Introduction to Multiscale Analysis and Examples related to PCB

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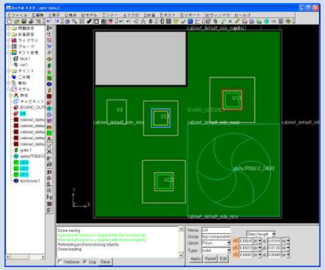
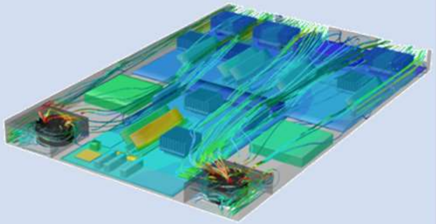
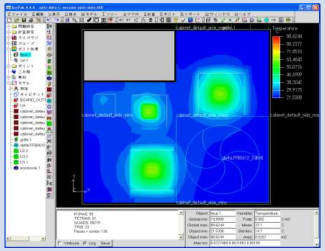
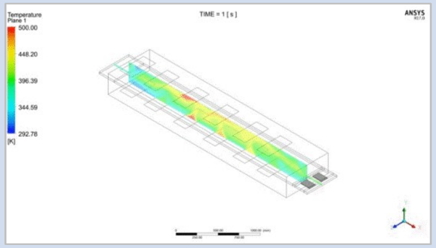
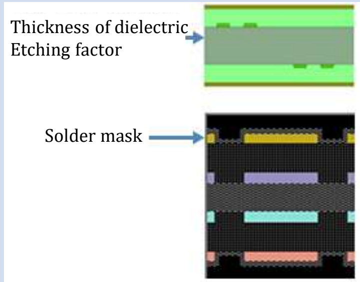
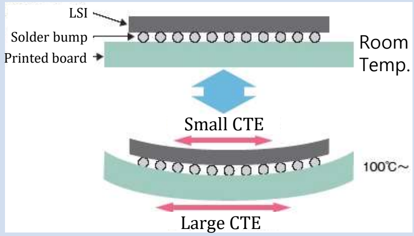
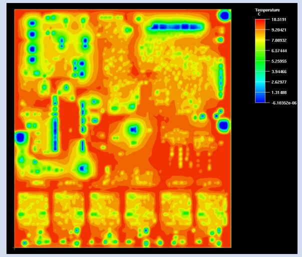
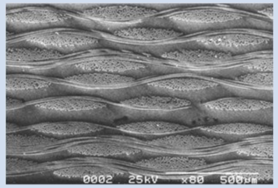
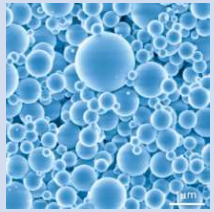
Taesung S&E

CONTENTS

Background

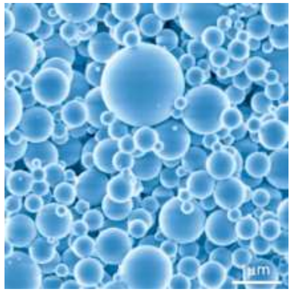
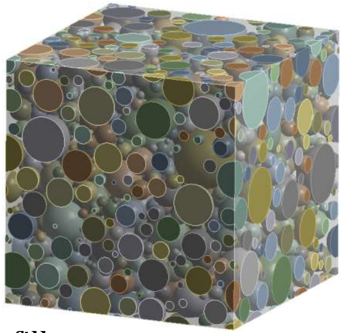
Occurrence factor of warpage in PCB

Problem	Distributed temperature	Mismatched material constants	Non homogeneous materials
Image	  In operation cooling by fans or fins  Heat generation by el ectronic components  In reflow process	 	  Wiring distribution   GFRP (FR4) Under fill
CAE tools for analysis	ANSYS Fluent ANSYS Icepack ANSYS SI wave	ANSYS Mechanical	Multiscale.Sim(CMAS) ANSYS Mechanical

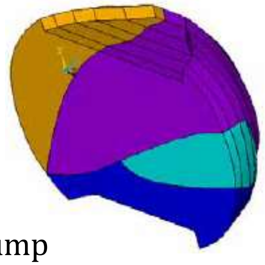
PCB made by Multi Material

PCB is constructed by many kinds of <u>composite materials</u>

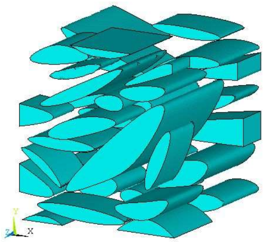
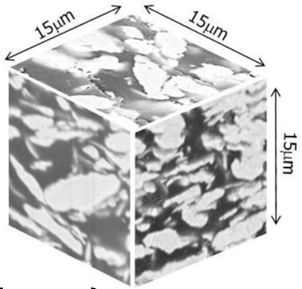
Need an-isotropic material constants for CAE analysis

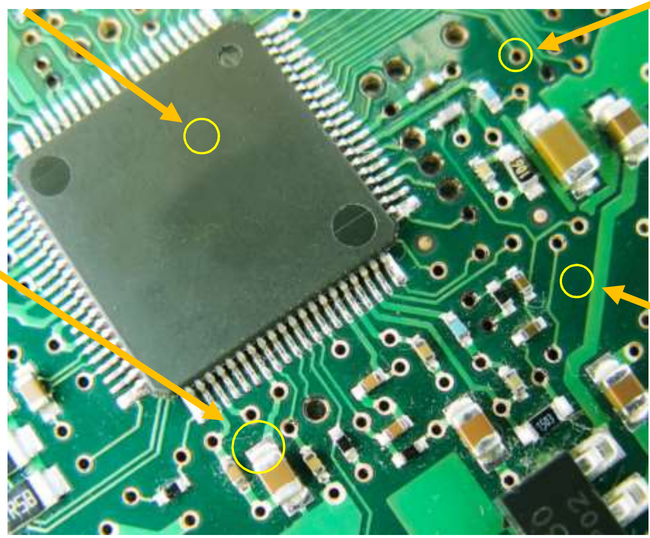
Under fill

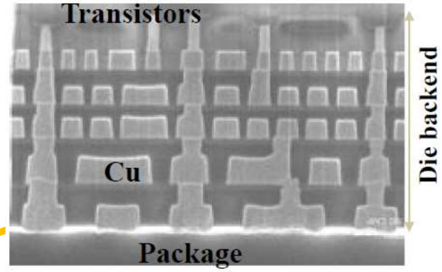



Solder bump

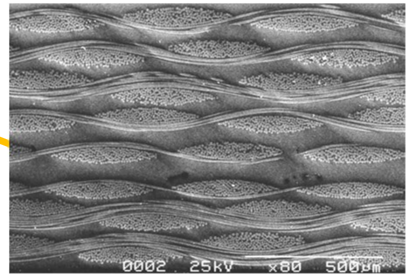



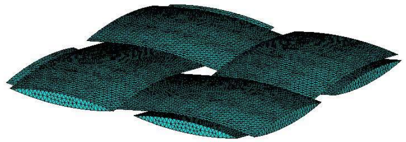
Conductive adhesive(Epoxy & Filler etc.)





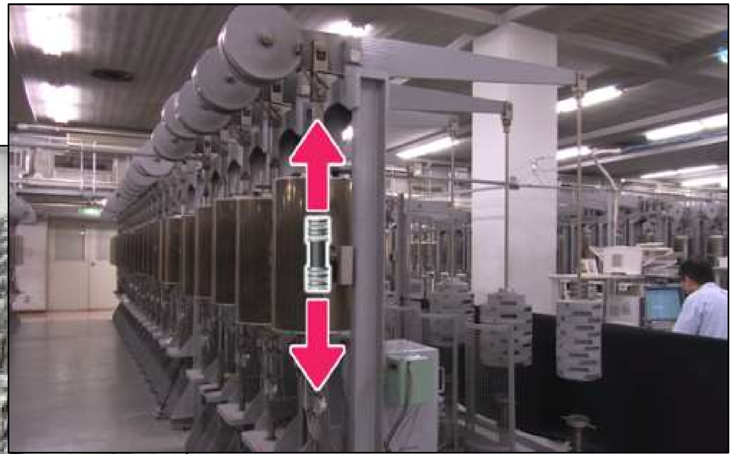
Wiring, Via etc.





Base material (FR4)

Testing just waiting earnestly for a long time



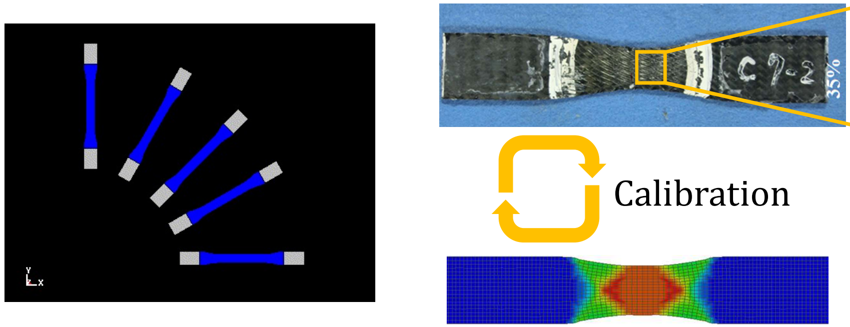
The longest record with respect to creep testing
=
50 years

There are 380 testing machines in the room which has 15m * 50m

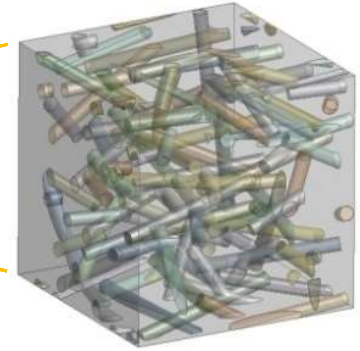
Reference) National Institute for Materials Science
https://www.nims.go.jp/publicity/digital/movie/mov150916.html

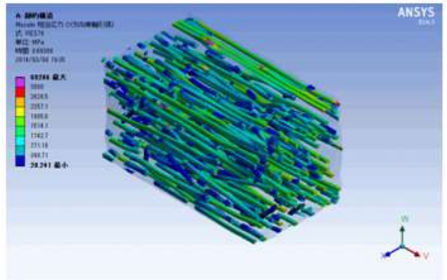
Analysis for Material Constants Identification

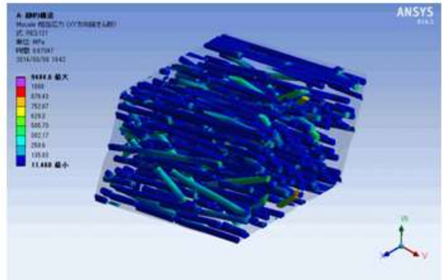
- Analysis approach to identify material constants
  - Dumbbell specimen model : Reverse identification by calibration
  - Unit cell model : Evaluated definitively from analysis results



Analysis by dumbbell specimen







Analysis by unit cell specimen

Characteristics	Dumbbell specimen	Unit Cell specimen
Cost for model creation	○	△(Tends to get large)
Boundary conditions	○	△(complex)
Consistent with actual tests	○	△
Executable deformation modes	× (limited)	○
Executable identification of all constants	△(limited)	○

