# INTRODUCTION TO OUT OF AUTOCLAVE PREPREG PROCESSING

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# YOUR HOSTS

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Co-Director of Advanced Materials Manufacturing MEL Program, UBC
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- Ph.D. and M.A.Sc. in Composite Materials Engineering
- Nearly 20 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

# PRESENTATION CONTRIBUTORS

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  - CKN Trainee Engineer

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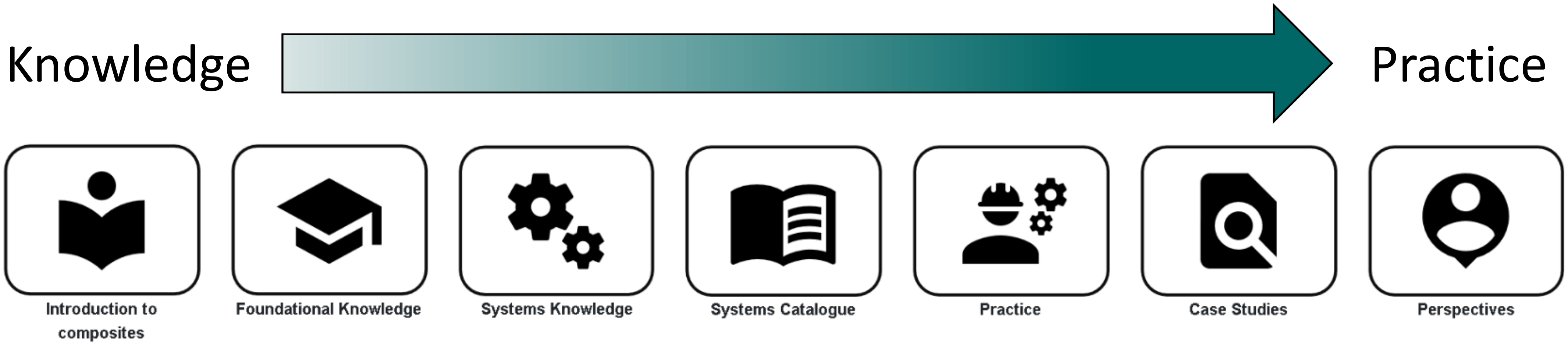
  - CKN Research Engineer

# KNOWLEDGE IN PRACTICE CENTRE (KPC)

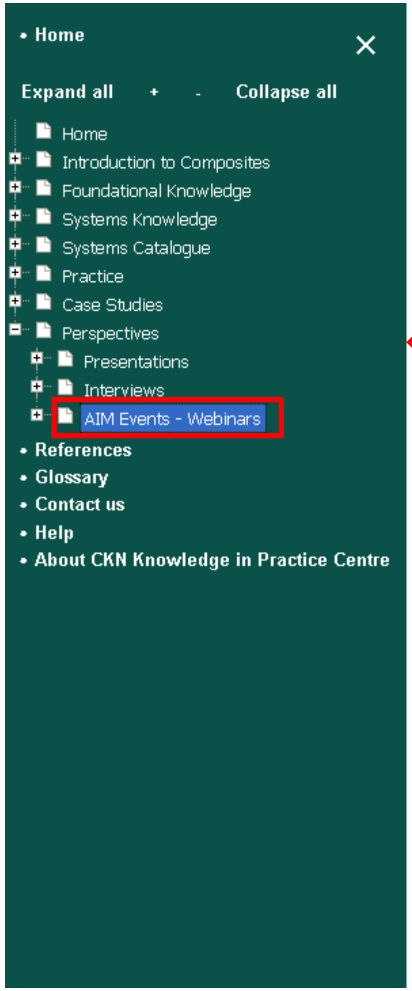
- A freely available online resource for composite materials engineering:

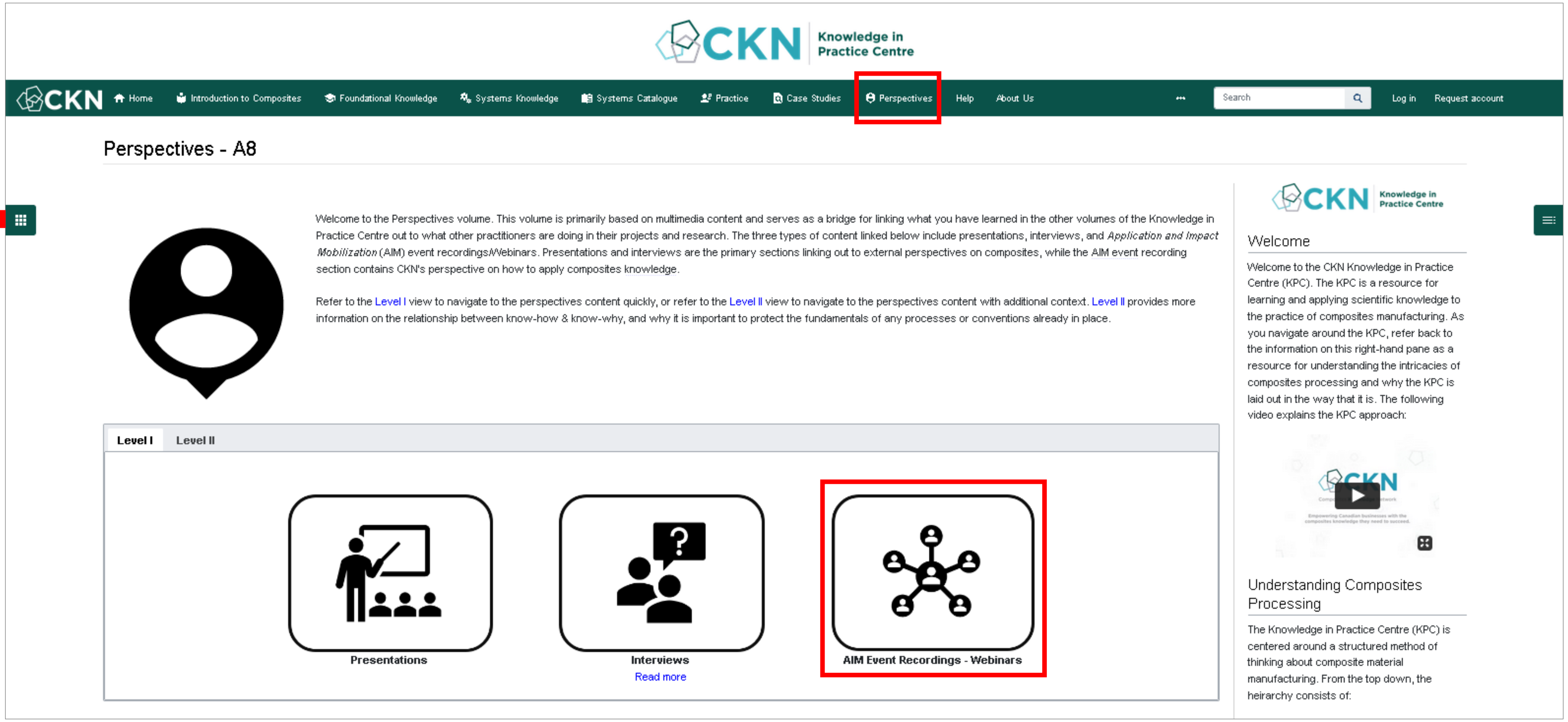
compositeskn.org/KPC

- Focus on practice, guided by foundational knowledge and a systems-based approach to thinking about composites manufacturing



# PAST WEBINAR RECORDINGS AVAILABLE




Today's Webinar will be posted at:
https://compositeskn.org/KPC/A393

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# TODAY'S TOPIC:

*Introduction to Out of Autoclave (OoA) Prepreg Processing*

# OUTLINE

- What is OoA Prepreg Processing?
- History and Applications
- Opportunities & Limitations
- High Level Comparison & Cost Analysis
- Key Considerations
- Making a Part
- Case Studies – Thermal Management & Mechanical Properties
- Defect Formation
- Summary

**BACKGROUND KNOWLEDGE**

**Prepreg page:**
https://compositeskn.org/KPC/A171

Webinar on prepreg processing:
https://compositeskn.org/KPC/A125

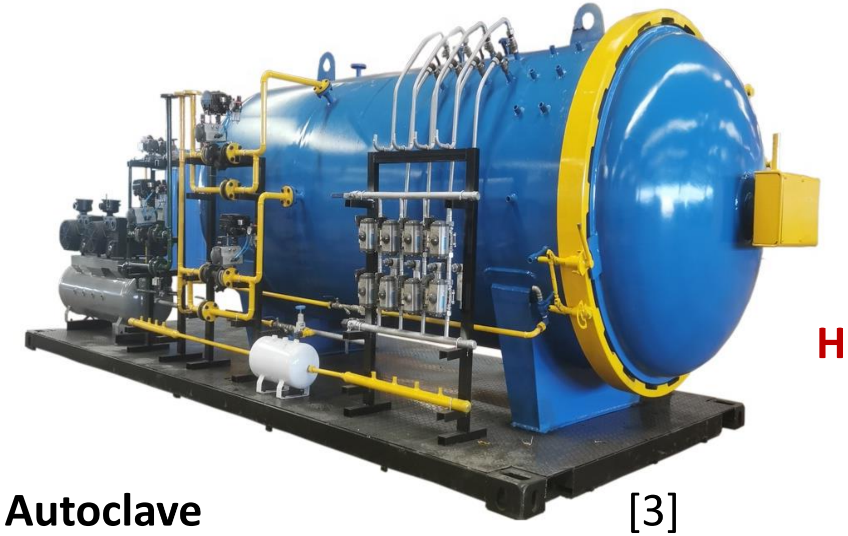
# WHAT IS OUT OF AUTOCLAVE PREPREG PROCESSING?

