Effect of processing parameters on bonded repair quality and strength

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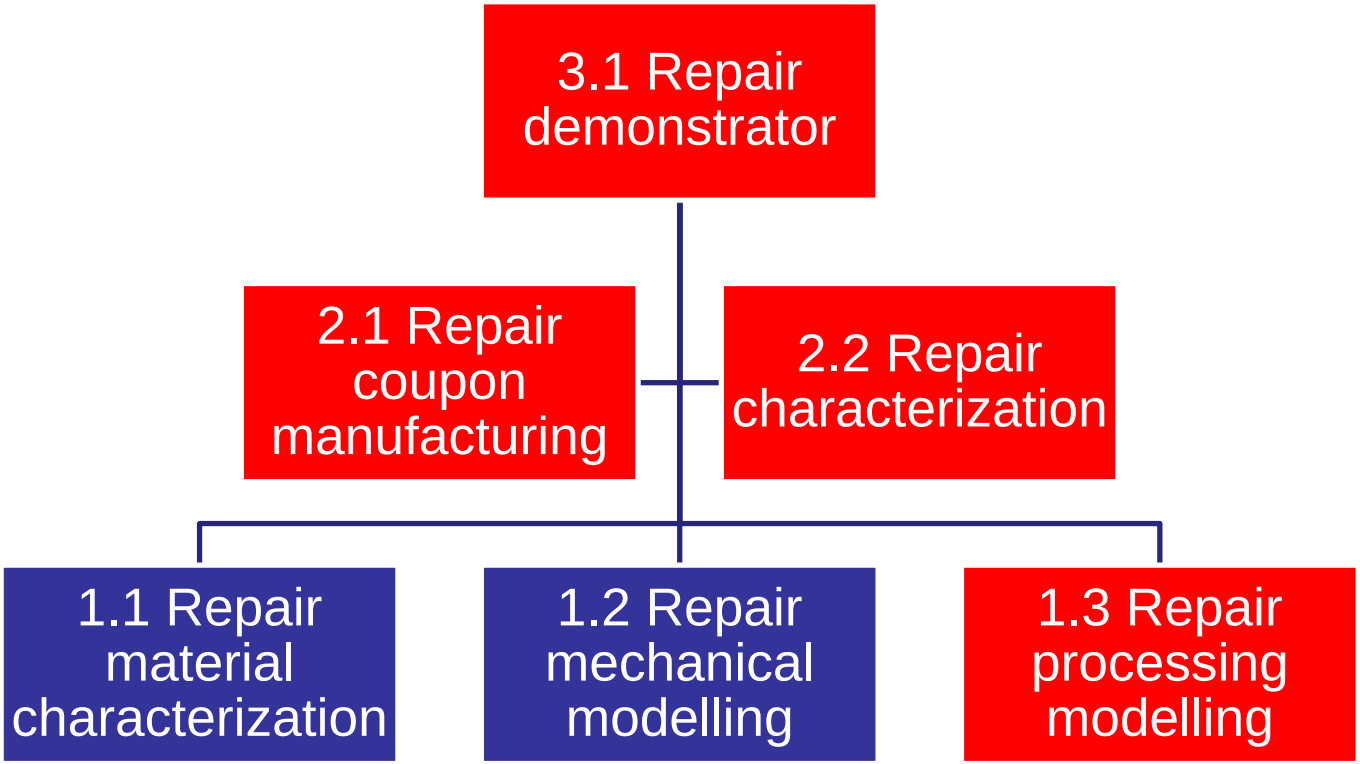
Background

- **Existing BCA experience with cobonded repairs is on secondary structure with both prepregs and wet-layup.**
- **The research objective of CRIAQ project (from Bombardier point of view) is to investigate future prepreg in-service repairs where strength recovery for a primary non-removable component would be more important than other logistical issues associated with the use of an OOA prepreg such as refrigerated storage, cost, shelf life and cure temperatures.**
- **Processing options to reduce porosity in co-bonded repairs form part of the project.**
  - **Porosity effects both mechanical properties and ultrasonic inspectability**

BCA = Bombardier Commercial Aircraft
CRIAQ = Le Consortium de recherche et d'innovation en aérospatiale au Québec
OOA = Out of Autoclave

Overall Project Objective

Develop analytical tools and protocols for the design of composite bonded repair for aerospace sandwich and stiffened panels.



Repair Processing Aspects

Main objective:

How processing parameters affect strength and durability of bonded repairs?

Specific objectives:

- How to minimize porosity?
- How pre-bond moisture affect repair quality?

Materials

Prepreg:

Cytec Cycom® 5320 Plain Weave (PW)

T650-35 3K, 196 g/m² areal weight, 36 % resin content

Repair adhesive film:

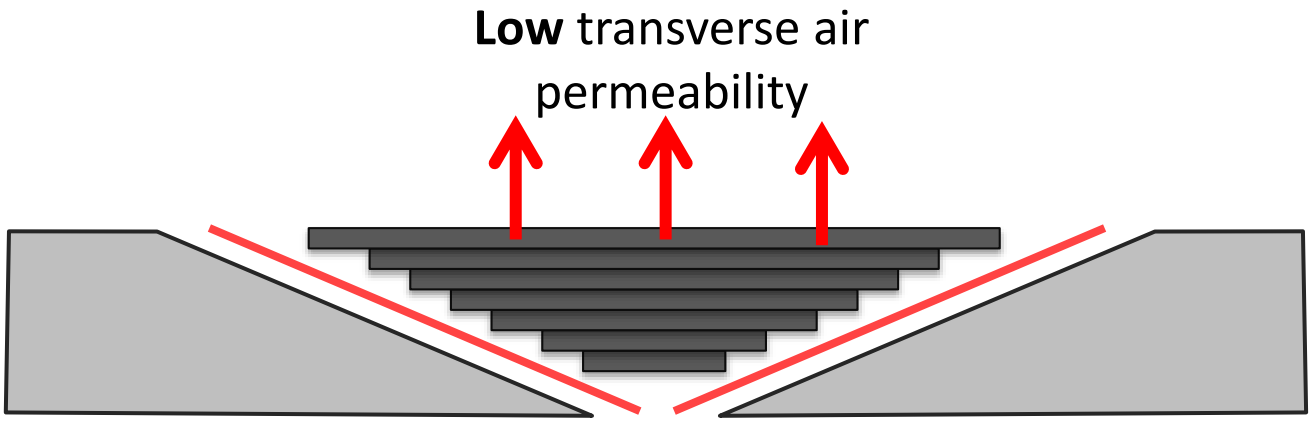
Cytec FM® 300-2M (293 g/m² areal weight)

0.25 mm nominal thickness

Nomex core:

Over-expended cells – 19 mm thick ECA-R 3/16-4.0

Air Evacuation in Scarf Repairs

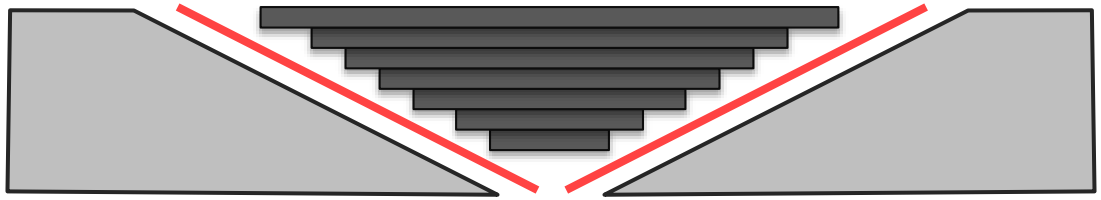


Only transverse air evacuation is available,
unless **the adhesive is air breathable**

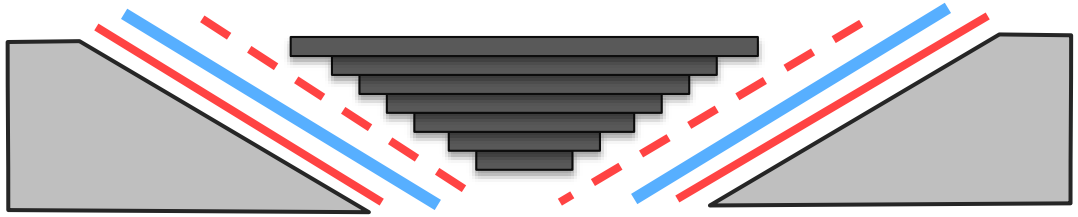
Kratz and Hubert, "Anisotropic air permeability in out-of-autoclave prepregs: Effect on honeycomb panel evacuation prior to cure," Composites Part A, 2013.

Air Evacuation Strategies

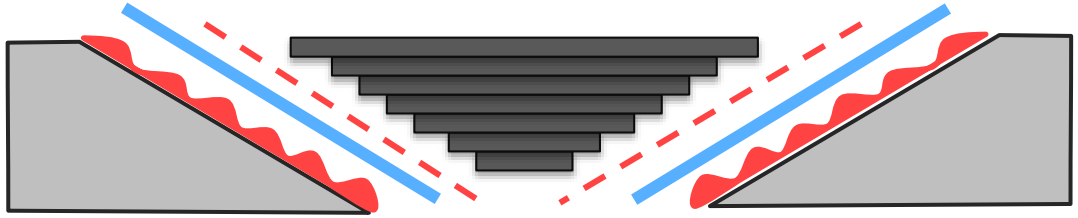
A – Baseline



B – Air breathable adhesive - 1

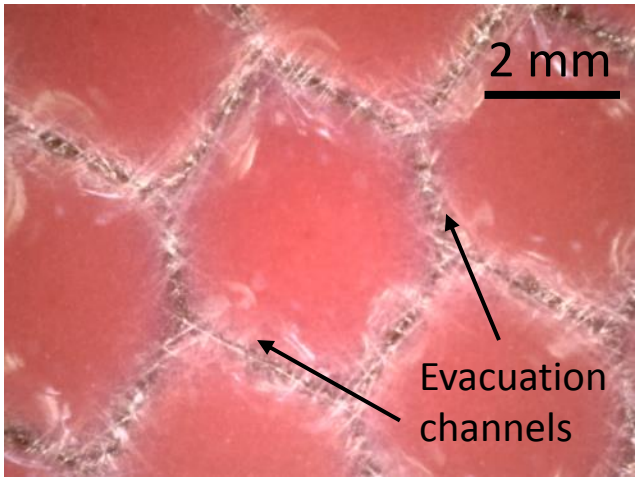


C – Air breathable adhesive - 2



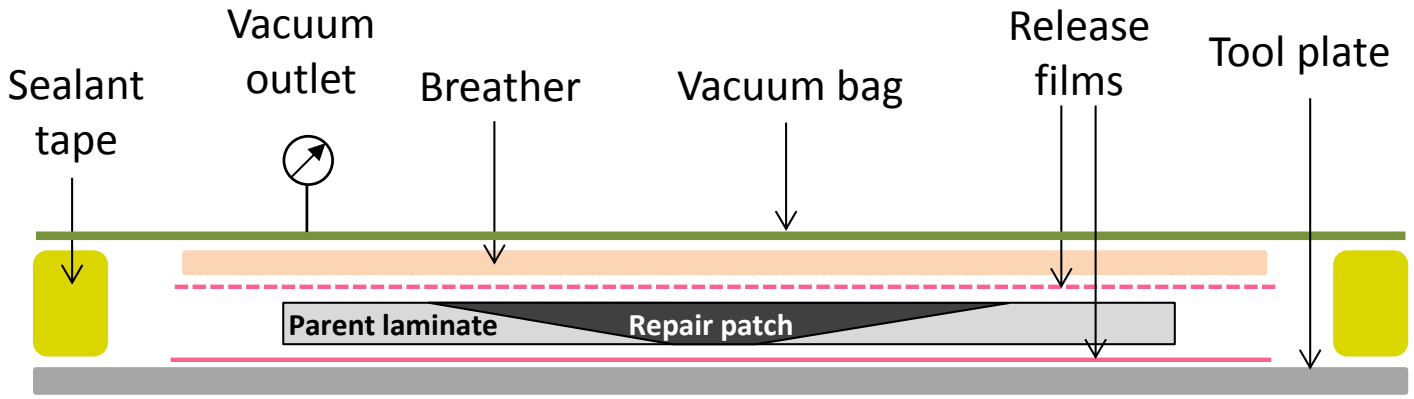
Film adhesive
Glass veil
Perforated film adhesive
Embossed adhesive

