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Personal History

–The Inquiring Scientific Mind

From a Lecture by Dr. Leo Esaki

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In 1992, Dr. Leo Esaki left the IBM T. J. Watson Research Center in New York after 32 years and became President of University of Tsukuba. He is now Chairman of the Science and Technology Promotion Foundation of Ibaraki and also has close ties to Tsukuba City, including his position as Chair of the Science Academy of Tsukuba (SAT). One of his most notable achievements is the discovery of the Esaki tunnel diode based on the semiconductor tunneling effect for which he received the Nobel Prize in Physics in 1973. Another notable achievement is the invention of the artificial semiconductor superlattice and subsequent groundbreaking research in this field, which is believed to be even more influential than the Esaki tunnel diode. These were truly pioneering work in nanotechnology. The lecture which Dr. Esaki gave recently at NIMS contained a wealth of suggestions and stimulating ideas for the researchers who will be responsible for the next generation.

What is the “inquiring scientific mind”?

I grew up during the period of war in the Showa Era (1926-1989). The Second Sino-Japanese War began one year before I started middle school, and the war between Japan and the United States began a year before I went on to high school. The war ended for Japan the year after I entered the Department of Physics, Faculty of Science at the University of Tokyo. I think that I hungered for truth and universal knowledge precisely because I had been placed in the hard-pressed environment of war. For that reason, I chose to major in physics as “natural philosophy.” On March 9, 1945, my lodgings in Hongo were burned in the night-time air raid on Tokyo, which resulted in 100,000 deaths. When I went to the university the next morning, Prof. Tsutomu Tanaka lectured on “Physics Experiment No. 1” as if nothing at all had happened. It was this time which taught me that learning is more important than anything else, namely, what we call the inquiring scientific mind.

Today, I would like to talk about this scientific mind. Here, we should use the word “mind” rather than “heart.” According to the definition by Prof. Yasuji Sawada of Tohoku University, mind means “mastering a strategy for controlling oneself which anticipates the environment in order to optimize one’s dynamic adaptability to a changing environment; as a result, subjectivity is born, and mind grows in this subjectivity.” As civilization becomes more advanced, humankind demands universality and objectivity. This is the scientific mind. The things which make science distinctive include the mathematical system of formal logic created in ancient times, the thinking “I” of Descartes, and systematic experimentation which identifies causality. The science which solves the mysteries of the universe and matter is constructed on a foundation of numerical analysis and reductionism. On the other hand, where weather and earthquakes are concerned, the volume of information involved is vast and the organizing principles are not clear. For this reason, we still do not fully understand these phenomena. And of course, in living organisms, the crucial organizing principle that the whole is greater than the sum of its parts is undoubtedly at work, but we still have not achieved a complete analysis.

So, what are the conditions for a researcher in the sciences? We can’t say that these conditions are satisfied simply by solving a given problem. The researcher must possess the creative mind which drives progress in science. The scientific mind discovers the problem and finds a solution by grasping its essence. That is creation. People normally gain a judicious mind as they grow older, but conversely, they lose their creative mind. Assuming that the creative mind is 100% and the judicious mind is 0% at age 20, and at age 70, the creative mind is 0% and the judicious mind is 100%, the point of intersection occurs at 45. Around this age, people experience a midlife crisis. Incidentally, I created the superlattice at age 44 (**Fig. 1**). Looking at the age distribution when Nobel Laureates produced the achievements for which they received the Nobel Prize, the peak is from age 35 to 39 (**Fig. 2**). I hope this will inspire all our young people. Older people should feel free to ignore it. Three conditions are necessary in an environment where the creative mind can flourish. The first is an intellectually free spirit which challenges limits, the second is intellectual exchanges which serve as a catalyst, and the third is a competitive environment based on fair evaluation. In other words, there is a willingness to let the student surpass the teacher. In the United States, researchers hope for students who will surpass them, but what is the case in Japan? This is also an important point.

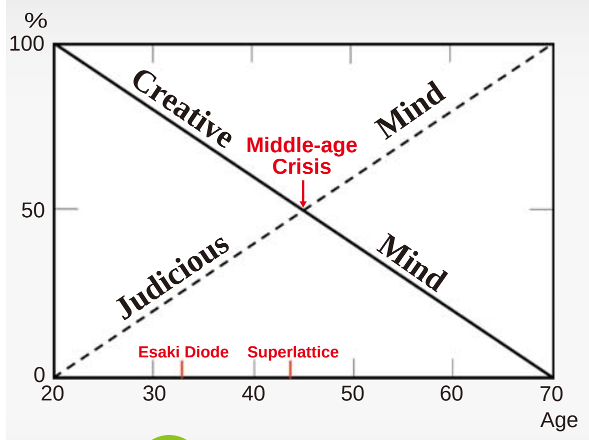
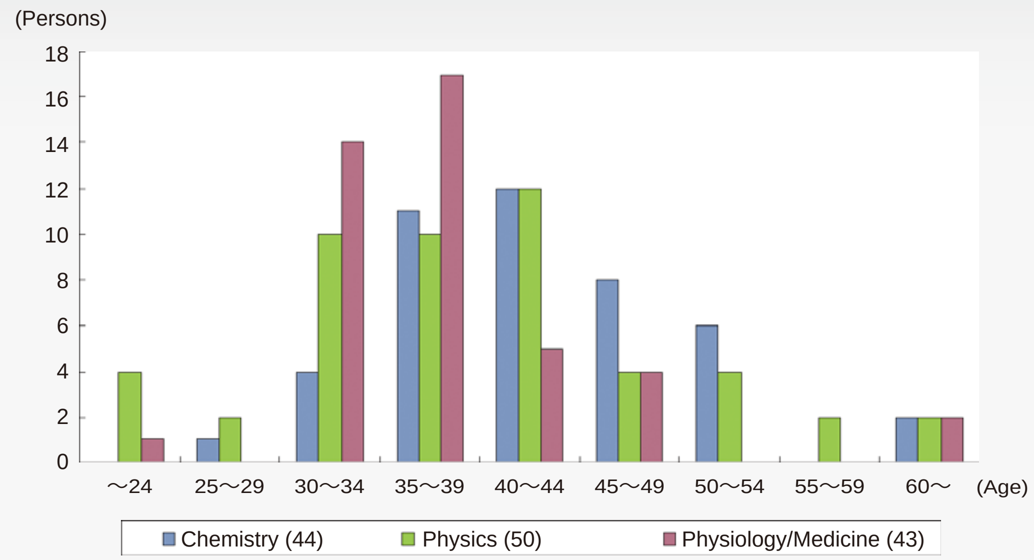


