



Composite Materials Research Program at McGill

Pascal Hubert

Werner Graupe Chair

in Sustainable Composite Manufacturing

May 2017



McGill

Structures & Composite
Materials Laboratory

McGill University



- Founded in 1821
- 1671 faculty members
- 39,989 students
- Ranked 1st in Canada
- Ranked 30th in the World
- 10 faculties and 12 schools
- Budget of \$B1.1

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Mechanical Engineering

- 30 faculty members
- 550 undergraduate students
- 110 PhD
- MEng (60 Thesis, 30 Non-thesis, 30 Aero)
- Ranked 2nd in Canada
- Honours Program
- Aeronautical Engineering or Design



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The window to McGill Aerospace Activities



- **35 professors**
- **\$20M in research**
- **250 students**
- **100 internships/yr**
- **6 research themes**

1. Support and develop collaborative aerospace research between McGill professors and international/national companies and universities
2. Evaluate and align aerospace programs in Faculty of Engineering to current technology and industry needs
3. Increase student awareness of and participation in aerospace sector
4. Provide students aerospace internships, activities, and events



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CREPEC

- Innovate and train highly qualified personnel (HQP) in the field of high performance polymers systems and composites

Universities

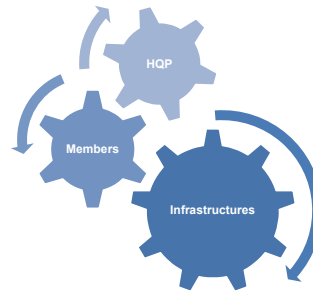


Colleges



Research Center for
High Performance Polymer
and Composite Systems

www.crepec.com



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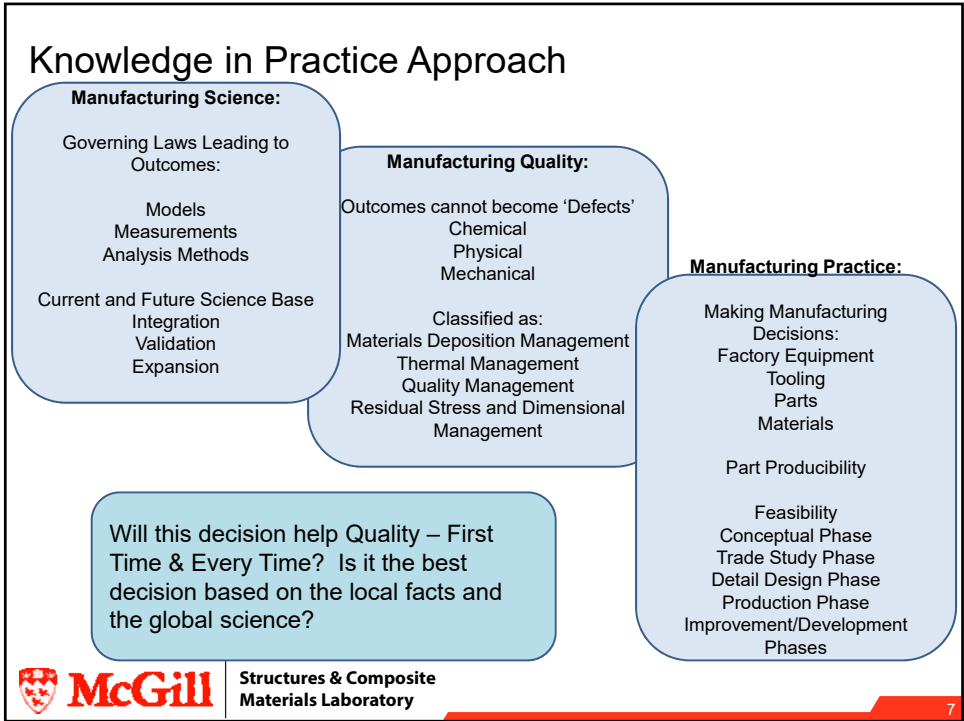
Composite Research Network Focus



- How do we create relevant manufacturing **science**, in an integrated science base?
 - Use manufacturing simulation as a tool to capture this science
- How can we make better **science** based manufacturing design **decisions**?
 - Right-sized for different industries and receptor capacity, from aerospace OEMs to industrial SMEs
 - Protect, advance, and disrupt manufacturing practice
- Demonstrate the value of this “Knowledge in Practice” approach in education, research, and industrial practice



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Tier I and II Members, Nodes, Funding Agencies

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Tier III Projects



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McGill Structures and Composite Materials Laboratory

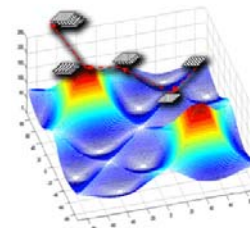
- Professor Pascal Hubert: Manufacturing and testing of composite material structures. Development of nano-modified polymer composites.
- Professor Larry Lessard: Design and development of composite structures. Optimization of composite material components.



Composite material structure processing simulation (Hubert)



Professor Pascal Hubert and two of his graduate students present their research on composite materials at McGill 'Applause' 2008



Composite layout optimization for aerospace structure (Lessard)

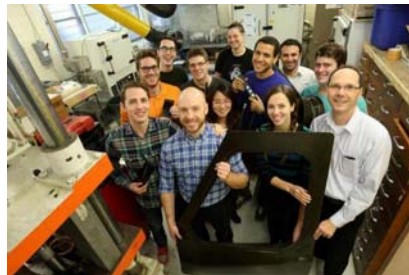
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Facilities

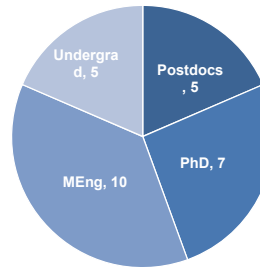
- **Characterization**
 - Thermal analyzers (DSC, TGA, TMA)
 - Rheometer
 - Dynamic mechanical analyzer
 - Servo-hydraulic testing frames
 - Electro-mechanical testing machine
 - Nanoindenter, Atomic Force Microscope
 - Electrical properties
- **Processing**
 - VARTM test-bed
 - RTM press and injection system
 - Ovens, heated tooling processing cell
 - Specialized out-of-autoclave testing jigs
 - Composite repair test cell
 - Access to hot-press, AFP machines, autoclave
- **Simulation**
 - COMPRO, RAVEN, 3DINFIL, PAM-RTM
 - ANSYS, Abaqus, Hypersizer
- **NDE**
 - Optical microscopy
 - Thermography
 - SEM, TEM, X-Ray, Micro-CT



People



~ 25 students/researchers



Sponsors & Collaborators



The Boeing Company
 MDA Corp.
 Ford Motor Company
 Bell Helicopter
 Bombardier
 Airbus
 Pratt & Whitney
 Delastek
 Heroux-Devtek
 Convergent Manufacturing Technologies
 Gurit
 Hutchinson
 Avior
 Stelia
 Southern Spars
 L3



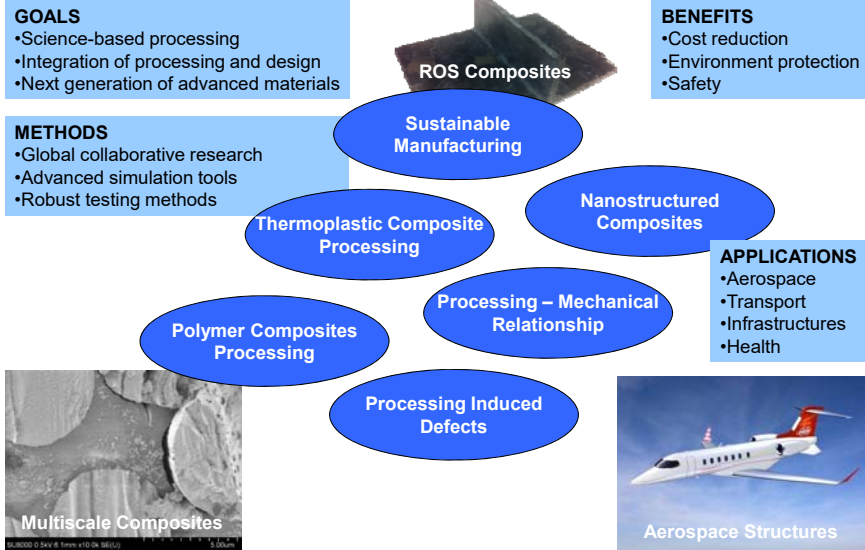
NASA Langley Research Center
 National Institute of Aerospace
 National Research Council
 CDCQ, CTA, CTT