Non-woven glass veil
tfp Optiveil™ 2053A (6 g/m²)



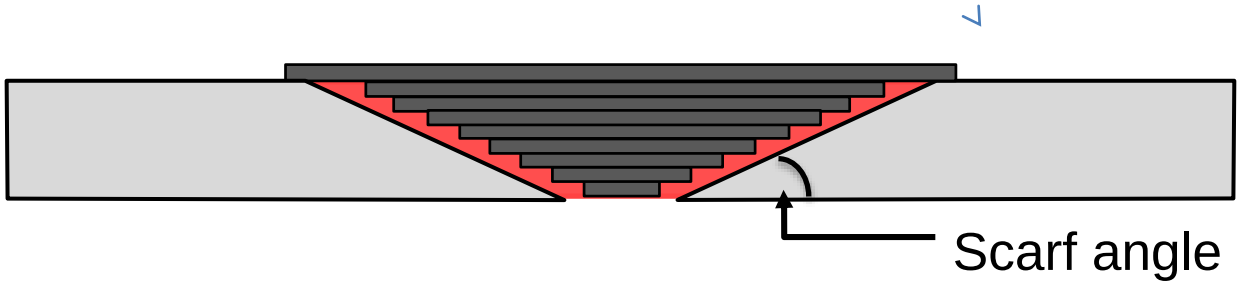
Repairs Processing

- **Parent laminate surface preparation: Acetone rinse, dry grinding with 120 grit silicon carbide paper, and dry-wipe**
- **Pre-cure vacuum hold: 16 hours**
- **Oven vacuum-cure: 121 °C for 2 hours, and 2 hours free-standing post-cure at 180 °C**



Experimental Methodology

Factors	Levels
Scarf angle [°]	2.6 ; 3.0 ; 3.2 ; and 6.0
Bondline thickness [mm]	0.25 and 0.5
Repair strategies	A, B and C

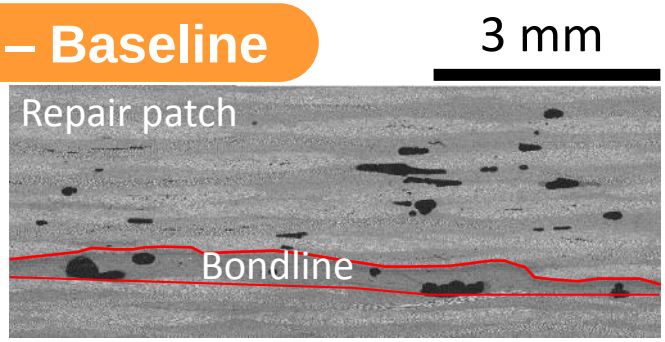


- **Patch quality: Optical microscopy**
- **Bondline quality: X-Ray radiography**
- **Strength recovery: Quasi-static tensile tests**

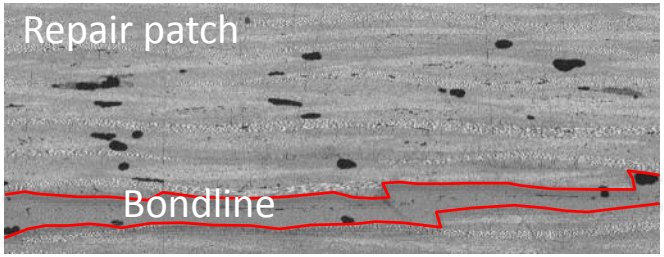
$$\frac{UTS_{repair}}{UTS_{unnotched}}$$

