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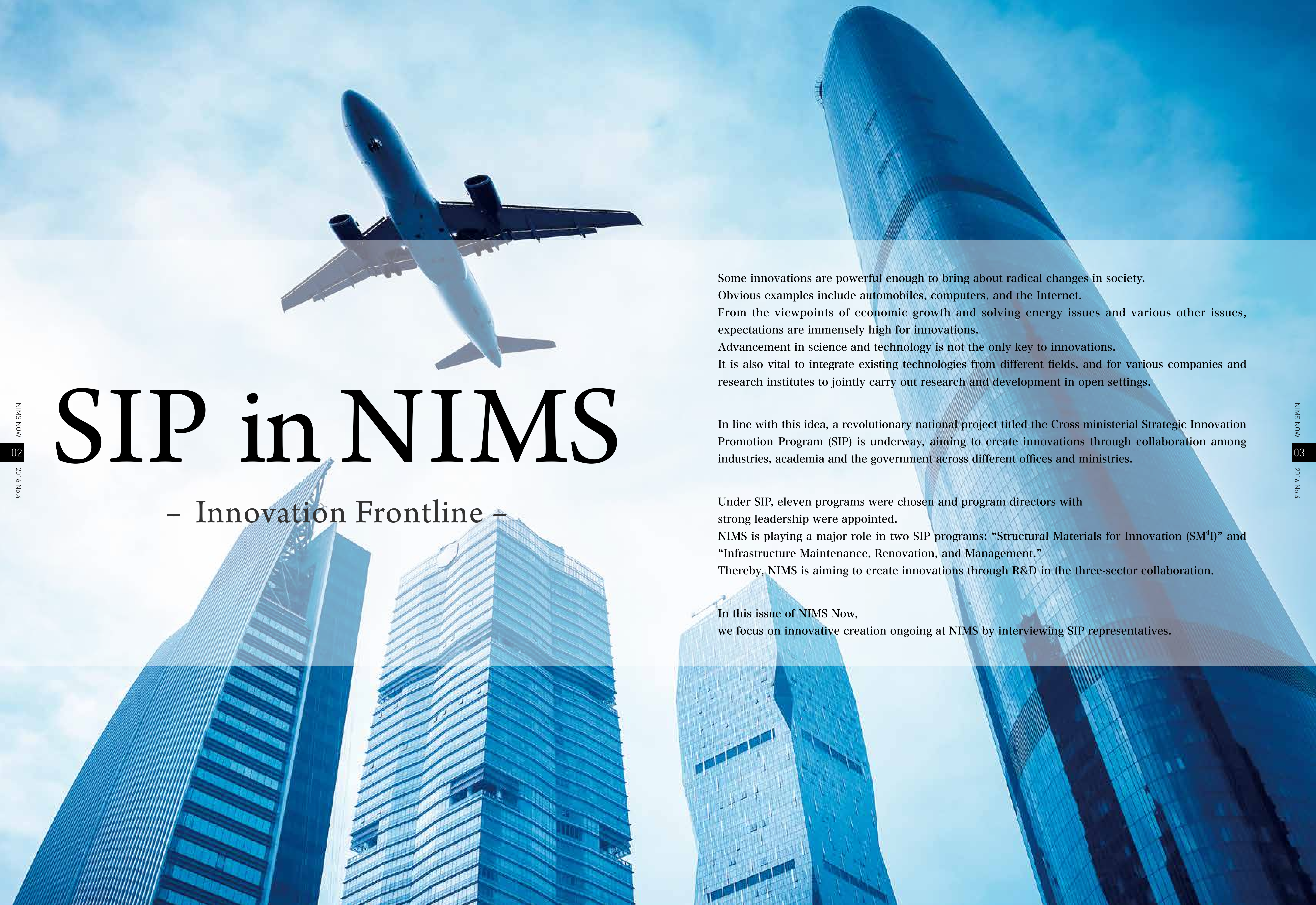
SIP in NIMS

– Innovation Frontline –



SIP in NIMS

– Innovation Frontline –

Some innovations are powerful enough to bring about radical changes in society.
Obvious examples include automobiles, computers, and the Internet.
From the viewpoints of economic growth and solving energy issues and various other issues, expectations are immensely high for innovations.
Advancement in science and technology is not the only key to innovations.
It is also vital to integrate existing technologies from different fields, and for various companies and research institutes to jointly carry out research and development in open settings.

In line with this idea, a revolutionary national project titled the Cross-ministerial Strategic Innovation Promotion Program (SIP) is underway, aiming to create innovations through collaboration among industries, academia and the government across different offices and ministries.

Under SIP, eleven programs were chosen and program directors with strong leadership were appointed.
NIMS is playing a major role in two SIP programs: “Structural Materials for Innovation (SM^{4}I)” and “Infrastructure Maintenance, Renovation, and Management.”
Thereby, NIMS is aiming to create innovations through R&D in the three-sector collaboration.

In this issue of NIMS Now,
we focus on innovative creation ongoing at NIMS by interviewing SIP representatives.

Japan's innovation strategy and the ambitious SIP program

Kazuo Kyuma

Executive member,
Council for Science,
Technology and Innovation,
Cabinet Office

The Cross-ministerial Strategic Innovation Promotion Program (SIP) aims to achieve total R&D steps—from basic research to the development/commercialization of final products—in five years. The Council for Science, Technology and Innovation (CSTI) at the Cabinet Office takes charge of SIP. We asked Dr. Kazuo Kyuma, who is CSTI member and chair of the SIP Governing Board, about Japan's innovation strategies and SIP.

— The 5th Science and Technology Basic Plan, which is the Japan's overall plans in the field of science and technology for the next five years, started in April 2016. What is the feature of the plan?

Kyuma The 5th Science and Technology Basic Plan was the first plan made by the CSTI after the Council for Science and Technology Policy (CSTP) was reorganized into the CSTI. The industrial sector was fully involved in the plan-making process. The plan predicts ideal future forms of the industrial structure and social system for Japan, and specify the kinds of scientific/technological innovations necessary to realize these forms. These concepts were newly added to the fifth plan, and that is a major change from the previous versions.

