Curing Simulation for Composites - Residual Stresses and Process Induced Distortions

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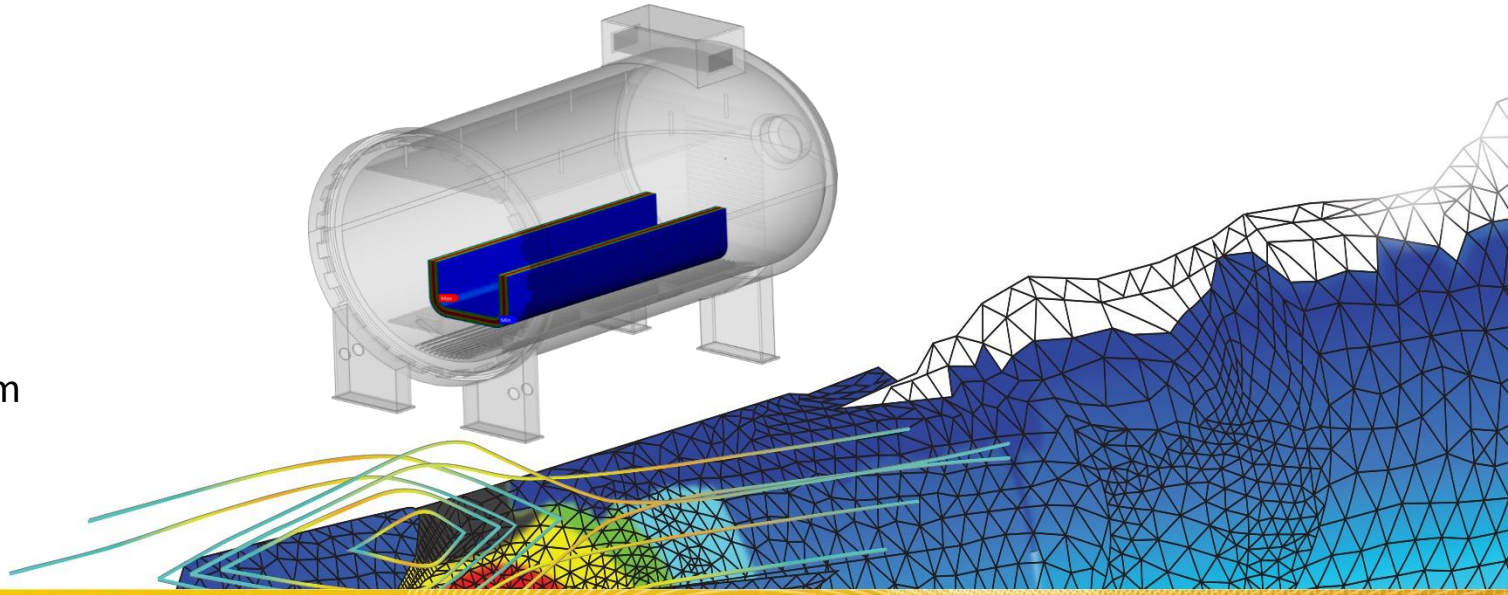


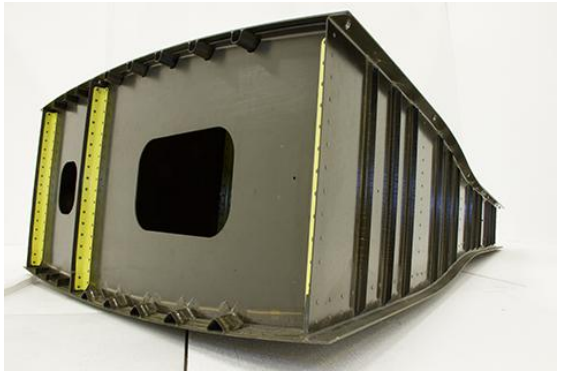
Outline

- Introduction and Motivation
- Curing of Composites – Terms and Challenges
- ANSYS Composite Cure Simulation (ACCS)
- Use Cases:
  - Winglet
  - Optimizing the Manufacturing Process
  - Excessive Heat

Introduction and Motivation

- Industry is pushing the limits
- Increasing complexity
  - Shape and layup
  - Integral construction and assembly (tight tolerances)
  - Reduce process time and waste (costs)
- Guarantee product performance (live time)

→ Build accurate and reproducible



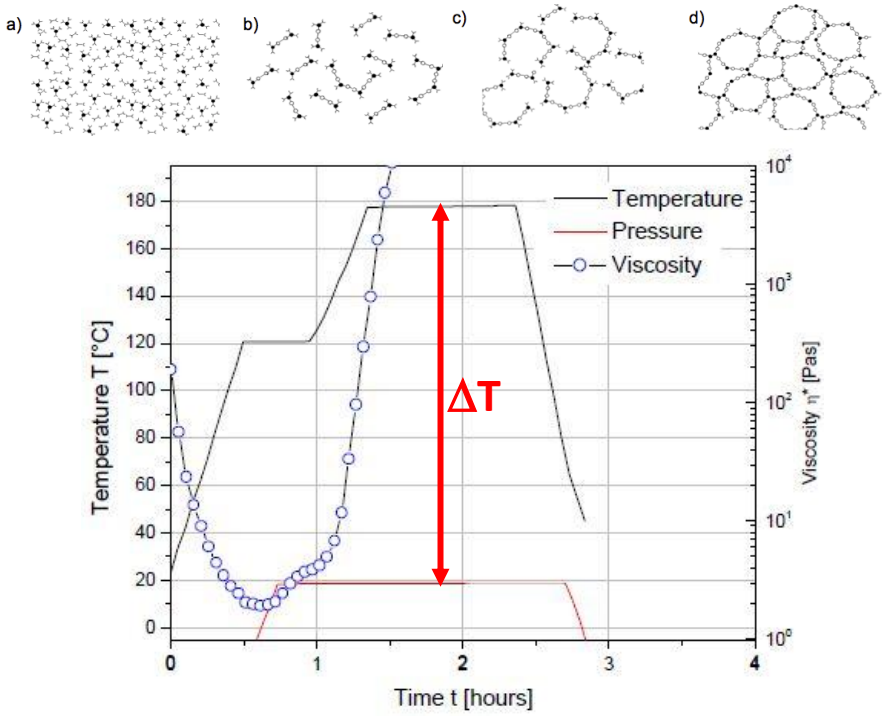
Predict and compensate process induced distortions

