Structural Materials for Innovation
Cross-ministerial Strategic Innovation Promotion Program (SIP)

Introduction to “Structural Materials for Innovation”

Program Director’s Introductory Address

SIP (Cross-ministerial Strategic Innovation Promotion Program) was established by the Council for Science, Technology and Innovation (CSTI) of the Cabinet Office in order to realize scientific and technological innovation strategically under its initiative. In SIP, industry-academia-government collaboration is emphasized to link between fundamental scientific research and applied technology development.

SM4i (Structural Materials for Innovation) is one of the 11 R&D subjects of SIP. Material industry of Japan, especially structural materials, has been the backbone of the whole Japanese industry. However, in addition to the United States and Europe, several emerging countries are catching up, and strengthening the global competitiveness is one of the most important issues of Japan. Besides, from a viewpoint of energy and environment, the reduction of greenhouse gas emission is also a critical issue.

In the project on Structural Materials for Innovation, the R&D target is strong, light, and heat-resistant materials for the application in transportation industry including aircrafts and energy industry and the improvement of energy conversion and usage efficiencies. Furthermore, the great contribution of materials technologies to the development of the aircraft industry of Japan and its related industries is expected.

For the achievement of the above objectives, the following R&D domains on the development of aircraft engines and airframes have been designated.

(A) Polymers and FRP
(B) Heat resistant alloys and intermetallic compounds
(C) Ceramics coatings
(D) Materials integration

As well as R&D, the establishment of research centers and researcher networks for structural materials, capacity building, and international collaboration are also key issues of SM4i. Your support for SM4i is greatly appreciated.

Outline

- PD: Teruo Kishi (Professor Emeritus, The University of Tokyo)
- Deputy PD: Yutaka Kagawa (Professor, The University of Tokyo)
  Chiaki Tanaka (Advisor, Toray Industries, Inc.)
  Yasuo Kitaoka (Professor, Osaka University)
- Administrative Institution: Japan Science and Technology Agency
- Research domains:
  (A) Polymers and FRP
  (B) Heat resistant alloys and intermetallic compounds
  (C) Ceramics coatings
  (D) Materials integration
- Number of members: 77 (FY2016)
  (industry: 29, university: 39, public (non-profit) institution: 9
- Implementation period: FY2014〜2018
- Annual budget: 3.690 billion JPY for FY2016

http://www8.cao.go.jp/cstp/gaiyo/sip/
http://www.jst.go.jp/sip/
SIP-5M4I Structural Materials for Innovation

Framework for Structural Materials Research Supported by the Government of Japan

MEXT (Ministry of Education, Culture, Sports, Science and Technology)
- Fundamental research
  - Polymers and FRP
  - Ceramics coatings
  - Heat resistant alloys & intermetallic compounds
  - Materials integration
- Innovative development
  - Materials informatics

CAO (Cabinet Office)
- Power generation
- Aircrafts
- Railway transportation
- Automobiles
- Industrial equipment

METI (Ministry of Economy, Trade and Industry)
- Verification

Establishment of Research Centers and Researcher Network and Capacity Building

Research centers and researcher network covering are being established for the sustainable materials research in Japan even after the SIP-5M4I Project is completed. On this basis, advanced nano-scale characterization technologies utilization for breakthrough of unsolved issues, capacity building for young scientists, and international collaboration by cooperating with WMRIF* are being promoted.

Required Functions of Research Centers
- Core Competence: forging simulators (1,500 ton), MI system, CFRP performance evaluation technologies, ceramics coating technologies, etc.
- Industry-academia-government R&D collaboration
  - Supporting researcher network (portal site, etc.)
  - Organizing symposia and workshops
  - Strategy and management of intellectual property rights, survey, benchmarking, etc.
- Organizing capacity building programs
- Organizing international collaboration


The Meeting of 15 directors of national materials research institutes from 8 countries was organized by NIMS in 2005, and the forum was founded to promote networking, research collaboration, capacity building, and benchmarking among the member institutes. As of 2014, 50 institutes from 21 countries are members.
Development of Polymer Based Materials and Fiber Reinforced Plastics (FRP)

- Alternative to the existing autoclave method, development of material and its application technologies for structural members (tail etc.) with high-quality (toughness), low-production cost and high-productivity. And development of low-cost and high-quality (toughness) prepreg aiming at the application of the main structural members (main wing, airframe etc.).
- Weight savings of aero engine parts through development of heat resistant and impact resistant thermoplastic matrix prepregs and their manufacturing technology, and development of parts manufacturing technology with heat resistant thermosetting resin matrix composites.
- Monitoring technology of curing process, quality assurance technology and contactless and nondestructive inspection technology.