Purdue University
 Ecole Polytechnique de Montreal
 Universite Laval
 ETS
 Concordia University
 University of Ottawa
 The University of British Columbia
 University of Bristol
 TUM
 EPFL
 University of Southern California
 University of Auckland

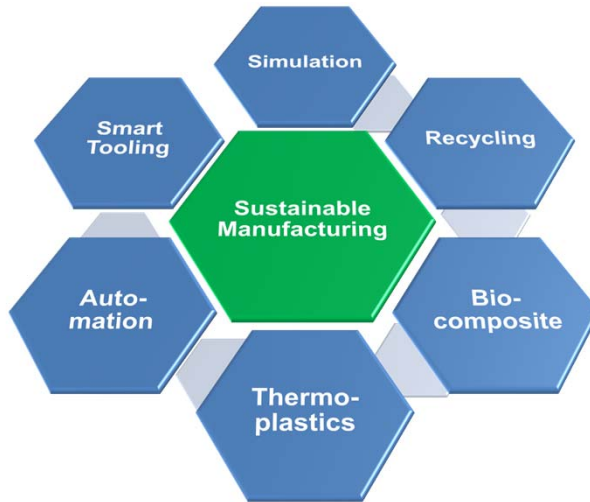
**Structures & Composite
 Materials Laboratory**



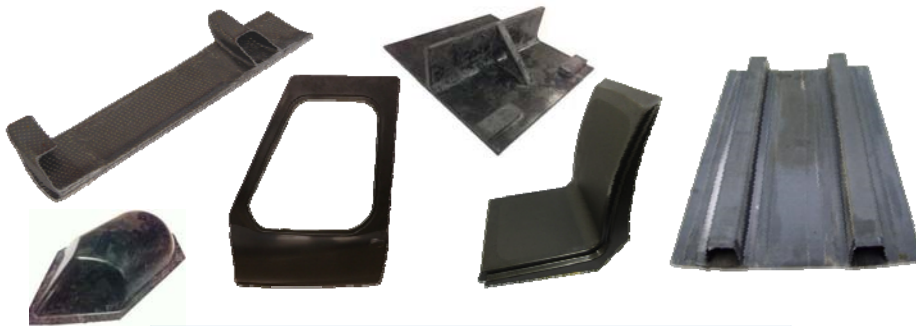
Research Overview



Composites Sustainable Manufacturing



Aerospace Research



Process	Issues
RTM, Autoclave, Oven, Compression moulding, AFP, Infusion	Process modelling Process optimization Effect of defects Quality - performance
Repair	Process development

Automotive Research

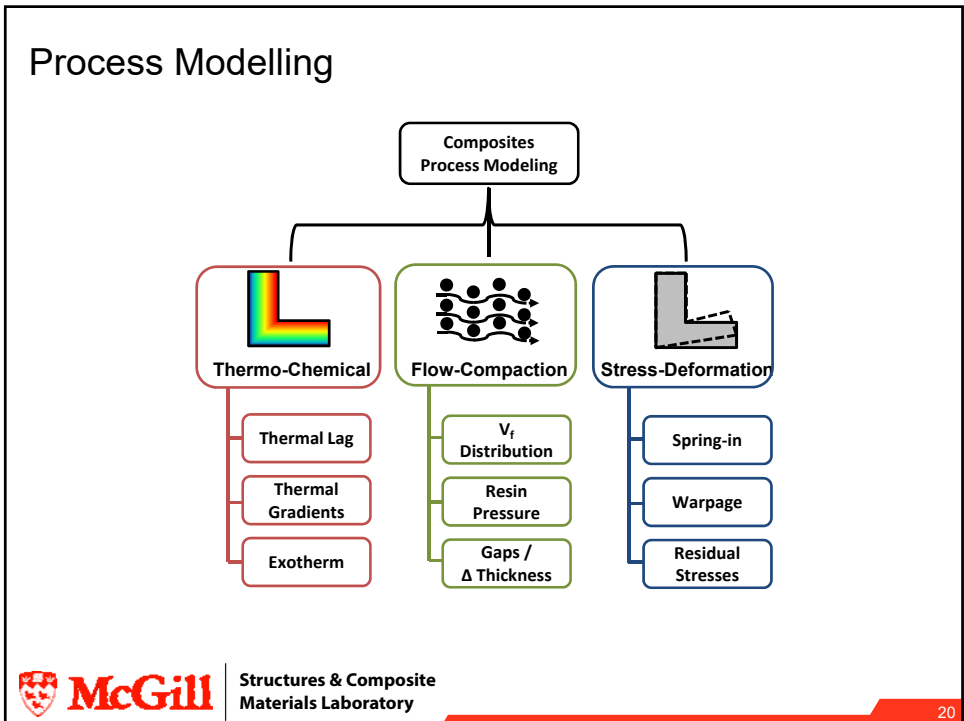
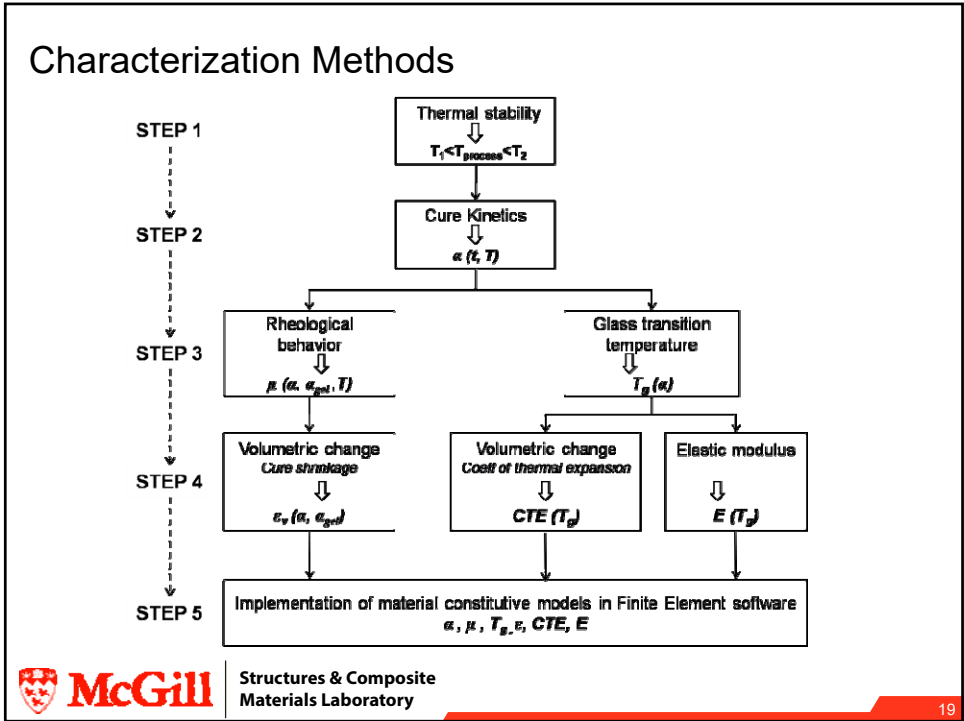


Process	Issues
RTM	Surface finish Bio-based composites
Laser Welding	Process modelling Process optimization

Nanocomposites Research



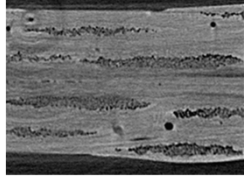
Process	Issues
Resin Film Infusion, Prepreg	Dispersion characterization Structural health monitoring Toughness
Fibre Melt Spinning	Processing - performance



Out-of-autoclave Process Modelling

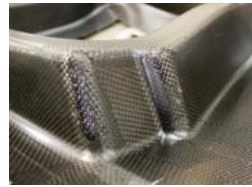
Materials and process conditions

Impregnation



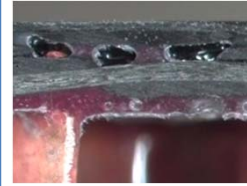
Tooling

Complex shapes



Moisture

Sandwich

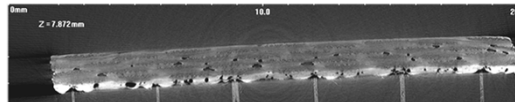


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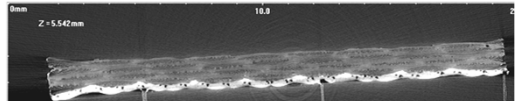
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Micro CT during Processing