Optimize process cycles

Curing of Composites (Epoxies)

Curing of epoxies usually involves elevated temperatures and pressures. This may lead to development of residual stresses, distortions and cracking

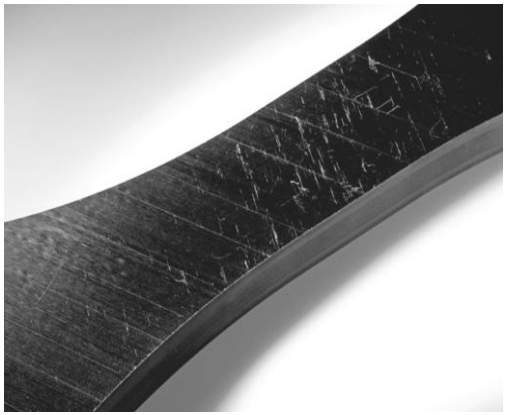
A composite component is positioned within the autoclave at American Airlines' composite repair shop, at the airline's Tulsa, Oklahoma, maintenance complex. Credit: American Airlines



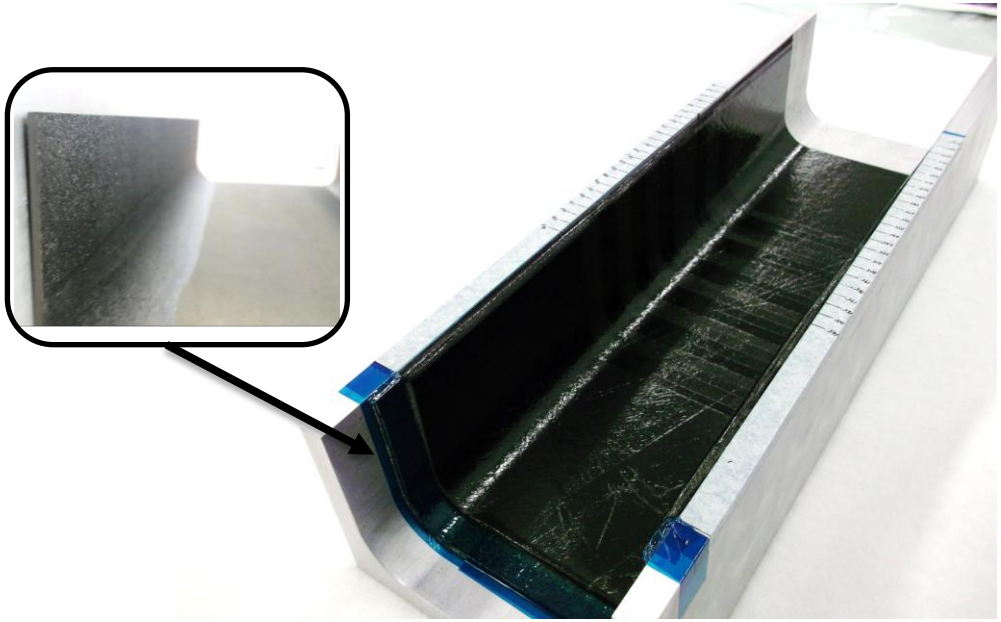
a) monomer stage, b) linear growth and branching c) formation of gelled but incompletely cross linked network, d) fully cured thermoset

