Innovative Aircraft Polymer Matrix Composites

Development of high production rate CFRP products for aircraft and quality assurance technology

Although carbon fiber reinforced polymer (CFRP) composites have been extensively used in many aerospace structures such as Boeing 787 and Airbus 350, low-cost and high-rate production CFRP are in high demand for next-generation single-aisle commercial aircraft. Competition has been increasing between CFRP and lightweight metals among countries producing CFRP structures.

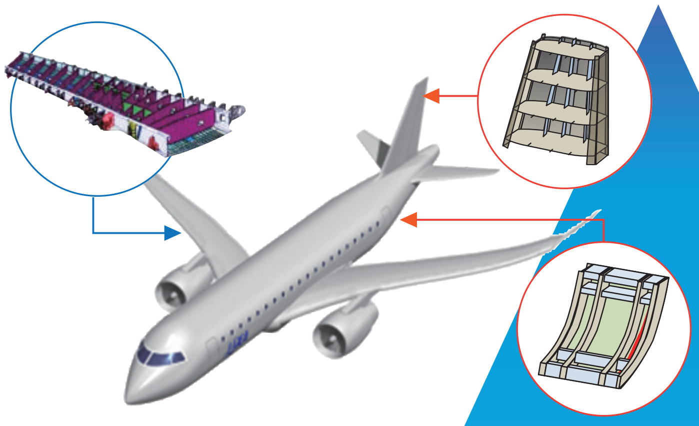
Several ways to develop low-cost and high-rate production CFRP exist. One is to develop low-cost and high-rate production autoclave CFRP prepregs. The mechanical properties must not be sacrificed with the low-cost manufacturing process. Alternatively, thermoplastic CFRP (CFRTP) and out-of-autoclave (OoA) CFRP are promising material systems, as well. These CFRPs 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.

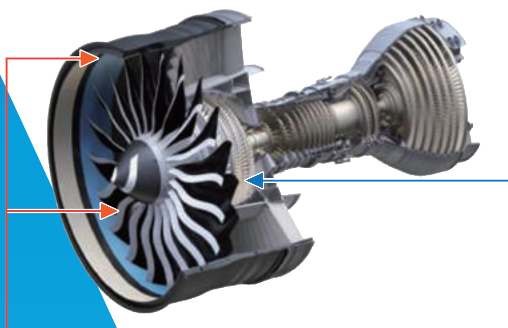
SIP Cross-ministerial Strategic Innovation Promotion Program

Concept and Approach

The main purpose of this project is to develop high-rate production aircraft PMC products and quality assurance technology for next-generation CFRP aircraft structures.

This project consists of five research units, (1) OoA CFRP (Airframe) Unit, (2) Low-Cost/High-Toughness Autoclave CFRP (Airframe) Unit, (3) CFRTP (Engine) Unit, (4) High-Temperature CFRP (Engine) Unit, and (5) Academic Support and Material Evaluation Unit. A strong collaboration among fiber/matrix industries, aircraft manufacturing industries, universities, and national institutes is key for the success of this program





Low-Cost/High-Toughness Autoclave CFRP (Airframe) Unit

Development of Novel High-Toughness Autoclave Cured CFRP

MHI, FHI, KHI, Toray

CFRTP (Engine) Unit

Development of New Thermoplastic Polymers and CFRTP

Nagoya Univ, IHI, Mitsui Chemicals, Mitsubishi Rayon, Fukui Pref, Gifu Univ

OoA CFRP (Airframe) Unit

Smart Manufacturing of High Reliability OoA CFRP

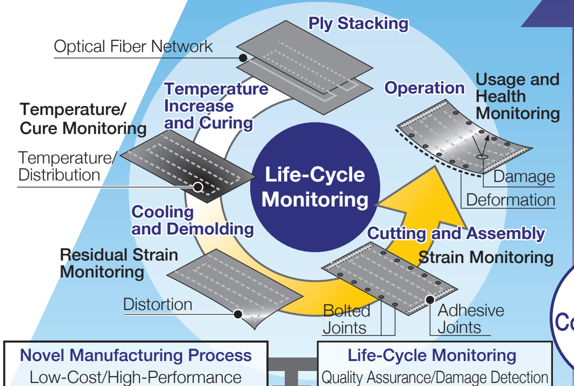
Toray, Kyoto Univ, Tokyo Univ Sci (TUS), Ehime Univ

High-Temperature CFRP (Engine) Unit

Development of High-Temperature CFRP and Applications

JAXA, **IHI**, TUS, Shimadzu, Tokyo Univ Agr Tech (TUAT)

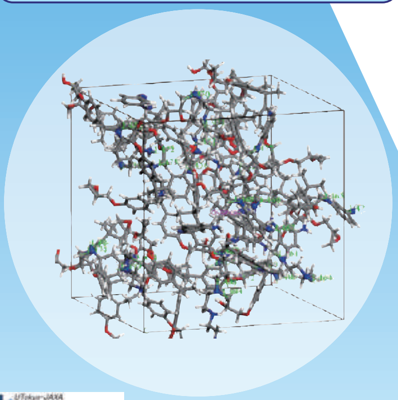
Process Monitoring and Modeling Technology



Concept of Low-Cost/High-Reliability Innovative CFRP Structures

Network Collaboration

Material Simulation Technology



Academic Support and Material Evaluation Unit [TJCC + JAXA Structural/Composite Materials Technology Unit]

Long-Term Durability Evaluation	Process and Life-Cycle Monitoring and Quality Assurance	Multi-Scale Process Modeling and Simulation	Material/Structure Modeling and Simulation
Kanazawa Inst Tech	TJCC Univ Tokyo, Kochi Univ Tech	Tohoku Univ, Shizuoka Univ	Univ Tokyo, JAXA

Domain Director: Nobuo Takeda Deputy Director: Yutaka Iwahori

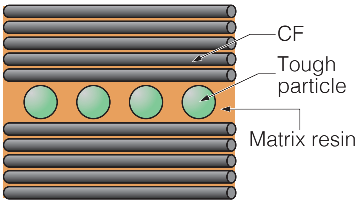
Research and Development in Innovative Aircraft Polymer Matrix Composites

OoA CFRP (Airframe) Unit

High rate Production System for CFRP Structures by Out-of-Autoclave

- Innovative molding technology for aircraft wing structure based on active thermal control system with a novel interlayer toughened prepreg specified to Out-of-Autoclave process
- Demonstration of door panel by 3D-Gap RTM technology
- Establishment of process monitoring techniques (resin-flow and resin-curing reaction processes)

