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Next-generation bonding technology

—To use right materials in the right place—

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Damage to epoxy adhesive joints between steel and CFRP (carbon fiber reinforced plastic) materials observed in a destruction test
Photo by Kimiyoshi Naito

—To use right materials in the right place—

Materials can be joined together using bolts, welding and other means.
This NIMS NOW issue features adhesive bonding technologies.
Potentially, adhesive technology can bond all types of materials.
It is also feasible to add desirable functions to adhesives, so they can be removed as needed or have antimicrobial properties.

Recently, adhesive bonding technology is drawing attention as the key to the application of "multi-materials," a concept that promotes the use of the right material in the right place.
For example, the concept of multi-materials can be applied to airplanes and automobiles.
It is plausible to make these vehicles lightweight and cost efficient to produce without compromising their safety, by applying hard and heavy metals in parts that need strength and using light metals and resins in parts that do not.
Bonding technology is indispensable as a means to connect different types of materials.

NIMS has been developing the technology from unique viewpoints such as learning from other organisms and using water.
In addition, NIMS evaluates adhesive materials by performing stringent tests in order to ensure their reliability before they are put to practical use.
Research at NIMS on adhesive materials will lead to the application of multi-materials and other future technologies.

Special talk

New bonding technology changes the way of design and manufacturing

Nozomu Kawasetsu

General Manager,
Manufacturing Technology Research Department,
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Mitsubishi Heavy Industries, Ltd.

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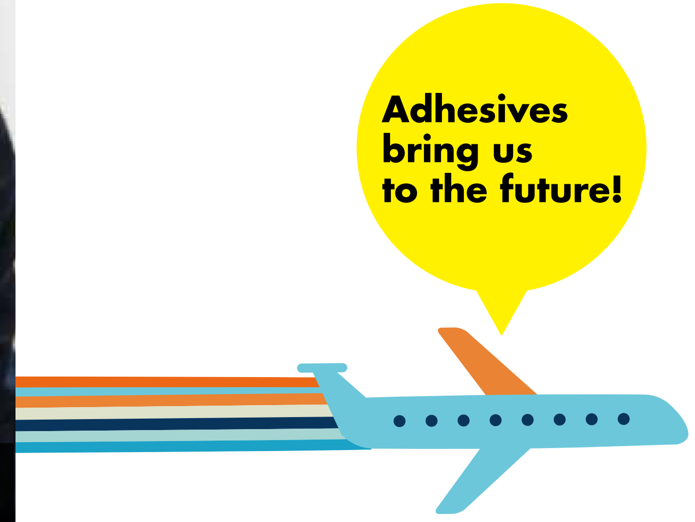


Advancement of adhesive materials and expectations for NIMS

Bonding technology is indispensable in creating various things, ranging from small semiconductors to gigantic aircrafts and rockets. Nozomu Kawasetsu of Mitsubishi Heavy Industries, a user of bonding technology, and Koichi Tsuchiya of NIMS, who is aiming to develop innovative bonding technology, discussed the current status and the future of the technology.

Ambition to create aircrafts using only adhesives

Tsuchiya Mitsubishi Heavy Industries manufactures a variety of products including machine tools, power plants, chemical plants, ships, aircrafts and even rockets. I am very interested in hearing your views, as you represent users of adhesive materials.

Kawasetsu Our products are very diverse, and technology to join parts is essential for our work. When we were primarily dealing with metals many years ago, we joined them using welding and bolts. However, the needs for joining technology have changed dramatically since about 30 years ago.

As demands for lightweight and multi-functional products have increased, the demand for applying multi-materials—right combinations of resins, ceramics, composite materials and other materials in relation to the purposes of their use—have also increased. Welding is not applicable to resins and ceramics, and the use of bolts will make products heavy. To address these issues, many chemical manufacturers tried to develop adhesive materials to join different types of materials. As a result, adhesive materials that are effective in bonding small parts together became available. However, adhesives that can be applied to structural materials, including those for aircrafts, are not available yet at a level satisfactory to the users.

Tsuchiya What kind of problems are there?

Kawasetsu The biggest problem is that it is difficult to judge the reliability of adhesives.

In the case of welding metals, it has been practiced for over 200 years, and welding techniques have already been standardized, and joint strength and durability resulting from welding have been well studied. If parts are welded together following the standardized procedure, sufficient reliability can be attained.

In contrast, the history of adhesive materials is much shorter, and methods to measure their strengths and durability have not yet been established. As such, we cannot even judge whether they are reliable or not.

Tsuchiya Bonding structural materials together requires enormously powerful adhesion compared to bonding used for small machines. How are you handling this issue?

Kawasetsu As for aircrafts, we, of course, use adhesive materials approved for that purpose. However, the approval does not automatically ensure their reliability. If joining surfaces are contaminated with oil or other materials, that weakens the bonding strength. Bonding strength is also influenced by the temperature and humidity at which joining takes place. Consequently, we need to inspect the conditions of all bonded parts, but the problem is that no method is available to inspect bonding strength.

Tsuchiya Bonding strength changes over time and depending on the environment in which the products are used. Moreover, it is not practical to perform durability tests for all products.

Kawasetsu That is right. Only limited data is available regarding how bonding strength changes over a long term and in relation to the type of the environment in which the products concerned are used. That is why we use both adhesive materials and bolts in combination to ensure safety.

Our ambition is to create aircrafts using only adhesive materials as a means to join parts together.

Identifying the mechanism of adhesion

Tsuchiya In July 2016, NIMS launched a Research Cluster for Adhesive Materials (see P. 12) in TOPAS (Tsukuba Open Plaza for Advanced Structural Materials), which is run by the Research Center for Structural Materials (RCSM). The cluster aims to establish methods to evaluate the bonding strength and durability of adhesive materials.

Kawasetsu My impression of NIMS had been that it is an institute devoted to the research of metal materials, so I was surprised to learn that it also carries out R&D of adhesive materials.

Tsuchiya It was only 10 years ago when NIMS began R&D of joining technology that involves means other than welding. We took this initiative to meet the needs of society: the application of multi-materials.

