Structural Materials for Innovation (SM⁴I)

Innovative Structural Materials for Aircraft—Strong, Light, and Heat-resistant

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 improved fuel consumption. In the same vein, there is strong interest in future structural materials innovations leading to even more energy efficiency gains. If Japan can develop heat-resistant materials superior to conventional materials, these can contribute to improving the fuel efficiency of the engine itself. The goal of the Structural Materials for Innovation (SM⁴I) 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 the Japanese structural materials industry and contribute to a leap forward in Japanese aviation industry.

Program Director

Teruo Kishi

Innovative Structural Materials Association
President
The University of Tokyo
Professor Emeritus
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Advisor Emeritus

Profile

Dr. Kishi holds a Ph.D. in engineering from the University of Tokyo. He has variously served as professor at the University of Göttingen in Germany and in the University of Tokyo Research Center for Advanced Science and Technology (RCAST), as well as the director general of RCAST, director general of the National Institute for Advanced Interdisciplinary Research, president of the National Institute for Materials Science (currently advisor emeritus), and president of the Innovative Structural Materials Association. He has also served as vice president of the Science Council of Japan, chairperson of the Japan Federation of Engineering Societies, and Science and Technology Advisor to the Minister for Foreign Affairs. 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.

Research and Development Topics

(A) Develop polymers and CFRP for aircraft

Secure the national production of heat-moldable thermoplastic resins and the development of CFRP using these resins; establish technologies to manufacture CFRP with thermosetting resins that do not require autoclaves; and build on these technologies to expand the applicable scope of polymers and CFRP components in small- and medium-sized aircraft (engine fan cases, fan blades, etc.). Target large-format CFRP manufacturing technologies and establish related foundational technologies to accelerate the practical adoption of these technologies.

(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 applications), and TiAl intermetallics (offering superior weight savings and heat resistance).

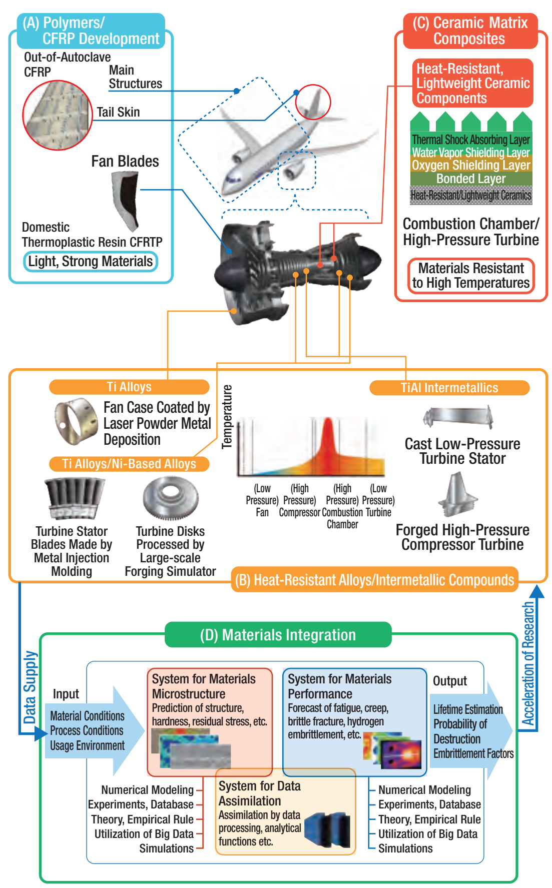
(C) Develop ceramic matrix composites (CMC)

Develop ceramic coating materials that offer an environmental barrier at a world-best 1,400°C; develop low-cost, 1,200°C SiC fiber-reinforced SiC (SiC/SiC) composites; facilitate dramatic gains in material weight savings, heat resistance, durability and reliability; tie to the adoption of these technologies into actual products.

(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.