●Interlayer particle toughened prepreg



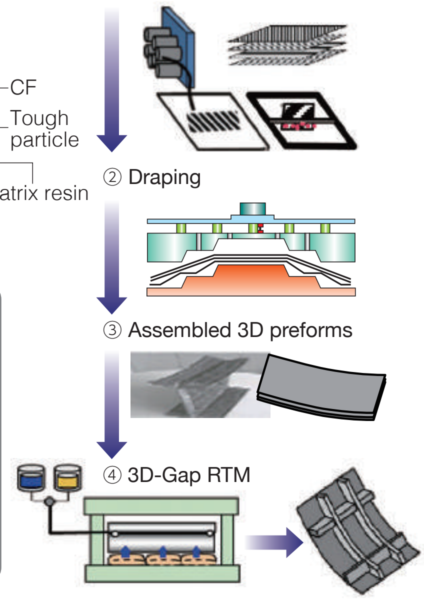
Material development

- **Toray Industries Inc.** Interlayer toughened prepreg development specified to OoA process
- ↑ Proposal for material development
- **Kyoto Univ.** Mechanism investigation on delamination growth

Fabrication process development

- **Toray Industries Inc.** Development of Fabrication system
- ← Proposal for controlling fabrication condition
- **TUS** Methodology for optimizing cure process condition
- ↑ Proposal for method to predict dimensional error
- **Univ.Tokyo, TJCC** Development of strain monitoring technique during cure process
- ↔ Improvement of prediction method
- **Ehime Univ.** Establish prediction for dimensional error

Started in 2016.



Low-Cast/High-Toughness Autoclave CFRP (Airframe) Unit

Application on primary structure – Toughened CFRP

- All Japan Standard CFRP for primary structures (wing and fuselage) Adding favorable attributes such as low cost and tough material (50% tougher than benchmark)
- All Japan collaboration for future airplane development (Material manufacturer) Toray + (Airframe manufacturers) MHI, FHI , KHI

①**Improved anti-delamination characteristics**

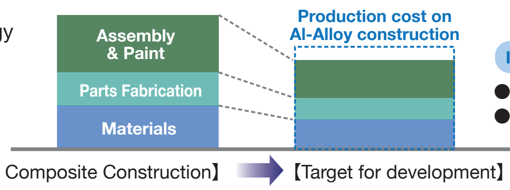
➡Low cost fiber + toughened resin and inter-layer toughened technology

②**Process time improvement**

➡Efficient cure process and resin technology

Tough and High Produce-ability CFRP Development

- **Toray**
  - ●Material Specification
  - ●Cost Target
  - ●Produce-ability on Parts Fabrication
- ↔
- **MHI (Unit Leader)**
  - ●Thick parts configuration
  - ●Material requirements
  - ●Evaluation
- **FHI**
  - ●Thick parts configuration
  - ●Material requirements
  - ●Evaluation
- **KHI**
  - ●Thin parts configuration
  - ●Material requirements
  - ●Evaluation



Improvement on LCA

- ●Low Maintenance Cost
- ●Improve fuel efficiency

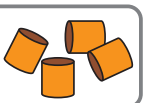
Started in 2016.

CFRTP (Engine) Unit

Development of Impact Resistant High-temp Thermoplastic prepreg and CFRP forming process technologies

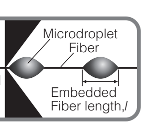
- To further reduce the weight of aviation engine large structures, SIP development will achieve impact and heat resistant low-cost domestic thermoplastic resin prepreg and CFRTP, as well as a high molding technology.

Thermoplastic resin 【Mitsui Chemical】

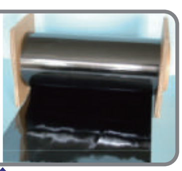


Carbon Fiber 【Mitsubishi Rayon】

Fiber/Rein Interfaceevaluation & Mechanismof Strength Development 【Univ. of Gifu】

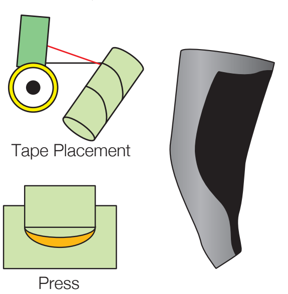


Prepreg Development 【Fukui, IHI】



Material Evaluation 【IHI】

CFRTP Forming Process 【Univ. Nagoya, IHI】



High-Temperature CFRP (Engine) Unit

Development of high temperature polymer matrix composites and application technology for jet engine parts

■Research and development of the material, processing and evaluation technologies for applying high-temperature polymer matrix composites such as polyimide and bismaleimide composites to turbo-fan engine parts (Target operating temperatures are 200 ~ 250 °C)

【Material technology】

R&D of micromechanical test method and viscoelasticity at elevated temperatures, and thermal analysis for processing technology

TUS, Shimadzu

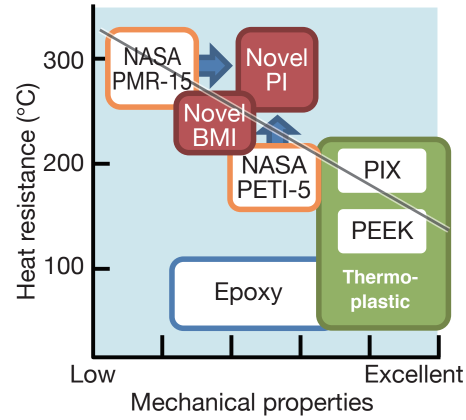
【Processing technology】

Establishment of a fundamental fabrication process to produce flat panels of high temperature composites and construction of database

IHI, JAXA, TUAT

【High temperature evaluation technology】

Establishment of tensile, compressive, and shear test methods at elevated temperatures **JAXA, TUAT, Shimadzu, IHI**

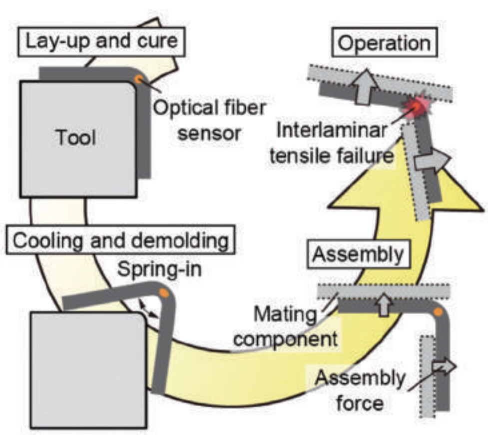


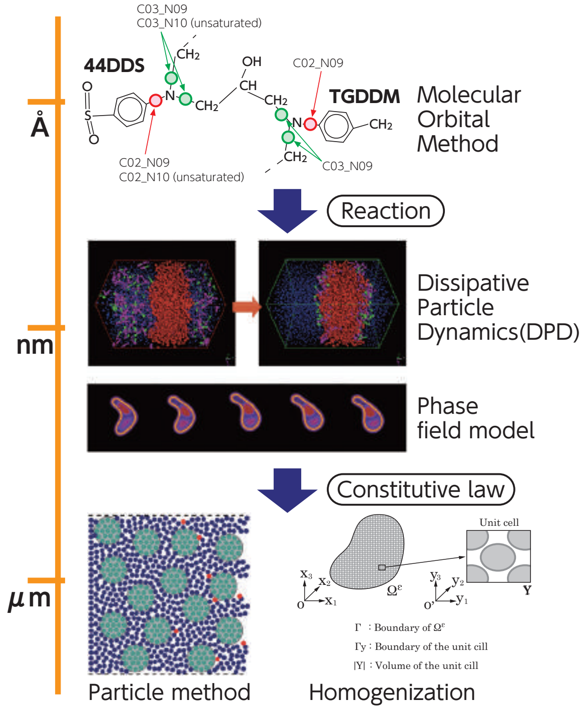
Academic Support and Material Evaluation Unit