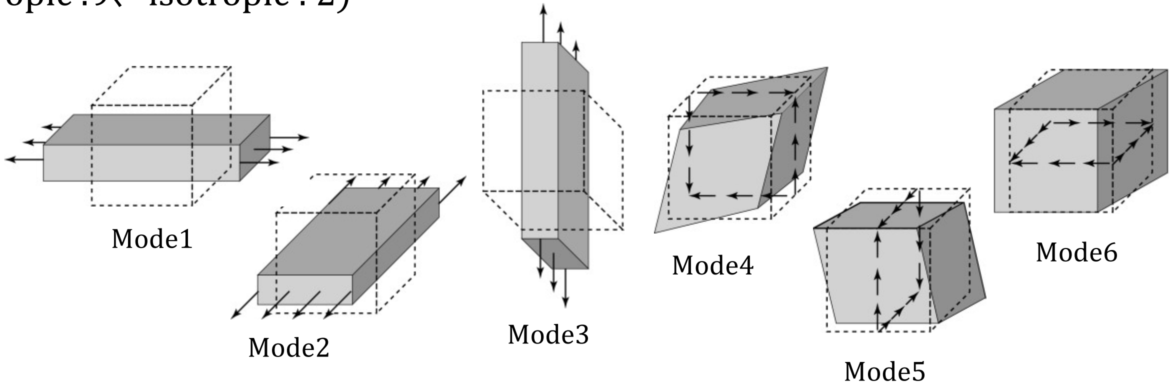
× : bad
△ : medium
○ : good

Material Constants for an isotropic property

- Stiffness matrix for solid

Number of material constant (an isotropic:21、 orthotropic :9、 isotropic : 2)

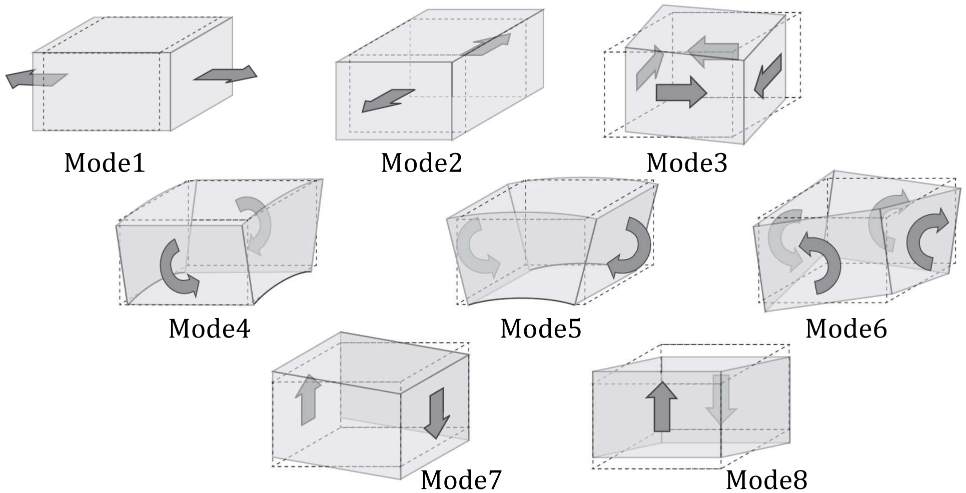
$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{xz} \end{Bmatrix} = \underbrace{\begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ C_{21} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ C_{31} & C_{32} & C_{33} & C_{34} & C_{35} & C_{36} \\ C_{41} & C_{42} & C_{43} & C_{44} & C_{45} & C_{46} \\ C_{51} & C_{52} & C_{53} & C_{54} & C_{55} & C_{56} \\ C_{61} & C_{62} & C_{63} & C_{64} & C_{65} & C_{66} \end{bmatrix}}_{\text{Unknown Parameters}} \begin{Bmatrix} \epsilon_{xx} \\ \epsilon_{yy} \\ \epsilon_{zz} \\ \epsilon_{xy} \\ \epsilon_{yz} \\ \epsilon_{xz} \end{Bmatrix}$$



- Stiffness matrix for shell

Number of material constant : 21

$$\underbrace{\begin{Bmatrix} N_{11} \\ N_{22} \\ N_{12} \\ M_{11} \\ M_{22} \\ M_{12} \\ S_{23} \\ S_{13} \end{Bmatrix}}_{\text{Resultant stress}} = \underbrace{\begin{bmatrix} A_{11} & A_{12} & A_{13} & B_{11} & B_{21} & B_{31} & 0 & 0 \\ A_{21} & A_{22} & A_{23} & B_{12} & B_{22} & B_{32} & 0 & 0 \\ A_{31} & A_{32} & A_{33} & B_{13} & B_{23} & B_{33} & 0 & 0 \\ B_{11} & B_{12} & B_{13} & D_{11} & D_{12} & D_{13} & 0 & 0 \\ B_{21} & B_{22} & B_{23} & D_{21} & D_{22} & D_{23} & 0 & 0 \\ B_{31} & B_{32} & B_{33} & D_{31} & D_{32} & D_{33} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & E_{11} & E_{12} \\ 0 & 0 & 0 & 0 & 0 & 0 & E_{21} & E_{22} \end{bmatrix}}_{\text{Unknown Parameters}} \begin{Bmatrix} e_{11} \\ e_{22} \\ e_{12} \\ \kappa_{11} \\ \kappa_{22} \\ \kappa_{12} \\ g_{23} \\ g_{13} \end{Bmatrix}$$

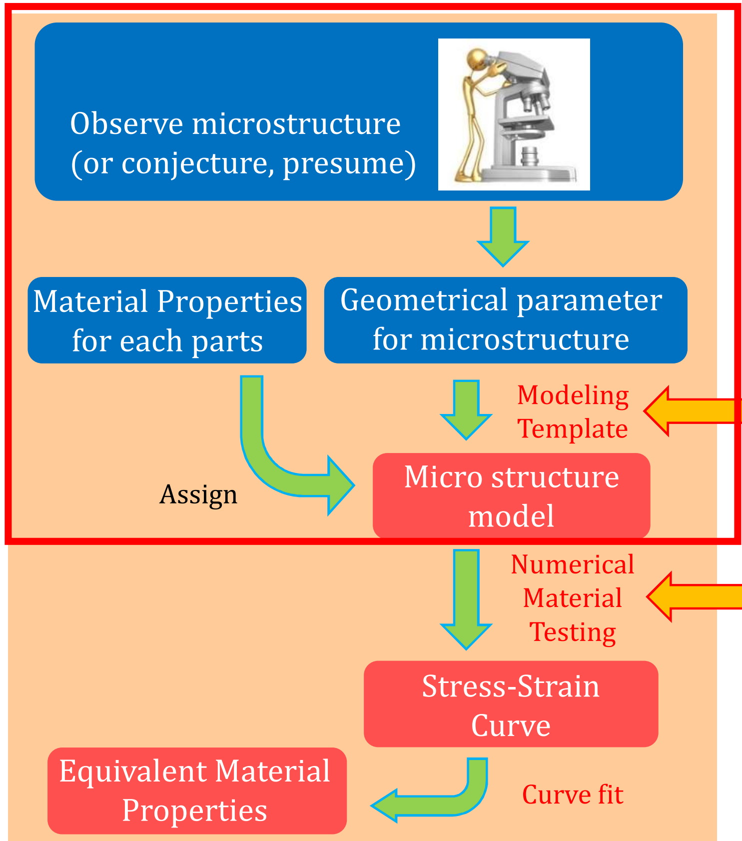


Introduction of Multiscale Analysis

Homogenization analysis using Multiscale.Sim

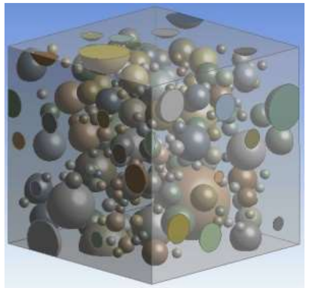
Multiscale.Sim

What is Multiscale.Sim?
Add in tool to homogenization analysis on ANSYS Workbench

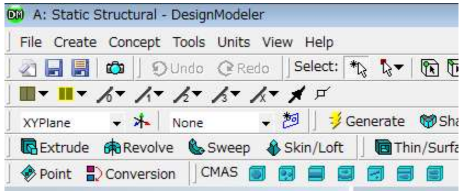


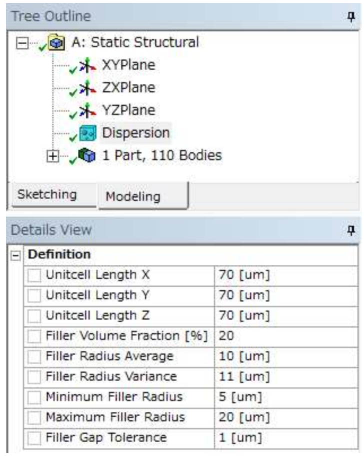
: input : output

Homogenization analysis flow

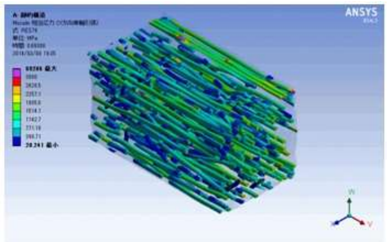


Model for microstructure

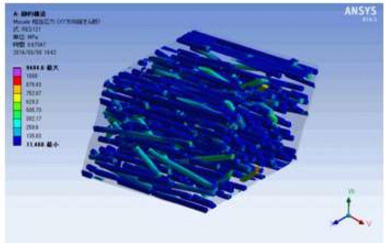




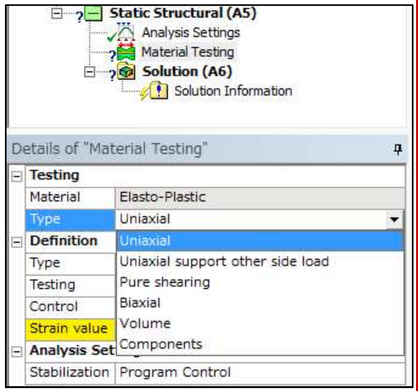
Modeling Template GUI is integrated to Design Modeler



Uniaxial tension for x dir.

