FE-Analysis of Shape Distortions in Composites

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SICOMP AB

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Swedish Institute for Composites

is a Non profit Research Organization located in Sweden
with focus on:

Processing and Design of Composites

SICOMP in brief

Research and development within the filed of polymer composites

Research areas are:

- ✓ Material science (polymer chemistry, analyses, characterisation)
- ✓ Mechanics (design, calculations, simulations)
- ✓ Damage tolerance
- ✓ Process technology
- ✓ Natural fibre composites
- ✓ Product development and prototype manufacturing

Offering our customer:

- ✓ Membership in R&D Programmes
- ✓ Consultancy work
- ✓ Courses, seminars and conferences
- ✓ Technical transfer through papers, lectures, report and magazines

23 employees

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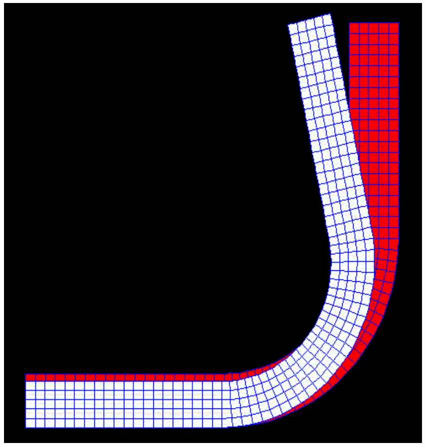
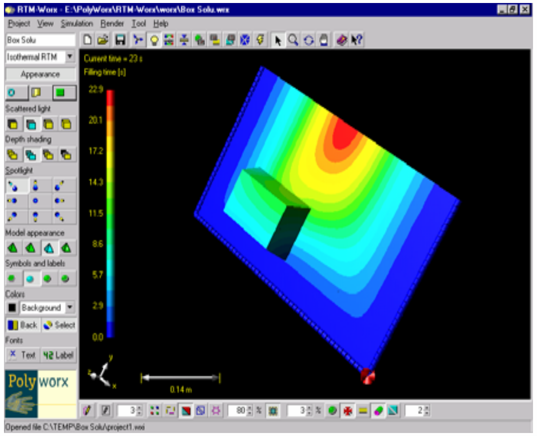
Mechanics group
- Process mechanics



Development of process models

- ✓ Mould filling/consolidation
- ✓ Curing/crystallisation
- ✓ Residual stresses
- ✓ Shape distortions

Process simulation



- ✓ Liquid composites moulding
- ✓ (RTM, VARI)
- ✓ Compression moulding
- ✓ (SMC, GMT)
- ✓ Filament winding

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FE-analysis of Shape Distortions in Composites

Outline

- Introduction
- Mechanical constitutive relation
- Shape distortion of a angle bracket
- Examples of possible benefits by using cure simulations
- Industrial use of cure simulations

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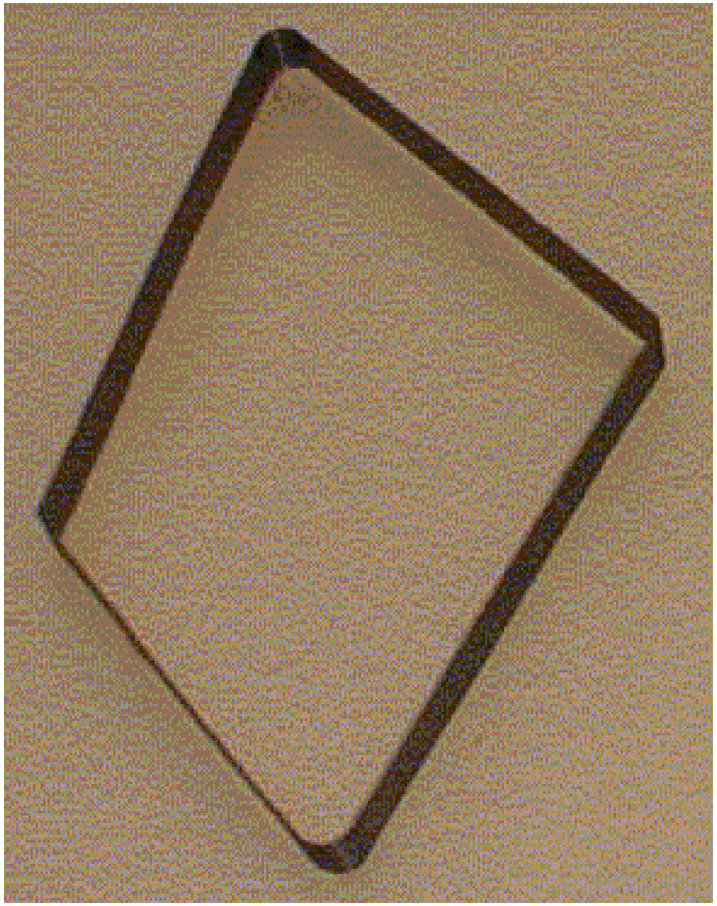
Release of residual stresses forming shape distortions



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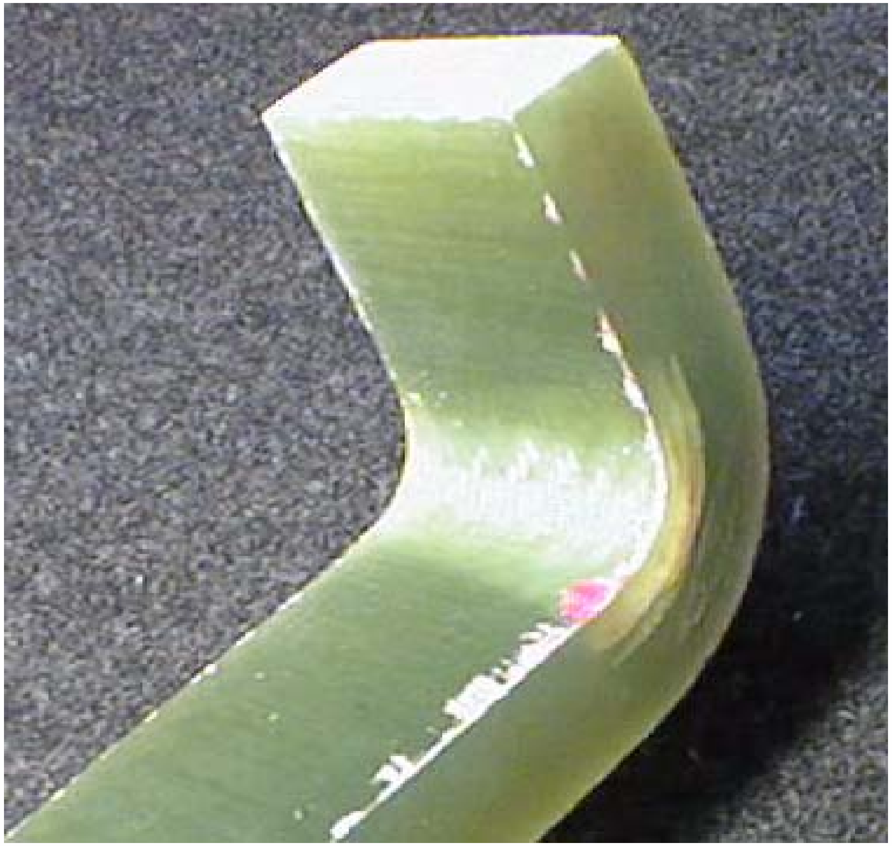
Problems due to residual stresses