Kawasetsu It would be very helpful to have a system that allows us to implement the concept of multi-materials; if we enter necessary information into the system—such as materials we want to join together, say iron and aluminum, and conditions under which we plan to use the product, for example, in the sea at a temperature of 10°C, then the system displays candidate adhesive materials and the optimum bonding temperature and humidity. To build such a system, an appropriate database is essential.

Tsuchiya We are planning to construct a basic database for adhesive materials by testing the strength and durability of adhesives when they are applied to a wide variety of materials, and by compiling all measurement data from these tests. We intend to make the database useful as a tool to select optimum adhesive materials under given conditions.

Kawasetsu I have great expectations for NIMS to develop methods to evaluate bonding strength. If a scale of 0 to 100 is set for bonding strength measurement with 100 representing ideal conditions, I want to know the strength of adhesive materials in terms of a score like 80 or 50. If the strength of adhesives can be measured in this manner, we can use them with confidence.

Tsuchiya To evaluate the strength and durability of adhesives, it is also important to understand the physical mechanisms of how they work. Adhesives have become a common item for everyday life, but in reality, it is not well understood how they join things together. Adhesives form a very thin layer after application. To reveal the mechanism, it is necessary to identify the states of molecules and electrons in that layer, and that is not easy. Nevertheless, we would like to take on that challenge.

A variety of characterization instruments is available at NIMS. In addition, new analysis tools that use synchrotron radiation, neutrons and other means became available to us more recently. We will take full advantage of these resources in order to identify the physical mechanisms of adhesion.

Kawasetsu That sort of research is difficult for us to carry out in industries. I hope NIMS will succeed in that endeavor. If the mechanisms of adhesion are identified, I am optimistic that the findings will lead to the development of superior adhesive materials and evaluation methods.

Creating innovative adhesive materials by studying other organisms

Tsuchiya It seems to me that all source materials for adhesives had been explored exhaustively. Therefore, we are making attempts to develop totally new adhesive materials. For example, we are studying an adhesive protein, which is secreted by blue mussels and is used to attach themselves to ship bottoms (see P. 8), and the foot structure of geckos that can move around vertically or upside down on a wall and ceiling (see P. 13).

Kawasetsu Yes, biomimetics is a fascinating field. We studied the microscopic surface structure of owls' wings when we developed aircrafts. Some organisms possess amazing functions which humans do not. I think it is a great idea to study these functions and apply the findings to various products including adhesive materials. When NIMS succeeds in creating fabulous adhesives, please let us know.

Collaboration under the framework of Research Cluster for Adhesive Materials

Kawasetsu Only a few private companies in the world have a license to supply adhesive materials that can be used with structural materials for aircrafts. All of the companies are based in Europe or the United States. That is part of the reason why we often go overseas to conduct joint research on adhesive bonding technology. However, Japanese chemical manufacturers have advanced technology and would be capable of independently developing adhesive materials for aircrafts, if they set their minds to do so. It would be great if we could procure adhesives made in Japan for use in aircrafts building. To advance this idea further, we intend to strengthen collaboration with NIMS and domestic chemical manufacturers.

Tsuchiya The Research Cluster for Adhesive Materials consists not only of NIMS researchers but also researchers from chemical manufacturers, companies that use adhesive materials and universities.

Kawasetsu We hold frequent discussions with researchers from chemical manufacturers. I expect it would also be stimulating to have discussions with people from research institutes like NIMS as they have different perspectives from us. Also, companies that use adhesives encounter technical issues, and a single company cannot resolve them by itself. I am hopeful that the cluster will play a major role in resolving such issues.

Taking advantage of rich knowledge on metal materials

Tsuchiya You said earlier that you had a strong impression of NIMS as a research institute of metal materials. Actually, my expertise is in the area of metal materials. Metal researchers observe the internal structures of materials under a microscope. Through this observation, they can more or less determine various characteristics of a material such as its brittleness and strength. If we take a similar approach to adhesive materials that are made of polymers, and observe them from different angles, perhaps we can see something new about the material, which we could not see before.

Kawasetsu I have dealt with various types of materials such as composite materials, ceramics, aluminum and steel. As I worked on these materials more and more, I realized that metals are superior to anything else (laughing). Metals can be handled more easily than any other materials. On the other hand, application of multi-materials is also vital in terms of reducing the weight of products and adding desirable functions to products in light of the global movement toward energy saving and environmental protection. To implement this approach, it is critical to advance bonding technology, and when more effective adhesives become available, the way things are created will change fundamentally. I believe that NIMS has more knowledge and data about metal materials than any other organizations in Japan. I have high expectations for NIMS to create new adhesive materials in a manner only NIMS can achieve by applying all the knowledge about metal materials that NIMS has accumulated to adhesive materials including polymers.

(by Shino Suzuki, PhotonCreate)

Adhesive materials that play a major role in Super-Smart Society

Contributing to the improvement of fuel efficiency in automobiles and airplanes

Masanobu Naito

Group Leader,
Adhesive Materials Group,
Transportation Machinery Materials Field,
Research Center for Structural Materials (RCSM)

Amid concerns about global warming, it is urgent to increase the fuel efficiency of airplanes, automobiles and other means of transportation. To deal with this issue, active technology development is underway to reduce the structural weight of these vehicles. One approach to achieve this is the application of multi-materials. In this technology, different types of materials are joined together, and therefore, adhesive materials play an important role. To meet such needs, the Adhesive Materials Group was launched in RCSM. We asked group leader Masanobu Naito about the group's current status and the content of research in progress.

New framework for multi-materials research

Application of multi-materials refers to combinations of different types of materials, such as metals and composite materials/resin, so that materials with desirable functions can be used in the right places. Recently, demand for this "multi-materials" is on the rise. For example, carbon fiber reinforced plastic (CFRP), which is lighter and stronger than metal, was developed in Japan, and was used in a part of the frame of the Boeing 787 Dreamliner. In light of these movements, NIMS organized the Adhesive Materials Group under RCSM's Transportation Machinery Materials Field in April 2016. Group leader Masanobu Naito talks about the significance of the new establishment.

"It had been rare for organic/polymer materials researchers and metallic materials researchers to talk face-to-face about each other's needs and ideas and work together. I feel the establishment of the Adhesive Materials Group in RCSM is a ground-breaking movement as it created the venue for collaboration among professionals specialized in different structural materials."