Prepregs are a type of fibre reinforcement pre-impregnated with an activated resin matrix [1]

- OoA definition: processing of prepregs without an autoclave
  - Sometimes referred to as *VBO* (vacuum bag only)
- Benefits: lower capital/energy costs


Heat

Oven [2]



Heat + Pressure

Autoclave [3]

[1] https://www.compositesworld.com/articles/rediscovering-the-benefits-of-prepregs-in-composites-manufacturing?
[2] https://ovens.lewcoinc.com/products/industrial-batch-ovens/enhanced-duty-composite-curing-ovens/350f-177c/ewr03ed-composite-curing-oven/
[3] https://www.alibaba.com/showroom/used-composite-autoclave-for-sale.html

# OPPORTUNITIES

## Lower capital & operational costs

- ✓ Avoids expensive autoclave, nitrogen systems and ongoing maintenance.

## Reduced energy consumption

- ✓ Uses ambient air and lower temperatures, significantly cutting energy use.

## Faster setup & lead times

- ✓ Ovens are simpler, cheaper, and quicker to procure and comission.

## Simpler & safer processing

- ✓ No need for high-pressure vessels or hazardous nitrogen infrastructure.

## Easier facility integration

- ✓ Smaller, less complex equipment footprint unlocks more locations.

## Broader industry access

- ✓ Opens composite manufacturing to non-aerospace sectors

# LIMITATIONS

## Lower Consolidation Pressure

- Vacuum bag only consolidation makes it harder to eliminate voids and achieve consistent, high fiber volume fractions.

## Higher Risk of Porosity

- Without extra compaction, residual air or moisture can raise void contents and degrade performance.

## Tighter control required

- Prepregs require strict cold-storage and dry handling to prevent resin migration or moisture uptake.

## Limited part complexity

- Deep draws, thick laminates, and tight contours may be harder to consolidate uniformly under vacuum.

## Narrower processing window

- OoA resins demand precise control of temperature ramps, soak levels, and vacuum integrity.

## Longer dwell times & cure cycles

- Typical OoA cycles add low-temp dwell and extended cures, lengthening overall processing time.

# HISTORY OF OoA [1]

**Drivers:** Rising autoclave costs; need for agile, cellular workflows; push for lower carbon footprint and formal OoA standards. [1]

## Mid-1990s – 2006 Early Research

- AFRL/DARPA funds ACG's LTM series (first VBO prepregs)
- SpaceShipOne & Boeing X45A cured at ~60 °C under vacuum
- Drawbacks: high porosity, ~1 week out-times, modest toughness

## 2007 – 2010 Qualification & Uptake

- DARPA/Boeing/AFRL drive OoA to autoclave levels (MTM45-1 & Cytec 5320)
- Key demonstrators: Lockheed ACCA fuselage and Boeing/Aurora UAV structures
- Proved large-scale OOA possible, but materials still in qualification

[2]

## 2010s Process Highlights

- Engineered Vacuum Channels (EVACs) for self-breathing prepregs
- Edge-breathing vacuum holds (hours → half-day pre-cure)
- High-temperature post-cures narrow cycle-time gap vs. autoclave

## 2010s – today Advanced Materials & Outlook

- New OoA materials (BMIs, polyimides) now match autoclave-cured strength
- Automated layup with oven cures is proven on pilot lines for higher-volume production [3]
- OoA cuts life-cycle carbon footprint by 20–30 % compared to autoclave

[1] https://www.compositesworld.com/articles/out-of-autoclave-prepregs-hype-or-revolution
[2] https://www.jbcharleston.jb.mil/News/Article-Display/Article/236093/advanced-composite-cargo-aircraft-makes-first-flight/
[3] Ridgard, C. (2009). Out-of-Autoclave Composite Technology for Aerospace, Defense and Space Structures. In *Proceedings of the SAMPE 2009 Conference*

# OOA APPLICATIONS

***NASA** Composite Cryotank Technologies & Demonstration*

[1]

**Advanced demonstration**

- Full-scale ground tests in a relevant environment;
- near flight-ready but not yet in service

***Marine Current Turbine** SeaGen Tidal Turbine*

[2]

**Field-proven commercial prototype**

- Full-scale, grid-connected 1.2 MW tidal turbine
- Operated from 2008–2019

***We are One Composites** Bicycle Components*

[3]

**Commercial product**

- In mass-market sale

***Cirrus** SR-22*


[4]

**Production aircraft**

- In serial production, FAA-certified and in widespread service

[1] https://www.sciencedirect.com/science/article/pii/S003436171270108X
[2] https://www.spacelaunchschedule.com/space-news/composite-cryotank-technologies-and-demonstration-cctd/
[3] https://cyclingindustry.news/we-are-one-composites-carbon-done-different-canada-made/
[4] https://www.aircharter.com.hk/aircraft-guide/private/cirrus-usa/cirrussr-22

