A 12 PART WEBINAR SERIES ON:

COMPOSITE MATERIALS ENGINEERING

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YOUR HOST

Casey Keulen, Ph.D, P.Eng.
Assistant Professor of Teaching, University of British Columbia
Co-Director, Master of Engineering Leadership, AMM Program, UBC
Lead of Continuing Professional Development, CKN

- Ph.D. and M.A.Sc. in Composite Materials Engineering
- Over 15 years experience in industry and academia working on polymer matrix composites in aerospace, automotive, marine, energy, recreation and others
- Experience working with over 150 companies from SME to major international corporations
- Expertise in liquid composite moulding and thermal management

PAST WEBINAR RECORDINGS NOW POSTED

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OVERVIEW OF WEBINAR SERIES

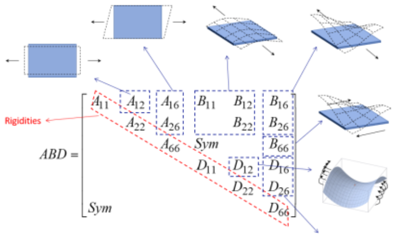
- **Series of 12 webinars, 1 hour each**

Introduction
Constituent Materials
Thermal Management

Processing (Manufacturing)
Prepreg Processing
Liquid Composite Moulding

Mechanics of Composites
Micromechanics
Lamina and Laminate Level
Failure

$$\begin{Bmatrix} N \\ M \end{Bmatrix} = \begin{bmatrix} A & B \\ B & D \end{bmatrix} \begin{Bmatrix} \varepsilon_0 \\ \kappa \end{Bmatrix}$$



Common Defects
Testing Composites

- **For more information on dates and times visit:**
  https://compositeskn.org/aimevents/

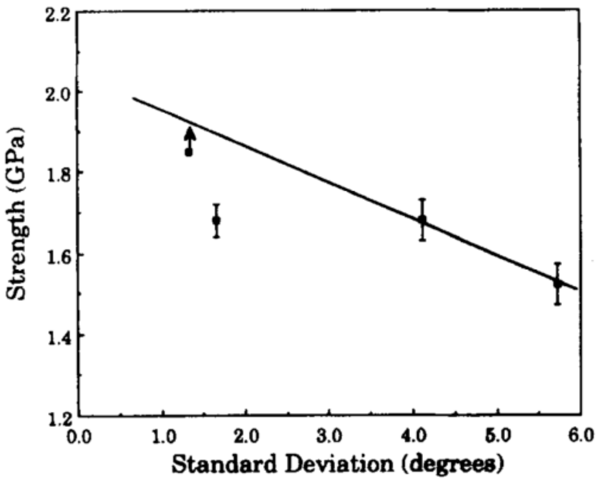
OUTCOMES OF THIS WEBINAR

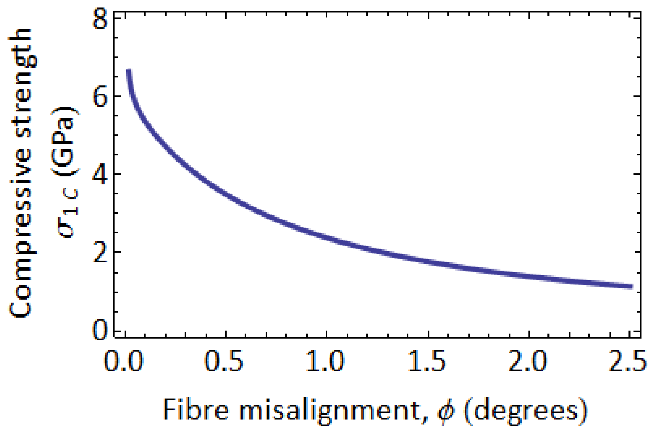
- Understand and identify common defects due to processing composites
- Understand the basics of defects related to or classified as:
  - Thermal management
  - Dimensional control
  - Porosity
  - Fiber misalignment

- **Upcoming, final webinar in this series**
  - How do I measure mechanical properties of a composite?

INTRODUCTION

- A defect is an aspect of the part/material that is not the way the designer intended it to be, it is ‘out of spec’
- Defects can have a significant effect on a variety of properties of a composite material/part
- There are a wide variety of defect sources: processing parameters, material variability, inclusion of foreign bodies, machining, handling, etc.
- Defects are a large contributor to the higher safety factors required for composite parts



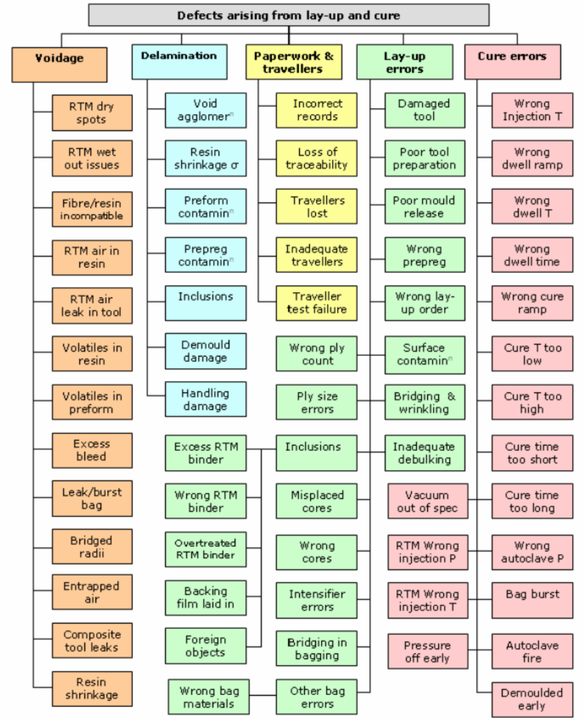


Piggott, M. R. (1995). The effect of fibre waviness on the mechanical properties of unidirectional fibre composites: A review. *Composites Science and Technology*, *53*(2), 201–205.

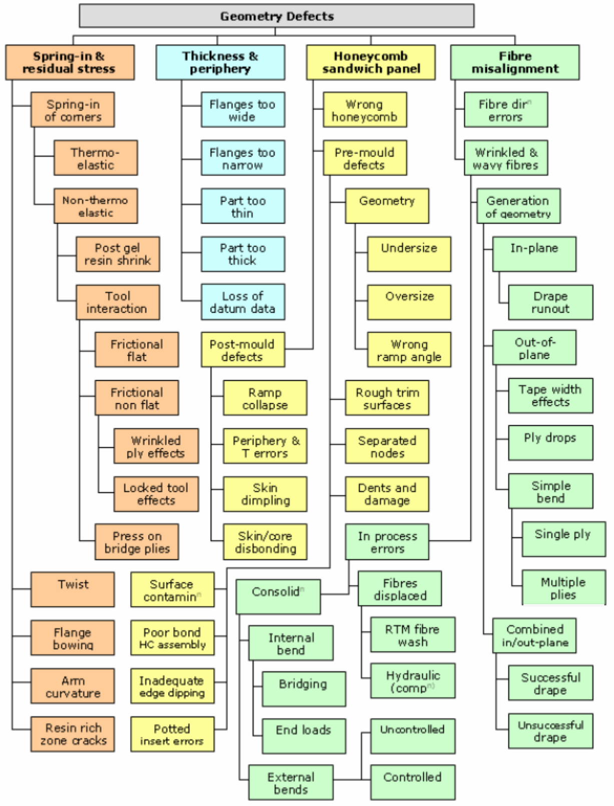
CLASSIFICATION OF DEFECTS

- Understanding and classifying defects. Adapted from Potter et al. 2009[1]

