西门子复合材料制造工艺仿真

叶枭 SIEMENS STS复合材料工程师

Realize innovation.

制造工艺仿真

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Ingenuity for life

高性能复合材料制造工艺

复合材料制造工艺（DFM）

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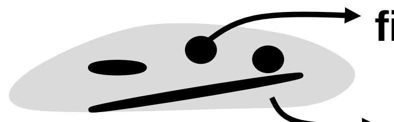
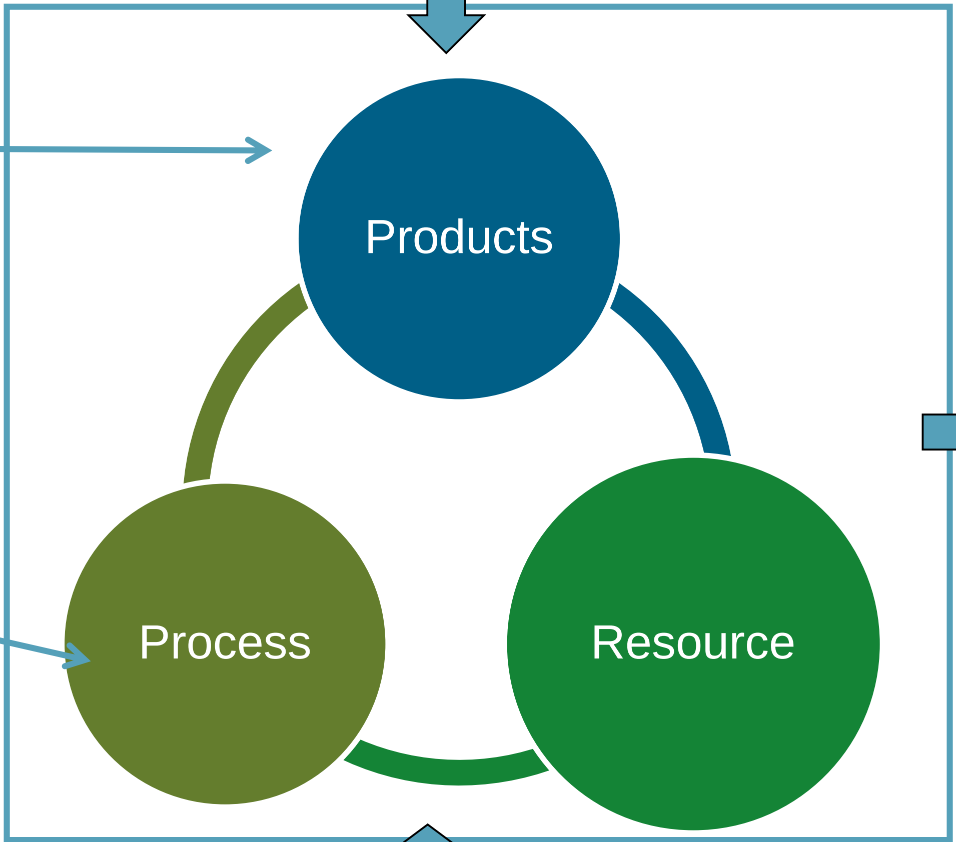
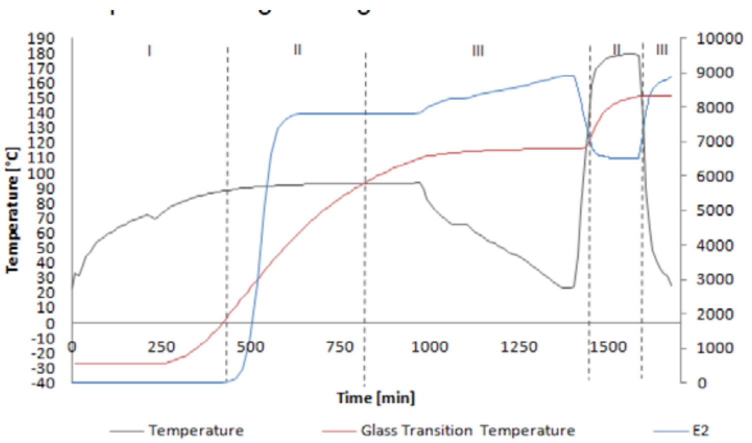
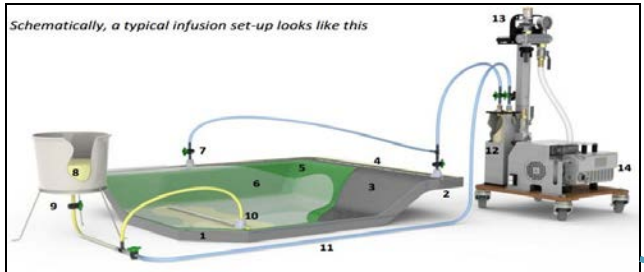
Context: extended enterprise, integrated production design, ...
Objectives: technological traceability, accuracy, global optimization
Constraints: pertinence, accuracy, responsiveness

Products: function, structure, material, shape, tolerance









Process : resin infusion molding, pre preg autoclave, filament winding, Compression (SMC, BMC)

