Structural Materials for Innovation (SM^{4}I)

——Strong, Light, Heat-Resistant Innovative Structural Materials

Lightweight carbon-fiber-reinforced-plastics (CRFP) made by Japanese manufacturers have been adopted for use in some of the latest passenger airplanes, making a significant contribution to energy efficiency. In the same vein, there is strong interest in future structural materials innovations leading to even more energy efficiency gains. If Japan can develop materials that are incredibly resistant to heat, the country could make a significant contribution to the efficiency of the engine itself. The goal of the Structural Materials for Innovation (SM^{4}I) Program is to develop and adapt advanced materials—from polymers to metals—that are light, strong, and resistant to heat. These materials, developed rapidly through the use of computational science, will be used in airframes and engines, . The results of this program should bolster Japan's structural materials industry and contribute to a leap forward in Japan's aviation industry.

Structural Materials for Innovation (SM^{4}I)

Program Director

Teruo Kishi

Professor Emeritus, University of Tokyo
Advisor, National Institute for Materials Science

Profile

Dr. Kishi holds a Ph.D. in engineering from the University of Tokyo. He has variously served as professor in the University of Tokyo Research Center for Advanced Science and Technology (RCAST), director general of RCAST, director general of the National Institute for Advanced Interdisciplinary Research, president of the National Institute for Materials Science, vice-president of the Science Council of Japan, and chairperson of the Japan Federation of Engineering Societies. Dr. Kishi has been recognized by the Honda Foundation, and has been awarded honors including the Officier de l'Ordre National du Merite, France, the Barkhausen Award, and the USA Distinguished Life Membership, ASM, USA.

Teruo Kishi

Strengthening Japan's Industrial Materials Industry to Support Exports

Today, the field of industrial materials—particularly advanced materials—has been an increasing presence in Japan's export industries. The field is enjoying so much momentum that it is driving the international competitiveness of other industries. Meanwhile, emerging countries are in hot pursuit of these technologies, making these advanced materials all the more important for Japan's future ability to compete in the global industrial markets. We expect that Japan will be able to exploit its competitive advantage in this field to develop advanced structural materials that contribute to improvements in energy conversion and utilization. Our goal is to develop materials that are strong, light, and resistant to heat, leading to innovation in aviation and power generation industries. These advances will also result in better energy conversion and utilization, as well as potentially create new industries in Japan. Another goal of this program is to add ¥1 trillion to Japan's components and materials shipments by the year 2030.

Lightness and Heat-Resistance: The Most Important Issues in Materials Development

Dr. Teruo Kishi serves as the program director for this research and development program. Kishi states his ambitions for the project, saying, "To put it simply, you can approach the issues of structural materials from two directions, namely, reducing weight or improving heat resistance. Of these two, the SIP is mainly concerned with research and development related to heat resistance. If we can make dramatic improvements in heat resistance, then we can use these materials in core systems that are subject to extreme conditions. Making gains here will surely strengthen Japan's industrial materials industry for the future."

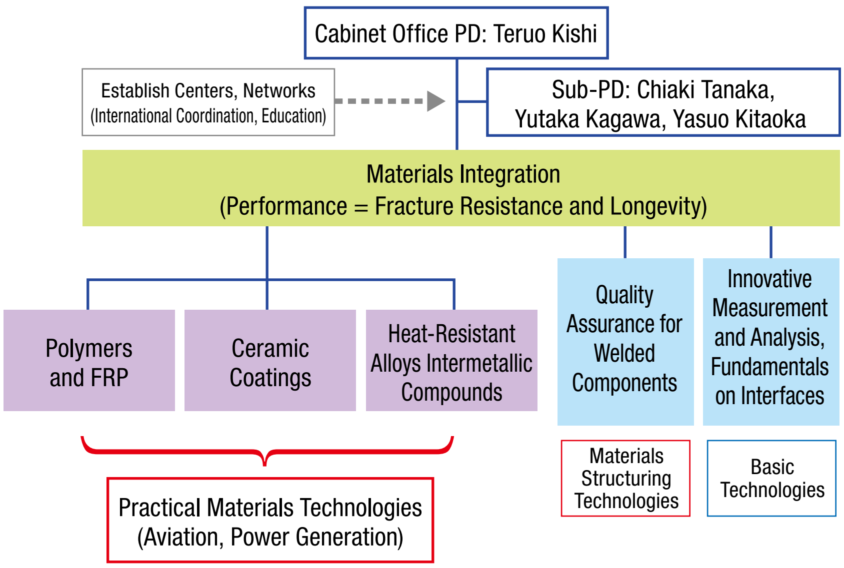
In the meantime, Dr. Kishi also serves as the president of the Innovative Structural Materials Association (ISMA), a post in which he has served since 2013. "ISMA is one of the Future Pioneering Projects under the Ministry of Economy, Trade and Industry. The objective of this particular program is to encourage the development of light, strong multi-materials for application in Japan's automotive industry. At present, Japan has quite a technological advantage in high tensile strength steel, titanium materials, and so on. Making materials lighter can lead to major gains in automobile fuel efficiency," says Kishi. "At the same time, the SIP is conducting research and development into highly heat-resistant materials such as alloys, intermetallic compounds, and ceramics, which should be helpful in making engines more efficient. I believe that if we can coordinate the work of these two projects, Japan will leap ahead of the rest of the world in the field of structural materials."