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Our goal

Develop and validate simulation tool and methodology for use in product development of composites

- ✓ Sufficiently accurate
- ✓ Reasonable requirements on material and process characterisation
- ✓ Reasonable requirements on computer resources

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Mechanical constitutive relations

Linear elasticity

- ✓Incorrect representation of rubber to glass transition

Incremental elasticity

- ✓Incorrect representation of glass to rubber transition

Viscoelasticity

- ✓Realistic material description
- ✓Expensive material characterisation
- ✓Large requirements on computer resources

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Mechanical constitutive relation

Thermo-rheologically simple visco-elasticity

$$\sigma(t) = \int_0^t C(\xi - \xi') \frac{\partial\left(\varepsilon - \varepsilon^E\right)}{\partial \tau} d\tau$$

Relaxation modulus

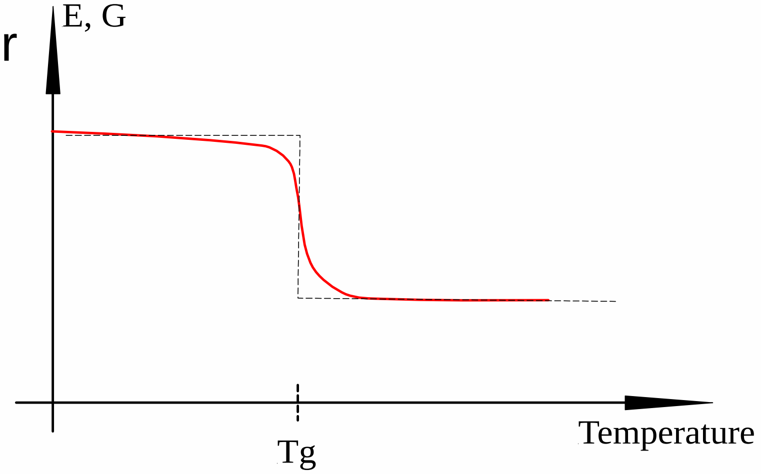
$$C(t) = C^\infty + \sum_{p=1}^{P} C^p \cdot \left(e^{\frac{-t}{\rho^p}} \right)$$

Reduced time

$$\xi = \int_0^t \frac{1}{a_T} dt'$$

Approximation of the shift factor

$$a_T = \lim_{\omega \to 0} \begin{cases} \omega & , T \geq T_g\left(X\right) \\ \dfrac{1}{\omega} & , T < T_g\left(X\right) \end{cases}$$



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Mechanical constitutive relation

Total strain formulation

$$\boldsymbol{\sigma}=\begin{cases}\mathbf{C}^r\left(\boldsymbol{\varepsilon}-\boldsymbol{\varepsilon}^E\right) & , T\geq T_g\\ \mathbf{C}^g\left(\boldsymbol{\varepsilon}-\boldsymbol{\varepsilon}^E-\boldsymbol{\varepsilon}^F\right) & , T<T_g\end{cases}$$

$$\boldsymbol{\varepsilon}^F=\left(\mathbf{1}-\left(\mathbf{C}^g\right)^{-1}\mathbf{C}^r\right)\left(\boldsymbol{\varepsilon}-\boldsymbol{\varepsilon}^E\right)\Big|_{t=t_{vit}}$$

Incremental formulation

$$\Delta\boldsymbol{\sigma}=\begin{cases}\mathbf{C}^r\left(\Delta\boldsymbol{\varepsilon}-\Delta\boldsymbol{\varepsilon}^E\right)-\mathbf{S}(t) & , T\geq T_g\\ \mathbf{C}^g\left(\Delta\boldsymbol{\varepsilon}-\Delta\boldsymbol{\varepsilon}^E\right) & , T<T_g\end{cases}$$

$$\mathbf{S}(t+\Delta t)=\begin{cases}0 & , T\geq T_g\\ \mathbf{S}(t)+\left(\mathbf{C}^g-\mathbf{C}^r\right)\cdot\left(\Delta\boldsymbol{\varepsilon}-\Delta\boldsymbol{\varepsilon}^E\right) & , T<T_g\end{cases}$$

Expansional strains

$$\boldsymbol{\varepsilon}^E=\boldsymbol{\varepsilon}^T+\boldsymbol{\varepsilon}^C=\int_0^t\boldsymbol{\alpha}(T,X)\frac{dT}{dt'}dt'+\int_0^t\boldsymbol{\beta}(T,X)\frac{dX}{dt'}dt'$$

Mechanical constitutive relation

Minimum requirements

- Thermal expansion
- Chemical shrinkage
- Phase transitions
  - ✓ Stiffness changes
  - ✓ Expansion coefficient changes
  - ✓ Frozen-in deformations
- Explicit time dependence not necessary