Fig.1 Change according to Age

The importance of using quantum mechanics in industry.

Looking back on the 20th century, I think that the greatest invention was the semiconductor transistor, which was invented in 1947 by Bardeen and Brattain, and later by Shockley, and the greatest discovery was the elucidation of the structure of DNA by Watson and Crick in 1953. Learning from the past – in other words, inquiring about the old in order to know the new – is a common expression, but in science, we find guidance by inquiring about the future.

I took a job in industry when I graduated from university with a sense of purpose, wanting to create some type of quantum device using the new knowledge of quantum mechan-



Age of achievement means the age when the Nobel Laureate published the paper, etc. which was the basis for the award of the Nobel Prize.
(source: Ministry of Education, Culture, Sports, Science and Technology)

Fig.2 Age of achievements of Nobel Laureates (1987~2006) ics. I thought that quantum mechanics would be considered absolutely necessary in industry. I soon moved Sony, which was a brand-new company called Tokyo Tsushin Kogyo K.K. (Tokyo Telecommunications Engineering Corporation) at the time, and it was there that I created the Esaki tunnel diode. The Ph.D. dissertation “Quantum-Mechanical Tunnel Diode” which I submitted to the University of Tokyo on this subject was highly evaluated and led later to my receiving the Nobel Prize. In the United States, 40% of those who take doctorates are working in industry. In Japan, the number is only 20%. Thus, in order to improve the level of industry, I think it is necessary to hire more people with doctoral degrees. The culture in industry and that in universities is certainly different, but while I was working at IBM in the United States, I was also a Visiting Professor at the University of Illinois and elsewhere. Strong exchanges between industry and academia exist in that form.

“Creative failure” is an accompaniment of new attempts in science. The challenges that should be pursued are frequently concealed in the shadows of creative failure. The Zener tunneling is an example. Zener assumed that breakdown in electrical insulation was caused by a tunneling effect, but this was not true – in fact, it was an avalanche phenomenon. Precisely because of this creative failure, I made a p-n junction and was able to observe the phenomenon that had been considered the Zener tunneling. I published the paper in Physical Review in 1958, exactly 50 years ago. I hope that you won’t forget that research is finally completed when it is rounding out and published in a paper.

That year, I went to an international conference on solid-state physics and made the first presentation on the tunnel diode. At the time, Dr. Shockley, who had won the Nobel Prize in 1956, took up my work in his keynote address as one example of important recent research, and praised it as “the most beautiful demonstration of the Zener effect.” As a result, the hall where I gave my own presentation was standing room only. On the way back to Japan, I visited the United States, where I had an opportunity to see the memorial stone commemorating the 100th anniversary of the birth of Alexander Graham Bell, which had been erected in 1947. As it happened, 1947 was also the year when the transistor was invented. Bell’s word’s were engraved in the stone: “Leave the beaten track occasionally and dive into the woods. You will be certain to find something that you have never seen before.” Indeed!, I thought, and soon I made up my mind to go to America.

Proposing the concept of the artificial superlattice.

I went to the United States and, in 1969, proposed the concept of the superlattice at the IBM T. J. Watson Research Center in New York. However, Physical Review had declined to carry the paper, and it was published in IBM’s journal. The energy state of the electrons in crystals is expressed by the Bloch function. When an electrical field is applied to a crystal, the energy is quantized, resulting in levels which are discretized at an equidistant separaation. This energy separation is given by eFd, in which e is the charge, F is the field intensity, and d is the lattice constant. The condition for electric quantization is $eFd > h/\tau$, where h is Planck’s constant. In reality, however, this is almost never materialized in natural crystals. Therefore, I conceived the idea of creating an artificial superlattice which would satisfy the condition for quantization by artificially increasing the lattice constant. Quantization occurs when an electrical field is applied to a superlattice. The oscillation based on the transition during this period is Bloch oscillation. Bloch oscillation is an extremely interesting phenomenon, as it is a macroscopic quantum effect. Although I say artificially increasing the crystal lattice, because this was at the nanometer scale, this work was truly a forerunner of nanoscience and nanotechnology, and later achieved great progress.

My joint researcher, with whom I proposed the concept of the semiconductor superlattice, was a Chinese scientist, Dr. Raphael Tsu, who recently wrote a book entitled “Superlattice to Nanoelectronics,” in which he kindly said that “Frankly, without Esaki’s experience and forcefulness, I would have given up.” He also wrote that I told him “Experts are not always right.”

At the IBM Watson Research Center after winning the Nobel Prize.

Photo courtesy of Yukio Shimura.

An individual-oriented society is necessary.

