University of BRISTOL
Bristol Composites Institute

University of BRISTOL
EPSRC Centre for Doctoral Training in Composites Science, Engineering and Manufacturing

UKRI Engineering and Physical Sciences Research Council

Thickness control of Snap-Cure Prepregs in Automated Placement Conditions

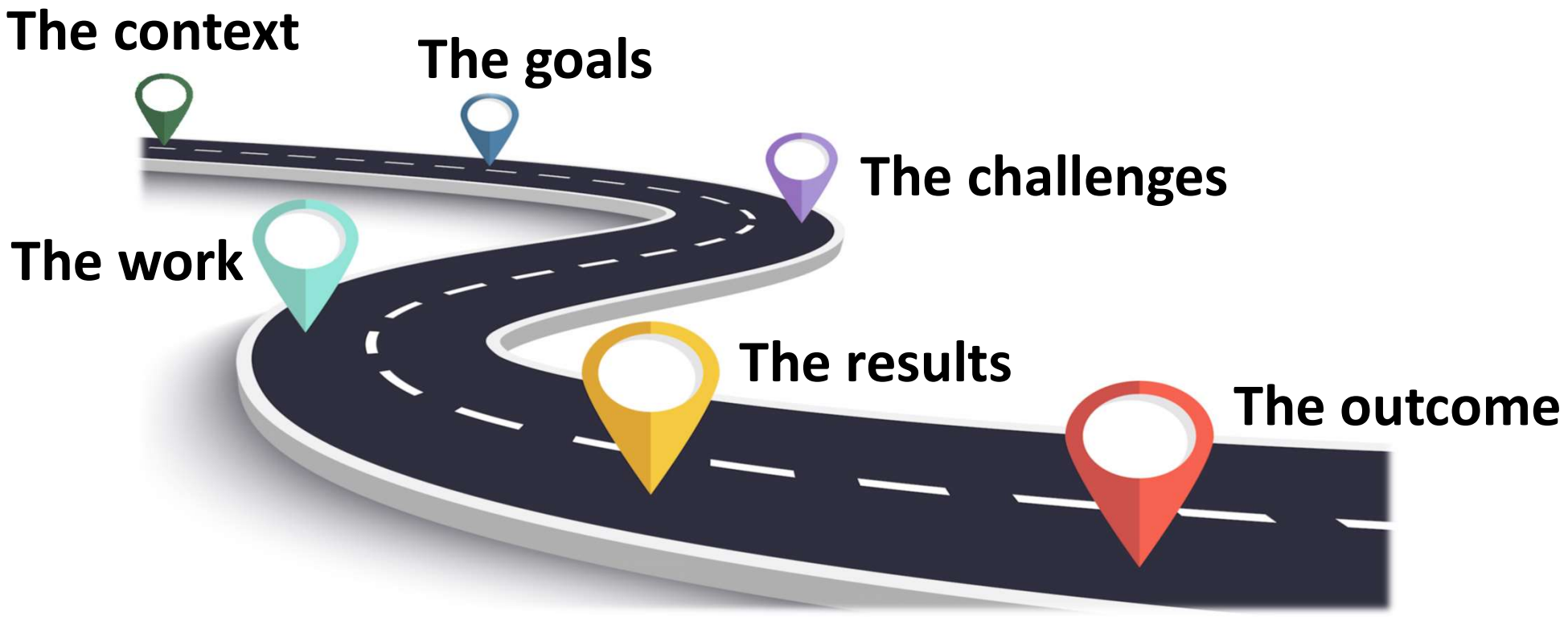
Authors:

Axel WOWOGNO, Robin HARTLEY**,** Iryna TRETIAK, Stephen R. HALLETT, James KRATZ

bristol.ac.uk/composites

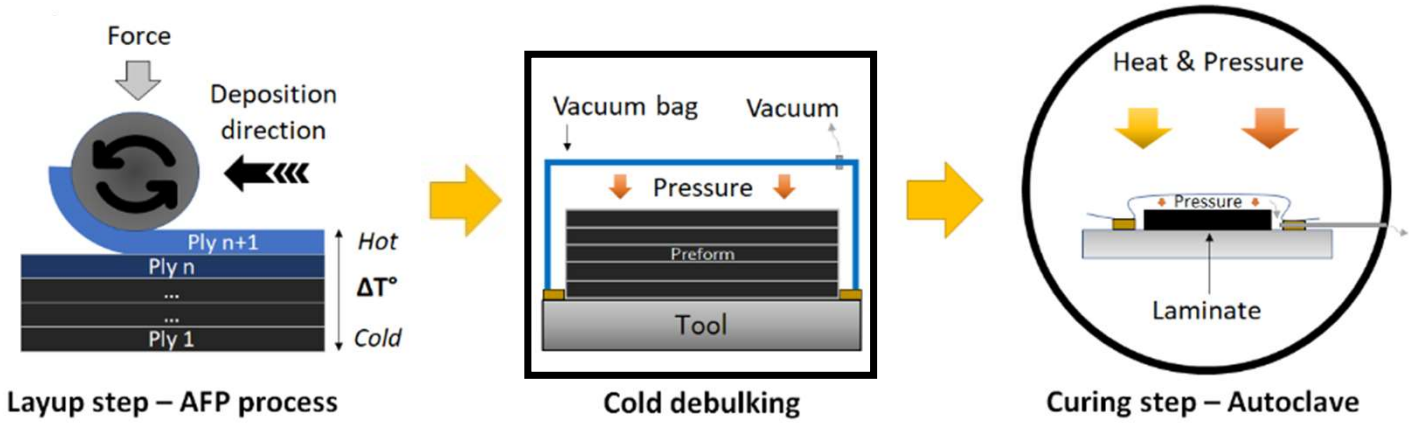
International Conference On Composite Materials

CONTENTS


The context
The goals
The challenges
The work
The results
The outcome

CONTEXT

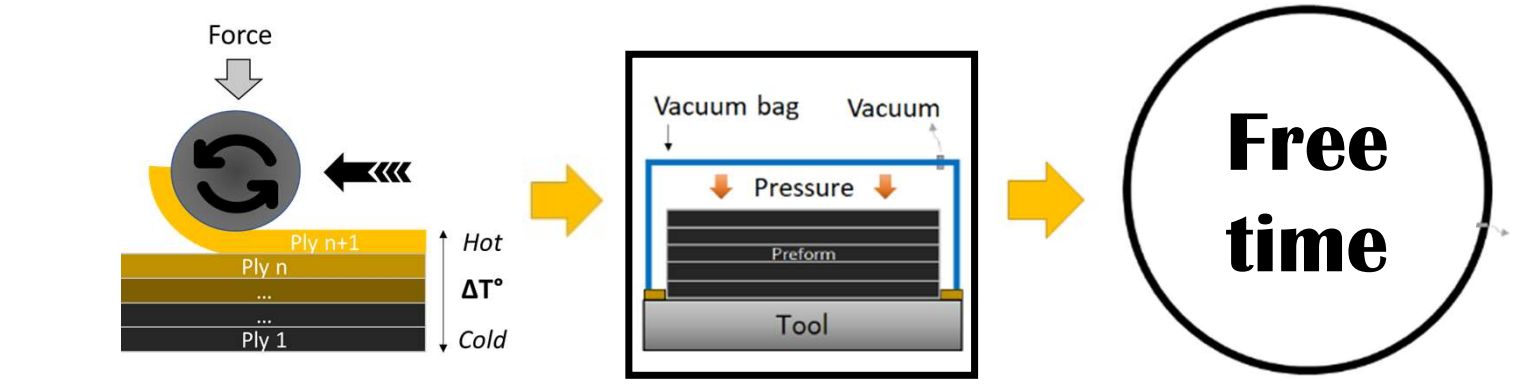
- **Automated Fibre Placement (AFP) :** Good method for preform production
- **Autoclave manufacturing :** Quality parts, but bottleneck in workflows
- **Technology Need :** Alternative composites manufacturing methods
- **Solutions :** Different materials and heating/curing methods



Autoclave : Three step manufacturing method

CONTEXT

- **Automated Fibre Placement (AFP) :** Good method for preform production
  - **Autoclave manufacturing :** Quality parts, but bottleneck in workflows
    - **Technology Need :** Alternative composites manufacturing methods
      - **Solutions :** Different materials and heating/curing methods



