MnS in the oxide was also investigated.

4.2 Interaction between Nonmetallic Inclusions and Solidification Shell [Mr. Malmberg (KTH, Visiting Researcher)]

During the solidification of steel, some kinds of inclusions are trapped by the solidification shell, but the others are pushed out. To elucidate this phenomenon, the solidification front of steel with various deoxidation methods was observed by confocal scanning laser microscopy.
4.3 Heterogeneous Nucleation of Iron-based Alloy [Prof. Shibata]

For obtaining a suitable steel structure, it is of importance to control the nucleation site of steel during solidification. Nonmetallic inclusions are required as nucleants in the case of steels. In this research, the contact angle between pure molten iron and several single-crystal oxides and its relation with supercooling behavior were evaluated by using a sessile drop technique under a precisely controlled oxygen pressure. It was elucidated that the change in the impurity content of a liquid droplet by the formation of a reaction layer had a large influence on the supercooling behavior. Further, this year, the future research plan was discussed.


5.1 Transport Properties of Zr-based Bulk Metallic Glass [Mr. Takeda (M2)]

Using the laser flash technique, the thermal diffusivity of Zr-based metallic glass was measured in a wide temperature range, i.e., in the solid state from room temperature to near the melting temperatures and the liquid state. In addition, the density, specific heat, and electric conductivity of the glass were measured. On the basis of these results, the critical cooling rate and maximum diameter of the specimen for forming metallic glass were evaluated.


6.1 Direct Formation of High Purity Solid Steel by Hydrogen Gas [Mr. Ono (M1)]

Because of the extremely low oxygen potential, impurities such as phosphorus and silicon are also reduced by the blast furnace process. On the contrary, reduction by hydrogen can possibly result in the production of high purity steel directly, as the oxygen potential can be controlled. In this research, distributions of phosphorus, manganese, and silicon between molten slag and solid steel were investigated. The equipment was installed and the experimental method was established.

6.2 Reduction in Radioactive Waste by Low Activation Steel [Prof. Kitamura]

Whenever a nuclear power plant is shut down, large amounts of steel scraps are generated. Since these scraps are radioactive wastes with low energy levels, their disposal incurs a very high cost. Such scraps can be recycled and used by decreasing the amount of radioactive elements in the steel scraps. The distribution ratio of cobalt between slag and metal was investigated, and low temperature and low basic slag were found to exhibit a high distribution ratio. This year, the project was summarized and the next step was discussed.

6.3 Utilization of Stainless Steel Slag by Mixing with Nonferrous Slag [Prof. Maruoka]

The dusting behavior of slag generated by the stainless steel refining process, which is caused by the phase transformation of dicalcium-silicate during cooling, is one of its disadvantages for the utilization of stainless steel slag. On the other hand, in some cases, the slag generated by nonferrous smelting contains heavy metals. The aim of this research was to develop a novel technology for utilizing slag generated by
the industrial linkage of ferrous and nonferrous metallurgies. Basic researches on the dusting behavior of slag and the distribution behavior of heavy metals between slag and metal phases have been conducted. This year, another method for utilizing nonferrous slag in the steelmaking process was discussed.