Now I’d like to think about individuals and groups. Up to now, Japan has prospered as a result of “groupthink.” This was a society in which priority was placed on the prosperity and stability of the entire group, and the individual was expected to work for the whole. On the other hand, Western Europe is an individual-oriented society. It is important that the individual demonstrate creativity, and the group perhaps serves to support the activities of the individual. In Japan as well, it will be necessary to move to an individual-oriented society in the future. If we don’t do this, it will be difficult to demonstrate leadership in Asia. A paradigm shift is occurring in today’s society. Horizontal networking is progressing, the service sector is developing in diverse ways, and a knowledge-intensive, globally-competitive society is emerging. Venture companies are being launched in large numbers, and the internet is actively utilized. This is an era of individuals, when diverse talents are in full bloom.

I think that we must aim at an intelligence-based country. The creation of knowledge, transfer of knowledge, and use of knowledge by universities and research institutes is becoming increasingly important. The Age of Science has truly arrived. The relationship between academia and industry in designated research and its development are shown in the following figure (Fig. 3). Although it is extremely difficult to leap over the differences in the respective cultures, new industries are born by surviving the “Darwinian Sea of selection", and venture companies are producing billionaires. Innovation is extremely valuable in the conversion from inventions and discoveries into new industry.

Five conditions for winning the Nobel Prize.

Finally, I would like to propose five don’ts that you must avoid if you want to win the Nobel Prize. First, don’t be bound by the conditions that have existed until now. Second, although it’s fine to respect your teacher, don’t be slavishly devoted. Third, be selective so that you don’t be swept away by today’s great wave of information. Fourth, don’t avoid fighting to have your own ideas accepted. This is unexpectedly important. And fifth, don’t grow tired of a youthful sensibility and lose your curiosity. These five are necessary conditions. However, don’t forget that they are by no means sufficient conditions.

Democritus, who proposed the concept of the atom, said that “Everything existing in the universe is the fruit of chance and necessity,” but how far is the Nobel Prize chance, and how far is necessity? In my case, I calculated that the tunnel

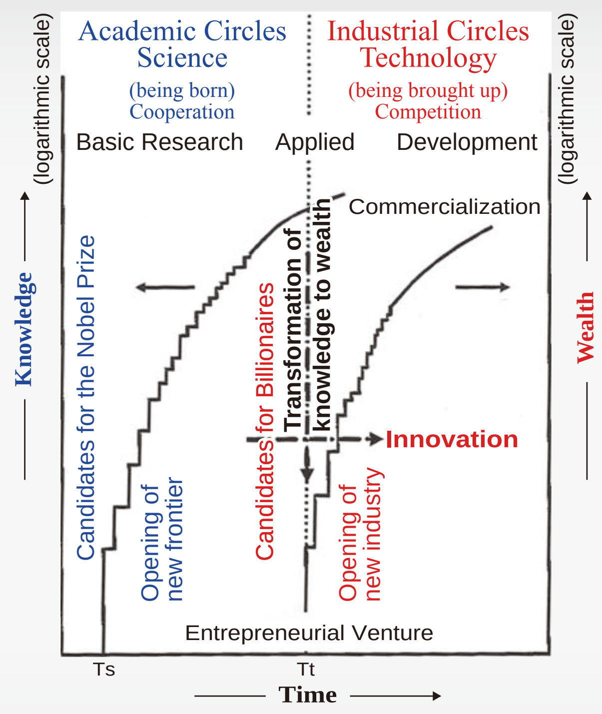


Fig.3 Progress Pattern in a Particular Field

effect couldn’t be observed if the width of the p-n junction wasn’t around 10nm, so I introduced impurities to narrow the width. This can perhaps be called necessity. However, the fact that interesting phenomena occur in the forward direction of the p-n junction was completely unexpected. This was chance. This is what’s interesting about research. However, if you don’t have the capability to seize chance when it occurs, it comes to nothing. As Louis Pasteur said, “Chance favors the prepared mind.”

I think that I was able to do the work of discovering the Esaki diode when I was 32 years old because this was a new field, and furthermore, because I didn’t have any boss. Setting out for unexplored territory without a boss, resolutely determined to do good work, is one way. One remarkable difference between today and my day is the fact that today’s Japan has become a society in which the importance of scientific research is recognized. I would like to conclude my remarks by expressing my hope that all of you will take advantage of this blessed environment to produce outstanding achievements.

Materials Manufacturing and Engineering Station

Supporting *Monodzukuri* in Research

This Station was established as a unit which supports leading-edge research in NIMS from the viewpoint of "*monodzukuri*," meaning distinctively Japanese manufacturing technologies. In carrying out research, first, it is necessary to create a research environment. Development and improvement of the unique devices which are indispensable in developmental research, and processes from fabrication of the material of interest in research to processing of specimens for use in evaluation are important. Concretely, this Station provides technical support from the upstream processes to fabrication of test specimens, including processing of materials, design and fabrication of equipment, sample making, glass work, and melting, forging, rolling, and heat treatment of metals. If we may say so, we are a key behind-the-scenes group in materials research. The Station comprises (1) the Material Engineering Section and (2) the Materials Manufacturing Section. The following will outline the main work of the respective sections.

(1) Material Engineering Section

◆ Mechanical Workshop

The main work of the Mechanical Workshop is design and fabrication of devices which are necessary in research using CAD, improvement of devices, fabrication of various types of parts, jigs, etc., maintenance and management of equipments, holding of classes on machine operation and safety, and technical consultation. Both of the NIMS Namiki Workshop and the Sengen Workshop are the bases for material processing, and are involved in technical development specializing in "ultra-precision/fine machining," which has been the object of a rapidly increasing number of requests.

◆ Sample Making Workshop

The Sample Making Workshop possesses various types of grinding machines for preparation of specimens for use with SEM (scanning electron microscope), EDS (energy dispersive X-ray spectroscopy), and X-ray diffraction devices, and thin film specimens for use in research employing TEM (transmission electron microscope) and other devices. The Workshop is also equipped with a gas absorption measurement apparatus, automatic specific surface area measurement apparatus, and other devices for user convenience. Among other activities, the group provides technical consultation on hard-to-polish and process materials and technical guidance on the operation of related equipment.