Layup step – AFP process / Hot debulking **Curing step – VBO**

Autoclave : Three step manufacturing method

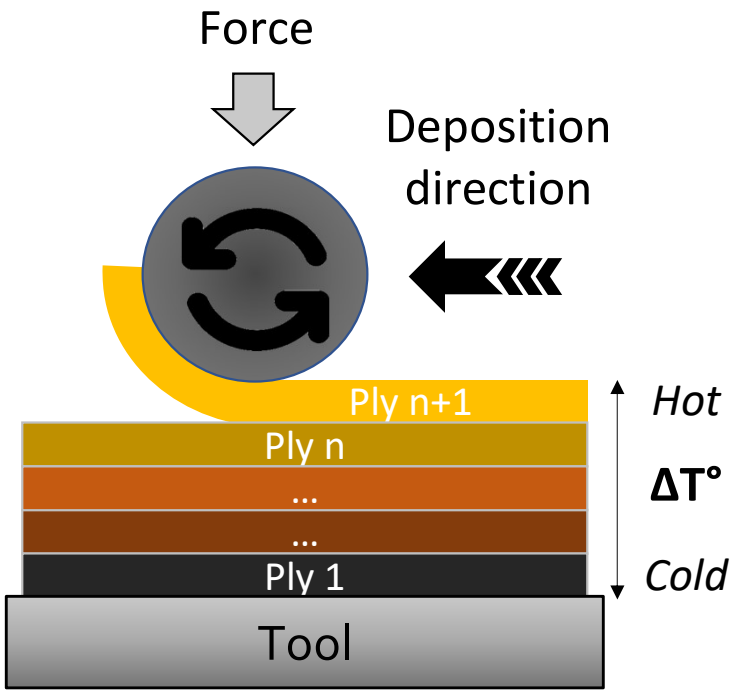
AFP + VBO : Two step manufacturing method

GOALS

- **Goal: Enhance the AFP process and enable on-line curing with thermosets (Layer-by-layer manufacturing)**

- Current manufacturing processes :
  - 3-steps process : Cold deposition
  - 2-steps process : Hot deposition
    - 1-step process : In-situ AFP

- Approach : Perform compaction tests to characterise materials and process



Desired one-step process

In-situ consolidation with thermosets: Curing during the AFP layup step

CHALLENGES

Feasibility?

Interface ?

Temperature ?

Porosity ?

Degree of Cure ?

Parameters control ?

- **Levers :** AFP Processing parameters
- **Target :** Assess material's suitability
- **Focus :** Control of thickness & voids

MATERIAL & SETUP

Material : Hexcel M78.1

(Epoxy / Carbon Fibre Prepreg)

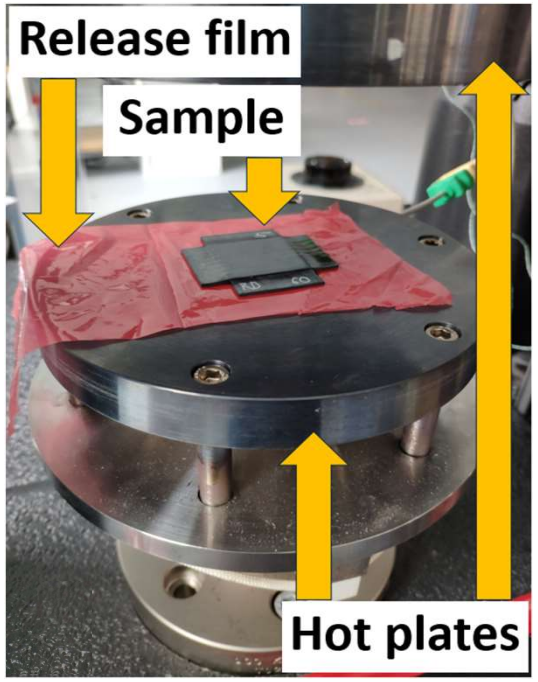
Ply Thickness = 0.32 mm

Isothermal Cure Properties by DSC *[1]*

Temperature	Cure Time (95%)
110°C	≤18min
120°C	≤8min
130°C	≤6min
140°C	≤3min
150°C	≤2min
160°C	≤1.5min

[1] : Hexcel, "HexPly® M78.1 Datasheet", 2020.

Setup : Universal Instron machine, with custom made heater plates

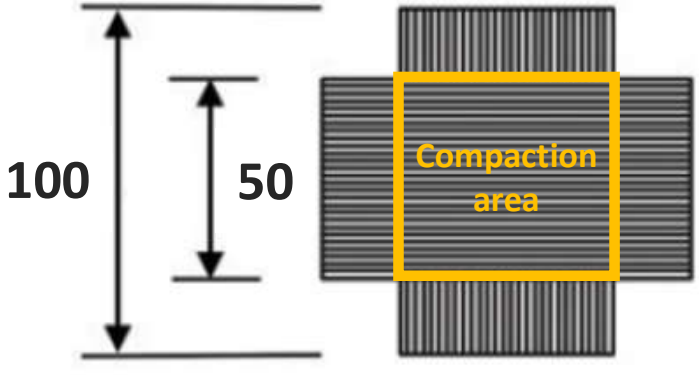


MATERIAL & SETUP

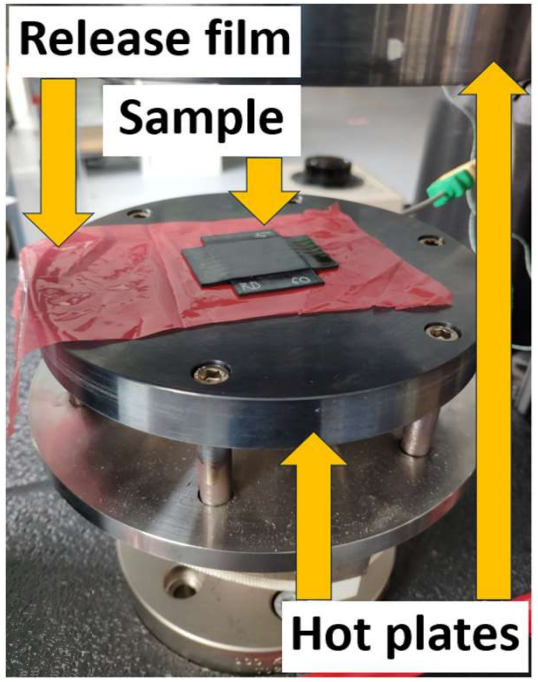
Material : Hexcel M78.1
(Epoxy / Carbon Fibre Prepreg)

Ply Thickness = 0.32 mm

Cross-ply / Hand lay-up

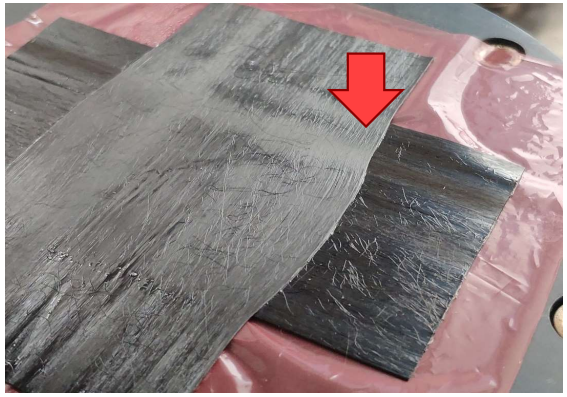


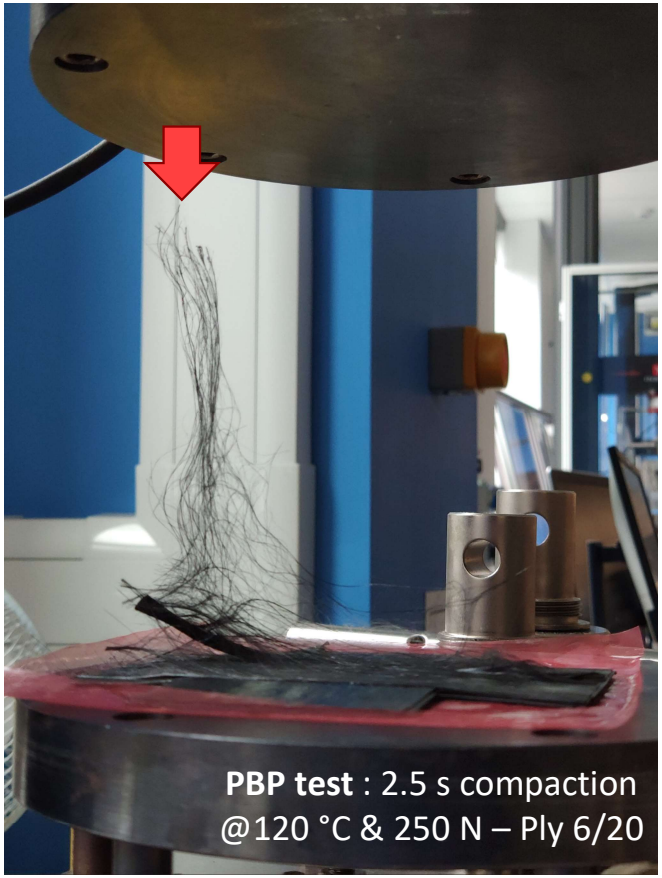
Setup : Universal Instron machine, with custom made heater plates