Bonding of different types of materials is not a new practice. However, past bonding technology had limitations in terms of the types of materials that can be joined and their combinations. In contrast, demand is rising these days for high-quality steel, including stainless steel and high tensile strength steel, in addition to conventional steel, and metals that are lighter such as aluminum and magnesium. Also, demand is diversifying for characteristics of resin. As demands for structural materials are increasing/diversifying, needs for developing versatile adhesive materials are also growing.

Learning bonding technology from other organisms

In efforts to develop adhesive materials, Naito has been studying proteins of blue mussels since around 2007. The mussels are marine fouling organisms that are often seen attaching themselves to ship bottoms and rock reefs in dense groups. They secrete an adhesive protein. The protein can strongly bond various inorganic and organic materials as it hardens. "Because the mussels can firmly attach themselves to objects in water and the secretion is harmless to human bodies, it has been a subject of active study primarily to develop bioadhesive materials. But I aimed to develop versatile adhesive materials that are applicable to structural materials as well (Fig. 1)."

Since the olden days, urushiol (a lacquer ingredient) and bile acids (a bittering component in astringent persimmons) have been used as coating or adhesive materials. "Like these substances, the adhesive protein from blue mussels contains catechol. Catechol is an organic substance consisting of two adjacent hydroxyl groups attached to a benzene ring. These groups form coordinate bonds or hydrogen bonds with the surfaces of other objects, allowing mussels to adhere stubbornly. Maybe that is the most versatile and powerful adhesive material produced through the long evolutionary history of life."

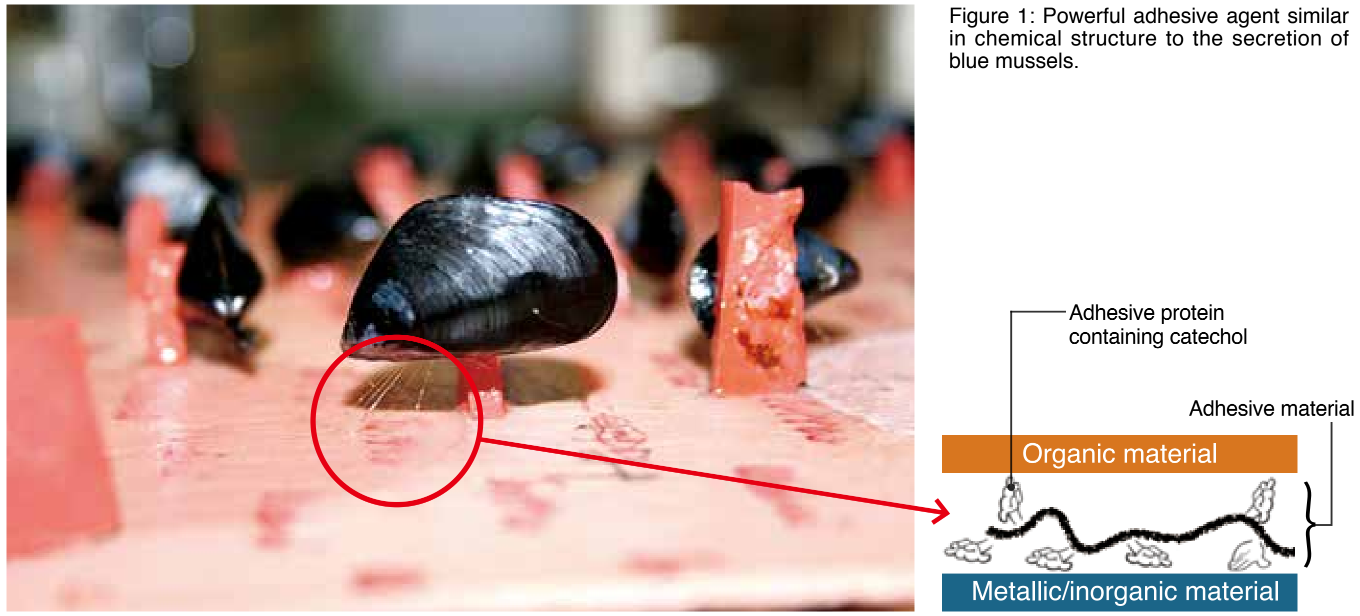


Figure 1: Powerful adhesive agent similar in chemical structure to the secretion of blue mussels.

Naito has concluded a license agreement with several companies and is conducting R&D of an adhesive material that is similar in chemical structure to the blue mussels adhesive protein and is applicable to structural materials. He wants to achieve its practical application within two years.

"Among metallic materials, light metals such as aluminum and magnesium are particularly popular lately as desirable materials to be combined with resin. My goal is to develop an adhesive material that enables combining a wide range of structural materials."

The biggest issue toward the practical use of the adhesive material under development is high production cost. Synthesis of catechol requires an expensive substance called dopamine, so its production is inevitably costly. To address this issue, Naito came up with a method to add small amounts of catechol to inexpensive, versatile polymers. "For example, I found that an addition of 10 wt% or less amount of catechol maintains high adhesive strength."

Finding new functions other than gluing

It was also found that this adhesive material is effective in repairing concrete. When this material is applied to internally alkaline concrete, it permeates concrete, hardens, and forms a hydrophobic, waterproof coating over the concrete surface (Fig. 2). "Due to this property, the material can protect reinforcing steel from rust and thus prevent concrete from deteriorating."

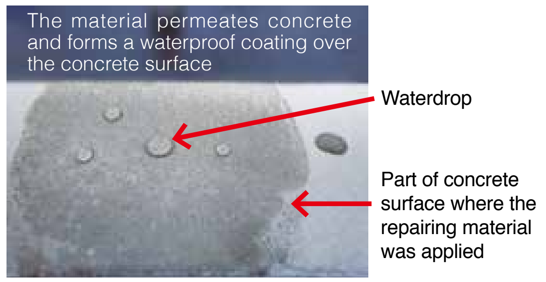
Naito is also developing another adhesive material using biomass such as wood obtained from forest thinning.