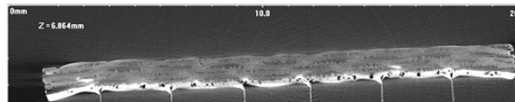
RT



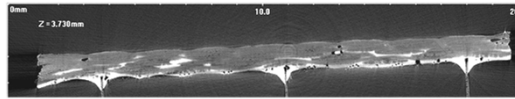
40°C



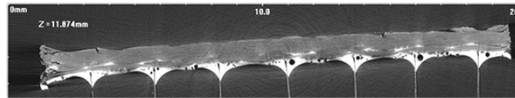
60°C



80°C



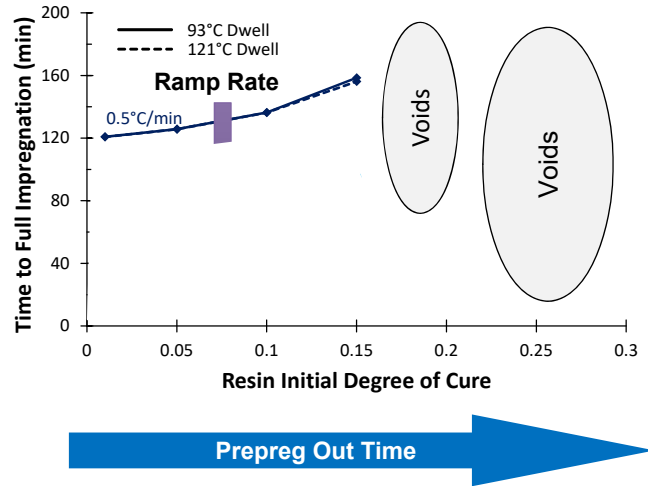
100°C



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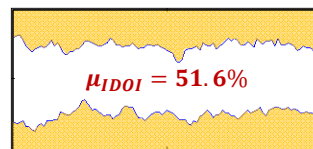
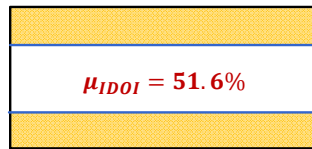
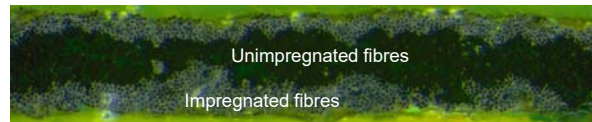
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Prepreg Tow Impregnation Modelling



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Stochastic Modelling



$\mu_{voids} = 0.00\%$
 $\sigma = 0.00\%$

$\mu_{voids} = 0.290\%$
 $\sigma = 0.055\%$

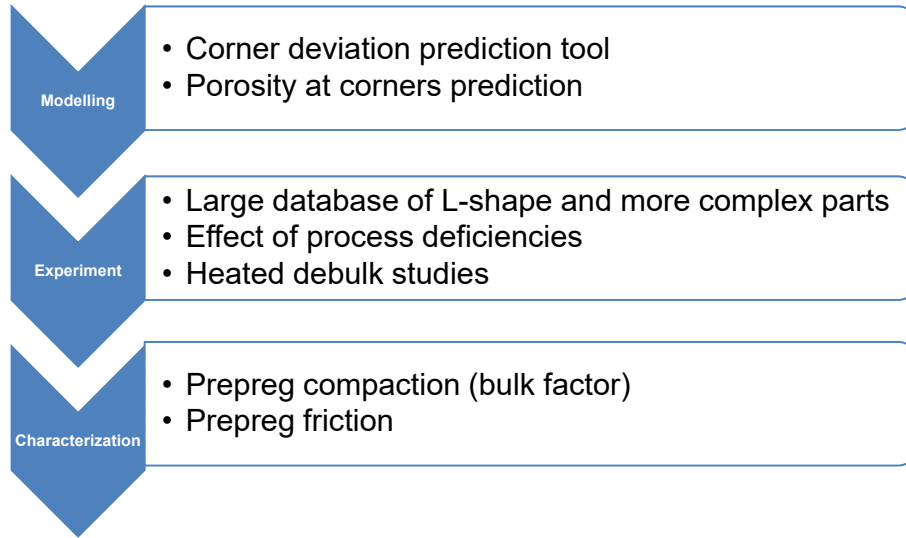
Uniform IDOI

Variable IDOI

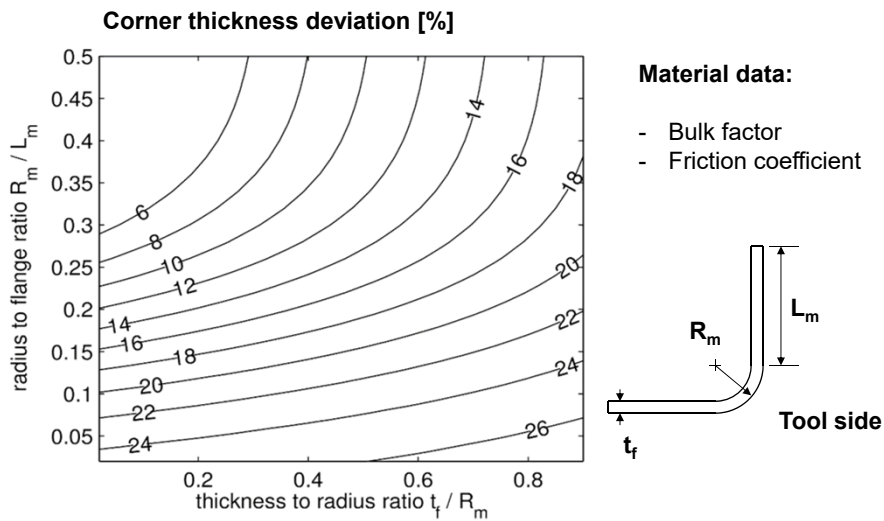


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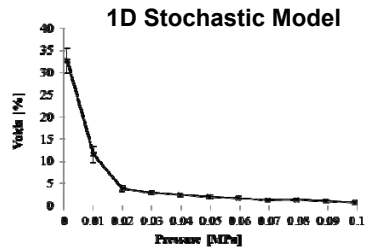
Complex Shapes Processing



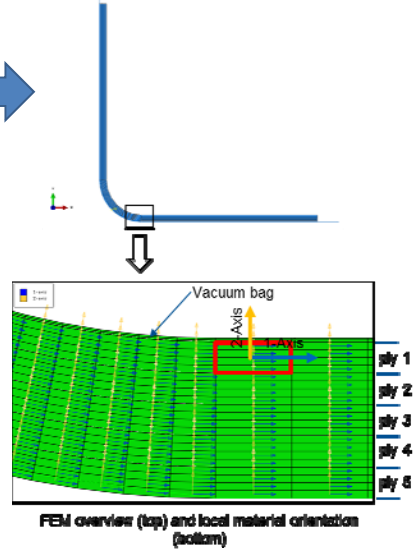
Design Chart



Void Modelling Approach

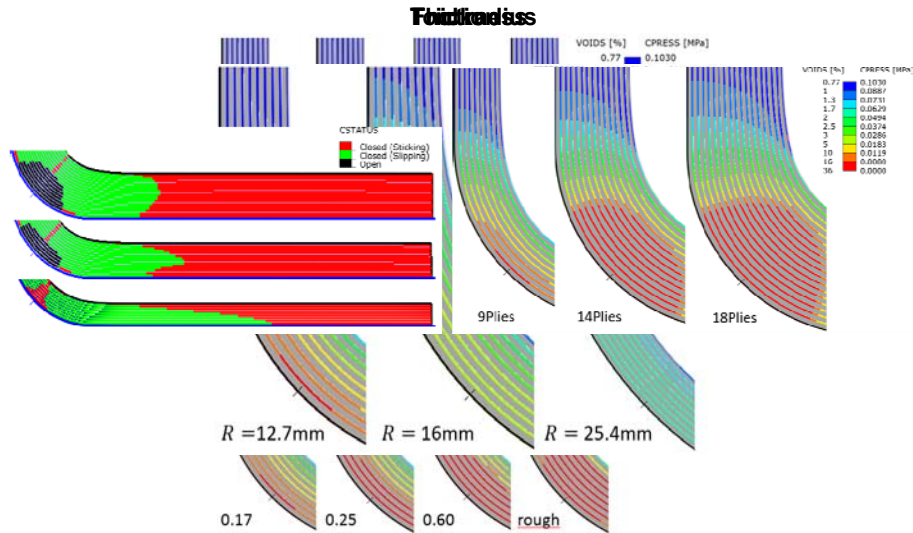


2D FE Model



- Elastic material (E_L E_T G_{LT})
- Frictional contact (stick – slip)
 - Ply - ply
 - Tool - ply
 - Ply - vacuum bag
- Rigid tool
- Output target variable CPRESS

Parametric Studies



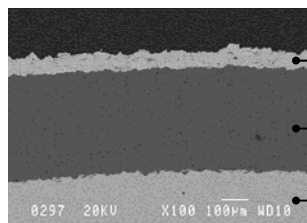
OOA Summary

- A building block approach was used to investigate the processing of OOA preregs
 - development of characterization tools
 - development of processing models
 - reduction of risks associated with scaling up issues
- OOA composites quality is strongly influenced by:

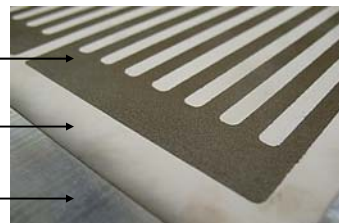
Material Properties	Layup Operation	Processing Conditions
<ul style="list-style-type: none"> • Fabric architecture • Resin viscosity 	<ul style="list-style-type: none"> • Out-time • Moisture absorption 	<ul style="list-style-type: none"> • Heat-up rate • Atmospheric pressure • Vacuum level

TCX™ Heating Element

- Element deposited via thermal spray
- Multilayer system consisting of:
 - a) Resistive coating
 - b) Ceramic insulation
 - c) Tooling Substrate



SEM image of TCX™ element cross-section



Underside of McGill's Heated Tool Plate

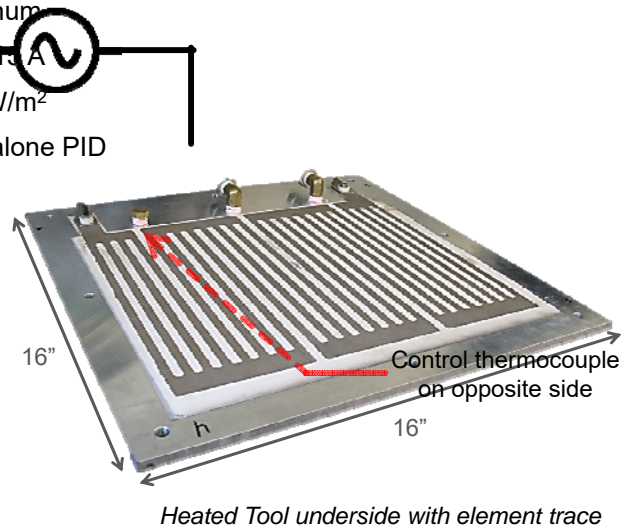
Prototype 1 - Heated Tool Plate

Tooling Material: Aluminum

Power Supply: 110 V / 15 A

Power Density: 7.8 kW/m²

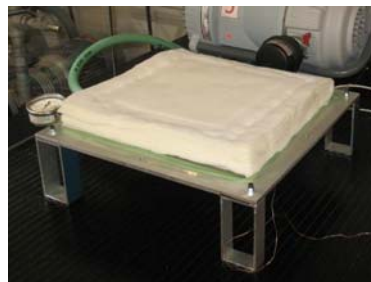
Control System: Standalone PID



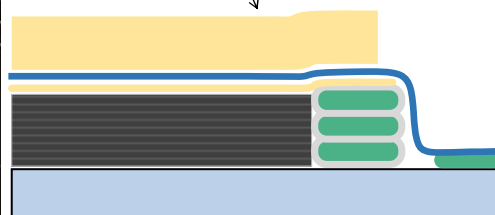
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TCX Bagging Setup



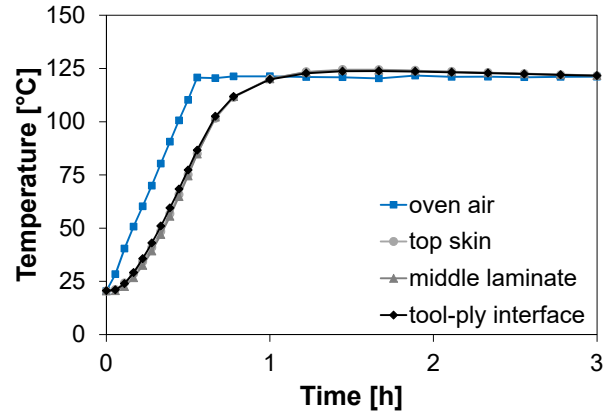
Polyester insulation added to VBO



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Oven Thermal Profile



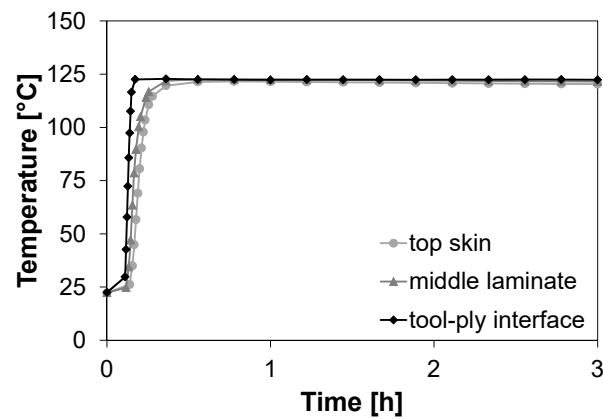
OVEN – 24 plies (9.6 mm) – 3 °C/min



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TCX Thermal Profile



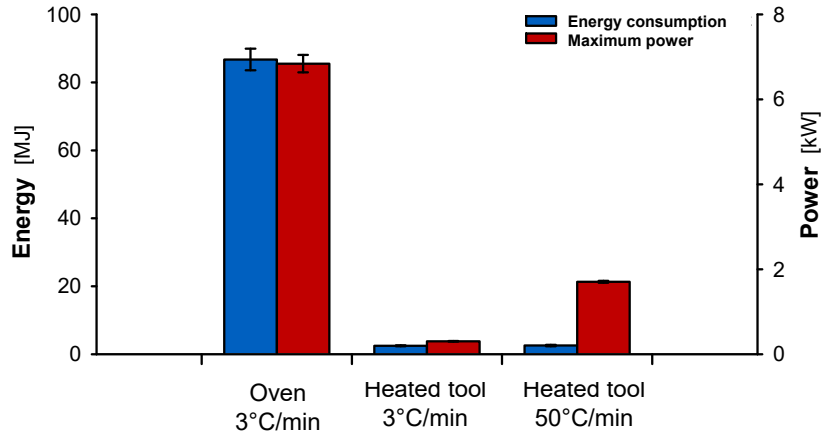
HTP – 24 plies (9.6 mm) – 50 °C/min



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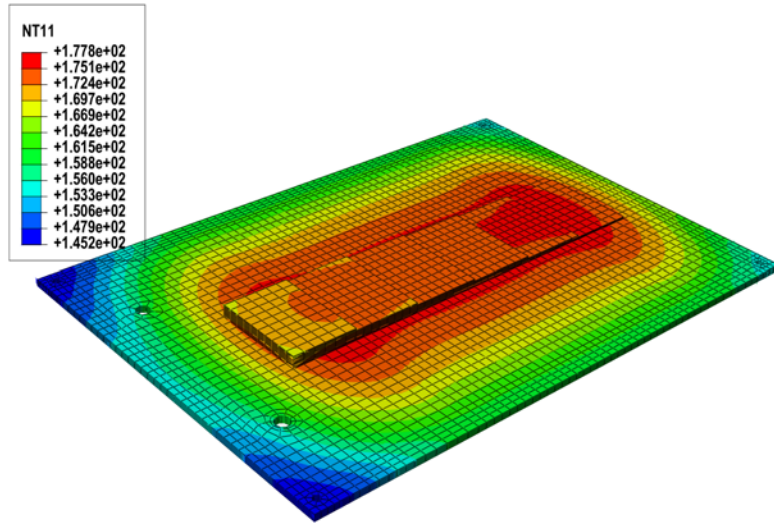
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Low Consumption



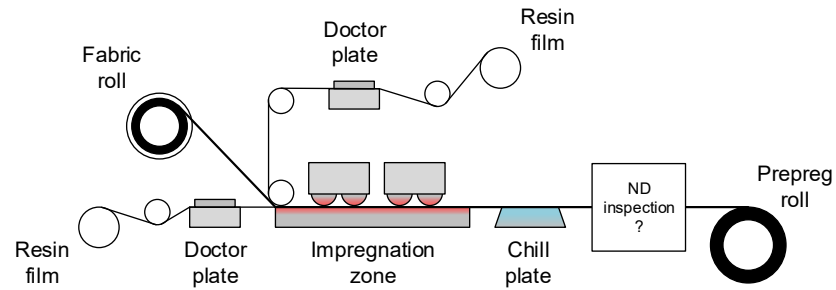
Heated Tool represents 66-92% energy savings

Heated Element Design



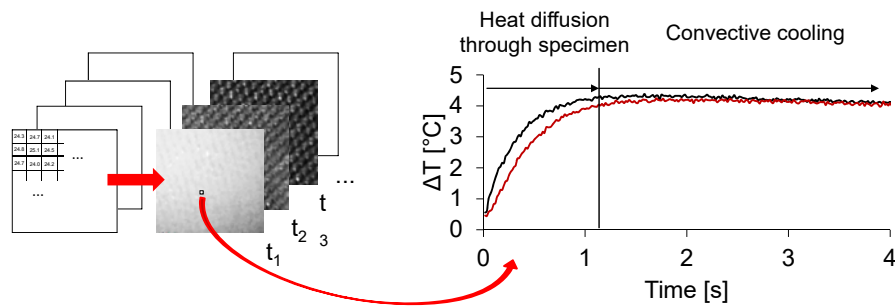
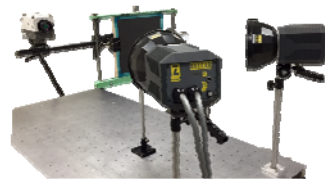
Prepreg In-line Inspection

Investigate the potential use of IR thermography as a method to quantify the degree of impregnation of out-of-autoclave prepreg.