◆ Glass Workshop

The Glass Workshop performs work which is indispensable in research and development and research for practical application at NIMS, such as fabrication of glass apparatuses and devices, vacuum enclosure of specimens, and replacement and enclosure of various kinds of gases. In particular, manufacturing of prototypes of unique research equipment incorporating glass devices must be carried out in close cooperation with researchers because there are limits on trial manufacture under outside contract. This section provides support for trial manufacture in line with the requests of researchers.

(2) Materials Manufacturing Section

◆ Melting and Rolling Workshop

This group possesses the integrated technologies and equipment required in research on metallic materials, from melting of the basic material to plastic working, and responds to requests in connection with material creation from researchers inside and outside of NIMS by supplying and developing materials suited to the needs of the individual researcher and providing technical support for research experiments. Other activities include technical consultation services for outside researchers and supply of samples.

[Production of various types of alloys, melting of pure metals, plastic working in various temperature regions, material molding, various types of research experiments]

- Pure metals (Ti, Zr, V, Nb, Cr, Mn, Fe, Co, Ni, Cu, Al, etc.)
- Steel (mild steel, high carbon steel, stainless steel, Cr-Mo steel, etc.)
- Alloys (titanium-, manganese-, and magnesium-based, etc.)

Strain rate controlled rolling mill

Please see the followings regarding joint research or technical consultation by this Station.

Material Engineering Section:
http://www.nims.go.jp/gwsp1/index-e.html

Materials Manufacturing Section:
http://www.nims.go.jp/dmi_nims/e/mmes.html

Or contact us: matman@nims.go.jp

Project for Social Acceptance of Nanomaterials

The aim of the Social Acceptance of Nanomaterials Cluster is to contribute to the sound development of nanomaterials use by synthesizing reference nanomaterials, evaluating the toxicity of nanomaterials, and promoting basic research in connection with the mechanism by which their toxicity is manifested. The core units in this Cluster are the Advanced Nano Materials Laboratory, Advanced Nano Characterization Center, and Biomaterials Center. Research is promoted in cooperation with the NIMS International Affairs Office, Transmission Electron Microscopy Cluster, and Innovative Materials Engineering Laboratory.

In general, as substances are reduced to the nanometer size, they display outstanding functions which do not exist in the bulk material, and anomalous phenomena are observed. By skillfully using this "size effect," it is possible to create outstanding catalysts, integrated circuits, high strength materials, and other desirable products. However, because nanomaterials are extremely small, there is concern that they may slip through the scavenger function possessed by living organisms, be taken into the body, and remain there with harmful effects. This has led to strong calls for basic research to provide guidelines for the safe use of nanomaterials. However, because it is impossible to investigate all nanomaterials, it is necessary to investigate toxicity using reference materials with clear features.

This Cluster synthesizes nanofibers (fullerene nanofibers) comprising fullerene molecules including C_{60} (**Fig. (a)**), etc. as references materials with distinct shapes and physical properties, which are evaluated using nanocharacterization techniques. The toxicity of fullerene nanofibers is evaluated by *in vitro* tests*1 at the cellular level. Although fullerene nanofibers are not ingested into lung cells, research has revealed that they are ingested by macrophage-like cells.*2 Studies on the interaction with cells using multiple indices to date suggest that fullerene nanofibers do not have strong cytotoxicity. Therefore, bioapplications of fullerene nanofibers are now being studied.

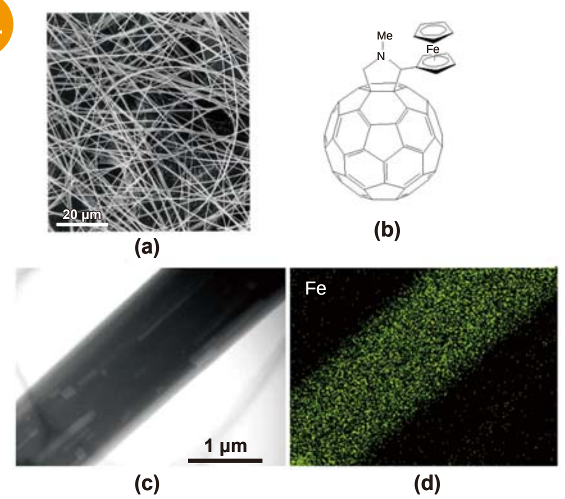
In addition to this work, the Cluster is also involved in the synthesis of fullerene nanofibers with a marker function, which will enable easy identification of their existence in cellular tissue. **Fig. (c)** shows a transmission electron microscope (TEM) image of a fullerene fiber in which a ferrocene derivative (**Fig. (b)**) of C_{60} was dispersed in a C_{60} matrix. In the energy dispersive X-ray analysis (EDX) in **Fig. (d)**, a condition in which iron atoms are uniformly dispersed in the fullerene fiber in **Fig. (c)** can be observed. This type of fullerene nanofiber containing marker atoms is expected to be a useful internal body marker for monitoring changes and removal of nanosubstances after ingestion into cells.

Although this brief article has focused on fullerenes, the Cluster is also engaged in research on the cytotoxicity of substances other than fullerenes, such as titanium oxide nanoparticles, among others.

*1 *In vitro* test
The methods used in toxicity studies include *in vivo* tests, which are performed using experimental animals, and *in vitro* tests, which are performed to evaluate toxicity using human or animal cells. The merit of *in vivo* tests is that it is possible to observe the effect on the entire living organism, but the complexity and high cost of this method are drawbacks. As advantages of the *in vitro* method, tests are comparatively simple and a large number of samples can be treated.