# COMPARISON OF PROCESSING REQUIREMENTS

| Aspect | Autoclave | Oven |
|---|---|---|
| Equipment Cost [1] | USD ~$400 K for a 72”×96” autoclave | USD ~$100 K for a 105”x135” oven |
| Operational Requirements | Electricity/gas, pressurizing gas, vessel maintenance, heavy-handling labor | Electricity/gas, vacuum-pump upkeep, bagging consumables, simple handling |
| Pressure | ~7 atm (100 psi/0.7 MPa) | ~1 atm (14.7 psi/0.1 MPa) |
| MRCC-MTM45 [2] | Ramp 1–2 °C/min → 120 °C (4 h) → ramp → 180 °C (2 h); cooldown ≤ 3 °C/min → 60°C | Ramp 1–2 °C/min → 80 °C (0.5 h) → ramp → 120 °C (4 h) → ramp → 180 °C (2 h); cooldown ≤ 3 °C/min → 60°C |
| Cycle Time | ≈ 6 h total (incl. ramps, cooldown & post-cure). | ≈ 8 h total (incl. dwell, ramps, cooldown & post-cure). |
| Void Content | Typically < 0.5 vol % | Typically < 2 vol % |
| Part Size & Geometry | Complex shapes | Simpler geometries |
| Materials | Any autoclave-grade resin | Typically only low-exotherm, lower-viscosity systems |
| Energy Use | Very high (pressure + heating) | Moderate (heating only) |
| Environment | Inert Gas | Ambient Air |
| Maintenance & Safety | Vessel certification, seal checks, safety interlocks | Vacuum-pump upkeep, basic electrical safety checks |

[1] ASC Autoclave and Oven Internal Quotations
[2] MTM45-1 Material Data Sheet

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# OOA CURING STAGES

- Three critical stages define successful air evacuation, fibre packing, and final part quality in OoA processing [1]

## Stage I – Room-Temp

- **Vacuum hold:** High-viscosity B-stage resin resists flow; vacuum compacts the plies and evacuates large air pockets
- **Resin flow:** Minimal at this stage due to high viscosity

## Stage II – Heating

- **Viscosity drops:** Resin starts to saturate dry tows and collapse void channels
- **Thickness decreases:** Laminate consolidates toward cured-ply dimensions
- **Last chance for migration:** Volatiles can still migrate before entrapment

## Stage III – Cure

- **Gelation & Vitrification:** Resin cross-links, viscosity spikes, air evacuation halts
- **Effect:** Fibre architecture locked in; residual voids fixed — quality depends on prior stages

[1] Pascal Hubert, Timotei Centea, Lessa Grunefelder, Steven Nutt, James Kratz, et al.. Out-of-Autoclave Prepreg Processing. Comprehensive Composite Materials II, 2, Elsevier, pp.63-94, 2018

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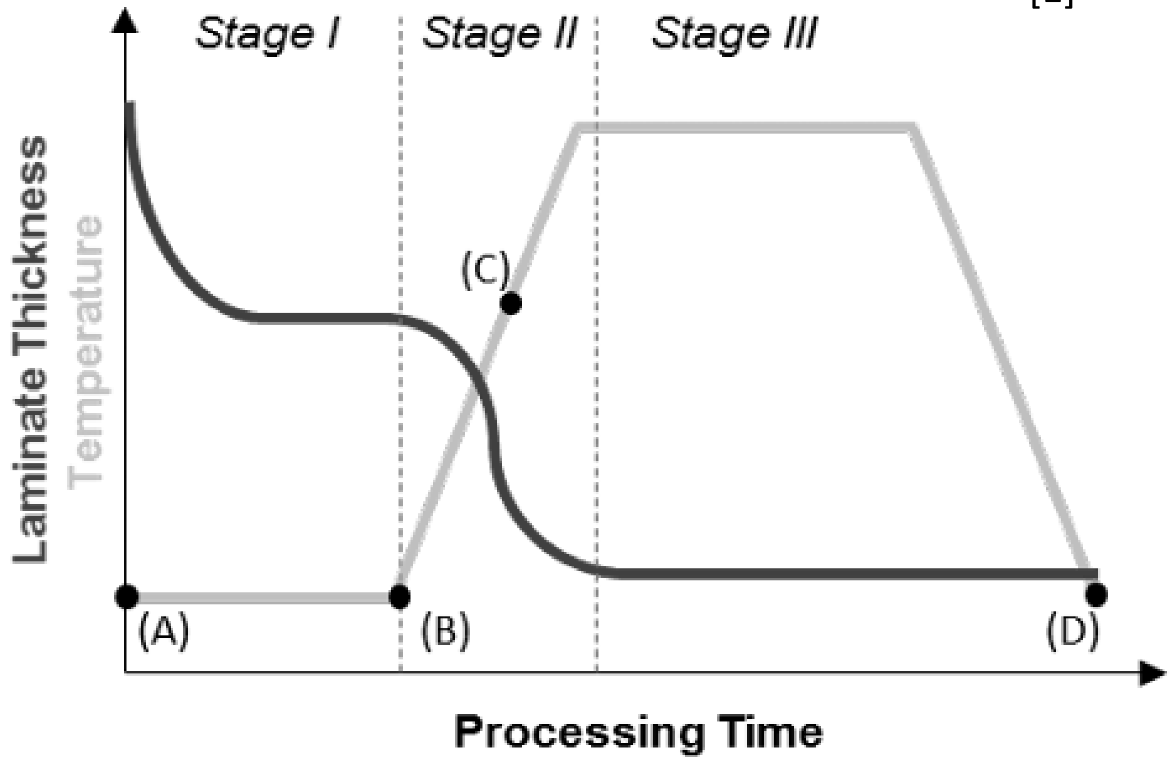