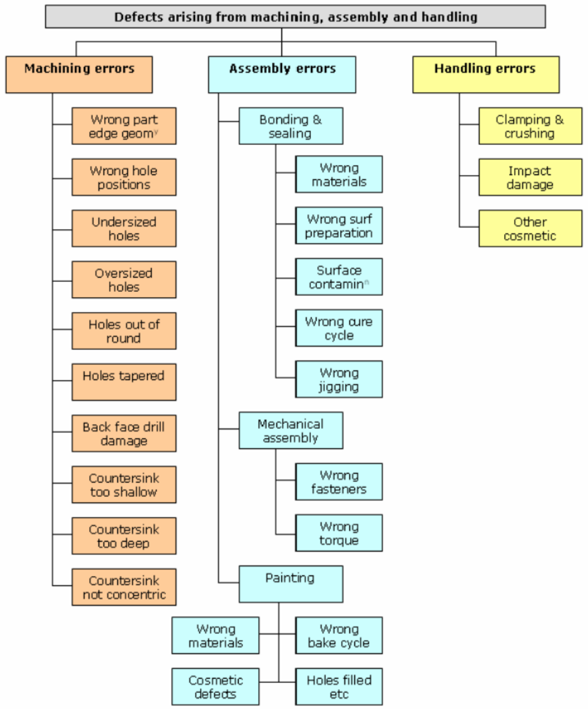
Deposition and Cure



Geometry



Machining, Assembly and Handling



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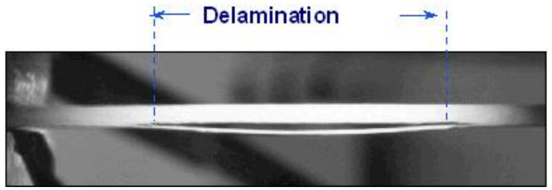
[1] K.D. Potter, Understanding the Origins of Defects and Variability in Composites Manufacture, Proceedings of ICCM17, 2009.

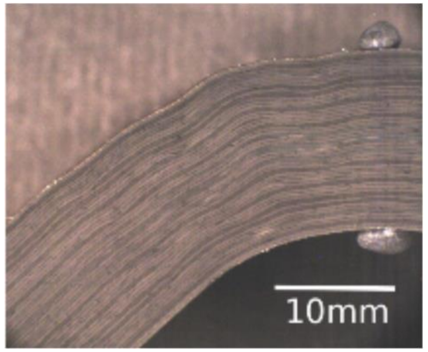
CLASSIFICATION OF DEFECTS: DEPOSITION AND CURE

- Defects that occur due to deposition or cure

Dry spots (voids)



Delamination



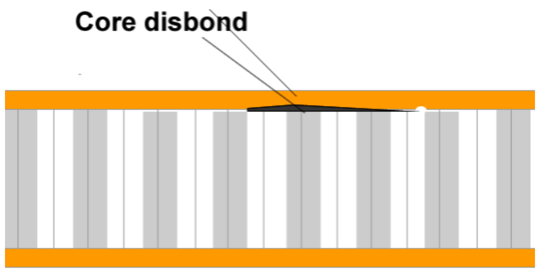
Fiber misalignment

Deposition and Cure
- Voids
- Delamination
- Under-cure
- Material Deposition

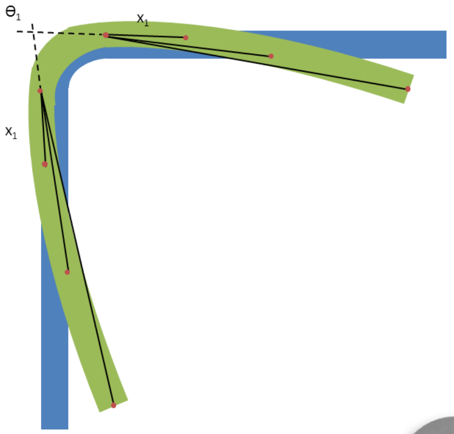
Porosity (voids)

CLASSIFICATION OF DEFECTS: GEOMETRY

- Anything physically out of spec



Disbonding

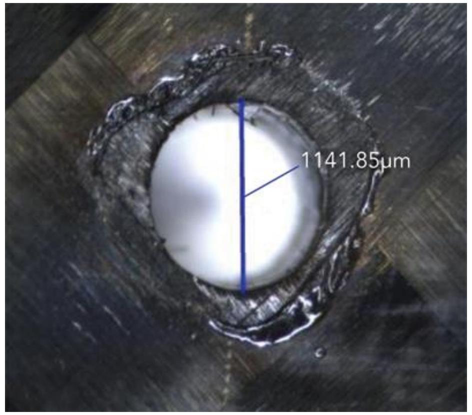

Spring-in

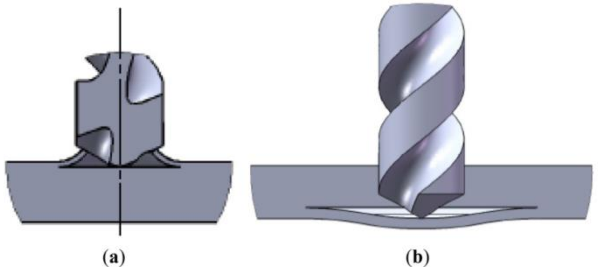
- Geometry
  - Dimensional errors
  - Honeycomb sandwich panel
  - Fibre misalignment
  - Surface quality