MATERIAL CHALLENGES

- Fibre alignment & stickiness
- Impregnation & flow issues
- Surface defects (channels)

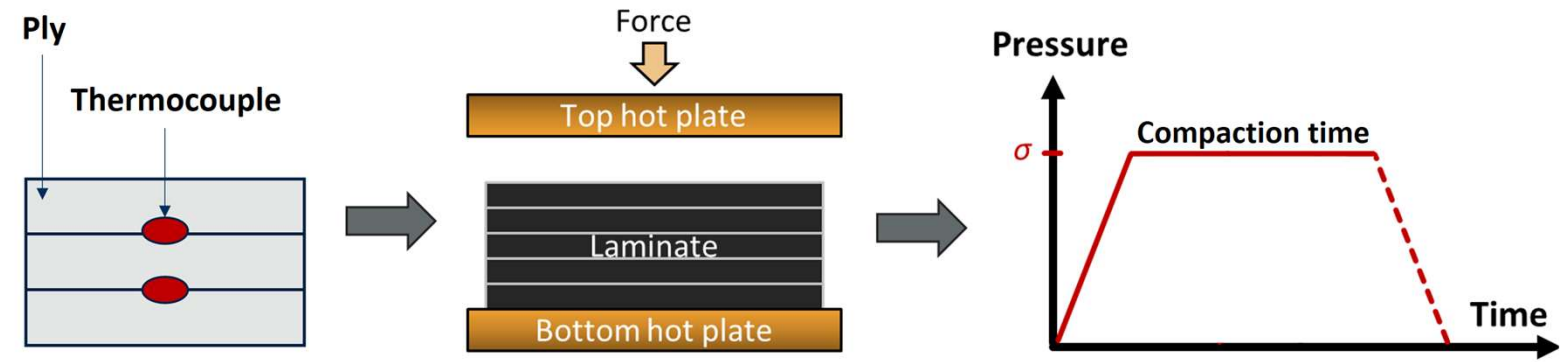




METHODS (1/2) – Bulk samples

Test : Bulk laminates of 5 to 30 plies + Compression at 0.1 MPa (1 bar) for 5 min

Goal : Assess the effect of laminate thickness on
final sample thickness & through thickness temperature evolution

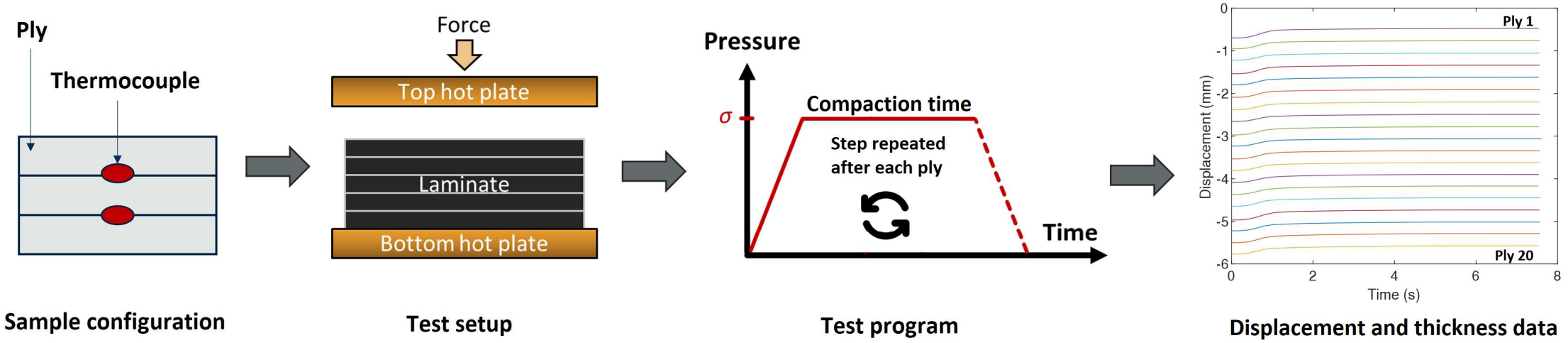


Sample configuration | Test setup | Test program

METHODS (2/2) – Ply-by-Ply samples

Test : Creation of laminates by compressing each ply at 0.1 MPa (1 bar) for 2.5s

Goal : Assess the process on thickness and porosity evolution

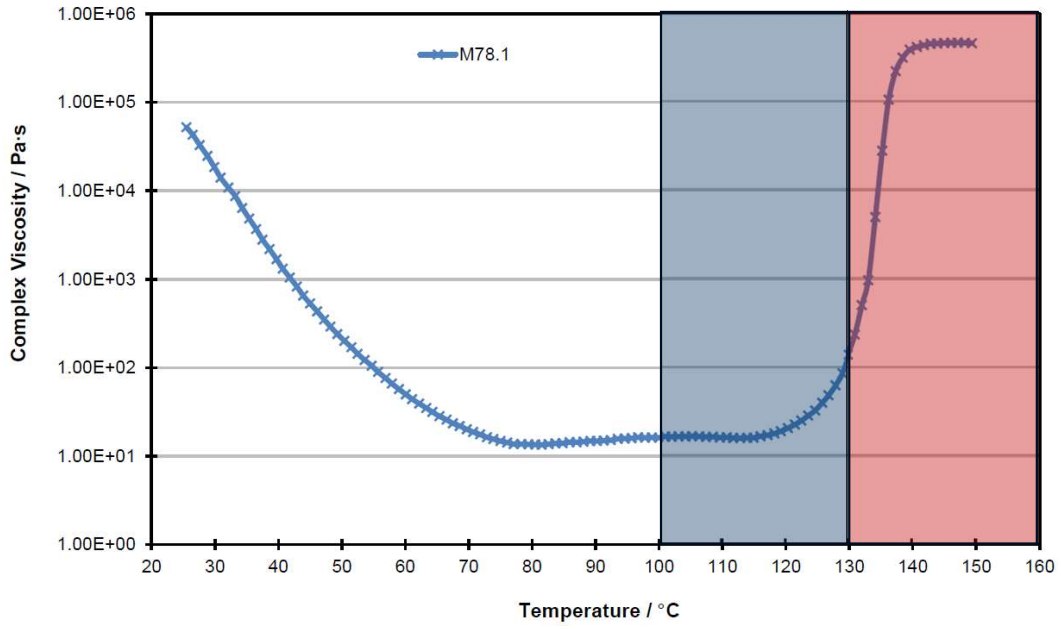


Sample configuration | Test setup | Test program | Displacement and thickness data

MAIN OBSERVATIONS (1/3)

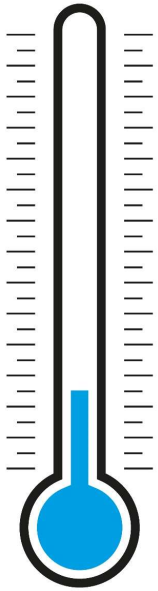
- M78.1 shows the high reactivity desirable for LBL curing of composite materials.
  - Usable even at low processing temperatures such as 100°C.

Dynamic Complex Viscosity of HexPly® M78.1 @ 5°C/min **[1] : Hexcel, "HexPly® M78.1 Datasheet", 2020.**



MAIN OBSERVATIONS (2/3)

- M78.1 shows the high reactivity desirable for LBL curing of composite materials.
  - Usable even at low processing temperatures such as 100°C.



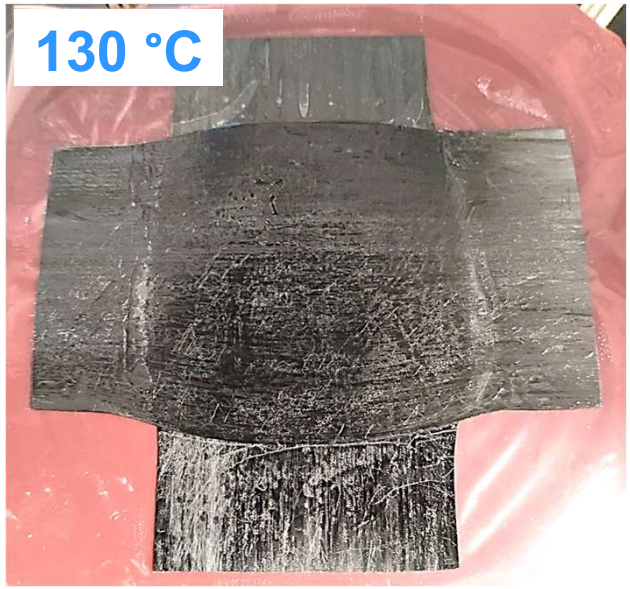
Low temperatures (100-130°C)

=

Low viscosity and low cure rate

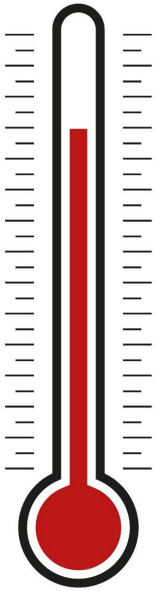
=

Improvement of the plies bonding



MAIN OBSERVATIONS (3/3)

- M78.1 shows the high reactivity desirable for LBL curing of composite materials.
  - Usable even at low processing temperatures such as 100°C.