*2 Macrophage-like cell
Macrophages display a function of defending against various types of infections by ingesting microorganisms which enter the body as foreign matter. It is possible to differentiate cells which have a function similar to that of macrophages by applying a differentiation inducer to cells separated from leukemia cells. The resulting cell is called a "macrophage-like cell."

Fig.



(a) Scanning electron microscope (SEM) image of C_{60} fullerene nanofibers
(b) Model of a ferrocene derivative (C_{60}-Fc) of C_{60}.
(c) Transmission electron microscope (TEM) image of a fullerene fiber containing solid-soluted of C_{60}-Fc
(d) TEM-EDX image showing the distribution of iron in the fullerene fiber containing C_{60}-Fc shown in (c) (by NIMS Senior Researcher Takatsugu Wakahara).

Development of Ultra High Molecular Weight Polyethylene Coating by Warm Spray

Coating Materials Group, Composites and Coatings Center
Materials Manufacturing and Engineering Station[†]

Jin Kawakita, *Managing Director* Seiji Kuroda, Masayuki Komatsu[†]

Ultra high molecular weight polyethylene (UHMWPE) is a type of polyethylene in which the ordinary molecular weight of 20,000~300,000 is increased to 1~7 million, and is one of the super engineering plastics (thermoplastic resins which can be used for extended periods without thermal deformation, even at temperatures in excess of 150ºC). UHMWPE has excellent impact absorbing properties, friction/wear resistance, and chemical resistance, and has an adhesion prevention effect against foreign matter, and is also safe for humans.

Because higher added value can be realized in many industrial products (e.g., transport rollers for use with hard materials) by imparting the properties of UHMWPE to the product surface, the development of a coating technology has been desired. However, UHMWPE has extremely low fluidity in the molten state, and thus cannot be used with coating methods in which a powder is melted and fluidized. Although the conventional thermal spray coating techniques have also been studied, severe thermal deterioration of the material has been reported.

This research began from a review of heating methods suitable for the thermal properties of plastic materials in atmospheric spray coating methods. In previous work, this Group established a warm spray method (**Figs. 1 and 2**) which enables coating of metals, inorganic materials, and their composites while avoiding thermal deterioration of these materials.

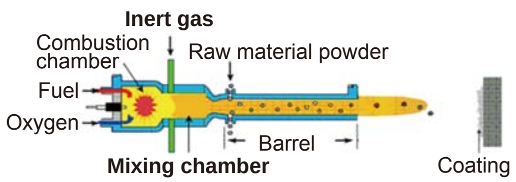
In the warm spray method, a cooling gas such as nitrogen is mixed with a combustion jet obtained from a fuel (kerosene) and oxygen, the supplied materials powder is accelerated and heated by a supersonic jet while controlling the jet temperature, and coating is accomplished by continuous impact/deposition of the coating material on a substrate. In the present work, the gun barrel, which is the part used to heat and accelerate the material particles, was designed optimally for UHMWPE, which has both low thermal conductivity and a low decomposition temperature. This enables extended heating at a temperature more than 300ºC lower than in the conventional methods. As a result, in comparison with conventional thermal spray techniques, it was possible to obtain a dense, pore-free coating with dramatically reduced thermal deterioration of UHMWPE (**Figs. 3 and 4**).

With the warm spray method developed in this work, it is considered possible to perform coating on objects with large areas and complex shapes. Thus, application to resin covers on various types of rolls which can be used in printing presses, and environment-resistant coating of metal materials for use in chemical plants, is considered possible. This technology is also expected to be applied to formation of thick coatings (>50 μm) of high performance engineering plastics such as poly-ether ether ketone (PEEK), which can be used continuously at 250ºC.

Fig.1

Appearance of the warm spray gun.

Fig.2

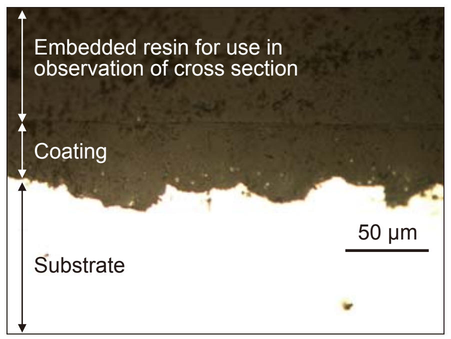


Schematic diagram of the warm spray gun.

Fig.3

Photograph showing the appearance of a UHMWPE coating on a carbon steel substrate.

Fig.4



Cross-sectional photograph of the UHMWPE coating on the carbon steel substrate. (Note that the surface of the coating is smooth in spite of the irregular surface shape of the substrate.)

Research Highlights

Direct Observation of Alignment Process of Fine Particles using Neutron Diffraction Technique

Neutron Scattering Group, Quantum Beam Center
Fine Particle Processing Group, Nano Ceramics Center[†]
Japan Atomic Energy Agency[††]

Group Leader Hideaki Kitazawa, Tohru S. Suzuki[†]
Managing Director Noriaki Terada, Hiroyuki Suzuki, Yoshio Sakka[†]
(Not shown) Koji Kaneko,[††] Naoto Metoki[††]

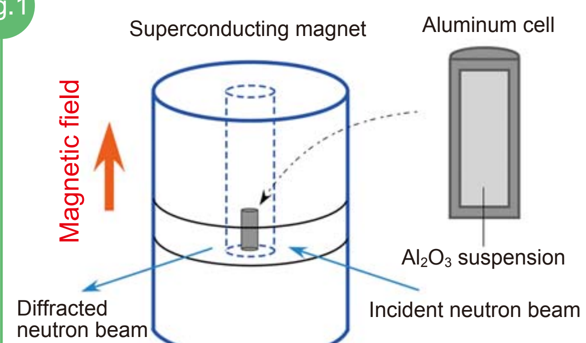
Ceramic materials are used in a wide variety of applications, taking advantage of their excellent electrical insulating property, heat resistance, and mechanical properties. It is known that these properties vary widely depending on the alignment of the orientations of the crystal grains which comprise the ceramic material. One method of aligning fine particles is rotation of the particles using a magnetic field. Elucidation of this alignment process is extremely important for the development of more outstanding ceramic materials. In conventional research, when ceramic materials were fabricated by sintering in a magnetic field, the degree of alignment of the ceramic as a whole was evaluated by observing the material surface by electron microscopy or X-ray techniques, etc. However, because the degree of alignment differs significantly depending not only on the magnetic field, but also on the sintering temperature, the direct relationship between the magnetic field and the degree of alignment of the ceramic was unknown.