Quality Assessment by Microscopy

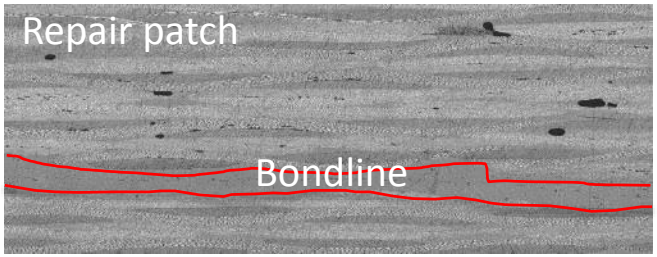
A – Baseline

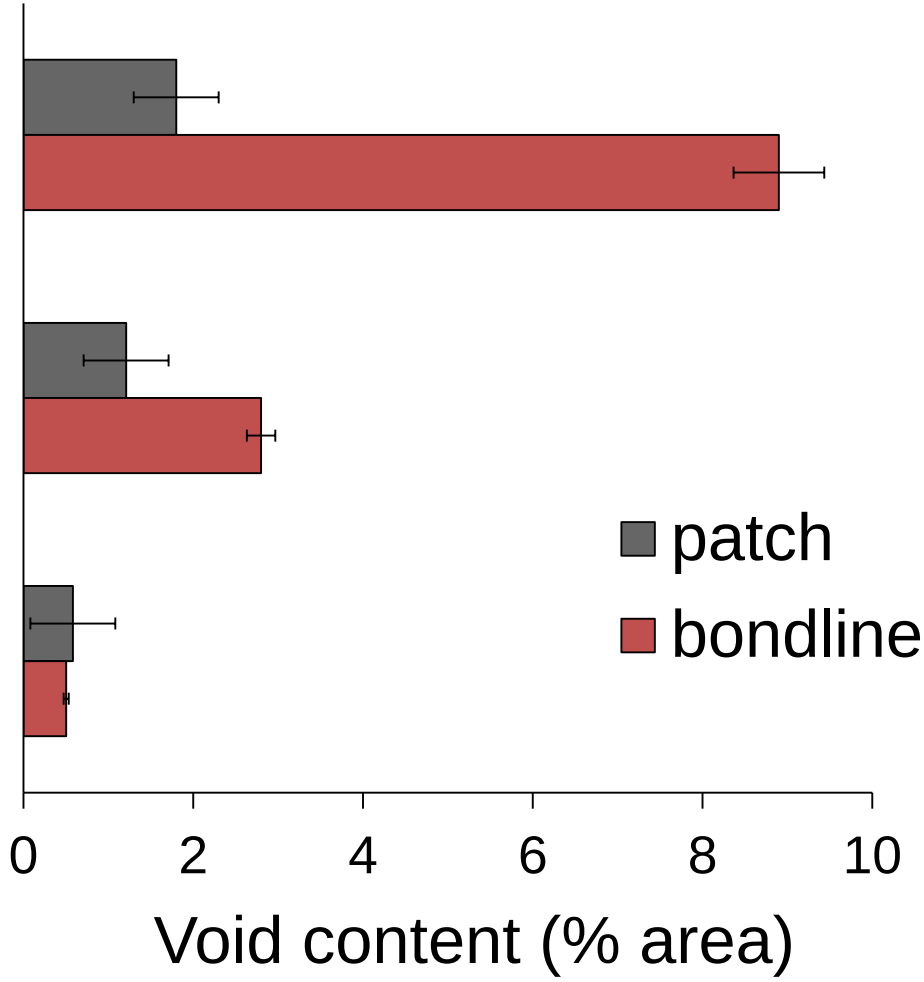


B – Air breathable adhesive - 1



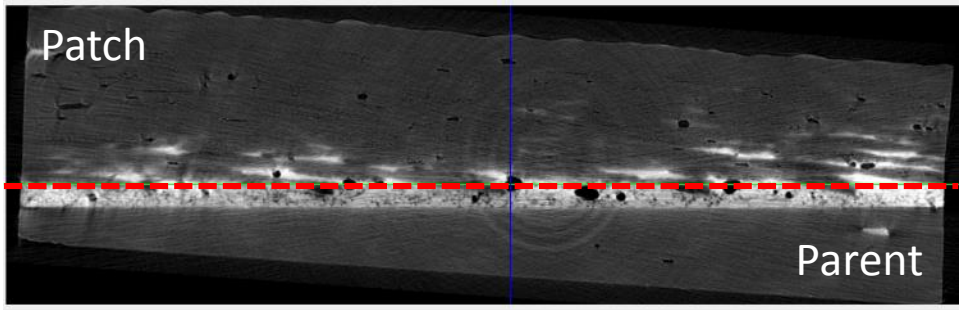
C – B + embossing



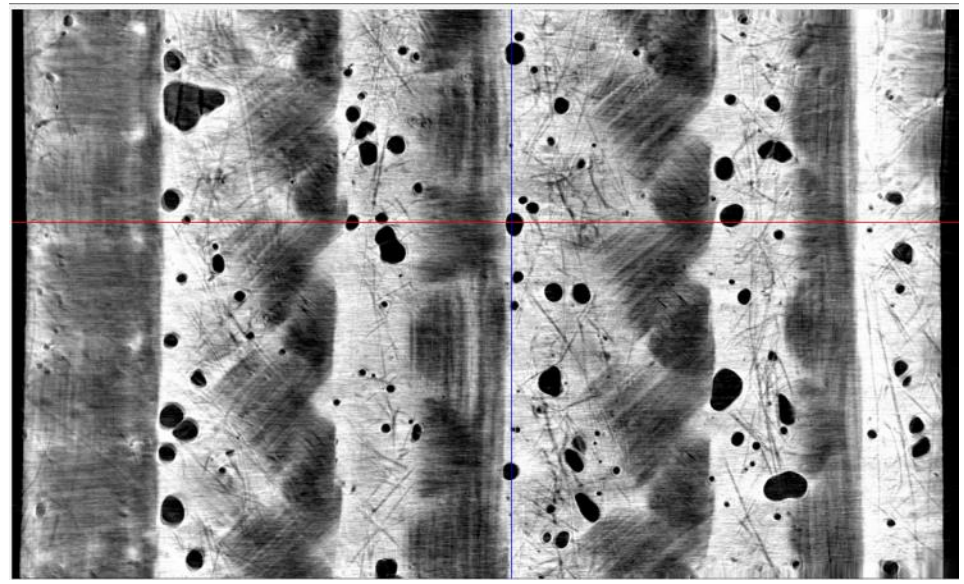


Bondline Observation by Micro-CT

Cross-section



Coronal view



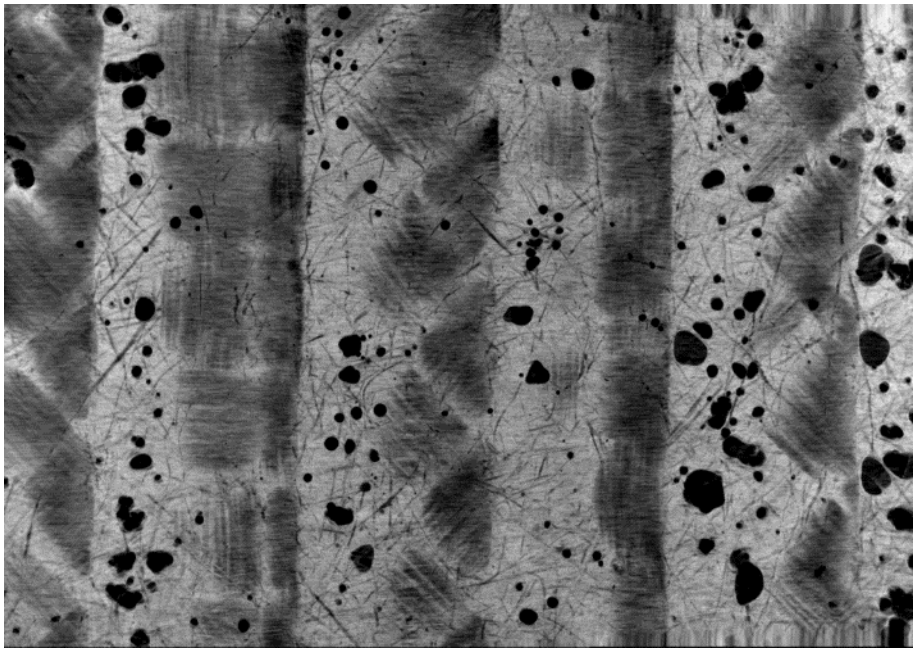
Able to visualize:

- Overlap step distance
- Ply orientation
- Non-woven carrier
- Adhesive flowing in the patch
- Voids

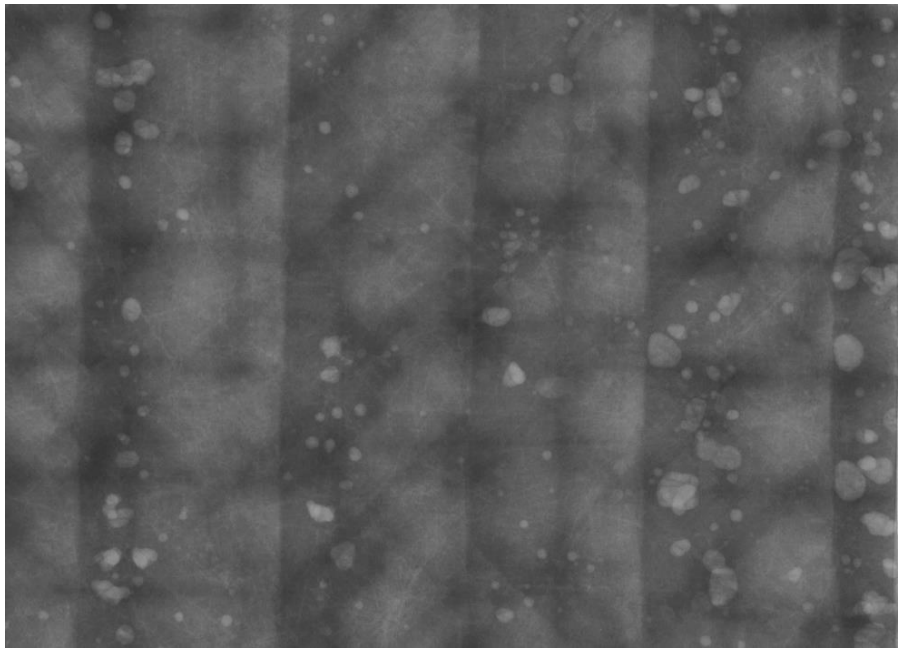
Bondline Observation by X-Ray

B – Air breathable adhesive - 1

2 mm



Coronal images by micro-CT

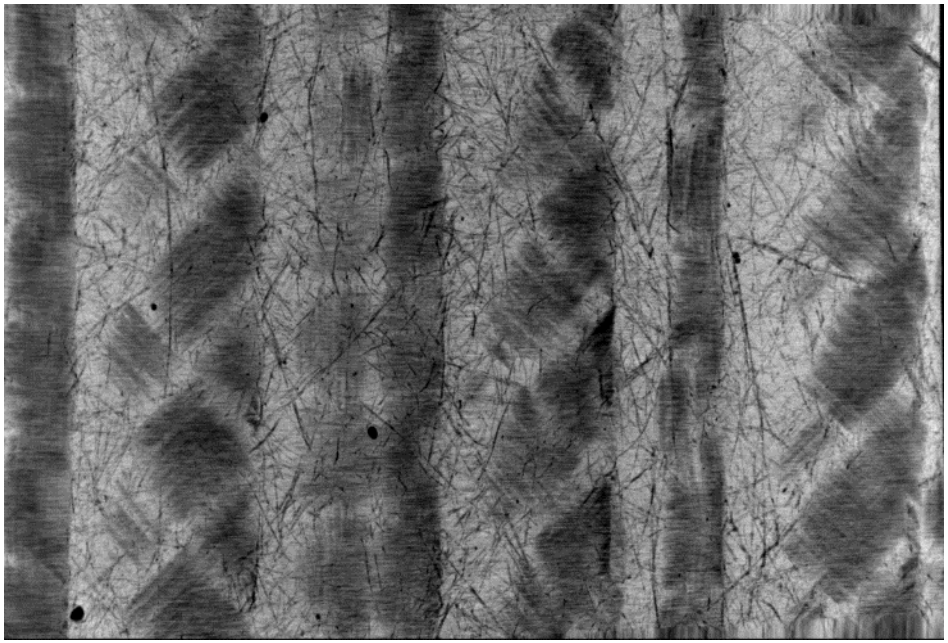


X-Ray radiograph of specimen
Adhesive porosity

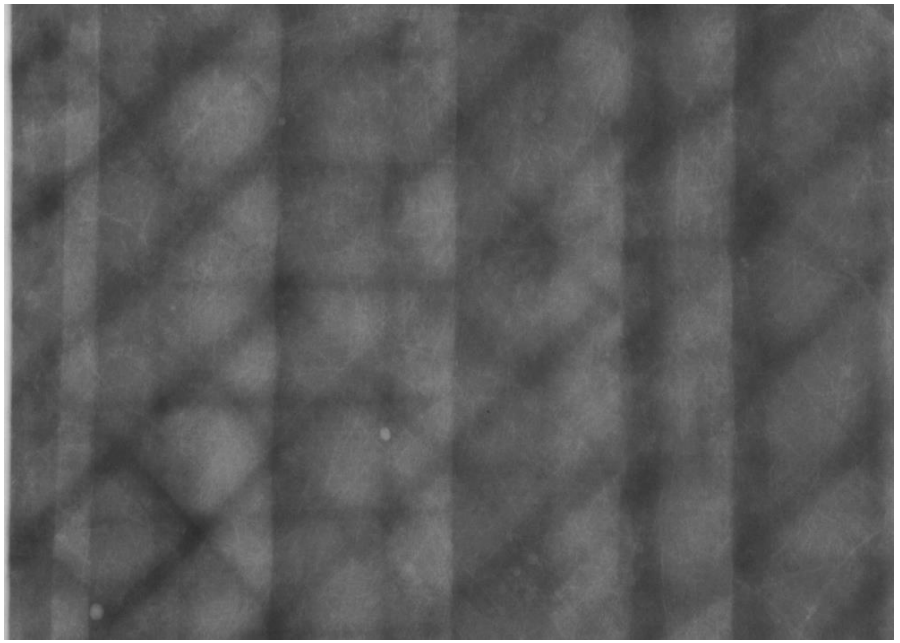
Bondline Observation by X-Ray

C – Air breathable adhesive -2 (+ embossing)

