Structural Materials for Innovation (SM^4I)

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

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 the improvement of fuel efficiency for engine itself. The goal of the Structural Materials for Innovation (SM^4I) Program is to develop and adapt advanced materials—from polymers to metals—that are light, strong, and resistant to heat. These materials being developed rapidly through the use of computational science will be used for 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
National Institute for Materials Science
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) Development of Polymers and CFRP

Low-cost and high-rate production CFRP are in high demand for next-generation single-aisle commercial aircraft. Several ways to develop such CFRP exist. One is to develop low-cost and high-rate production autoclave CFRP prepregs. The mechanical properties must not be sacrificed with the low-cost manufacturing process. Alternatively, thermoplastic CFRP(CFRTP) and out-of-autoclave (OoA) CFRP are promising material systems as well. These CFRP may be used as airframe secondary structures before being applied to primary structures. CFRP structures have also been used in turbo-fan engines. High impact resistant CFRTP are being used in fan blades as well as fan cases. High-temperature CFRP, made by replacing titanium alloys, are highly demanded for inner frames. However, quality assurance is a key issue to be solved before these materials can be used in practical aircraft applications. A strong collaboration among fiber/matrix industries, aircraft manufacturing industries, universities, and national institutes is a key to the success of this program.

(B) Development of Heat Resistant Alloys and Intermetallic Compounds

It is crucial for the future engine materials to achieve the development of stable high-quality, maintenance-free care, lightweight, near-net shape manufacturing, low-cost and so on. Since Ti alloys and Ni-based alloys are usually processed by forging methods, the simulation of the forging process with high accuracy and the prediction of product performance greatly enhance the efficiencies of designs and productions. It is also tackled to accomplish the practical applications of lightweight and heat-resistant TiAl intermetallic compounds by dramatically improving their workability and mechanical properties. Furthermore, the technologies using metallic powder, such as thermal spraying, injection molding and additive manufacturing, are being developed.

(C) Development of Ceramic Matrix Composites (CMCs)

The combustion at higher temperature is essential for the improvement of thermal efficiency and therefore the advanced CMCs have a great expectation for enabling this as they are highly competitive and promising material. We have been working on the development of ceramic coating that can be applicable up to 1400˚C as well as the development of SiC fiber reinforced SiC matrix composites that can be applicable up to 1200˚C with high price competitiveness.

(D) Development of Materials Integration (MI) System

We are developing the systems for predicting the microstructure of structural materials depending on chemical compositions and manufacturing processes, and for predicting performance and life-time of structures by integrating theories, empirical rules, computational simulations, databases, and information technologies. These approaches are inevitable as the main tools for developing advanced materials required in a knowledge intensive society, and they will also contribute to maintain international competitiveness of Japan in the field of materials. These approaches are applied to not only metallic materials, but also polymer and ceramic coating materials.

Implementation Structure

Structural Materials for Innovation consists of four research domains (from A to D) constructed from 34 research projects. The research collaboration among universities, industries and national institutes is promoted by joint research contracts signed in each project because the total research organizations such as companies, national institutes and universities are approximately 140. The Japan Science and Technology Agency (JST) manages all research domains through the cooperation of the Cabinet Office. JST organizes the Advisory Board consisted of domestic and international experts in order to evaluate the researches in this program. JST not only organizes intellectual property committee to manage patents and publications, but also publicizes the research results thorough the press release and symposium.