In order to isolate the effect of magnetic field on the alignment of fine particles, we used the neutron diffraction technique to investigate the rotation of the particles due to the magnetic field in a condition in which the particles were dispersed in water. Neutrons are electrically-uncharged particles and have an excellent ability to pass through matter. Furthermore, by utilizing the wave nature of neutrons, it is possible to determine the structure and degree of alignment of substances in the same way as with X-ray diffraction. In this experiment, as shown schematically in **Fig. 1**,a suspension of fine particles of aluminum oxide (alumina: Al_2O_3) which had been introduced into a metallic container was placed in a superconducting-magnet, and the field-related changes in the neutron diffraction pattern were observed. Based on experiments in fields up to 10T, it was found that the process of alignment of fine particles in water can be described in terms of the balance of the force which attempts to align the particles in the direction of the field and the force which attempts to cause random alignment, due mainly to collision between the particles and water molecules. From a comparison with the theoretical curve, as shown in **Fig. 2**, it was understood that a high field of 20T or more is necessary for perfect alignment of fine alumina particles in a suspension.

This experiment is the first example of direct observation of the process of alignment of fine particles by the neutron diffraction technique. With these results as a starting point, elucidation of the alignment process of various other kinds of particles using neutron techniques is expected.

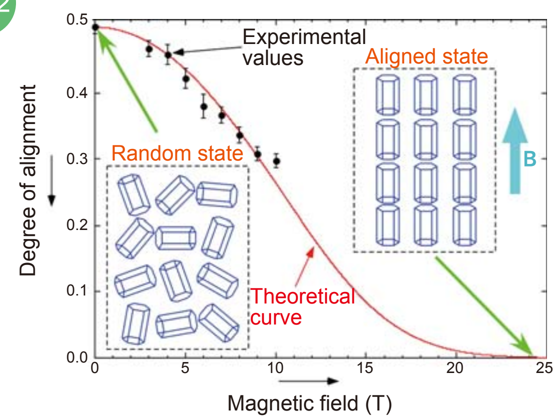
N. Terada, H. S. Suzuki, T. S. Suzuki, H. Kitazawa, Y. Sakka, K. Kaneko and N. Metoki, Applied Physics Letters 2008, 92, 112507.

Fig.1



Schematic illustration of the neutron diffraction experiment. A suspension of alumina particles was inserted into a superconducting magnet capable of generating fields up to 10T, and neutron diffraction was performed.

Fig.2



Magnetic field dependence of the degree of alignment of fine alumina particles in a suspension. Particles which had been aligned randomly in the absence of a magnetic field become perfectly aligned under magnetic fields of 20T or higher. (The hexagonal columns in the figure represent single crystals of the fine particles. The longitudinal direction of the hexagonal column is the easy axis of magnetization (c axis)).

Extreme environments are necessary in testing of the structural materials of space-rockets using liquid hydrogen, superconducting equipment using liquid helium, and similar technologies. For this reason, it has been virtually impossible to obtain the data on properties necessary for design and improvement of the material reliability. A revolutionary technique in material testing under these extremely low temperature conditions was developed by Dr. Toshio Ogata, Managing Director of the NIMS Materials Reliability Center. This achievement won the Commendation for Science and Technology by the Minister of MEXT* for FY2008.

Toshio Ogata
Managing Director, Materials Reliability Center

Reliability is the result of the pursuit of material properties

What was the reason for focusing on this achievement?

The impetus for this research was the accident involving the No. 8 Japanese H-II rocket in 1999. The turbo pump inducer had the most serious problem. The aim was to evaluate the properties that led to failure in the material of this part. The problem at the time was the fact that the NASDA (now JAXA: Japan Aerospace Exploration Agency) lacked suitable data on material properties for conducting evaluations of materials. Because this rocket uses liquid hydrogen (-253ºC, 20K), data for temperatures of 20K and under are necessary. It was thought that this kind of data couldn't be obtained in Japan, so data that were publicly available from NASA (National Aeronautics and Space Administration) in the US were used. However, because this was data for thin plates, the properties were different from those of the material used in the H-II, which was machined from a large block, and thus were not completely useful in analysis of the accident. To remedy this problem, NIMS conducted tests on the properties of this material and produced the relevant data.

So your work was useful in the successful launch of the H-IIA rocket?

The H-IIA is an improved version of the H-II. By participating in the elucidation of the material properties of the H-IIA engine, we contributed to the successful launch of 13 vehicles. Of course, this was not simply the result of the data that we produced using the cryogenic material test method that I developed, but I think that the fact that these data are being used, and are being reflected in the design and operating conditions of the equipment, has contributed to the current series of successful launches. Because the H-IIA rocket embodies the essence of Japan's technologies, we definitely want to cooperate in this project.

Can you explain the cryogenic material test method that you developed?