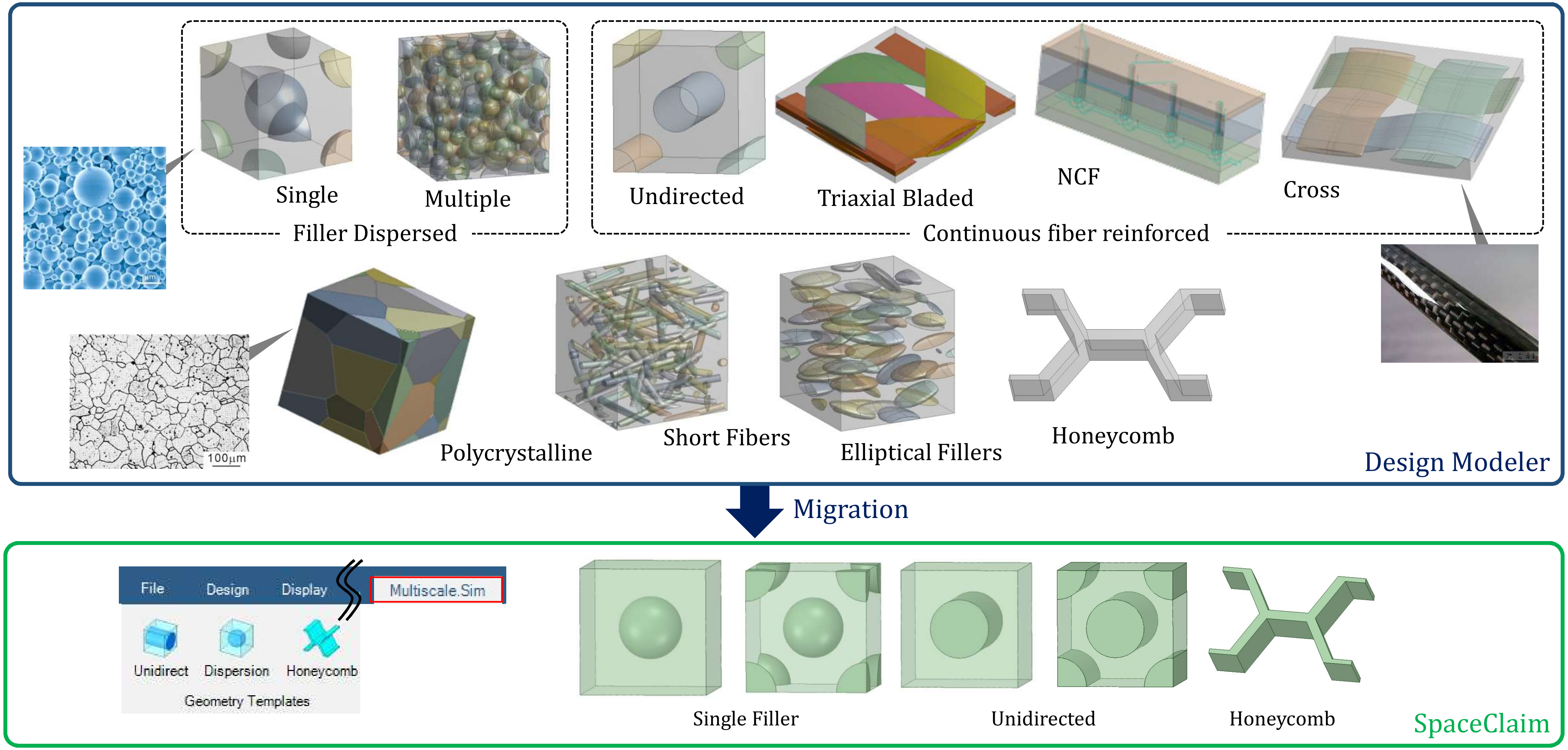


Pure shearing for xy dir.



Material test for any deformation mode and loading history

Templates for Micro Model Creation

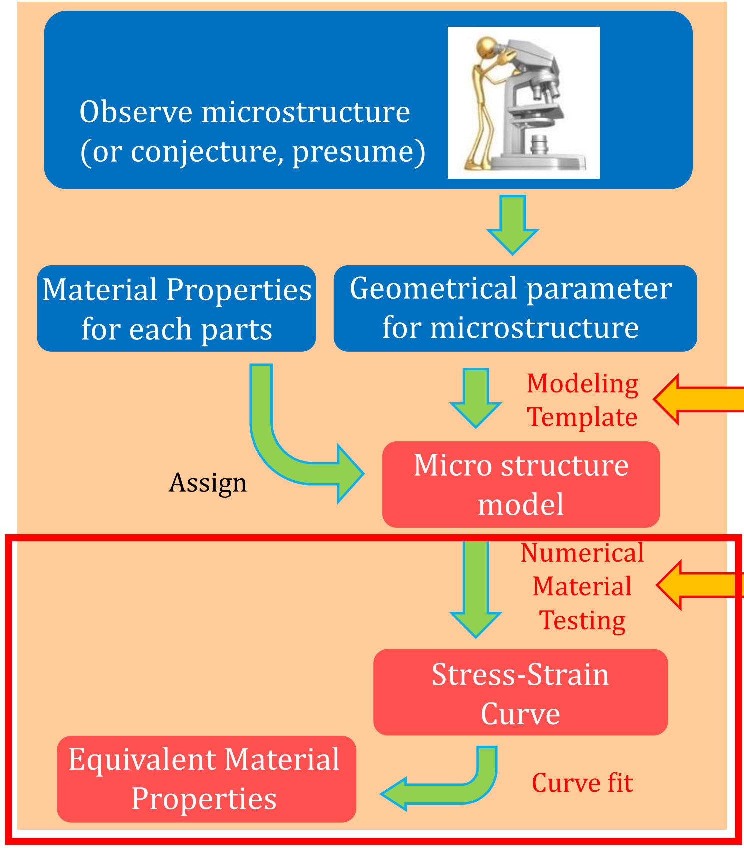


Representative microstructure which can be made by Multiscale.Sim

Multiscale.Sim

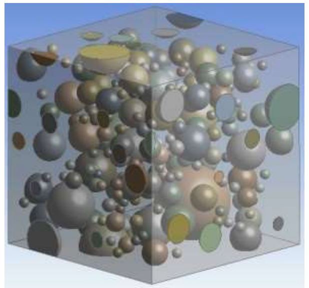
Homogenization analysis using Multiscale.Sim

What is Multiscale.Sim?
Add in tool to homogenization analysis on ANSYS Workbench

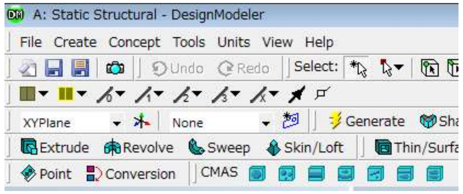


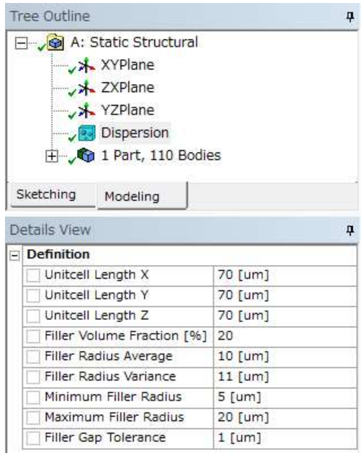
: input : output

Homogenization analysis flow

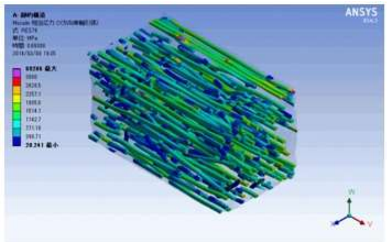


Model for microstructure

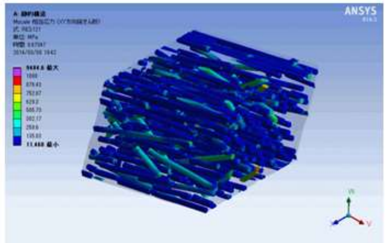




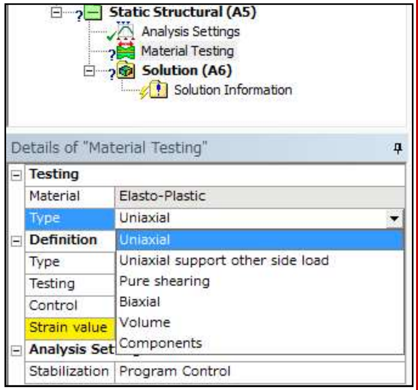
Modeling Template GUI is integrated to Design Modeler



Uniaxial tension for x dir.

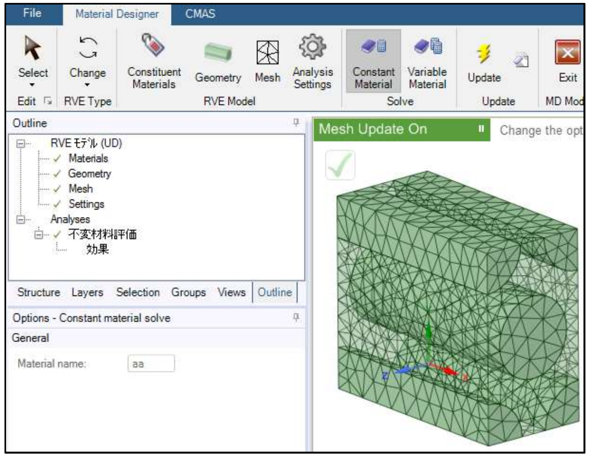


Pure shearing for xy dir.

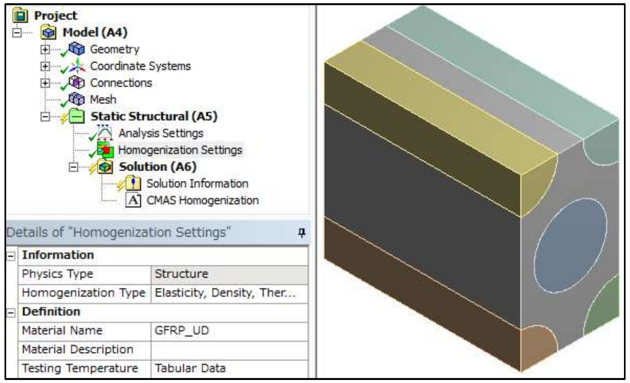


Material test for any deformation mode and loading history

Material Designer vs. Multiscale.Sim



Material Designer released from 2019
(SpaceClaim GUI)



Multiscale.Sim released from 2007
(Mechanical GUI)

Homogenization analysis tool is made by broadly two features which are model creation and homogenization analysis.