2 mm

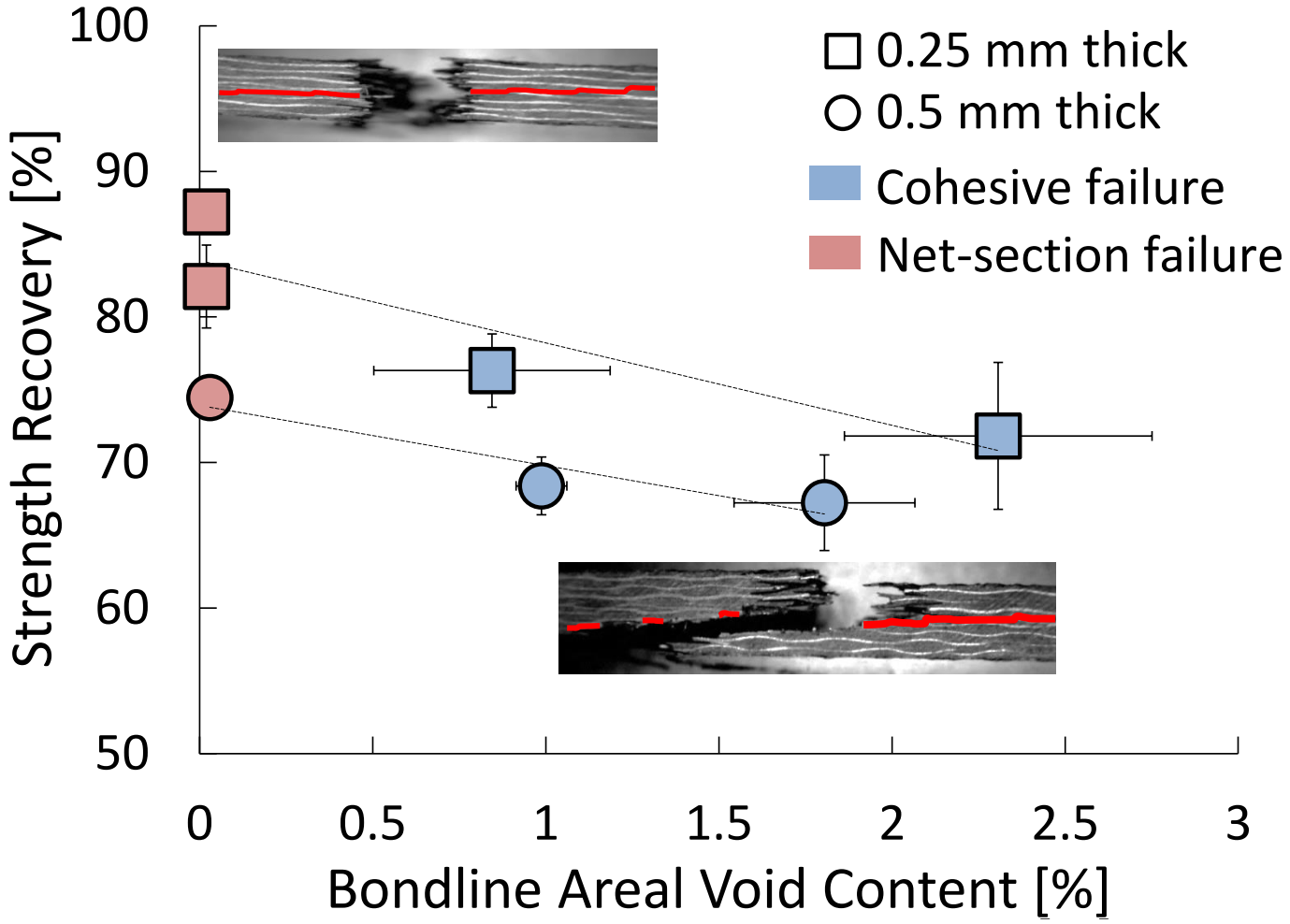


Coronal images by micro-CT

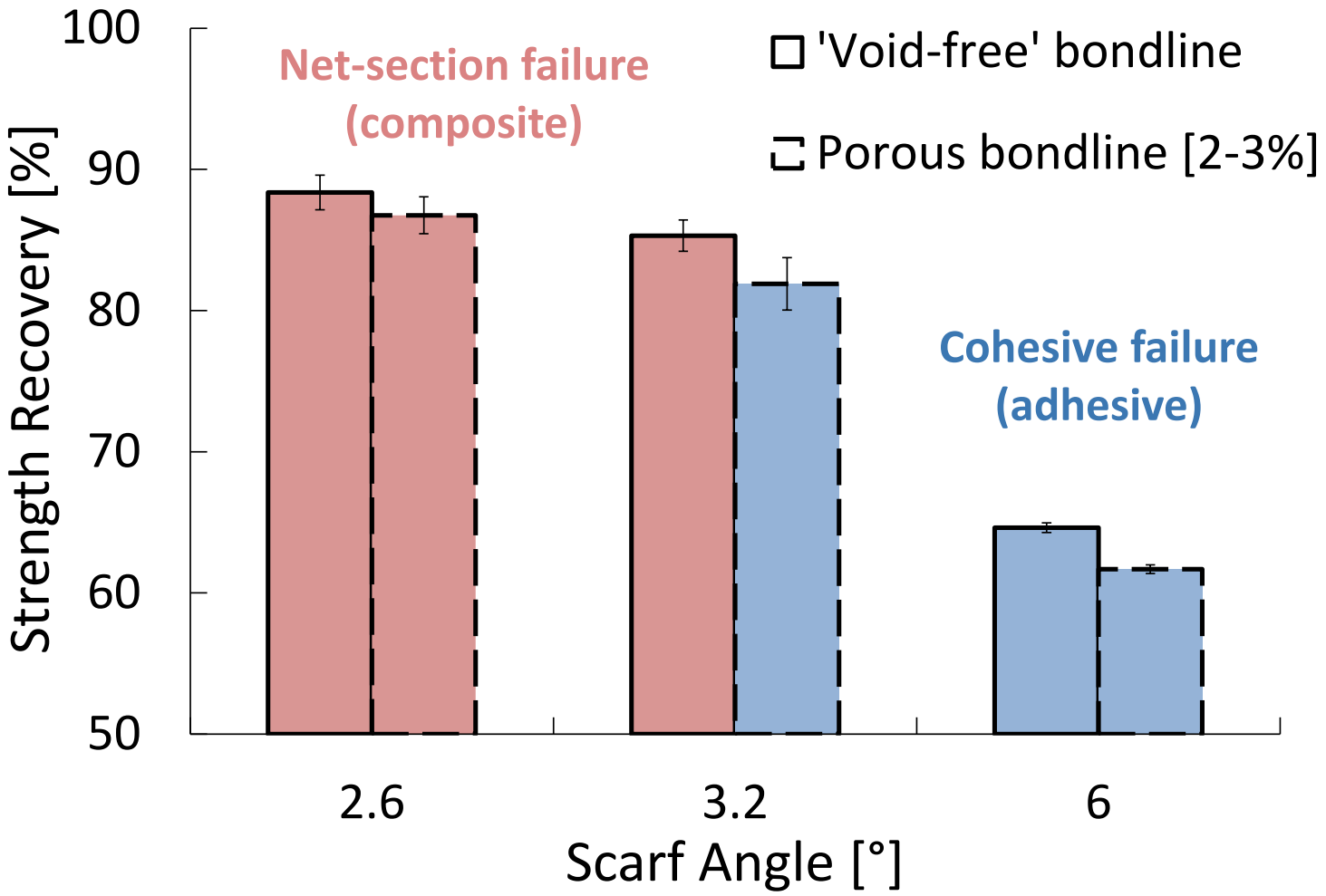


X-Ray radiograph of specimen
Adhesive porosity

Strength Recovery and Porosity [3°]



Scarf Angle and Bondline Porosity



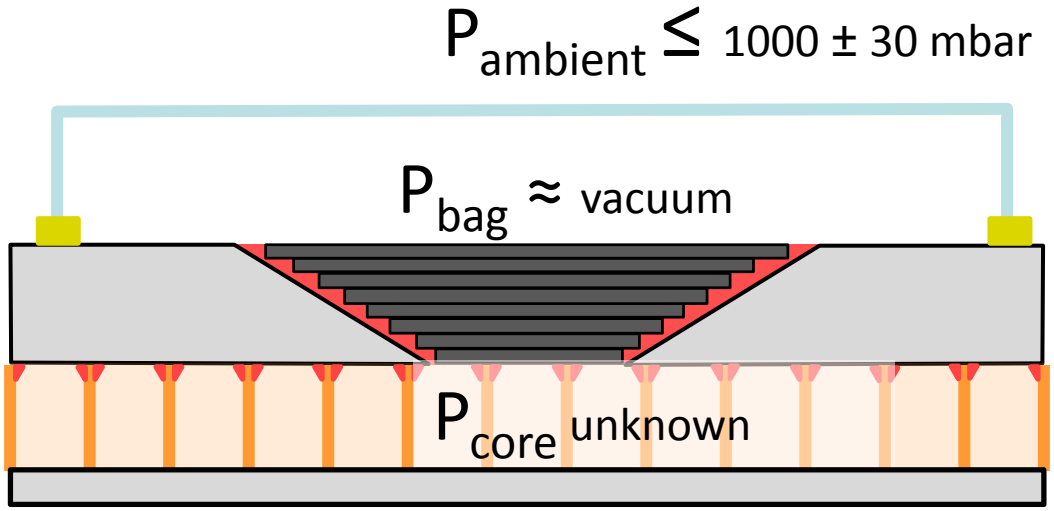
Summary

- **An ‘air breathable’ adhesive is a strategy to reduce porosity in bondline and repair patch in Vacuum Bag Only repairs**

- **5 % of the unnotched tensile strength recovery is lost per 1 % areal adhesive void content**

- **Final failure mode changes for ‘void-free’ repairs towards quasi-net section failures (from cohesive failures in case of porous bondlines)**

Air Evacuation in Sandwich Panel Repairs



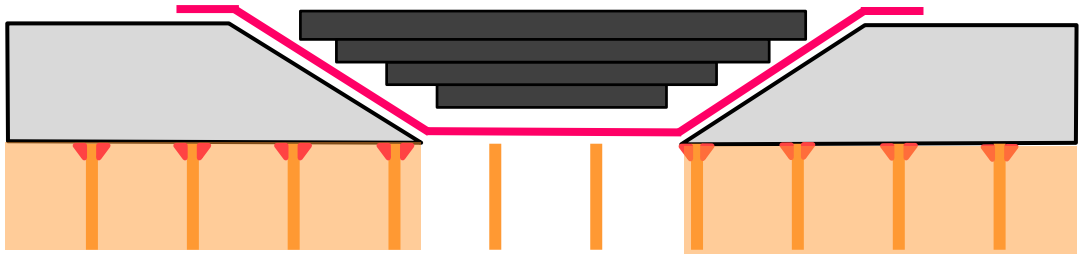
Prepregs and adhesive **transverse air permeability** is very low or zero

Kratz and Hubert, "Anisotropic air permeability in out-of-autoclave prepregs: Effect on honeycomb panel evacuation prior to cure," Composites Part A, 2013.

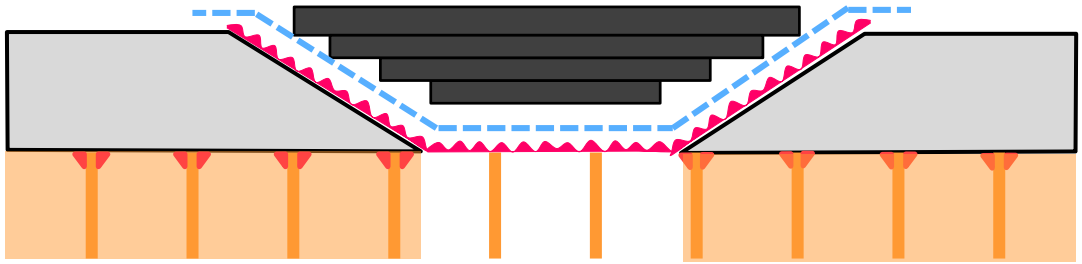
Tavares *et al.*, "Vacuum-bag processing of sandwich structures: Role of honeycomb pressure level on skin–core adhesion and skin quality," Composites Science and Technology, 2010.