**Applied materials parts**

- Tail skin: Advanced cost-saving and productive molding technology replacing autoclave molding technology.
- Fan blade: Light weight, cost saving and increase in domestic production ratio. Advanced prepreg (heat and impact resistant properties) and processing technologies.
- Inner frame:

**Materials processing and Technology**

- to place carbon fibers → apply binders → composite preform forming → forming by 3D-gap RTM
- Prepregs impregnate thermo-plastic polymers into carbon fibers → tape placement → hot mold pressing
- In-situ measurement of temperature, strain etc. by embedded optical fiber → increase in inspection performance and reliability

- Development of tough composite material with high productivity

**Innovative PMC research center at U. Tokyo and JAXA**

- Industry member, university and public research institute member
- Upper members: leader and co-leader

- A01: Heat resistant thermoplastic PMC for engine parts
  - Nagoya U., JAXA
- A02: PMC for vertical tail and door
  - TOYAY
- A03: Heat resistant PMC for engine parts (higher temperature area)
  - JAXA, IHI
- A04: PMC for main frame and airframe
  - U. Tokyo, JAXA
- A07: High-strength and transparency GF-PPC
  - Idemitsu Kisan, Asahi Fiber Glass, Tokyo U. of Science, Idemitsu Kisan
- A08: Textile composites
  - Asahi Kasei, Gifu U., Honda
- A09: Fibrillated cellulose reinforced composite
  - Furukawa Electric, Tokyo U. of Science, U. Shiga Pref.
- A10: CFRP derived from biomass
  - Kansai U., Bio-energy
- A11: Development of high modulus composites with high productivity
  - JAXA, IHI, KHI, FH
- A12: Development of high modulus composites with high productivity
  - JAXA, IHI, KHI, FH
- A13: Development of high modulus composites with high productivity
  - JAXA, IHI, KHI, FH
- A14: Development of high modulus composites with high productivity
  - JAXA, IHI, KHI, FH
- A15: Development of high modulus composites with high productivity
  - JAXA, IHI, KHI, FH
Development of Innovative Technology of High Temperature Ti- and Ni-based Alloys and TiAl-Intermetallic Compounds

- Innovative large-scale and practical forging technology using computer simulation and material data base for Ti- and Ni-based alloys which are key materials in aero engines and power generation turbines.
- Laser metal deposition with excellent workability and productivity, and metal injection molding with high dimensional accuracy and fatigue performance, both of technologies being applied to key components of aircrafts and turbines.
- Fundamental technology of Ti- and Ni-based alloys for new alloy design.
- Material designing, casting and forging technologies of TiAl-intermetallic compounds for high-pressure compressor and low-pressure turbine blades.

**Materials processing and technology**

- Forging technology
  - Consistent process technology development from melting to manufacturing
- Casting technology
- Melting technology

**Applied materials parts**

- **Ti-Alloys**
- Fan Case
  - Near-net shape forming by laser powder metal deposition or metal injection molding
- **Ti- and Ni-Based Alloy**
  - Compressor and Turbine Stator Vane
  - Compressor and Turbine Disk
- **TiAl-intermetallic compounds**
  - Low Pressure Turbine Rotor Blade
    - Near-net shape casting
  - High Pressure Compressor Rotor Blade
    - High-speed forging without temperature controller

**Heat Resistance of Materials**

- Fan Temperature (LP) (HP)
- Kishi PD
- Kitaoka Deputy PD
- Mitorai Research Domain Director
- PRISM: Process Innovation for Super Heat-resistant Metals

**Innovative large-scale forging technology**

- Innovative materials development base
- NIMS, Kobe Steel, Daido Steel, Hitachi Metals, Kagawa U., Gifu U., Tohoku U., Osaka U., Tokyo Denki U., Nagoya U., TIT, U. Tsukuba, Meijo U.