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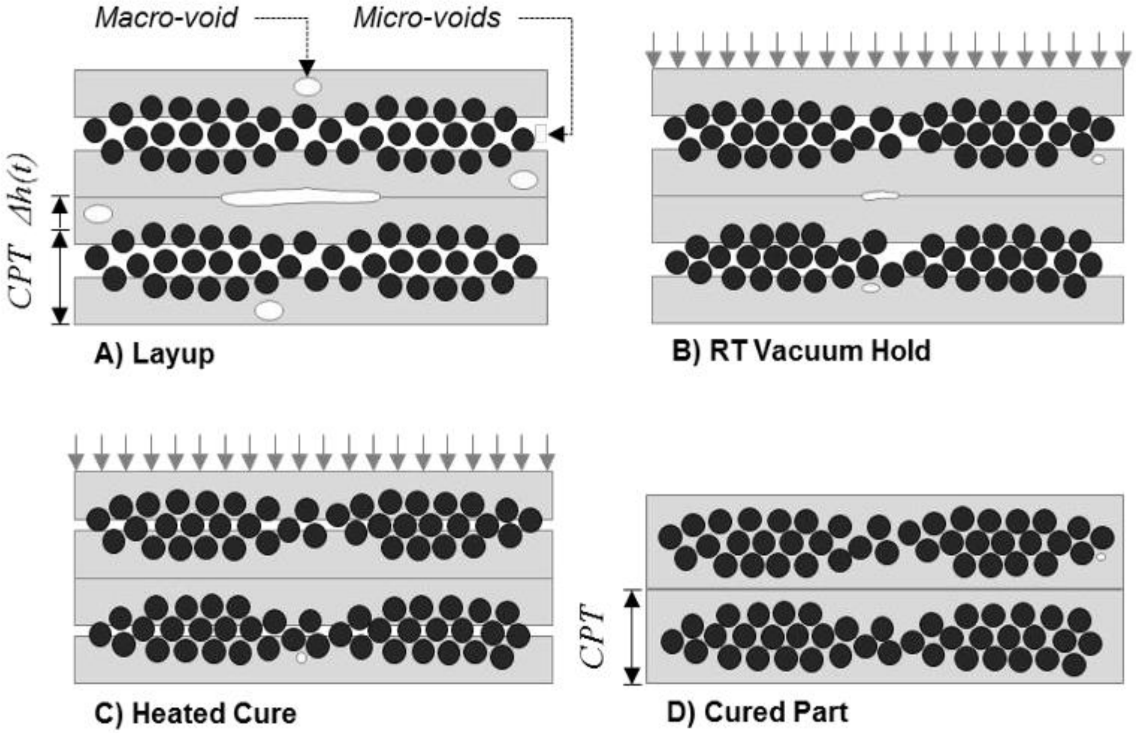


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# VISCOSITY

- OoA processing relies on vacuum-only pressure (~1 atm), making the resin's viscosity profile vital for effective air evacuation and fibre wet-out. [1]

**High Room-Temperature Viscosity**

- Prevents cold flow during long vacuum holds – avoiding premature resin migration that would seal evacuation channels and trap volatiles.