Process and Life-Cycle Monitoring and Quality Assurance

■Development of Optical Fiber Based In-Process Material Quality Monitoring and Quality Assurance Methodology as a Basic Academic Technology. Establishment of Manufacturing Process Foundation to Avoid Trials and Errors

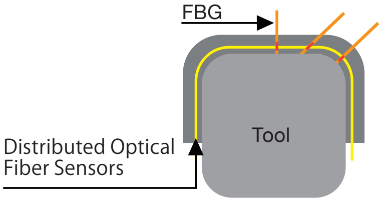
■Development of Multi-Scale Simulation Methodology in Manufacturing Process and Structural Characterization



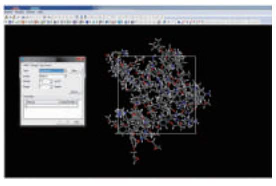


Long-Term Durability Evaluation	Process and Life-Cycle Monitoring and Quality Assurance	Multi-Scale Process Modeling and Simulation	Material/Structure Modeling and Simulation
Kanazawa Inst Tech	TJCC Univ Tokyo, Kochi Univ Tech	Tohoku Univ, Shizuoka Univ	Univ Tokyo, JAXA

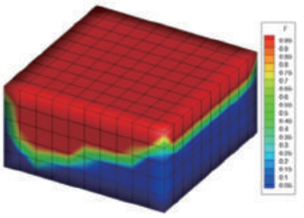
■Development of In-Process Residual Strain Measurement and High-Precision Simulation Methodology to Provide Efficient and Optimum Processing Conditions for Novel CFRP Materials



Development of Residual Strain Measurement Technology in Process and Life Cycle and Quality Assurance



Development of Multi-Scale Simulation Methodology Based on Systematic Polymer Cure Reaction Calculation



Three-Dimensional Polymer Impregnation Simulation

Japan Science and Technology Agency

Department of Innovation Platform
Japan Science and Technology Agency (JST)
7,Gobancho, Chiyoda-ku, Tokyo 102-0076, Japan
http://www.jst.go.jp/sip/k03.html

Members of Research Domain A: “Innovative Polymer Matrix Composites”

Goals and expectations of Research Domain A

TERUO KISHI
Program Director, SIP Innovative Structural Materials for Innovation

Domain Director
NOBUO TAKEDA
The University of Tokyo

Deputy Director
YUTAKA IWAHORI
JAXA

Lightweight yet strong CFRP have been recently used in many airframes and engines. Many research efforts were made to develop CFRP materials and processing technologies. However, current CFRP processing technologies using high-cost theromosetting polymer prepregs and autoclaves must be extensively improved for low-cost/high-rate production of large-sized and complex-shaped CFRP structures. Novel and more efficient CFRP prepregs for autoclave and Out-of-Autoclave (OoA) processing, as well as more impact resistant theromoplastic polymer CFRP prepregs, must be developed with associated processing technologies. I hope these efforts result in an expansion of the Japanese aircraft industry.

Advanced polymer composites, such as CFRP, have been extensively used in modern commercial aircraft. Although Japanese industries are dominant in such production, there is great competition for applications to next-generation single-aisle aircraft that require low-cost and high-rate production. In Domain A “Innovative Polymer Matrix Composites,” we are developing several new CFRP materials and processing technologies for next-generation airframes and engines. Fiber/Polymer manufacturers and aircraft fabricators are working together along with academic researchers in universities and JAXA to strengthen the CFRP manufacturing technologies in aircraft industries.

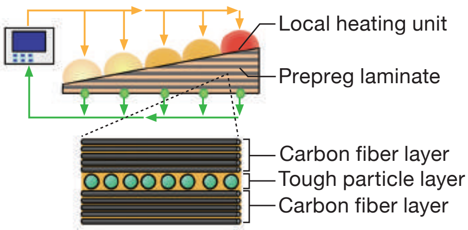
Establishment of intelligent production system for CFRP structure with high rate and reliability by out of autoclave molding technologies

Keywords : Out of autoclave molding, prepreg, interlayer toughening, CFRP, dry fiber placement, RTM

OoA CFRP Unit

MAKOTO ENDO
Composite Materials Research Laboratories, Toray Industries, Inc.

An autoclave is a pressure and heating chamber generally used to mold CFRP parts for aircraft structures. However, the high initial investment cost most likely prevents the higher production rate process. In this project, a novel material and molding system are proposed to make it possible to mold high quality CFRP parts without autoclave. Specifically, the following two approaches are developed: (a) Innovative molding technology based on active thermal control system with a novel interlayer toughened prepreg specified to vacuum assisted molding process under atmosphere, and (b) Resin transfer molding technology assisted by pressure for 3D-shaped dry carbon fiber fabrics.



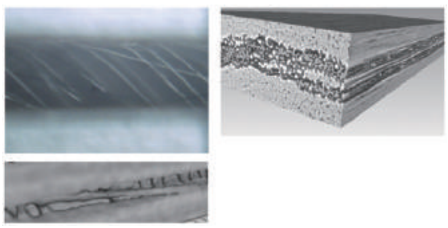
Characterization of effects of fabrication condition on mechanical properties in CFRP laminates

Keywords: Interlaminar delamination, Intralaminar delamination, Structural integrity, Defects and fracture mechanism, non-destructive evaluation.

OoA CFRP Unit

MASAKI HOJO
Department of Mechanical Engineering and Science, Kyoto University

Durability for impact and fatigue loads is required in the development of high rate production systems for CFRP primary structures. The strength inside a single layer is expected to be different from that at prepreg interface in the particle-toughened systems with advanced vacuum technology. Defects can be generated both at the interlayer region and inside a single layer. Therefore, it is essential to develop a test method for the spatial distribution of through-the-thickness strength, and to investigate the minimum value. In this project, we develop an evaluation method to distinguish the fracture mechanical properties of intralaminar and interlaminar delamination both for non-toughened and toughened lamnates. The micromechanical fracture mechanism is investigated through three-dimensional observation at the damaged zone (see the attached figures). This micromechanical characterization contributes to establishing the design and preparation of the high performance materials with the advanced vacuum molding technology, through the proposal of suppression methods for crack growth. We also try characterization of spatial distribution of fatigue delamination resistance in order to establish long term structural integrity based on our group’s unique and advanced experimental methods.