**Laser metal deposition**

- KHI, NIMS, Kyushu U., IHI
- Osaka Titanium-tech.

**Metal injection molding**

- MHPS, Tohoku U., Tohoku U., Osaka U., Metal Tech. Co., NIMS.

**Candidate materials for aircraft engines**

- Fan Case
  - CFPR (Specific strength ~450)
  - Heat resistant alloys research center at NIMS (Mitorai Manager)
- Compressor and Turbine Disk
  - TiAl-intermetallic compounds research center at TIT (Takayama Manager)

**Intermetallic compounds research center**

- TIT, Osaka U., Metal Tech. Co., NIMS
Development of Ceramic Environmental Barrier Coating

- Environmental barrier coating (EBC) protects the surface of heat-resistant and light-weight ceramic components from harsh external environmental for long-term use. Development of EBC technology is necessary for the practical application of the ceramic components expected to contribute significantly to improve fuel efficiency and reducing CO₂ emissions from aircraft jet engines.
- EBC technology is applicable to the production of the light-weight ceramic components with high toughness and heat resistibility.

Material processing and technology

Coating design and deposition process

- **Environmental barrier coating**
  - Controlling of EBC structure and composition of the layer by electron beam PVD
- **Interface-controlled coating**
  - Analysis and evaluation of Interface-controlled coating by mechanical and damage tolerance properties
  - High power laser
  - Feed gas
  - Laser CVD, etc.
- **Evaluation of coating**
  - Evaluation of applicability to actual equipment by thermal cycling with combustion gas

Environmental shielding design

- Oxygen and water vapor at 1400°C

Bibliography:

- C41: Coating process technology
  - JFCC
  - Tohoku U., Yokohama National U.
- C42: Evaluation of EBC performance
  - NIMS, IHI
  - TIT, U. Tokyo
  - JUTEM
- C43: Evaluation of Interface-controlled coating performance
  - JAXA
  - IHI
- C45: Oxide ceramics matrix composite coating
  - MHI Aero Engine
  - NIMS, Artixyaku, Nityo
Materials Integration (MI)

Materials Integration system is an infrastructure to support and to accelerate developments of advanced materials from engineering viewpoint by utilizing accumulated theoretical and practical knowledge of materials science, and by integrating advanced technologies such as database, experiment, computational simulation, big data analysis, and so on.

Main subjects of Materials Integration system are to contribute to the large reduction of development time and cost, to optimization of the selection of materials and processes, to improvements of the reliability prediction, to the reduction of diagnosis and maintenance cost. We are going to develop Materials Integration systems for metallic, polymeric and ceramic materials, and also aiming to establish R&D center, capacity building and global network.

MI: Integration of theories, experiments, computation and data

<table>
<thead>
<tr>
<th>Performance</th>
<th>Structure</th>
<th>Properties</th>
<th>Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time-dependent Fatigue, Corrosion, Creep...</td>
<td>Stresses, Grain-size, Grain-orientation...</td>
<td>Strength, Ductility, Toughness</td>
<td>Rolling, Forging, Welding...</td>
</tr>
</tbody>
</table>

MI for Metals (weld joint of HSS is implemented in advance as a typical challenge)

- System for Materials Microstructure
  - prediction of structure, hardness, residual stresses, etc.

- System for Materials Performance
  - estimation of life-time, probability of destruction, factors of embrittlement

Integrated System (exert the function of MI)

System for Data Assimilation
- numerical modeling experiments, database
- theory, experimental knowledge
- utilization of big data
- numerical simulation

MI for Various Structural Materials

- System for Materials Microstructure
  - prediction of structure, hardness, residual stresses, etc.

- System for Materials Performance
  - prediction of fatigue, creep, brittle fracture, hydrogen embrittlement, etc.