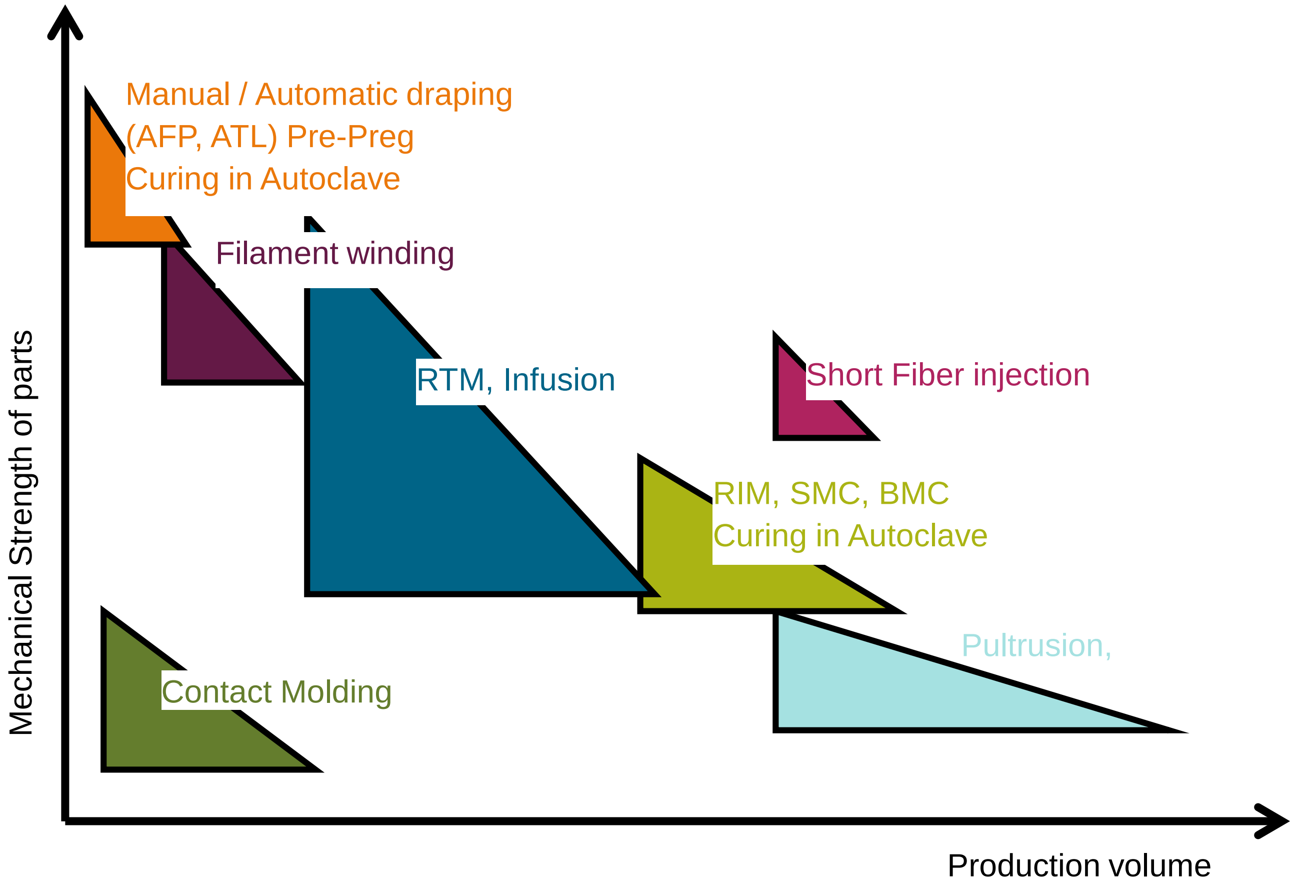
Manufactural part
Manufacturing Process
Cost
Manufacturing facility
Qualification process

Model, Method, tools : simulation, tests, …

如何选择制造工艺

- Manufacturing method
  - Time
    - Production volume
    - Conception time
      - Consistent performance and processing characteristics
  - Performance
    - Mass
      - Weight Saving
        - Weight / performance ratio
    - Mechanical performance
      - Fatigue, tensile, Stiffness
      - Corrosion
      - Good ageing
      - Repair
  - Cost
    - Cost of material
    - Tooling costs
      - Investment cost
      - Fabrication cost (energy consumption,…)

如何选择制造工艺



COURS pour Formation Doctorale GdR MIC

高性能结构复合材料制造工艺(固化)流程

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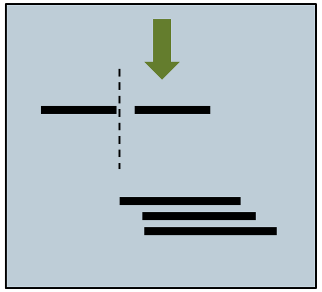
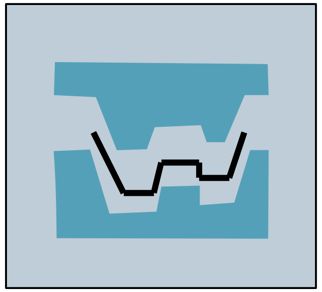
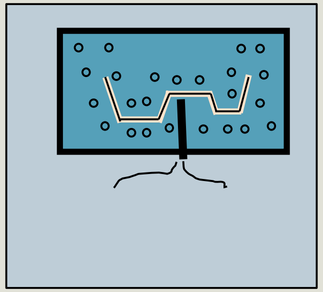


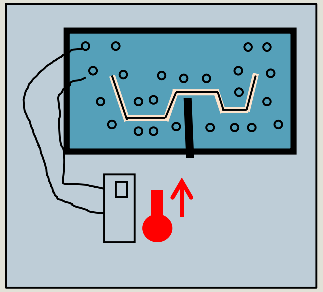
Preparation of textile



Draping + Form

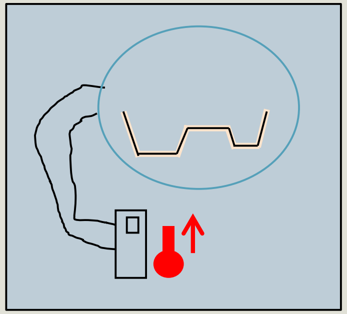


Resin Flow

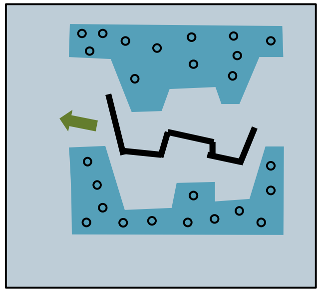


In tools

CURING

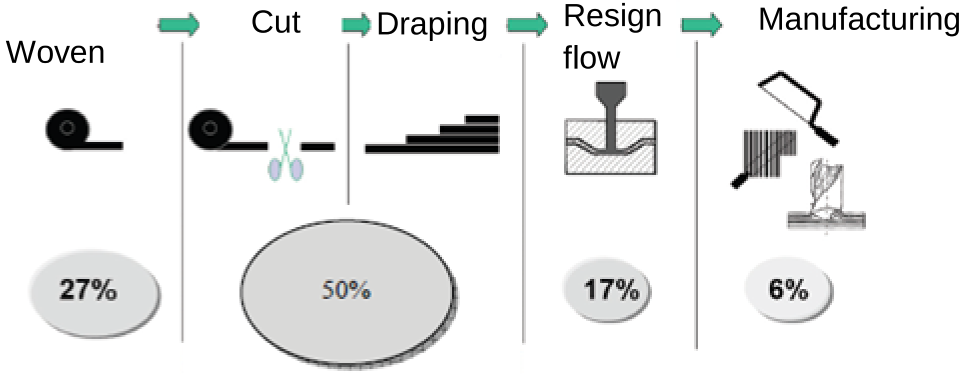


In autoclave



De-molding

Cost by operation



Source : [OGA06]. A. Ogale, P. Mitschang, R. Schmidt, « Implementation of preform-LCM process chain for the manufacturing of rotor hub and shaft combination », Proceedings, 27th International Symposium on Materials Science, Roskilde, Denmark, p. 271-278, 2006.