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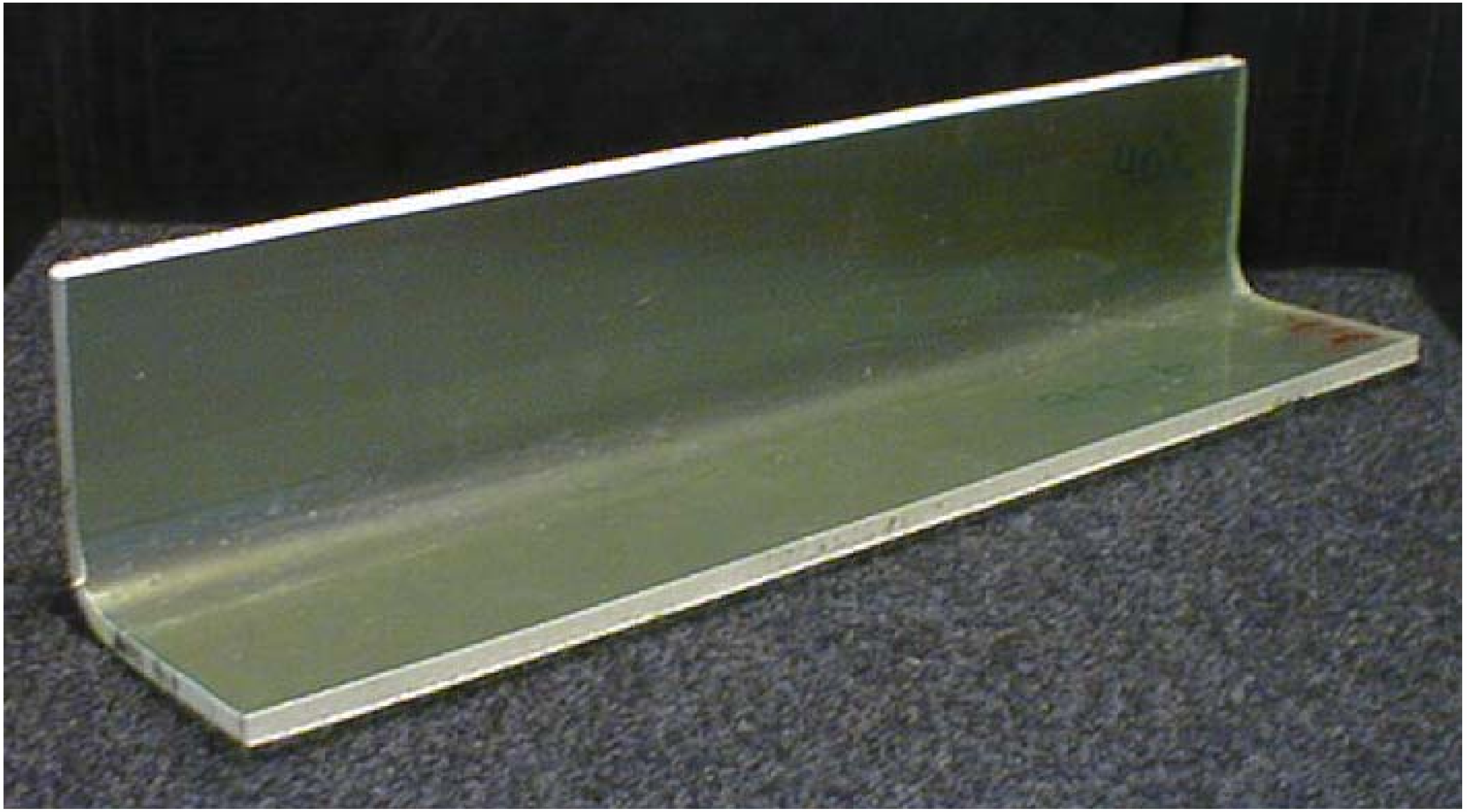
Shape distortion of a angle bracket



Material
Epoxy, ®Araldite LY5052 / Hardener HY5052
Glass weave, Hexcel 7781-127
Fibre fraction 49% by volume

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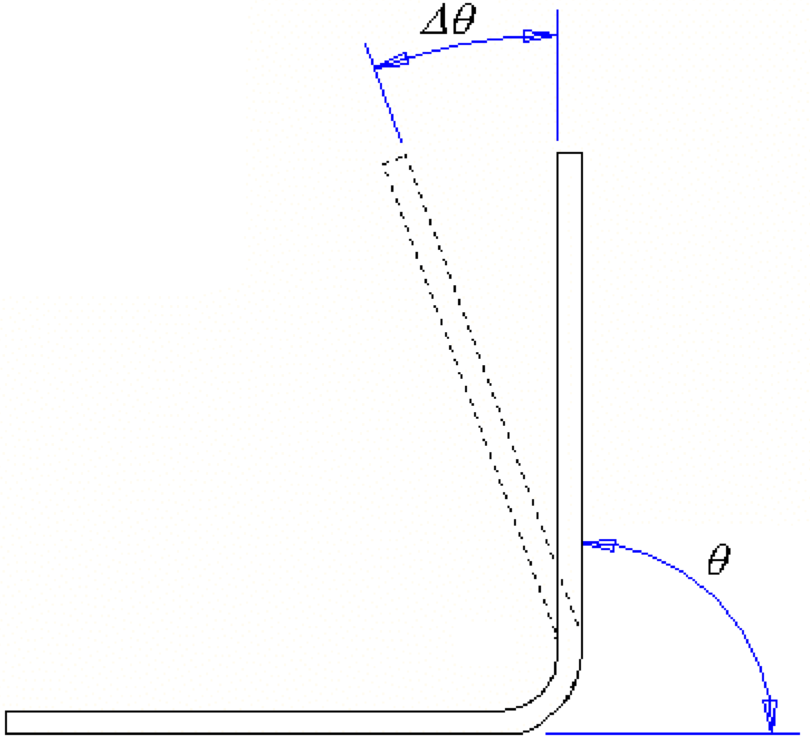
Shape distortion of a single curved composite component

Spring-in



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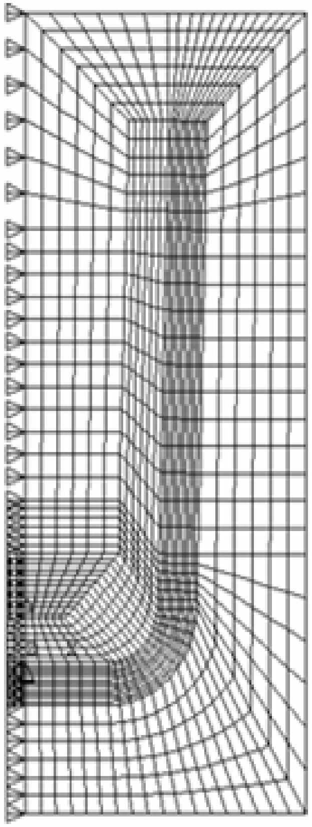
Simulations – FE model and BC