Distortions and Cracking in Prepreg Composites

Residual stress induced cracking

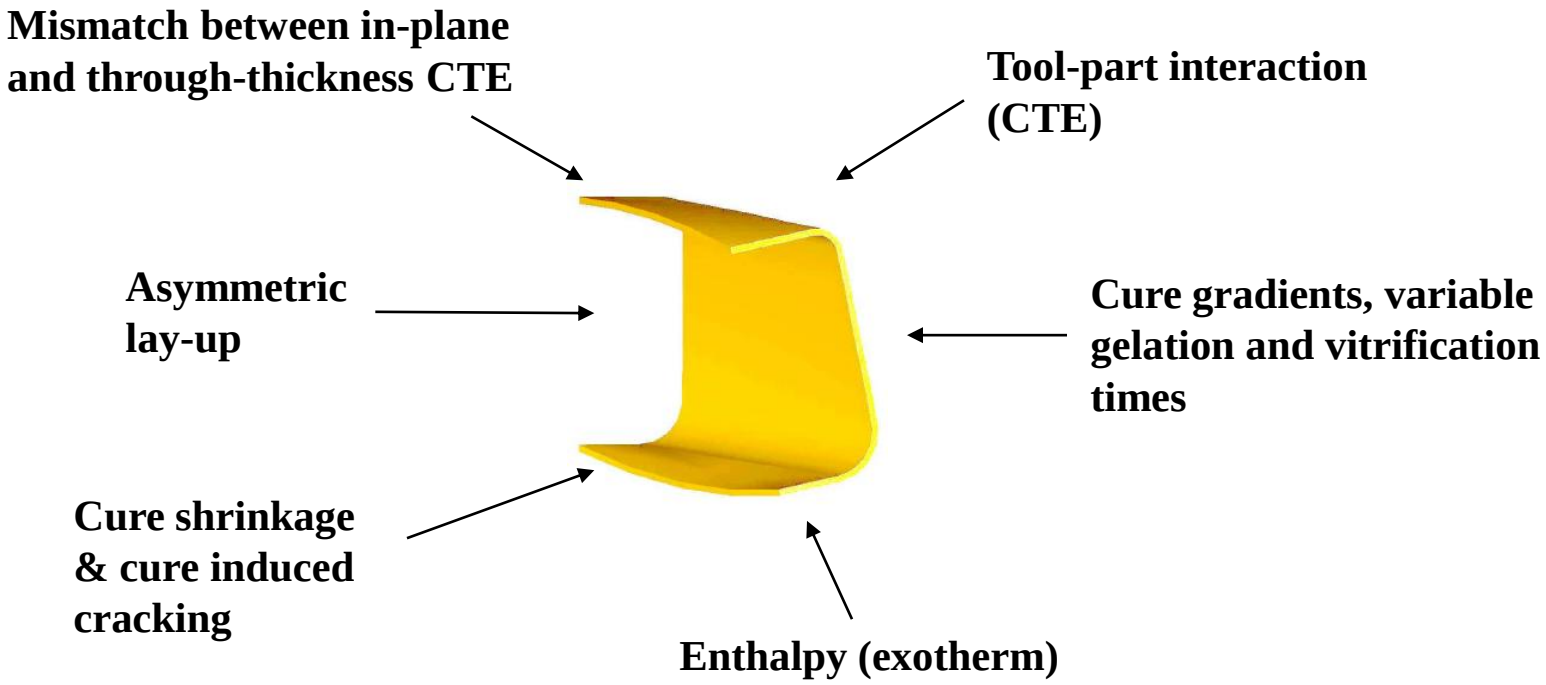


Spring-in in a composite spar section



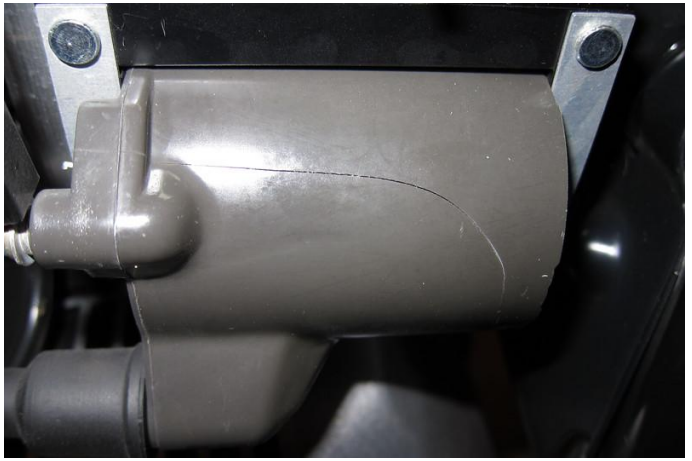
What Is Causing The Problem?

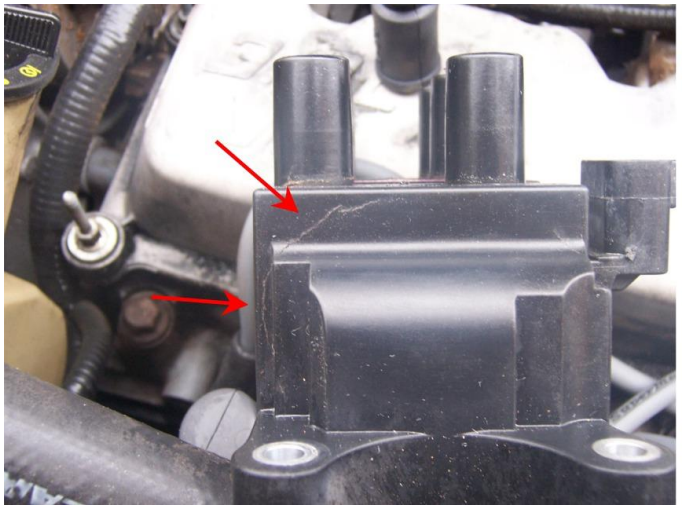
Residual stresses that develop during cure lead to distortion or cracking significantly impacting on the final product performance