High resolution X-ray computed tomography and digital microscopy for fiber and resin damage near the crack tip of intralaminar delamination.

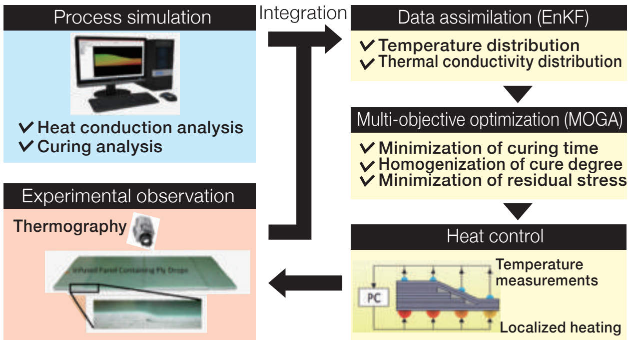
Development of optimization method of curing process of CFRP using data assimilation

Keywords: data assimilation, process simulation, process optimization, heat control, quality assurance

OoA CFRP Unit

RYOSUKE MATSUZAKI
Department Mechanical Engineering, Tokyo University of Science

We have developed a precise prediction method of curing process of composite materials while taking into account the uncertainty of material properties. Data assimilation is used for the prediction by integrating numerical simulation of composite processing and experimental observation. In addition, on the basis of the predicted composite states, we construct optimized heat curing. These technologies will contribute to high quality and low cost aircraft manufacturing with out-of-autoclave processing.



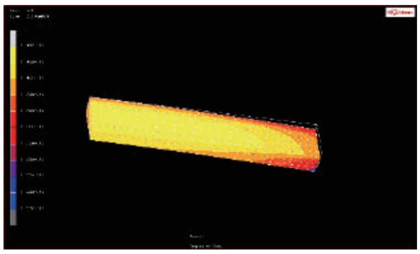
Development of prediction methods of process-induced residual stress

Keywords：Process-induced residual stress、Cure shrinkage、Prediction of deformation、Low-cost analysis、Quality assurance

OoA CFRP Unit

KEIJI OGI
Graduate School of Science and Engineering, Ehime University

It is essential to minimize unintended deformation in the fabrication of thermosetting CFRP parts for quality assurance. Cure shrinkage of resin, change in viscoelastic properties, and thermal shrinkage are coupled in the fabrication process. This research aims to establish a high-accuracy and low-cost analysis method using a commercial finite element analysis software by building a simple but reasonable mathematical model. The low-cost analysis is achieved by predicting properties of the CFRP from measured ones of resin. The result of this study contributes to high-quality fabrication technology in out-of-autoclave processing.



Distribution of cure degree and distorted shape after processing

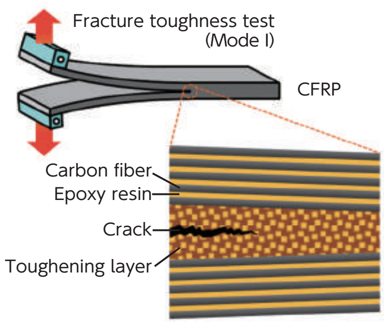
Proposal of novel composite materials with high productivity and high toughness

Keywords : High toughness, Carbon fiber, Prepreg, CFRP, Autoclave molding

Autoclave cured toughened CFRP Unit

TAKASHI OCHI
Composite Materials Research Laboratories, Toray Industries, Inc.

Carbon fiber reinforced plastics (CFRP) are widely used for aircraft structural material because of their stiff, strong, and lightweight qualities. Improvements of fracture toughness and productivity of CFRP are essential for greater use of lightweight CFRP in aircraft structures. In this project, we propose a novel CFRP laminate with high fracture toughness, especially under mode I and mode II loadings, by the following approaches: (a) Localizing tough material in the interlayer region, (b) Improvement of adhesion between carbon fibers and matrix resin, and (c) Improvement of fracture toughness of matrix resin itself. At the same time, technology to shorten molding time is also developed by controlling cure properties of the matrix resin to raise CFRP productivity.



Members of Research Domain A: “Innovative Polymer Matrix Composites”

Tough and high volume production-ability for CFRP development

Keyword: toughness, delamination, low cost

Autoclave cured toughnened CFRP Unit

TOSHIO ABE
Mitsubishi Heavy Industries, Ltd

Several composite inherent failures, typically known as delamination, have been observed that remain challenging for all stakeholders in aircraft development. Based on my knowledge and expertise, I will contribute to CFRP material development that achieves low-cost and high-volume production with efficient and standard design procedures.

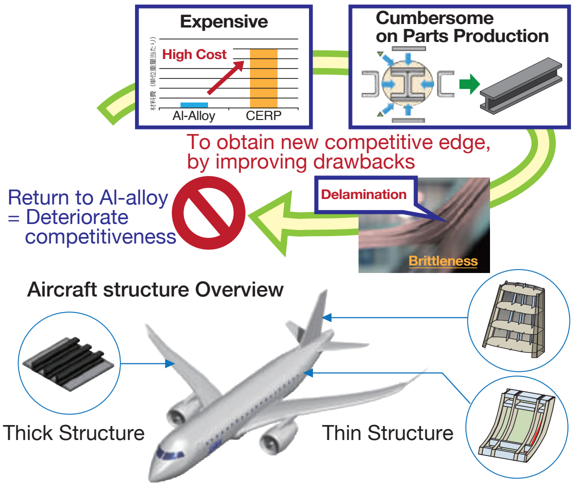
TOSHIMICHI OGISU
Fuji Heavy Industries Ltd.

Composite material has been widely-applied in recent airplane structures.
However, the potential of the material is compromised because of unstable and invisible fractures , I would like to work in our all Japan team on developing a low-cost composite materials that have the acquired toughness suitable for thick plate structures

YOSHIHIRO NAKAYAMA
Kawasaki Heavy Industries, Ltd.

In this program we will challenge advanced CFRP development with All Japan team.
Using our expertise and knowledge, KHI will strongly support the team to define specifications and the material evaluation regarding thin CFRP structures of airplanes.

Composite usages on commercial airplanes have become common after the debut of Boeing 787. However, several challenges remain, such as high material and machine cost, as well as a lack of standard philosophy regarding failure and design rationale. Several airplanes have suffered unexpected failures and program delay due to an uncertainty of the composite material. Material development activity will be sought after in order to add favorable attributes, such as toughness for overcoming delamination issues and standardized design procedures. The aim of the development is to realize cost effective production of composite parts and, finally, to contribute to the next generation of aircraft development with full utilization of knowledge of the A04 unit and material integration field.