In-mould cure BC's

1) Free-standing
2) Frictionless contact
3) Fixed (Perfect bonding)

Post cure BC's

- Free-standing

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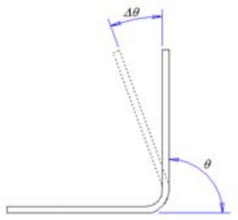
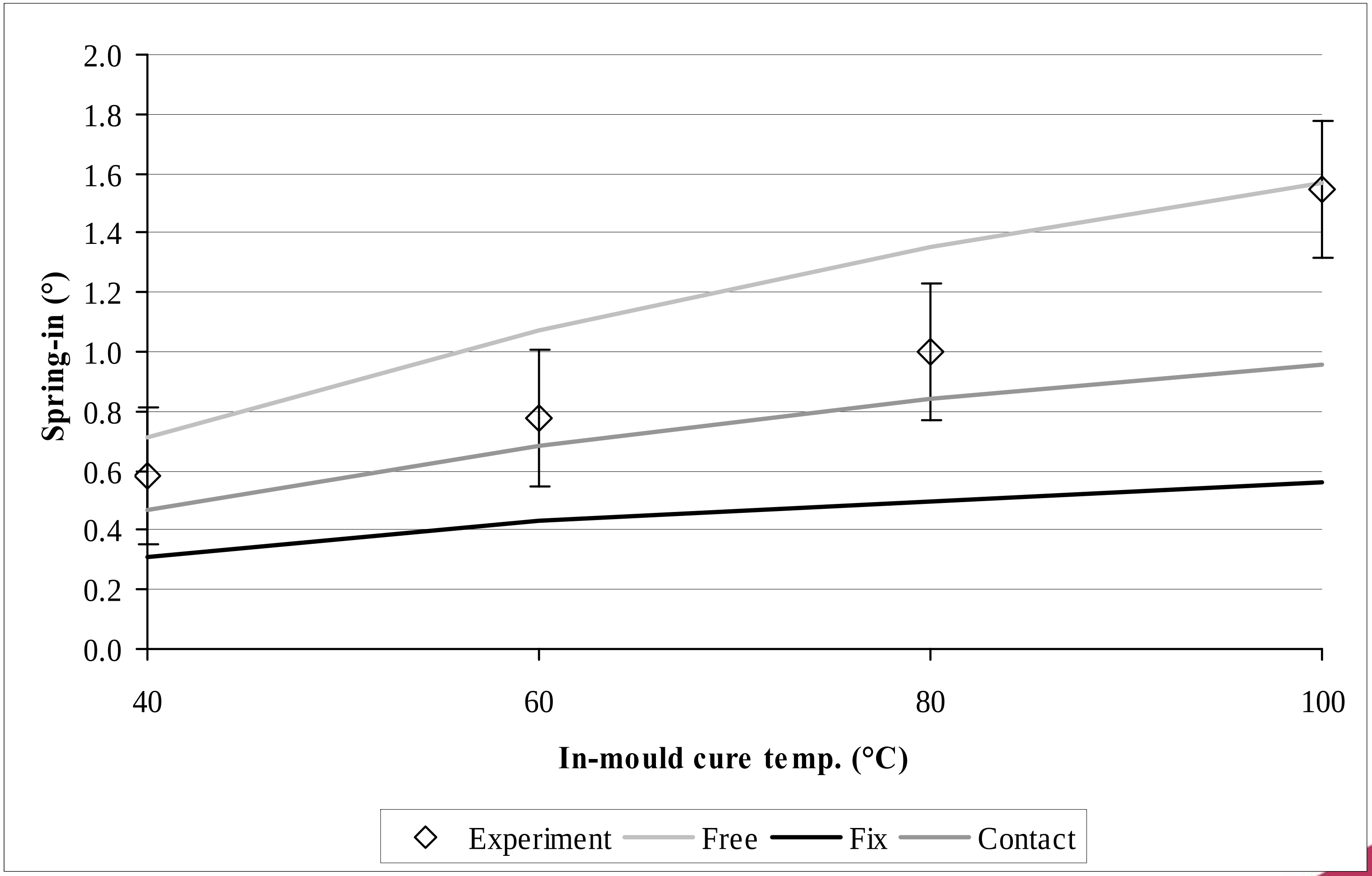
Spring-in after in-mould cure