The ideal form of Japan we predict refers to the realization of a "super smart society" named "Society 5.0," with which Japan aims to solve both economic and social issues, so that living conditions of all citizens will be improved, using information and communications technology (ICT). The industrial sector proposed the name "Society 5.0" based on the concept that scientific and technological innovations will advance Japan to a new phase of society after its transitions from a hunting society to an agricultural society, to an industrial society, and then to an information society.

The super smart society consists of cyber-physical systems—the integration between actual physical space and virtual cyberspace. Japan has strength in hardware industries associated with physical space but is weak in software industries associated with cyberspace. It is critical for Japan to fully strengthen ICT and create new industries through scientific/technological innovations, while taking advantage of its strength in the hardware industry. An increase in industrial competitiveness and economic growth are essential to put Society 5.0 into practice in Japan.

But, how will we create innovations? It is critical for industries, academia, and government to make real collaboration. I believe the key to success is twofold: These three sectors should clarify their respective roles and authorities and fulfill their responsibilities, and when they work together in R&D, they should have clear exit strategies.

— What are the vital roles of NIMS and academia in the 5th Science and Technology Basic Plan?

Kyuma Every researcher should have the strong resolve to put Society 5.0 into practice, thereby making strong industries and wealthy society. Accordingly, researchers have to undertake not only the kinds of studies that aim to solve immediate problems but also the kinds of studies that industries cannot perform. Moreover, researchers need to develop basic technologies. By sowing seeds of innovations in this way, it is possible that society will benefit from the continuous flow of scientific and technological accomplishments.

— Before the 5th Science and Technology Basic Plan started, SIP was launched to promote collaboration across ministries and among industries, academia, and government. Could you tell us the circumstances that led to the initiation of SIP?

Kyuma When I joined the CSTP in 2013, I noticed two things: Different ministries work in isolation, and both academic and industrial sectors were not functioning normally in the aftermath of the Lehman's collapse. Since other CSTP members also shared the same sense of crisis as mine, we started two programs in June 2013. The first one is SIP, which aims to make the entire R&D process, from basic research to commercialization, in five years through the cross-ministerial approach and industry–academia–government collaboration. And the other is the Impulsing Paradigm Change through Disruptive Technologies Program (ImPACT), which aims to create disruptive scientific/technological innovations.

Under SIP, we selected 10 programs in September 2013 and additional program in November 2015. All these programs are important economic and social issues in Japan. As these SIP programs are quite important for Japan, we have considered to succeed all of them. We chose program directors (PDs) with strong leadership through an open recruitment process. We assigned PDs from industries for the programs closely linked to the industrial sector, such as those concerning automated driving systems and energy carriers, and assigned PDs from academia for the programs dealing with social issues regarding infrastructure and disaster prevention/reduction.

— Dr. Teruo Kishi, an Emeritus Advisor of NIMS, is serving as a PD for "Structural Materials for Innovation (SM^4I).

Kyuma The aim of that program is to develop innovative high-strength, heat-resistant, and lightweight materials for aircraft and power generators. One of the research groups in the program is making development of the materials integration system, which is a fusion of experiments, theories, computational science, and data science, and is drawing much attention. Moreover, the group installed a large, precise forging simulator at NIMS. Taking account of these achievements made, the program is making good progress under the strong leadership of Professor Kishi, who has rich experience in both the academic and industrial sectors.

NIMS researchers are also participating in the program of "Infrastructure Maintenance, Renovation, and Management," and developing materials such as corrosion-resistant reinforcing steel and concrete repairing materials. These are very important technologies, although it might take some time to complete them. I really hope that the research group will make a huge impact by developing valuable industrial use products.

— Almost two years have passed since the initiation of individual SIP programs. What is your opinion regarding the progress of the overall SIP program so far? Also, what kind of impact do you think the program will have after completion?

Kyuma The program is making very good progress overall. I think the good progress is attributed to the fact that we clearly defined the role, authority and responsibility of PDs and exit strategies in terms of products to be commercialized in five years. For research groups who are a bit behind schedule, we need to urge them to catch up so that at the end, we can achieve a perfect record: 11 wins and zero losses.

As part of the SIP initiatives, we are creating bases for collaborative research and research facilities available for shared use. The forging simulator at NIMS is one of such achievements. If we stop using these assets after SIP ends in five years, it will be a waste of the resources. So it is important to make them available for continued use. Also, taking advantage of the CSTI's higher hierarchical position compared to ministries, we should continue to promote collaboration among different ministries, and extend the duration of SIP or launch similar projects to replace SIP.

— What is your view on NIMS's efforts to create innovations?

Kyuma I know that NIMS is playing a leading role in facilitating collaboration with industries. But I also want NIMS to play an even greater role in leading the open innovation program. With the fund and outstanding researchers from collaborating companies, the program will make research achievements and apply them to the commercialization of new technology in very short time. I believe that the program is working effectively, as NIMS has brilliant researchers and has accumulated many excellent technologies. I hope NIMS will make super R&D accomplishments that give the surprising efforts to the scientific community.

(by Shino Suzuki, PhotonCreate)

Researchers should undertake studies with the ambition to make society better and to make Japanese industry more competitive.

Special Interview 1

Program Director of SIP Structural Materials for Innovation (SM^{4}I)

Teruo Kishi Professor Emeritus, The University of Tokyo
Emeritus Advisor, NIMS

Strong, light, and heat-resistant innovative structural materials for revolutionizing Japan's aviation industry

— What is the aim and significance of the SIP Structural Materials for Innovation (SM^{4}I) program?

Kishi Its aim is to develop revolutionary structural materials that are strong, lightweight and heat-resistant, and to make them available to transport and energy industries for use as aircraft materials, etc., thereby increasing energy conversion/use efficiencies.