制造工艺仿真

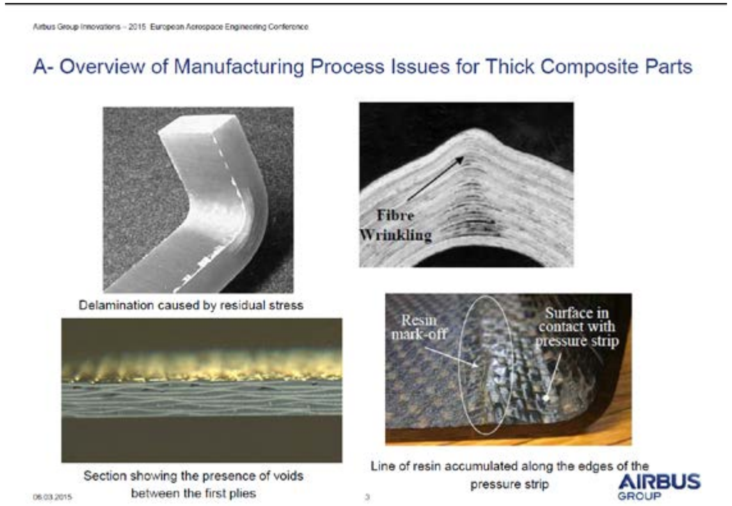
制造工艺仿真 – 目的

Firstly :

- Check manufacturability
- Determination of process induced deformations (dimensional accuracy)
- Evaluation of the effects of residual stress (structural analysis)

Next :

- Process optimization / Compare manufacturing options :
  - Curing Cycle,
  - Stacking definition (material, thickness, orientation)
  - Design
  - Mold (design, material, tools)
- Process control



Profits :

Production support – process for a robust design

Optimization of the process

Control on potential dimensional (for assemblies)

制造工艺仿真 – 获得结果

Prediction of with time history

- Internal stresses during curing
- Deformation during curing
- Temperature distribution,
- Degree of cure

- Residual stresses after de-molding
- Deformation after de-modeling

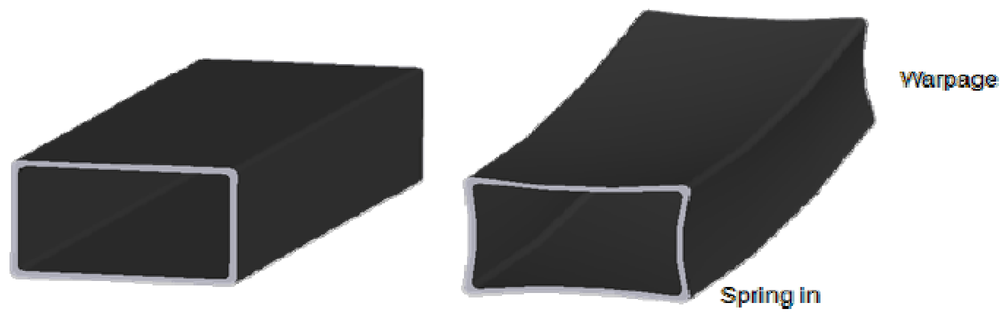
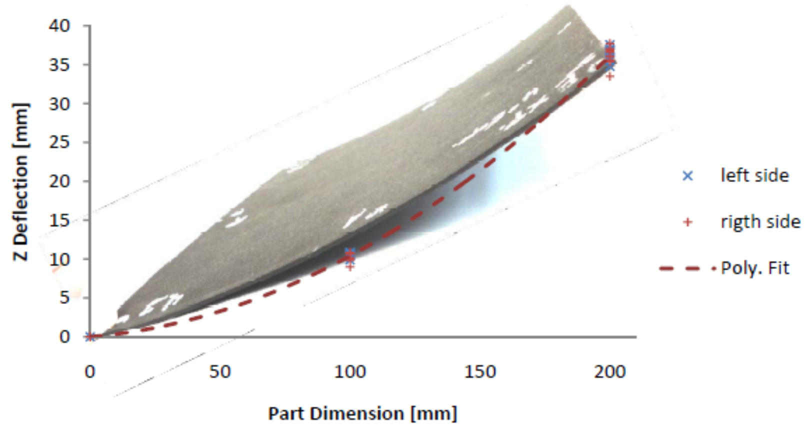


Figure 5 Deformed box structure due to a thinner upper side

Source:
Thesis : Analysis of process-induced distortions and residual stresses of composite structures
University of Bremen (GE)
Christian Brauner



Take into account

- Material history during curing process (temperature and degree of cure)
- Thermal and Mechanical interaction with the mold

Assesement:

- Mounting tolerances, dimensions of tool

西门子制造工艺仿真整体解决方案

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复材构件

Siemens PLM Software
Fibersim

真实纤维朝向

模具数模

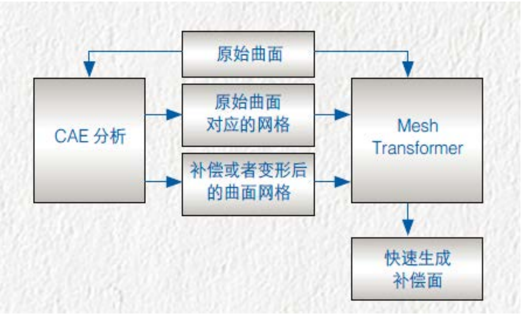
Siemens PLM Software
Samcef

- Cure kinetic model
- Matrix properties
- Homogenization (orthotropic UD)

材料热化学/力学属性

力学边界条件（接触）

Siemens PLM Software
Thermal / Flow



residual stresses
deformed geometry
(spring-in / spring-out)

Siemens PLM Software
NX morphing

西门子制造工艺仿真整体解决方案

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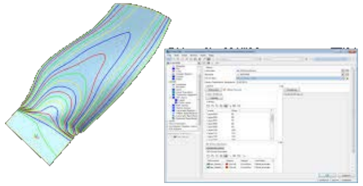
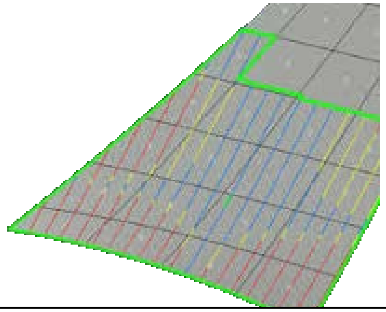
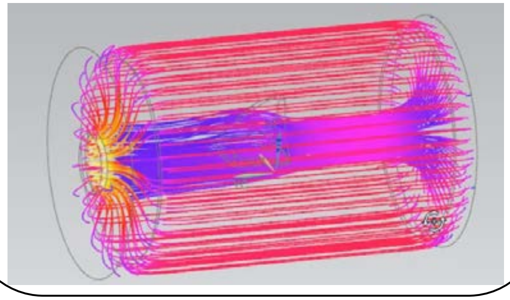
Composite Part