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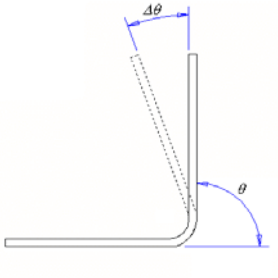
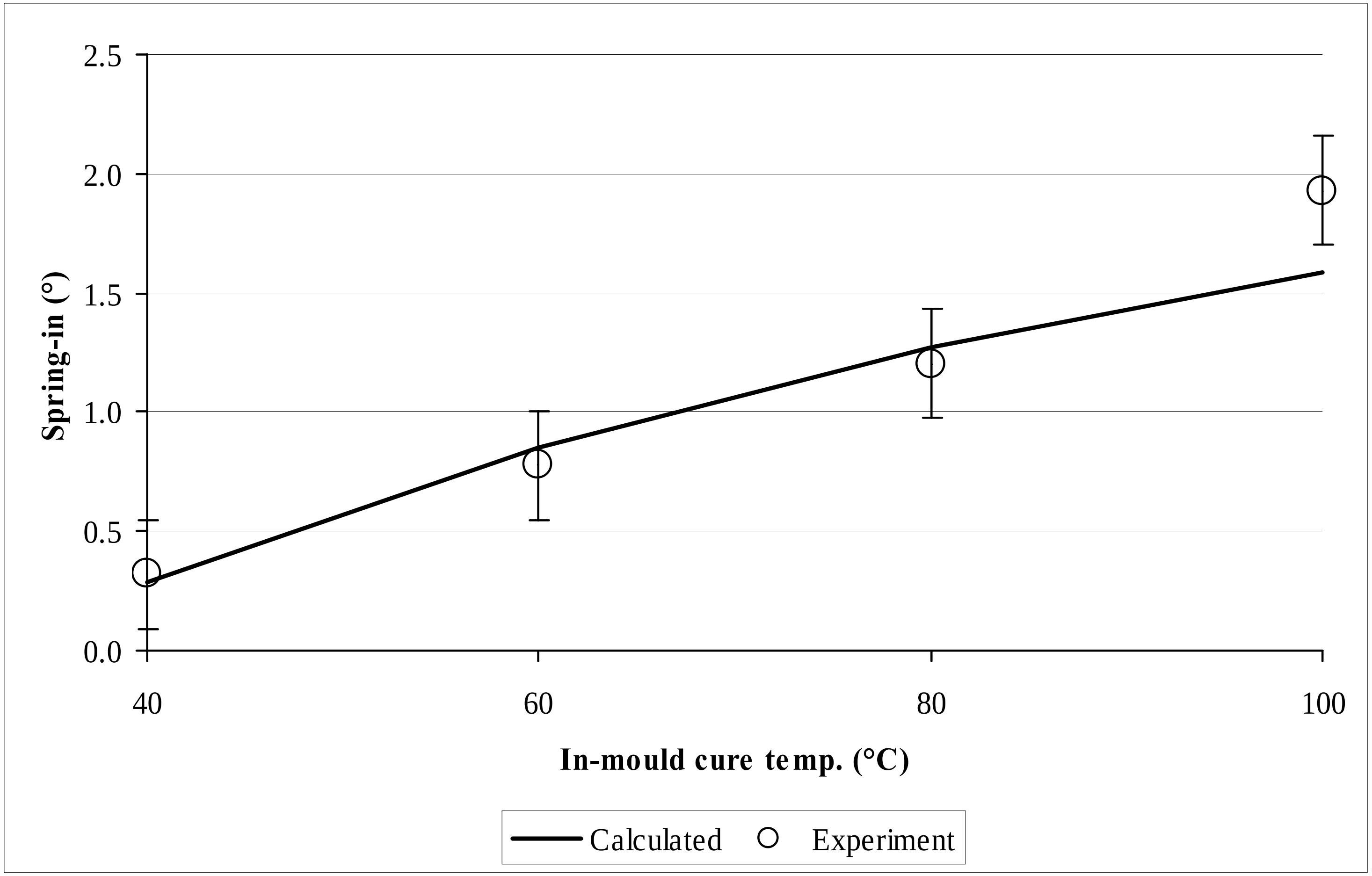
Spring-in after free post cure





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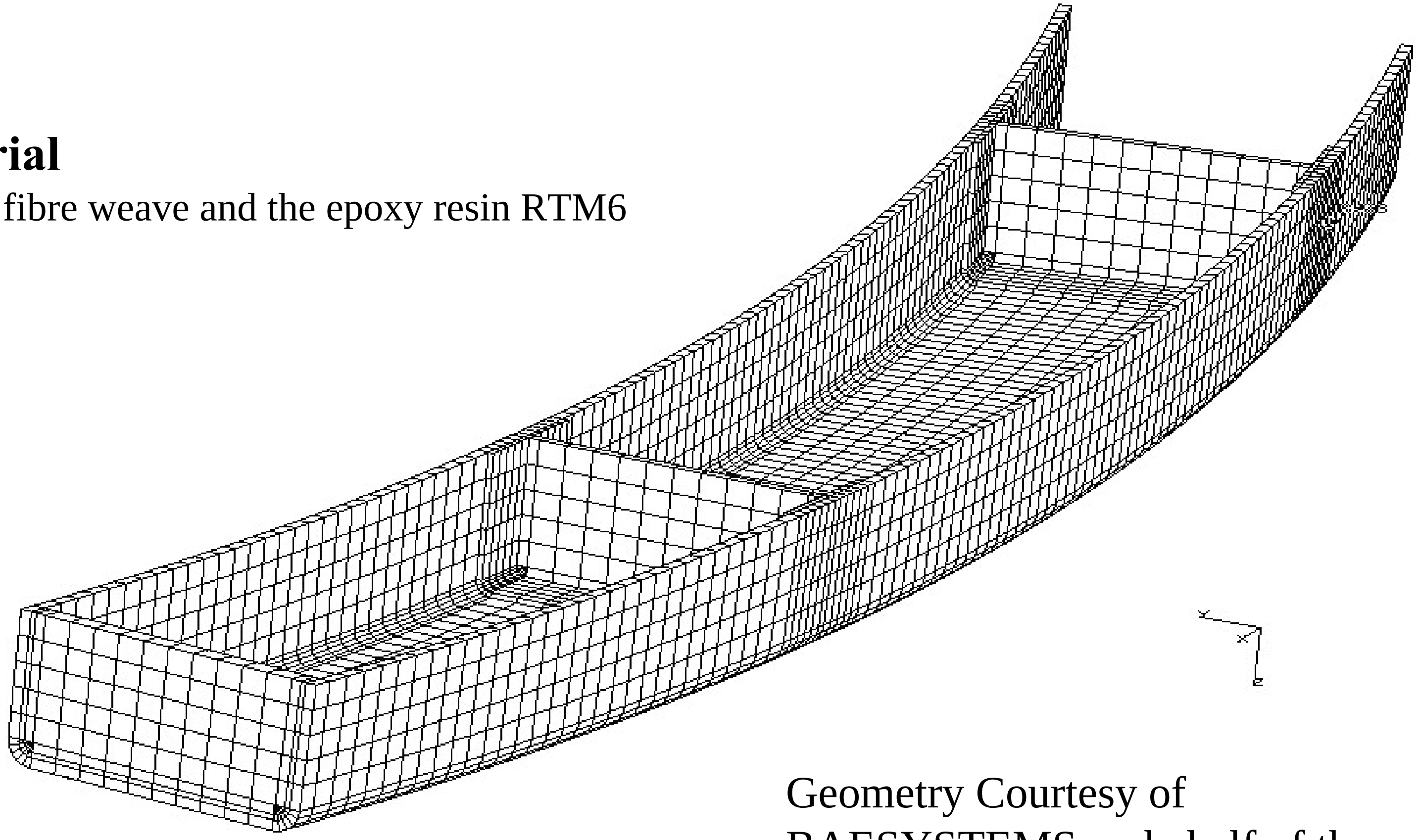
Simulations a useful assistance when a mould geometry is compensated for shape distortions.