•Adoption of Innovative Structural Materials in Aircraft



Exit Strategies

Target-oriented R&D

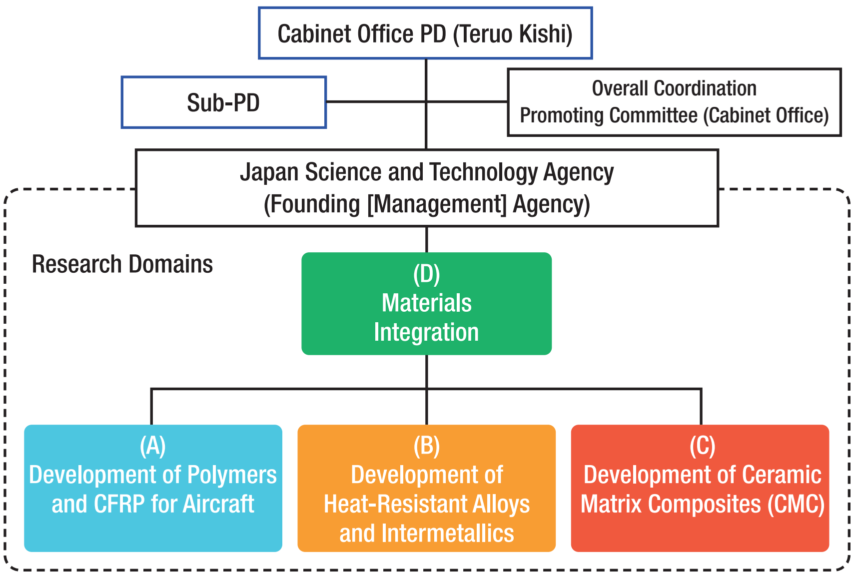
- Develop innovative structural materials with a view to the complete range of the aircraft value chain, from basic materials technology to design and production.
- Speed up the application of structural materials through materials integration. Establish centers and networks for innovative structural materials through industry-academia-government coordination, and build long-term innovation strategies via international coordination.

Measures for practical adoption

- Establish measures for standardization, normalization, safety assessment methods, and certification methods tailored to the aircraft field. Promote use of developed materials.
- Survey the future ideal for structural materials over the medium and long term. Engage in management that leads to optimal research.

Implementation Structure

Utilizing grants provided to the Japan Science and Technology Agency (JST), assistance is provided to the Program Director (PD) and Promoting Committee (progress management for research and development, administrative support, etc.) in cooperation with the New Energy and Industrial Technology Development Organization (NEDO). Research projects and principal investigators are selected from applicants, and the research structure is modified flexibly, based on the progress of research projects, the results of technology surveys and according to changes in social conditions. An International Advisory Board; and a co-leader structure is being adopted for research units.



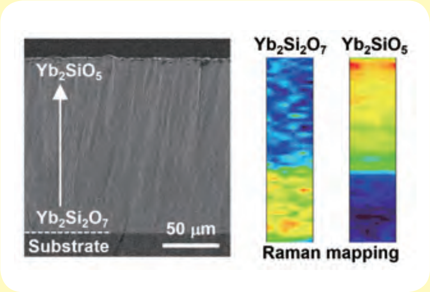
Progress to Date

Steady Progress Toward Practical Adoption in Each Project

We have achieved numerical characteristic targets for CFRP made from heat-moldable thermoplastic resins. Further, experiments using a 1,500-ton forging press simulator have allowed us to prove both forgeability and high strength for titanium and nickel-based alloys. In terms of developing environmental barrier coating (EBC) for ceramics, we have succeeded in precise control for composites/microstructures using a double-electron-beam physical vapor deposition (PVD) technique. As for materials integration, we have completed an alpha-version of a system. Calculation of weld fatigue in steel structures matched the results of experiments.

•Installation of Large-scale Forging Equipment

We also developed a high-precision large-scale forging simulator to devise a model for forged structure/characteristic prediction for titanium and nickel-based alloys. Our researchers were the first in the world to prove both forgeability and high strength.