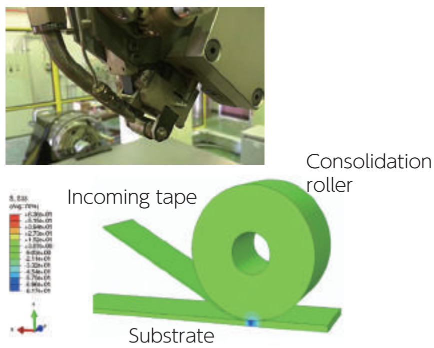
Development of a tape placement molding and reliability evaluation of CFRTP

Keyword: CFRTP,Tape Laying Fiber Placement

CFRTP(Engine) Unit

MASAHIRO ARAI
Nagoya University, Dept. Aerospace Engineering

In recent years, recycling of fiber reinforced composite and alternative manufacturing methods without autoclave have been required. Therefore, the carbon fiber reinforced thermoplastic (CFRTP) material has been given much attention. Since the CFRTP has high toughness, strength and heat-resistance, CFRTP is expected to be applied for aeronautical structure, especially for the fan blade of jet-engines and main structures of the airplane. In our group, a tape placement manufacturing method (Automated Tape Laying (ATL)/Automated Fiber Placement; AFP) has been employed to make CFRTP laminates. The molding condition controls elements such as pressure, temperature, and heating rate, and the optimal condition for ATL and AFP is found in the present study. Not only the strength and rigidity of the CFRTP laminate but also the fracture toughness and residual stress are measured using finite element analysis and boundary element analysis. Finally, the reliability of the CFRTP is estimated and clarified by a series of studies by our group.



Snapshot of Automated Tape Placement and the FEM Analyses

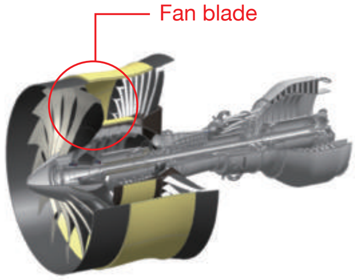
Development of thermoplastic CFRP for aero-engines

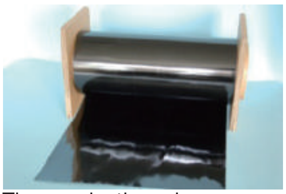
Keywords : Thermoplastic polyimide resin, Molding process, CFRP

CFRTP(Engine) Unit

KATSUYOSHI MORIYA
Aero-Engine & Space Operations, IHI Corporation

Large-size structural members of aero-engines such as fan blades require impact resistance to bird strikes and 150 °C heat resistance. It is necessary to develop thermoplastic prepreg and CFRP suitable for this application, and to establish a molding technology.
In SIP development, IHI will obtain new domestic heat thermo-plastic resin prepreg that is impact-resistant by using an optimal combination of fiber and resin.





Thermoplastic resin prepreg

Development of thermoplastic polyimide resin

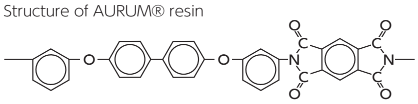
Keywords : thermoplastic polyimide resin、Heat　Resistance、Toughness

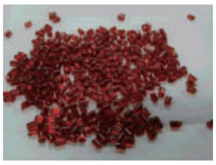
CFRTP(Engine) Unit

TAKASHI HAMA
MITSUI CHEMICALS, INC. Polymeric Materials Laboratory

Mitsui Chemicals holds the unique super engineering plastic resin, AURUM®.
It has the highest glass transition temperature (250°C) in the world and is optimal for melting and machining (thermoplastic polyimide resin) of prepreg.
Mitsui Chemicals assembles its fundamental material technology in order to develop and provide adequate resin materials for aero engine application (CFRTP).
AURUM® opens up a new dimension in the development of FRP materials with advanced and high resistance properties.
In this research, Mitsui Chemicals will select and supply the most appropriate thermoplastic resin materials.
Furthermore, Mitsui Chemicals will provide basic resin data properties for its prototype and examine the best manufacturing method for low cost prepreg.

Structure of AURUM® resin





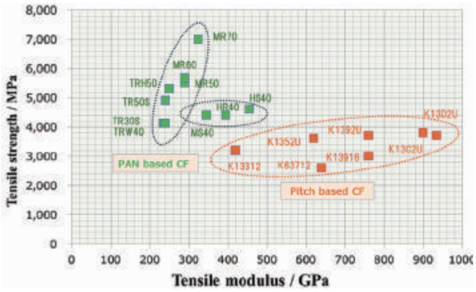
Optimum design technology of carbon fiber for thermoplastics prepreg materials

Keywords : Carbon fiber, Surface structure, Interface characteristics

CFRTP(Engine) Unit

NAOKI SUGIURA
MITSUBISHI RAYON Co., LTD. Composite materials development center

Carbon fiber is a material with high strength and high stiffness, and behaves in a typical brittle manner. Thus, the fiber is mainly used in composite materials with resin. As presented in the figure, Mitsubishi Rayon produces carbon fibers that have a variety of strength and modulus. The carbon fiber being developed in SIP is a PAN-based high strength fiber and 290 GPa in modulus, and has a superior impact tolerance in CFRP with a high heat resistant thermoplastic resin. We will elucidate the characteristic of a carbon fiber that affects the impact tolerance, and particularly focus on the surface structure of the fiber and the interfacial properties between the fiber and resin.



Members of Research Domain A:
"Innovative Polymer Matrix Composites"

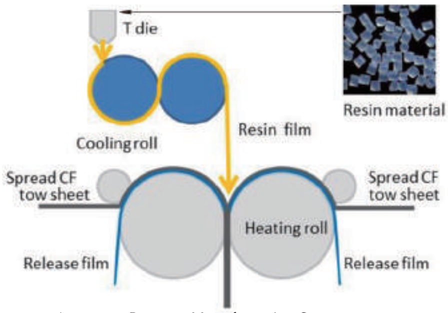
The development of low-cost manufacturing technology of the thin thermoplastic prepreg

Keywords : Thermoplastic prepreg, Low-cost manufacturing technology

CFRTP(Engine) Unit

KAZUMASA KAWABE
Industrial Technology Center of Fukui (ITCF) advanced composite material (ACM) group

It is necessary to use the resin film in a conventional method for manufacturing the thermoplastic prepreg of which the matrix resin has a high heat resistance. However the resin film is very expensive, which pushes up the manufacturing cost of the prepreg. Therefore, a low-cost manufacturing technology that enables the production of the prepreg directly from raw resin and carbon fiber without purchasing the expensive resin film is developed in this project. The low-cost manufacturing technology can be established by combining our original tow-spreading technology and the manufacturing technology of high-performance thermoplastic resin film.