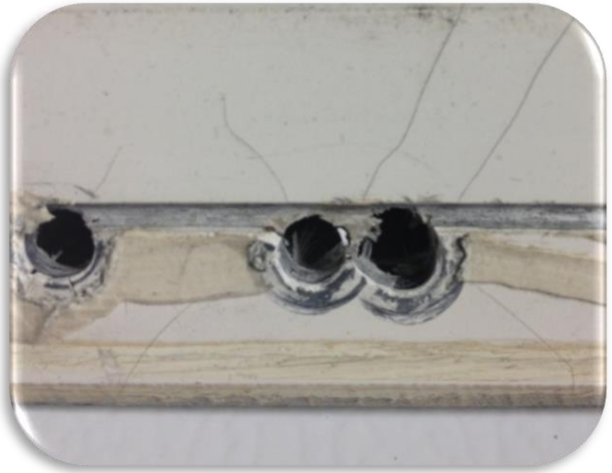

Surface finish

CLASSIFICATION OF DEFECTS: MACHINING, ASSEMBLY, HANDLING

- Post processing



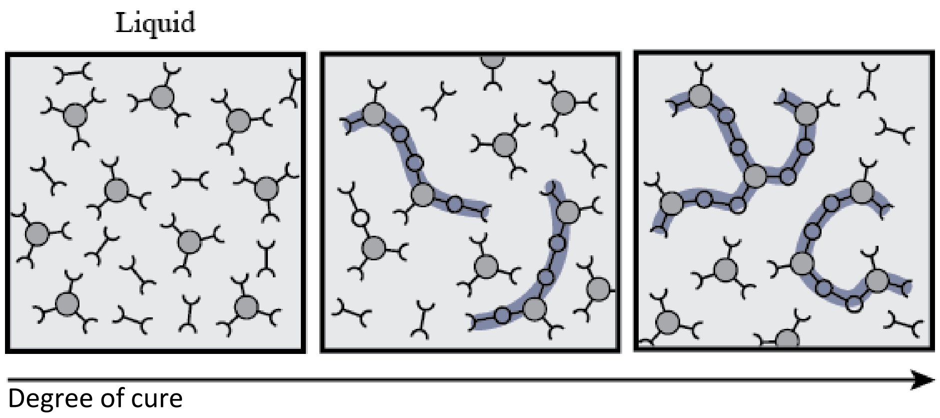


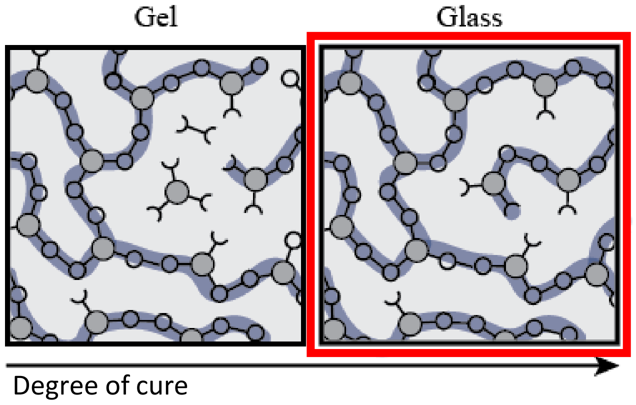


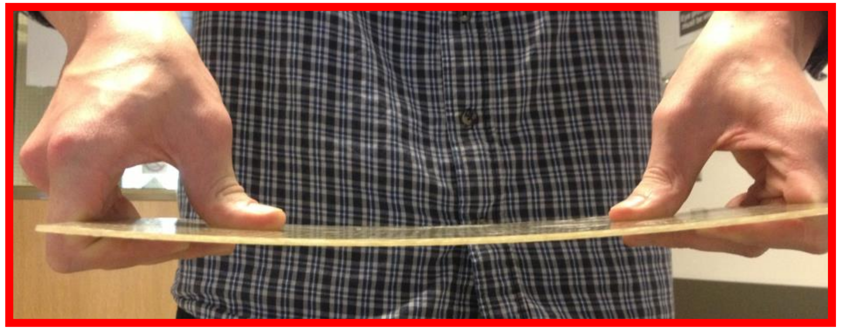
Machining, Assembly and Handling
- Machining errors
- Assembly errors
- Handling errors

UNDER-CURE

- What happens during cure?
  - Molecules link and form a network, this leads to increased stiffness

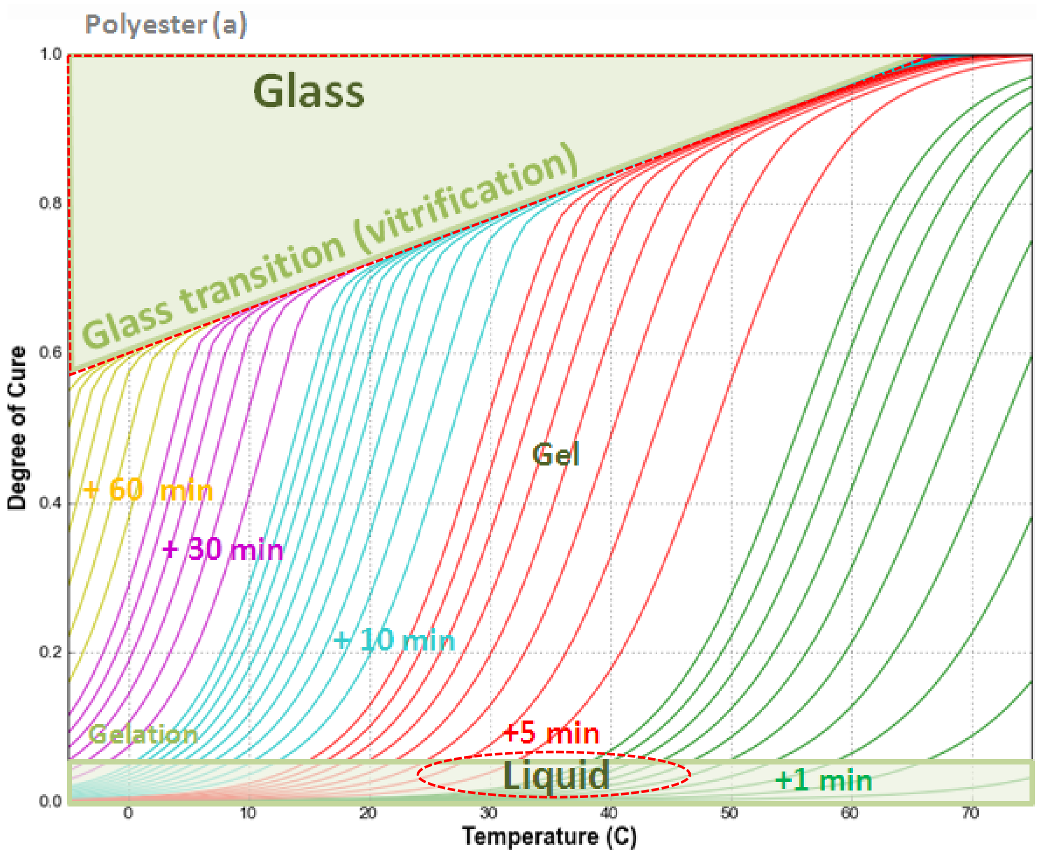






UNDER-CURE

- How does under-cure happen?



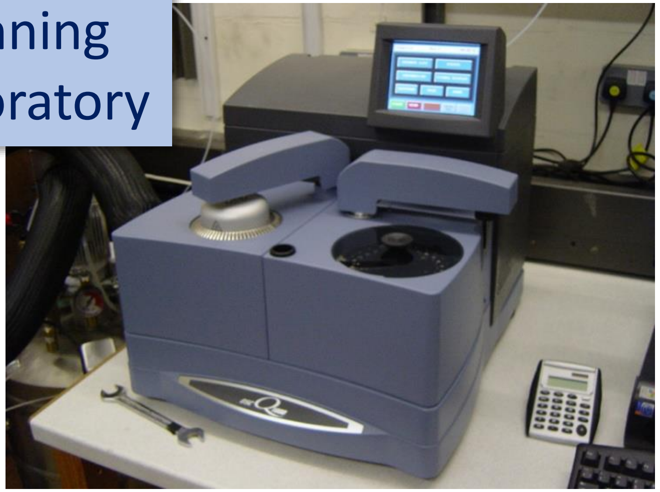
A **PROCESS MAP** illustrates how degree of cure changes during processing.

- Does not always reach 100%
- Transition between liquid and "glass"

UNDER-CURE

- How to detect/measure it?

Differential Scanning Calorimetry - laboratory



Barcol hardness tester – in-the-field

Portable FTIR – in-the-field

UNDER-CURE

- **Consequences/effects of under-cure:**
  - Lower mechanical properties
    - Stiffness (Young's and shear modulus)
    - Potential for lower fiber/resin bond strength
    - Less brittle (may be beneficial)
  - Physical-Chemical Properties
    - Moisture/chemical resistance lower
    - Tg lower
      - Potential for deformation at lower temperature
    - Reduced dimensional control

UNDER-CURE

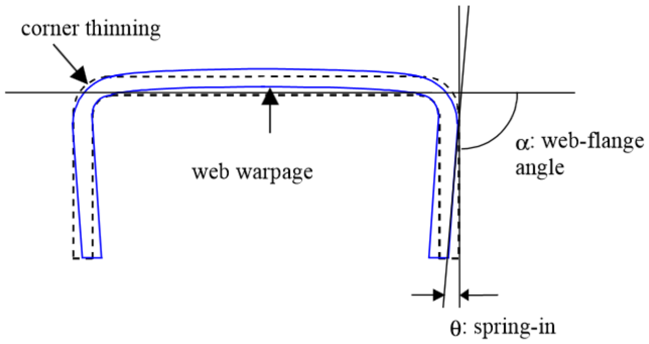
- **What can be done about it?**
  - Proper, accurate control of the cure
  - Instrumentation to document the process
    - Typically thermocouples