•Ceramic Coating

Success in precise control for composites/microstructures using a double-electron-beam physical vapor deposition (PVD) technique

Program Director **Teruo Kishi** Interview

Creating a Japanese Aircraft Industry through Innovative Structural Materials

While Japan is a leading nation in the field of aircraft materials, we have yet to assert our presence in the aircraft industry as a whole. We intend to open the gate to the creation of a new industry by developing highly heat-resistant and innovative structural materials and new structural materials development methods.

A Turning Point in Industry-academia Collaboration

"One of the greatest advantages of the SIP project is the degree of freedom allowed. At the same time, we have encountered the type of challenges one finds in a project of this scale. However, the greatest challenge might be in coordinating across sectors from industry, academia and the government," says Teruo Kishi, program director of the Structural Materials for Innovation (SM^4I) program.

Says Kishi, "In the 70 years following the end of the war, Japan had no foundation for industry-academia collaboration. Over the past 20 years, we have made progress in this type of cooperation; however, there have been no particular successes to point to. With the SIP, I believe we may have finally turned a corner."

Kishi sees the emerging industry-academia-government collaboration as an important turning point in producing an opportunity for innovative technological development. Kishi continued, discussing the results stemming from the change in attitude among researchers over the two years since the launch of the SIP.

Steady Progress toward Practical Adoption of Heat-resistant Components

The Structural Materials for Innovation program encompasses four domains of research and development.

One area is the development of polymers for aircraft and CFRP through the pursuit of light-weight, strong, and highly heat-resistant structural materials. Here, the program has made advancements in developing materials without the use of an autoclave, reducing the manufacturing time of tail skin. Researchers now see a path toward the practical adoption of this technology. Other researchers are working on CFRP made from highly heat-resistant thermoplastic resins for use in engine fans in the future. They have already achieved numerical characteristic targets in their work.

In terms of the development of heat-resistant alloys and intermetallics, a 1,500-ton forge simulator has been developed and installed, based on a large-scale 50,000-ton large-scale forging press owned by Japan Aeroforge, Ltd.

Says Kishi, "We are the first in the world to establish prediction models of microstructures and materials properties after forging process for titanium alloy and nickel-based alloy, proving both to be forgeable and high-strength."

The program took on the challenge of developing high heat-resistant components made by nickel, a field that overseas manufacturers have yet to attempt. In this work, researchers are looking to create a global market for Japanese-made forged parts for aircraft.

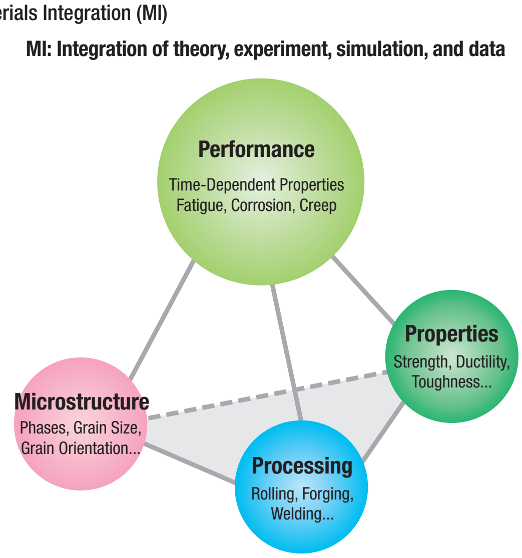
The development of ceramic matrix composites is currently the most competitive area in the world. In addition to the development of environmental barrier coating (EBC), the development of low-cost SiC fiber-reinforced SiC (SiC/SiC) composites, with a view to practical application, was added to the program as a new area of development.

Alpha-version Complete for Materials Integration

Materials integration (MI) combines materials science, computer science, and informatics to create new design concepts for the development of structural materials. Beginning with materials development focusing on materials structure and characteristics, Japanese researchers are working to make a series of advancements from processes to performance forecasting.