I am also serving as a president of the Innovative Structural Materials Association (ISMA), which was launched in fiscal 2013. At ISMA, we are developing strong and lightweight materials with high strength-to-weight ratios, with the goal of applying them to automobiles and vehicles. This project is commissioned by the Ministry of Economy, Trade and Industry, as well as the New Energy and Industrial Technology Development Organization (NEDO). On the other hand, in the SIP Structural Materials for Innovation (SM^{4}I) program, being led by the Cabinet Office, we are also developing strong and lightweight materials with an added heat-resistant property, and enhancing their manufacturing processes. The goal of this program is to apply these new materials to aviation and power generation industries. In addition, there is a third project called the Elements Strategy Initiative for Structural Materials, launched in fiscal 2012 by the MEXT[*1]. Through these three projects, we are dealing with critical issues in the development of innovative structural materials in Japan. There are high expectations for SIP participants to spearhead this whole movement by promoting collaboration between the Cabinet Office and relevant ministries, and among industry, academia and government.

There is a globally common notion that only truly advanced nations are capable of developing leading-edge materials. Japan's industrial materials for export are highly reputable internationally, and their export values are about to surpass the export values of Japanese automobiles in recent years. At the same time, some emerging countries are rapidly catching up in this field. Given the situation, it is important for Japan to develop innovative structural materials ahead of other countries, which will strengthen Japan's global competitiveness and raise the standard of Japanese industry.

— There are four research areas in the SIP SM^{4}I program: polymers and fiber-reinforced plastics, ceramic coatings, heat-resistant alloys intermetallic compounds, and materials integration (MI). NIMS is playing a major role for the latter two areas. Among them, MI is the central feature of the program as it applies to three other research areas.

Kishi MI denotes the fusion among theory, experiment, computational science and data science in the field of materials science, and it is clearly distinctive from conventional simulations. Its objectives are to develop materials efficiently and reduce development cost and time drastically. The idea of MI emerged in efforts to fuse three fields related to materials science: computations, measurements and materials, which was initiated at the GREEN[*2] launched in fiscal 2009. MI is a new concept that firmly links four key elements for structural materials development: processing (e.g., welding), metallographic structure (e.g., particle size), property (e.g., strength), and performance which is time and environment dependent (e.g., fatigue, corrosion and creep). Other similar projects have been implemented in Japan and overseas including the Materials Genome Initiative (MGI) in the United States. But MI is truly unique for its approach to integrate these four elements mentioned above.

— The group in charge of developing heat-resistant alloys and intermetallic compounds completed the installation of a 1,500-ton forging simulator at NIMS during the second year of the SIP initiative.

Kishi In materials science, forging and other plasticity processing are mainstream and very important structure control methods. There is a world-class, 50,000-ton forging press in Japan. To utilize this press to the fullest potential, we plan to collect a variety of material data using the recently acquired forging simulator. I have great hope that in the future, new technologies to process metal parts and to control materials property will be developed, including forging technologies applicable to titanium alloys and nickel-based alloys that are used for aircraft engine disks.

— Lastly, please tell us how the SIP program is progressing and what your expectations for NIMS are.

Kishi We are checking the progress of materials development using technology readiness level (TRL), an index for estimating the capability of resolving technological issues. We are currently about 1.5 years into the program, and have slightly less than three years left. While we have made steady progress in all areas of the program, the really critical stage of the program is yet to come. I also hope for NIMS to make good progress in materials development in the next three years. Also, after the completion of this program, I hope that NIMS will serve as Japan's premier structural materials R&D hub.
(by Kumi Yamada)

*1 Ministry of Education, Culture, Sports, Science and Technology
*2 Global Research Center for Environment and Energy based on Nanomaterials Science

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Special Interview 2

Program Director of SIP Infrastructure Maintenance, Renovation, and Management

Yozo Fujino Distinguished Professor,
Institute of Advanced Sciences, Yokohama National University

Creating "attractive technologies" to users in dealing with aging infrastructure

— Please tell us about the circumstances behind the adoption of the SIP Infrastructure Maintenance, Renovation, and Management program, and the characteristics of the program.

Fujino Much of Japan's infrastructure, including roads, bridges and tunnels, was constructed nearly 50 years ago, during the period of rapid economic growth. To prevent accidents similar to the one that occurred in the Sasago Tunnel in 2012[*1], adequate technologies are needed to maintain and repair aging infrastructure.

Normally, the MLIT[*2] and the MAFF[*3] are in charge of maintaining infrastructure, but for the first time, a cross-ministerial research project was launched to maintain infrastructure, involving the MEXT[*4] and the METI[*5]. The project is also carried out collaboratively by infrastructure construction industries as well as companies, universities and research institutes with expertise in advanced technologies related to sensors, information, materials, etc. This is a groundbreaking, but also challenging, initiative. I conducted studies with researchers specialized in measurements, information and other fields in order to apply advanced technologies to bridge engineering, my specialty. I hope this approach will bring success to the project.

— There are five R&D objectives in this project. Please tell us about specific actions being taken to achieve these objectives.

Fujino The first objective is to develop inspection, monitoring, and diagnostic technologies that will enable field workers to comprehend the condition of infrastructure non-destructively, quickly, effectively and at low cost. The second objective is to develop robotics technologies capable of performing inspection and repair even in places inaccessible to humans, e.g. high places, narrow places and disaster sites. They also may be useful in making up for labor shortage. The third objective is to develop information and communications technologies. It has become mandatory to inspect 700,000 bridges and 10,000 tunnels in Japan once every five years. These technologies are vital in terms of collecting, analyzing, utilizing and applying a vast amount of information. The fourth objective is to develop structural materials, deterioration mechanisms, repairs, and reinforcement technologies. They will be used to develop materials resistant to salt corrosion and freeze damage and materials that are easily repairable, and to identify mechanisms of material deterioration. And the fifth objective is to develop asset management technologies, which are critical for the success of the project.

— What are asset management technologies?

Fujino They are the systems that will realize preventative maintenance with actual application to infrastructure by combining all technologies developed in the first four objectives. Preventative maintenance is performed to predict the future state of infrastructure deterioration based on inspection and monitoring data, and to effectively repair them before they are severely damaged. Such system will enable preventing accidents due to aging infrastructure, and reducing maintenance cost.