In fact, there is a good reason for running these two programs in parallel. Both programs are dealing with the common issue of being able to accurately assess the usable lifetime of a material at the time it is being processed. The materials integration concept pursued under the SIP program is what will make this possible. "This is why I believe we must move forward with the SIP and the ISMA projects in parallel," says Kishi. The main reasons that Dr. Kishi was selected as program director for this SIP project were his expertise and experience in working with a variety of materials, as well has his proven leadership skills that will help him direct both SIP and ISMA projects concurrently.

Materials Integration, A Combination of Materials Science and Informatics

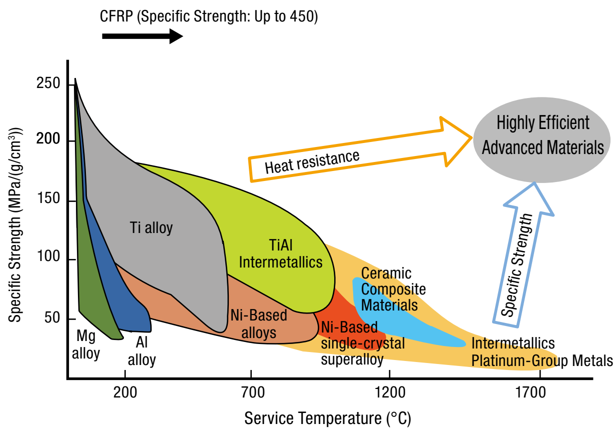
Dr. Kishi goes on to say that the concept of materials integration is perhaps the defining concept of the research conducted in this project. This is in addition to blending theories and experiments of materials science, simulations and other computer methods, database assimilation leveraging the knowledge base of informatics, and other related methods have been brought into the mix, adding new design concepts and tools for structural materials development.

"Materials development requires four critical elements: a manufacturing process, the structure of the material, the properties of the material, and the technologies to use the material. A different, computer-based approach, called materials informatics, places the focus on the structure and properties of the material—almost exclusively functional approach. Our concept of materials integration extends to the actual predictions of performance from the processing stage," says Kishi. "Alternatively, I hope that we will be able to use the tools and systems we develop in this project to work backwards, creating suggested processes from desired performance. If we can accomplish this, we should be able to dramatically reduce the volume of tests and shorten development time."

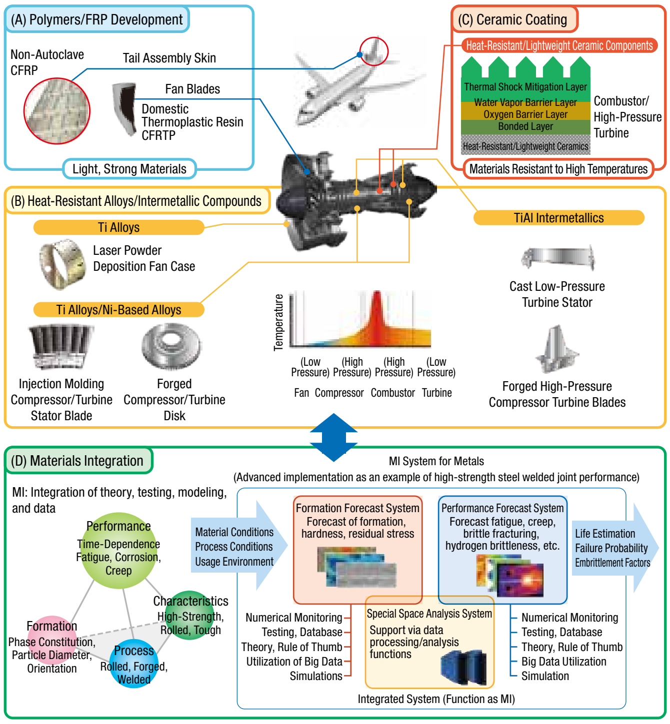


•Implementation Structure

Teruo Kishi



•Mapping properties of materials in specific strength versus service temperature



•Adoption of Innovative Structural Materials in Aircraft

"Given the large number of factors that must be verified, this is actually quite a challenging initiative," Dr. Kishi continues, expressing both caution and confidence. Kishi's confidence most likely stems from the rapid pace of advancements in computer science, as well as his own experience in the quantitative assessment of cracks in materials utilizing acoustic emission signals (AE signals).