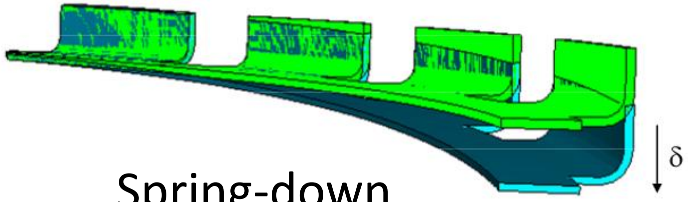
EXOTHERM

- Exotherm is essentially the opposite of under-cure
- Exotherm refers to a situation where the exothermic reaction creates so much heat that it degrades the polymer (causes the polymer to start to burn)
- This is typically visually apparent (darkened regions, cracking)

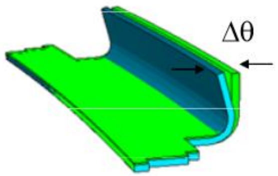
DIMENSIONAL CONTROL

- What is dimensional control?
  - *Laminate thickness:* based on combination of fiber, resin, voids and processing parameters
  - *Geometric deviations:* parts can deviate from their desired/expected geometry during/due to processing

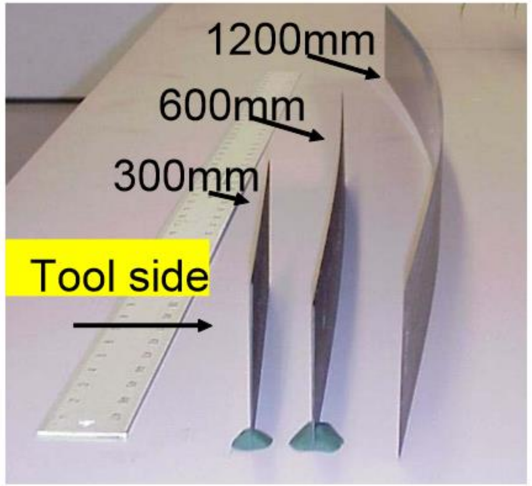




Spring-down



Spring-in



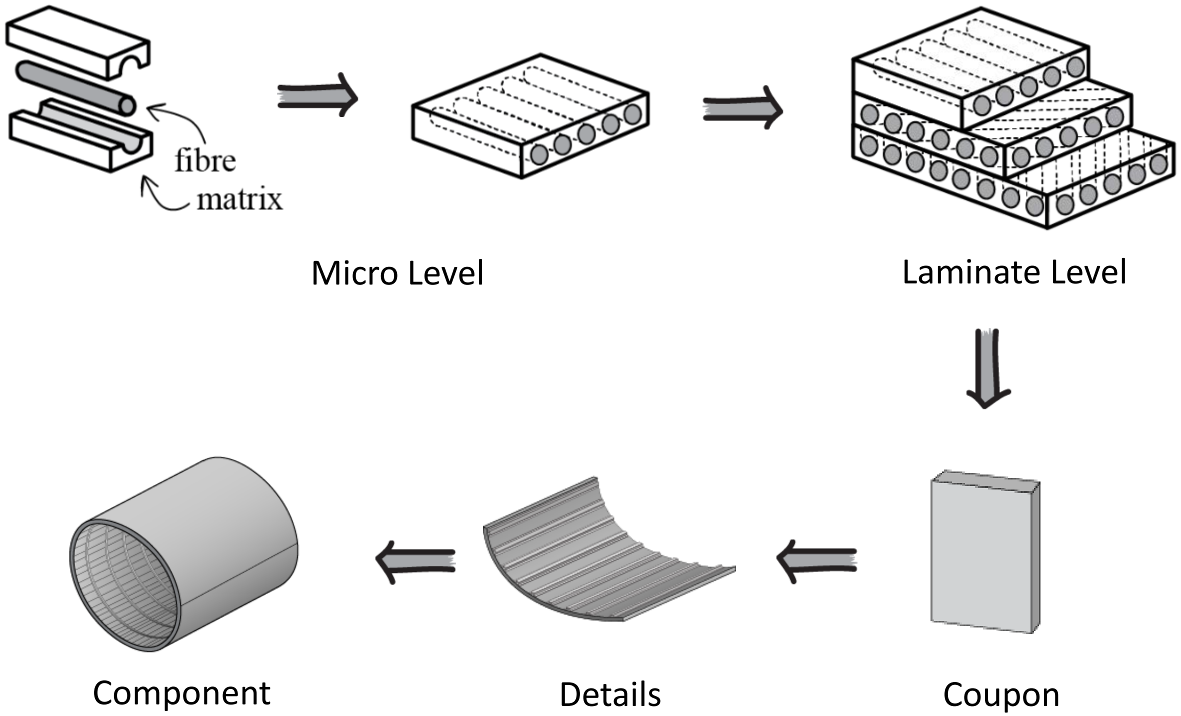
Warpage

DIMENSIONAL CONTROL

- How does a dimensional change happen?

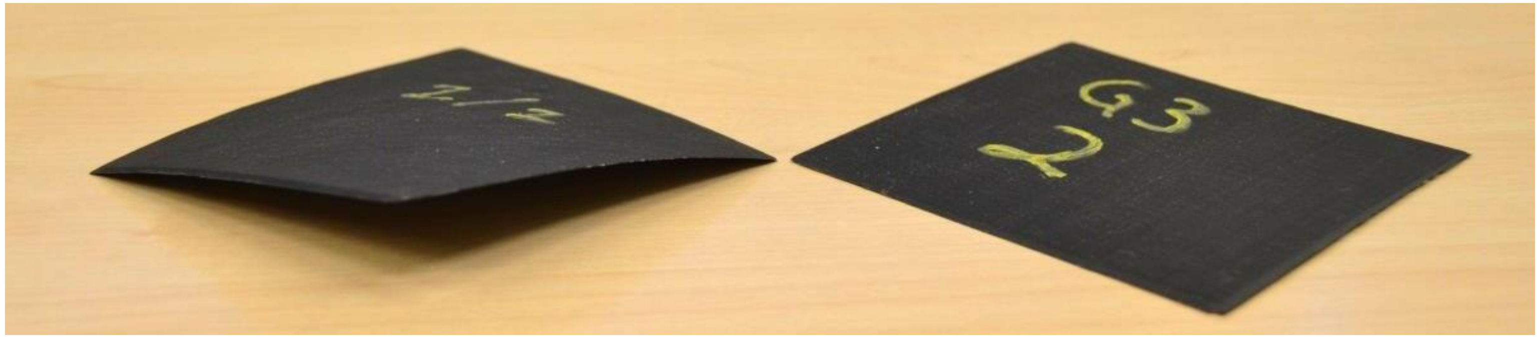
SOURCES:

- Cure shrinkage
- CTE mismatch
- Tool-part interaction
- Lay-up
- Temperature/cure gradients
- Part details/Geometry
- Post curing
- Drilling and assembly
- Moisture absorption