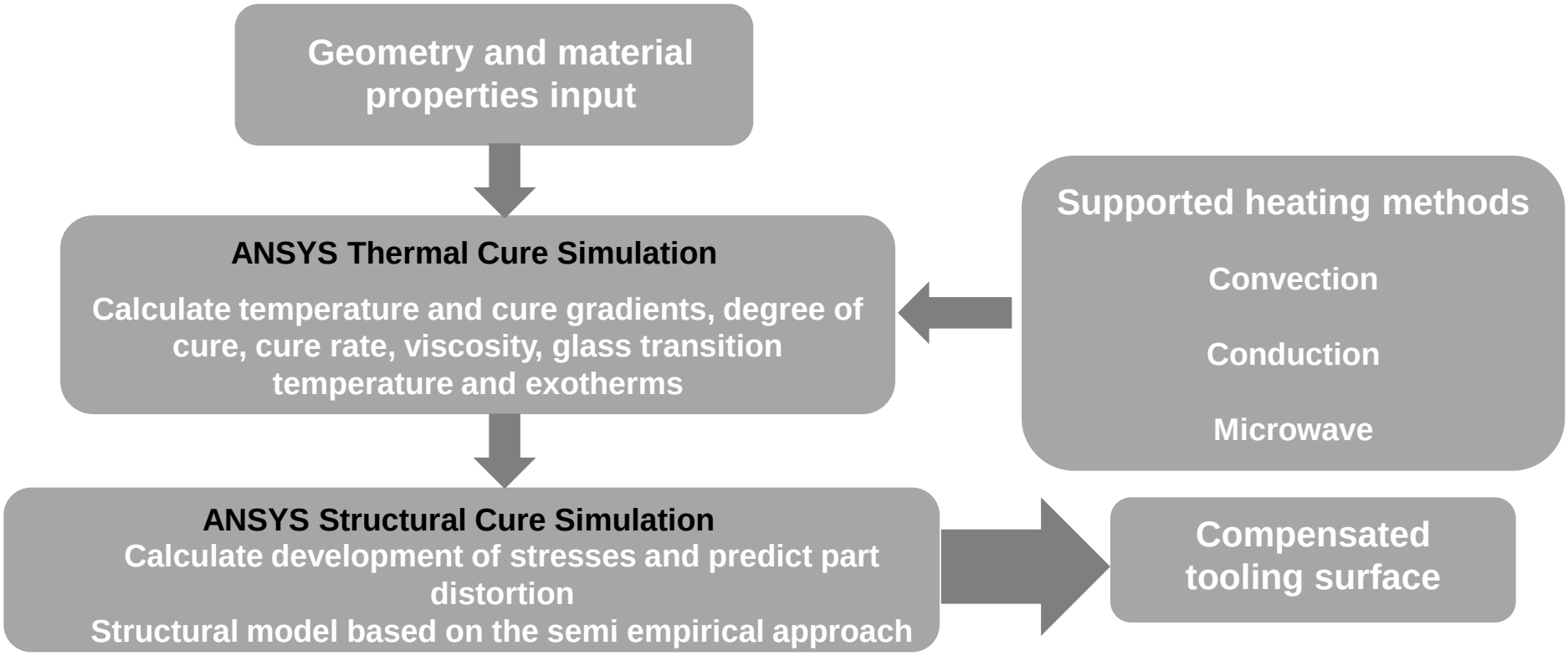
from T Garstka. Separation of process induced distortions in curved laminates, PhD thesis, Bristol,2005

