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

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

Lightweight carbon fiber reinforced plastics (CFRP) 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^{4}I) 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

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Profile

Prof. 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 at the University of Tokyo Research Center for Advanced Science and Technology (RCAST), as well as director general at RCAST and at the National Institute for Advanced Interdisciplinary Research. He was President of the National Institute for Materials Science and is now 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 of Foreign Affairs. He has been recognized by the Honda Foundation, and has been awarded honors, including the Officer 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 was a key to the success of this program.

(B) Development of Heat Resistant Alloys and Intermetallic Compounds

It is crucial for future engine materials to achieve the development of a high-level of quality consistency, maintenance-free characteristics, lightweight, near net-shape manufacturing, and low cost. We have been engaged in efforts seeking to (1) predict product performance using high-precision simulations of the forging processes for Ti alloys and Ni -based alloys, (2) accomplish practical applications of lightweight, heat-resistant TiAl intermetallic compounds by improving a balance of both workability and mechanical properties, and (3) develop various technologies utilizing metallic powders, such as laser overlaying, injection molding and additive manufacturing.

(C) Development of Ceramic Matrix Composites (CMCs)

Combustion at higher temperatures is essential for the improvement of thermal efficiency. The materials expected to enable this are ceramics. We have worked on the development of ceramic coating technologies capable of withstanding temperatures of up to 1400˚C, as well as the development of SiC fiber-reinforced SiC matrix composites (SiC/SiC) capable of withstanding temperatures up to 1200 ˚C that offer a high level of price competitiveness.

(D) Development of Materials Integration (MI) System

We have accumulated the latest theoretical and empirical knowledge and data on the microstructure of structural materials depending on their chemical composition and manufacturing processes, their material properties as a result of these structural properties, and their performance as displayed under actual conditions of use; and engaged in attempts to utilize this information, including approaches based on information science. We have also developed systems seeking to consolidate and utilize the knowledge of numerous Japanese researchers, with regard to not only metallic materials, but also polymers and ceramic coatings. These approaches are essential as main tools for developing and utilizing advanced materials in our knowledge intensive society, and will also contribute to maintaining and developing the international competitiveness of Japan in the field of materials utilization.

Implementation Structure

Structural Materials for Innovation (SM^{4}I) consists of a total of 34 research and development projects (units) in four research domains (from A to D). These projects have been conducted through research collaboration among universities, industries and national research institutes, based on joint research and development contracts signed for each unit. The total number of participating research organizations was approximately 140. The Japan Science and Technology Agency (JST) closely manages all research domains under the leadership of the Cabinet Office. JST has also planned and executed third-party evaluations of research under this program by an Advisory Board consisting of domestic and international experts, as well as handling intellectual property management, and communicating and publicizing research outcomes through result presentation symposiums.

Achievement over the last 5 years

(A) Development of Polymers and CFRP : Increasing Performance and Reducing the Cost of High Specific Strength Materials with Major Benefits for Reducing Environmental Impact