"Wood contains tannin, which is a type of polyphenol with a structure similar to catechol, and is therefore adhesive. It is a naturally-occurring, inexpensive, and environmentally-friendly material. Moreover, it has antimicrobial and antioxidative properties. For those reasons, I am thinking that tannin is potentially useful in healthcare, medical care and nursing care," says Naito.

Until now, most people thought of adhesive materials as mere tools to glue things together. However, people today tend to expect more from adhesive materials, such as additional functionalities, like antimicrobial and rust-proofing effects.

NIMS has been advancing R&D under the framework of industry-government-academia collaboration at its RCSM, serving as a research hub. In line with this effort, Naito led to establish a "Research Cluster for Adhesive Materials" (see P. 12). The idea of this arrangement is to promote researchers from different sectors to share issues concerning currently available adhesive materials and accelerate technological development. "In connection with Japan's 'super-smart society (Society 5.0)' initiative, I expect that many things will be invented one after another, including IoT-related devices. Under such circumstances, I believe that adhesive materials will play a major role if they are added with advanced functionalities, such as an adhesive that is removable as needed. Under the framework of the research cluster, I hope to develop adhesive materials that will make a contribution to future society."
(by Kumi Yamada)

Figure 2. When the repairing material reacts with internally alkaline concrete, it hardens and makes the concrete surface waterproof.



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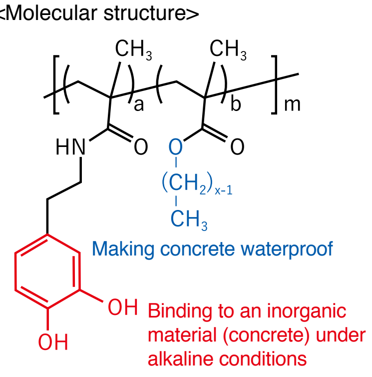


Designing reliable evaluation methods for adhesive materials

Urgent need to evaluate the performance of adhesive materials to promote their practical use

Kimiyoshi Naito
Group Leader,
Polymer Matrix Hybrid Composite Materials Group,
Transportation Machinery Materials Field,
Research Center for Structural Materials (RCSM)

The need for adhesive materials to join different types of materials is increasing. In light of this trend, in addition to R&D related to new adhesive materials, NIMS is striving to establish appropriate methods to evaluate and analyze the strength, durability and performance of adhesive materials to promote their practical use. We interviewed Kimiyoshi Naito, who is responsible for pursuing these goals.

Quick, appropriate evaluations

In the past, vehicle structural components were assembled mechanically through such means as bolts, rivets and welding. Multi-materials enable the application of materials (e.g. resins) to the appropriate locations, thereby optimizing and reducing the weight of finished products. Demand for multi-materials is therefore rising, and conventional assembly methods are becoming less useful as a result.

With regard to shifting demand, Naito had the following remarks. “Adhesive materials are compatible with the application of multi-materials, but many manufacturers prefer conventional bolt-and-rivet assembly. This is primarily because they do not trust adhesive materials. However, if multi-materials are incorporated into products using numerous bolts or rivets, the products may become heavier, defeating the purpose of using multi-materials. To gain the trust of manufacturers, it is vital to demonstrate the performance of adhesive materials in terms of reliable numerical scores.”

In the past, many adhesive material manufacturers performed independent strength, durability and performance tests each time they developed new adhesive materials. Each manufacturer used a different testing methodology, leading to inconsistent evaluation. The reliability of their measurements is questionable. In addition, development of more materials also increased the combinations of different materials to be bonded. Consequently, it has become difficult for manufacturers to test the performance of their adhesive products while taking all bonding needs into account.

“To address this issue, I thought NIMS should take the lead, as a national R&D institute, in establishing appropriate methods to evaluate the performance of adhesive materials.”

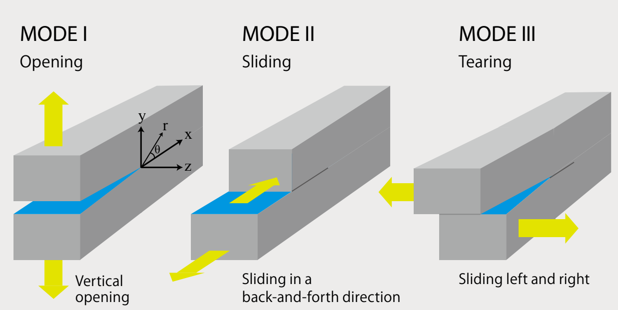
Naito is currently carrying out various tests using commercially available adhesive materials in order to develop new performance evaluation methods. He hopes to design methods that will enable quick and reliable evaluation of the performance of newly developed adhesive materials. He is primarily focusing on methods of evaluating the strength and fracture mechanics of materials.

Evaluation of material strength refers to a method of measuring the strength of a material by quantifying the relationship between the external force applied to a material, the stress generated in the material, and the deformation of the material resulting from the applied force. A tensile shear test is one way of measuring material strength. In this test, a specimen is prepared by bonding two pieces of materials together. The edges of the specimen are then pulled in opposite directions, and the stress generated in the specimen is measured (Fig. 1).

On the other hand, an evaluation of fracture mechanics is applicable to such materials that are found to be defective and cracked. In such an evaluation, external force is applied to a cracked material, and the fracture resulting from the force is classified into three modes based on fracture mechanics. Stress gradients and energy exerted at the tip of the crack are then measured. A double cantilever beam (DCB) test is a method of evaluating fracture mechanics under a mode I load. In such a test, a specimen consisting of two bonded materials is pulled upward and downward simultaneously. The energy required to propagate a crack in the specimen is then quantified (Fig. 2). “I believe it is feasible to increase measurement reliability by evaluating the performance of materials under scientifically sound and consistent conditions,” says Naito.

What “modes” are used in fracture mechanics?

These modes represent the types of deformation occurring in a cracked material. They are generally used to classify cracks in structural materials. Deformation is quantified using a set of terms: the point of origin (the crack tip); x, y and z axes, which extend from the point of origin; angle θ; and distance r.



Issues concerning data from rigidity/strength analysis

In addition to the need to develop performance evaluation methods, it is also important to improve the quality of the measurement data obtained during evaluations.

Automobile and airplane manufacturers take the application of multi-materials into consideration in their product designs. Accordingly, they assume gaps between components to be bonded ranging from several hundred microns to several millimeter when preparing 3D computer-aided design (CAD) data.