— In this project, NIMS is taking part in the development of corrosion-resistant reinforcing steel, a repair agent which easily form waterproof film on the surfaces of concrete, and sheets that make cracks in concrete visible by changing their colors.

Fujino Deterioration of concrete resulting from the corrosion of reinforcing steel is a major problem in areas near the sea and cold regions where people sprinkle salt to prevent freezing. Accordingly, the development of corrosion-resistant reinforcing steel is a particularly important matter. NIMS is reputable in advanced materials research at both basic and applied levels. I have high expectations for NIMS for the development of useful materials. I should note, however, that in this project, we are aiming to develop technologies that are attractive to people who actually use them, such as corrosion-resistant reinforcing steel, and not leading-edge technologies from the viewpoint of researchers. To meet this end, it is important to consider the kinds of problems users want to resolve and the kinds of technologies users want to acquire, and convey that information to basic researchers so they can conduct R&D with clear objectives. I want all basic researchers, including those at NIMS, to more deeply observe, feel and know actual infrastructure.

— What are the goals of SIP at its completion?

Fujino Our goal is practical application of all technologies being developed. Europe and the United States are also facing similar issues of aging infrastructure. In Asia, construction of infrastructure is taking place in many locations, but its maintenance is already becoming an issue. At present, we are the only group across the world who is developing infrastructure maintenance technologies in a cross-organizational manner. We are considering applying technologies we are developing in this project overseas.
(by Shino Suzuki, PhotonCreate)

*1 Ceiling of the tunnel collapsed and crushed three vehicles. Nine people died and two were injured.
*2 Ministry of Land, Infrastructure, Transport and Tourism
*3 Ministry of Agriculture, Forestry and Fisheries
*4 Ministry of Education, Culture, Sports, Science and Technology
*5 Ministry of Economy, Trade and Industry

NIMS & new forging simulator

Construction of one of the world's largest forging simulators completed! Revolutionizing processing technology for heat-resistant alloy components

The SIP Structural Materials for Innovation (SM^{4}I) program, led by Program Director Teruo Kishi, has four research and development themes, focusing on components of aircraft engines and airframes. Yoko Mitarai, a Deputy Director-General of the NIMS Research Center for Structural Materials (RCSM), is leading one of the SM^{4}I projects: the development of heat-resistant alloys and intermetallic compounds. Also, the RCSM-SIP Laboratory, situated in the RCSM, is playing a central role in coordinating and promoting activities of industries, universities and the governmental organizations taking part in the project. We asked Mitarai, who is also a Director of the lab, about the objectives of and specific activities in the project.

The number of in-service aircraft in the world, particularly of small and medium sizes, is expected to double in the next 20 years. From the perspective of energy and environmental conservation, it is of paramount importance to increase the fuel efficiency of aircraft engines. The higher the fuel combustion temperature is, the higher the fuel efficiency is. To apply this principle to aircraft engines, it is critical to develop more heat-resistant alloy components. R&D of such components and processing technology has been carried out mainly in Europe and the United States, and competition among countries is intensifying.

Amid the situation, NIMS has initiated the PRISM (PRocess Innovation for Super-Heat Resistant Metals) project under the framework of the aforementioned SIP program. The PRISM researchers are striving to develop innovative processing technologies for the development of heat-resistant alloy components to be used in aircraft engines ahead of other countries amid the fierce global competition.


New large forging simulator in NIMS

Aiming to bring a breakthrough to the aircraft industry

Mitarai explains the objectives of the PRISM project, saying, "In this project, we are aiming to develop innovative processing technologies for efficient development of heat-resistant alloy components with desirable properties, which will be used in aircraft engine."

In Japan, intuition and experience of veteran technicians at forging companies have played a major role in the development of heat-resistant alloy components. However, in this trial-and-error approach, it takes a long time to develop new alloy components with desirable properties.

A unique thing about the aircraft industry compared to other industries is that all aircraft components produced must be certified internationally. Since European and U.S. aircraft manufacturers serve as certificate providers, aircraft components developers in Europe and the U.S. work in tandem with these manufacturers. In contrast, Japanese companies developing aircraft components are in tough situations—when they receive orders from European and U.S. companies, they must provide the components with the requested properties more quickly to the clients than their European and the U.S. counterparts.

Mitarai says, "To overcome Japan's disadvantageous situation, we came up with the idea of acquiring a forging simulator comprehensively consisting of the following: a large experimental forging press, capable of precise control of temperature and other conditions; databases based on various types of data collected in forging experiments; and computational prediction tools for reliable estimation of alloys' metallographic structures and properties."

Understanding the relationship among forging conditions, alloys' metallographic structures and their properties

Yoko Mitarai

Deputy Director-General, Research Center for Structural Materials (RCSM), Laboratory Director, SIP-Forging Lab, RCSM

In terms of metal processing technology, forging denotes shaping of metals by heating, compressing and hammering them using tools and dies. Depending on the temperature, load and cooling-down period selected for a forging process, the resulting metallographic structures vary greatly. Accordingly, metal properties that affect components reliability, e.g. tensile, fatigue and creep properties, also differ considerably.

Currently, the development of large metal components, including those for aircraft engines, is achieved by means of forging. However, implementation of this method is becoming more difficult as the strength of alloys has dramatically increased. There is a world-class, 50,000-metric ton forging press in Japan, owned by Japan Aeroforge, Ltd. To utilize this press to its fullest potential, it is ideal to quickly identify beforehand optimum manufacturing process conditions to create alloy components with desirable properties. The large forging simulator is highly suited for this purpose. By collecting various data obtained by the forging simulator under different conditions, researchers can determine the relationship among forging conditions, alloys' metallographic structures and their properties. Then, using the data and computational prediction tools, researchers can calculate and recommend optimum forging conditions to create alloy components with desirable properties. Subsequently, researchers should be able to efficiently and more quickly develop desirable alloy components without solely relying on veteran technicians' intuition and experience.