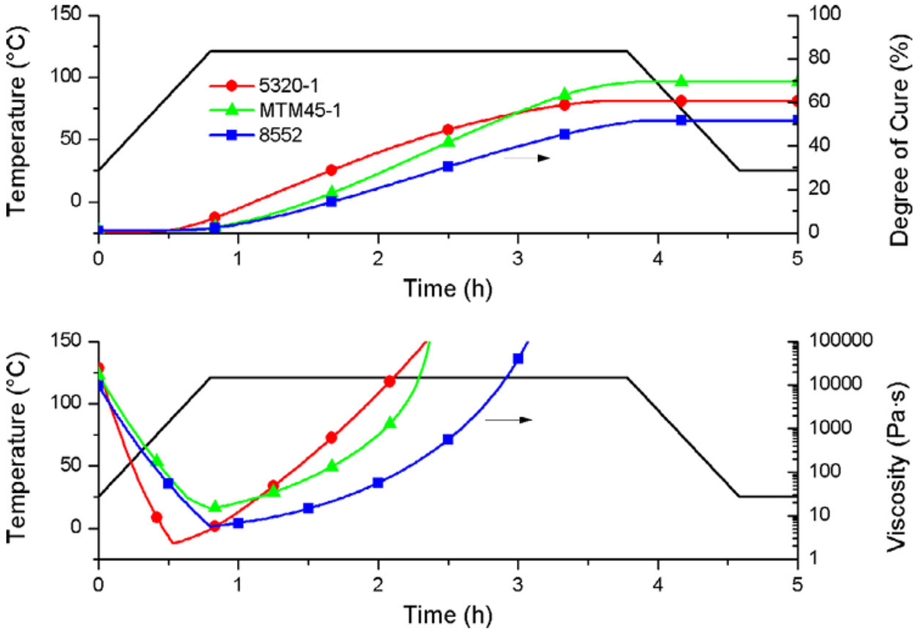
**Low Cure-Stage Viscosity**

- During the **intermediate dwell** (~120 °C), resin must flow sufficiently to fully impregnate the fiber bed before gelation

**Balanced Flow Window**

- Resin must be viscous enough early to maintain vent paths
- Fluid enough later to saturate dry zones and minimize voids
- Critical for void-free, high-quality OoA laminates

[1]



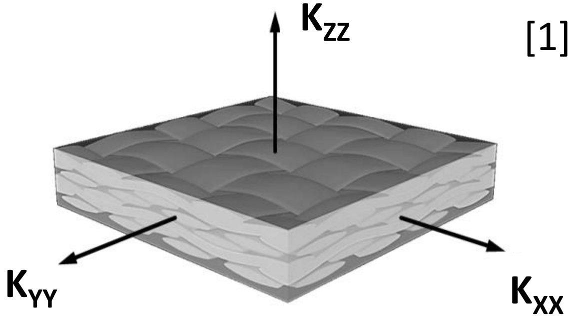

[1] T. Centea, L.K. Grunenfelder, S.R. Nutt, “A review of out-of-autoclave prepregs – Material properties, process phenomena, and manufacturing considerations,” Composites Part A, Vol. 70, 2015, pp. 132–154.

# PERMEABILITY

Ability of air to escape through fibre bed is crucial for void-free OoA cures. [1]

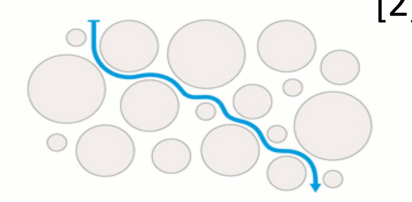
**Out of Autoclave:**

- **Partial impregnation** creates planar channels between tows, giving **high in-plane** permeability **($K_{XX}$, $K_{YY}$)** for rapid edge evacuation
- **Low through-thickness** permeability **($K_{ZZ}$)** demands precise timing:
  - Too much compaction chokes vents, too rapid heating raises viscosity
- In-plane **($K_{XX}$, $K_{YY}$)** is 3-5 orders of magnitude higher than through-thickness **($K_{ZZ}$)** [1]
  - Boost $K_{ZZ}$ by spiking with porcupine rollers or embedded flow paths



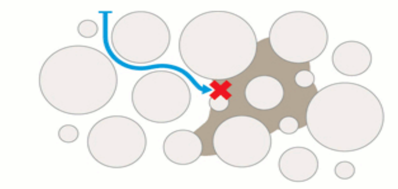

[1]

Good Permeability



[2]

Bad Permeability



**Autoclave:**

- **Fully** impregnated resin → inherently low air permeability
- High external **pressure** assists with compaction and void collapse
- Pressure + heat relax timing constraints and compensate for poor permeability

[1] Pascal Hubert, Timotei Centea, Lessa Grunefelder, Steven Nutt, James Kratz, et al.. Out-of-Autoclave Prepreg Processing. Comprehensive Composite Materials II, 2, Elsevier, pp.63-94, 2018
[2] https://resources.vic.gov.au/projects/past-projects/victorian-gas-program/onshore-conventional-gas/porosity-permeability

# AIR EVACUATION

OoA prepregs are intentionally porous to enable air and volatile evacuation via debulk and vacuum hold, a critical step in producing high-quality parts without autoclave pressure. [1]