Air Evacuation Strategy

A – Baseline



B – Breathable adhesive



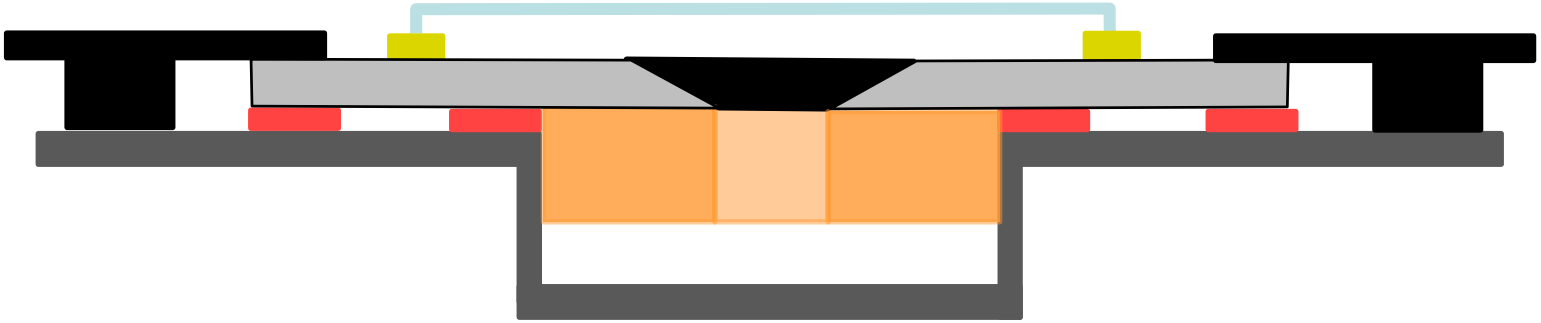
Film adhesive

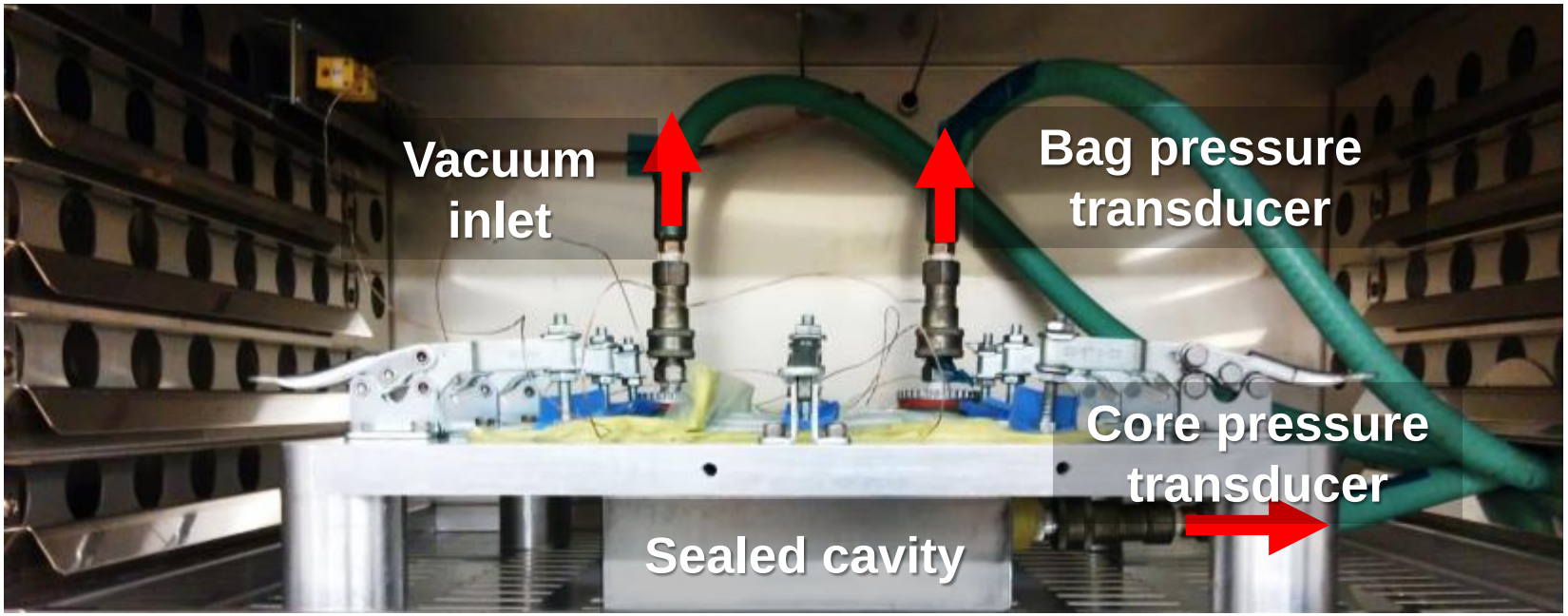
Glass veil

Embossed and perforated adhesive

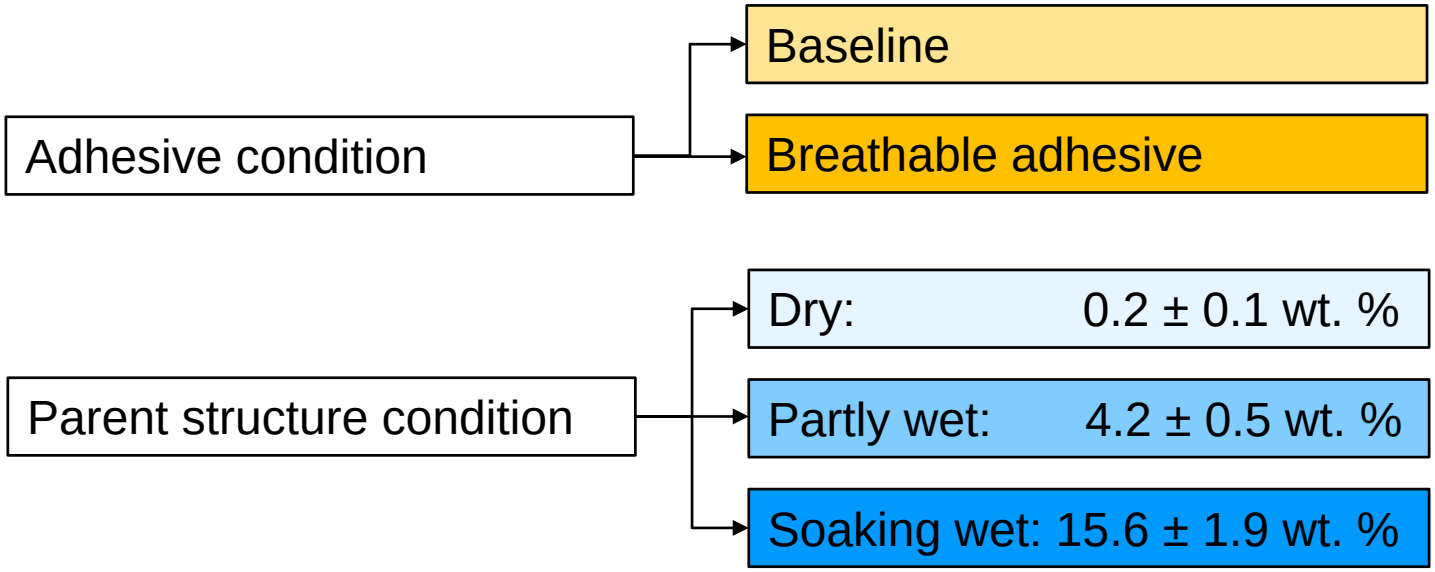
Sandwich Panel Repair Setup

Vacuum bag, and clamping mechanism





Experimental Methodology

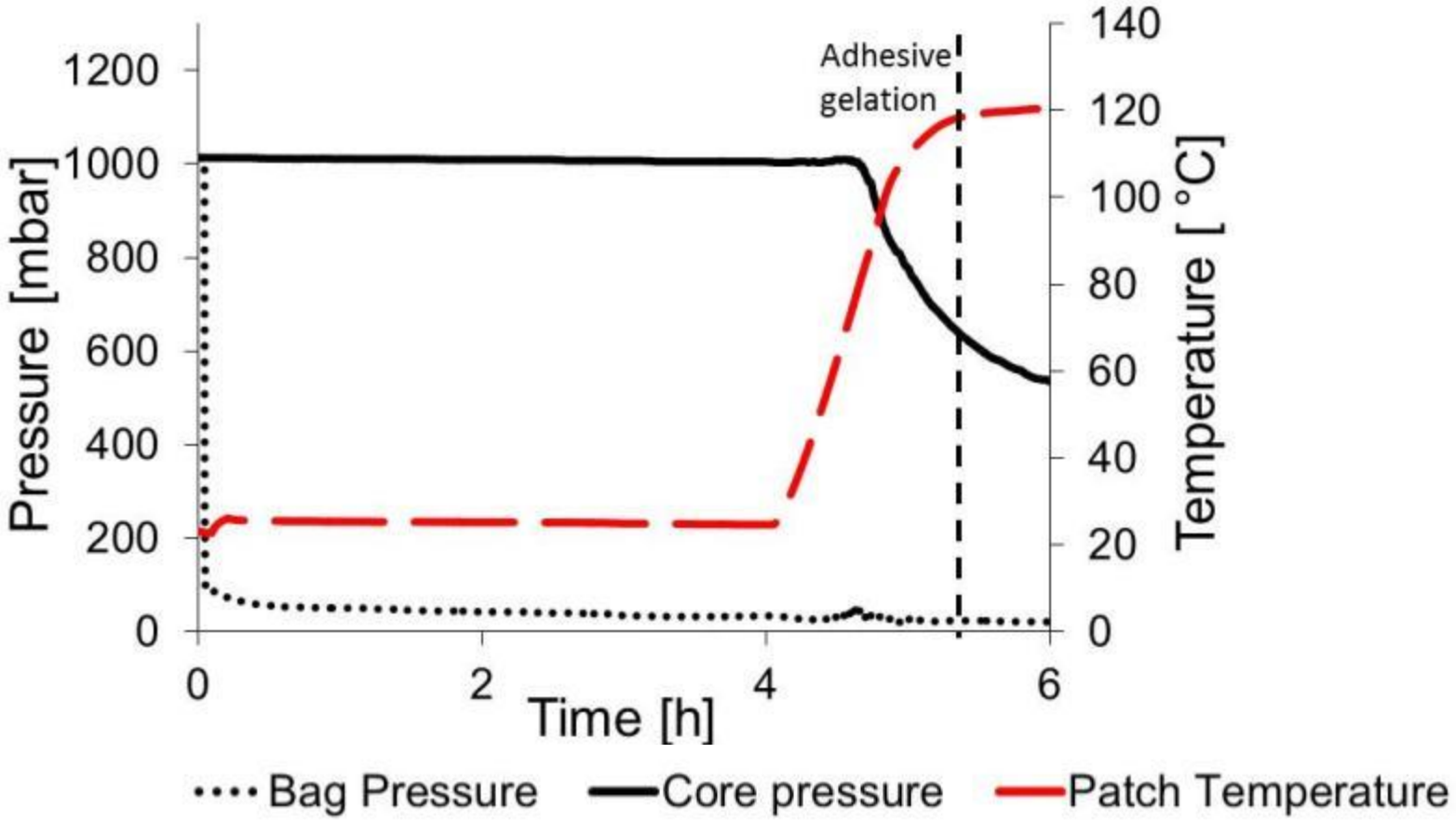


- **Process monitoring during vacuum hold and heat application**
- **Post-repair quality evaluation**