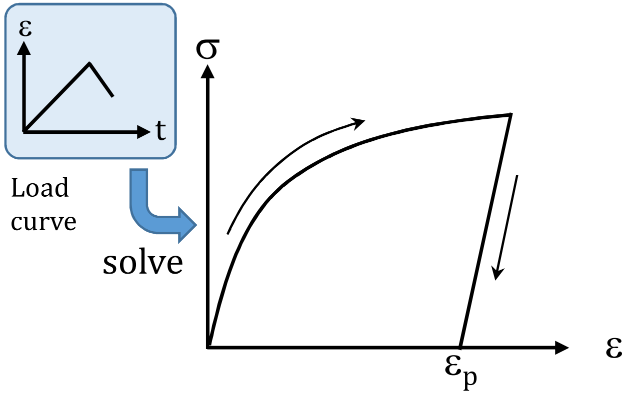
Feature comparison between two tools (as of Aug. 28, 2019)

Features		Material Designer	Multiscale.Sim
GUI		SpaceClaim	Mechanical
Micro model creation		5 types	17 types (Design Modeler)
License to use		ANSYS Mechanical Enterprise	Multiscale.Sim
Linear Homogenization	Elasticity	✓	✓
	Thermal expans.	✓	✓
	Integrated section		✓
	Thermal conduct.	✓	✓
	Seepage coeff.		✓
	Permeability for Electric and Magnetic		✓
Nonlinear Homogenization	Next slides for detail		✓
Localization			✓

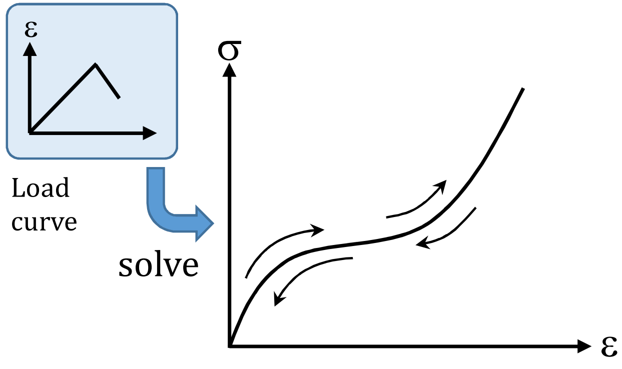
Supported Material Behavior in Multiscale.Sim

Nonlinear homogenization features

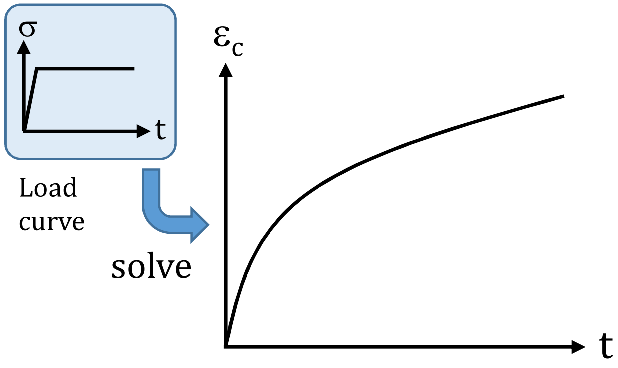
- ➢ Numerical Material testing
  - Any deformation mode
  - Any loading history
- ➢ Curve fitting
  - Original optimization algorithm (Tuned for each material models)



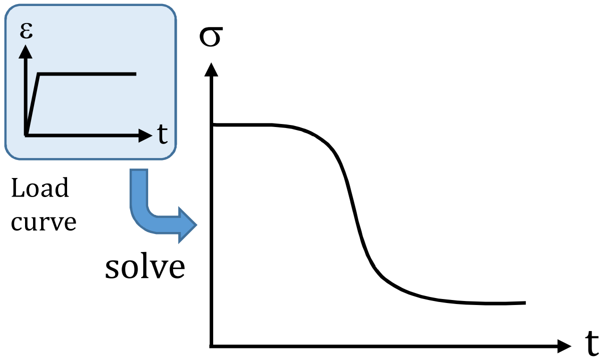
Elasto Plastic
(Hill's potential)



Hyper Elastic
(Kariske's model)

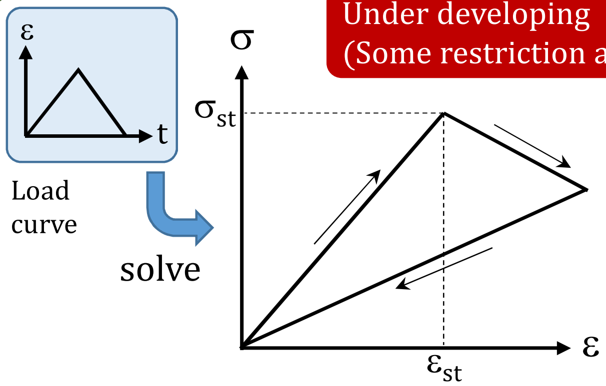


Creep
(Hill's potential)



Visco Elastic
(an-isotropic generalized maxwell)

Under developing
(Some restriction at now)



Damaged
(** and ** for UD)

Operational Demonstration1

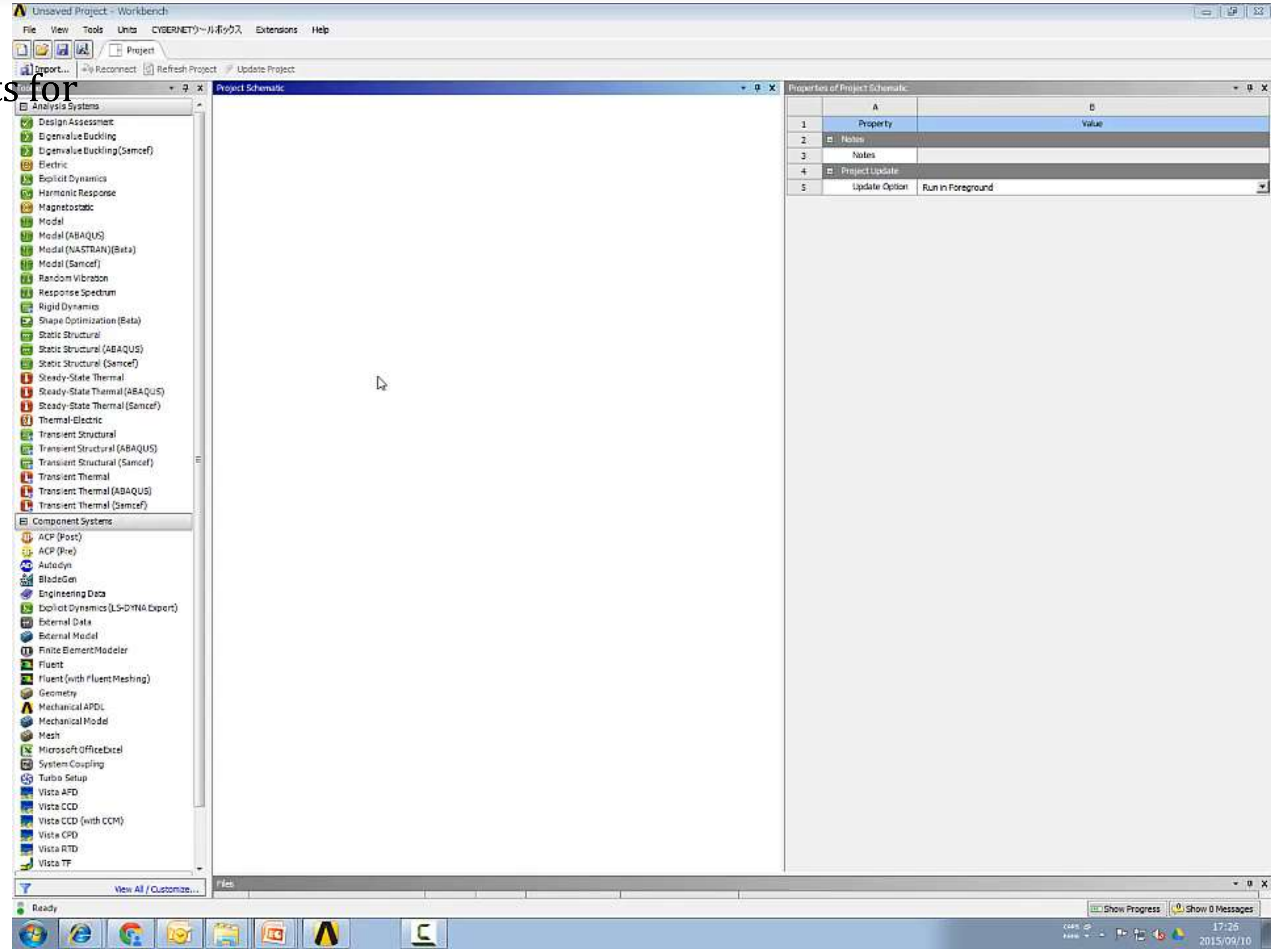
- **Purpose**

  Identification equivalent material constants for
  - Orthotropic elasticity
  - Coefficient of thermal expansion
  - Density

- **Analysis Model**
  - SiC matrix & Aluminum filler
  - Spherical filler dispersed in SiC

- **Material Type**
  - SiC : Pure Elastic
  - Aluminum : Pure Elastic

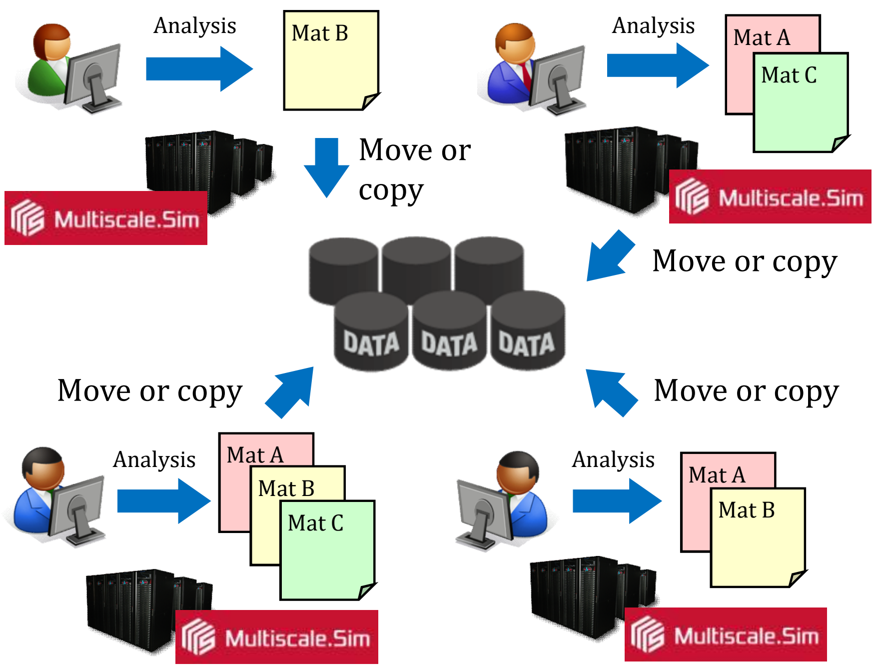
- **Operational Procedure**
  - Create Analysis System
  - Creating microstructure
  - Assigning material properties & Meshing
  - Insert linear homogenization objects
  - Confirmation results