It was extremely difficult to evaluate mechanical properties of structural materials using liquid helium (-269ºC, 4K). At the time, however, it was extremely difficult to evaluate properties using liquid helium, not only because liquid helium was expensive, but also because it evaporates easily. The test method that I developed and applied practically includes a tensile test method and impact test method, and also a method by which only the part that has evaporated is recondensed and returned to a sealed container. This method is simpler, and it enables fatigue testing which evaluates the life of the material more accurately. A further extension of the development to date is the "Universal Environmental Material Test Method." For example, it is possible to assess the influence of a high pressure hydrogen environment by filling a tiny space of only 0.1cm^3 in a test specimen with hydrogen at 70MPa. In other words, in comparison with the conventional technique, which requires a high pressure test chamber and large-scale equipment for using high pressure hydrogen, it is possible to obtain the necessary data on tensile properties and fatigue properties for the desired temperature simply by introducing a very small amount of high pressure hydrogen into the test piece.

International standardization for the material test method was also highly evaluated.

The results obtained by evaluatiny the properties of materials at cryogenic temperatures were established as an international testing standard by the ISO. Because international standards are also used in commercial transactions, the fact that Japan has the power to create this kind of international standard is extremely important economically. Furthermore, terminology in international standards had been defined differently depending on the type of test. In the field of mechanical testing of metallic materials. Terminology has been defined through an exchange of opinions among specialist from each country, but not easily agreed. The fact that the members of the committee finally said they would "leave it up to me" was important. We proceeded while adjusting opinions among people from the US and Europe, but I think it has been very beneficial for Japan that the Japanese had taken the lead. Japan also should be continuously involved as a representative of one of the advanced nations. Because this kind of international standardization activity is, in a certain sense, a kind of diplomacy for researchers, this activity shall be received more positive support.

Dr. Ogata and his wife at the award ceremony

*Ministry of Education, Culture, Sports, Science and Technology

Development of Cryogenic Material Test Method and Elucidation of Material Properties

Recipient of the FY2008 Commendation for Science and Technology (Research Division) by the Minister of MEXT

Toshio Ogata

In the same way that people become frozen and numb with cold, materials also become hard and brittle at low temperatures. Materials that resist embrittlement at low temperatures have been developed and used, depending on the application, but in practical application of materials, evaluation of the properties of the material in the use environment is indispensable.

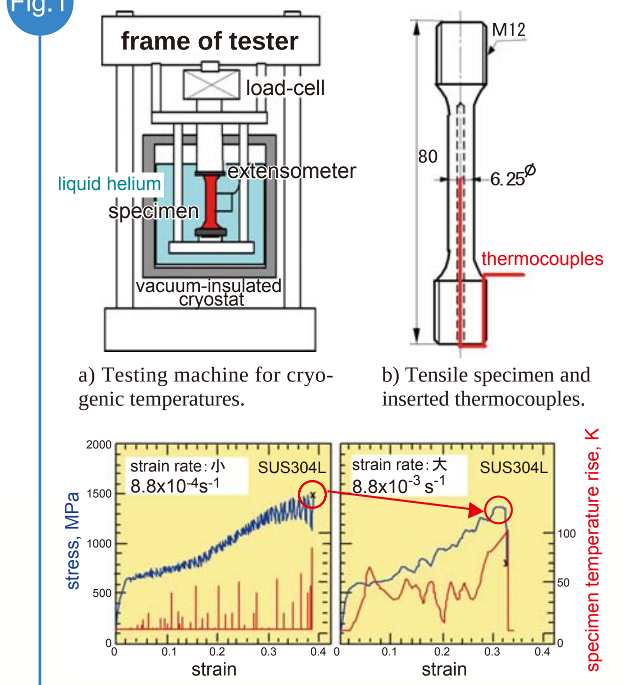
In this research, first, a tensile test was performed in liquid helium in a vacuum insulated container, as shown in **Fig. 1a**. The internal temperature of the test piece was measured for the first time by inserting a thermocouple into the piece, as shown in **Fig. 1b**. This was intended to be a test at 4K (temperature of liquid helium). However, depending on the test conditions, for example, in tests with a high strain rate, the internal temperature of the test piece remained elevated, rising by more than 100K (**Fig. 1c**). As a result, it was discovered that there are large variations in the obtained mechanical properties. The facts that the specific heat and thermal conductivity of metal materials become extremely small at temperatures of 20K and lower, and very small local plastic deformation causes large increases in temperature, were clarified subsequently in simulations by calculation. Because helium gas is a valuable resource and liquid helium evaporates easily, tests that require an extended length of time incur a substantial cost. On the other hand, if testing is carried out quickly to reduce costs, it may not be possible to obtain correct results, which leads to discrepancies between the properties obtained at different test institutes. Therefore, appropriate test conditions (strain rate, etc.) and test methods were proposed.

This tensile test method in liquid helium attracted the attention of the NBS (National Bureau of Standards; now NIST) in the United States from the time it was first announced, and was standardized without delay under the JIS*1 and ASTM*2 standards. After verification in VAMAS (Versailles Project on Advanced Materials and Standards) with round robin tests*3 among worldwide institutes, a proposal was made to ISO*4. And an international standard was established as ISO 19819. Subsequently, standard terminology covering the entire field of testing of the mechanical properties of metallic materials was commissioned, and this was established as ISO 23718. The dimension (world) of international standardization activities differs from that of research aimed simply at the publication of papers. These activities can be considered a kind of "diplomacy," and national interests are occasionally apparent in the results.

In addition, this research also contributed to success in the operation of a low temperature fatigue tester which is capable of maintaining liquid helium for an extended period of time (**Fig. 2a**) and obtaining data on fatigue (**Fig. 2b**). The test methods which are developed, standardized, and established, and the data on material properties which were collected and analyzed using the testing machines, were reflected in the design of the engine of Japan's domestically developed H-IIA space rocket, which uses liquid hydrogen as fuel, and in improvement of its operating conditions, thereby contributing to a consecutive series of successful launches of the H-IIA.