-Curved composite C-spar

Material
Carbon fibre weave and the epoxy resin RTM6



Geometry Courtesy of BAESYSTEMS on behalf of the PRECIMOULD consortium.

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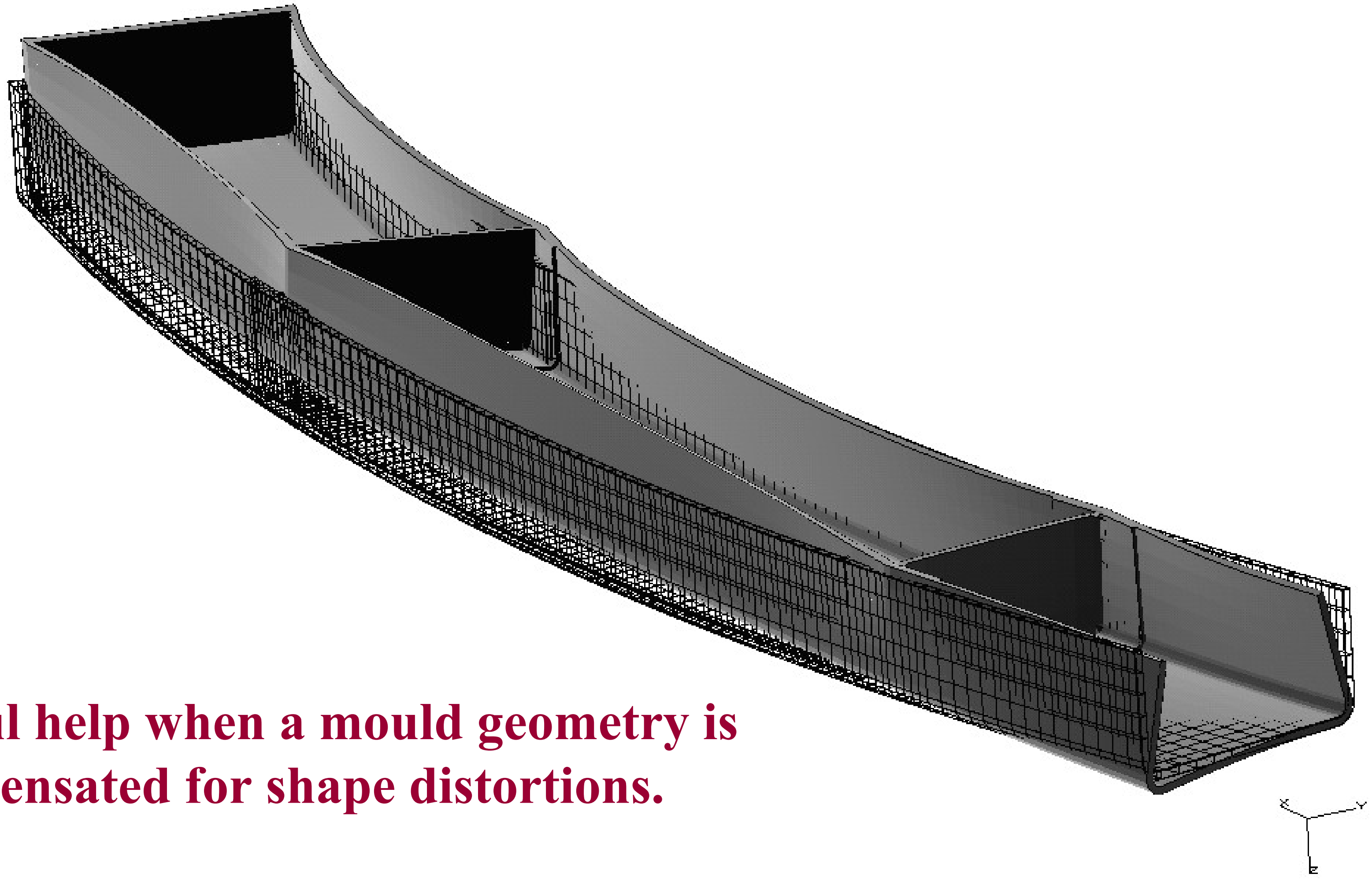
C-spar – Global results



Useful help when a mould geometry is compensated for shape distortions.

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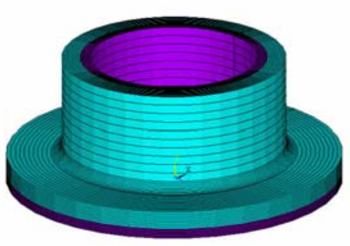
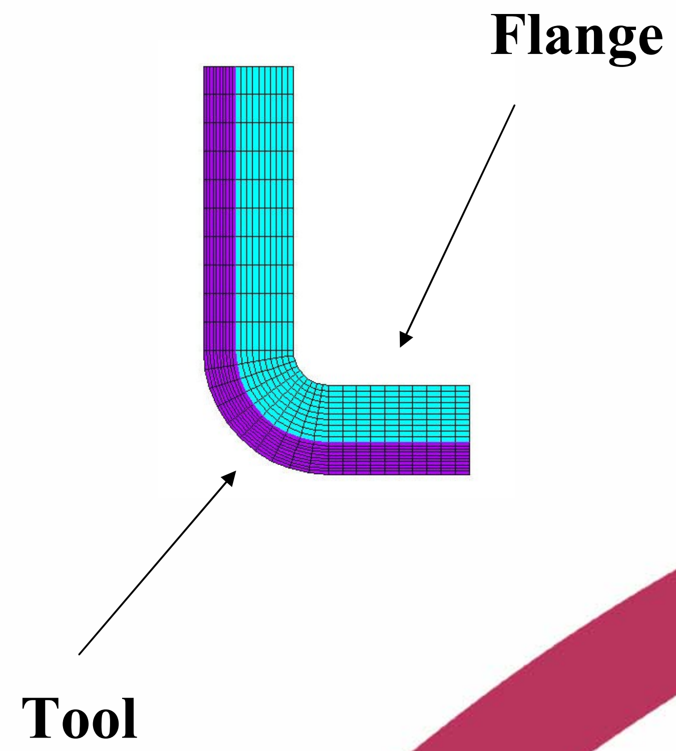
Evaluation of different cure schedules, materials, mould geometry etc. before first prototype is manufactured. Example: Insulator flange (Cobraid)