Mathematical approach, Incorporation of time-dependency

Prediction of life-times or performances by innovative measurement and analysis for structural materials (SIP-IMASM)

<table>
<thead>
<tr>
<th>mm</th>
<th>µm</th>
<th>nm</th>
<th>mm</th>
</tr>
</thead>
</table>

2D Imaging of H, B, C, N and O by PIXE (Particle Induced X-ray Emission)

3D Imaging of voids formation during plastic deformation by positron annihilation

3D Imaging of precipitates at grain boundary by 3D-AP (atom probe)

3D Imaging of interface and crack initiation by XAFS (X-ray absorption fine structure)-CT

Common basic science and technology

Mathematical approach, Incorporation of time-dependency

Metal MI (weld joint of HSS is implemented in advance as a typical challenge)

Ceramics Coating MI

Polymer MI

Koski Research Domain Director
Kagawa Deputy PD

MI research center at U. Tokyo and NIMS (Koski Manager)
List of Research Projects

Development of Polymer Based Materials and Fiber Reinforced Plastics (FRP)

<table>
<thead>
<tr>
<th>No.</th>
<th>Research Project</th>
<th>Research Unit</th>
<th>Unit Leader</th>
</tr>
</thead>
<tbody>
<tr>
<td>A01</td>
<td>Development of Innovative Manufacturing Process and Quality Assurance Technology of Highly Productive Polymer Matrix Composites for Aircraft</td>
<td>Thermoplastic Composites for Aero-engines</td>
<td>Masahiro Ari (Nagoya Univ.) and Toshihiko Koseki (Univ. Tokyo)</td>
</tr>
<tr>
<td>A02</td>
<td>Development of Innovative Processing Technology for Novel Improving Polymeric Materials</td>
<td>Highly Productive and Innovative Non-autoclave CFRP Production Technologies</td>
<td>Makoto Endo (TVK Industries, Inc.)</td>
</tr>
<tr>
<td>A03</td>
<td>Development of Innovative PMCs for Aircraft</td>
<td>High Temperature Polymer Matrix Composites</td>
<td>Yoshi Uehda (IAXA) and katsuyoshi Motyai (Hi-Co.)</td>
</tr>
<tr>
<td>A04</td>
<td>Development of Innovative Hybrid PMCs</td>
<td>Fundamental Study of Process Monitoring and Modeling</td>
<td>Nobuo Takeda (Univ. Tokyo)</td>
</tr>
</tbody>
</table>

Unit Project

A10 Development of Carbon Fiber Reinforced Plastic Derived from Plant Biomass | Katsuki Hirayama (Kawasaki Univ.) and Yuki Hatta (Bio-energy Co.)

Development of Innovative Technology of High Temperature Ti- and Ni-based Alloys and TiAl-Intermetallic Compounds

<table>
<thead>
<tr>
<th>No.</th>
<th>Research Project</th>
<th>Research Unit</th>
<th>Unit Leader</th>
</tr>
</thead>
<tbody>
<tr>
<td>B21</td>
<td>Process Innovation for Super Heat-resistant Metals (PRISMA)</td>
<td>Development of Innovative Forging Process Technology and Construction of Material/Process Database with the Large-Scale and Precise Forging Simulator</td>
<td>Yoko Mita (NIMS) and Tatsuya Inagaki (Japan Aerospace, Ltd.)</td>
</tr>
<tr>
<td>B22</td>
<td>Development of Innovative Production Technology Utilizing Laser Metal Deposition for Aero Engine Components</td>
<td>Development of Metal Injection Molding Process Technology for Aero Engine Components</td>
<td>Hideki Murai (Kyushu Univ.) and Hiroshi Koizumi (Hi-Co.)</td>
</tr>
</tbody>
</table>

Unit Project

B32 Development of Manufacturing Technique for TiAl Turbine Blade with Oriented Lamellae | Development of Manufacturing Technique for TiAl Turbine Blade with Oriented Lamellae | Hideshi Miura (Kyushu Univ.)

B30 Development of New Manufacturing Process for High Quality and Low Cost TiAl Ingot | Development of New Manufacturing Process for High Quality and Low Cost TiAl Ingot | Koichi Sakamoto (Kobe Steel, Ltd.)