In order to apply structural analysis software to CAD data and accurately assess product rigidity/strength, it is necessary to enter various data on adhesive materials (e.g., elastic modulus, strength, fracture strain, and fracture energy). Naito had the following to say on this. “Measurement data on adhesive materials which can be used by software is currently insufficient. However, NIMS has instruments to collect these types of data. NIMS also has other high performance instruments, including chemical analysis devices and high-resolution electron microscopes, although current software is not yet capable of using these types of data. Once appropriate evaluation methods are established, we will strive to collect detailed and reliable measurement data using these methods.”

Moreover, Naito is intensively studying a cohesive zone model (CZM). While this model existed as early as the 1960s, it began drawing global attention only recently when it was recognized as an effective analytical method and due to advancements in computer technology.

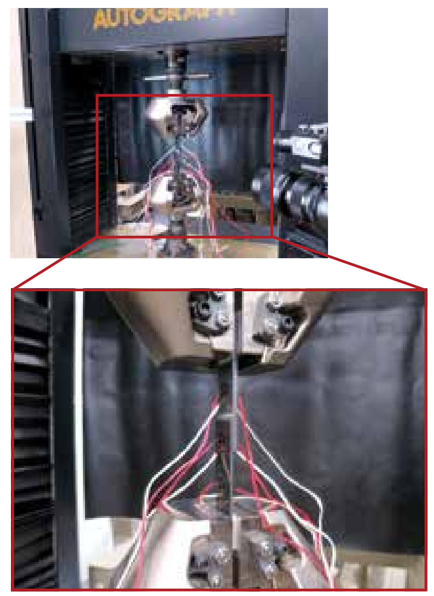
“In a CZM, separation of material surfaces at the tip of a crack is expressed in terms of the distribution of cohesive forces and the amount of energy required to cause fracture. Therefore, the CZM can be viewed as an analytical method that takes account of both the strength of materials and fracture mechanics. In the past, we had to analyze these two aspects separately, which was a great hindrance. Due to theoretical constraints, these two aspects could not be analyzed in an integrated manner. While some unresolved issues with CZM remain, it allows us to analyze these two aspects together. In other words, the model enables us to seamlessly analyze a series of events from the occurrence of stress in a material to the fracture of the material.” Naito hopes to apply the outcome of CZM analysis to the development and evaluation of adhesive materials.

Users are generally interested in the bonding strength and durability of adhesive materials, but are not particularly interested in detailed mechanisms that determine these factors. As a consequence, many aspects of adhesion are still not well understood. In light of this, Naito is planning to investigate the mechanisms of adhesion in collaboration with other researchers under the framework of the Research Cluster for Adhesive Materials (see P. 12), which was launched in July 2016.

“Our ultimate goals are to develop reliable adhesive materials, which can be used with confidence by manufacturers of structural parts for means of transport, and to put the adhesive materials into practical use as soon as possible. Through these achievements, we want to accelerate the application of multi-materials.”

(by Kumi Yamada)

Figure 1: Tensile shear test



Instrument that tests the strength of adhesive materials. A specimen is prepared by joining two materials using an adhesive material. The specimen is placed in the instrument and pulled in opposite directions at a constant rate. The instrument measures the stress generated in the specimen.