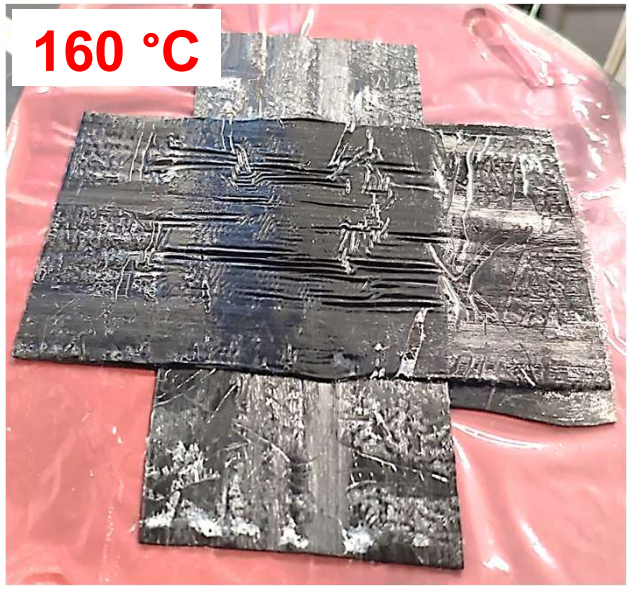
High temperatures (140-160°C)

=

Less ply adhesion and dimensional change

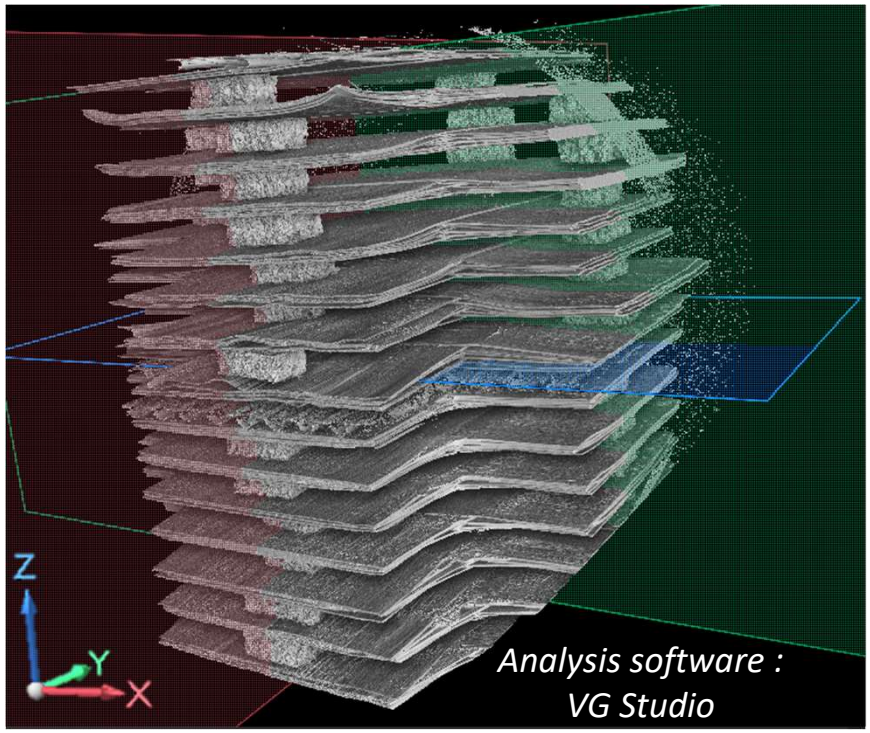
=

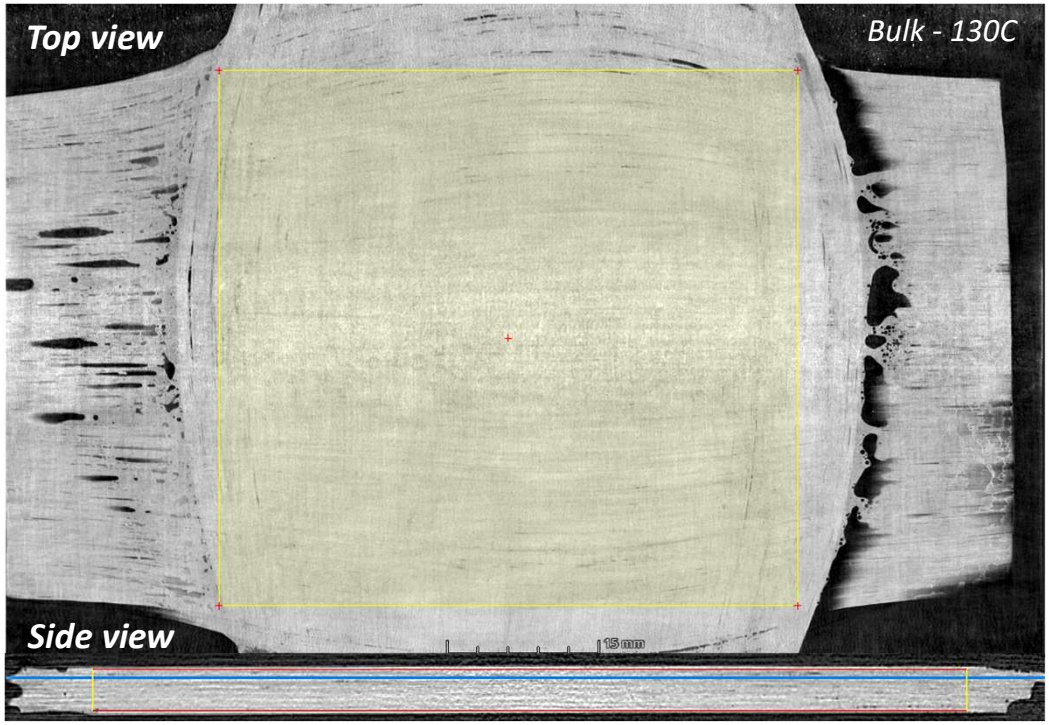
Generation of defects



CT SCANS (1/4)

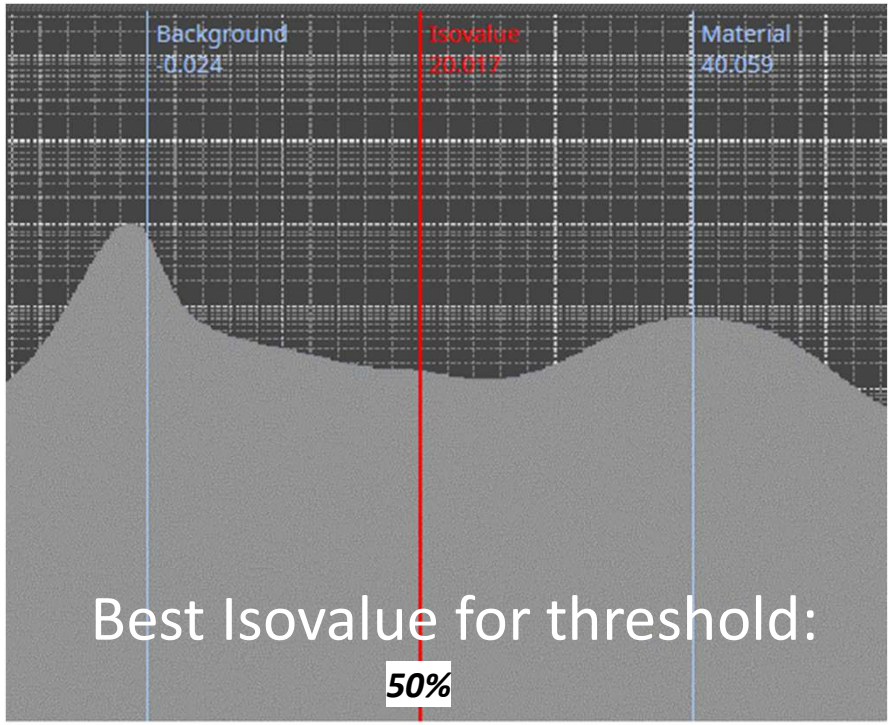
Computed Tomography : Feature observation & Porosity measurement