Compute the fiber orientation

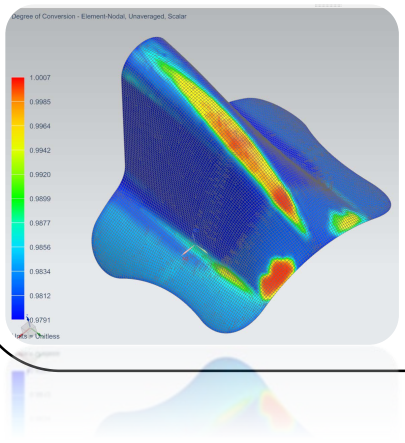


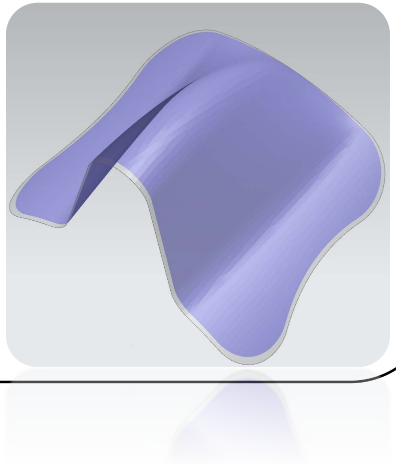


Compute Thermal / Flow

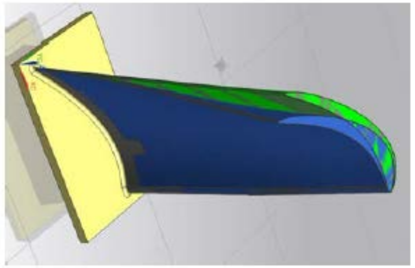


Compute the deformed stage & stress state

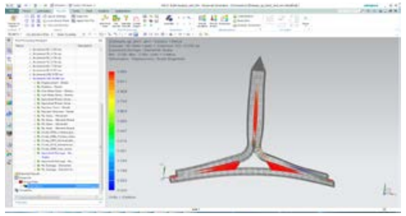




Update the CAD



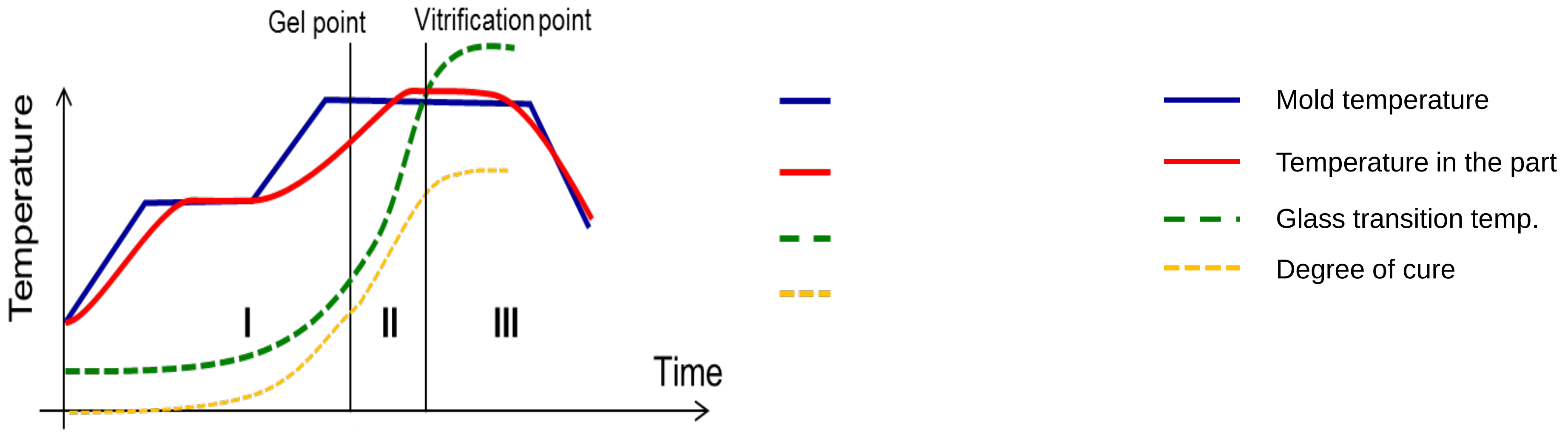
Design as manufactured



热分析

固化过程热分析

Thermal modeling: evolution of temperatures, degree of cure, T_g over time and space



gelation
$X \geq X_{gel}$

glass transition
$T_g(X) \geq T$

UNCURED RESIN

Purely viscous →

no load
no residual stress

I. LIQUID

Visco-elastic →

stress generation
but relaxation

II. RUBBERY

Elastic →

linear
behavior

III. GLASSY

FULLY CURED RESIN

热模型

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Thermal initial-boundary value problem:

$$\rho \frac{\partial (c\,T)}{\partial t} = -\frac{\partial}{\partial x_i}\left(-k_{ij}\frac{\partial T}{\partial x_j}\right) + \boldsymbol{q}$$

Internal heat generation:

$$\boxed{q = \rho H_{TOT}\frac{\partial \boldsymbol{X}}{\partial t}\left(1 - M_f\right)}$$

Degree of conversion (degree of cure):

$$0 \leq \boldsymbol{X}(\boldsymbol{t}) = \frac{H(t)}{H_{TOT}} = \int_0^t \dot{X}\,dt \leq 1$$

固化动力学模型

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Cure kinetic models in SAMCEF

$$\boxed{\dot{X}(t) = f(X, T)}$$

- **n-order**

$$\dot{X} = k\,(1 - X)^n \qquad k(T) = A\exp\left(-\frac{E}{RT}\right)$$

- **autocatalytic**

$$\dot{X} = k\,X^m(1 - X)^n \qquad k(T) = A\exp\left(-\frac{E}{RT}\right)$$

- **Kamal & Sourour**

$$\dot{X} = (k_1 + k_2\,X^m)\,(1 - X)^n \qquad k_i(T) = A_i\exp\left(-\frac{E_i}{RT}\right)$$