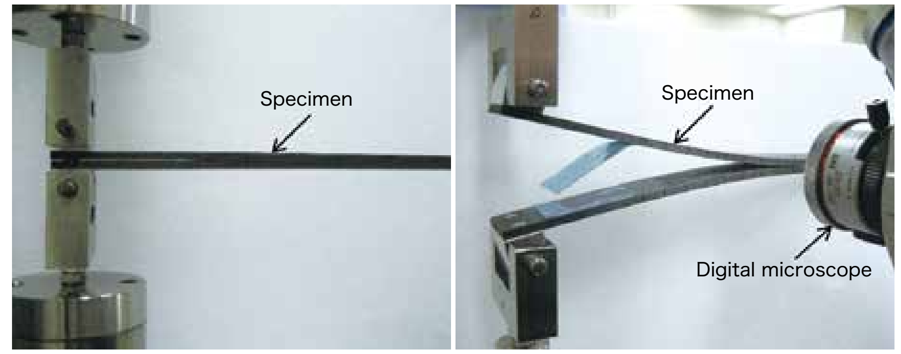


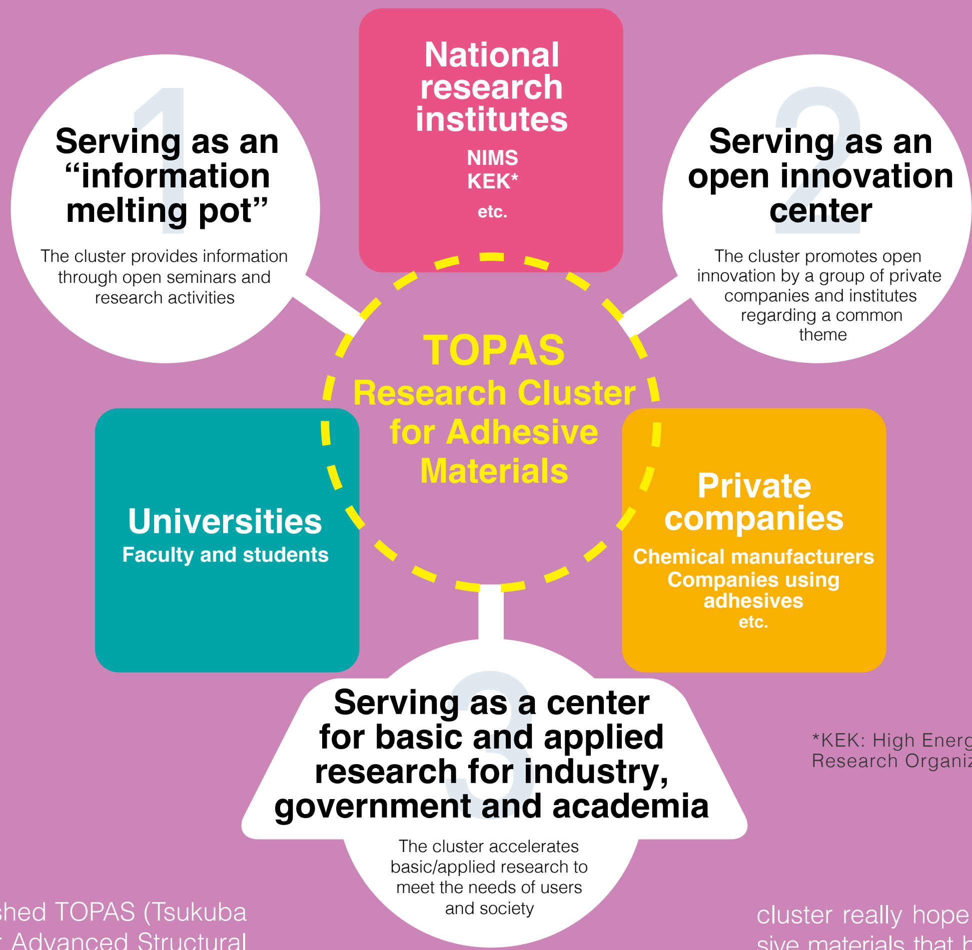
Figure 2: DCB test

Test that quantifies the energy required to propagate a crack in a specimen when a mode I load (see the diagram in the bottom of P. 10) is applied. The specimen, consisting of two materials bonded together in accordance with the standardized procedure, is pulled upward and downward simultaneously. During this process, fracturing of the specimen is observed under a microscope and the length of the crack is measured.

NIMS initiative

TOPAS Research Cluster for Adhesive Materials

Three roles of the cluster



*KEK: High Energy Accelerator Research Organization

NIMS established TOPAS (Tsukuba Open Plaza for Advanced Structural Materials) at its Research Center for Structural Materials (RCSM) as a consortium to promote collaborative research and development among industry, government and academia.

TOPAS consists of theme-specific clusters and provides venues for joint research, standardization, information exchange and human resource development. Following the launch of the Research Cluster for Infrastructure Materials, the Research Cluster for Adhesive Materials kicked off in July 2016 as a second cluster.

The aim of the cluster is to attract researchers studying adhesive materials from various fields, and to share issues they are encountering. As a first step, we encourage them to engage in active discussion in order to identify issues associated with adhesive materials and technology, and accelerate both basic and applied research. The cluster intends to lead open innovation in adhesive materials research.

At present, more private companies are joining the cluster from various types of businesses, including chemical manufacturers that develop and sell adhesive materials, and companies that use adhesives, such as those dealing with steel, railroad and infrastructure, as well as general contractors and heavy industries.

The director of the cluster, Masanobu Naito, says, "We plan to analyze adhesive interfaces at micro/nano levels using NIMS's world-class analytical instruments. By doing so, we hope to scientifically identify detailed mechanisms of adhesion for the first time. For example, we want to know how efficiently chemical bonding takes place in adhesive interfaces, and how the efficiency of the chemical bonding affects the durability of adhesives. In light of the fact that the use of multi-materials as structural materials is increasing, we as the cluster really hope to develop adhesive materials that bring about a revolutionary change to structural material industries."

From the viewpoint of practical use, it is crucial to have knowledge about deterioration and destruction of adhesive materials. To address this point, performance evaluation experts from NIMS will join the cluster and perform rigorous evaluation for adhesives' bonding strength and durability. Then, measurements from the evaluation will be compiled to construct a basic database for adhesive materials. To develop innovative structural materials efficiently, NIMS is also implementing machine learning techniques, so desirable materials can be searched through a computational approach. We expect that this database will become a valuable resource for the design of multi-materials .

The cluster recruits new researchers active in various fields from industry, government and academia as needed.

Materials that stick and detach as needed

Mechanism of "removable" adhesive materials: learning from geckos and leaf beetles

Naoe Hosoda

Group Leader,
Adhesion and Surface Science Group,
Structural Materials Science Field,
Research Center for Structural Materials (RCSM)

In order to reduce environmental impact, it is critical to utilize precious resources effectively. In this regard, recycling of used products is of great importance. To date, many products were created by firmly and permanently joining different parts, and this practice has made recycling of these products difficult. To address the recycling and environmental issues, Naoe Hosoda is studying and developing bonding/joining technologies that enable adhesive materials to be removable as needed.

Hosoda has been studying a discipline called biomimetics for many years. Organisms possess various remarkable mechanisms that are highly functional, highly efficient, and recyclable. By imitating and applying these mechanisms, she hopes to make society more environmentally friendly and recycling oriented.

Among various mechanisms found in organisms, Hosoda is particularly interested in adhesive mechanisms found in legs of small animals such as leaf beetles, jumping spiders and geckos.

Geckos are agile even when they are oriented vertically or upside down on a wall or ceiling. Many insects including leaf beetles can easily walk on a window glass and other slippery surfaces without falling, even when their claws are ineffective to hang on to these surfaces. That is because they have numerous, microscopic and adhesive hairs on their tarsi (analogous to human feet).

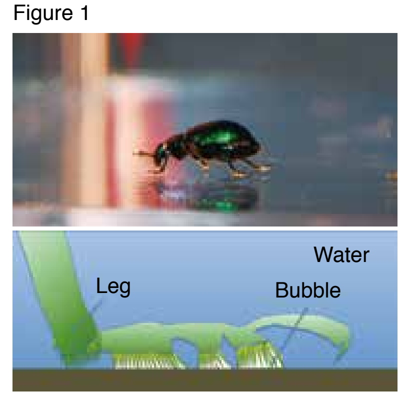
"Tarsal hairs of small animals form weak bonds between the hair and the surface in contact due to friction, van der Waals force, capillary force and adhesion. This mechanism allows these animals to easily attach and detach themselves to/from a slippery surface. That is, they are capable of taking seemingly two opposite actions whenever they want. Also, some small creatures can firmly attach themselves to bumpy leaf surfaces as their tarsal hairs are sufficiently thin relative to the scale of leaf bumpiness, so that the hairs make contact with a large area of a leaf surface," says Hosoda.