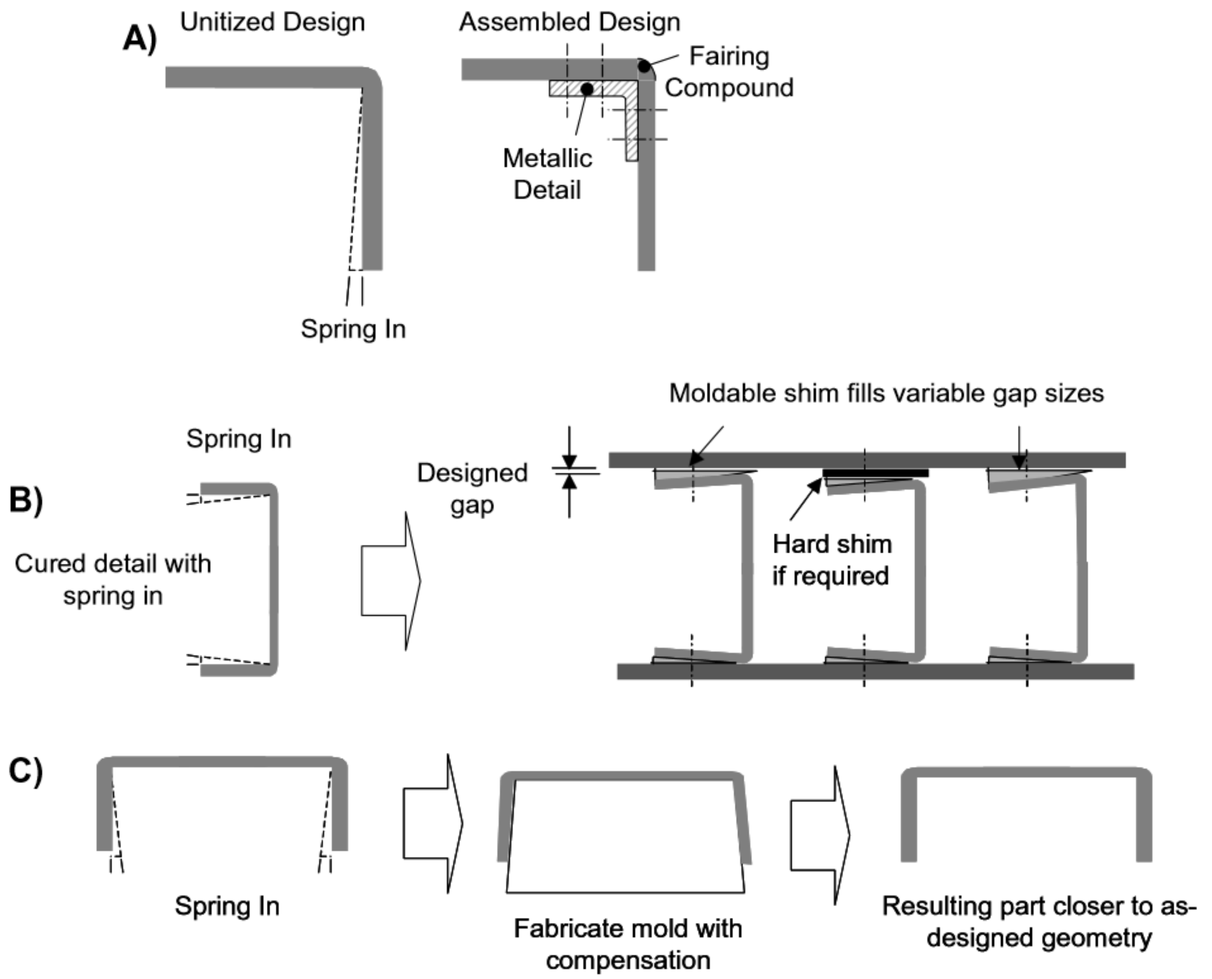
DIMENSIONAL CONTROL

- Consequences/effects of dimensional control
  - Poor fit-up
  - Unintended changes in structural response (eg. deflection shape, aerodynamics, etc.)
  - Structural integrity may be compromised
    - Parts may be forced to fit thereby imposing stress
    - A dimensional control issue may be a symptom of something more critical (ie. improper cure, etc.)



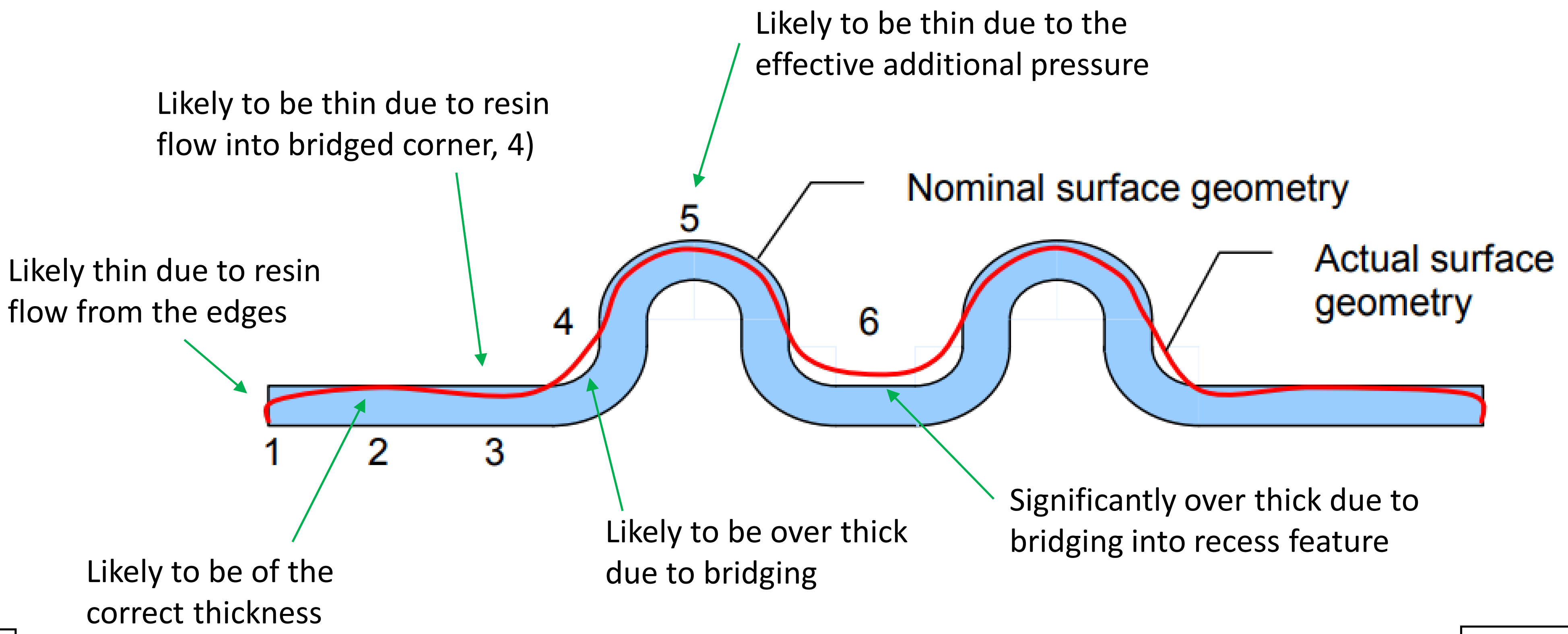
DIMENSIONAL CONTROL

- *What can be done about it?*
  - Design compensation
  - Assembly compensation
  - Mould geometry compensation
  - Process design