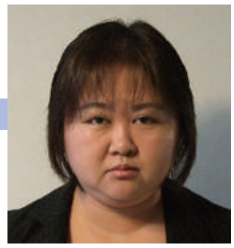
Low-cost Prepreg Manufacturing System

Establishment of evaluation method for in-situ interface properties and clarification of improvement mechanism of impact properties

Keywords : Molding process, In-situ interface, Micro fracture behavior, Impact property

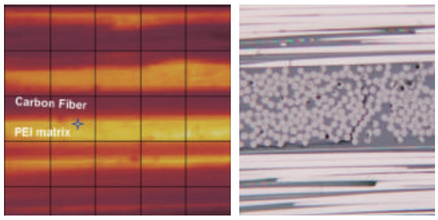
CFRTP(Engine) Unit

ASAMI NAKAI
Faculty of Engineering, Gifu University



Interface properties between fiber and matrics contribute to impact properties. It is known that the interface properties were affected by the molding conditions in the case of thermoplastic composites. Therefore, existing evaluation methods of interface properties with single fiber could not reflect the effects of molding conditions.

In this study, evaluation methods of in-situ interface properties (namely, interphase properties in molded composites) will be constructed. Then, considering the correlation between the interface properties and impact properties, an improvement mechanism of impact properties will be clarified. Based on the feedback of these results, newly developed prepreg for thermoplastic composite with high impact properties will be designed. The final goal of this study is standardization of in-situ interface measurement.



Evaluation method of in-situ interface
(Nano indentation, micro fracture behavior)

Development of processing technology and high temperature evaluation method for high temperature polymer matrix composites

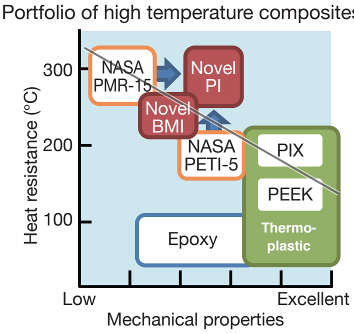
Keywords : High temperature composite, Processing technology, High temperature evaluation technology

High-Temperature CFRP Unit

YUICHI ISHIDA
Aeronautical Technology Directorate, Japan Aerospace Exploration Agency (JAXA)

In order to apply high-temperature polymer matrix composites to turbo-fan engine parts, the construction of a materials database, as well as processing and evaluation technologies are being researched and developed by JAXA. Target operating temperatures are 250 °C for long duration and 300 °C for short duration. Solution prepreg-making machines and high temperature autoclave were installed at JAXA. The experimentation cycle (from the prepreg preparation to the completion of the experiment) can be shortened by introducing this equipment.

Portfolio of high temperature composites.



SIP-SM^4I Structural Materials for Innovation

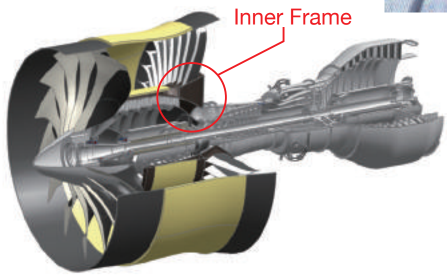
Application technology research of heat-resistant polymer-based composite material (PMC)

Keywords : Heat-resistant polymer, Molding process, CFRP

KATSUYOSHI MORIYA
Aero-Engine & Space Operations, IHI Corporation

High-Temperature CFRP Unit

The application of heat resistance/durability polyimide resin to aircraft structures, such as the fan frame of turbofan engine (200°C~250°C) will be selected in SIP development. In addition, the material characteristics of heat-resistant PMC as engine parts will be obtained with reasonably established test methods.



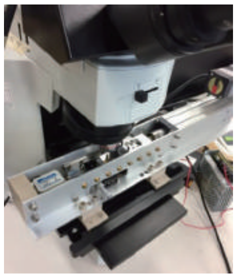
Evaluations of fiber/matrix interfacial mechanical properties and long-term durability for heat resistance CFRP

Key words: Interfacial mechanical properties, Micromechanical testing, Thermo-viscoelasticity, Finite element analysis, Time-temperature superposition principle

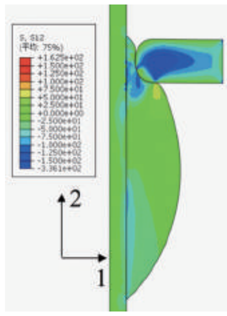
JUN KOYANAGI
Faculty of Industrial Science and Technology, Tokyo University of Science

High-Temperature CFRP Unit

Fiber/matrix interface strength and long-term durability of newly developed heat-resistant CFRP are evaluated in order to apply this CFRP to an inner frame part inside aircraft jet engines. For estimating strength and durability, knowing interface strength is indispensable. A micromechanical testing machine is fabricated and microbond test is conducted. Combined with finite element analysis, the interface strength is precisely evaluated. In the finite element analysis, thermo-viscoelasticity, continuum damage mechanics, and cohesive zone modeling are considered to obtain realistic stress distribution. A long-term durability of this CFRP is investigated using the interface strength.



Finite Element Analysis



Micromechanical testing Machine

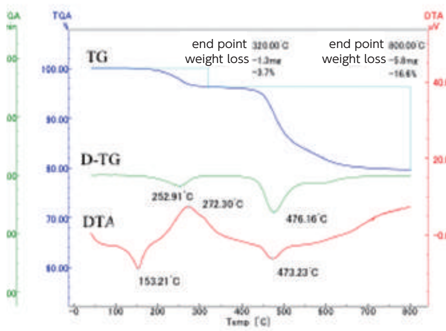
Research of basic evaluation technology of materials (chemical analysis of molding and deterioration process)

Key words : Thermal Analysis, Molding process, Evolved gas analysis, High-temperature test

MITSURU OHTA
Analytical & Measuring Instruments Division Shimadzu Corporation

High-Temperature CFRP Unit

Developing testing and analytical technology for the rational acquisition of specific data of materials necessary for applying heat-resistant PMC selected or developed by SIP for aircraft engine parts. Theme①Acquiring thermal analysis data such as basic thermo-physical properties of existing PMC and matrix polymer that can be compared with developed heat-resistant PMC;②Simultaneously acquiring thermal analysis and evolved gas analysis data under a heat cycle program simulating the molding process of PMC;③Developing and verifying a high-temperature bath for testing the physical properties of PMC under high temperature atmosphere in which a stable method and testing system has not been proposed.