Mimicking leaf beetle's mechanism to walk easily underwater

Hosoda carried out detailed study on how leaf beetles can attach themselves to any object. She discovered with surprise that leaf beetles, which are terrestrial, can walk even in water. Then she investigated in depth the mechanism behind the beetles' capability to do so.

She found that when the beetles are placed in water, they take advantage of bubbles present in water. The beetles trap bubbles, which are themselves adhesive, in fine tarsal hairs and thereby they utilize bubbles' adhesiveness. She also found that tarsal hairs are protected by bubbles and prevent hairs from getting wet, so that the beetles can walk in water as easily as they can on land. (Fig. 1).

Figure 1



A leaf beetle walking in water (top) and a schematic showing the beetle's tarsal structure.

In an effort to mimic the characteristics of tarsal hairs of the leaf beetle, she tested PDMS (polydimethylsiloxane) and other polymer materials. When these materials were attached to a device part and placed in water, they trapped bubbles and firmly adhered to the glass surface (Fig. 2).

"Through application of this mechanism, I believe that environmentally-friendly, clean adhesive materials can be developed for use in water," says Hosoda.

It might be feasible to create, for example, a robot capable of easily walking around and performing various tasks in water by applying adhesive polymer materials to the robot's arms and legs.

"Future development of bonding/joining technologies should assume from the beginning the need to remove or peel off adhesive materials as needed. To implement this idea, a project called "Innovative joining and separating technologies to realize a recycling-oriented society" was launched by the Council on Competitiveness-Nippon (COCN) in fiscal 2016. I will continue to focus my effort on R&D of bonding/joining technologies in the hope that they contribute to reducing environmental impact."

(by Kumi Yamada)

Figure 2

A polymer material was attached to the bottom of a bulldozer model to mimic the mechanism of tarsal hairs of the leaf beetle. When bubbles are applied to the material underwater using a syringe, so that the material's surface catches the bubbles, the material tightly adheres to the glass surface.

Combining automotive structural parts and electronic boards into one unit

Firmly bonding organic materials to metals/semiconductors using “water”

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For the purpose of reducing the weight of automobiles, the development of lightweight composite materials has been intensifying. However, it is vital to maintain the level of safety. For that reason, demand for installing electronic boards, which are used in sensors that detect danger, is expected to rise. Akitsu Shigetou is attempting in her research to join automobile body parts and electronic boards into one unit during production using a technology to bind different types of materials.

At present, packaged electronic boards installed in automobiles are mounted to structural parts using screws and adhesives. However, the joining made in this manner is prone to deterioration and a short life, as it is exposed to the harsh automotive environment involving vibration, high temperature and excessive oil. To address this issue, Shigetou is taking an approach to combine structural parts and electronic boards into one unit (Fig. 1). This approach is promising in terms of preventing deterioration of joining parts, simplifying the structure that contains electronic boards, and enhancing the function of the structure.

However, this approach requires joining many different types of materials, such as organic materials, semiconductors and metals, into stack of layers. If different joining methods need to be applied for different materials, that would be enormously labor intensive and costly. Instead, Shigetou came up with an innovative method using water at low temperature under ambient atmospheric pressure.

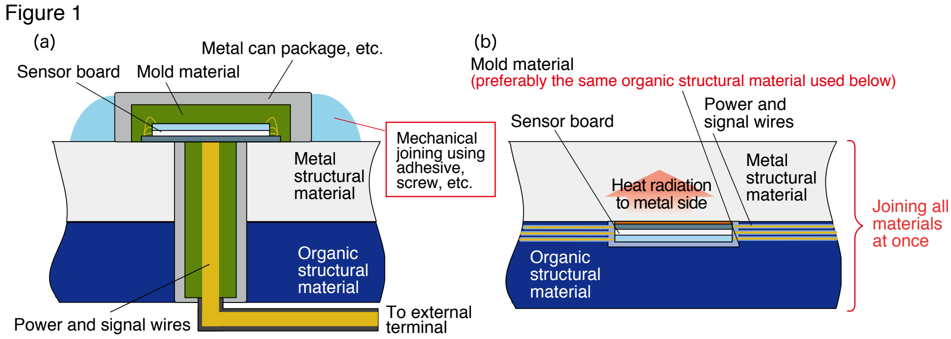
Strong adhesion produced by intermolecular bonding

Under ambient atmospheric pressure, various chemical substances, including organic matters, are attached to material surfaces. Most organic matters can be removed by irradiating vacuum ultraviolet radiation at a wavelength of 200 nanometers or shorter. Then, if water molecules are added to a clean material surface, a layer of bridging molecules is formed over the surface. Using this technique, organic material surfaces in contact can be easily and firmly bound. This method, which can be practiced at low temperature, is particularly useful when joining organic materials, which are susceptible to high temperature.

Unlike organic materials, semiconductors and metals are covered with a thick layer of stable substances such as oxides. As such, irradiation of vacuum ultraviolet radiation alone is not sufficient to remove the layer. To overcome this issue, Shigetou added water molecules into a device that irradiates vacuum ultraviolet radiation. “By doing so, the radiation hits water molecules and breaks them into hydrogen and hydroxyl radicals. Consequently, hydrogen radicals reduce oxides, and then, reduced oxides react with hydroxyl radicals, leading to the formation of a hydrate film over the surface of treated materials.” If you allow these treated material surfaces to come into contact and raise the temperature to about 150°C, a dehydration condensation reaction is triggered between hydrate films. Thus, Shigetou succeeded in bonding several different materials simultaneously at a lower temperature than conventional methods (several hundred degrees Celsius) under ambient atmospheric pressure (Fig. 2).

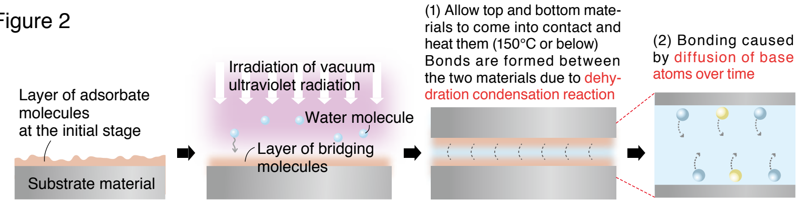
This technology is environmentally friendly and is applicable to any materials if their surfaces can be converted into hydrophilic ones. “I hope that the technology will be put into practical use within five years through collaborative development with private companies,” says Shigetou enthusiastically. (by Kumi Yamada)

Figure 1



During the fabrication of a hybrid structural part, different materials are joined together and electronic boards are embedded between interfaces of different materials.
(a) Sensor mounted on an automotive structural part using a conventional method.
(b) Sensor function embedded in an automotive structural part.