Cracking in Epoxy Packaged Components



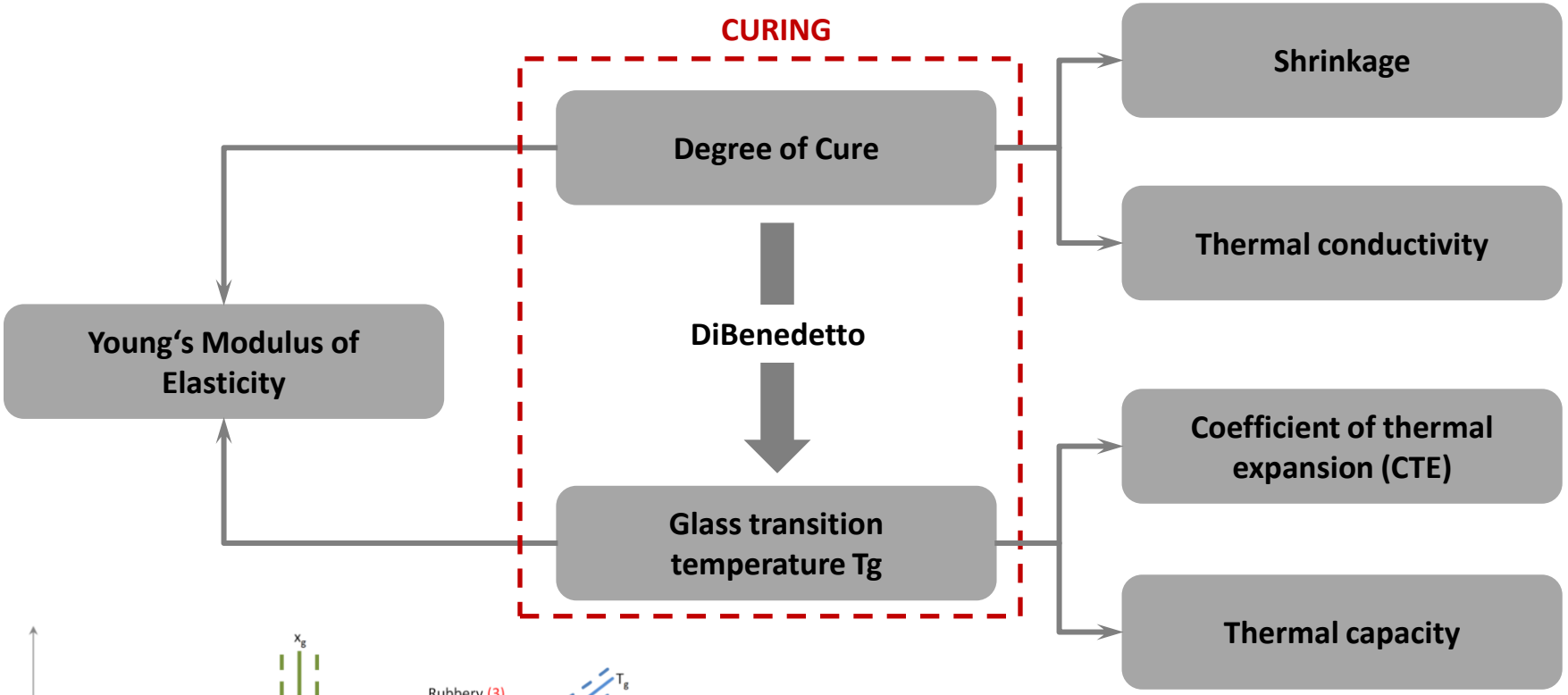


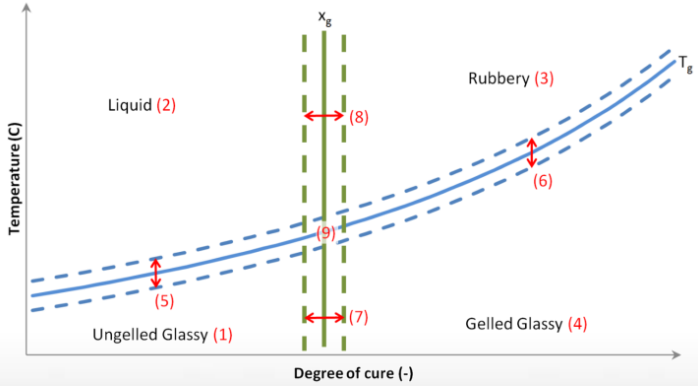
ANSYS Composite Cure Simulation (ACCS)



The analysis is semi coupled. First we evaluate temperature and degree of cure using thermal solver and then degree of cure and temperature is passed to structural simulation to analyse development of stresses and distortions

ANSYS Composite Cure Simulation (ACCS)





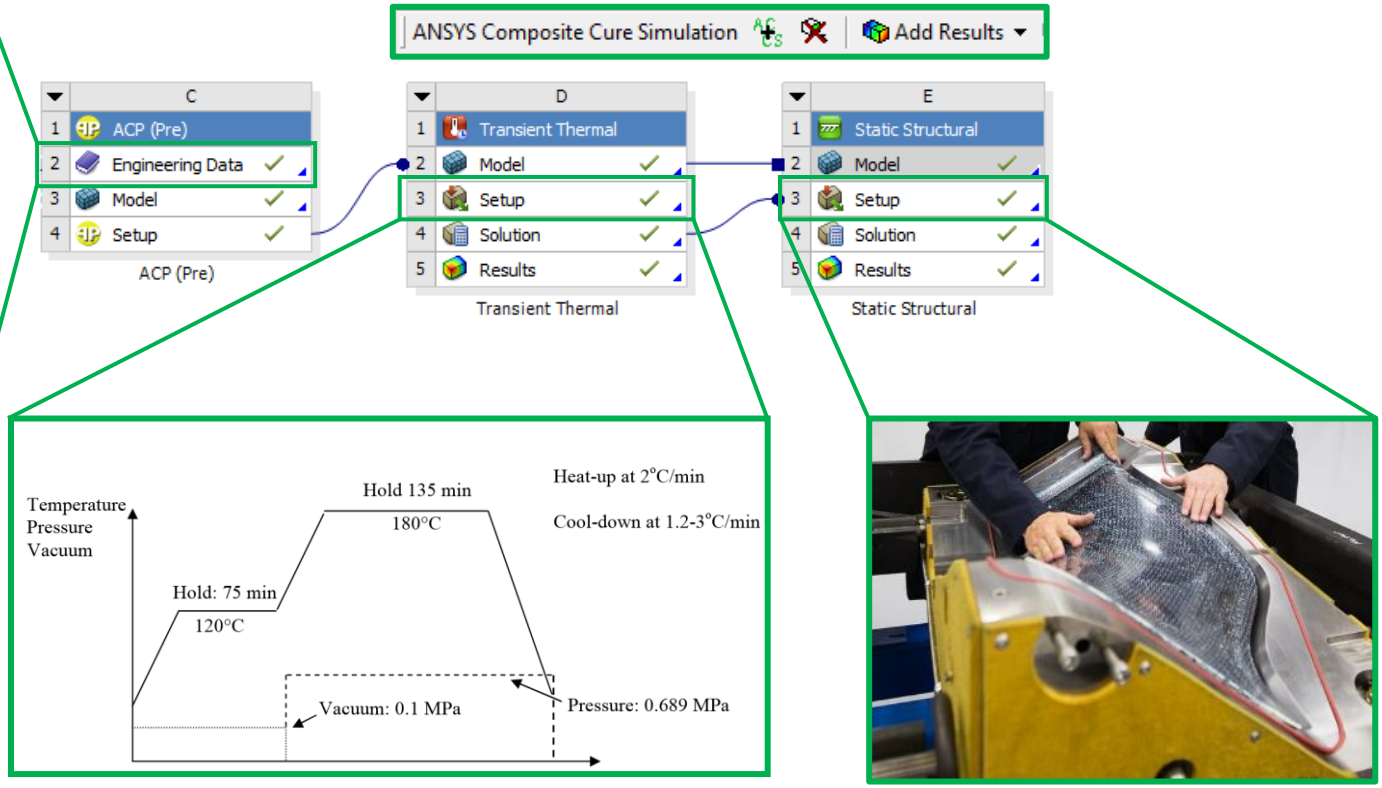
Workflow In ANSYS WB: Full

For all laminates:

Fully captures the evolution of heat transfers and related distortions

Properties of Outline Row 3: Hexcel AS4-8552

	A
1	Property
2	Density
3	Orthotropic Instantaneous Coefficient of Thermal Expansion
7	Orthotropic Elasticity
17	Orthotropic Thermal Conductivity
21	Specific Heat
22	Autocatalytic Cure Kinetic Equation
27	Resin Properties
32	Total Heat of Reaction
33	Diffusion Limitation
37	Glass Transition Temperature
41	Orthotropic Cure Shrinkage
42	Material Properties Evolution
45	Orthotropic Liquid Pseudo Elasticity
55	Orthotropic Rubbery Elasticity
65	Orthotropic Instantaneous Liquid Coefficient of Thermal Expansion
69	Orthotropic Instantaneous Rubbery Coefficient of Thermal Expansion



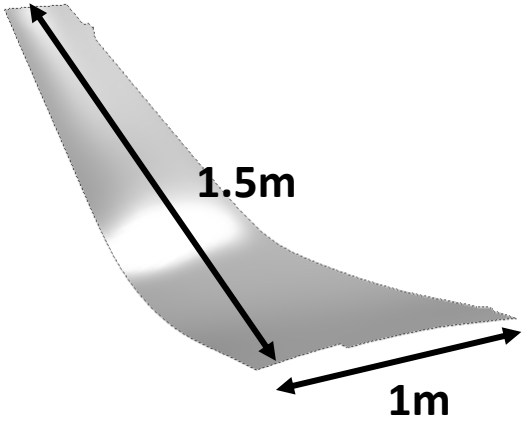
Winglet: Process Induced Distortions

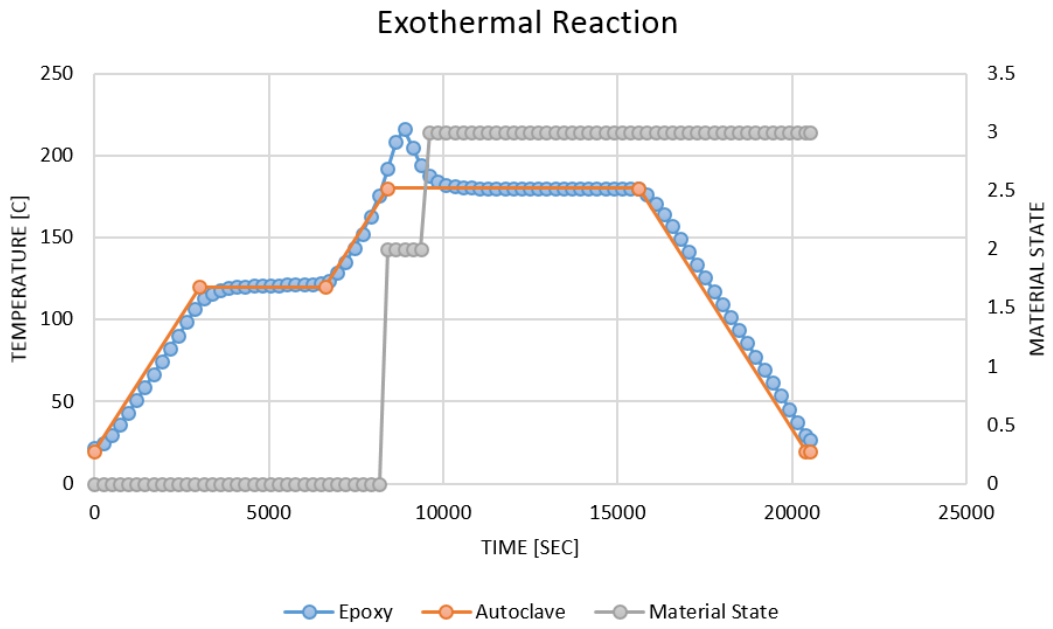
Material: Hexcel AS4-8552

Structure: Upper skin

Dimension: 1x1.5 m

Laminate: Quasi isotropic

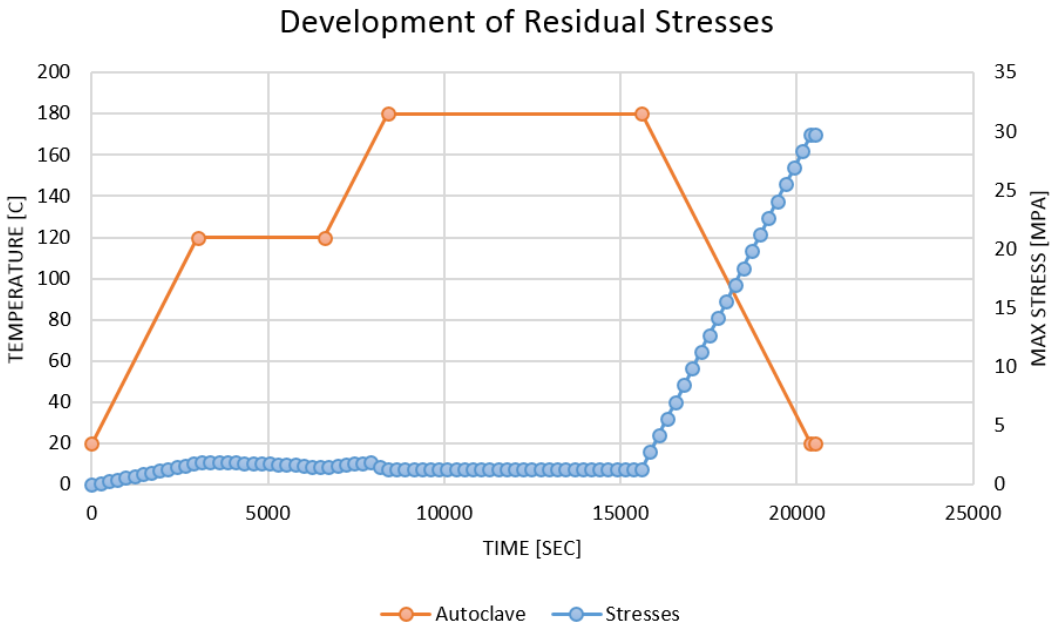


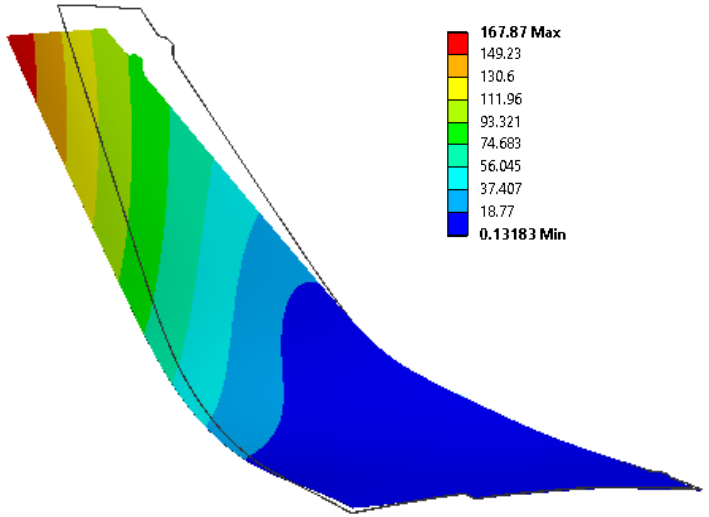


Winglet: Process Induced Distortions (cont.)

Structural analysis:

- **Development of residual stresses**
- **Process induces distortions**



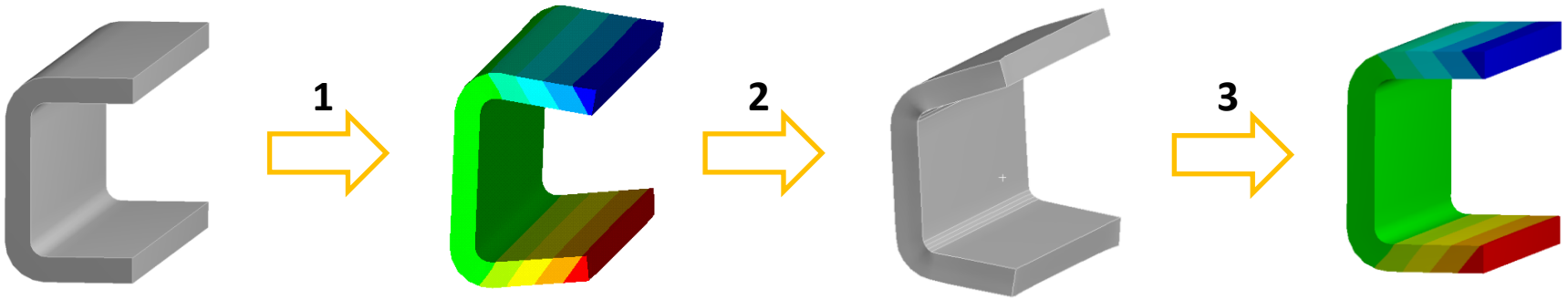


Process Induced Distortions: Simulation

1) Predict process induced distortions of the composite part

2) Invert part distortion and use it to design tooling

3) Verify result



Nominal geometry

Out of tolerance geometry from nominal geometry

Compensated geometry before cure

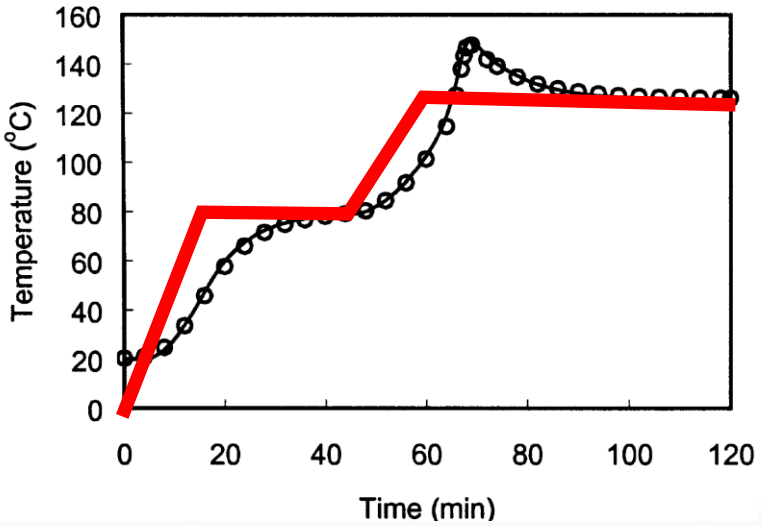
In tolerance post cure geometry

Optimizing the Manufacturing Process

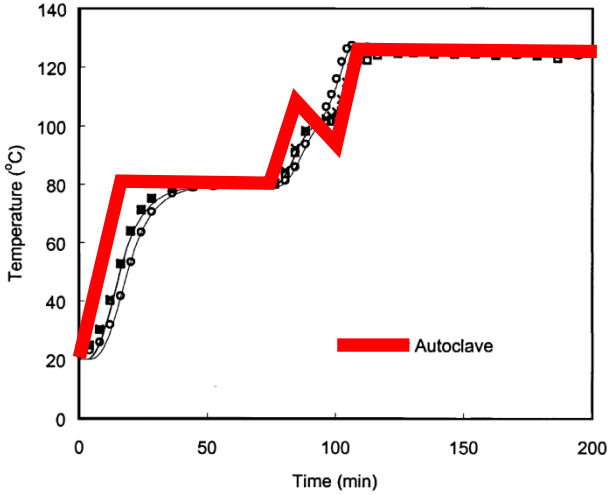
1. **Predict crosslinking process and the exothermal reaction**

2. **Optimise the manufacturing process to minimise excessive heat, minimise processing time and energy**

Before the optimization:
High exothermic peak

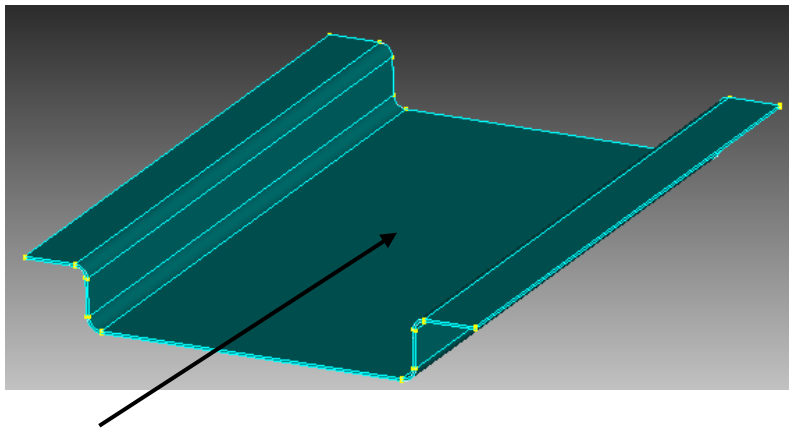


After the temperature optimization

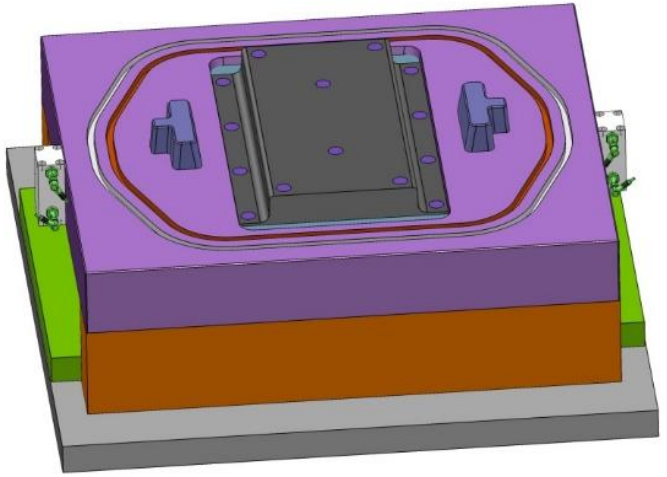


Automotive Use Case: Excessive Heat

- **A recent example of the use of ACCS was in the UK's Composite Innovation Cluster project called RITAA.**
- **2 mm thick U–shaped laminate was infused at 40bars followed by a 4 min cure cycle at 120°C**