NIMS as premier research hub for heat-resistant alloys

Mitarai's first task in the PRISM project was to develop a forging simulator capable of conducting 1,500-metric ton forging experiments. Two kinds of heat-resistant alloys—titanium alloys and nickel-based alloys—will be the target materials.

The vision of acquiring a forging simulator existed as early as eight years ago, and parties involved gave it serious consideration as they were motivated by the SIP initiative. The installation of the simulator on the premises of NIMS began in November 2015. After many trials and errors, the construction of the simulator was successfully completed in March 2016. "Companies participating in the PRISM project had conflicting requests for the simulator, so it was very difficult to finalize its specifications. Moreover, it was a very rare occasion to install such a large system at NIMS, and we had to set up the system including preparation of the premises and infrastructure without a clear direction. So, we are very relieved now for at least having completed setting it up," says Mitarai.

This forging simulator is special for four reasons. First, it is exceptionally large experimental equipment of this kind compared to others around the world. Due to its scale, it should enable researchers to conduct realistic forging experiments even when dealing with hard materials that are difficult to process, such as titanium and nickel-based alloys. Second, the simulator is capable of performing forging at high temperatures, and it can raise the temperature of alloy materials up to 1,200°C. Third, the simulator is capable of cooling forged components at a controlled cooling rate. And fourth, the simulator is capable of changing the rate of load application across a wider low-to-high range compared to conventional equipment.

In the immediate future, researchers will conduct forging experiments using this new simulator, and will build forging databases and develop computational prediction tools.

Mitarai says, "We expect that Japan will increase the production of small- and medium-sized aircraft as represented by HondaJet and Mitsubishi Regional Jet. In addition, if Japan will successfully develop groundbreaking heat-resistant alloy components before any other country, aircraft manufacturers in Europe and US are more likely to purchase them from Japan. Accordingly, in the PRISM project, we will continue to work on innovative processing technologies for the development of heat-resistant alloy components. Then, after the completion of the project, we plan to make NIMS a heat-resistant alloy R&D hub to promote collaboration among industry, governmental organization and university researchers. I hope that these initiatives will contribute to prosperity of the aircraft components industry in Japan."

(by Kumi Yamada)

NIMS & materials integration

Bringing paradigm shift to structural materials development through the integration of theory, experiment, computation and data

NIMS is leading Materials Integration (MI), one of the four R&D projects in the Structural Materials for Innovation (SM^{4}I) program, with The University of Tokyo. We asked Makoto Watanabe, a Director of the SIP-MI Laboratory, who represents NIMS and shares the role of leading the MI project, about objectives and specifics of the project.

Makoto Watanabe

Laboratory Director, SIP-MI Lab
Research Center for Structural Materials (RCSM)

Due to global competition for the development of structural materials, expectations for material quality are rising in terms of heat resistance and durability, for example. For the Japanese structural materials industry to remain competitive in this field, it is vital to greatly shorten development time, increase development efficiency, and reduce development cost. Accordingly, researchers in the SM^{4}I program are focusing their efforts on MI technology as a means to support the industry.

MI is a new concept of materials science aiming to integrate theory, experiment, computation and data. At present, industry, government and university researchers are working together to develop structural materials for the aircraft industry. In this initiative, researchers are aiming to build MI system and apply it to research field such as metals, ceramics and polymers.

Relationships among four elements of materials development

One objective of MI is to understand relationships among the four elements of materials development. In the case of metals, for example, processing (e.g., forging and welding), metallographic structure (e.g., grain size and crystal orientation), property (e.g., strength, ductility and toughness), and performance (e.g., fatigue, corrosion and creep) are all closely related. However, materials development in the past often relied on the intuition and experience of technicians and was not always based on a quantitative link among the four elements. In addition, while it is important to ensure that developed structural materials are safe in terms of fatigue strength and creep strength, for example, such evaluations require many hours of experiments. This had been a key reason for prolonged development time.

In contrast, the MI approach aims to quantify relationships among the four elements and identify the mechanism behind the performance of target materials through the integration of the results of past materials science studies and empirical knowledge to the following areas of advanced data science: databases for individual materials, numerical simulations, machine learning and artificial intelligence. Watanabe says, “Through this approach, structural materials can be developed in a scientifically and logically sound manner. The use of MI will make it possible to select optimum materials and processes, greatly shorten the time it takes to evaluate/predict materials’ performance, and drastically reduce development time and cost.”

Establishing structural materials R&D hub at NIMS

Currently, researchers at NIMS and The University of Tokyo are developing an MI system focusing on the welded parts of high-strength steel. “We selected welded parts for this project because it covers a wide range of issues related to the four elements. With this approach, we believe we can build a versatile MI system,” says Watanabe.

The MI system under development consists of four components: a system for predicting materials’ microstructure, a system for predicting materials’ performance, data analysis modules, which support first two components through data processing and analysis, and an integration system, which combines all of these components.

The University of Tokyo is playing a central role in performing prediction of materials’ microstructure and performance in collaboration with researchers from other universities and companies. They studied how the microstructure of welded parts changed in relation to the welding conditions (e.g., temperature) and the type of welding material applied using numerical simulation techniques (e.g., phase-field method and finite element method). Based on these results, they are now developing various modules to be used for predicting materials’ performance.

Regarding data analysis modules, the researchers implemented data science methods such as machine learning and data assimilation techniques. Through this approach and using materials databases, they are aiming to provide vital information for the two prediction systems.

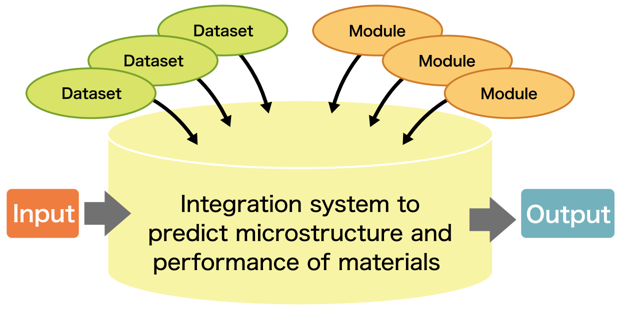
Moreover, the researchers integrated a set of modules to perform prediction of materials’ microstructure/performance and property space analysis with materials databases, and produced workflows with different combinations of processes depending on the materials chosen. NIMS is leading the development of an integration system that will be used to manage and run the workflows.