- **Lee, Chiu & Lin**

$$\dot{X} = k_1(1 - X)^{n_1} + k_2\,X^m(1 - X)^{n_2} \qquad k_i(T) = A_i\exp\left(-\frac{E_i}{RT}\right)$$

- **Lee, Loos & Springer**

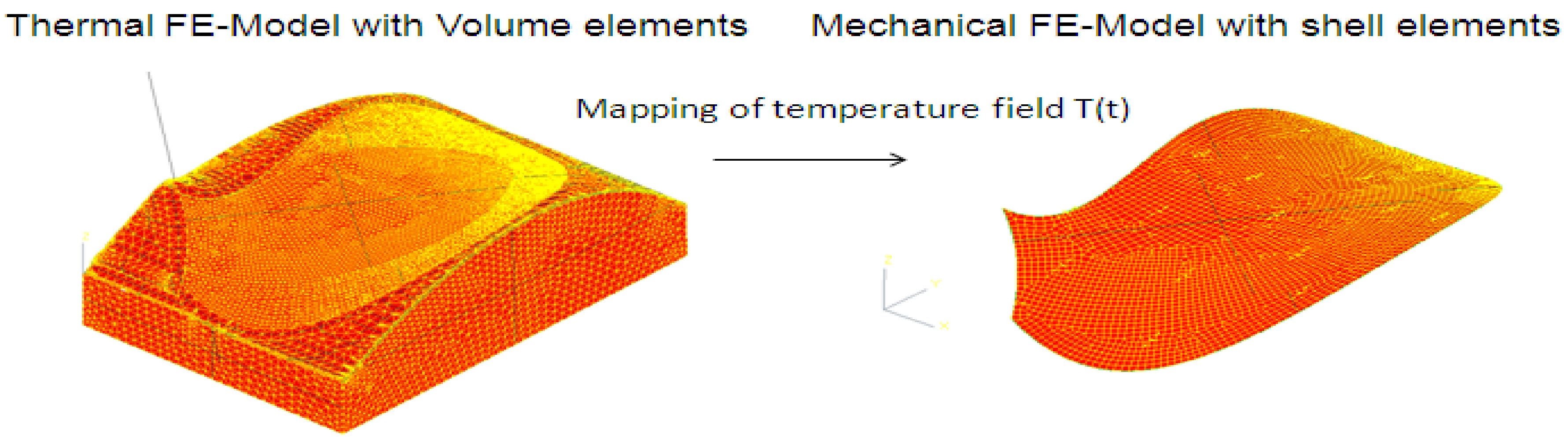
$$\dot{X} = \begin{cases} (k_1 + k_2\,X)(1 - X)(B - X) & \forall T \le X_C \\ k_3(1 - X) & \forall X > X_C \end{cases} \qquad k_i(T) = A_i\exp\left(-\frac{E_i}{RT}\right)$$

- **User-defined**

映射分析

映射分析

Simulation strategy : Sequential coupled thermo mechanical analysis



Advantages of sequential coupling:

- Dependency from thermal to mechanical but not reverse
- Less CPU time
- Flexible coupling, possibility to use different discretization / mesh

力学分析

固化过程力学分析

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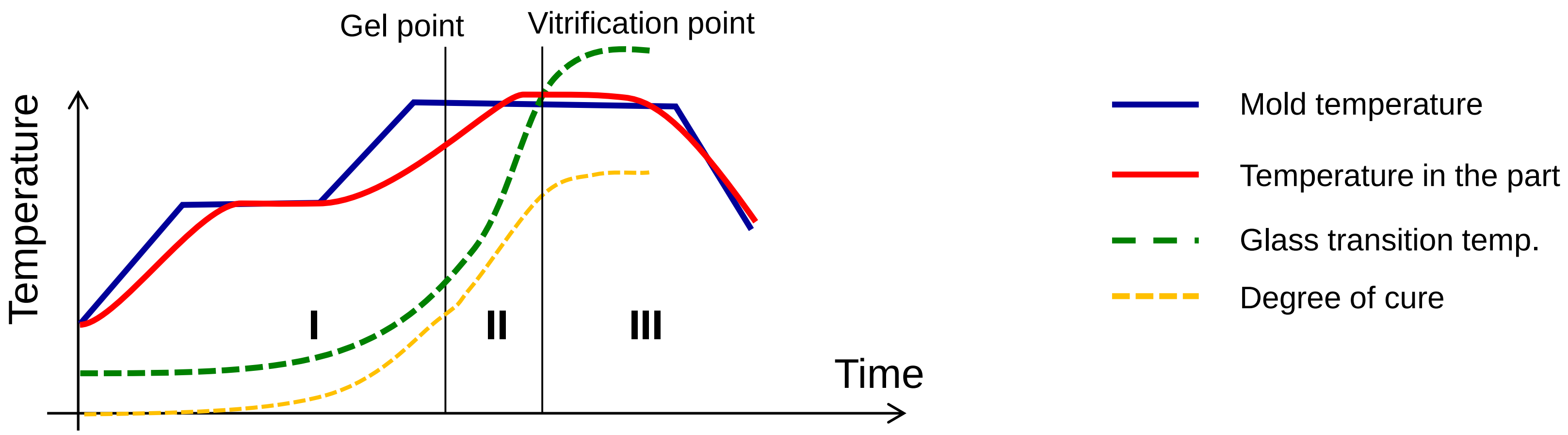
Mechanical modeling: evolution of mechanical properties of the matrix during curing