B27 Development of Large Scale and High Strength Wrought Disk Components for Steam Power Generation | Development of Large Scale and High Strength Wrought Disk Components for Steam Power Generation | Kazuhito Kimura (Tohoku Univ.) and Toshihiko Koseki (Univ. Tokyo)


B33 Development of Wrought TiAl Alloy Blade for Down Power Generation | Development of Wrought TiAl Alloy Blade for Down Power Generation | Moritsugu Yawata (Osaka Univ.) and Jun Sato (Mitsubishi Hitachi Power Systems, Ltd.)

Development of Ceramic Environmental Barrier Coating

<table>
<thead>
<tr>
<th>No.</th>
<th>Research Project</th>
<th>Research Unit</th>
<th>Unit Leader</th>
</tr>
</thead>
<tbody>
<tr>
<td>C41</td>
<td>Structural Optimization and Reliability Improvement of Ceramic Environmental Barrier Coating</td>
<td>Development of Coating Promoters</td>
<td>Masataka Takata (IPLC)</td>
</tr>
<tr>
<td>C42</td>
<td>Development of Advanced Ceramics</td>
<td>Evaluation Analysis of ESC Performance</td>
<td>Takashi Nakamura (Hi-Co.) and Hitoshi Katsumi (NIMS)</td>
</tr>
<tr>
<td>C43</td>
<td>Development of Interface-Controlled Coating Performance</td>
<td>Evaluation Analysis of Interface-controlled Coating Performance</td>
<td>Ken Goto (IAXA)</td>
</tr>
</tbody>
</table>

Unit Project

C45 Development of the oxide ceramics matrix composite coating sheet | Development of the oxide ceramics matrix composite coating sheet | Masahiro Uehda (Mitsubishi Heavy Industries Aero Engines, Ltd.)

Materials Integration (MI)

<table>
<thead>
<tr>
<th>No.</th>
<th>Research Project</th>
<th>Research Unit</th>
<th>Unit Leader</th>
</tr>
</thead>
<tbody>
<tr>
<td>D41</td>
<td>Development of Multiscale Analysis for Structural Materials</td>
<td>Development of System for Materials Microstructure</td>
<td>Masataka Takata (IPLC)</td>
</tr>
<tr>
<td>D42</td>
<td>Development of Simulation Technique for Performance Assurance of Welding Processes</td>
<td>Development of System for Materials Performance</td>
<td>Manabu Enoki (Univ. Tokyo)</td>
</tr>
<tr>
<td>D43</td>
<td>Development of System for Data Assimilation</td>
<td>Development of System for Data Assimilation</td>
<td>Junya Ito (Univ. Tokyo)</td>
</tr>
<tr>
<td>D44</td>
<td>Development of Integrated System</td>
<td>Development of System for Data Assimilation</td>
<td>Masanori Watanabe (NIMS)</td>
</tr>
</tbody>
</table>

Unit Project

D06 Development of Simulation Technique for Performance Assurance of Welding Processes | Development of Simulation Technique for Performance Assurance of Welding Processes | Toshihiro Koseki (Univ. Tokyo) and Akira Hirose (Osaka Univ.)


D08 Development of Design and Manufacturing Techniques for TiAl-Intermetallic Compounds for Aeronautical Structural Components | Development of Design and Manufacturing Techniques for TiAl-Intermetallic Compounds for Aeronautical Structural Components | Yasuhiro Iwahori (JAXA) and takahiro Kubo (Toshiba Co.)


D10 Development of Practical Design and Manufacturing Techniques (Practical Design and Manufacturing Techniques) | Development of Practical Design and Manufacturing Techniques (Practical Design and Manufacturing Techniques) | Akira Hirose (Osaka Univ.) and Yutaka Iwahori (JAXA)

D11 Development of Advanced Structural Materials | Development of Advanced Structural Materials | Hisashi Kato (Tohoku Univ.)

D12 Development of Advanced Structural Materials | Development of Advanced Structural Materials | katsuyoshi Motyai (Hi-Co.) and Toshifumi Koseki (Univ. Tokyo)

D13 Development of Advanced Structural Materials | Development of Advanced Structural Materials | Toshihiko Koseki (Univ. Tokyo)

D14 Development of Advanced Structural Materials | Development of Advanced Structural Materials | Toshihiko Koseki (Univ. Tokyo) and Toshifumi Koseki (Univ. Tokyo)