DIMENSIONAL CONTROL

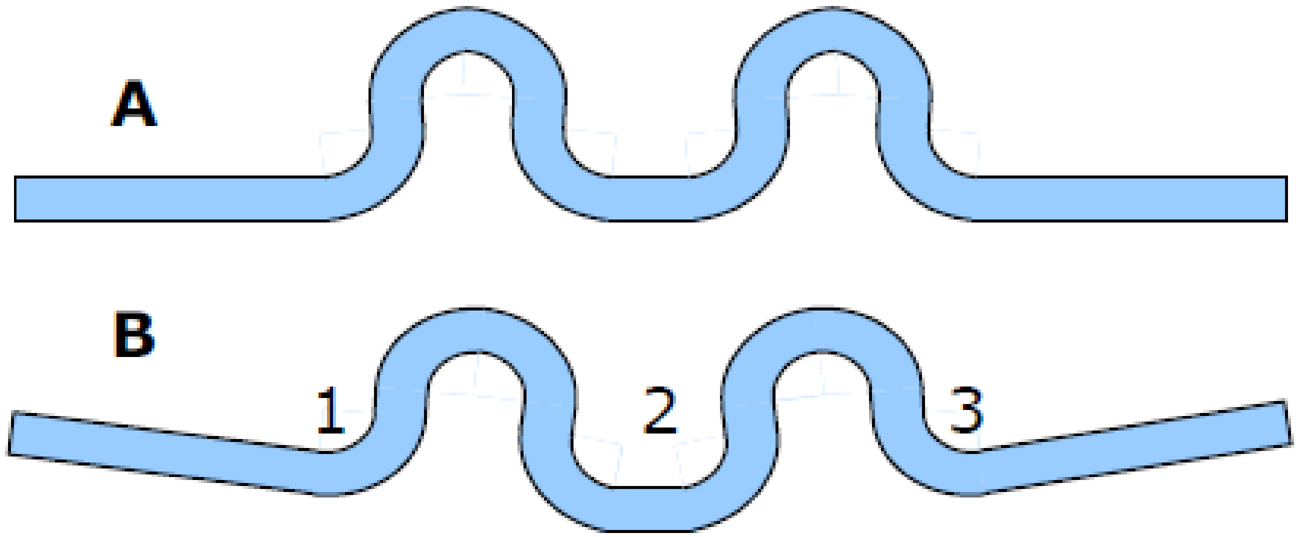
- Example of thickness change in laminate[1]



[1] K.D. Potter, Understanding the Origins of Defects and Variability in Composites Manufacture, Proceedings of ICCM17, 2009.

DIMENSIONAL CONTROL

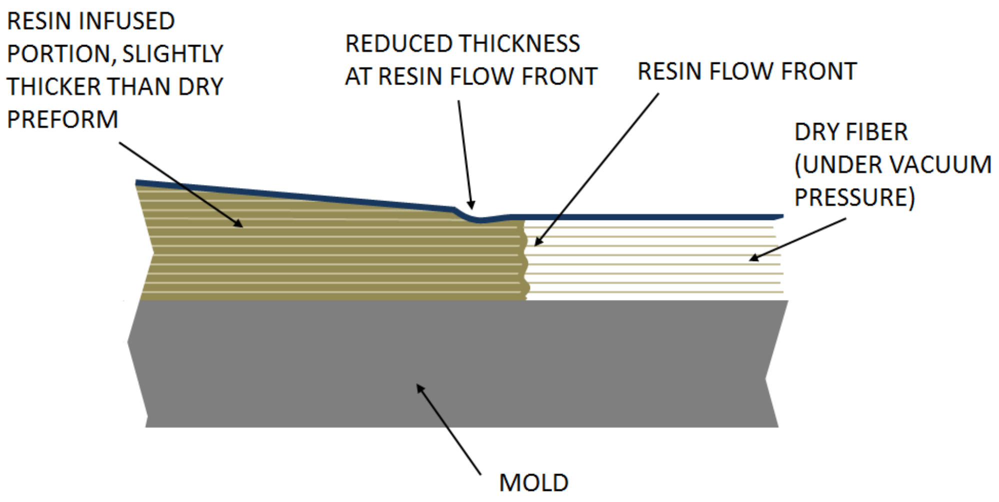
- Example of dimensional change due to spring-in[1]
- 'A' shows theoretical cancelling out of spring-in at each corner
- 'B' shows exaggerated result from variations in thickness



[1] K.D. Potter, Understanding the Origins of Defects and Variability in Composites Manufacture, Proceedings of ICCM17, 2009.

DIMENSIONAL CONTROL

- What causes a change in laminate thickness?
  - Improper processing parameters
  - Lay-up error (the wrong materials go into the part)
  - Human variation (spray up)

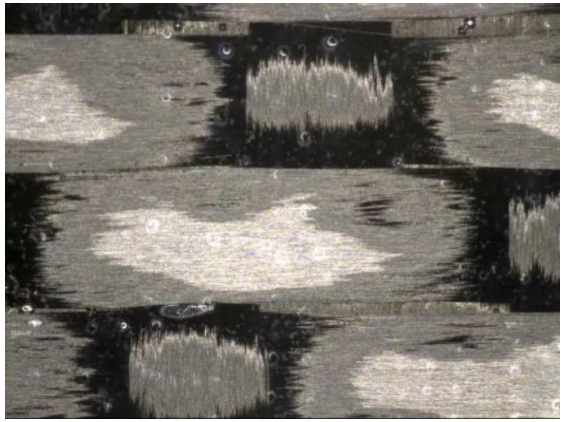


Thickness variation during vacuum infusion

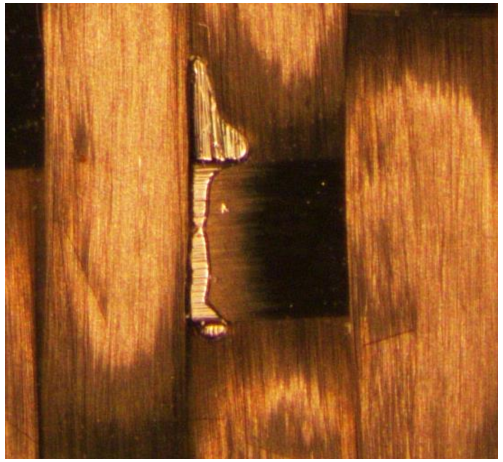
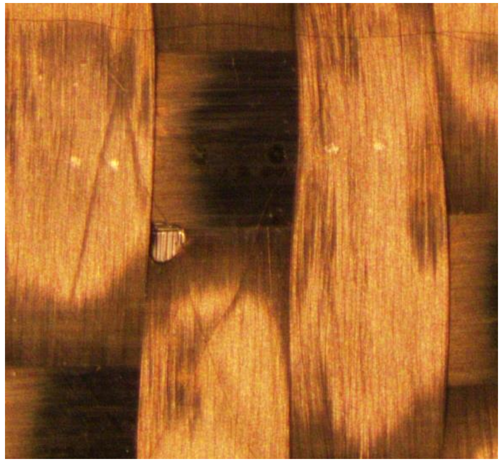
POROSITY

- Porosity refers to small resin voids/air bubbles within the composite
- Typically classified as:
  - Surface porosity: porosity only on the surface
  - Bulk porosity: porosity within the part
    - Porosity within tows
    - Porosity between tows
- Wide variety of sources:
  - Entrapped air
  - Improper consolidation
  - Volatiles trapped in the resin that come out of solution due to pressure/temperature change
  - Inadequate preform conformability
  - Etc…