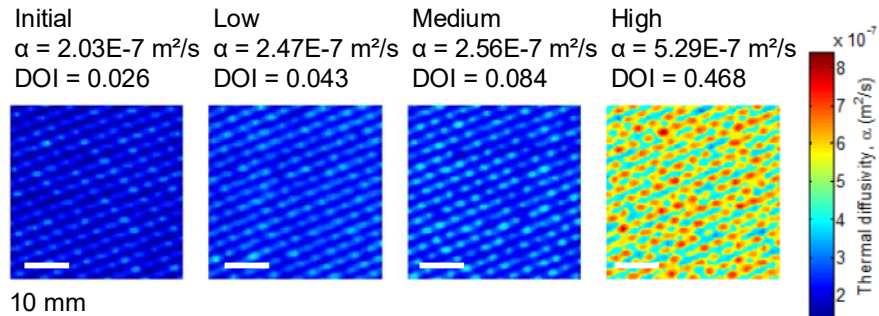


IR Thermography Prepreg Inspection

- Used as a NDE technique for laminates
- Active through thickness setup
- DOI affects heat transfer through the specimen

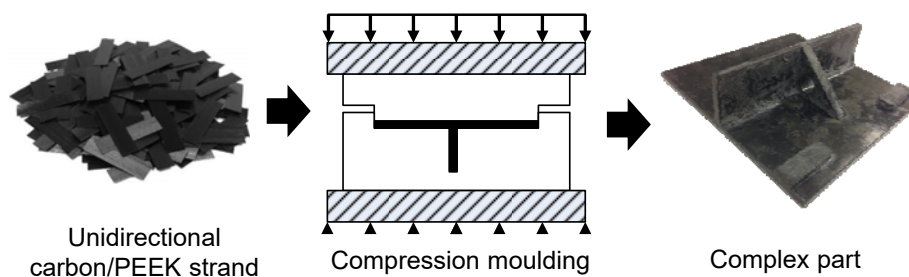


IR Thermography – Results, 8HS



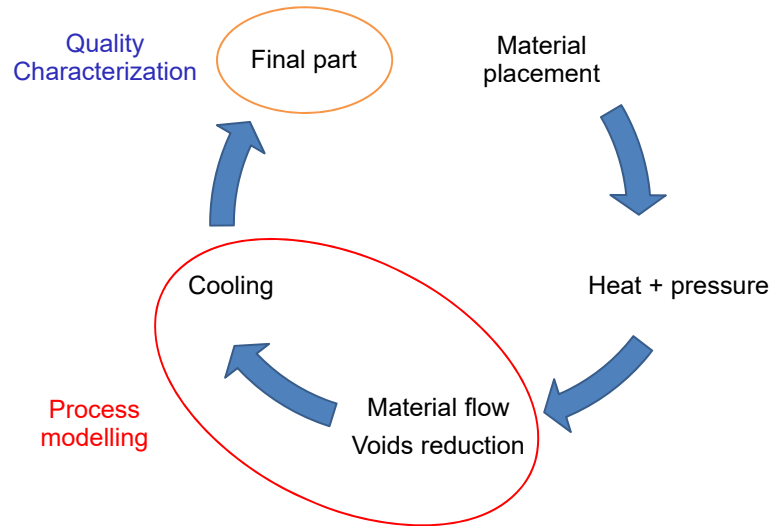
- Thermal diffusivity increases with increasing *DOI*
→ Less entrapped air, less thermal insulation.
- Visible pattern characteristic of fabric architecture.

Discontinuous Long Fibre (DLF) Composites

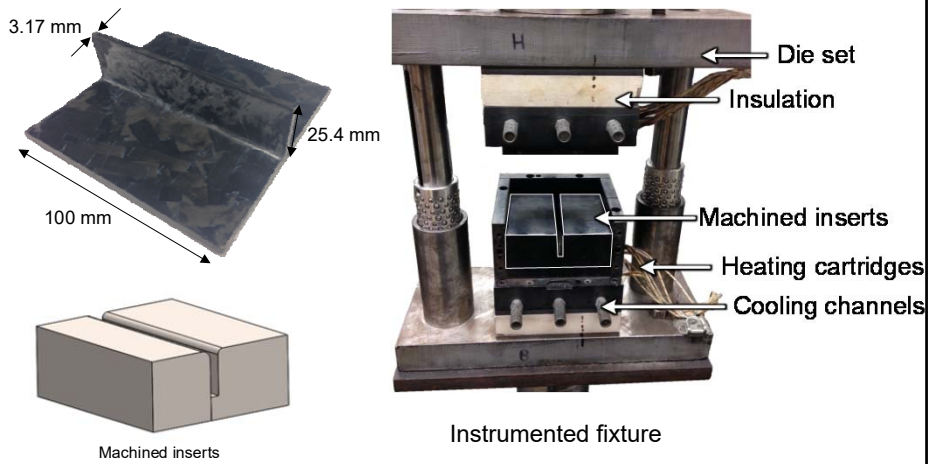


- Short processing cycle → No material cutting/layup time
- Complex geometries
- Net-shape parts
- High fibre volume fraction
- Recyclable