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固化力学分析流程

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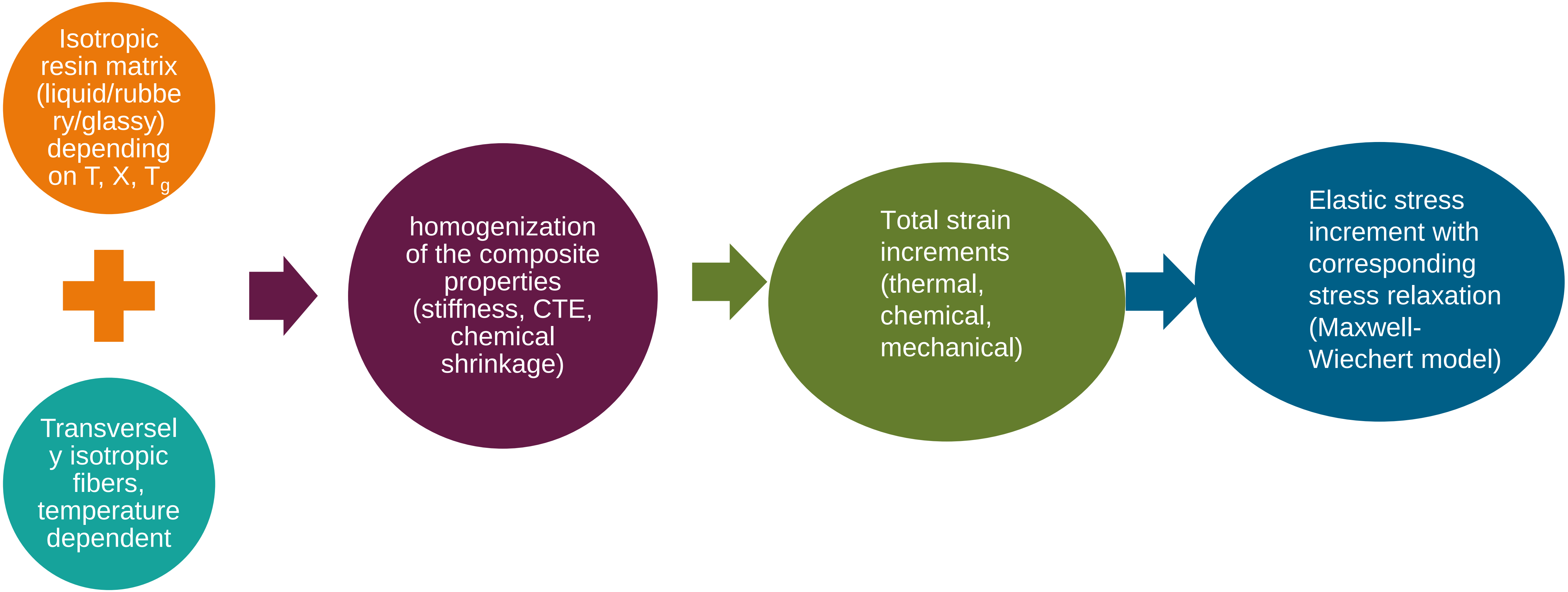
Computation at each Gauss point:



材料参数识别

固化分析所需材料参数

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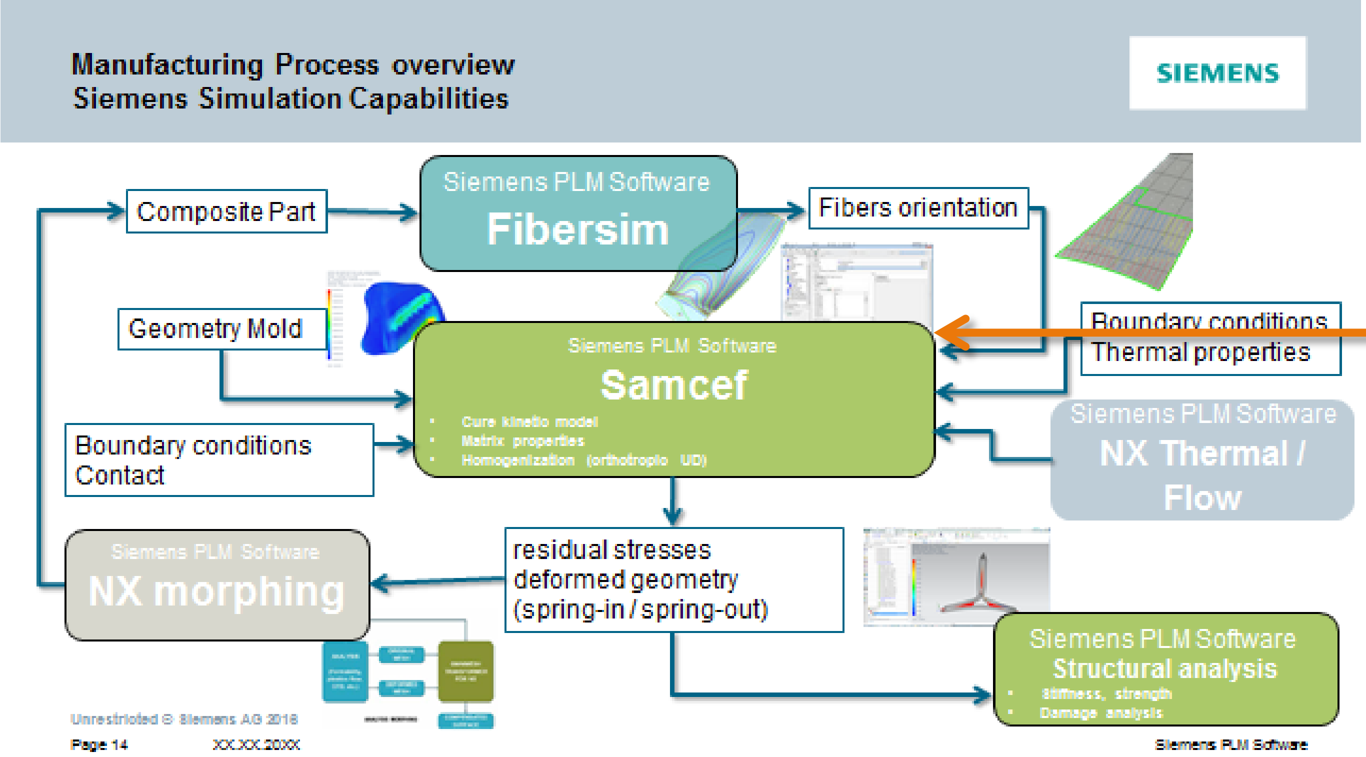


Material properties to support the simulation process :

- Thermo-chemical characterization
  - Kinetic of the curing reaction
  - Characterization of the specific heat
  - Characterization of the glass transition temperature
  - Volumetric characterization
- Rheological characterization
- Thermo-mechanical characterization (to different material state)

Some properties are provided by material suppliers but not all as requested

Some parameters are already available on research communities

基本热物理属性测定方法

Differential Scanning Calorimetry (DSC)

- allows to obtain the evolution of the degree of curing depending on the temperature
- obtain the evolution of Tg according to the degree of curing,