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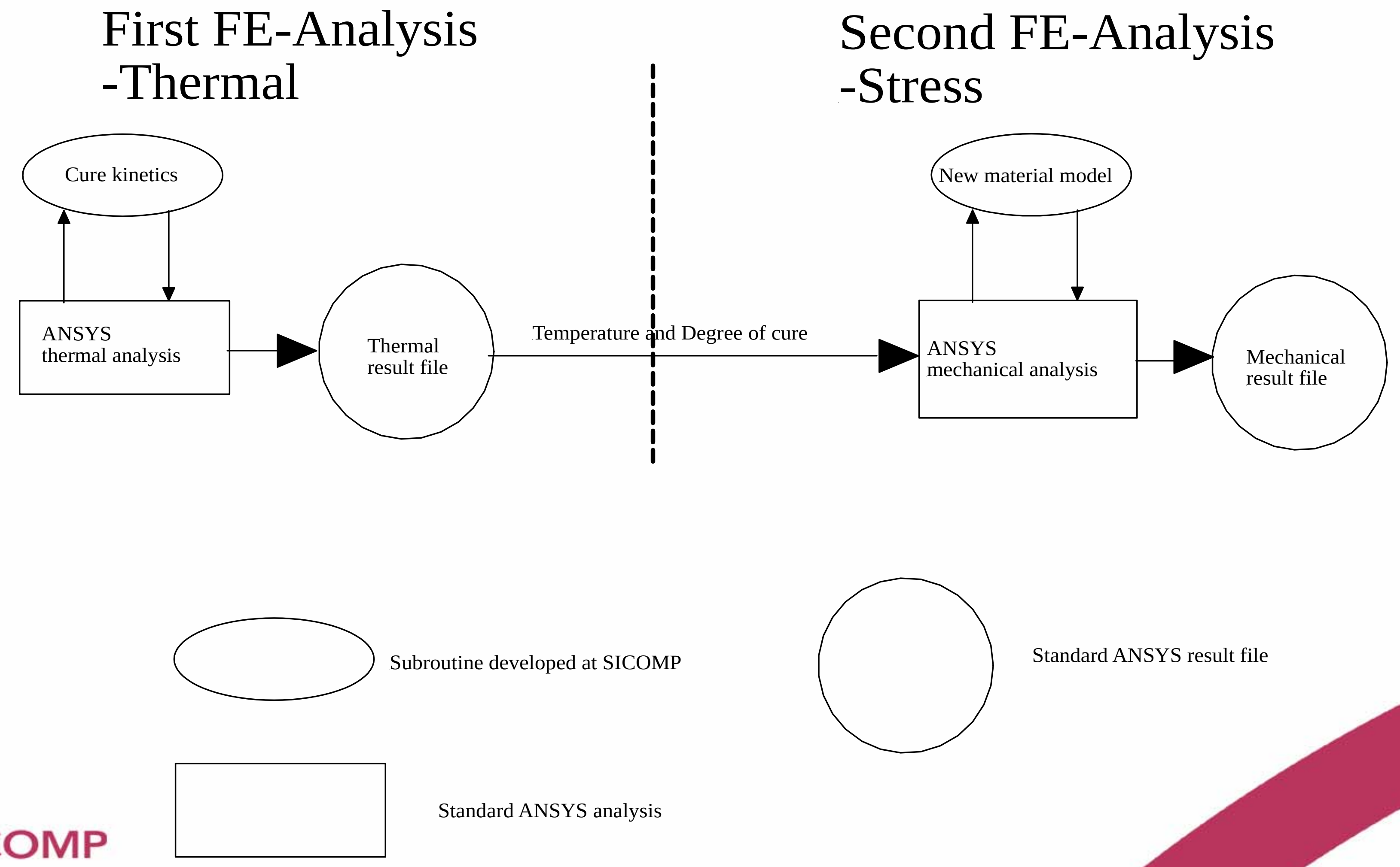
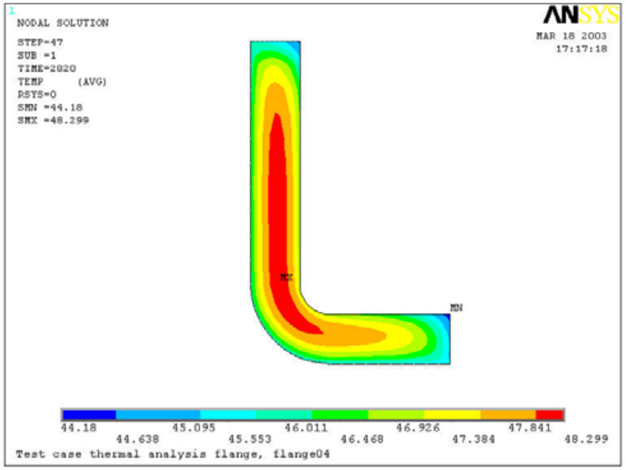
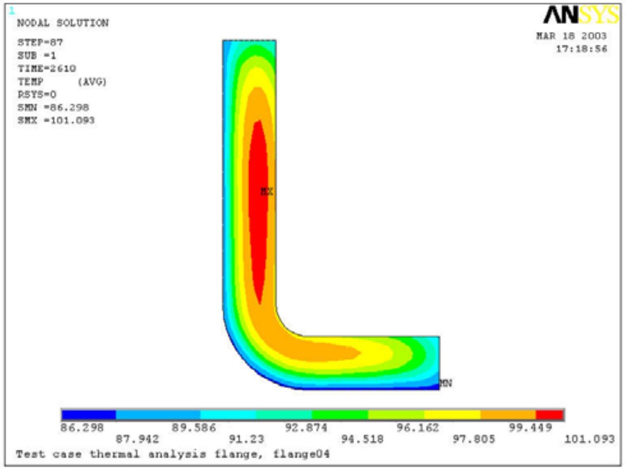
Simulation strategy