“The integration system is MI’s paramount feature. In an MI system, each module that is uniquely designed by researchers is connected to the system using a platform. For example, when a researcher wants to predict the performance of a hypothetical structural material using specific elements and processes of his/her choice, he/she considers various combinations of modules by producing workflows, and evaluates analysis results. This practice is expected to enhance the performance of the overall MI system,” explains Watanabe.

NIMS was assigned to direct the development of the integration system nested in the MI system primarily because NIMS owns a series of structural materials datasheets published over many years and “MatNavi,” one of the world’s largest materials databases. It is of critical importance to accumulate structural material-related data in Japan by enhancing analytical methods for each module and using NIMS’s datasets.

“I think NIMS is obliged to play a central role in the development of the MI system for structural materials in Japan even after completing the SIP program. I will continue to enthusiastically promote the MI project, believing that application of MI will bring a paradigm shift to structural materials development,” says Watanabe.

(by Kumi Yamada)



Schematic figure of MI System

Special round-table talks

NIMS & UTokyo

Impact of and hope for government–academia collaboration

Researchers at NIMS and the University of Tokyo are leading the development of a materials integration (MI) system at the MI center directed by Professor Toshihiko Koseki, Department of Materials Engineering, The University of Tokyo. We asked six young members of the MI project to discuss the impact and hope for this collaborative effort.

(photo from left)

1 **Takuya Kadohira**
Senior Engineer, SIP-MI Lab, Research Center for Structural Materials (RCSM), NIMS

2 **Satoshi Minamoto**
Team Submanager, SIP-MI Lab, RCSM, NIMS

3 **Makoto Watanabe**
Laboratory Director, SIP-MI Lab, RCSM, NIMS

4 **Masahiko Demura**
Project Professor, Research Center for Advanced Science and Technology, The University of Tokyo, (concurrently) Laboratory Directorial Aide, SIP-MI Lab, Directorial Aide, RCSM, NIMS

5 **Junya Inoue**
Associate Professor, Research Center for Advanced Science and Technology, The University of Tokyo,

6 **Kaita Itoh**
Lecturer, Department of Material Engineering, The University of Tokyo

Role of each organization and synergic effect of collaboration

Watanabe First, I would like to discuss the impact and significance of the collaboration between Univ. of Tokyo and NIMS. Researchers at NIMS conduct various materials-related studies. But most of them were unfamiliar with data science, which is also referred to as the "fourth science" after theoretical, experimental and computational sciences.

Kadohira That is why it was vital for NIMS to collaborate with Univ. of Tokyo, who has researchers with adequate expertise, for example, information scientists and mathematicians who are knowledgeable about cutting-edge data science.

Inoue In this collaborative project, Univ. of Tokyo is in charge of three R&D areas: microstructure prediction, performance prediction, and property space analysis. However, we cannot cover all these areas by ourselves. In fact, there are many other participants from various universities in this MI project. So, I see that Univ. of Tokyo is serving as a representative of participating universities.

Demura I heard that Professor Inoue has been studying structural materials using numerical simulations over many years.

Inoue Yes. However, I frequently encounter a major issue in my research—computational outcomes are not consistent with actual experimental data. Due to this experience, I am very enthusiastic about the idea of incorporating NIMS's outstanding experimental data into MI.

Watanabe Professor Ito is fundamentally a materials researcher and is also knowledgeable about computational and information sciences. How do you feel about this collaboration with NIMS?

Ito To me, the most attractive aspect of this collaboration is that it allows project members to have access to NIMS's vast amount of experimental data on materials. Databases are a crucial component of the MI system, so NIMS's contribution to this project is absolutely critical.

Minamoto Also, even after completion of the SIP program, we still need to continue managing and operating the MI system by adding new experimental data to its database and updating its programs.

Inoue In that regard, I think it is totally appropriate for NIMS, a national research institute, to preside over the integration system.

Demura On the other hand, university researchers, led by the Univ. of Tokyo, are in charge of developing different types of modules that will form the MI system. So, again, it is very important for NIMS and the Univ. of Tokyo to closely work together from the beginning of the system development and hold frequent discussions in order to create a high-performance and user-friendly system.

Current status and future goals

Inoue Regarding the development of modules, we are currently focusing our R&D efforts on the prediction of materials' microstructure and performance. When dealing with structural materials, it is very difficult to identify the internal microstructure of materials in detail solely based on experiments. So, we are predicting materials' microstructures first and then using them to predict the performance more accurately. We have been reconfirming the importance of relating the well-defined microstructures to the performance.

Ito I have great expectations that our new approach to connecting different modules will revolutionize structural materials R&D. I also hope that this MI system, when completed, will help make the Japanese structural materials industry more competitive internationally.

Minamoto Meanwhile, NIMS researchers are making progress in the development of the integration system. The goals of this initiative are to integrate various modules, analysis methods/numerical models, and databases developed by researchers, and to make the system capable of automatically formulating appropriate workflows corresponding to users' needs for materials development. By achieving these goals, I believe we can attain capability to accurately predict deterioration trends of structural materials to be developed in terms of their lifetime and performance.

Kadohira I really feel fortunate that we as NIMS researchers can frequently exchange information and communicate with the Univ. of Tokyo researchers who are developing modules. This collaboration is helping us tremendously in the development of the integration system.

Demura So far, we have completed one-third of the project. The development of the MI system is a unique attempt with no parallel in the world, so we experienced some confusion at the beginning. But we finally agreed on the direction in which we should move forward, and all members started to tackle the project harmoniously with each other toward the same goal. I am a little relieved for that for now. At the same time, my sense of responsibility to successfully develop the system is intensifying.