Exit Strategies

Promoting target-oriented R&D

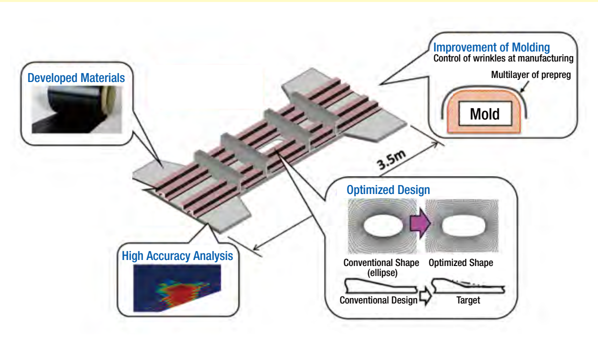
- Through industry-academia collaboration led by companies responsible for practical application and the intellectual property committee, we are aiming to maintain a high international competitiveness of industries by promoting planning the efficient research and development supported by strong patents, considering not only materials, but also manufacturing technologies.
- As the fields of aircraft industry are highly competitive, we are always carrying out an international benchmarking and also verify the eligibility of our goals and the research approaches by domestic and overseas advisors.

Measures for practical adoption

- Implementation of Technology Readiness Level (TRL) benchmark and accomplishment of required tasks for the practical realization at each development stage.
- Selection of leaders from both the companies and the universities, and establishment of structures for the research and development to realize the industry-academia cooperation, including a conclusion of the joint research agreement.
- Arrangement of the technical professionals at the administrative side, and proper management of the project with frequent consultation in order to enhance the realization.

Progress to Date

(A) Development of Polymers and CFRP



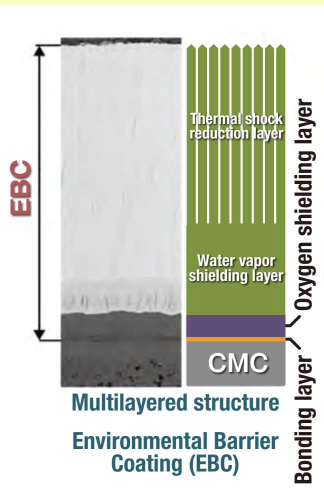
Aerospace grade composites with 50% higher resistance to propagation of internal damage than benchmark materials have been developed along with their optimum structural design and strength characterization method. Subcomponent structures with skin/stringer were fabricated and evaluated under assumed flight loads.

(B) Development of Heat Resistant Alloys and Intermetallic Compounds

HPC Blades LPT Blades

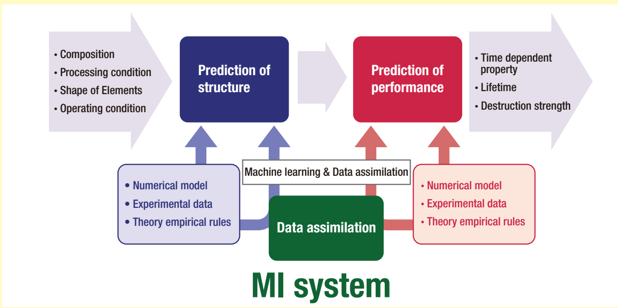
After introducing 1,500 ton forging equipment and constructing the models to predict microstructures and properties of forged Ti alloys and Ni-based alloys, the precision of the model predictions for the forging experiments is being examined. With the success of development of TiAl alloys having excellent properties and workability at high temperature and superior ductility at room temperature, the low-pressure turbine blades are now being manufactured by way of trial.

(C) Development of Ceramic Matrix Composites (CMCs)



We have developed advanced Environmental Barrier Coating (EBC) structure and its manufacturing technologies. We have evaluated the thermal cyclic properties of EBC under simulated atmosphere at 1400˚C and then have newly established an evaluation method about the interface toughness for an EBC bounded to a SiC/SiC substrate.

(D) Development of Materials Integration (MI) System



We have developed various kinds of modules for predicting microstructure and performances such as fatigue strength, creep strength, hydrogen embrittlement, brittle fracture, data-driven prediction tools, and the Materials Integration (MI) System, the α-version based on manual connection of these modules. We aim to automate the system by using information technology and continue to enhance the kinds of modules.

Program Director **Teruo Kishi** Interview

Creating a Japanese Aircraft Industry through Innovative Structural Materials

Japan is leading the world in the field of aircraft materials, but it is hard to show its presence in the aircraft industry. We will open doors to create new industries by developing innovative structural materials with highly heat-resistance, and also new structural materials development methods.