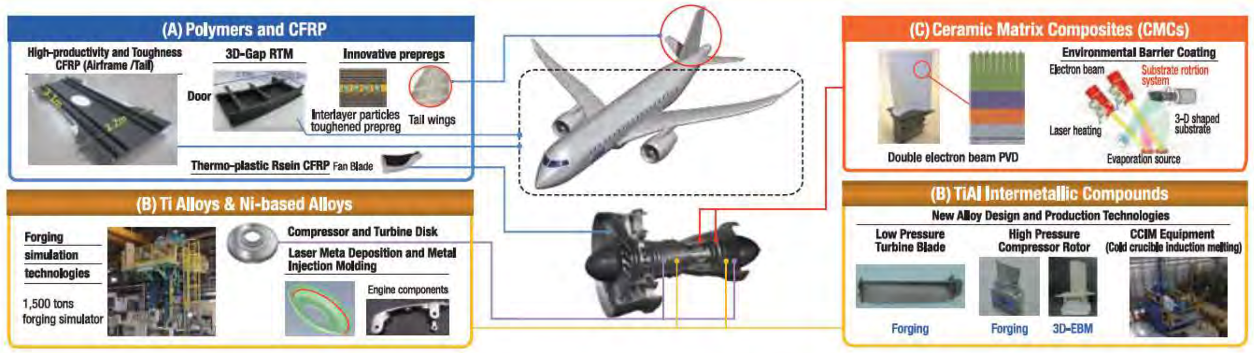
We have developed strong composite materials for use in the main wings and fuselages of aircraft; we have achieved 50% higher toughness than benchmark materials used in Boeing 787 airframes and these materials and design technology development outcomes have been validated by the strength test of full-sized (3.1m x 2.1m) structural component mockups. We have also developed Out-of-Autoclave (OoA) molding technologies for reducing manufacturing costs; we have developed innovative prepregs, active control method, and 3D-gap resin transfer molding (RTM) technologies, and have created mockup structural components for tail (2m x 1.5m) and door (1m x 0.5m) parts, which enabled us to verify that they could reproduce mechanical properties equivalent to those of autoclave-produced materials. Furthermore, we have developed prepregs that met requirements for impact resistance in order to improve thermoplastic CFRP (CFRTP) for use in aircraft engine fans.

(B) Development of Heat Resistant Alloys and Intermetallic Compounds: Forging Process Simulation Technologies for Maximum Utilization of the Capabilities of Japan's Cutting-Edge, World-Class Scale 5,000 tons Pressing Equipment

We have developed forging simulation technologies of Ti alloys and Ni-based alloys required for the manufacture of compressor and turbine disks used in aircraft engines; we combined data accumulated from 1,500 tons precision forging simulations and various other simulations with numerical analysis technologies, developed statistical prediction tools for predicting plastic workability, structure and properties, and demonstrated the high accuracy of predictions produced by these techniques using Japan's cutting-edge, world-class scale 50,000 tons pressing equipment. We have also developed TiAl alloys with lightweight and excellent heat resistance; we have overcome the weaknesses of intermetallic compounds, such as brittleness and poor workability, and improved forged and cast alloys for manufacturing high-pressure compressor and low pressure turbine blades for aircraft engines.

(C) Development of Ceramic Matrix Composites (CMCs): Environment-Resistant Coating Technologies for Super Heat-Resistant Materials for Use in Next-Generation Aircraft Engines (Heat Resistant Up to 1400°C)

We have improved SiC/SiC Ceramic Matrix Composites (CMCs), which are highly expected as a super heat-resistant material for use in next-generation aircraft engines; we have developed environment-resistant coating technologies using new materials to prevent high-temperature oxidation by combustion gases, and verified their effectiveness by heat cycle testing (1,000 times at a temperature of 1400°C). We have also improved high-speed melt infiltration methods for increasing productivity; we have completed setting of basic process and component design techniques, and created mockup component prototypes.



(D) Development of Materials Integration (MI) System: MI System Ver.1.0 that Speeds Up R&D for Structural Materials through a Combination of Materials Science, Computational Science and Data Science

We have developed the MI System Ver.1.0, which integrates approaches from the fields of materials science, computational science and data science to recreate process, structure, properties and performance-related aspects, and then predicts useful service life as structural materials using computers. This development enables us to hasten the research and development process for structural materials which are used for long periods of time (from 10 to 100 years) and have a long way for their practical realization. As for metallic materials, we have developed 162 computational modules, 101 module-interconnecting workflows, and databases containing over 20,000 data objects, using representative destructive phenomena, such as fatigue, creep deformation, hydrogen embrittlement, brittle destruction. We have also improved computational modules for CFRP materials; we have developed three quantum chemistry computation modules, four molecular simulation modules, nine micro/meso/macro-scale modules, and three structural design modules, and then implemented commercial codes for Materials Studio and J-OCTA.