When materials are deformed to failure, they release the elastic strain energy stored inside. Ultrasonic analysis makes it possible to estimate the extent of crack propagation, which is one of the non-destructive inspection methods for probing the lifetime of a material. This requires researchers solve a reverse problem to find defects from the detected ultrasonic waves.

"There is no guarantee that we will find a unique solution to a given inverse problem. In other words, the challenge is in the fact that there may not be a single answer. But, several techniques to solve various inverse problems are already used in a variety of applications including earthquake and eruption forecasting. Solving this inverse problem is a critical part of analyzing the lifetime of a material and the time dependency of a fracture event. I believe that the knowledge base of informatics can play a major role in finding this solution," says Kishi. "The training and education of the information professional and the materials professional are quite different. Being able to integrate these backgrounds may be the greatest innovation that comes out of this project," he laughs.

Creating a Leap Forward in Japan's Aviation Industry through Advanced Materials

The main materials under study in this project are (A) polymers and FRP for airplanes, (B) heat-resistant alloys and intermetallics, and (C) ceramic coating technology. Says Dr. Kishi about his ambitions for the project, "With respect to FRP, we are studying new processes that should contribute to low-cost manufacturing. At the same time, our hope is to produce heat-resistant materials in complex shapes using thermoplastic resins that can be deformed under heat. We would be happy to see these materials used in airframes, engine fans and similar applications."

In the context of heat-resistant alloys and intermetallics, Kishi says that the goal for the program is to develop component processing technology—particularly forging technology—for Ti alloys used in aircraft engine disks and blades (400°C to 500°C) and Ni-based alloys (500°C to 800°C), which are critical for high-temperature components. The achievement will pioneer a path for the use of Japanese-designed heat-resistant alloys in engines. Program Director Kishi also mentions the challenge involved in developing components for engines using intermetallic compounds with low specific gravity such as TiAl. Concerning lightweight ceramic components for aircraft engines, Kishi states that the project aims to improve heat energy usage of aircraft engines by developing wold-leading ceramic coatings that can withstand up to 1400°C, where the current limit is 1200°C.

"The mission of this program is to promote Japan's materials industry, but we are also looking toward the future advancement of our aviation industry," says Kishi. "We want the results of this program to have an impact on Japan's aircraft development. To accomplish this, we need to create true, effective industry-academy-government coordination; I feel that this mentality is changing little by little. We should all be excited to see the results of this program," continues Dr. Kishi, who worked at the University of Tokyo's Institute of Space and Astronautical Science early in his career. Truly, this is just the beginning of the dream to leverage materials for the growth of Japan's aviation industry.

Research and Development Topics

(A) Develop aircraft polymers and FRP

Secure the national production of heat-moldable thermoplastic resins and the development of FRP using these resins; establish technologies to manufacture FRP with thermosetting resins that do not require autoclaves; and expand the applicable scope of polymers and FRP components in small- and medium-sized aircraft (engine fan cases, fan blades, etc.).

(B) Develop heat-resistant alloys and intermetallics

Develop rapid and precise cost-saving processing technologies for Ti alloys (used in aircraft engine disks, blades and other applications because of its light weight and strength), Ni-based alloys (indispensable as a high-temperature component for disks, blades, and other), and TiAl intermetallics (offering superior light weight and heat resistance).

(C) Develop ceramic coating technology

Develop ceramic coating materials that offer shielding of oxygen and water vapor at a world-best 1400°C; make dramatic gains in material weight savings, heat resistance, and durability.

(D) Pursue materials integration

Integrate computer science and informatics methods with the existing theories and experiments of materials science to develop tools to predict the performance of materials in use for rapid material design and production.

Exit Strategies

☑ Promote research and development for innovative structural materials

Develop innovative structural materials with a view to the complete range of the aircraft value chain, from basic materials technology to design and production. Extend work to encompass peripheral technologies such as joining, processing, and safety; produce an increase of ¥1 trillion in components and materials shipments by the year 2030.

☑ Establish a research and development system for rapid adoption in real-world products

Promote rapid application of structural materials through materials integration. Establish centers for innovative structural materials through an industry-academy-government coordination and network, including long-term innovation strategies via international coordination.

We would be thrilled to contribute to advances in Japan's aviation industry through work that encompasses the entire range of materials development, from basic research to practical applications.

Materials development and systems that reflect a complete view of the aircraft value chain