Fixing the awareness of industry-university collaboration will be a great turning point

Prof. Teruo Kishi, Program Director (PD), has pointed out that the SIP has not only the characteristic of high degree of freedom in research subjects, but also the difficulty of management as a big program. The most difficult thing is to maintain the industry-academia-government collaboration throughout the program.

"In Japan, we had no foundation of collaboration with industries, academia and government for 70 years after the World War II. In the last 20 years, the collaboration has been promoted, however, I regret to say that the achievements have not been good enough. The SIP may be a beginning of successful program", he also said.

Prof. Kishi has recognized the beginning of industry-academia-government collaboration for innovative research and development as the great turning point for Japan. He also pointed out that it is not easy to establish a foundation for collaborative R & D contracts and to form consultation place that the essential points of issues for practical application can be shown to universities, in order to promote such collaboration, because industries and universities have different missions.

Research Development of the Structural Materials to Proceed Smoothly for Practical Use for Aircrafts

As the production of relatively small aircrafts for single airlines is rapidly increasing, the markets of aircrafts will be certainly developed. The research and development have been done with international competition in order to achieve high quality, high productivity, weight reduction, and cost reduction. Structural Materials for Innovation consists of four research domains

Development of Polymer and CFRP

Toward a lightweight, high reliability and high productivity of CFRP, this domain conducts the following researches and demonstration tests.

- To newly manufacture the main body and wings of aircrafts, novel CFRP with high toughness and cost reduction is developed. In addition, the design and molding technique for utilization of the CFRP are also researched.
- To manufacture the tail and door of aircrafts, the manufacturing technique with low-cost and high production rate are developed. And the suitable novel CFRP for this technique is also investigated.

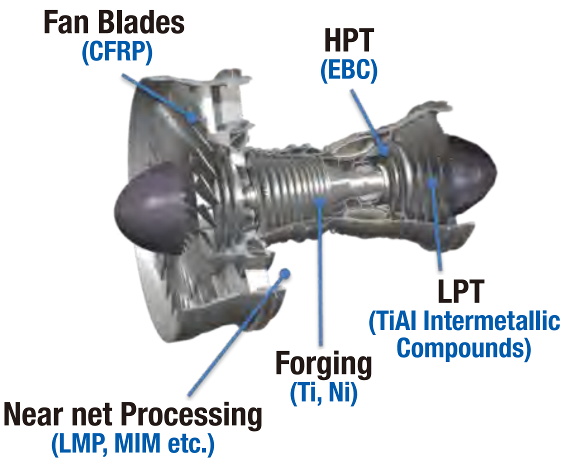
Development of Heat Resistant Alloys and Intermetallic Compounds

To develop aircraft engine, the novel alloy materials with heat resistance and lightweight are developed.

- The prediction system for the forged structure and properties of Ti alloys and Ni-based alloys is constructed by utilizing the 1500 tonne forging simulator designed, constructed and installed in this project, and the compatibility of workability and high strength will be realized for the first time in the world.
- Novel TiAl alloys with excellent workability at high temperature and suitable ductility at room temperature have been developed, and the TiAl alloys are utilized for LPT blade and being checked by durability test.

Development of Ceramic Matrix Composites

High heat resistant materials are developed for the high thermal efficiency. Not only Environmental Barrier Coating (EBC), but also low-cost SiC fiber-reinforced SiC substrate (SiC/SiC) are developed for the applications such as engine and turbine.



Materials Integration

The new design concept named as "Materials Integration (MI)" has been created in research and development of structural materials by combining materials engineering with computational science and information science. Research challenge in MI is not only for the materials development focusing on materials structures or properties, but also for the prediction of the performance from the processes and materials. The α version of MI was established in 2016. The knowledge and data on materials such as material structures, mechanical properties, and performance depending on temperature and loading conditions are accumulated in the MI system. For the total utilization of these information, workflows and interfaces in MI are also being developed. By the utilization by companies participating in this project, the MI system is being improved as a comprehensive system in materials science.

