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Research and Development at Nippon Steel (Three-part Series: 2)
—Collaboration of Three R&D Pillars and Integration of Research, Development and Engineering—

Operating Roundup

Financial Results for Fiscal 2004
Consolidated sales for fiscal 2004 (April 1, 2004 to March 31, 2005) came to ¥3,389.3 billion, a gain of ¥463.4 billion over the previous year, and consolidated operating profits ¥429.9 billion, or an increase of ¥205.4 billion.

“Documents: Consecrating to the Earth”
(A series of fieldwork installation by Kei Tsuji)
—Contribution for May 2005—
Installation in Karelia, Finland (2000)

Born in Tokyo 1953, Kei Tsuji displays her installations, centered on dyeing and weaving, in deserts, woodlands and waterfronts the world over. Produced through a fieldwork approach, her installations represent a continuous pursuit of the connection between herself (dyed and woven cloth) and the realm of time and space (principles of the natural world).
R&D at Nippon Steel *(Three-part Series: 2)*

**The Pursuit of Next-generation Products and Innovative Processes**

—A Serious Challenge Addressed By All Nippon Steel Researchers Through Knowledge Consolidation—

Nippon Steel promotes an array of integrated technological development activities ranging from basic and fundamental research to application development and engineering. This is done through close collaboration between the R&D Laboratories of Nippon Steel’s seven steelworks and the nucleus of this effort, the Research and Engineering (R&E) Center that began operation 13 years ago. Technological development at Nippon Steel is supported by the following five strengths:

- Solution technology development that is well in advance of other companies
- Greater developmental agility provided by the fusion of research, development and engineering
- A customer-oriented technological development system
- Environmental and energy technologies based on iron- and steelmaking processes
- Development efforts that capitalize on collaboration between industrial and academic sectors, as well as alliances with overseas partners

The topics addressed in this issue, and in the preceding and following issues, were featured in a round-table discussion by Nippon Steel researchers who speak exhaustively about their on-going work and about future tasks at three key R&D facilities—Steel Research Laboratories, Advanced Technology Research Laboratories and Environment & Process Technology Center. Development of customer-tailored products and solution technologies at these facilities is moving rapidly ahead.
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Participants at the round-table discussion (from left to right)

Akihiro Uenishi, Senior Researcher, Forming Technologies R&D Center, Steel Research Laboratories
Akihiko Kojima, Senior Researcher, Steel Products Research Lab.-II, Steel Research Laboratories
Masaaki Sugiyama, Chief Researcher, Materials Characterization Research Lab., Advanced Technology Research Laboratories
Shigeru Oshita, General Manager, Technical Development Planning Div. (moderator); currently Director of Steel Research Laboratories
Michio Nitta, Manager, Refractory Ceramics R&D Div., Environment & Process Technology Center
Kenji Kato, Chief Researcher, Ironmaking R&D Lab., Environment & Process Technology Center
By taking advantage of oxide metallurgy, a heritage left by our predecessors that was accumulated through integration of the steel plate-rolling and steelmaking departments, I aspire to improve the characteristic properties of steel virtually to their feasible limits.

—Akihiko Kojima, Senior Researcher

I want to introduce and develop advanced analytical technologies that are optimal for helping needs and seeds to spiral upward, thereby responding to technological tasks that arise on the job site or in the market.

—Masaaki Sugiyama, Chief Researcher

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Collaboration of Three R&D Pillars—Materials Development, Application and Processing Technology Development and Analytical Technology

Oshita: The strong point of R&D activity at the R&E Center lies in the fact that groups of researchers and equipment engineers with professional knowledge in diverse fields work together in one place. This helps to create an environment in which experts in their respective fields can engage in a freewheeling exchange of ideas that, in turn, accelerates technological development. Let’s talk about the state of collaboration in research on iron and steel.

Kojima: Analytical technology is of prime importance to promoting steel research. For instance, in cases when we attempt to increase the toughness of steel, analytical technology gives a clear image of the target product, especially with regard to the creation of microstructures containing fine particles scaled at several tens of nanometers. When conducting a trial 300-ton manufacturing run of a steel product on the production floor, such guiding images, or “evidence” of product analysis, serve as a cohesive force that focuses the attention of everyone involved on a common goal, thereby expediting the developmental process. Such a “cohesive force” is essential to any large-scale production-floor test that involves many people.