Operational Demonstration2

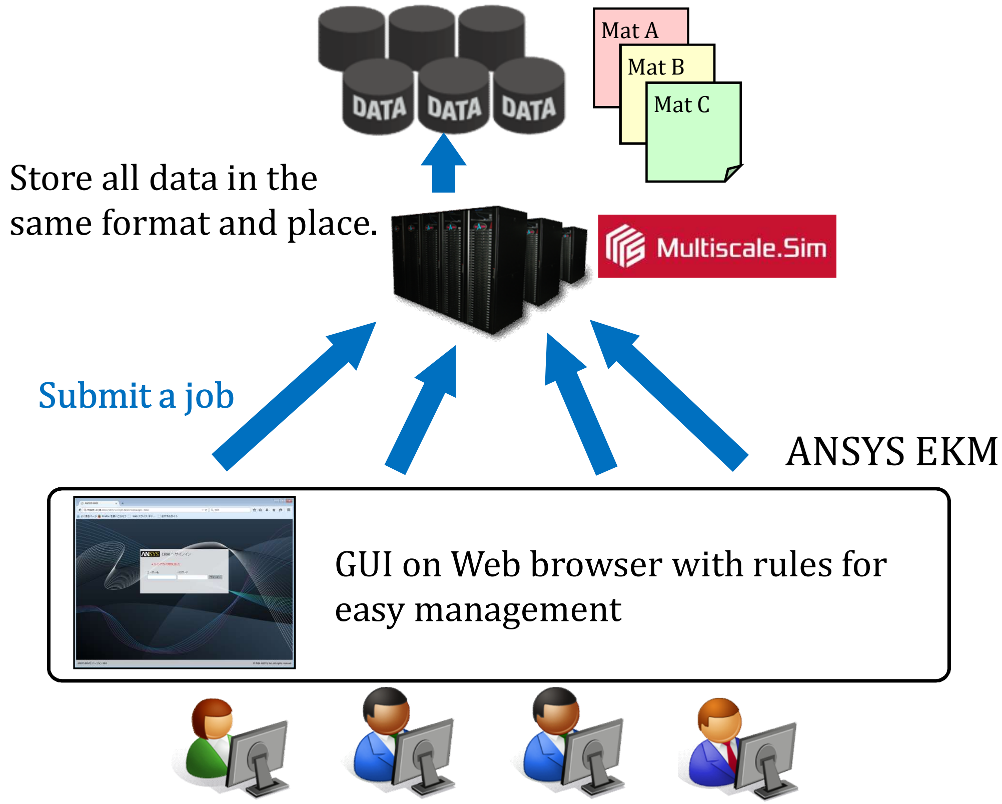
Homogenization analysis in SPDM system
(SPDM : Simulation Process and Data Management)

Conventional process

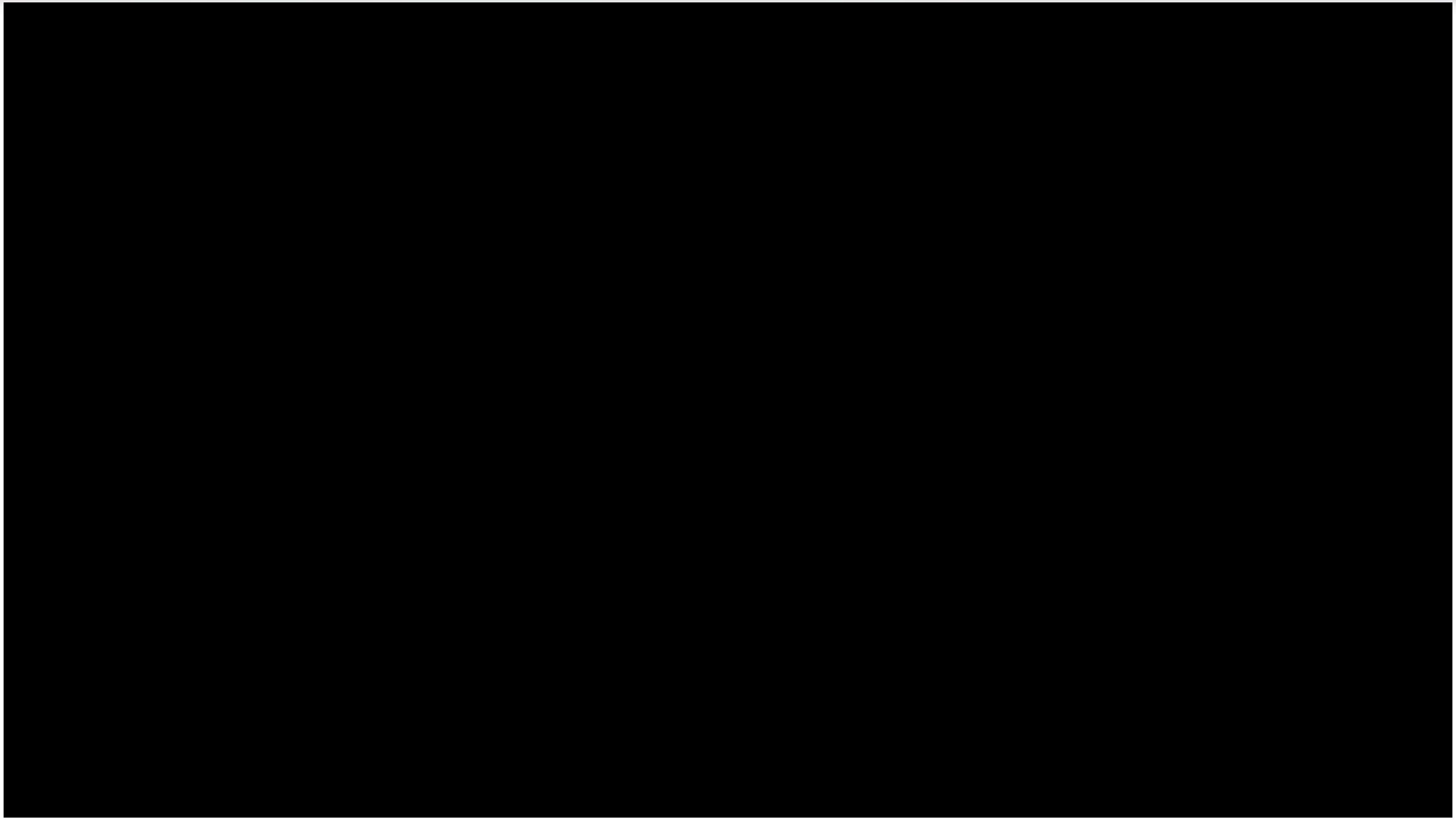


- Demerit
- Duplication of data
- Lack of unity (spelling inconsistency)
- Different information although same name
- Unknown source

SPDM process



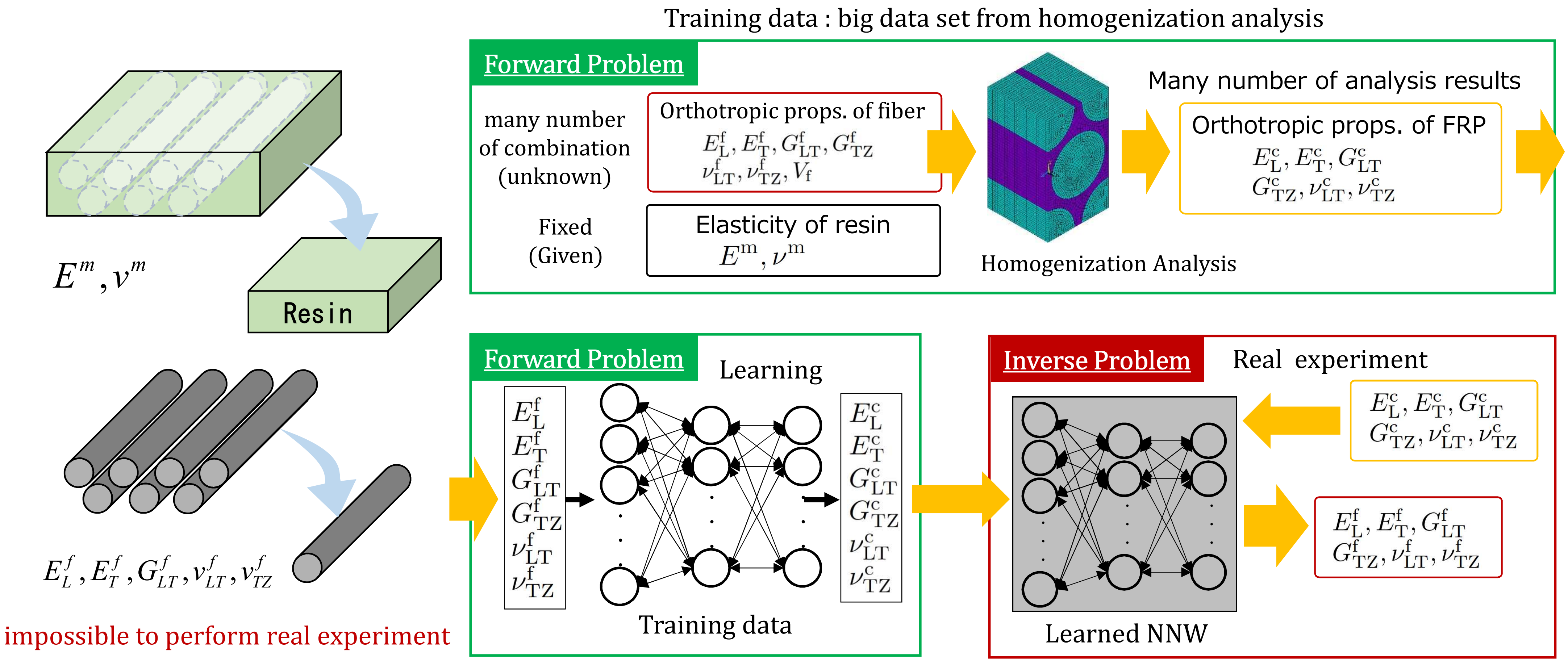
Operational Demonstration2



29th 태성에스엔이
CAE
Conference

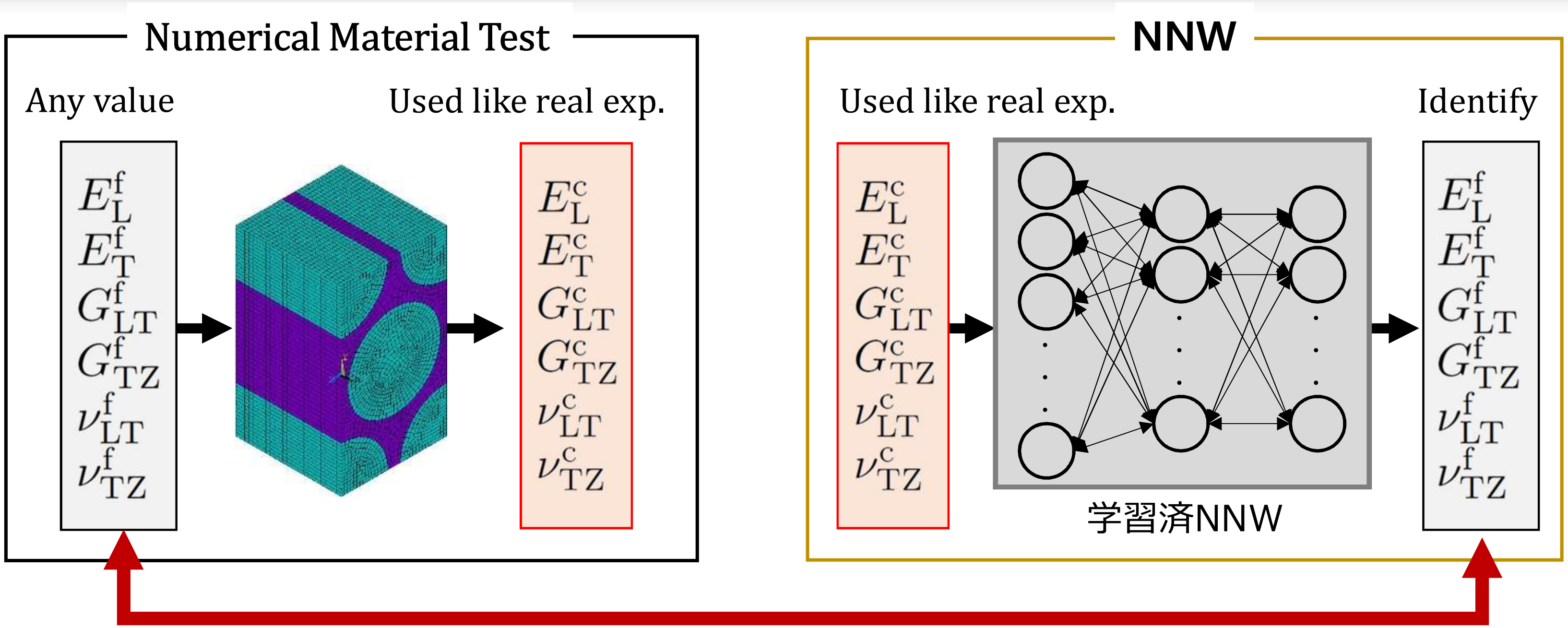
Analysis Examples

How to prepare material constants for input data



Reference) S. Tsuchida, N. Hirayama, Y. Ishibashi, K. Yamamoto, K. Terada, Identification of orthotropic elastic constants for carbon fiber, Composite Symposium in Japan (2018)