Figure 2



Artificial spider silk

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

There are diverse organisms on earth. Some people think that humans are the rulers among them, but is that really true?

Suppose that all organisms on earth go extinct tens to hundreds of thousands of years from now. Then, if intelligent extraterrestrials come to and explore earth, they should find that earth used to be a planet of abundant life, and insects must have been by far the dominant life form.

Insects are overwhelmingly abundant and fascinating organisms that have existed on earth over millennia. Their diversity and body structure, and ways their brain and nervous system work, are major factors for their successful existence over several hundreds of million years, which is incomparably longer than the span of human existence. Recently, biomimetics—the imitation of biological systems, including insects, to yield innovative and highly functional technologies—has been actively applied in advanced science and technology.

At present, much attention is drawn to mass production of artificial spider silk for clothing and many other purposes.

Spiders spin silk, build a web, and trap prey. They have been behaving this way for 400 million years.

A spider can produce seven types of silk with different chemical properties: some are highly elastic, some have high tensile strength, and some are sticky. Because of these intriguing properties of spider silk, some people passionately tried to develop artificial spider silk for human use. However, they seemed to give up their endeavors along the way as they were unable to figure out ways to mass-produce such silk.

Kazuhide Sekiyama, who studied biology at Keio University, made artificial spider silk and attempted to invent a mass production technology. After 10 years of struggle, he finally came up with a groundbreaking technique. If you mass-rear spiders in order to obtain a large amount of silk, they will start to eat each other.

Mr. Sekiyama scientifically analyzed spider silk and succeeded in its mass production using genetic engineering and microorganisms. By inserting foreign genes into microorganisms that multiply rapidly, they were able to mass-produce a substance with a chemical composition identical to that of spider silk. He then transformed the substance into artificial spider silk by applying a special solvent to the substance and stretching it to form a fibrous material.

A dress can be woven from this fiber, as can socks and neckties. The new fiber is like a dream material as it is highly elastic and lightweight, and has an excellent shock-absorbing property. The material potentially has a wide range of applications, including artificial blood vessels, surgical suture thread, tires and electronic devices.

Mr. Sekiyama is a representative executive officer of Spiber Inc., which is drawing global attention as the company has attracted researchers from around the world, and acquired 14 billion yen of funds from investors.

NIMS has been carrying out biomimetics research for a long time. We can learn a lot from other organisms in terms of developing new technologies. I hope that this discipline will continue to advance and be applied more.

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.

NIMS NEWS

1 French Government Honored Former NIMS President


Prof. Ushioda giving speech at the ceremony

(2016.11.30) French government honored the former NIMS President Professor Sukekatsu Ushioda by conferring the title of Chevalier, L'ordre national de la légion d'honneur (National Order of the Legion of Honour).

The citation for this award recognized Professor Ushioda's contribution to the development of France-Japan activities on creating innovations, collaborations and inviting a number of French scientists to NIMS. The conferment ceremony was held on November 29, 2016 at the official residence of the Ambassador of France in Tokyo, and H.E. Mr. Thierry Dana, the Ambassador of France to Japan, awarded a distinction to Professor Ushioda on behalf of President François Hollande.

*L'ordre national de la légion d'honneur is the highest French order for military and civil merits, established 1802 by Napoléon Bonaparte.

2 The WMRIF 5th International Workshop for Young Scientists


Ceremony for The WMRIF Young Scientists Award (Left: Dr. Stephen Frieman, NIST, Second from Left: Dr. Laurie Locascio, NIST, President of WMRIF, Second from right: Dr. Nishikawa, NIMS)

(2016.11.8-10) The "WMRIF 5th International Workshop for Young Scientists" had been held for three days from November 8th to 10th 2016 hosted by NIMS at Tsukuba International Congress Center.

WMRIF-World Materials Research Institute Forum was established by the former NIMS President Professor Teruo Kishi in 2005 to connect world-prestigious research institutes. Fifty research institutes in twenty-two countries have joined WMRIF as of November 2016 to promote innovative research and to discuss future strategies on Materials Science.

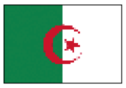
The theme of the workshop was "Structural Materials for Innovation and Integrated Computational Materials Engineering for Their Developments" collaborating with The Cross-ministerial Strategic Innovation Promotion Program (SIP). Twenty institutes in ten countries participated in the workshop and young scientists from the institutes presented their latest research achievements. Dr. Hideaki Nishikawa, researcher of Fatigue Property Group at Research Center for Structural Materials, NIMS, received The WMRIF Young Scientist Award that the best five presenters were selected for.

Hello from NIMS

Hello! My name is Nassim and I'm a teacher and a PhD student from Laghouat (Algeria). Since my early childhood, Japan was known to me through many comics, and then through its high-end products (electronics, cars, motorcycles...etc.). I had the chance to visit Japan in three different seasons and each season is a unique experience, the bloom of cherry-blossoms in spring, the yellowish and reddish color of Ginkgo trees in autumn, and the beautiful snow landscapes and illuminations all around city-centers in winter. During my stay I often try to experience not only the modern face, but also the magic of the cultural heritage and its diversity, enough reasons why Japan should be on everyone's bucket list. Living in Tsukuba, the "City of science", is particularly interesting as it offers the opportunity to meet world-class scientists and international fellows working inside prestigious universities and research institutes. At NIMS, I am received as a guest researcher among the group of Dr. Chikyow in MANA building. For one year, I will be able to finish my experiments within cutting-edge fabrication and characterization facilities in the institute. My research topic involves exploring new features for silicon clathrates. I am very grateful to everyone who allowed this dream to come true: my parents, my family, my teachers, my friends, and my supervisor Dr. M. Ferhat.


Enjoying the snow in Tsukuba


On my way to Kawaguchi-lake I took a short break at Akihabara and enjoyed a nice sushi for lunch.



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