As a bridge in the transfer of seeds acquired in fundamental research to the production floor, each R&D Lab. of the respective steelworks plays a significant role that is essential to spanning what Japanese people term the “Valley of Death” in R&D. In the development of HTUFF technology, too, the R&D Lab. formed a link between the R&E Center and the steelworks production floor. This made it possible to press ahead with large-scale production-floor testing and eventually to commercialize the technology.

In this way, success in developing HTUFF technology was the result of interdisciplinary R&D efforts. It is worth noting that the researchers and engineers working in the downstream process of plate manufacturing joined forces in this endeavor with their counterparts in the upstream steelmaking process. This is a wonderful corporate culture, a tradition acquired during the first generation of oxide metallurgy.
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**Sugiyama:** The microstructures of steel products are drastically different between high and low temperatures, and its control during a cooling process is very important. The use of advanced analytical technology reveals how the microstructures go through characteristic changes caused by fine precipitates during the transformation from an austenite into a ferrite phase. In order to control changes in microstructure, the key on the viewpoint of the metallurgy is only to exert control over the precipitates. It has become clear that, furthermore, when a grain boundary movement occurs, the precipitates serve a “pinning function” (as stoppers). We are also attempting to control these stoppers. One of the missions entrusted to the materials characterization research section is to gain an accurate understanding of the phenomena that actually occur during heating and cooling processing using an in situ observation at high temperature, or by any other appropriate means.

In the world of oxide metallurgy, “1st-generation” phenomena were first analytically studied and then clarified with regard to their mechanisms. Based on this, the concept of changing precipitates and other novel approaches were devised, opening the way to new “2nd-generation” and “3rd-generation” developments. At times when we attempt to raise the level of technology from one generation to another, we need an absolute technology for understanding mechanisms—i.e., materials characterization technology. According to this situation, since I am personally in a position to show final data or solutions essential to product development, I am under constant pressure to pursue materials characterization.

**Oshita:** What kinds of products and technologies are now most urgently required? To answer this, you must always remain sensitive to such market needs, don’t you?

**Sugiyama:** Just as Mt. Fuji looks different depending on the season and time, a precipitate property in steel appears quite different manner with its product conditions and the information about it varies depending on the precipitate site and its timing. Unless we fully understand the background of a phenomenon in close cooperation with the production and development sections, instead of merely analyzing it, we cannot arrive at a correct solution. Namely, “unless we deliberately look into an object, its true nature will never be revealed.”

**Uenishi:** For the development of automotive steel sheets, the strength of intra-company collaboration is brought fully into play. Our seven steelworks throughout the country, together with their R&D Labs., maintain close relations with their users, the automakers. Any medium- or long-term tasks that come to the fore in these relationships are transferred to the R&E Center for the rapid development of solutions. In the case of research on forming technologies, a targeted quality is to be set by combinations of seeds from fundamental metallurgical studies and needs from formability.

On the occasion of the start-up of a high strain-rate tensile testing machine, engineers working at the Environment & Process Technology Center (then known as the Plant Engineering & Technology Center) immediately designed a mechanical device to bear substantial impulse loads that were beyond the capabilities of ordinary mechanical testing machines. They did this by drawing upon experience accumulated through the operation of iron- and steelmaking facilities. I became keenly aware of the great power inherent in the high concentration...
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of human resources having expert knowledge in diverse fields. Today, in order to clarify such macroscopic phenomena as crash and stamping, the need to understand the movements of defects in or under sub-micron scale inside materials is increasingly recognized. In light of this, too, I realized the advantage of having a cluster of skilled human resources in one place.

Sugiyama: Currently, the need for a microscopic perspective in the design of steel materials extends beyond materials development to the stages of processing and utilization.

In fact, the analysis of microstructures now goes back to the phenomenon of dislocation*. This means that the micro- and nano-level analyses that we conduct are closely related to automobile safety, environmental soundness and other matters of significance in daily life. That is exceptionally gratifying. In addition, intra-company collaboration sharpens the senses of every researcher and engineer involved, thereby enlarging the scope of our collaboration in both breadth and depth.

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*Dislocation: A local 2D imperfection in iron crystals—Materials deform macroscopically due to the collective movement of dislocations.
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R-D-E Integration Magnifies the Strengths of Equipment and Process Technologies

Oshita: Equipment and process technologies, in particular, are areas that benefit from the advantages inherent in an integrated technological development system based on collaboration among research, development and engineering. Can you offer specific examples of such collaboration?