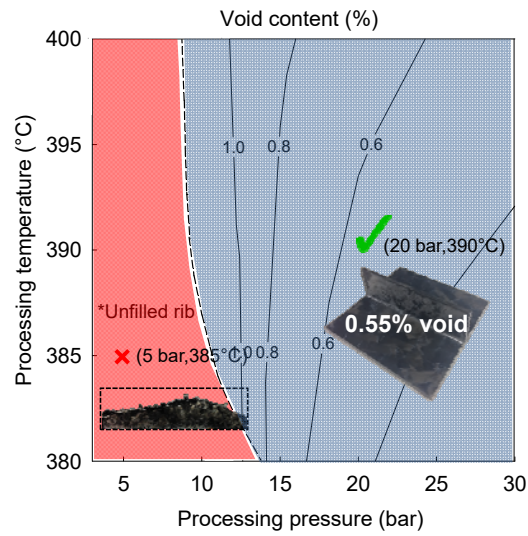
Moulding a DLF part



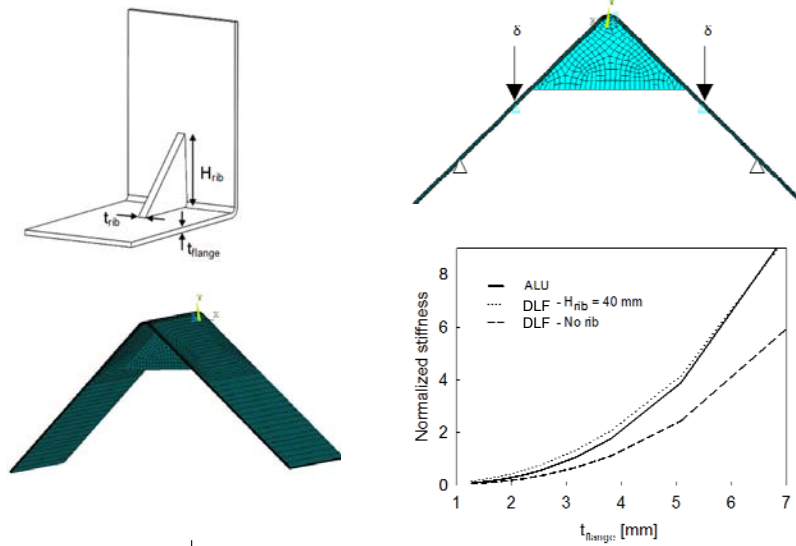
Processing of Complex Shape



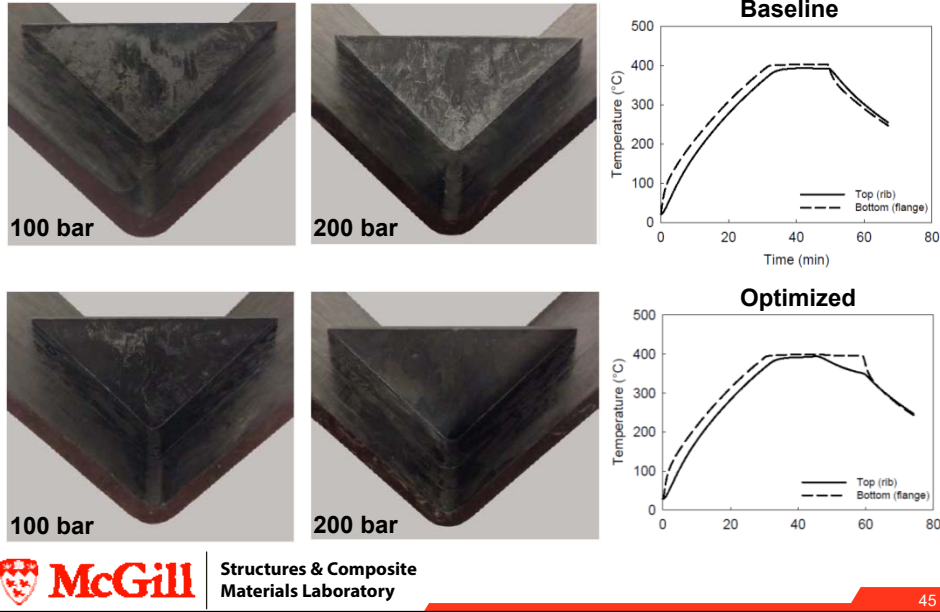
Rib Filling Process Map



Bracket Design

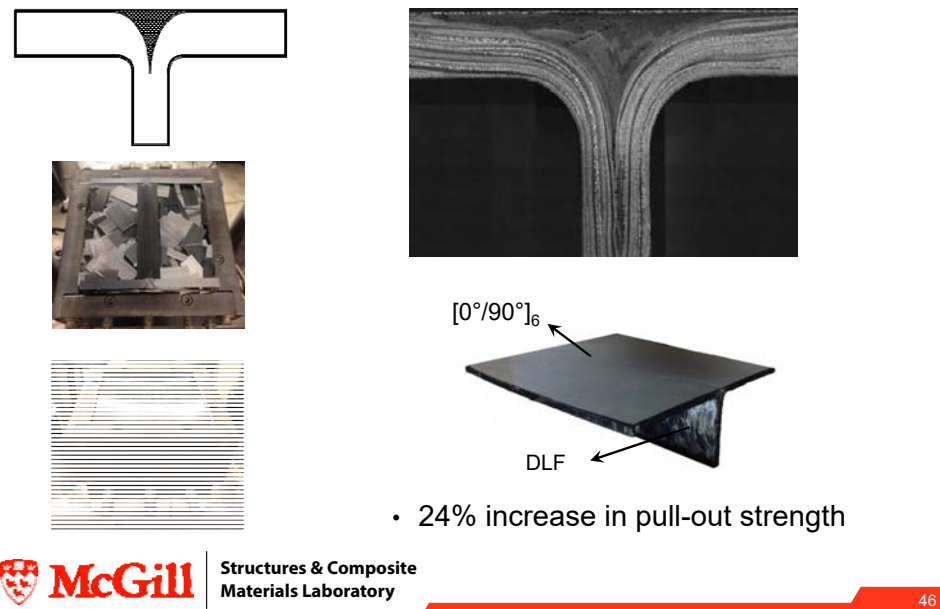


Process Cycle Optimization

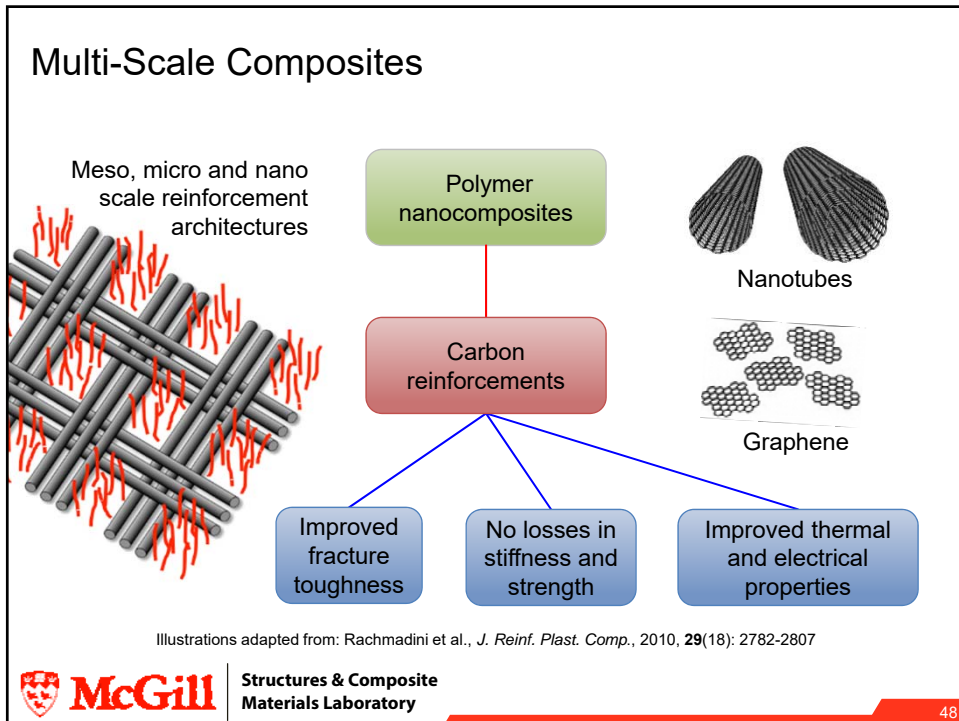
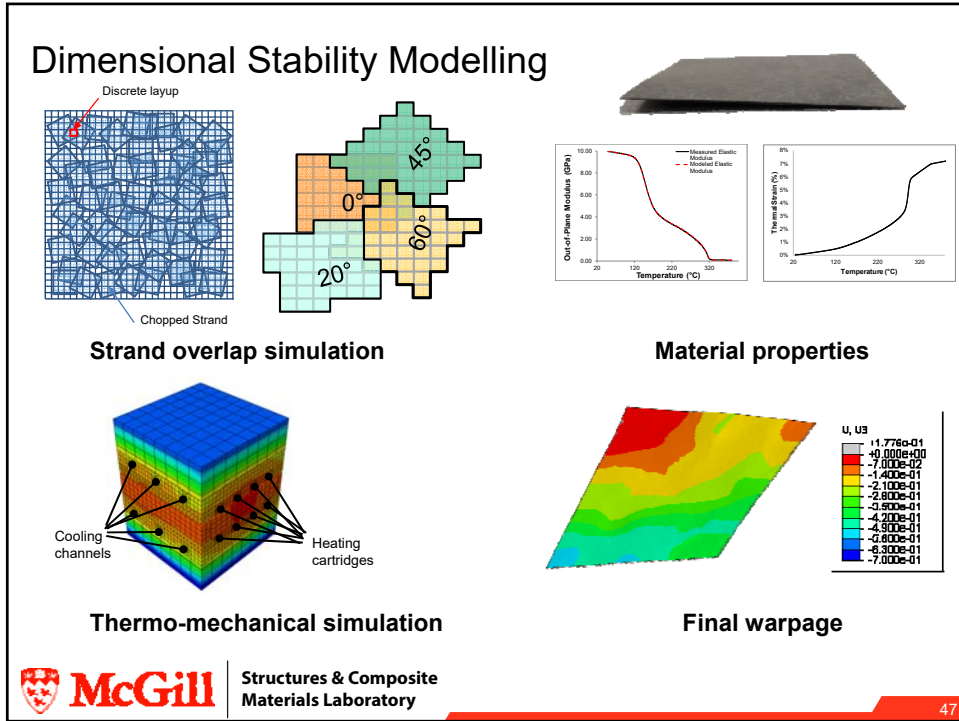