Thermal Analysis(TGA) data of PMC

Members of Research Domain A:
“Innovative Polymer Matrix Composites”

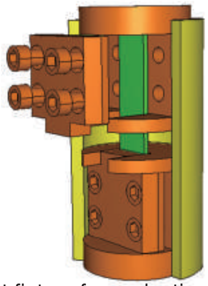
High-Temperature CFRP Unit

Development of test method for evaluating the mechanical properties of high-temperature polymer matrix composites

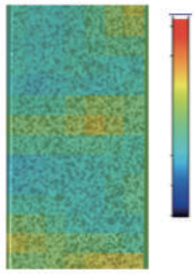
Keywords: High- temperature polymer matrix composites, Strength, Strain measurement, Digital image collation (DIC), Mechanical test method, Standardization

TOSHIO OGASAWARA
Tokyo University of Agriculture and Technology

Test methods for evaluating mechanical properties are indispensable for applying high temperature polymer matrix composites to actual turbo-fan engine components. However, test methods have not been authorized by domestic (JIS) and international organizations (ISO, ASTM). The objective of this study is to establish rational and useful test methods for evaluating mechanical properties such as non-hole compression, open-hole compression, in-plane shear, and inter-laminar shear at elevated temperatures (up to 300°C). Strain measurement methods are also examined using several techniques. Demonstration and verification of each test method are conducted using experiments and calculations. In addition, standardization of the test methods to JIS and/or ISO will be attempted in collaboration with stakeholders.



Test fixture for evaluating non-hole compression



Full field strain measurement using DIC

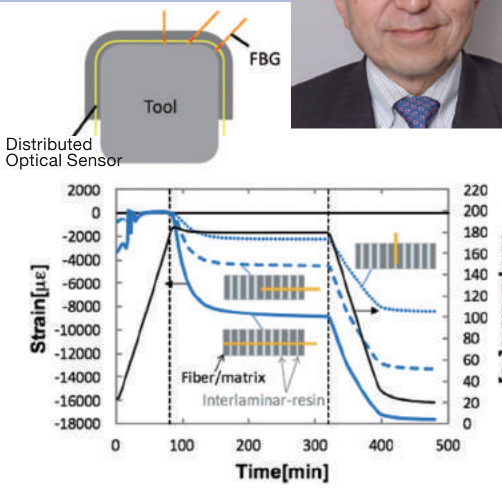
Academic Support and Material Evaluation Unit

Manufacturing process and life-cycle monitoring and quality assurance of CFRP structures

Keywords: Optical Fiber Sensor, Manufacturing Process, Life Cycle, Strain Monitoring, Quality Assurance

NOBUO TAKEDA
TJCC (UTokyo-JAXA Center for Composites)
Graduate School of Frontier Sciences, The University of Tokyo

In order to avoid enormous trials and errors in CFRP processing, a novel optical fiber sensing system has been developed to measure in-situ change in material properties in real manufacturing processes and applied to new CFRP materials under development. Optimum processing conditions are obtained by measuring and controlling the residual strains and deformations. In particular, multi-axial strains are measured in corner parts (See the above figure) and effects of interlaminar toughed layers on the anisotropic residual strains (See the lower figure) are also clarified. These measurements make it possible to develop a high-precision theoretical modelling methodology to assure the quality of CFRP structures.



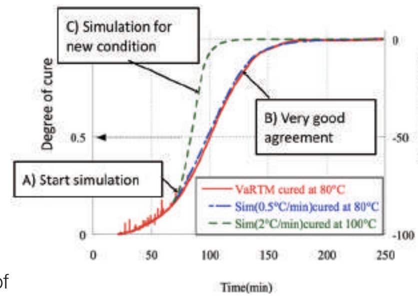
Academic Support and Material Evaluation Unit

Real-time measurement technology of degree-of-cure distribution by a high-precision optical fiber sensor

Keyword: Optical fiber sensor, Cure process, degree-of-cure measurement, process simulation, optimum molding system

TATSURO KOSAKA
School of Systems Engineering, Kochi University of Technology

In order to improve the efficiency and cost of manufacturing process of CFRP, real-time and in-situ measurement system of degree-of-cure distribution of CFRP has been developed by fiber-optic sensors proposed in our laboratory. Furthermore, the development of a real-time optimization system of cure process using real-time monitoring and simulation methods has been conducted. The right figure shows degree-of-cure curves of textile CFRP measured by the fiber-optic sensor in real time and simulated by a kinetic model. It appeared that the prediction curve based on the measured data at 70 minutes agreed very well with the experimental curve. Therefore, our system can precisely monitor and predict degree-of-cure of CFRP, in real time. In applying this technique for the optimization of the cure process, more efficient conditions for cure process may be suggested, as shown in the figure. In the future, this system will be improved to monitor and predict degree-of-cure distribution of large commercial CFRP parts in real time.



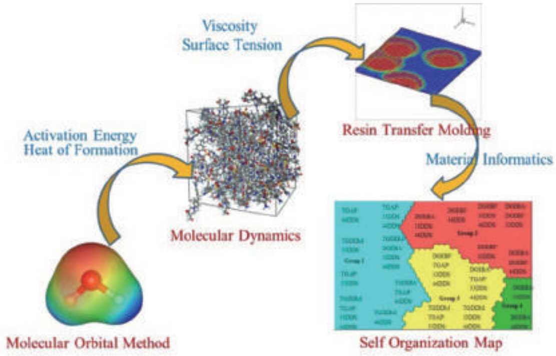
Academic Support and Material Evaluation Unit

Multiscale modeling of carbon fiber reinforced composites

Keywords : Multiscale modeling, Numerical prediction of material properties, Optimum material design, Material infomatics

TOOMONAGA OKABE
Department of Aerospace Engineering, Tohoku University

The scheme of multiscale modeling for the manufacturing process of carbon fiber reinforced composites has been studied to reduce their manufacturing costs. The material properties including Young modulus, density, bulk modulus, Tg and viscosity are calculated using the atomistic commercial software (Material studio) with atomistic structures, which are made with our proposed curing simulation (Okabe et. al., Polymer (2013)). The predicted properties agreed well with experiments (Okabe et. al., EPJ (2016)). The developed scheme will hopefully be used for the material selection of matrix of composites.



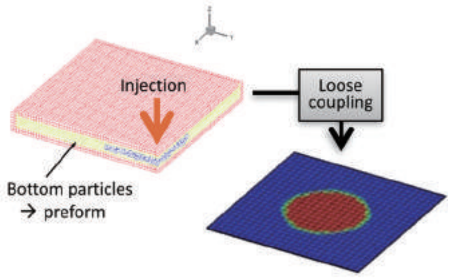
Academic Support and Material Evaluation Unit

Development of simulations for predicting resin flow and molding quality

Keywords: Molding process; resin impregnation; particle method; finite-element method

SHIGEKI YASHIRO
Department of Mechanical Engineering, Shizuoka University

In order to achieve a novel RTM technology, we will develop a unified simulator that predicts and evaluates the molding process as well as the quality of molded composite components, while considering material properties estimated by a molecular-scale simulation. This simulator is a finite-element based resin impregnation analysis combined with a resin flow analysis by a particle method (see the figure), and predicts weld lines and dry spots generated in the new RTM process. Moreover, we will develop a numerical approach to optimize gate positions that minimize these molding defects. By combining the present method with a molecular-scale simulation for matrix resin, which will also be developed in this project, a multiscale simulation technology will be developed for CFRP manufacturing.