Kato: I think that the development effort in the SCOPE21 project was a good example of R-D-E (research, development and engineering) collaboration, a unique feature of the R&E Center. What contributed greatly to this project were the results of fundamental research conducted by the Materials Characterization Research Lab., Advanced Technology Research Laboratories of Nippon Steel. This research examined the principles underlying an improvement in the caking property of coal by means of rapid preheating. With the conventional method, coal fluidity was assessed at temperatures of approximately 400 to 500°C, using a Gieseler plastometer. But, in an experiment using a high-temperature nuclear magnetic resonance (NMR**)

**NMR: Nuclear magnetic resonance—This mechanism is identical to medical MRI (magnetic resonance imaging) and is used to analyze material structures by observing the release and absorption of energy by atomic nuclei.

Advanced Research into Ironmaking Process

Next-generation Coke-making Process SCOPE21

Recycling Waste Plastics by Means of “Coke-oven Chemical Materials Recycling Technology”

With the aim of structuring a sustainable, recycling-oriented society, Nippon Steel has developed and succeeded in the practical use a waste plastic recycling technology that makes efficient use of the coke ovens used in ironmaking. With this technology, both waste plastics and coal are carbonized in coke ovens to be recycled as chemical materials. This technology has been approved as a recycling method under the Container Packaging Recycling Law, that was fully implemented in 2000, and is highly regarded because it can recycle nearly 100% of all waste plastics. A specific feature of this technology is that chlorine generated by the waste plastics can be made harmless through contact with ammonia derived from the coal. At Nippon Steel’s steelworks, coke oven chemical materials recycling technology is used to process annually about 160,000 tons of waste plastics for recycling.

Kenji Kato
Chief Researcher, Ironmaking R&D Lab.
Environment & Process Technology Center
spectrometer, coal was carbonized in a test coke oven while being subjected to rapid preheating. The behavior of the coking ingredients that continued to transform on that occasion was analyzed. In 2000, a paper detailing the results of this analysis was presented with the Tawara Best Paper Award by the Iron and Steel Institute of Japan.

Sugiyama: In the area of ironmaking, analytical technology is increasingly being applied to coal, coke and iron ore. In particular, the research group engaged in materials characterization from the perspective of chemical structures maintains a strong alliance with the group involved in ironmaking. Efforts to explore the possibilities of applying medical “MRI” technology in the steel industry led to the development of new probes and software etc. I hear that, by viewing materials on an entirely different aspect, the two groups having a different professional have often developed new and valuable ideas.

Nitta: Research into refractories also lies within the realm of the natural sciences. Consequently, the fact that refractories wear out is a natural phenomenon that must be properly assessed as...

***Kuniichi Tawara: World-renowned metallurgical scholar

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Development of the TiC-added Carbon Block, a Refractory for Withstanding Harsh Blast Furnace Operating Conditions

**Boundary Conditions of TiC Carbon Block with Molten Iron**

- Molten iron side (after solidification)
- Carbon block

**Distribution of iron**

The titanium component of the carbon block elutes out of the surface to form a high-viscosity protective layer, about 100 μm (0.1 mm) thick. When stabilized, this layer imparts highly effective erosion resistance to the carbon block, which is then protected from erosion by the molten iron.

**Demolition Surveys: Condition of refractories at furnace bottom just after blasting (No. 2 blast furnace at Oita Works)**

Carbon-type refractories were first used in blast furnaces in Germany during the 1920s. In 1952, Nippon Steel was the first company in Japan to introduce these refractories and remains the only steelmaker engaged in development activities associated with these materials. The company is the top competitor in the field of refractories.

Nippon Steel developed the TiC-added carbon block as a refractory material at the end of 2003. Its specific area of application is just below the tap hole where blast-furnace operating conditions are harshest. In the erosion-protection mechanism of this refractory, a high-viscosity protective layer is formed on the surface of the refractory by utilizing a phenomenon in which the addition of titanium increases the viscosity. The flow of molten iron, chemical and physical erosion, and other in-furnace phenomena were grasped in detail and then reproduced in the laboratories. It was here that where and why of refractory erosion were clarified, and it was this that led to the successful development of the new TiC-added refractory materials.

**Michio Nitta**
Manager, Refractory Ceramics R&D Div.
Environment & Process Technology Center
By advancing into the inside of materials at micro- and nano-levels, including methods for manufacturing, I hope to develop novel functions that are useful in meeting new application needs.