Promoting the innovation by continuing the tight dialogue

To be a real innovative national project, the objective evaluation has

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

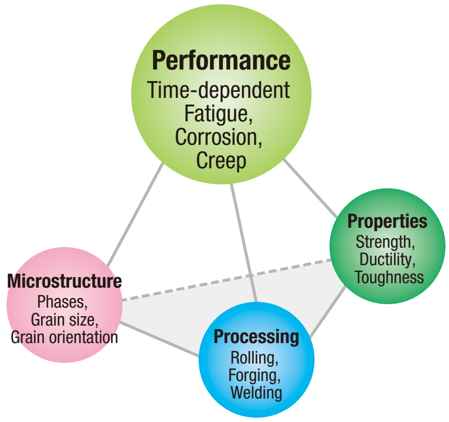
been conducted by more than 20 domestic and overseas advisors to receive constructive comments. All the units have two leaders from industry and academia for each, for the real industry-academia collaboration, to promote the research and development for high quality with the planning for practical realization. We are introducing the index of TRL for research and development, grasping the development stage and are trying to understand what is necessary at each stage for promoting effective and efficient development for practical use. It is also important to strategically promote discussions on intellectual properties, such as patents, copyrights, preparing authentications required later in the development, and presenting the achievements at the conferences. In addition, we are establishing the research center for each domain to maintain the research and development and to train young researchers and engineers, to prevent the disappearing of the achievements obtained as a result of this program after it has ended.

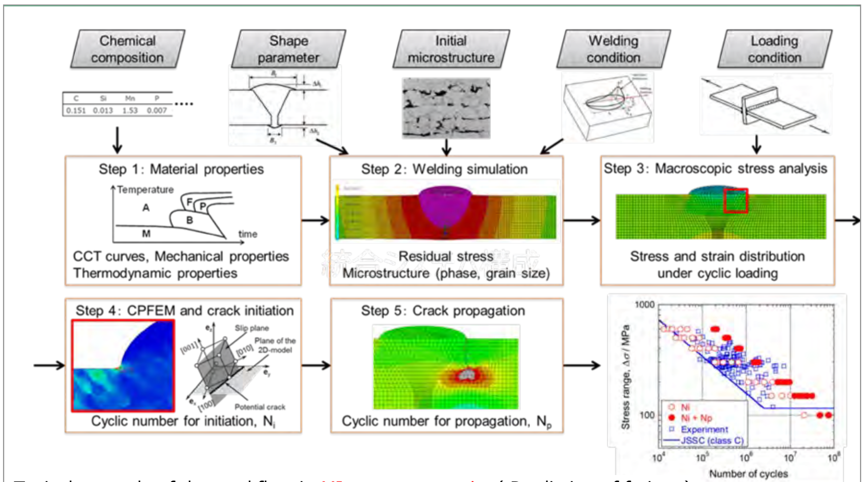
The participating research organizations are totally 140 in the research units. It is important to realize the innovation to increase the presence of Japan in the world not only in the materials industries for aircrafts, but also in aircrafts industries, through this program keeping dialogues between operation side and industries and academia.

Future Plans

The aircraft market is rapidly changing now by introducing large amount of small aircrafts for single line. The needs for aircraft are also being changed. The aircraft market requires materials and techniques with not only low-cost, but also lightweight, high efficiency and high reliability. In this program, the components and elements over 20 pieces in aircrafts have been developed, and not only materials development, but also production process have been investigated. In the final year, the actual components of aircraft will be constructed by integrating the developed materials, processes and design methods, and be verified reliability for strength, heat resistance. The development obtained as a result of this program will be introduced into next-generation aircrafts.

MI: Integration of theory, experiment, simulation, and data





Typical example of the workflow in MI system α version(Prediction of fatigue)

We hope that private sectors will utilize the knowledge of universities more and that universities will have a strong desire to create a Japanese aircraft industry. What the most important thing is to instill a spirit of commitment to create an aircraft industry in Japan.