Pressure Readings during Repair

Baseline

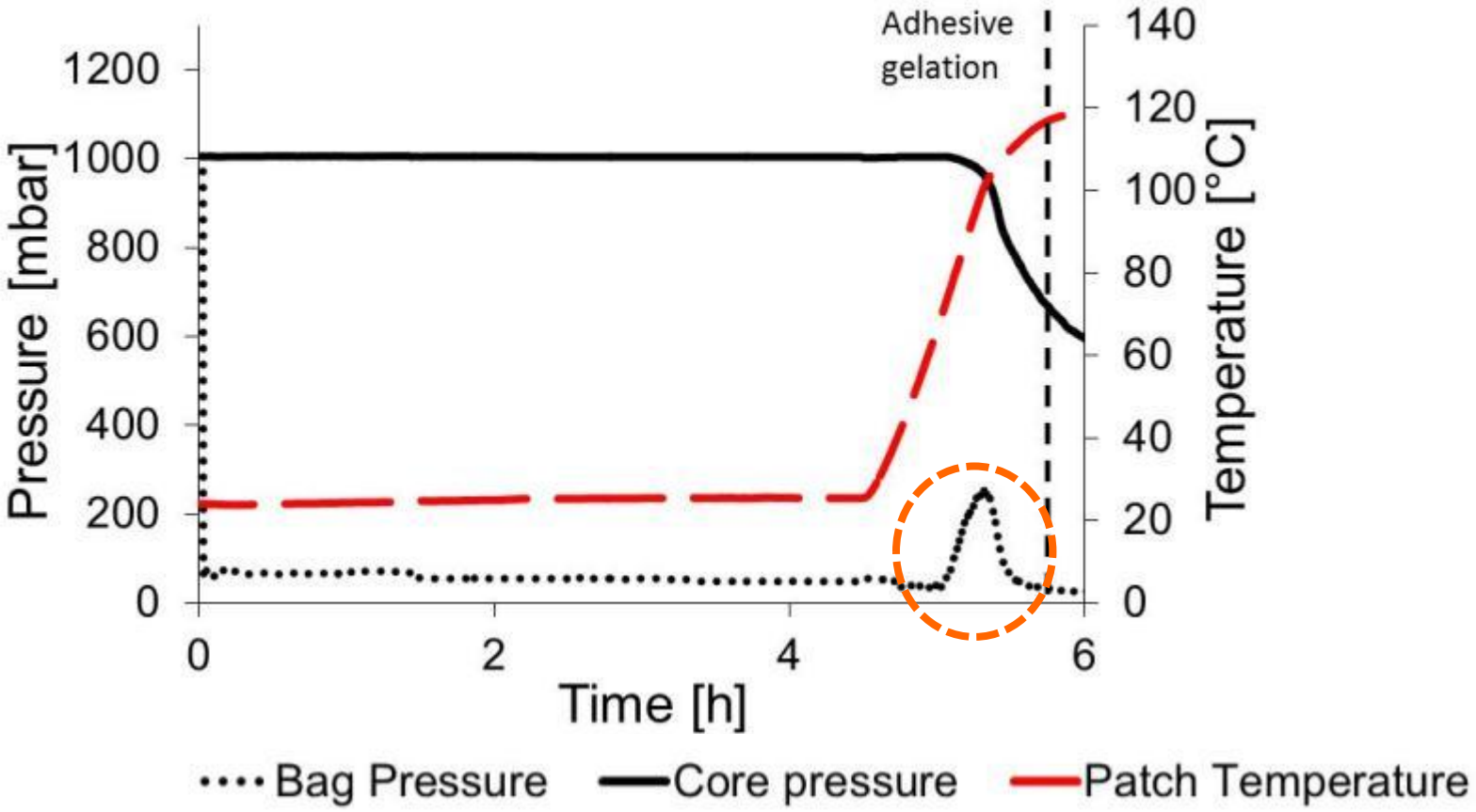
Dry: 0.2 %



Pressure Readings during Repair

Baseline

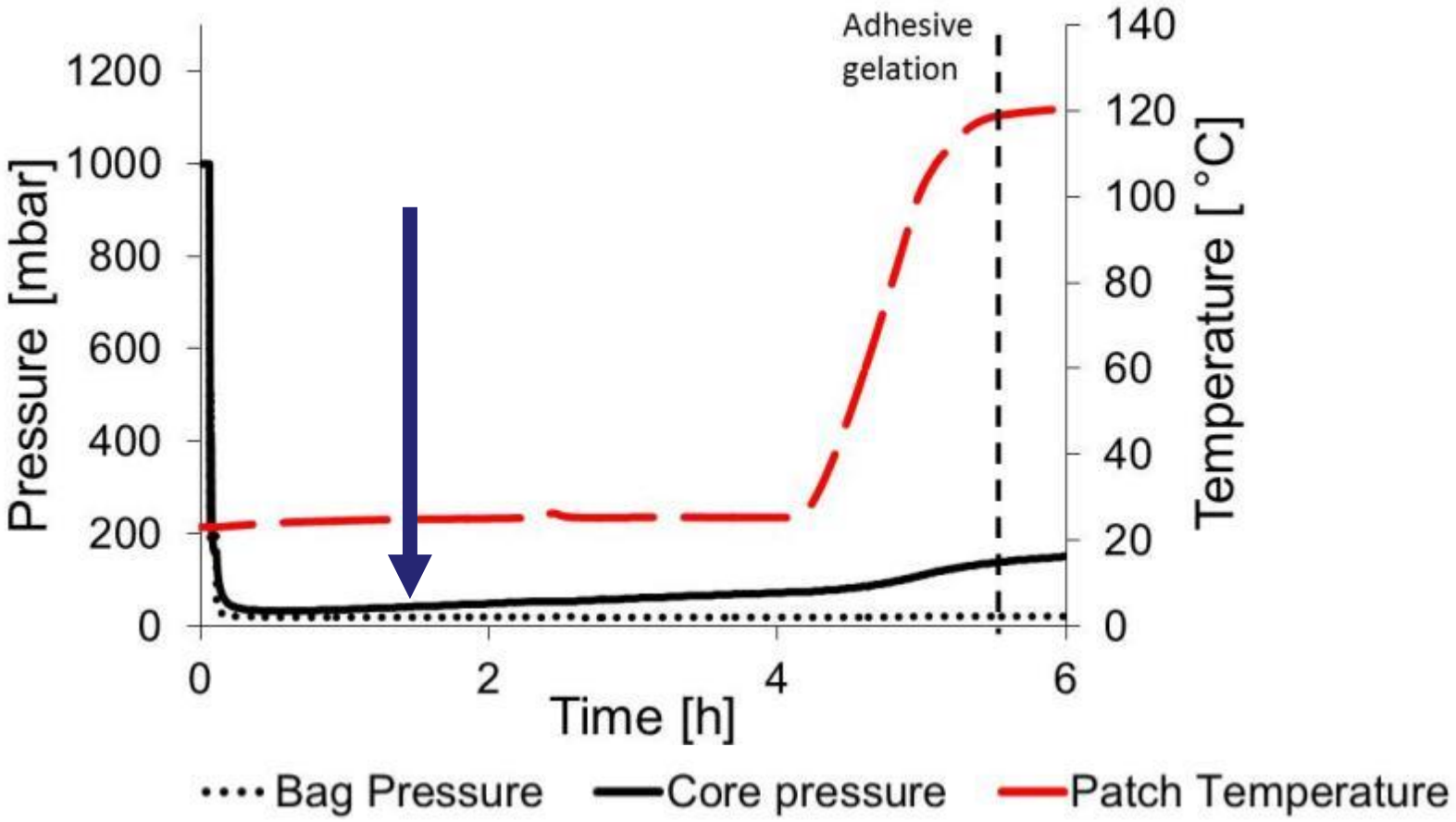
Partly wet: 4.2 %



Pressure Readings during Repair

Breathable adhesive

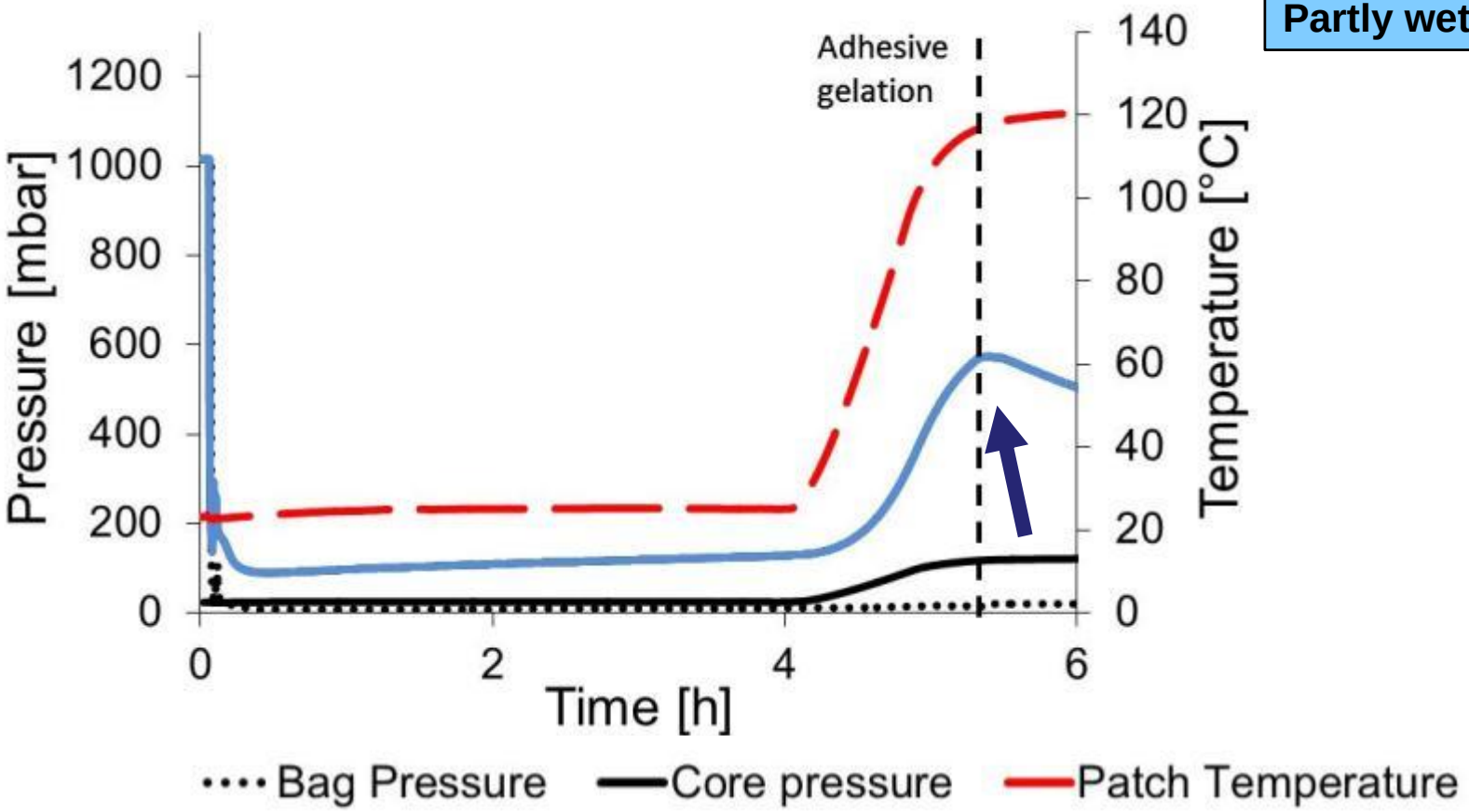
Dry: 0.2 %



Pressure Readings during Repair

Breathable adhesive

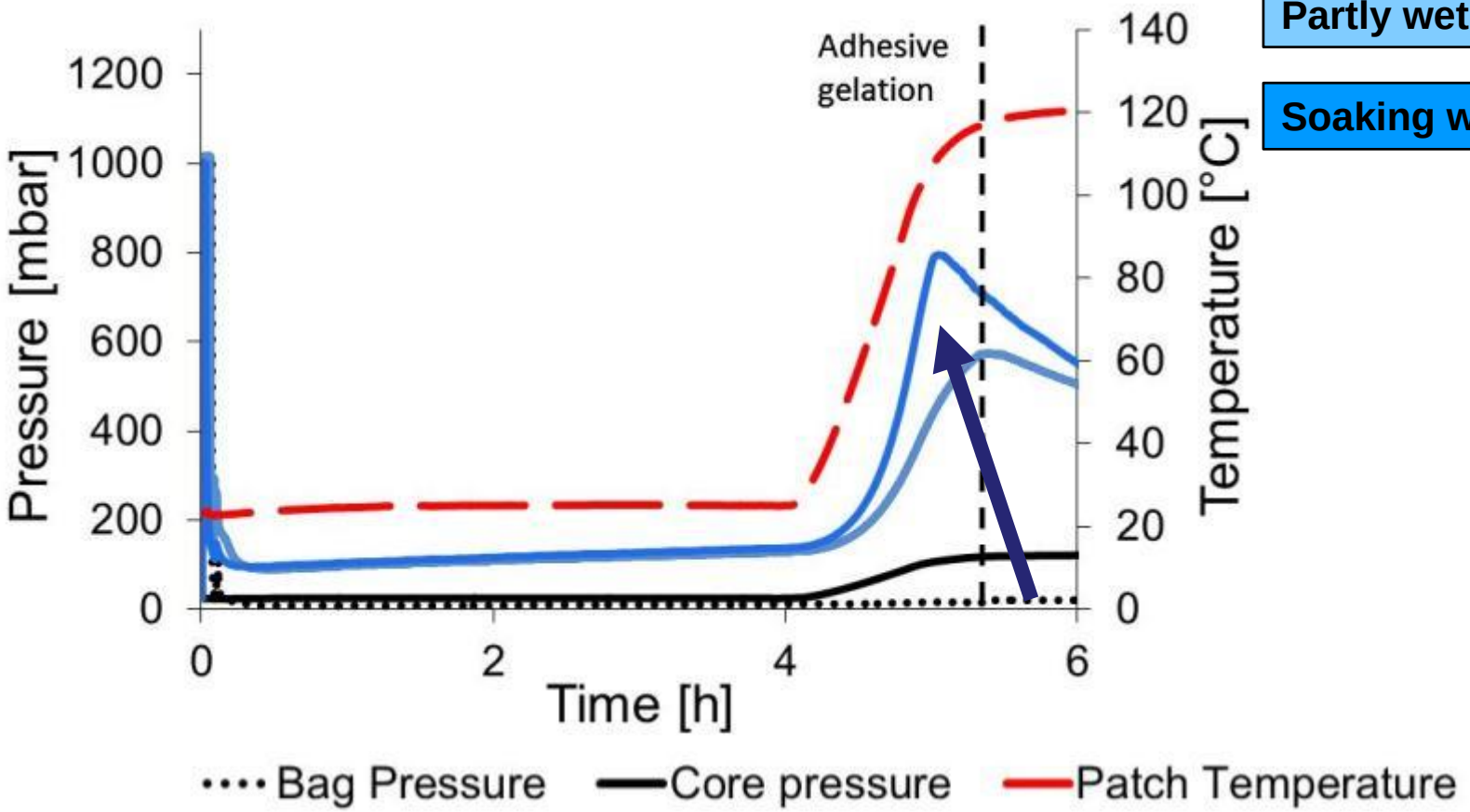
Dry:	**0.2 %**
Partly wet:	**4.2 %**



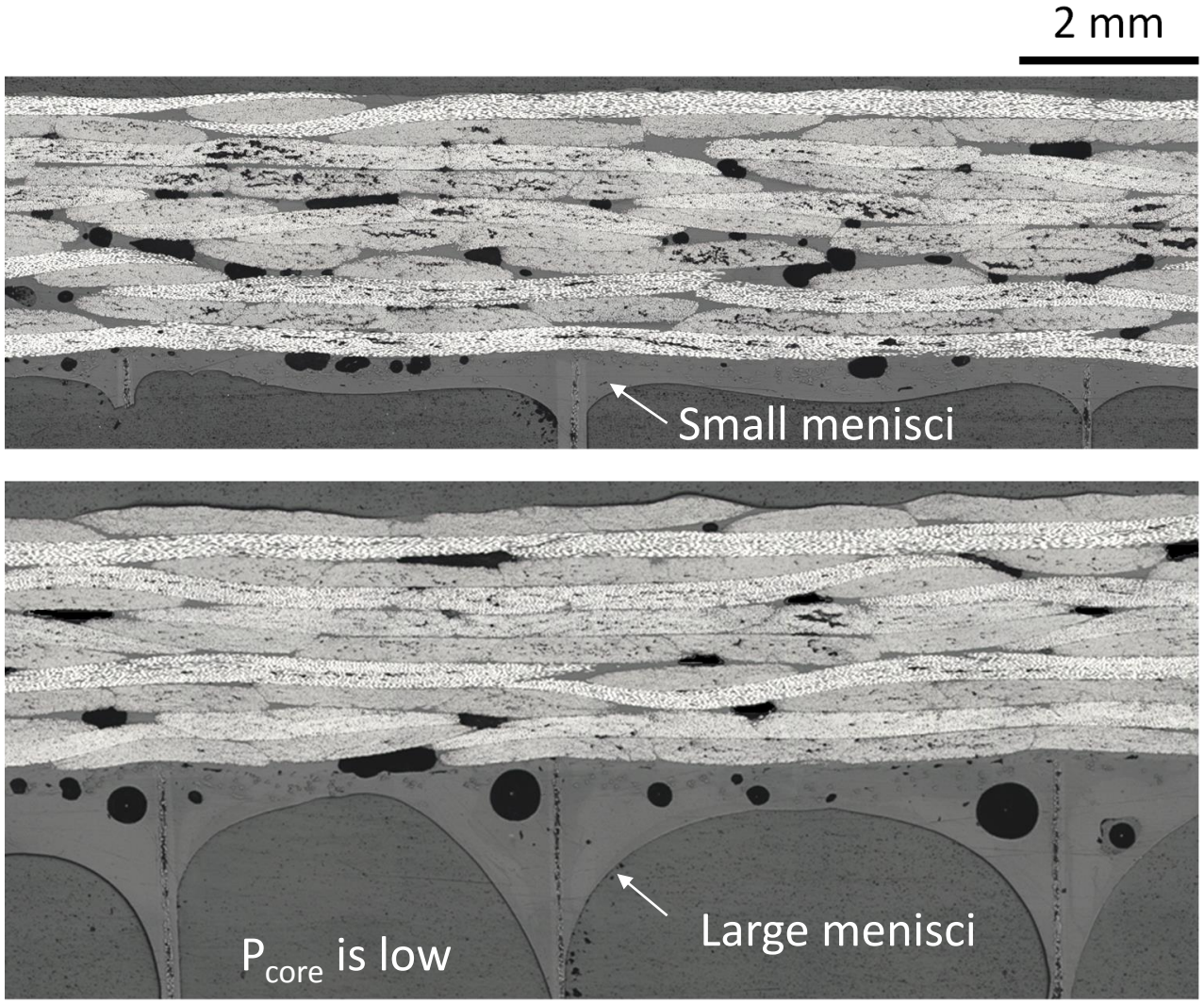
Pressure Readings during Repair

Breathable adhesive

Dry:	**0.2 %**
Partly wet:	**4.2 %**
Soaking wet:	**15.6 %**