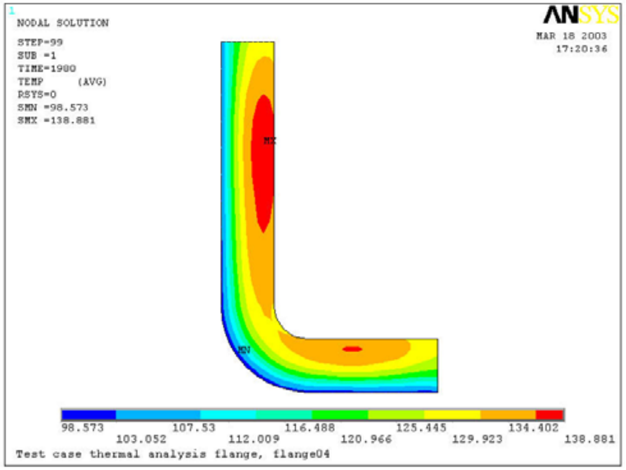
-sequentially coupled thermal-stress analysis using ANSYS



Evaluation of the cure temperature







Cure temperature:	**40 C**	**80 C**	**120 C**
Peak temperature:	**48 C**	**101 C**	**139 C**
Degree of cure:	**88%**	**98%**	**100%**

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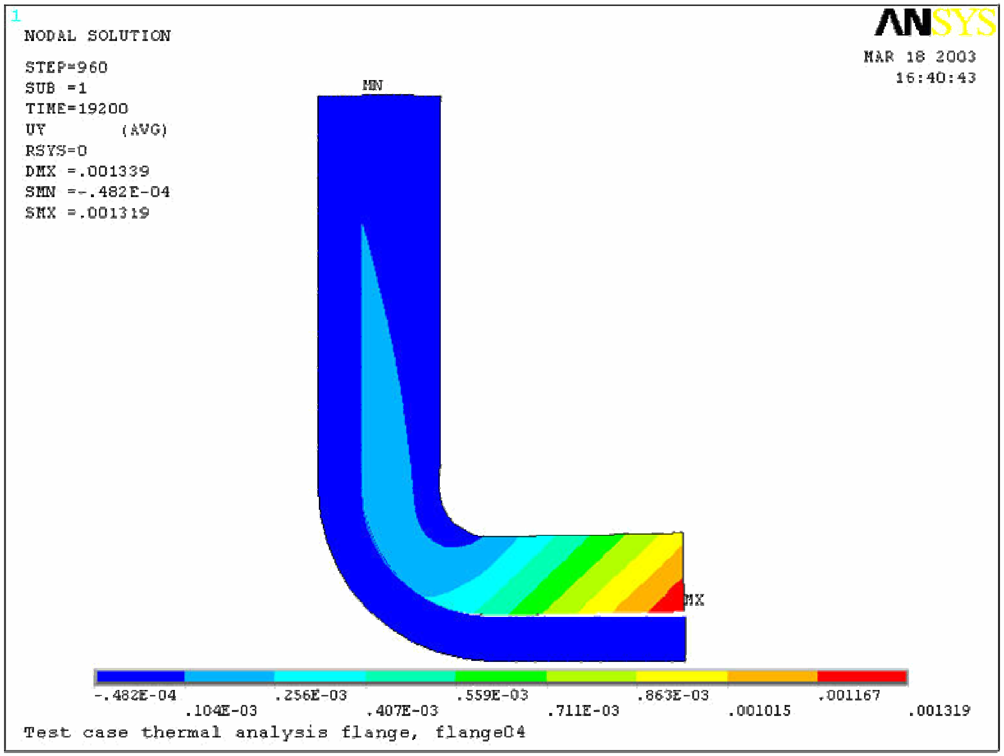
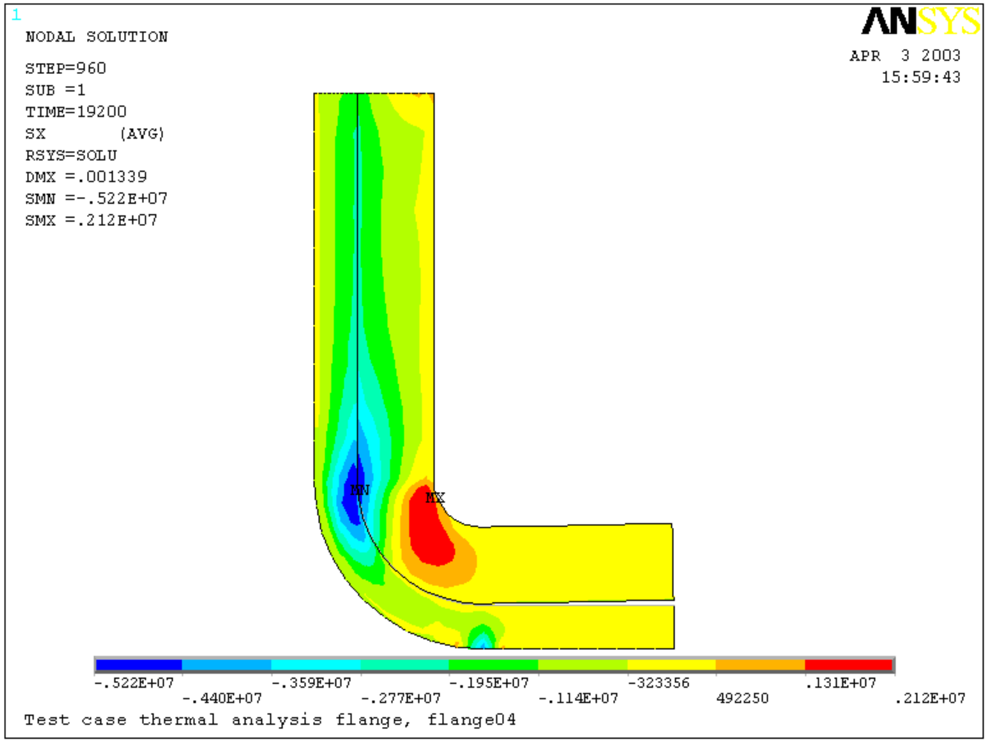
Evaluation of shape distortion and residual stresses



Shape distortion



Residual stress in the through thickness direction

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Possible industrial benefits

- Useful assistance when a mould geometry is compensated for shape distortions.
- Discover manufacturing related problems on a early stage e.g. high temperature peaks, residual stresses, delaminations.
- Evaluate different cure schedules, materials, mould geometry etc. before first prototype is manufactured.

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Industrial use of cure simulations

- Predictions of shape distortion is ready for industrial use
- But residual stress analysis is not ready, e.g. problems of how to use the results in following structural analysis

To reach widespread industrial use routines are needed for:

- generation of material data
- modelling of boundary conditions

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