Dynamic Mechanic Analysis

- Allow to obtain the evolution of Young modulus according the curing cycle

Traction test to different temperature

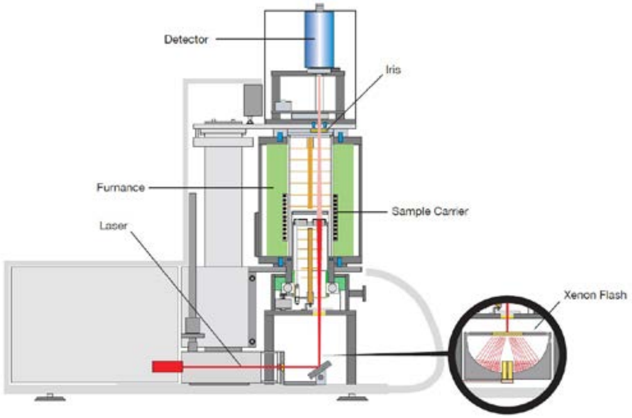
- Measuring the coefficient of thermal expansion

Thermo mechanical analysis (TMA)

- measuring the expansion of a sample as a function of the temperature cycle

Laser Flash, Rheometer, DTMA,, …

- Conductivity parameters



西门子材料参数识别解决方案

Assist for tests definition

- Protocol for material testing (few standard tests, but specific stacking sequences)
- Transfer of technology

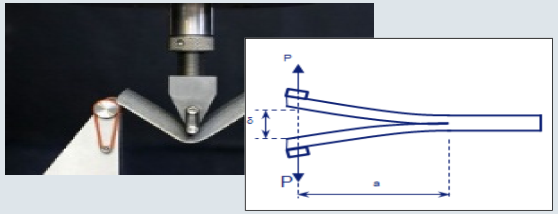
Guide through parameter identification

- Parameter identification (based on standard software; simple procedure)
- Transfer of technology

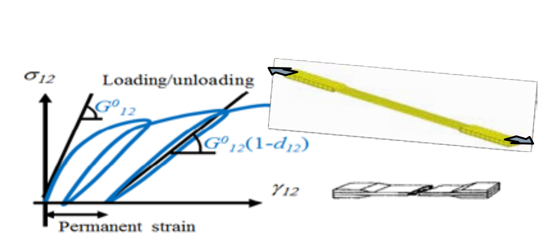
Curing analyses

- Support the virtual testing

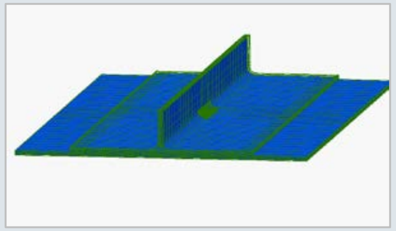
Test protocol



Parameter identification



FE Composite Modelling

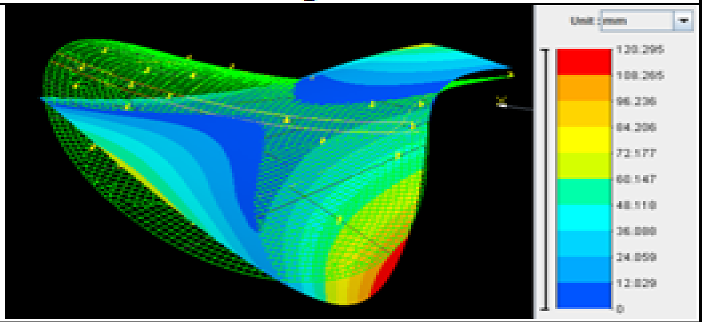
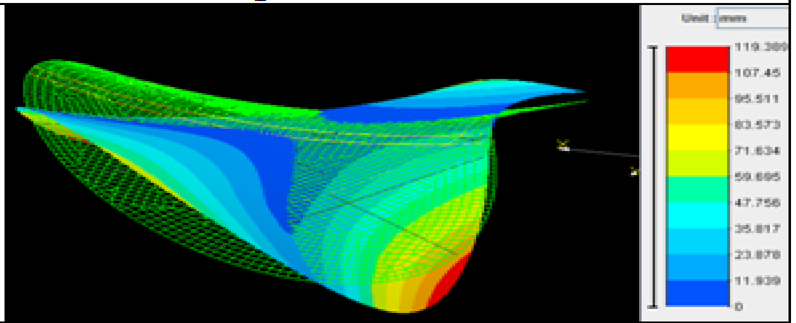
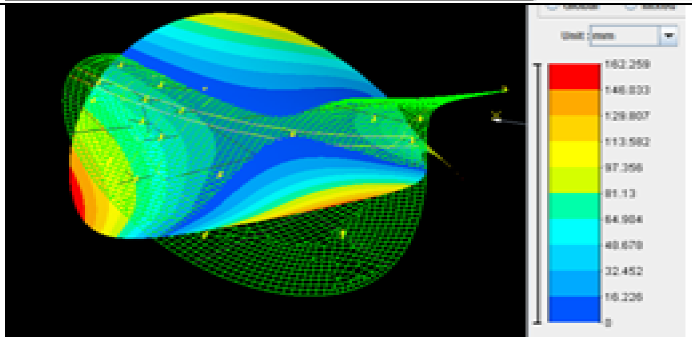
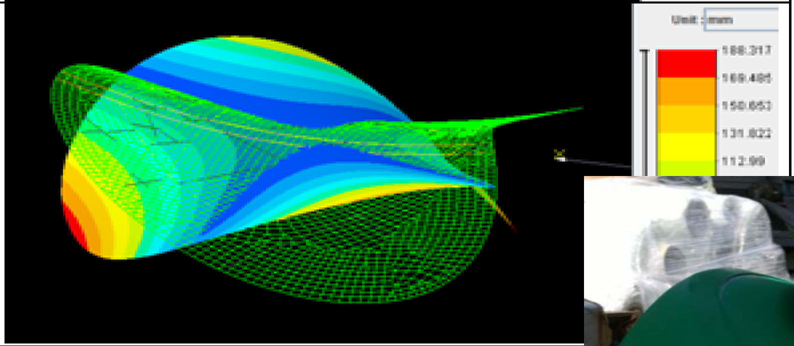