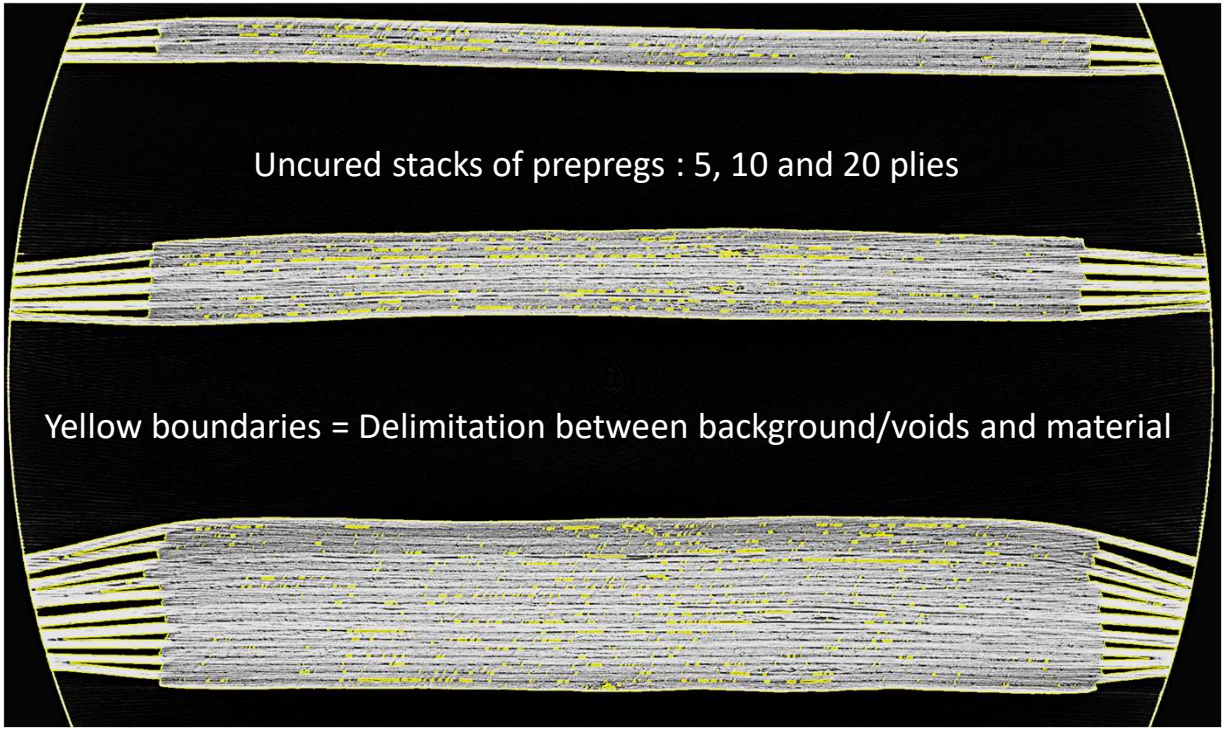


CT SCANS (2/4)

Histogram representation



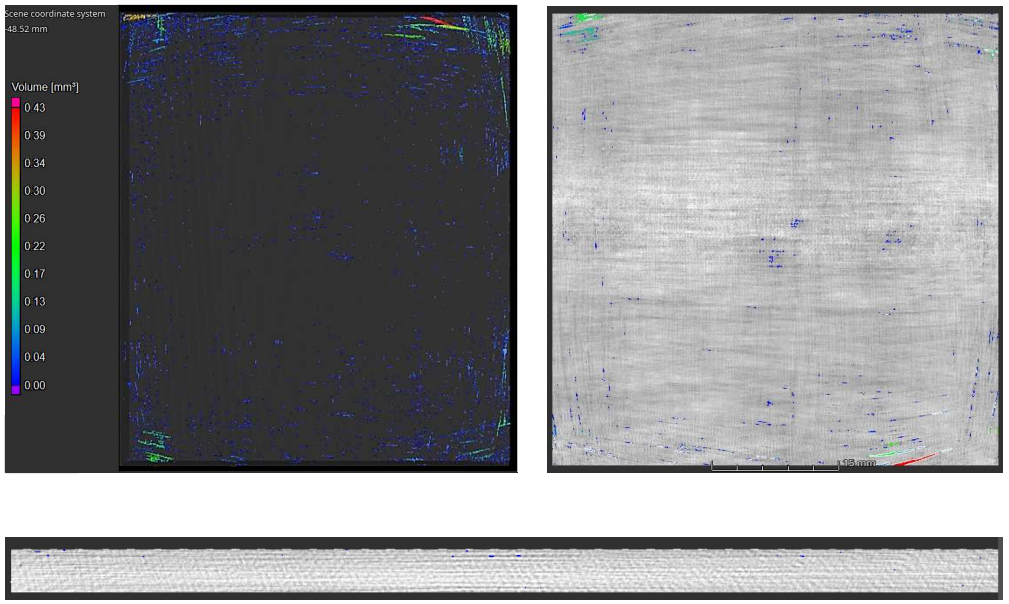
Porosity observation and measurement



CT SCANS (3/4)

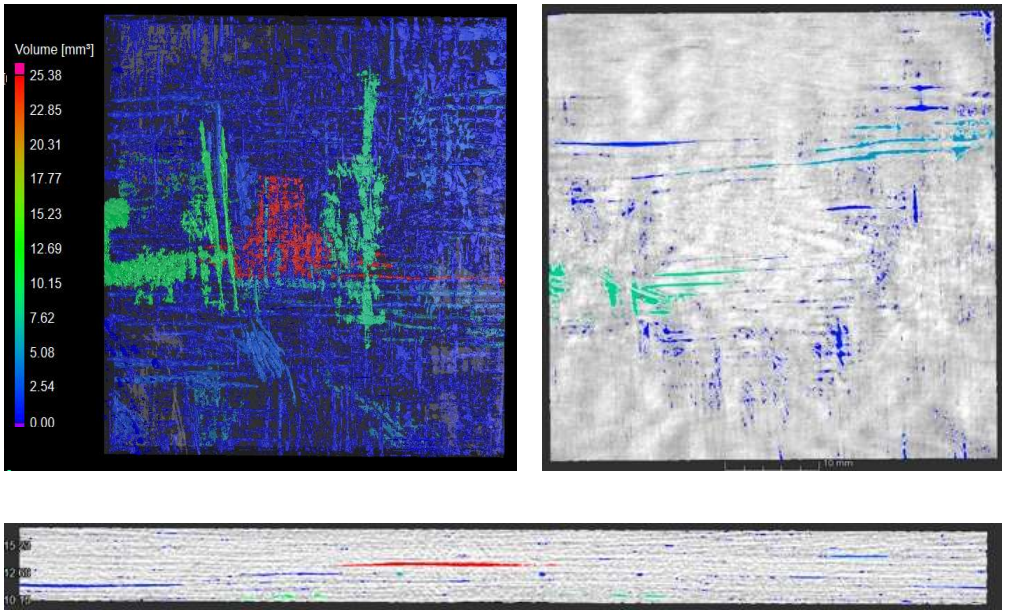
BULK laminate

(160C – 1bar – 5min)