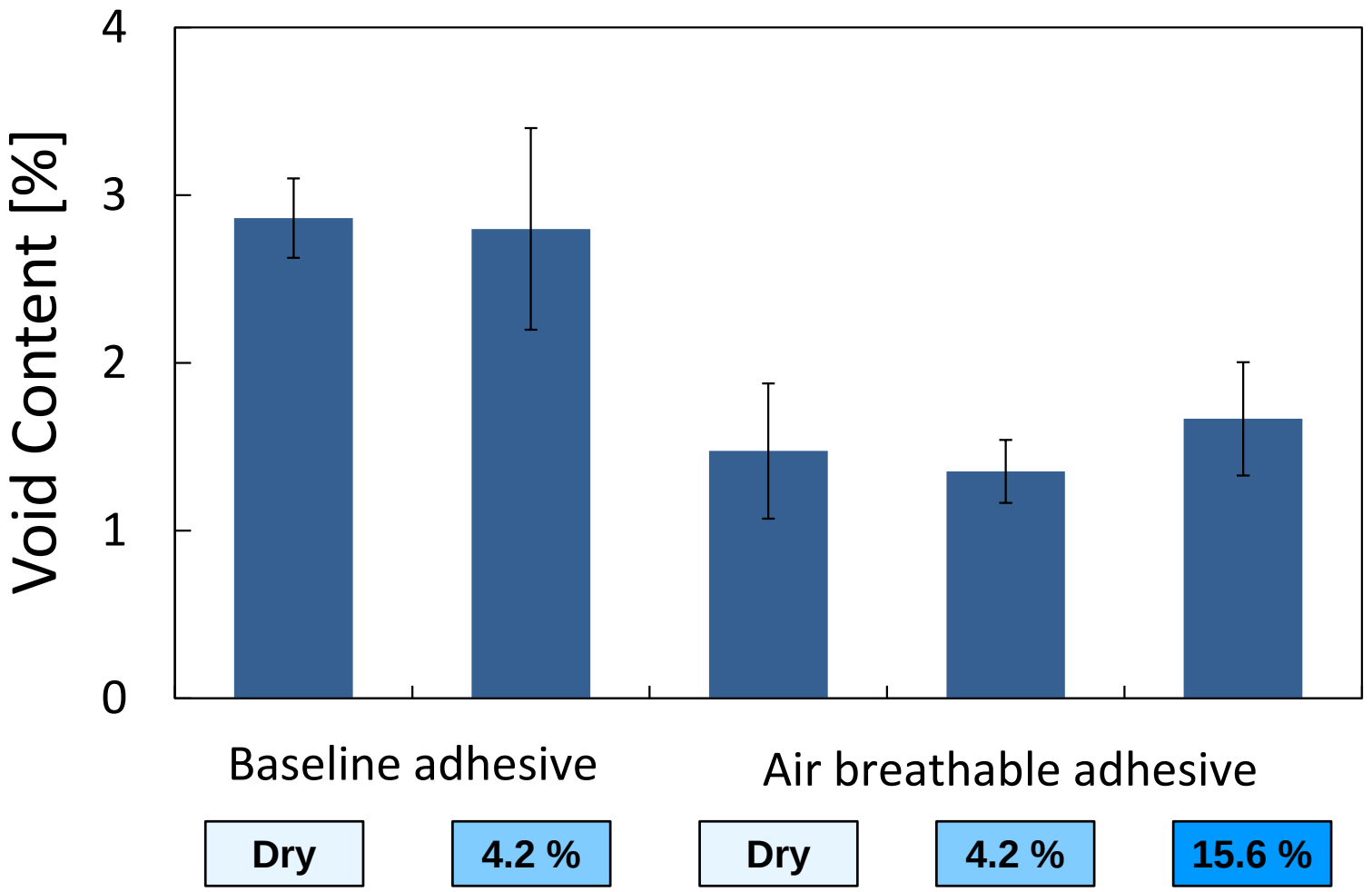
Patch Quality – Microscopy



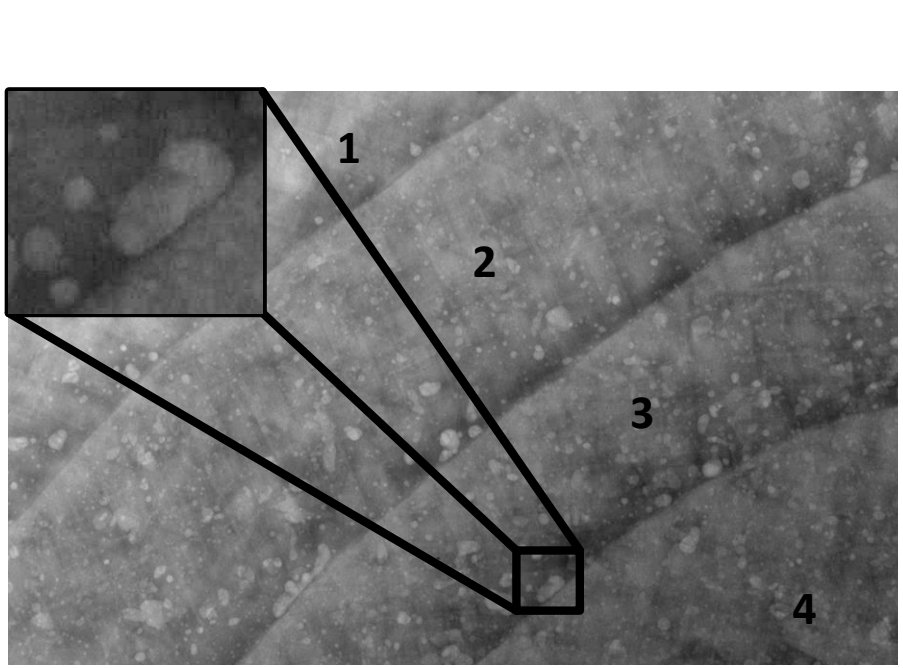
Baseline Adhesive

Air breathable adhesive

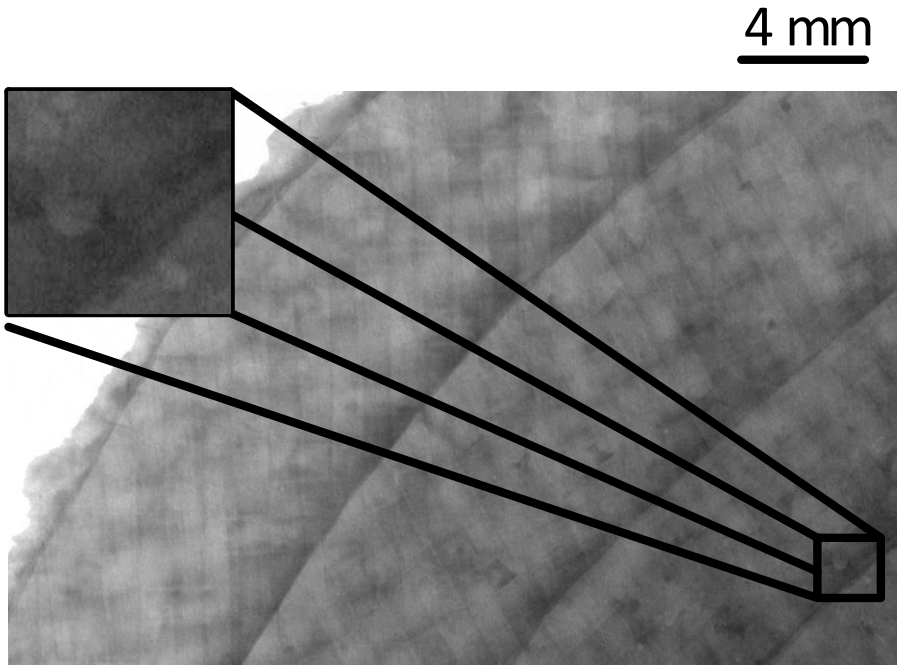
Repair Patch Porosity



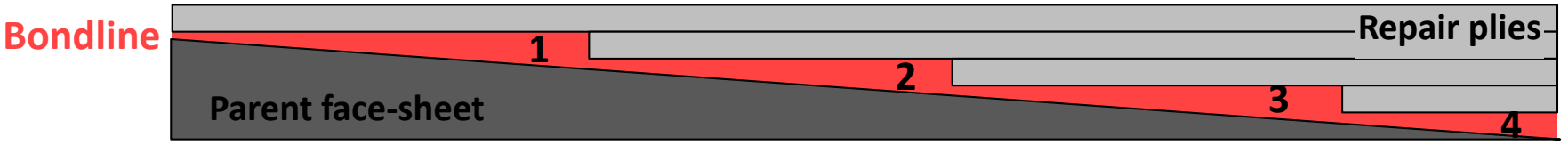
Bondline Quality – X-Ray



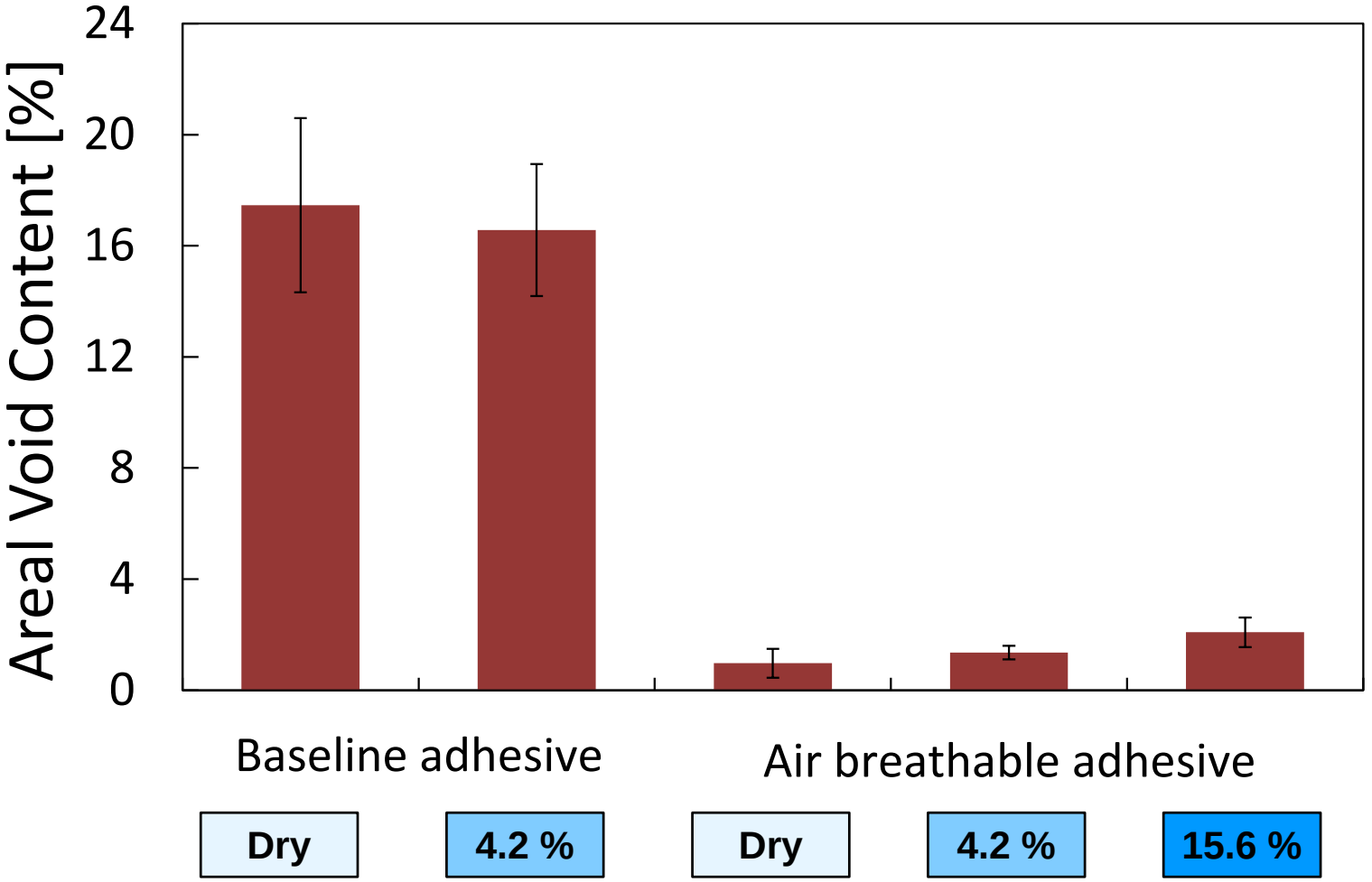
Baseline Adhesive



Air breathable adhesive



Bondline Porosity



Summary

- **The use of a breathable adhesive allows extraction of the air out of the semi-preg repair plies, and core plug.**

- **Initial low core pressure prevents the repair patch to 'pop-out', even if the parent structure is still wet.**

- **This leads to improvements in bondline, patch, and adhesive menisci quality, regardless of parent structure moisture condition.**

Future Work

- **Modelling of moisture transport during repair:**
  - **Analytic / FE modelling**
- **Sandwich repairs:**
  - **Realistic sandwich repairs (good/bad) with NDE**
- **Wet patch repair process:**
  - **Propose procedure to increase process robustness**
- **Repair demonstrator:**
  - **Apply prepreg patch breathing technique**
  - **Apply wet patch process**

Acknowledgements

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- **For veil donation:** tfp