*1 JIS: Japanese Industrial Standard
*2 ASTM: American Society for Testing and Materials
*3 Round robin test: Test methodology based on comparison of the test and measurement data obtained by participating organizations using common sample materials.
*4 ISO: International Organization for Standard

Fig.1

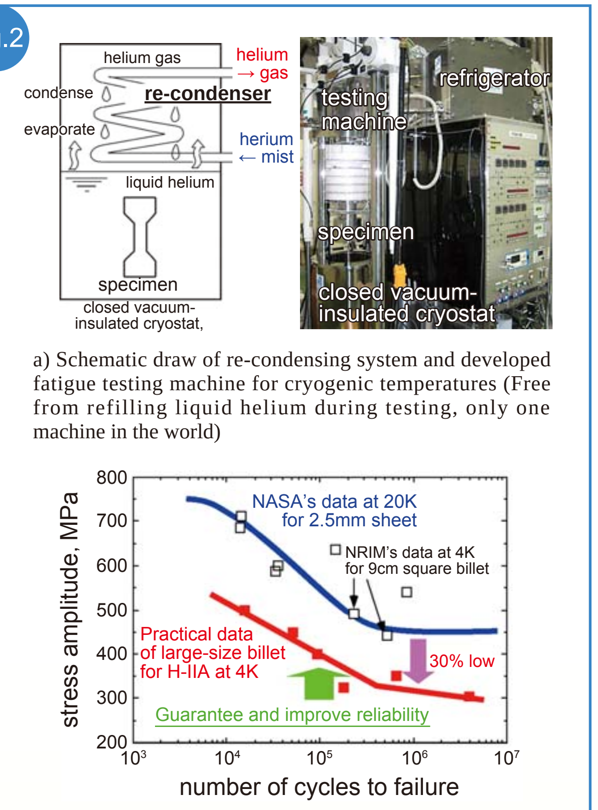


a) Testing machine for cryogenic temperatures.

b) Tensile specimen and inserted thermocouples.

c) Stress-strain curve and specimen temperature rise in tensile tests in liquid helium.

Fig.2



a) Schematic draw of re-condensing system and developed fatigue testing machine for cryogenic temperatures (Free from refilling liquid helium during testing, only one machine in the world)

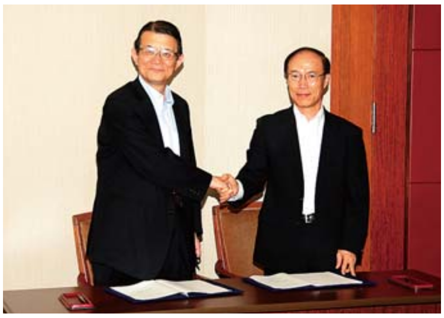
b) Comparison of fatigue life of Ti-5Al-2.5Sn ELI at cryogenic temperatures.

(NRIM: National Research Insitute for Metals, a predecessor of NIMS)

"NIMS-TOYOTA Materials Center of Excellence for Sustainable Mobility" Launches

(Jul. 18, 2008) The signing ceremony of the newly launched "NIMS-TOYOTA Materials Center of Excellence for Sustainable Mobility" was held at Toyota Motor Corporation, Tokyo Office.

The new research center office is located at Sengen site of NIMS. The collaborative research between NIMS and Toyota aims at elucidating the mechanism of fundamental phenomena and developing generic technology for creating next-generation automotive materials, and breaking through technical barriers in materials development. As development is urgently required from the viewpoint of environmental and energy problems, the research will start with next generation batteries for automobiles, then expand successively to include other materials that might help to protect the environment and conserve energy.



At the signing ceremony, Prof. Teruo Kishi, President of NIMS (left) and Mr. Masatami Takimoto, Executive Vice President of Toyota Motor Corp.

Hello from NIMS

Hola! Konnichiwa!

Gustavo Suarez (Argentina)
March 2007 to present
Fine Particle Processing Group,
Nano Ceramics Center

Hello everyone! I am Gustavo, from Argentina, and I will share with you the part of my life that brings me here, to this keyboard in my office in NIMS, Japan.

I am a PhD student of the National University of La Plata in Argentina and I have been completing the experimental part related to my thesis in NIMS since March 2007.

This is not my first time in Japan; I came here in 2005 with a JICA (Japanese International Cooperation Agency) training course in materials science held in Osaka for 3 month. That was my first visit to this wonderful country that has changed my life. During those three months, I have visited many temples and castles. I have read about *samurais*, *geishas* and *bushido* and I was really amazed by the story of "…the man who made the bird want to sing" - Toyotomi Hideyoshi. Stories like this one or the famous samurai called Musashi are full of ideas, especially philosophical ones that help "gaijins" understand more about the "Japanese way."

[Practicing Kendo in NIMS gymnasium.]

I have not only studied materials and visited temples, but I have also met my wife during my first visit in 2005. She is from Albania and her name is Alma (which means *soul* in Spanish). In 2006, Alma found the possibility of taking a master course at the University of Tokyo and I found the possibility of working in NIMS under the direction of my supervisor Dr. Sakka. In this way, we both came to start a new life together. Now I have the perfect wife and an excellent job in a wonderful country.

[In Tsukuba Mountain with my wife Alma.]

In NIMS, I have not only found excellence in the research field, but also new friends and the possibility of practicing the Japanese martial art of sword fighting, the "way of the sword," kendo. I am very happy practicing this sport and having the possibility to learn and practice with samurais' souls, from which I can learn much more than fighting techniques. I also practice soccer with many talented Japanese players. I can say that in NIMS I have found the perfect example of what is called "a healthy mind in a healthy body."

Thanks to all the people in NIMS and thanks Japan.

National Institute for Materials Science
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