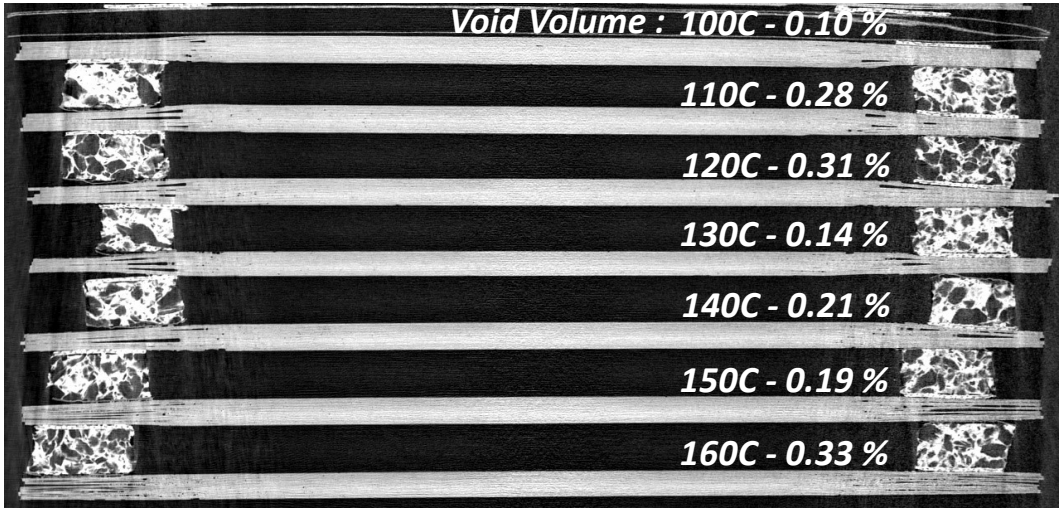
PBP laminate

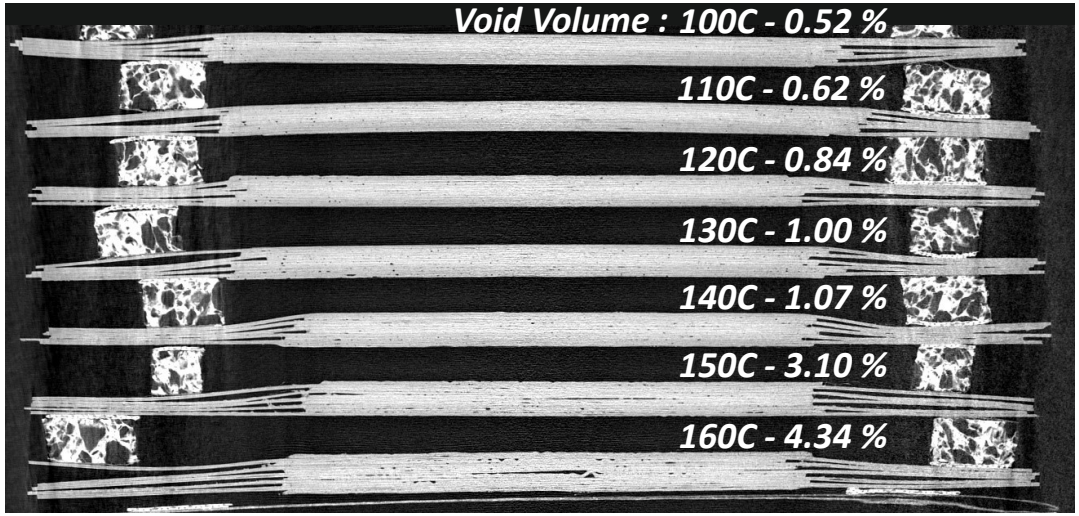
(160C – 1bar – 2.5s/ply)



CT SCANS (4/4)

Laminates comparison : Bulk vs Ply-by-Ply





BULK laminates

Key Parameters : 10 plies + 1 bar (250N) + 5 min

Cycle time : 5 min *(+ layup + debulking = 25 min)*

T_{Bulk} (°C) ↑ = Width ≈ Thickness ≈ Defects ≈

Ply-by-Ply laminates

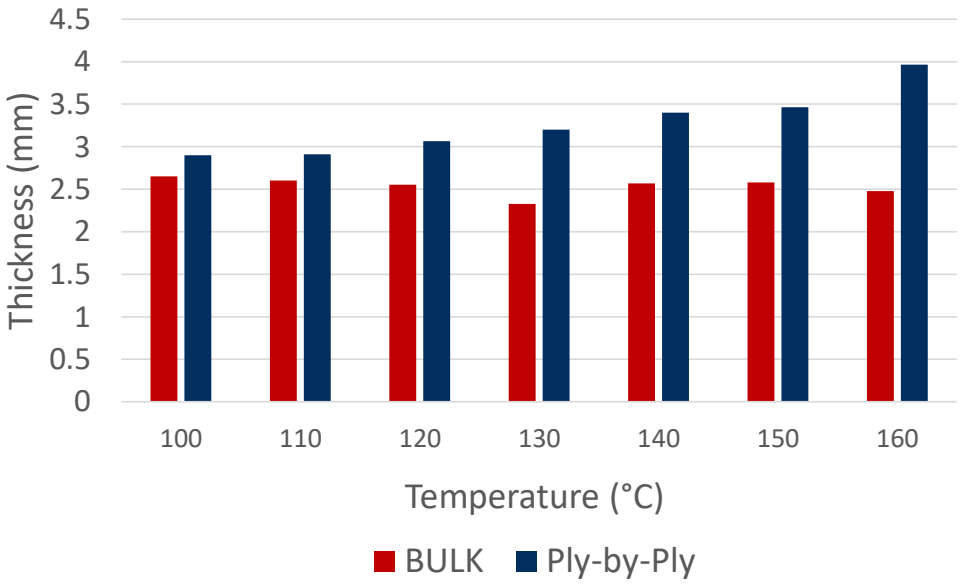
Key Parameters : 10 plies + 1 bar (250N) + 2.5s/ply

Total cycle time : 25 min (handling + compaction)

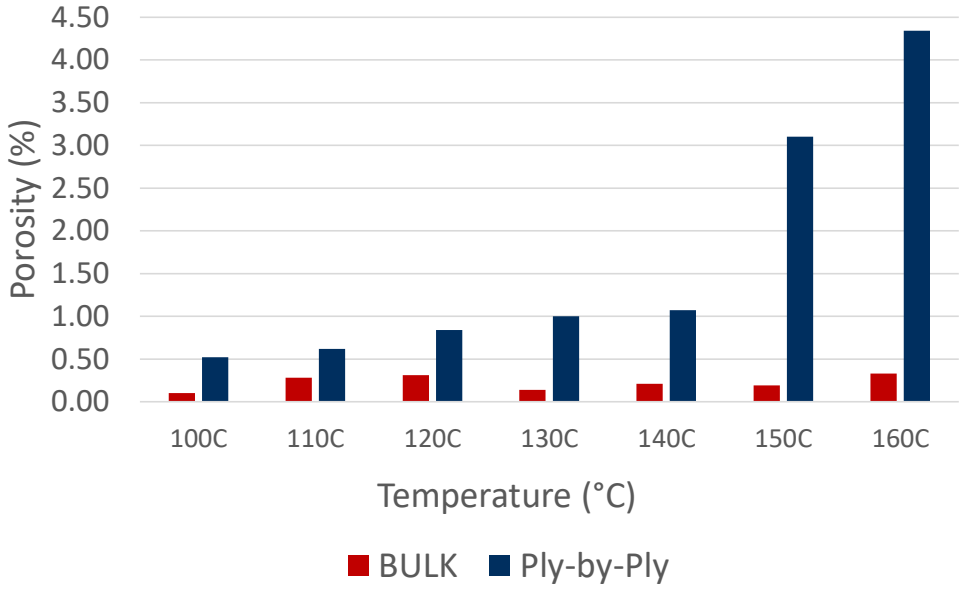
T_{PBP} (°C) ↑ = Width ↓ Thickness ↑ Defects ↑

FEATURE EVOLUTION

Thickness



Porosity



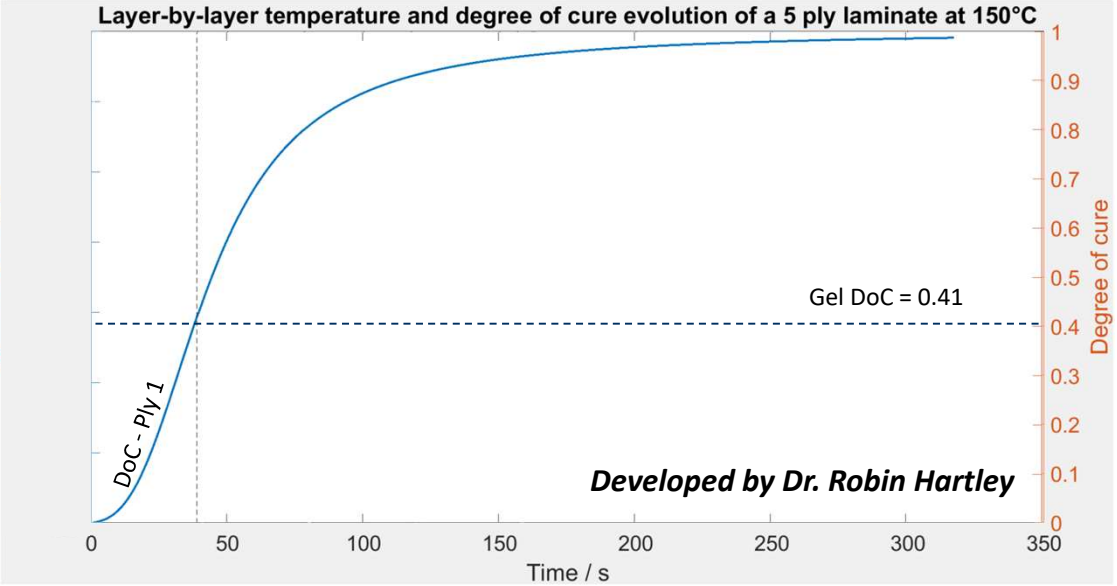
Recommendation : Use medium temperatures. Do not go above 130C for the ply-by-ply process

T_{Bulk} (°C) ↑ = Width ≈ Thickness ≈ Defects ≈ T_{PBP} (°C) ↑ = Width ↓ Thickness ↑ Defects ↑

CURE KINETICS MODEL

Tool developed to optimise compaction parameters (heating rate, hold time, target temperature) & understand in-process property development to achieve target DoC after each compaction cycle.