During Lay-up

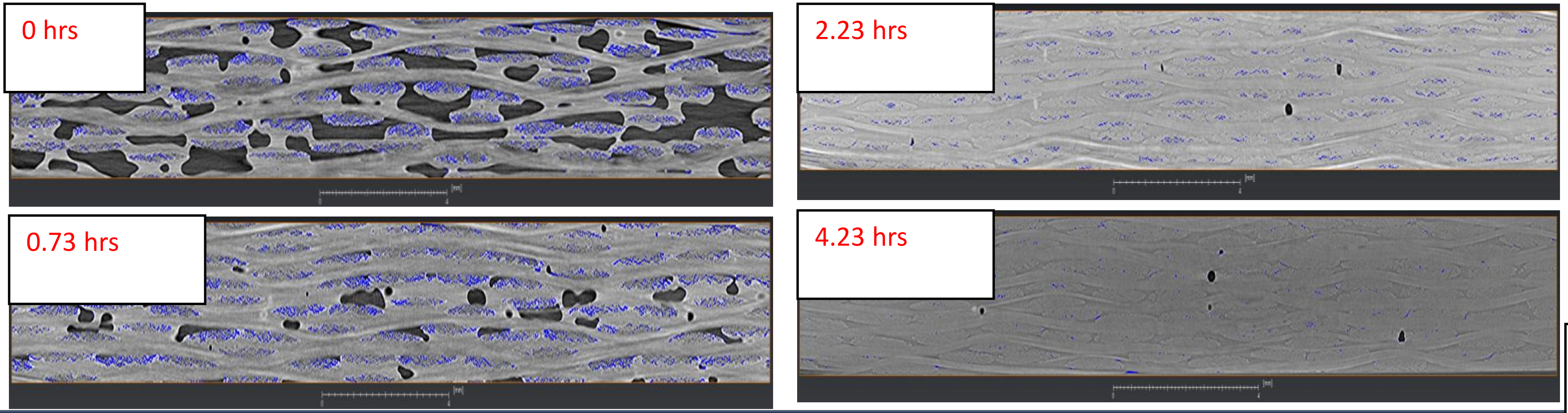
**"Debulking"** consists of drawing vacuum using a temporary vacuum setup

- Short pulls (5–20 min) after every 1–3 plies [1]
- Extracts air through just a few layers and helps new plies conform to the tool
- Skipping debulks can cause wrinkles and trapped bubbles in early layers

During Stage I

**"Vacuum holds"** consists of drawing vacuum on the final bagged part, at room temperature

- Designed to evacuate as much residual air/volatile as possible prior to heating
- Duration is a function of part size and prepreg permeability.

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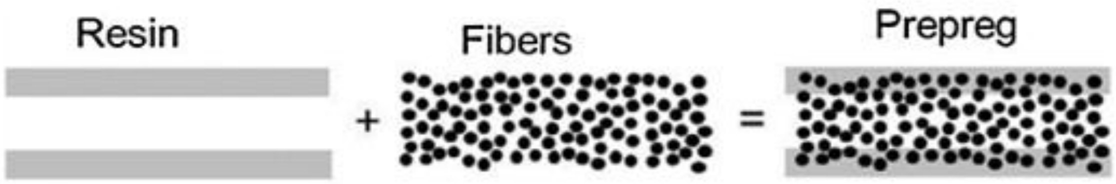
# ENGINEERED VACUUM CHANNELS (EVaCs)

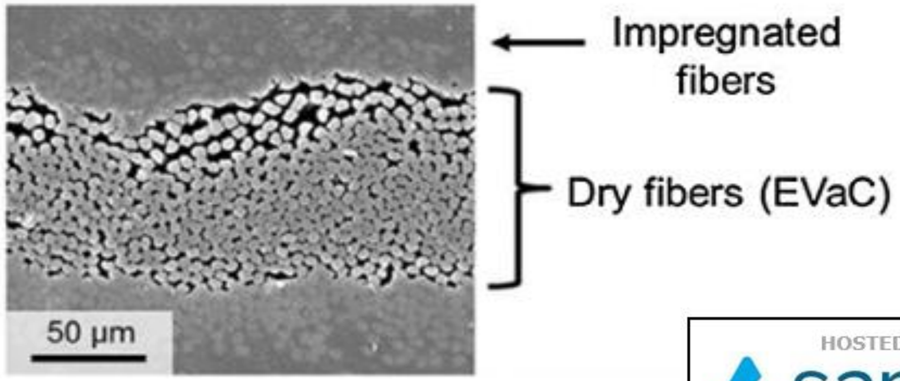
**Partially-impregnated** plies leave dry tow cores, called EVaCs, that form a built-in permeable network for air removal under vacuum only pressure. [1]

- **Stage I**: air and volatiles flow along EVaCs to the laminate edge/breather, compacting the stack
- **Stage II**: as resin viscosity drops, it infiltrates and seals the EVaCs, ideally producing < 1 % void content
- **Ensure continuity:** Edge-breathing dams & perforated release must stay continuous so every EVaC path reaches the breather cloth without excessive resin bleed
- **Autoclave prepreg:** autoclave plies are fully impregnated and rely on ~7 atm external pressure, while EVaCs provide the internal pathways that make 1 atm processing possible




[1]

[1]




[1] T. Centea, L.K. Grunenfelder, S.R. Nutt, "A review of out-of-autoclave prepregs – Material properties, process phenomena, and manufacturing considerations," *Composites Part A*, Vol. 70, 2015, pp. 132–154.