"While information for each module is important, it is also important to describe the structure and dynamic characteristics when these individual components are welded. Expected life span is predicted through the integration of modules, calculating across multiple scales of time and space. We have completed the Alpha Version, and are well on the way to trials by our corporate partner." (Kishi)

•Materials Integration (MI)



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

At present, MI projects are in progress around Japan, conducting research and development into functional materials, polymeric materials, ceramics and more. Advancements in MI for structural materials should lead to applications in other fields as well.

Promoting Innovation through the Adoption of TRL and a Co-leader Structure

In response to the changing world situation, projects were added to the program, including the development of CFRP using low-cost fibers and the development of non-destructive inspection methods for SiC ceramics. Some programs have outgrown projects towards the practical application, and progress has been satisfactory. The program is looking toward the rapid practical implementation of research and development by adopting Technological Readiness Level (TRL) standards to identify realistic development stages.

From the standpoint of innovation, projects are now using the co-leader structure for operational management. Under this system, each research unit includes a representative from the corporate sector. The program has also established an International Advisory Board, bringing in experts from around the world to promote this research internationally, as well as to coordinate with international entities.

In terms of human resources development, the program has entrusted MI to researchers aged 40 or younger, and is also running a colloquium to develop young professionals in the field.

Says Kishi, "To prevent the dispersion of our results after the end of the SIP, we must establish centers of excellence (COE) that will take over the research in each field. I hope to create a system where research can continue and technologies are accumulated for 20 or 30 years at least."

While Japan is a leader in the field of aircraft materials, the nation has yet to break through in the aircraft industry as a whole. Through the development of innovative structural materials and methods, Japan aims to create its own new aircraft industry.

Future Plans

Today, we are in a period where the aircraft industry is scrutinizing the cost of materials. As a new material, it is important that CFRP is developed under an effective intellectual asset strategy, including certification under U.S. codes and standards. At the same time, we must also develop the next generation of professionals who will support ongoing advancement in this field. In terms of technological development, the program has incorporated the TRL standards, aiming to advance progress to a stage just prior to prototype system fabrication by the end of the program.

Fiscal Year	2014	2015	2016	2017	2018
(A) Polymers/FRP Development ①Out-of-Autoclave Materials	Reduce curing time of CFRP for tail skin (void fraction < 1%)			Establish out-of-autoclave molding technologies and reduce costs at practical adoption levels	
②Heat-Resistant Polymers for Engines Composite Materials	Develop 200–250°C heat-resistant/durable PMC material molding technology under fan frame structure			Prepreg development, establish low-cost processes, establish CFRP fan component application methods	
③Main Structural Materials for Airframes High-Productivity/Tough Composites		Develop 1.5 times stronger CFRP standards for main structural polymers for aircraft		Develop technologies for improved peeling resistance and fast curing matrix polymers	
(B) Heat-Resistant Alloys/Intermetallic Compounds ①Forging Simulator	Design, install, create a forging database, and build systems for a 1,500-ton large-scale forging simulator			Establish center of excellence, establish forged design short-term structuring	
②TiAl Alloy Design/Ingot Manufacturing Technology	Propose TiAl model alloys, establish forging process basics, conduct mock environmental tests of actual 800°C-class equipment			Establish process design principles, conduct pilot equipment tests, reduce costs	
(C) Ceramic Coating	Improve dense/adhesion of coating film protecting components under high-temperature oxygen/steam environments and develop crack propagation control			Optimize processes based on optimal structure guidelines	
(D) Materials Integration	Limited publication of structural forecasting, performance forecasting, spatial characteristic analysis prototype completion, integrated systems (alpha version)			Complete each component system, develop integrated system for public operation	

We hope that the private sector will utilize the intellect at universities, and that universities will embrace the desire to create a Japanese aircraft industry. What is most important is instilling a spirit of commitment to creating an aircraft industry in Japan.