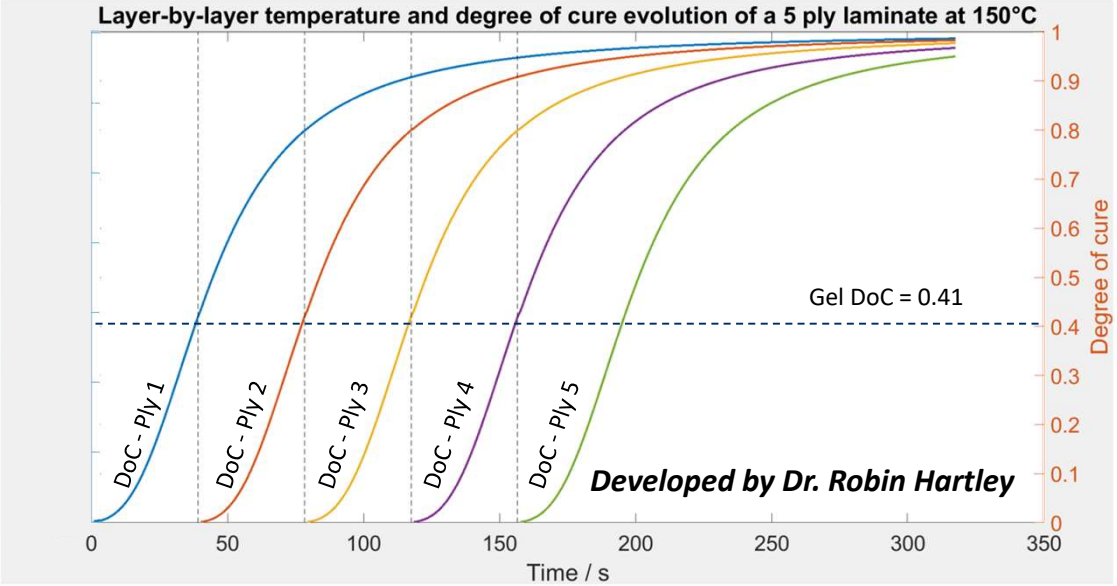
Outcomes : Ply-by-Ply Cure & Temperature monitoring / Prediction of isothermal times to reach $\alpha^{gel} = 0.41$



CURE KINETICS MODEL

Tool developed to optimise compaction parameters (heating rate, hold time, target temperature) & understand in-process property development to achieve target DoC after each compaction cycle.

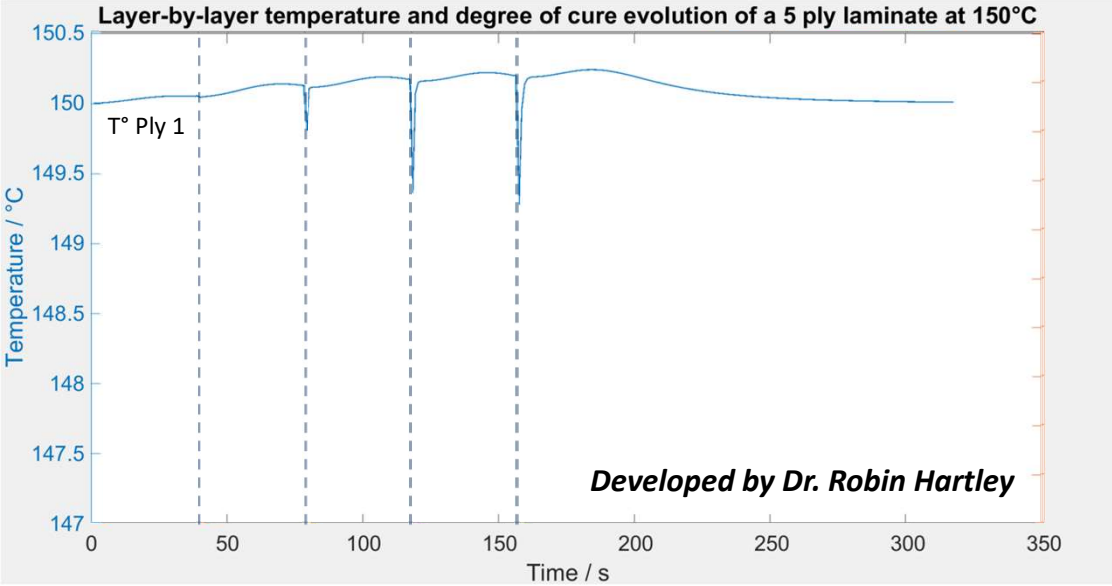
Outcomes : Ply-by-Ply Cure & Temperature monitoring / Prediction of isothermal times to reach $\alpha^{gel} = 0.41$

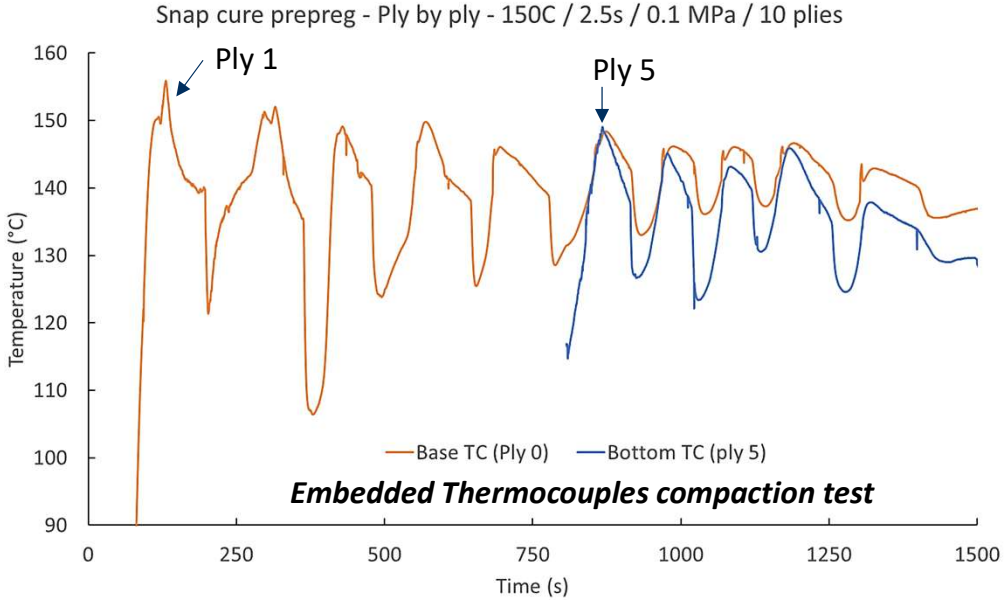


CURE KINETICS MODEL

Tool developed to optimise compaction parameters (heating rate, hold time, target temperature) & understand in-process property development to achieve target DoC after each compaction cycle.

Outcomes : Ply-by-Ply Cure & Temperature monitoring / Prediction of isothermal times to reach $\alpha^{gel} = 0.41$