Academic Support and Material Evaluation Unit

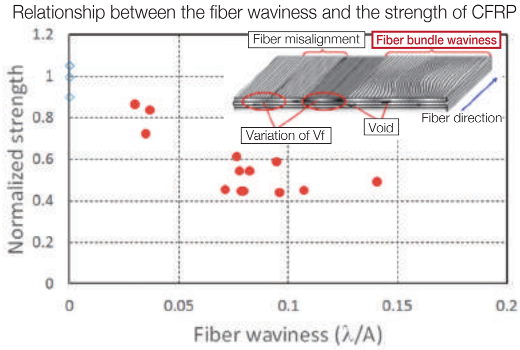
High-accuracy modelling of composite structures: Considering process-induced imperfection

Keywords: Quality Control, Manufacturing Process, Test Method, Imperfection

TOMOHIRO YOKOZEKI
Graduate school of the engineering, The University of Tokyo

Process-induced imperfection in CFRP reduces the mechanical properties of fabricated CFRP. It is necessary to make clear the effects of imperfection on the mechanical properties and to define the allowable degree of imperfection in CFRP for aircraft structures, which is of importance in terms of the quality control of the products and weight reduction of the structures. This study establishes a quantitative method of the process-induced fiber imperfections of thermoplastic CFRP, clarifies the relationship between the imperfections and the mechanical properties, and finally develops the predictive methodology of mechanical properties of CFRP with imperfections using micromechanical numerical methods. The obtained results contribute to the definition of allowable imperfections of the product and the development of CFRP in the SIP program.

Relationship between the fiber waviness and the strength of CFRP



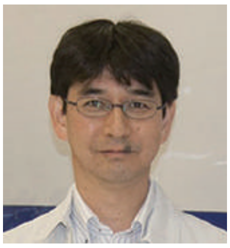
Members of Research Domain A:
“Innovative Polymer Matrix Composites”

High-accuracy modelling of composite structures: Modeling technology for material and structure considering microscopic and mesoscopic internal structures

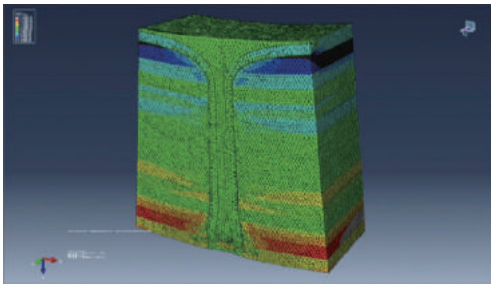
Keywords : High-precision analysis, Multiscale analysis, Finite element method, Damage simulation, Manufacturing simulation

Academic Support and Material Evaluation Unit

AKINORI YOSHIMURA
Structures and Advanced Composite Research Unit, Aeronautical Technology Directorate, Japan Aerospace Exploration



Deputy Director
YUTAKA IWABIRI
Structures and Advanced Composite Research Unit, Aeronautical Technology Directorate, Japan Aerospace Exploration



A large number of material tests must be conducted in order to adopt newly developed PMC to actual aircraft structure. This research aims to improve the precision of the modeling and simulation methods for PMC in order to reduce the number of tests. Because PMC consists of many fibers and matrix resin, there are microscopic internal structures (arrangement of fiber in the resin) and mesoscopic internal structures (arrangement and alignment of tows) in the PMC. Therefore, this research develops multiscale modeling methods that can consider microscopic and mesoscopic internal structures, and validates them. Damage and manufacturing simulation methods are developed as plug-ins for commercial FEM code in this research.

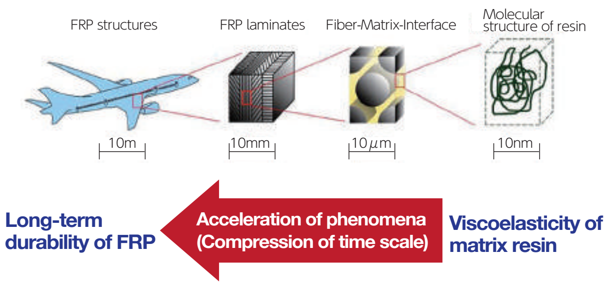
Evaluation for long-term durability

Keywords : Long-term durability, Viscoelasticity, Time-temperature superposition principle, Accelerate testing

Academic Support and Material Evaluation Unit

MASAYUKI NAKADA
Materials System Research Laboratory, Kanazawa Institute of Technology

The evaluation of long-term durability is important for the development of CFRP structures. Specifically, the evaluation of long-term durability of prototype CFRP to support the material development team in real time is needed. In this project, the basis of molding techniques of CFRP test specimens for the evaluation of long-term durability has been studied. Moving forward, we will construct accelerated testing methodology based on the time-temperature superposition principle, and then confirm the applicability of this methodology as an evaluation technique for long-term durability by accelerated testing using CFRP test specimens.



AKIRA HAMAMOTO
Collaboration Coordinator

TAKIKO HIRANO
Associate Collaboration Coordinator

In our research domain, we are developing one of the most critical and important technologies in CFRP manufacturing in the Japanese aircraft industry. It is necessary that fiber/matrix manufacturers, aircraft manufacturers, and academia collaborate with one another for successful development for the future. We are very proud to help such development.

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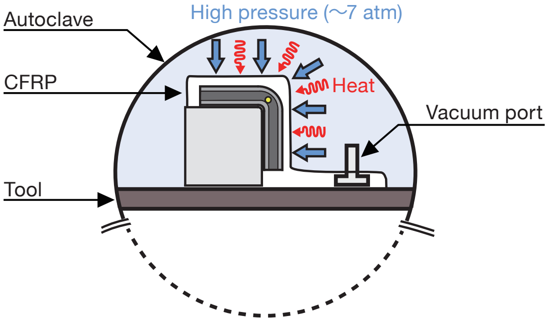
In conventional CFRP manufacturing, we normally use thin CFRP prepregs. These prepregs are made by impregnating polymers into aligned carbon fiber tows. Prepregs with different fiber directions are stacked, vacuum-bagged, and processed under certain temperatures and pressures in the autoclave (AC). However, more efforts are needed to develop a low-cost/high-rate production method for more efficient fabrication. In this SIP program, we develop novel high-quality yet low-cost AC processing methodology and OoA (Out-of Autoclave) prepregs and processing methodology.

■Autoclave (AC) processing



■Out-of-Autoclave (OoA) processing