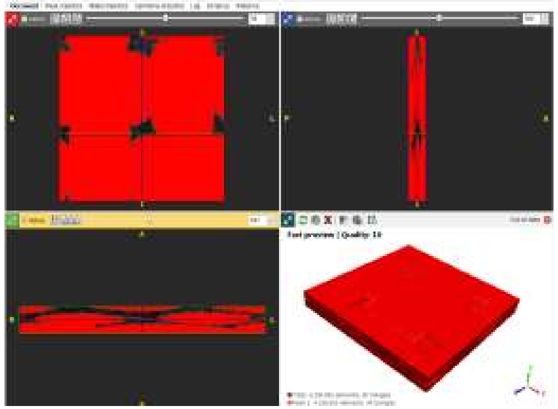
How to prepare material constants for input data



Props.	Unit	Data	NNW	Error rate [%]
E^f_L	GPa	237.5	239.1	0.67
E^f_T	GPa	16.5	16.90	2.30
G^f_{LT}	GPa	9.5	9.40	1.05
ν^f_{LT}	-	0.33	0.33	0.00
ν^f_{TZ}	-	0.50	0.51	2.00

Reference) S. Tsuchida, N. Hirayama, Y. Ishibashi, K. Yamamoto, K. Terada, Identification of orthotropic elastic constants for carbon fiber, Composite Symp osium in Japan (2018)

Elasticity homogenization for woven CFRP

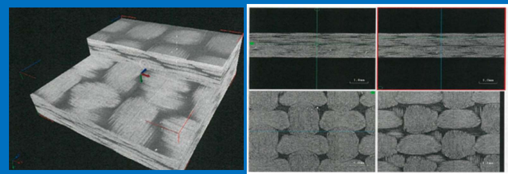


Simplware®

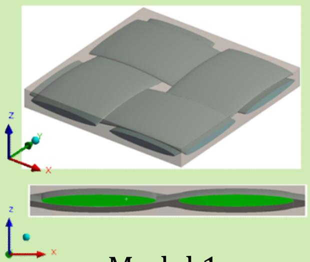
Image analysis for identification of geometrical parameters

Image info. by DICOM data

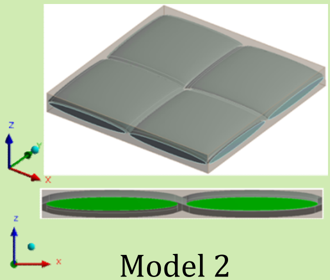
inspeXio SMX-225CT FPD HR from Shimadu corp.



Micro focus X-ray CT system

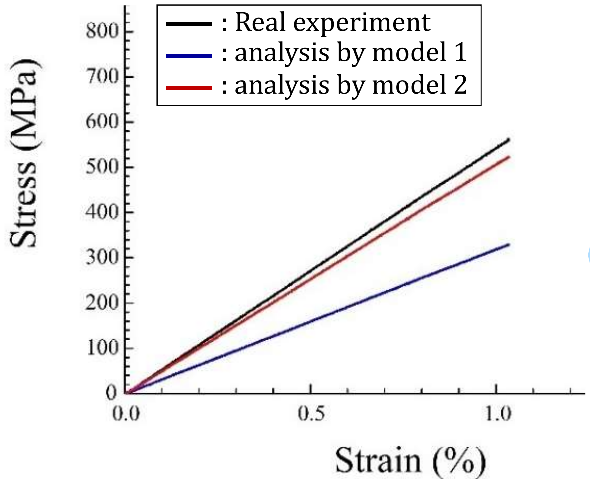


Model 1



Model 2

- Model 1
  - Modeled woven shape by sine curve function
  - Volume fraction is not accurate
- Model 2
  - Modeled based on geometrical parameter as a result of X-ray observation



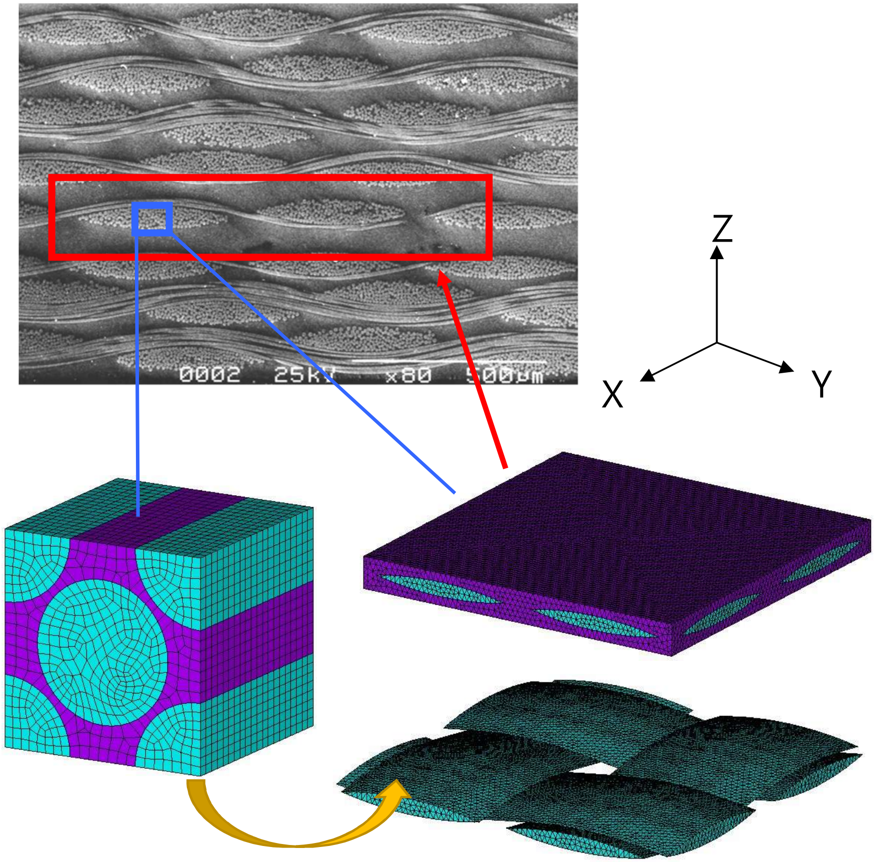
Validation

Autograph

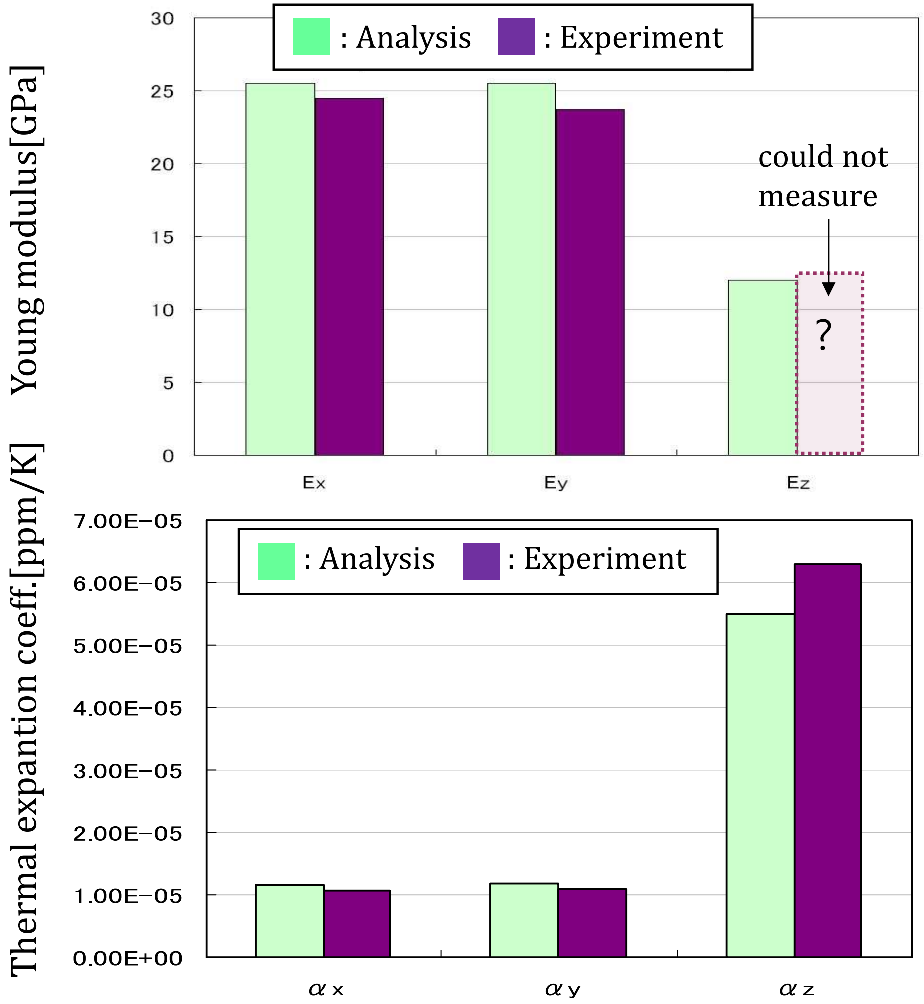
Precision universal tester

* Courtesy of Shimadzu corporation

- Grass cross used PCB and so on
- Evaluate elasticity and thermal expansion



Assigned equivalent material constants



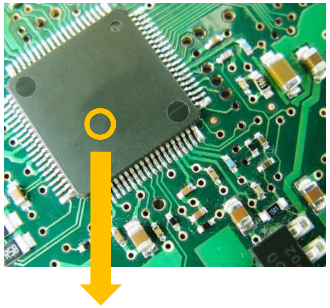
Courtesy of NITTO BOSEKI Co., Ltd.