Watanabe I hope to strengthen the current collaboration, including the fostering of skilled researchers, toward the development of a truly useful MI system for Japanese companies. I look forward to continuing working with all of you on this project.

(by Kumi Yamada)

DISCUSSION MEETING

NIMS Research projects in the SIP SM^4I program

Innovative measurement and analysis for structural materials

Tadakatsu Ohkubo
Group Leader, Magnetic Materials Analysis Group, Research Center for Magnetic and Spintronic Materials

We are investigating new structural materials applicable to performance prediction, life prediction and energy-saving manufacturing processes. For this purpose we are using advanced measurement and analysis systems owned by the TIA Platform for Open Innovation members (AIST, NIMS, Univ. of Tsukuba, KEK and Univ. of Tokyo). Moreover, we aim to create a research hub to discover characteristics determining the performance and life of structural materials, which may be applicable in detecting early signs of material deterioration even before it occurs.

Evaluating durability of ceramic coatings

Hideki Kakisawa
Principal Researcher, Structural Non-Oxide Ceramics Group, Research Center for Structural Materials (RCSM)

We are evaluating the durability of environmental barrier coating (EBC) made of heat-resistant ceramics, developed for use in aircraft engine parts. Specifically, we are conducting durability evaluation/analysis of chemically and thermomechanically damaged EBC (e.g., analysis of how delamination and cracking in materials progress under high temperature). We also aim to develop standardized evaluation techniques for these studies.

Formulating internal changes in ceramic coating

Byung-Nam Kim
Group Leader, Field-Assisted Sintering Group, Research Center for Functional Materials (RCFM)

Thermal resistance of ceramic coating declines when the material is exposed to high temperature. It has been suggested that the reduced thermal resistance may be caused by growth of ceramic crystal grains under high temperature, eliminating pores between grains. To verify this assumption, we plan to develop theoretical formulas using experimental data, which describe changes in crystal microstructure and the movement of pores in ceramic coating layers.

NIMS & corrosion issues

NIMS contributes to reinforcement of Japan’s infrastructure by developing corrosion-resistant reinforced concrete and deterioration diagnosis technology

Researchers in the SIP Infrastructure Maintenance, Renovation and Management program, directed by Yozo Fujino, are conducting R&D to reduce the maintenance cost of severely aging social infrastructure, such as roads, railroads, harbors and airports. The SIP-Social Infrastructure Materials Laboratory is a part of the NIMS Research Center for Structural Materials (RCSM), and Koichi Tsuchiya is a director for both the lab and the RCSM. The lab has been tackling with the R&D of “Structural Materials, Deterioration Mechanisms, Repairs, and Reinforcement Technologies,” one of five focus areas in the aforementioned SIP program. We asked Tsuchiya about objectives and details of the project.

Koichi Tsuchiya

Director,
Research Center for Structural Materials (RCSM),
Laboratory Director,
SIP-Social Infrastructure Materials Laboratory,
RCSM

Much of Japan’s social infrastructure, including roads, tunnels and bridges, was built around the same time as the period of rapid economic growth (1950s to 1970s), and their deterioration due to aging has been a serious problem. However, repair and rebuilding works are not progressing as planned due to worsening financial situations and shortage of workers. Since this problem cannot be fixed at once, it is necessary to prioritize target structures based on the risk of collapsing. Speed of deterioration in steel-reinforced concrete varies depending on the environment to which structures are exposed and materials/manufacturing methods used. For this reason, it is difficult to prioritize concrete structures based on their age and external appearance.

NIMS is playing a central role in the R&D focus area of “Structural Materials, Deterioration Mechanisms, Repairs, and Reinforcement Technologies,” in collaboration with universities, industries and the Public Works Research Institute. In this project, which targets steel-reinforced concrete, R&D efforts are focused on identification of deterioration mechanisms, development of deterioration-resistant materials, and development of technologies for reducing maintenance cost. In addition, NIMS is fostering researchers and technicians proficient in broad disciplines ranging from structural materials science to civil engineering.

Aiming at the development of long-life reinforced concrete

Deterioration of reinforced concrete is most commonly initiated by the corrosion of steel rebars embedded in the concrete. When seawater, rainwater or snow-melting agents infiltrate into concrete, they cause the rebars to corrode and expand. As a result, concrete is pushed from the inside and cracks. Then, corrosion of the rebars worsens as more seawater and rainwater reach them through cracks.

“The internal state of new concrete is alkaline. But as concrete is exposed to sea salt or is neutralized, its internal salt concentration increases and its pH decreases. Consequently, corrosion of the steel rods progresses. Our previous studies had revealed that when the salt concentration and pH in concrete exceed certain thresholds, corrosion advances rapidly,” explains Tsuchiya.

In light of these observations, NIMS developed a sensor capable of measuring salt concentration and pH inside concrete. Moreover, NIMS researchers found correlative relationships between the rate of steel rod corrosion and salt concentration/pH in concrete. Based on these results, the researchers successfully developed low-cost, corrosion-resistant reinforcing steel. NIMS and Kyoto University jointly manufactured concrete that was reinforced by the newly developed steel rods, and are currently performing demonstration experiments. They plan to achieve practical use of the product before the completion of the project.

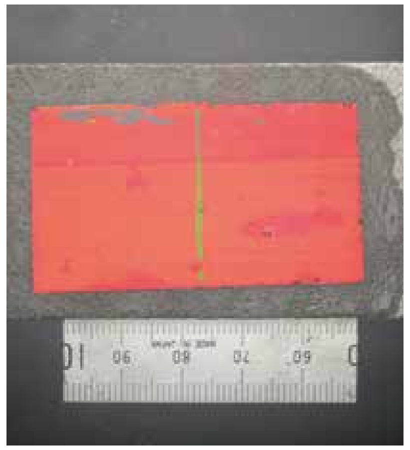
Appearance of conventional carbon steel (left) and newly developed corrosion-resistant steel (right) after used as concrete reinforcing steel during two-year exposure tests at the Irabu Ohashi Bridge. The concrete block containing carbon steel cracked due to expansion caused by steel corrosion, while the block containing corrosion-resistant steel did not.