POROSITY

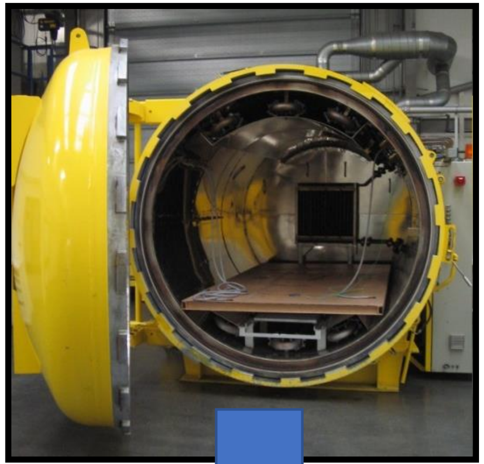


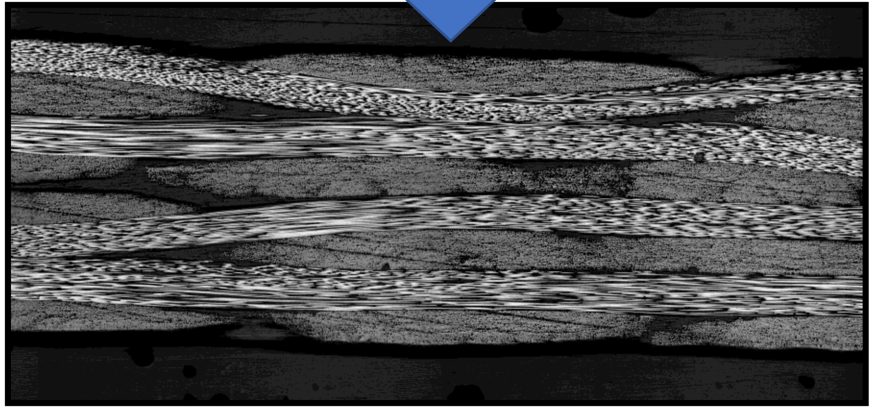

Intra-tow porosity

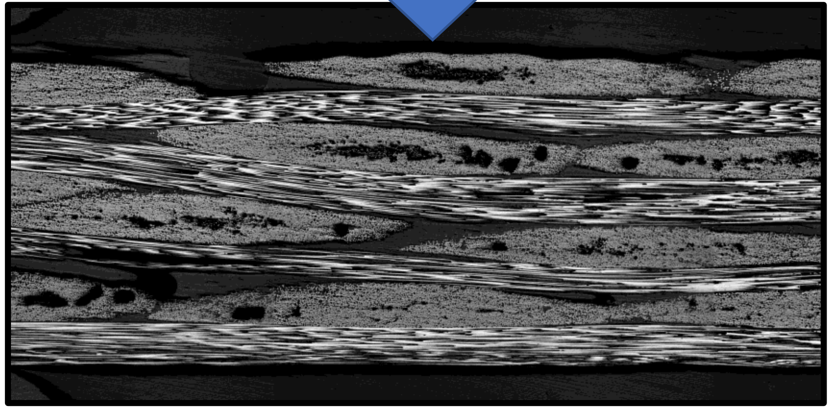
Inter-tow porosity

POROSITY





Processed in an autoclave



Processed out of an autoclave

FIBRE MISALIGNMENT

- Three main types of fiber misalignment:
  - Bulk misalignment, ie. ply is incorrectly positioned, added or missed
  - Fibers are slightly misaligned (could be only a few degrees)
  - Fibers are wavy/wrinkles in local areas

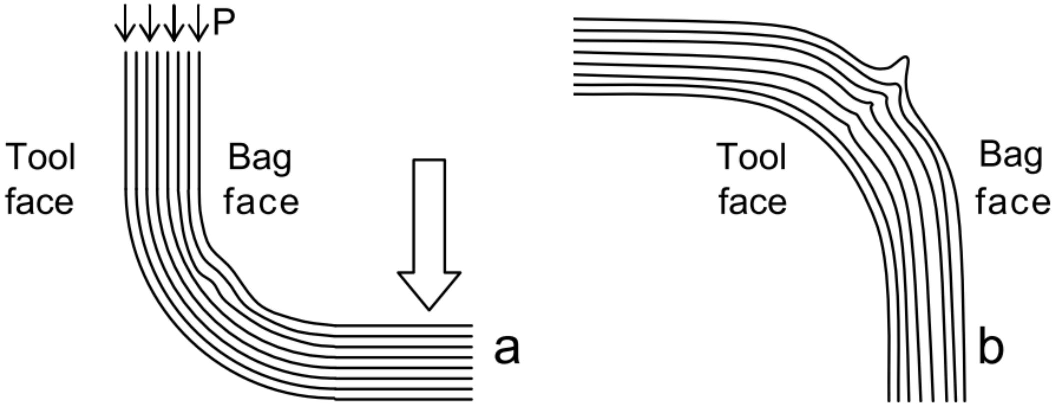
- Variety of reasons for fiber misalignment:
  - Human error (improperly placed or missed plys)
  - Inadequate debulk
  - Drape/excess length
  - Inadequate resin viscosity
  - Fiber/prepreg packaging
  - Low V_f (in RTM process)
  - Excessive injection pressure (in RTM process)

FIBRE MISALIGNMENT

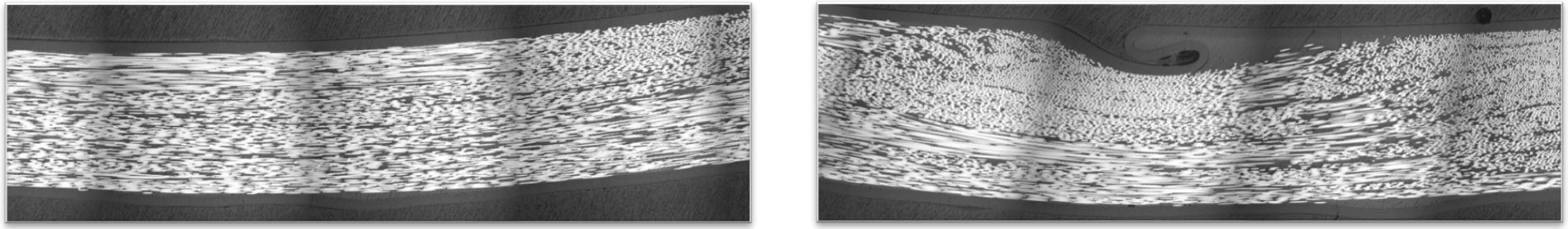
- *"Almost all of our mechanical property data is generated from flat laminates, but almost all useful components are of more complex geometry."* [1]

[1] K.D. Potter, Understanding the Origins of Defects and Variability in Composites Manufacture, Proceedings of ICCM17, 2009.

FIBRE MISALIGNMENT



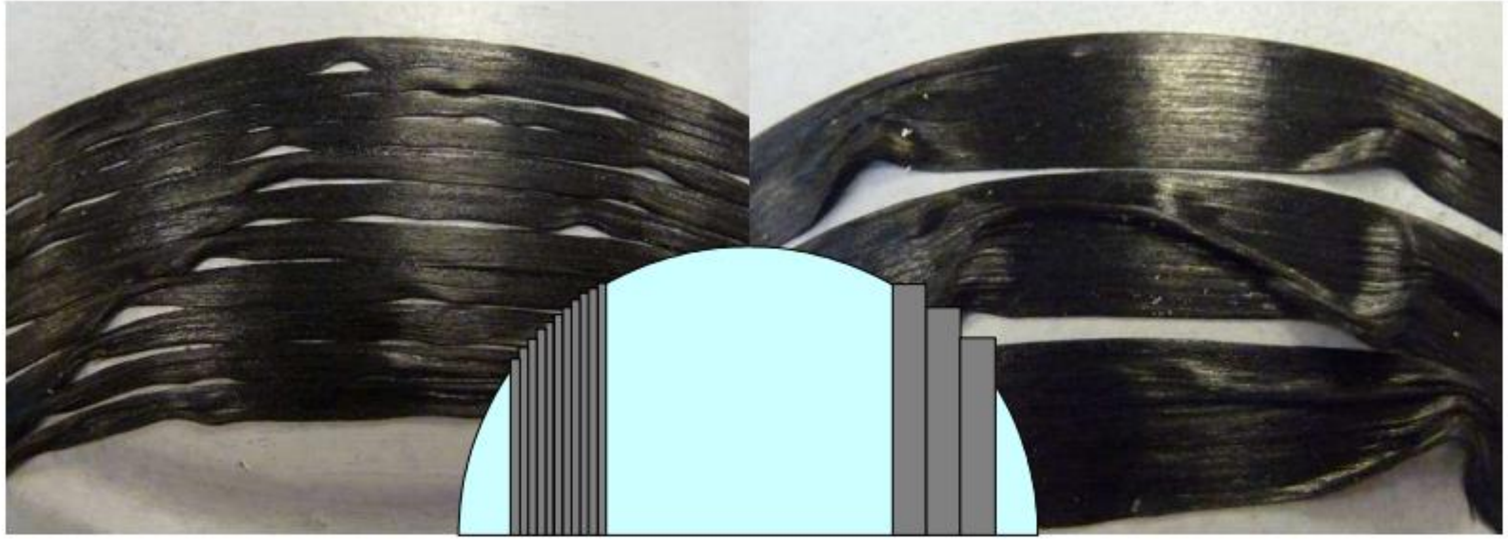
Wrinkles formed due to mismatch of radius on inside and outside of ply