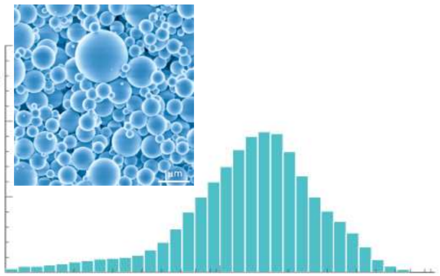
Filler dispersed composite

Sealing resin

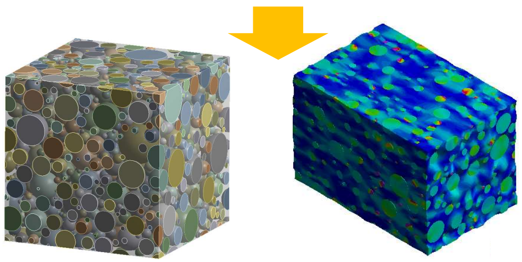
Material property is controlled by fillers

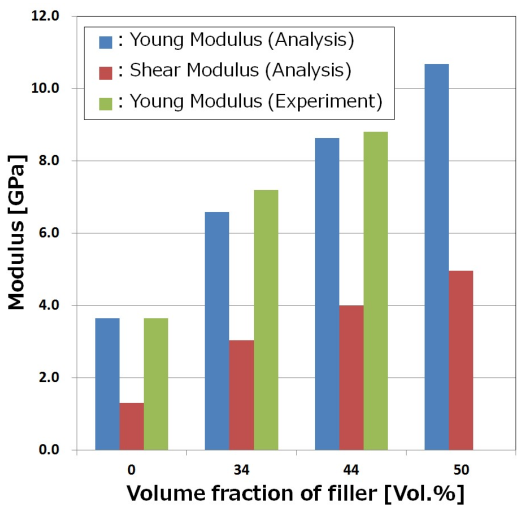
- Model
  - SiC filler + Epoxy resin
  - Spherical filler
  - Consider size distribution
- Homogenization
  - Elastic





Size distribution

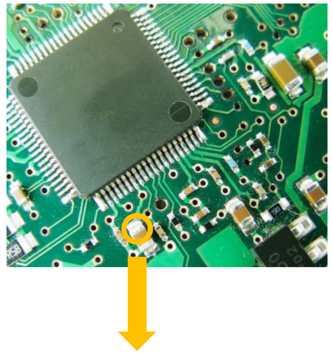


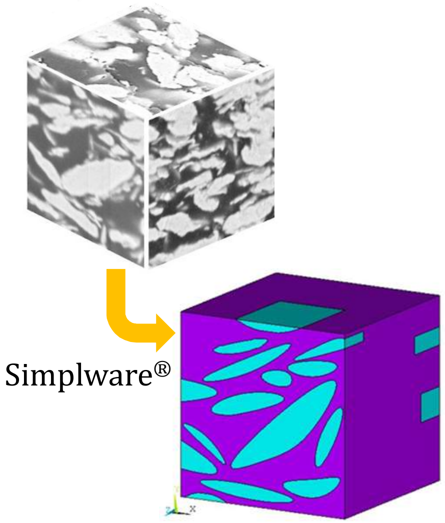


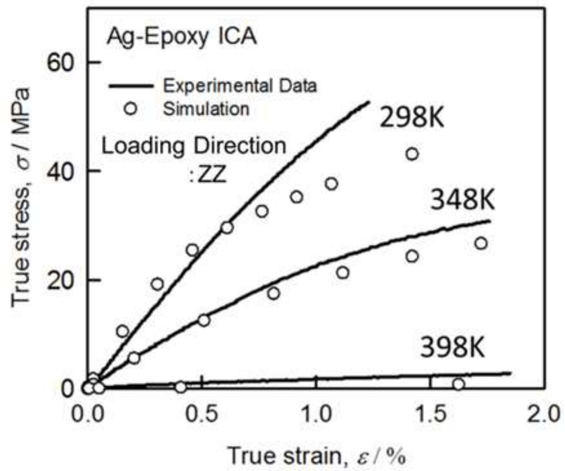
Conductive adhesive

Add Ag filler in matrix in order to achieve high conductivity

- Modeling
  - Ag filler + Epoxy resin
  - Complex filler's shape
  - Create by image base technique (Delete small parts)
- Homogenization
  - Elasto Plastic



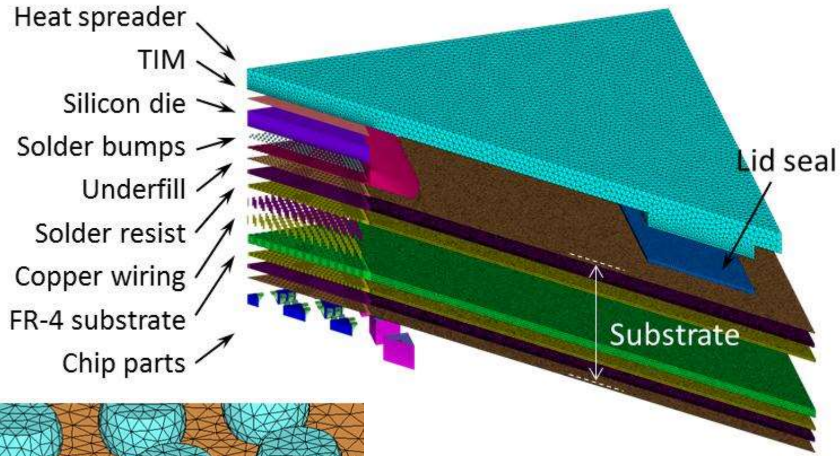


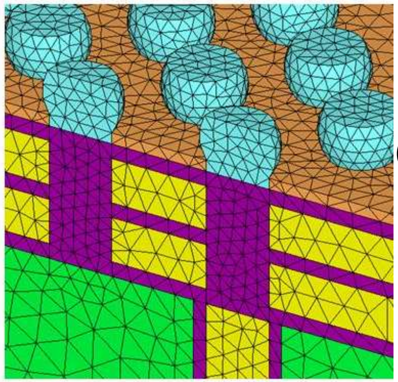


Semiconductor Package

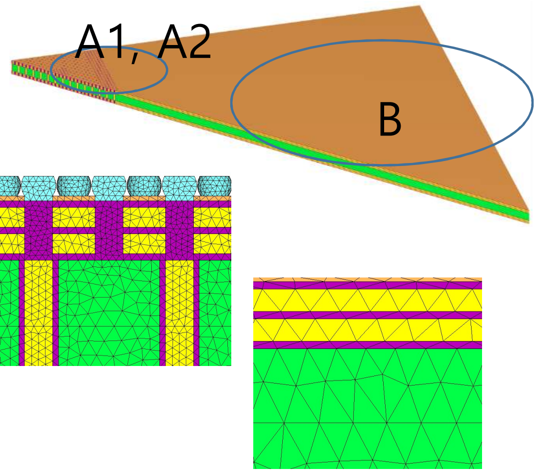
- Model
  Considering Cu wiring structure under the bump.

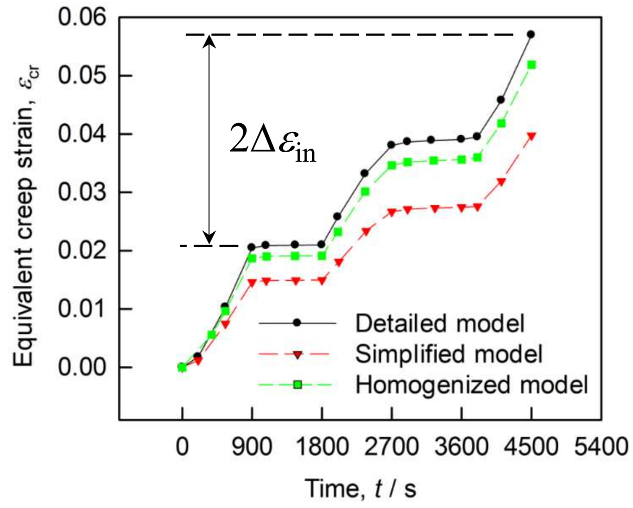
- Purpose
  Analyze the effect of wiring structure on the strain in bump.



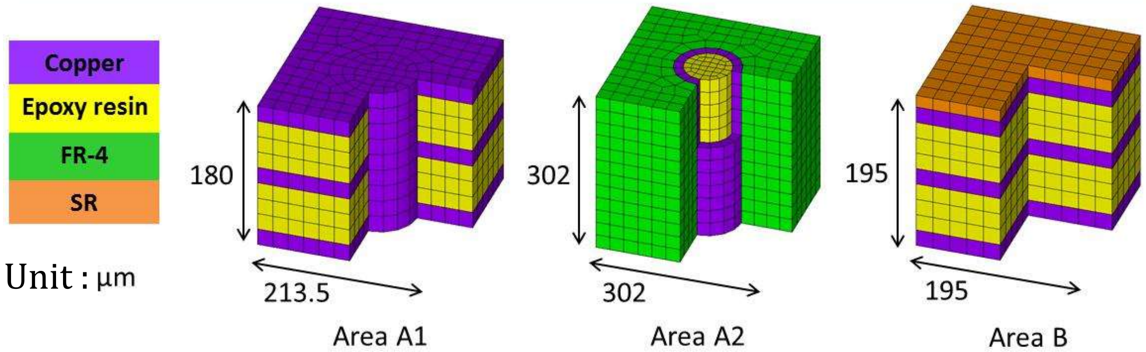


(About Ten million nodes)





Estimate anisotropic material constants at three point and replace homogenized model.

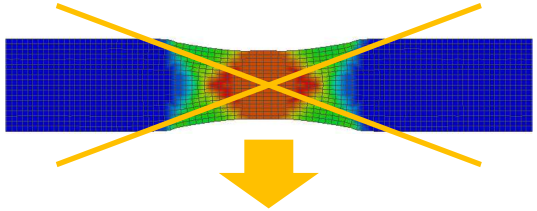


Summary

PCB is multi material product made by many composite.
It is important to prepare it's an-isotropic material constants.

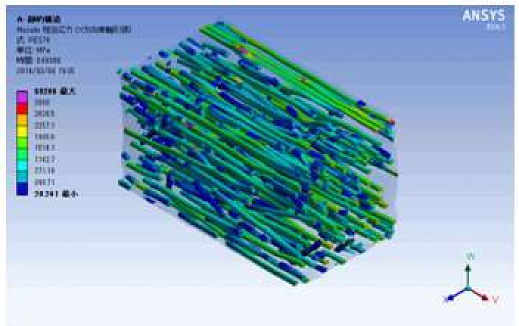
Multiscale analysis approach based on homogenization technique is quite effective.

Difficulties of real experiments
Making all deformation modes for identification of an-isotropic properties
Taking a long time to perform.