—Akihiro Uenishi, Senior Researcher

My desire, from a broad-ranging perspective, is to realize an alliance among industries for the construction of a sustainable recycling-oriented society.

—Kenji Kato, Chief Researcher

such. In order, then, to systematically advance the development of a new type of refractory through the stages of research, development and practical application, it is necessary to correctly understand the mechanism of erosion. This knowledge must be shared among all the researchers and engineers concerned. For instance, we came up with a conceptual picture of iron and titanium blending to form a viscous layer. But, more importantly, we had to explain in tangible form, using samples and data, what actually occurs on refractory surfaces that come into direct contact with molten iron in a blast furnace. At this time, we conferred with Mr. Sugiyama about how we could quantitatively detect a viscous layer that might be formed due to a reaction between iron and trace amounts of titanium. He helped us derive an ideal analytical method for accurately understanding what actually occurs on refractory surfaces. This then provided definitive analytical data clarifying the mechanism for forming a viscous layer. My impression at that time was: “When we came to a deadlock, we discussed it with an expert as if it were nothing important, only to rectify the situation quickly.” Since research laboratories dealing with different areas are in close proximity, we have only to walk around within the R&E Center with materials under our arm to gain an abundance of essential information.

Sugiyama: We are always ready to tackle the development of new analytical technologies. At the same time, one of my more important roles is to offer advice on what analytical methods would be most effective for arriving at optimum solutions and to promptly convey this information to both the affected development sections and the production floor. I believe that this scheme is made possible only by the integration of the research and development sections, another merit of the R&E center.

Oshita: Another major advantage, particularly given the fact that blast furnaces are currently being relined at several of our steelworks, is that engineers working at the Environment & Process Technology Center have some degree of experience in blast-furnace operations. It’s true, is it not, that engineering refractories for blast furnace relining entails a great deal of trouble.
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**Nitta:** Since refractories weighing hundreds of tons are arrayed at the furnace bottom, it is necessary to check the durability of the completed structure as a whole, in addition to the erosion resistance of individual refractories. During the course of relining, it is important to synchronize the engineering work with surveys looking into deterioration and other refractory defects, because such information cannot be extracted while a blast furnace is in operation. When relining a blast furnace in a relatively limited period, only a short amount of time is available for dismantling, thereby making it essential that all necessary information be gathered in an abbreviated survey period. Nevertheless, it is reassuring that the availability of any test sample would allow us to conduct an advanced analysis of it. Again, the integration of operations from research at the laboratory level to engineering and on-site surveying is a major strength of Nippon Steel.

**Oshita:** Refractories are indispensable materials for the vessels used in the iron- and steelmaking processes. Including the reheating furnaces, all of these vessels handle high-temperature molten iron and steel. Since erosion has a detrimental effect on the quality of the steel produced, the development of new furnace materials is an elementary technology of paramount importance.

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**HEAD OFFICE**

Public Relations Center
General Administration Div.
6-3, Otemachi 2-chome, Chiyoda-ku, Tokyo 100-8071, Japan
Phone: 81-3-3242-4111
Fax: 81-3-3275-5607

**OVERSEAS OFFICES**

**New York**
Phone: 1-212-486-7150  Fax: 1-212-593-3049

**Chicago**
Phone: 1-312-751-0800  Fax: 1-312-751-0345

**Mexico**
Phone: 52-55-5281-6123  Fax: 52-55-5280-0501

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Phone: 49-211-5306680  Fax: 49-211-5961163

**Sydney**
Phone: 61-2-9252-2077  Fax: 61-2-9252-2082

**Singapore**
Phone: 65-6223-6777  Fax: 65-6224-4207

More about Nippon Steel on the website: [http://www.nsc.co.jp](http://www.nsc.co.jp)

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**Bangkok**
Phone: 66-2-744-1480  Fax: 66-2-744-1485

**São Paulo**
Phone: 55-11-3371-4040  Fax: 55-11-3371-4041

**Beijing**
Phone: 86-10-6513-8593  Fax: 86-10-6513-7197

**Shanghai**
Phone: 86-21-6841-1812  Fax: 86-21-6841-5529

**Guangzhou**
Phone: 86-20-8386-8178  Fax: 86-20-8386-7066

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*My goal is to use the constituent technologies associated with refractories to conduct research on the creation of large schemes or processes.*

—Michio Nitta, Manager

*Currently Director of Steel Research Laboratories*