- **The part was infused through a single centrally placed injection head**



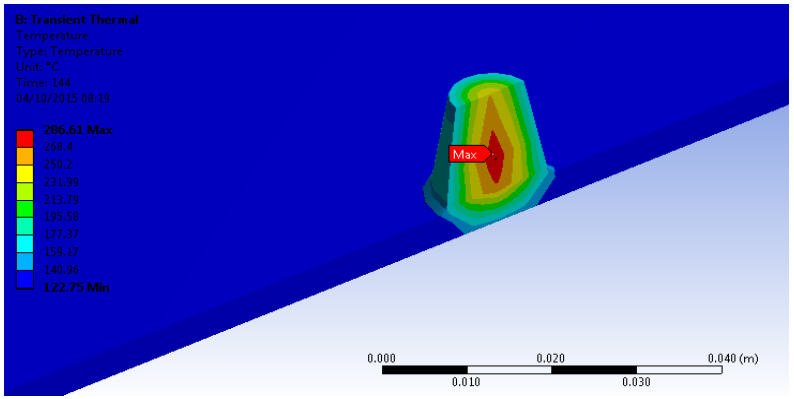
Injection location



High pressure RTM tooling courtesy of FORMAPLEX and RITAA project

Automotive Use Case

ACCS indicated excessive temperature rise in the injection manifold. This was confirmed with the experimentally measured temperature and the observed porosity of the cured part as shown below



→ Redesigned injection head and optimized process

Summary and Conclusions

- **Curing of epoxy composites is complex and may lead to significant built in stresses and distortions**
- **The exothermic reaction in epoxies may also cause considerable problems during manufacturing especially in the case of thick laminates**
- **ACCS allows to predict development of cure and subsequently build up of residual stresses**
- **ACCS allows removes the need for costly trial and error approach in tooling design. It significantly shortens product development time and the overall process cost.**

Thank you for your attention.

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