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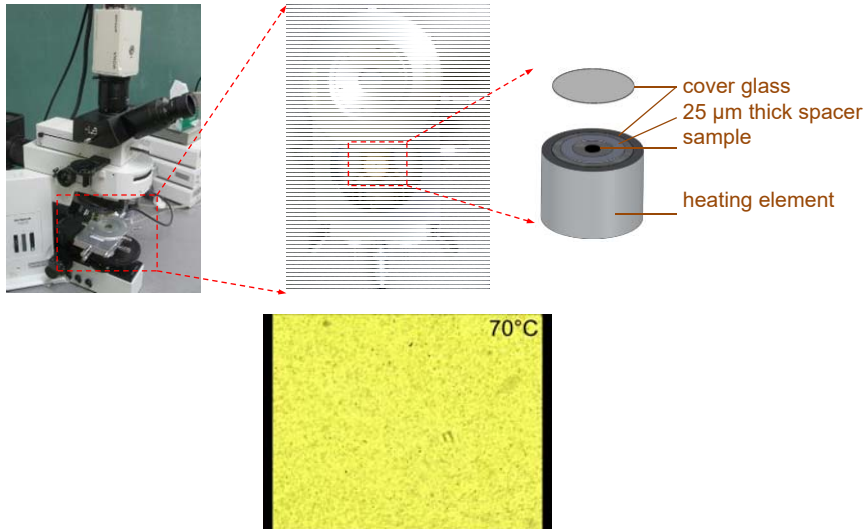
Hybrid DLF-Tape Flow Control



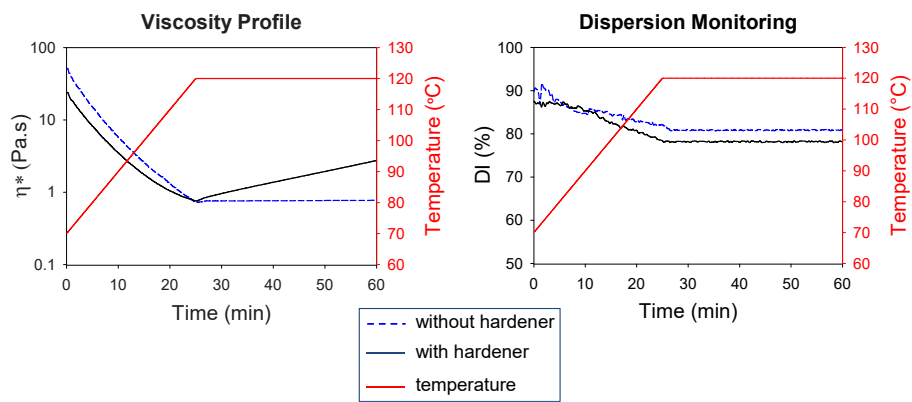
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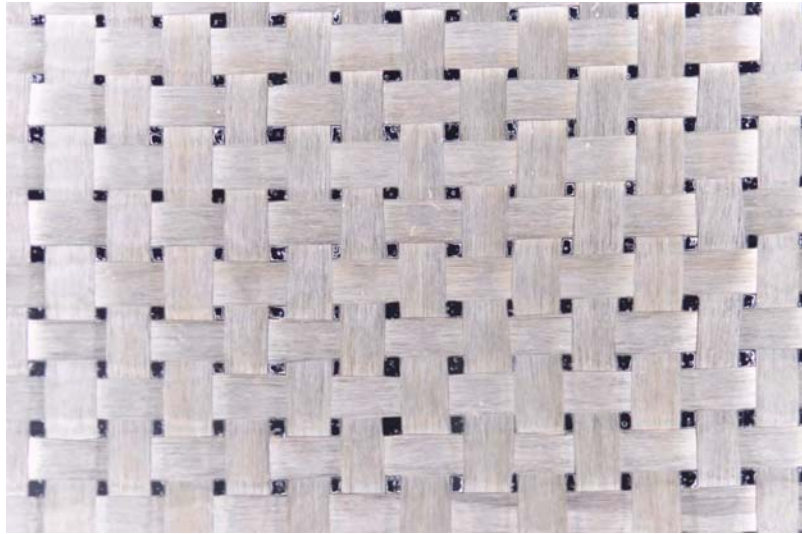
CNT Dispersion Stability



Dispersion Measurement



Resin Film Infusion CNT Stability



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Cure Cycle Optimization

- Low temperature cure to prevent agglomeration
- Cure at 60°C for 65 hours



Baseline cure



Long cure



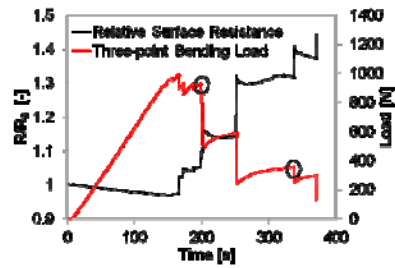
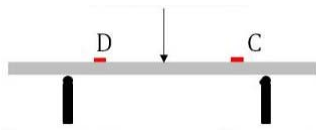
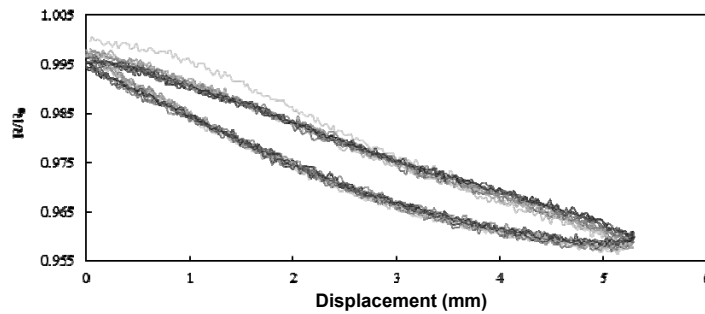
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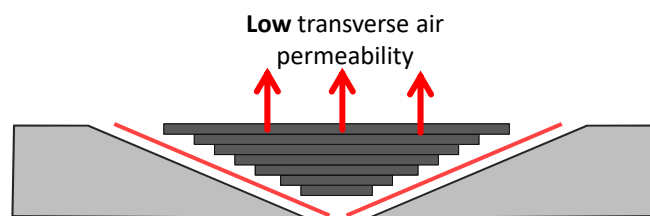
Sensor Application



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Air Evacuation in Scarf Repairs



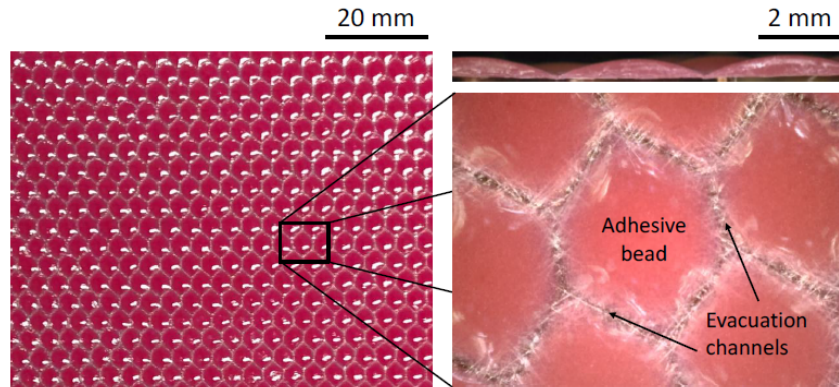
**Only transverse air evacuation is available,
unless the adhesive is air breathable**



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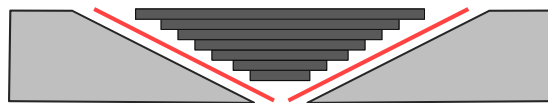
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Adhesive Film Texturing (Embossing)

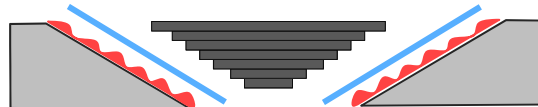





Patch Bondline Configurations

Baseline



Embossing

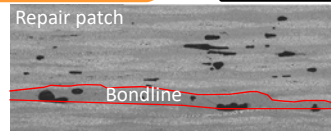


-  Film adhesive
-  Glass veil
-  Embossed adhesive

Quality Assessment

Baseline

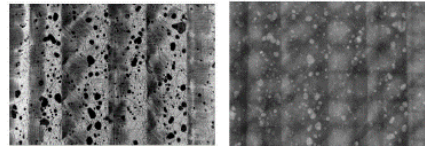
3 mm



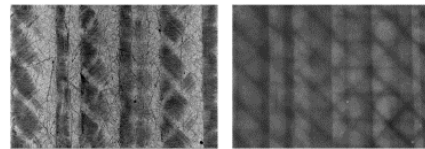
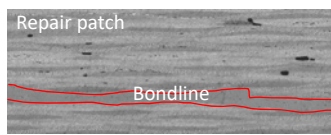
Superposed in-plane images from micro-CT scans

X-Ray images of specimen

4 mm



Embossing

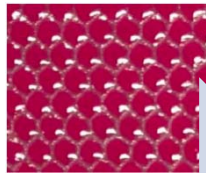
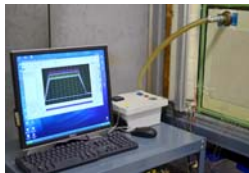