Homogenization analysis solution

- Micro Model Creation
  Many templates to create model automatically
- Numerical Material Test
  Available for any deformation modes and loading history
- Curve fitting
  Robust optimization algorithm to identify material constants



Good Material Database Leads Good Analysis

29th 태성에스엔이
CAE
Conference

Backup Slides

Simple examples for creep homogenization

29th 태성에스엔이 CAE Conference

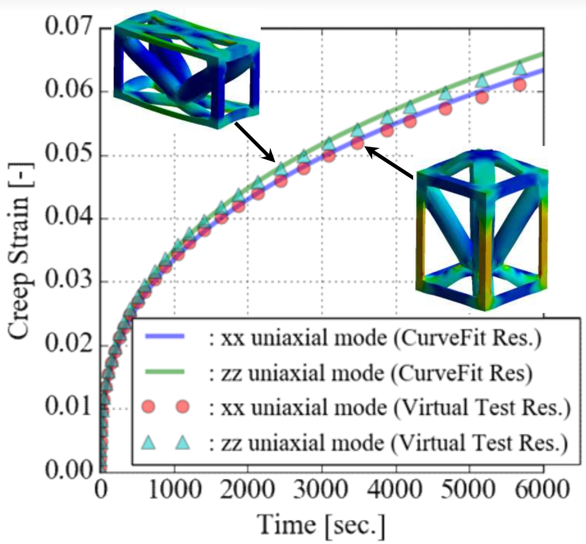
Multiscale creep analysis for lattice structure

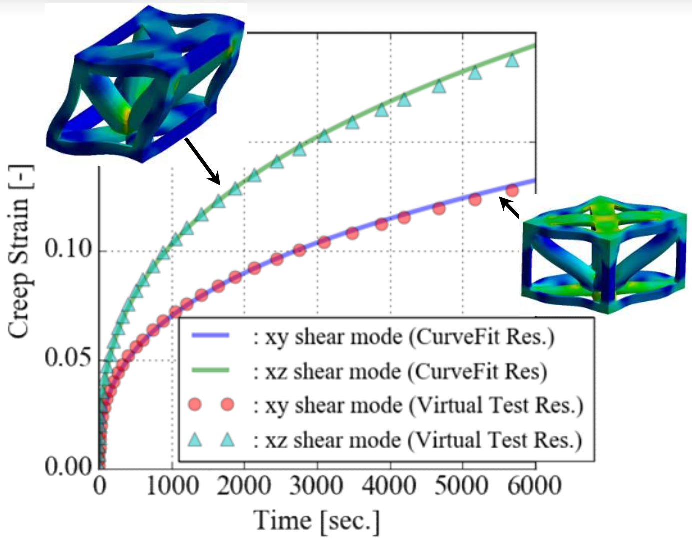
- **Creep homogenization analysis**
  - ➢ Virtual test for 6 modes
    - xx,yy,zz uniaxial modes
    - xy,yz,xz pure shearing modes
  - ➢ Curve fitting
    - PSO optimization
  - ➢ Macroscopic constitutive law
    - Time hardening & Hill's potential

$$\dot{\varepsilon}_{\mathrm{cr}} = \mathrm{C}_1 \sigma_{\mathrm{Hill}}^{\mathrm{C}_2} t^{\mathrm{C}_3} \exp\left(-\frac{\mathrm{C}_4}{T}\right)$$

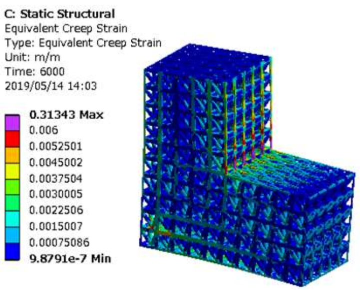
$$\sigma_{\mathrm{Hill}} = \left\{ F\left(\sigma_{\mathrm{yy}} - \sigma_{\mathrm{zz}}\right)^2 + G\left(\sigma_{\mathrm{zz}} - \sigma_{\mathrm{xx}}\right)^2 + H\left(\sigma_{\mathrm{xx}} - \sigma_{\mathrm{yy}}\right)^2 + 2N\tau_{\mathrm{xy}}^2 + 2L\tau_{\mathrm{yz}}^2 + 2M\tau_{\mathrm{xz}}^2 \right\}^{1/2}$$

- **Macro scale analysis**
  - Direct model is used for validation
  - Good correlation between 2 model.

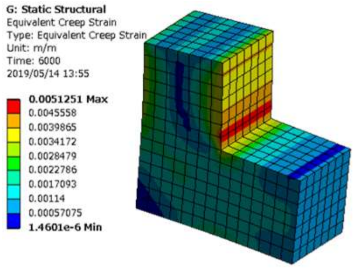




Creep behavior obtained virtual testing and the result of curve fitting

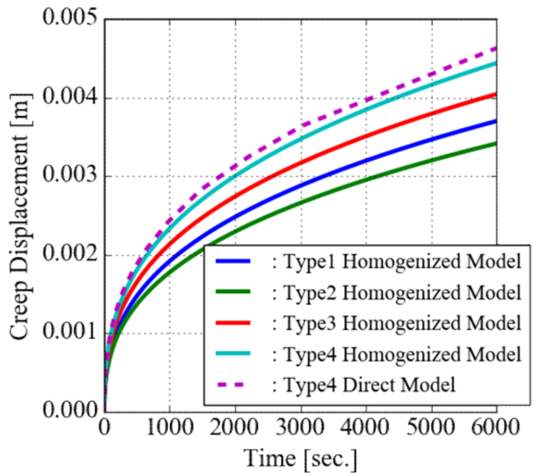


Direct Model
(Comput. Time=155 hours)



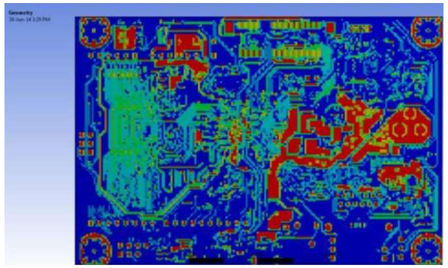
Homogenized Model
(Comput. Time=4 min)

Faster 2300 times

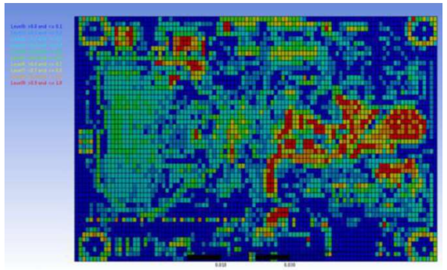


Trace Mapping vs. Homogenization

Trace Mapping



ECAD data



ECAD

- Mixing rule

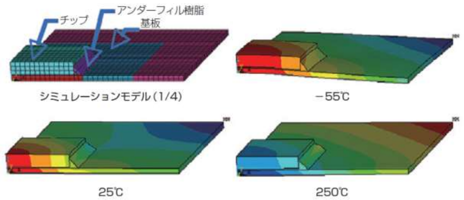
$$E_x^{\mathrm{eff}}, E_y^{\mathrm{eff}} = \frac{1}{\dfrac{f_s}{E_s} + \dfrac{f_u}{E_u} - \dfrac{f_s f_u (\nu_s E_u - \nu_u E_s)^2}{E_s E_u (f_s E_s - f_u E_u)}}$$

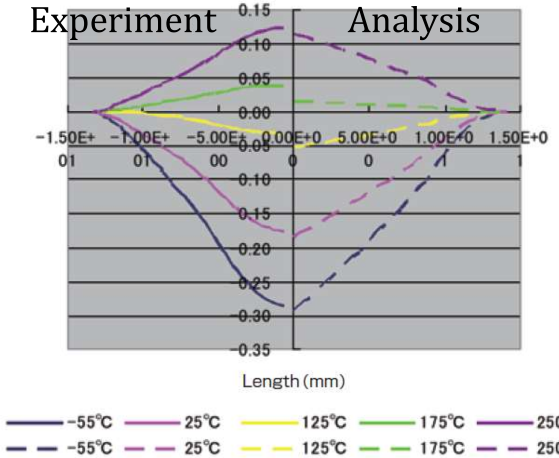
$$E_z^{\mathrm{eff}} = f_s E_s + f_u E_u \qquad \nu^{\mathrm{eff}} = f_s \nu_s + f_u \nu_u$$

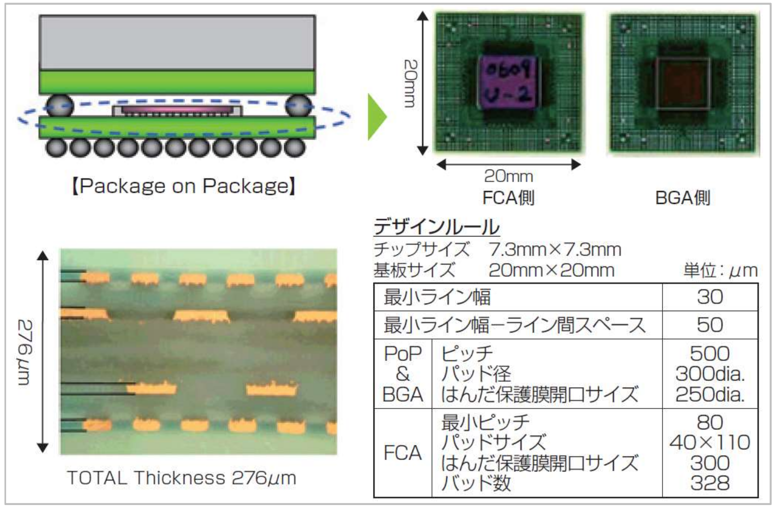
$$\alpha_z^{\mathrm{eff}} = \frac{f_s E_s \alpha_s + f_u E_u \alpha_u}{f_s E_s + f_u E_u}$$

$$\alpha_x^{\mathrm{eff}}, \alpha_y^{\mathrm{eff}} = (1 + \nu_u) + \alpha_u f_u + (1 + \nu_s)\,\alpha_s f_s - \alpha_z^{\mathrm{eff}} \nu^{\mathrm{eff}}$$

- Material property
  - Board : homogenized anisotropic CTE at 9 regions
  - UF : visco elastic property of UF
- Real experiment
  - DIC technique

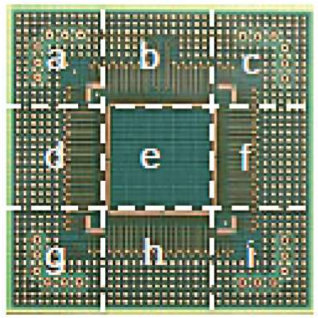






デザインルール
チップサイズ　7.3mm×7.3mm
基板サイズ　20mm×20mm
単位：μm

最小ライン幅		30
最小ライン幅ーライン間スペース		50
PoP & BGA	ピッチ パッド径 はんだ保護膜開口サイズ	500 300dia. 250dia.
FCA	最小ピッチ パッドサイズ はんだ保護膜開口サイズ パッド数	80 40×110 300 328



エリア	
α1	α2

X direction (ppm/℃)

a		b		c	
18.7	14.8	15.4	13.2	17.5	11.6
d		e		f	
15.4	13.2	15.3	17.6	17.2	14.8
g		h		i	
14.0	12.8	17.2	12.4	17.6	12.8

Y direction (ppm/℃)

a		b		c	
18.5	12.8	16.0	11.2	16.1	11.2
d		e		f	
17.8	12.8	16.6	18.8	16.8	14.8
g		h		i	
17.0	12.0	17.2	13.2	15.4	20.4