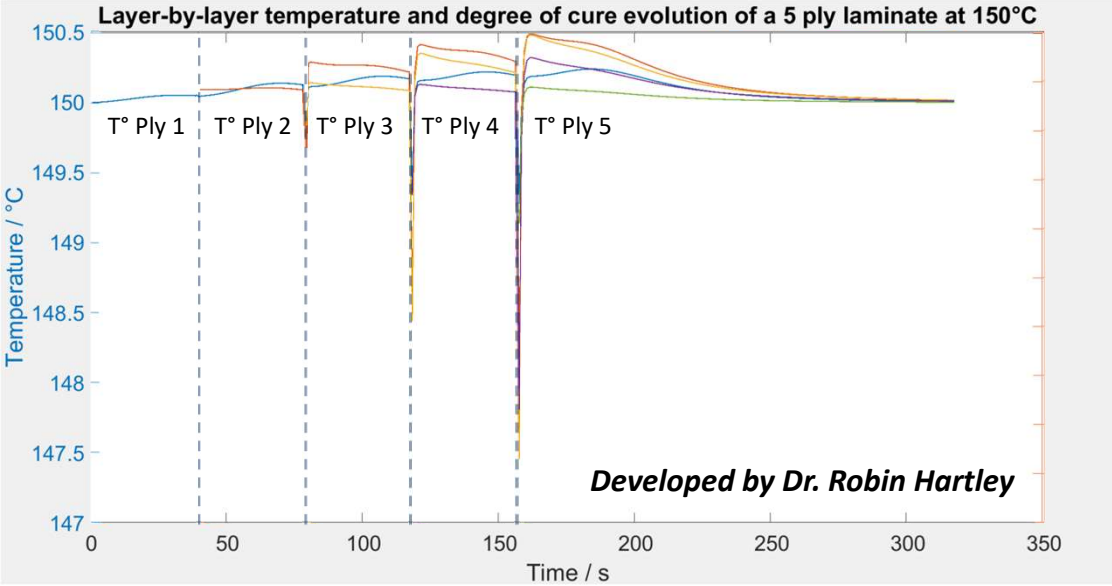


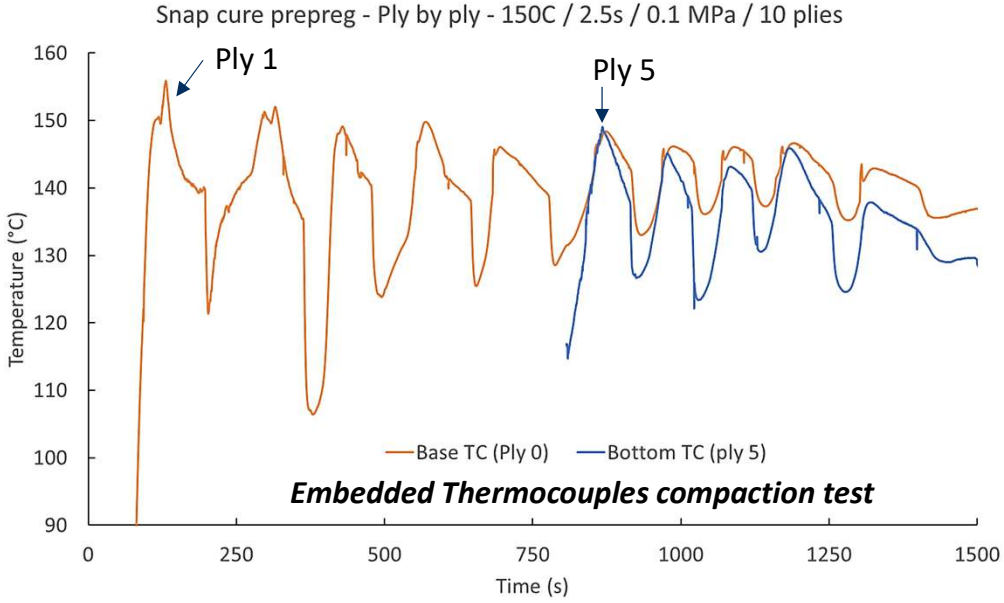


CURE KINETICS MODEL

Tool developed to optimise compaction parameters (heating rate, hold time, target temperature) & understand in-process property development to achieve target DoC after each compaction cycle.

Outcomes : Ply-by-Ply Cure & Temperature monitoring / Prediction of isothermal times to reach $\alpha^{gel} = 0.41$

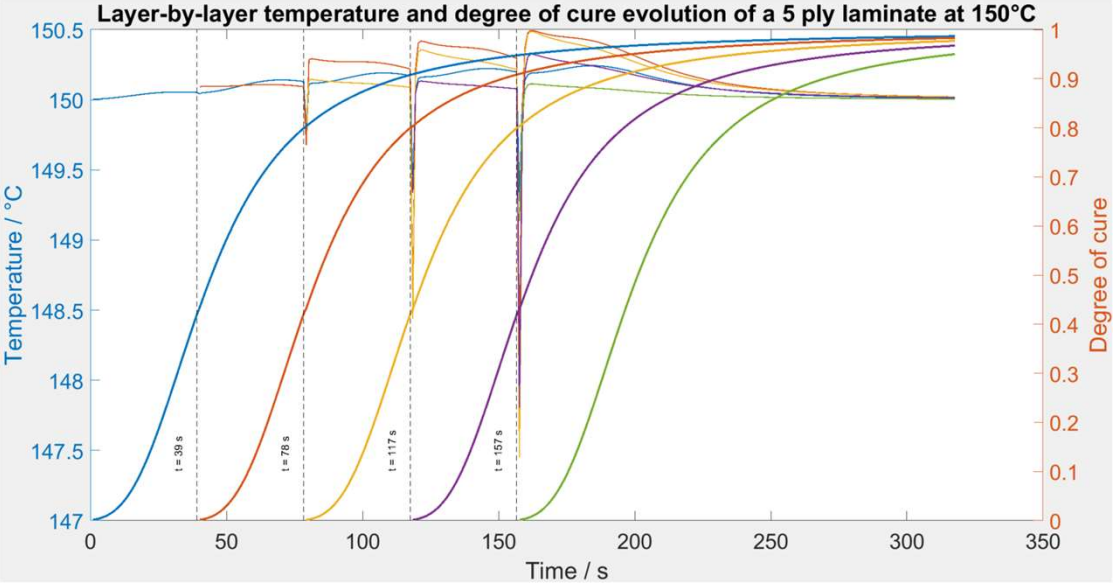


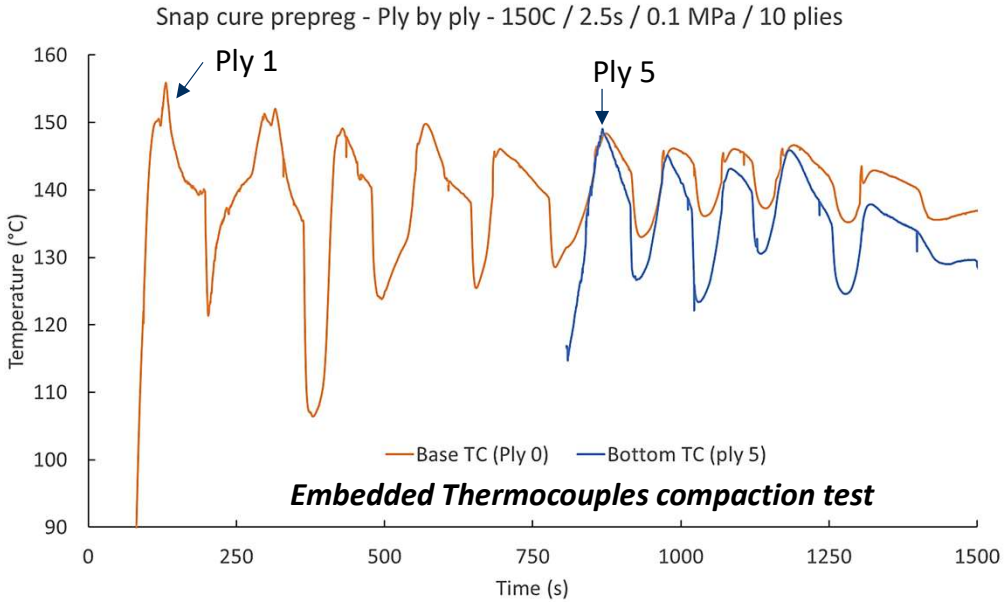


CURE KINETICS MODEL

Tool developed to optimise compaction parameters (heating rate, hold time, target temperature) & understand in-process property development to achieve target DoC after each compaction cycle.

Outcomes : Ply-by-Ply Cure & Temperature monitoring / Prediction of isothermal times to reach $\alpha^{gel} = 0.41$





KEY FINDINGS

- High temperature leads to :
  - Decreased ply width **(Gel before compaction = less expansion)**
  - Increased sample thickness **(Less expansion = less squeezing)**
  - Greater defect generation **(Less squeezing = Less consolidation)**

- Challenges for simultaneous cure-consolidation
  - The evolving DoC inhibits the consolidation process
  - Each ply will have a different DoC, processed time, and thickness

CONCLUSIONS

- M78.1 = Material suited for on-line curing via AFP (LBL consolidation)
- Control of thickness and porosity possible with AFP parameters
- Recommended parameters : 1 bar at 130 °C max.

Next steps

- Use of an AFP rig built in-house at the University of Bristol
- Use of the cure kinetics model to refine the characterisation
- OOA manufacturing of high-quality thermosets composites

University of BRISTOL
Bristol Composites Institute

ICCM 23
BELFAST 2023

University of BRISTOL
EPSRC Centre for Doctoral Training in Composites Science, Engineering and Manufacturing

UKRI Engineering and Physical Sciences Research Council

Thanks

Acknowledgements

The authors would like to acknowledge the support of **Rolls-Royce** plc through the Composites University Technology Centre (UTC) at the **University of Bristol** and the **EPSRC** through the CoSEM Centre for Doctoral Training (EP/S021728/1) and the Future Composites Manufacturing Hub (EP/P006701/1).

PhD project:
Layer by Layer manufacturing of complex composites

Contact : axel.wowogno@bristol.ac.uk

bristol.ac.uk/composites