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Robust Repair Protocols



Lab Scale

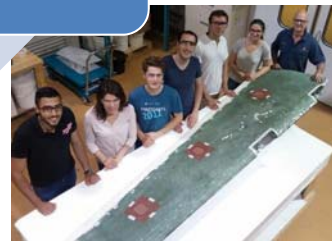
- Controlled process
- Defined boundary conditions

Methods & Tools

- Breathable adhesive
- Instrumented repair
- Impregnation method

Large Scale

- Process deviations
- Heat and air sink

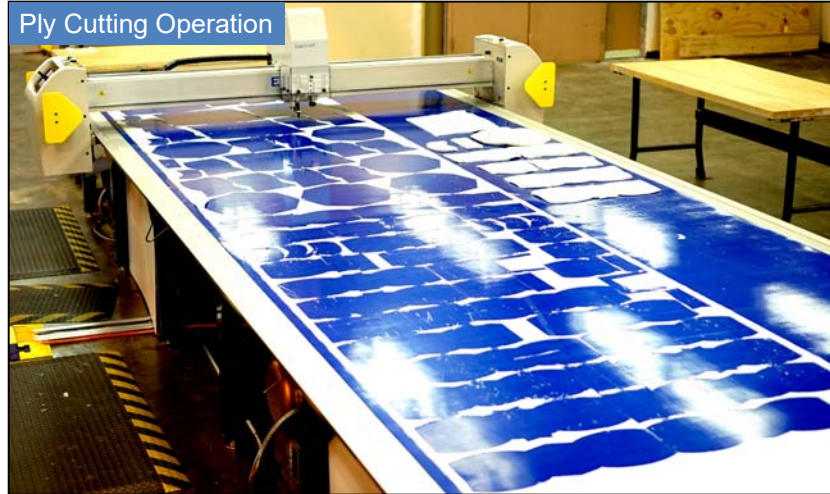


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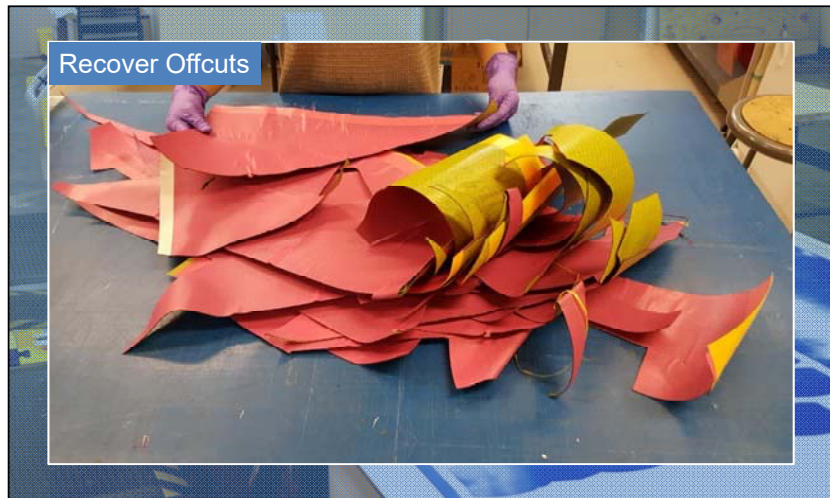
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Aerospace Prepreg Recycling



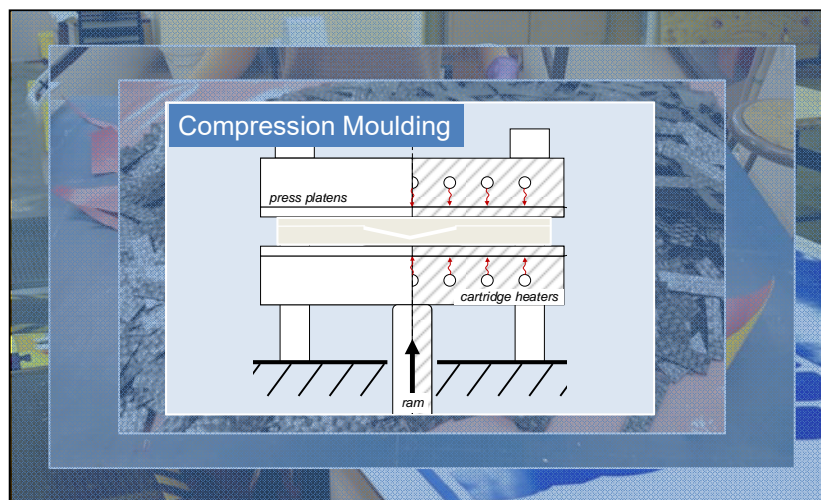
Aerospace Prepreg Recycling



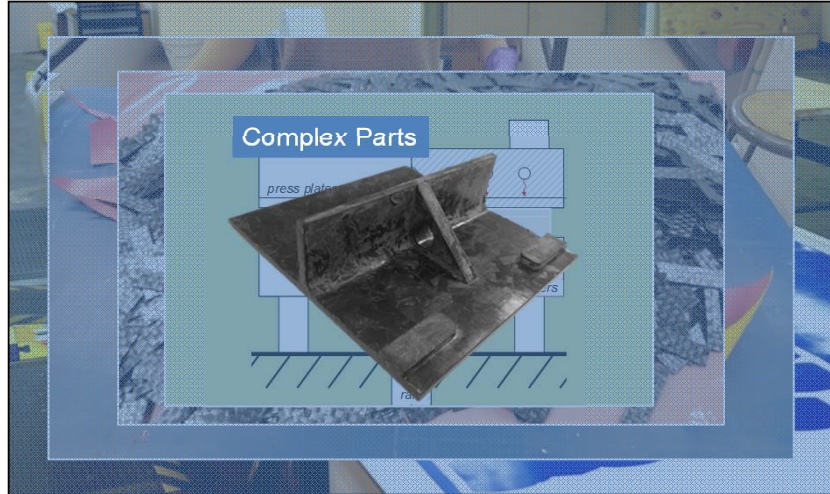
Aerospace Prepreg Recycling



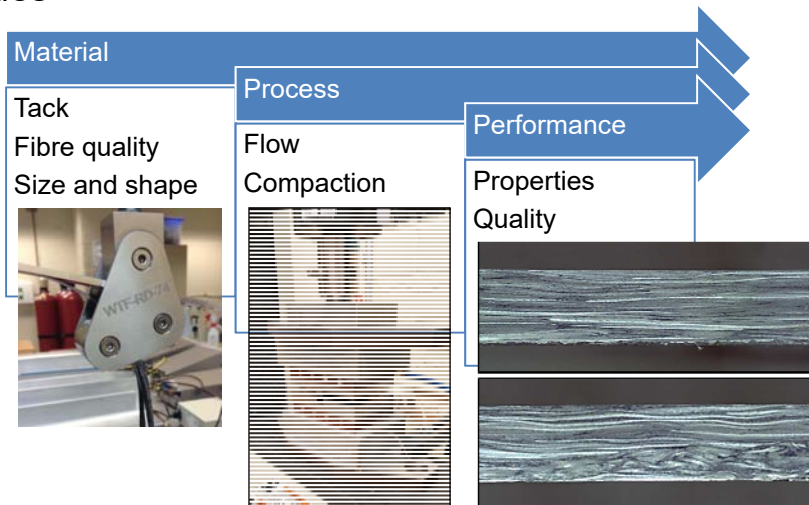
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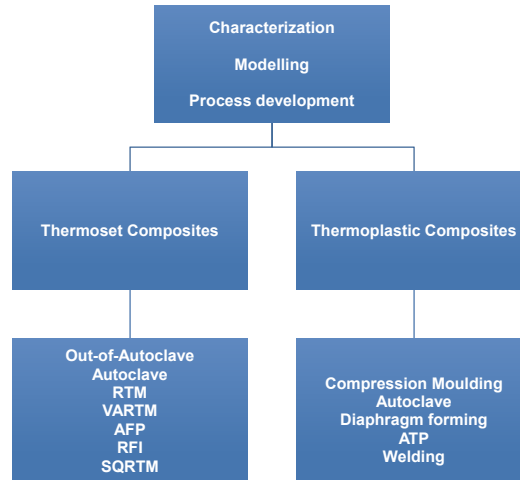
Aerospace Prepreg Recycling



Issues



McGill – Processing Expertise



Our Approach

- Material characterization
- Instrumented processing equipment
- Simple models to capture phenomena
- Knowledge transfer from the lab to the application

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Acknowledgments

- Past members of the Structure & Composite Materials Laboratory



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