In addition, the researchers are also developing a bioinspired adhesive repairing/reinforcing material. When the material is applied to concrete, it hardens by reacting with alkaline contents of the concrete, thereby making the concrete waterproof and protecting reinforcing steel from corrosion. Consequently, this material may extend the life of steel-reinforced concrete. NIMS is currently conducting studies and demonstration experiments with several collaborating companies toward mass production of the material.

Developing easy-to-use deterioration diagnosis sheets

NIMS is also developing sheets that make distortion in concrete visible. The sheets incorporate the principle of structural colors, which can be observed in some creatures such as buprestid beetles and kingfishers. Structural colors refer to certain metallic colors resulting from reflection of light at only specific wavelengths on the submicron level structured surface. To apply structural colors, NIMS developed a sheet product consisting of a thin plastic sheet coated with 0.2-micron-diameter polymer particles called polystyrene. The sheet emits red colors (see photo) as regularly arranged polystyrene particles serve as a nanostructured surface. When the sheet is distorted by bending or pulling, distances between particles change, which leads to reflection of light at different wavelengths. If the sheets are pasted at strategic spots of reinforced concrete, they will make cracks, formed by an earthquake, for example, easily visible by showing different colors where the cracks are.

“Most local governments have limited budgets for infrastructure maintenance and labor availability. So, diagnosis technologies for easily detecting infrastructure deterioration are valuable. From this perspective, I think the sheets that make distortion in concrete structures visible are a very useful tool,” says Tsuchiya.



A sheet which renders concrete distortion visible, enabling crack detection. The green line indicates a crack.

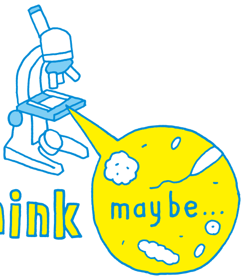
Making NIMS a research hub for infrastructure materials

NIMS has been fostering versatile researchers and technicians with broad knowledge ranging from materials to civil engineering, by hosting various activities, e.g. infrastructure materials forums for young people and summer school on infrastructure materials.

“NIMS is very good at assessing structural materials at the nanometer scale using electron microscopes and other analysis/evaluation systems. On the other hand, the field of civil engineering focuses on producing results based on intuition and experience, rather than theory. By NIMS teaming up with civil engineers in this project, I hope that we can create social infrastructure that has a long life and is inexpensive to maintain,” says Tsuchiya. After this project completes, NIMS is planning to serve as Japan’s R&D hub for infrastructure materials and center for training skillful researchers.

(by Kumi Yamada)

Science is even more amazing than you think



Nano adhesive plaster —invention by mistake

Written by Akio Etori
Illustration by Joe Okada (vision track)

When I was a child, I would play and run around in open fields and on beaches. So, I always had scratches on my arms and legs. To take care of the wounds, I used Mercurochrome (it has been replaced by other products) and Band-Aids. Band-Aids particularly came in handy to stop bleeding from a cut or after receiving a painful shot at hospital.

Adhesive plasters are still a very convenient first-aid item today, but due to technological advancement, totally new plaster products have emerged, including those that change colors as a wound heals, and those that act like artificial skin. One of the attention-grabbing products is “nano adhesive plasters.”

As the word “nano” in its name indicates, the plaster is extremely thin—approximately 60 nanometers, which is just one-100,000th the thickness of a regular plaster. Because the nano adhesive plaster is super thin, once attached to the skin, it is difficult to locate unless it is marked.

Nano adhesive plasters are made from biologically compatible materials, so not only can they be attached to the skin surface, but they can also be placed directly over a wound in an internal organ. The technology is applicable to everyday items. For example, its application to cosmetics and topical skin products has been under development. It is also conceivable to use it as a drug carrier based on the concept that a drug can be held in the plaster by processing it into either a folded sheet or cell-sized structure. Then, the drug can be delivered into the blood and transported directly to the affected area.

Furthermore, by changing the components of the plaster and attaching it to the skin, it can serve as an electronic nano adhesive plaster capable of measuring bioelectric signals. Similarly, it may be feasible to develop wearable devices that can easily measure various biological information including body temperature and pH.

The nano adhesive plaster was invented by a young Waseda University researcher, Toshinori Fujie, after he accidentally created a 1 cm square sheet of blood platelets during an effort to develop artificial platelets.

Born in Tokyo, Fujie received training in Italy as a researcher. Since returning to Japan, he has been studying bioelectronics, first at Tohoku University and presently at Waseda University.

I had a chance to talk with him in person. My impression of him was that he is a diligent researcher with a future-oriented mindset—as a scientist, he aims to contribute to society by producing results (he also actively gives talks on science to children and the general public). By talking with Fujie, I became convinced that Japan’s future as a major power in science is bright, as the strong tradition will be passed on to many young talents to emerge. The creativity of young scientists can be amazing, as Fujie invented the nano adhesive plaster out of the mistake of making a platelet sheet.

Japanese society has been rapidly aging and its younger population is declining. In addition to the issue, Japan also has to deal with many global issues that are of a scientific and technological nature. So, it is critical to make full efforts in scientific and technological R&D now. Unfortunately, Japan’s overall research efforts, in terms of budgets, workforces and facilities, are being downsized, however. In order for Japan to overcome the current adverse situation and make global contributions, it is vital to provide opportunities to diligent young researchers who are not afraid of making mistakes to grow and energetically tackle these urgent issues.

I think Japan seriously needs many more young talents like Fujie.

Akio Etori: Born in 1934. Science journalist. After graduating from College of Arts and Sciences, the University of Tokyo, he produced mainly science programs as a television producer and director at Nihon Educational Television (current TV Asahi) and TV Tokyo, after which he became the editor in chief of the science magazine Nikkei Science. Successively he held posts including director of Nikkei Science Inc., executive director of Mita Press Inc., visiting professor of the Research Center for Advanced Science and Technology, the University of Tokyo, and director of the Japan Science Foundation.

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