Micrographs of cross sectioned composite with misaligned fiber

FIBRE MISALIGNMENT

- Image below shows fibre misalignment due to draping of narrow and wide unidirectional tows
- Excess length problem, exasperated by wider tow width
- Important to distinguish between misalignment caused by successful drape vs. failed drape
- Misalignment due to successful drape is inevitable, must be taken into account during design phase

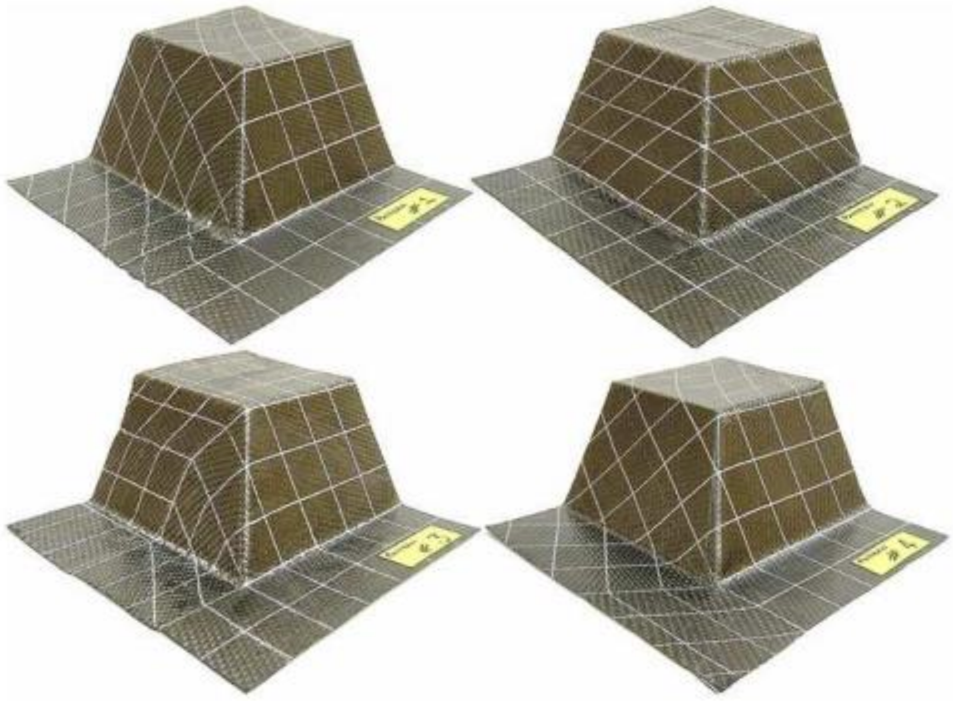


Fibre misalignment by draping narrow and wide UD prepreg on 100 mm hemisphere[1]

[1] K.D. Potter, Understanding the Origins of Defects and Variability in Composites Manufacture, Proceedings of ICCM17, 2009.

FIBRE MISALIGNMENT

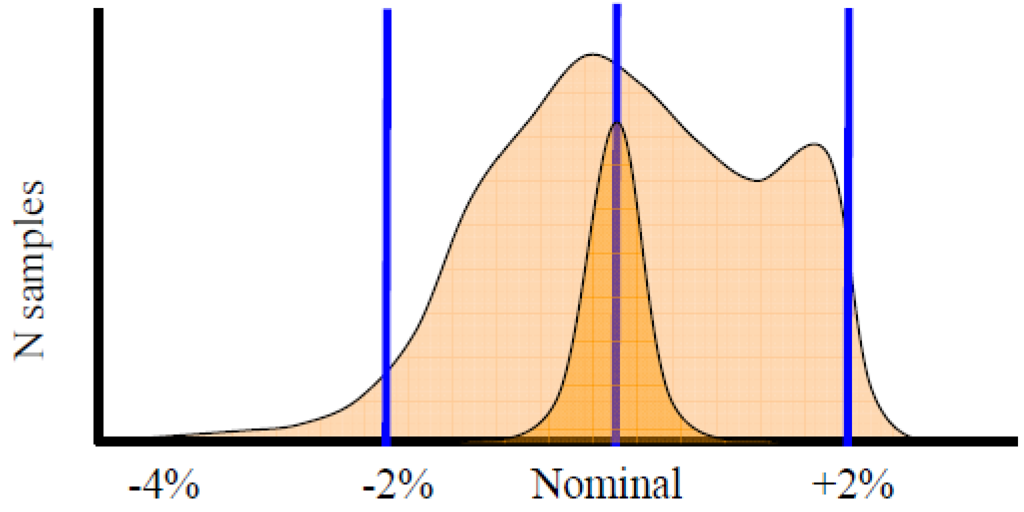
- Image below shows variations dur to draping woven fabric[1]
- Four different patterns for one geometry
- Note: bottom right corner starts out the same but fibre directions change across the geometry
- How does a factory control this?



[1] K.D. Potter, Understanding the Origins of Defects and Variability in Composites Manufacture, Proceedings of ICCM17, 2009.

INCOMING MATERIAL VARIABILITY

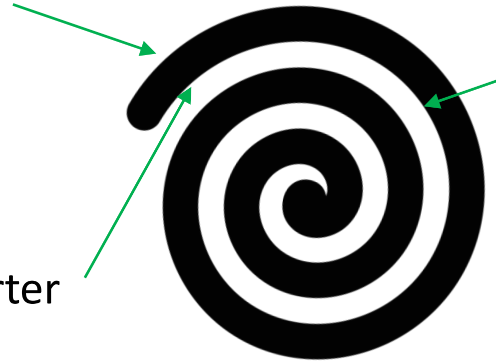
- Variability of areal weight of incoming material
- Attributed to various sources such as stiffness and alignment of roller[1]
- Various scales of variability: cm^2 to cm^2 vs m^2 to m^2
- Figure below shows variability in areal weight of 127 batches (381 test points)[1]



[1] K.D. Potter, Understanding the Origins of Defects and Variability in Composites Manufacture, Proceedings of ICCM17, 2009.

INCOMING MATERIAL VARIABILITY

- Fibre waviness is inherent to the material
- Typically attributed to fibre wrapping around the roll during manufacture
  - 300mm diameter drum with 0.25 mm thick prepreg wrapped around is 0.167% longer on outside than inside surface
  - To accommodate this path difference the fibres on the inside surface buckle to form wrinkles
  - Assume that the wrinkles are in the form of a sine wave, can calculate a characteristic maximum angle of 4.7^{o} is needed in a sinusoidal wrinkle



[1] K.D. Potter, Understanding the Origins of Defects and Variability in Composites Manufacture, Proceedings of ICCM17, 2009.

Thank you for joining us!

The next and final session is:

Session 12: Testing

November 18, 2020 @ 9:00 am PT

Questions?

For more information on future dates and times visit:

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