成功案例

船用双曲面螺旋桨叶片

Mechanical analysis

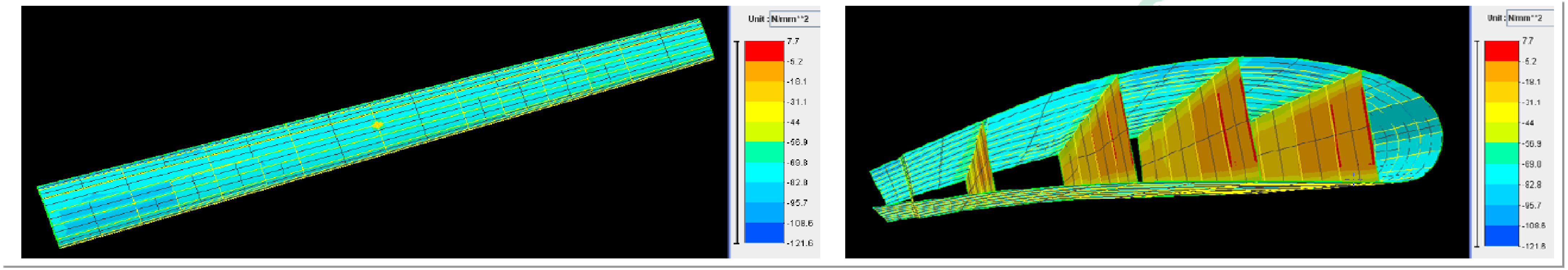
e.g. distortion of “As-planned” and “As-build” structures

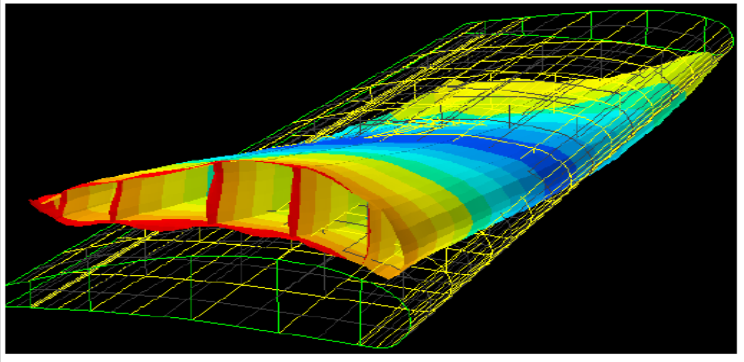
	“As Planned” Configuration	“As Build” Configuration
After first curing phase at 95°C		
After second post curing phase at 180 °C		

大型飞机机翼

- Use case 2: flap (4m long)

FASERINSTITUT FIBRE BREMEN

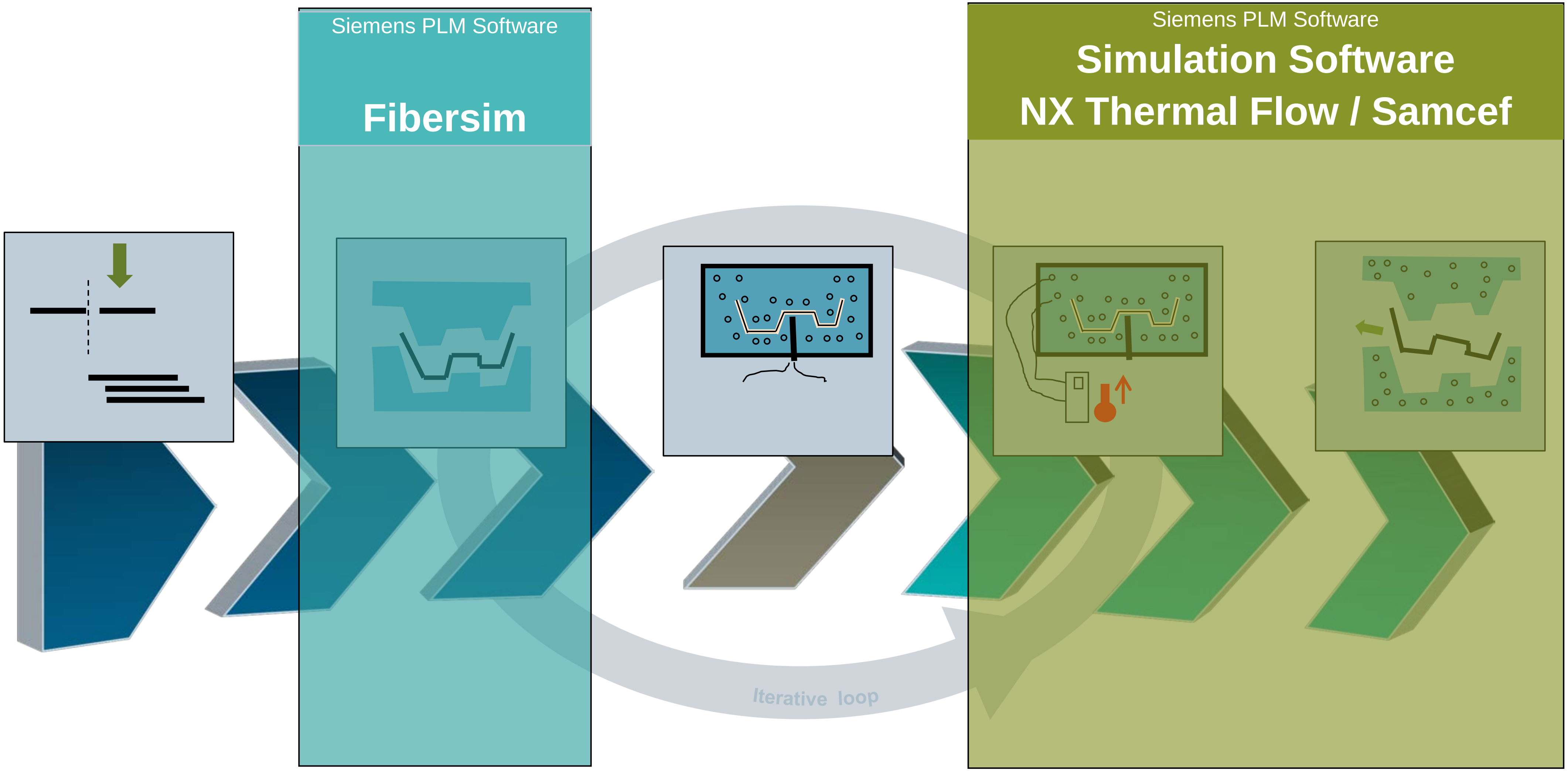




Shape distortion resulting from the curing

结论

Manufacturing Process overview
Siemens Solution



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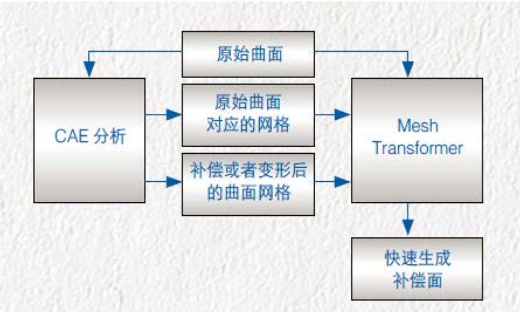

residual stresses
deformed geometry
(spring-in / spring-out)

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