# LAYUP PROCESS

Successful VBO processing requires a few specific arrangements: [1]

## Edge Breathing Dams

- Continuous dam around the full laminate perimeter
- Dam height ≈ uncured laminate thickness to avoid seal pinching
- Preserves in-plane air paths under 1 atm vacuum

## Release Film/Peel Ply

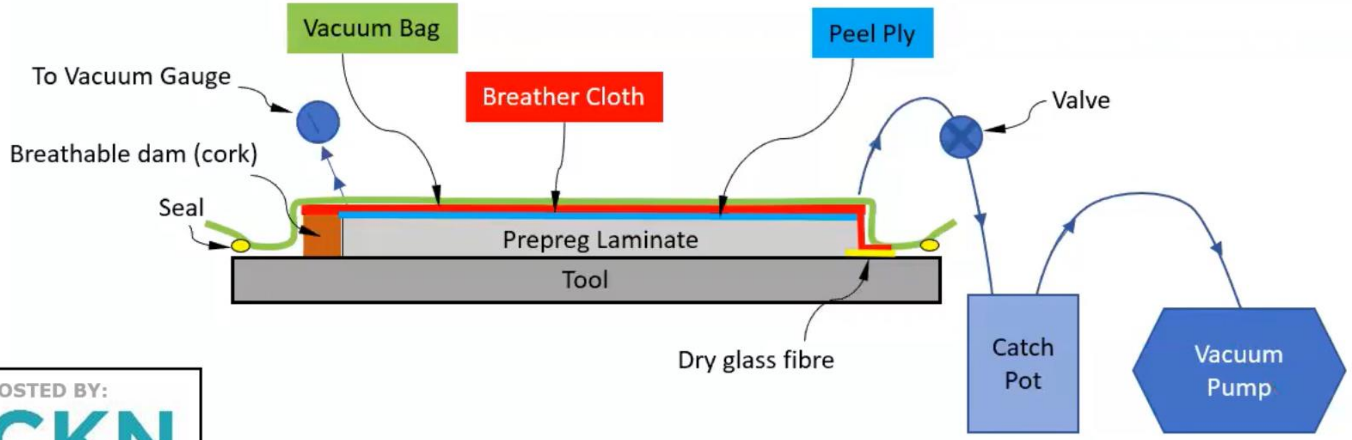
- Perforated film or peel-ply across the bag side
- Allows through-thickness air evacuation while trapping resin bleed
- Match perforation or weave to resin viscosity and part finish

## Breather Cloth & Bag

- Lay breather fabric over the release layer for uniform vacuum distribution
- Notch at tight radii to prevent bridging and trapped air
- Smooth bag, seal edges, and remove wrinkles

## Final Vacuum Check

- Pull down to target vacuum and isolate pump
- Monitor pressure rise as proof of bag integrity

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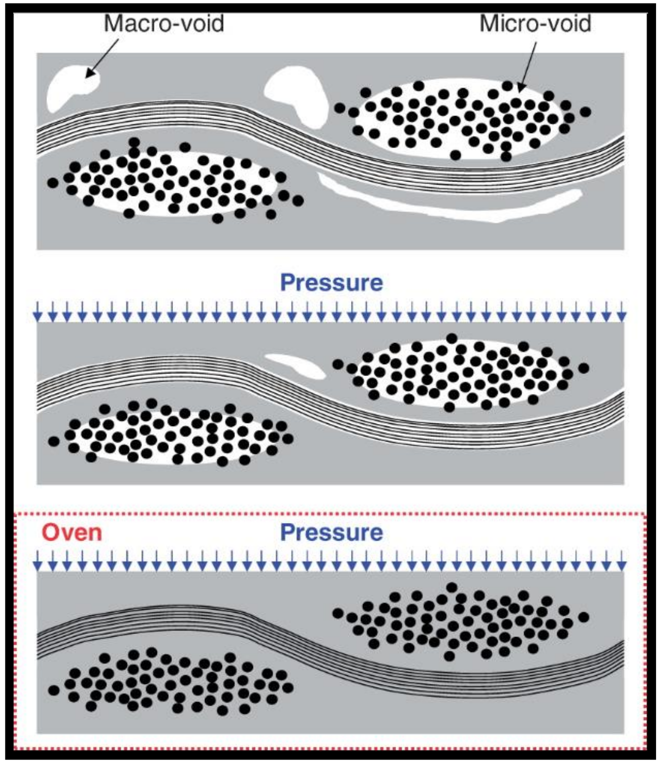
# CONSOLIDATION

Without autoclave pressure, air evacuation or fibre bed compaction, consolidation must be achieved entirely through material design and vacuum-driven flow.

[1]




**Autoclave prepreg processing:** [1]

- External pressure (~7 atm) actively compresses the laminate
- Resin pressure forces void collapse and full fibre impregnation
- Compaction is robust, even with poor nesting/permeability
- Produces uniform thickness, high fibre volume, and minimal voids

**Out-of-Autoclave (OoA) processing:** [1]

- Vacuum-only (~1 atm) provides limited compaction force
- Consolidation depends on resin flow and early air evacuation
- Critical timing: air must escape before resin gels and seals vent paths
- Trapped air → voids, dry spots, fibre bridging, and thickness variation
- Final part may fall short of structural or cosmetic requirements

[1] Centea, T., & Hubert, P. (2014). *Out-of-autoclave prepreg consolidation under deficient pressure conditions*. Composites Part A: Applied Science and Manufacturing, 58, 80–90.

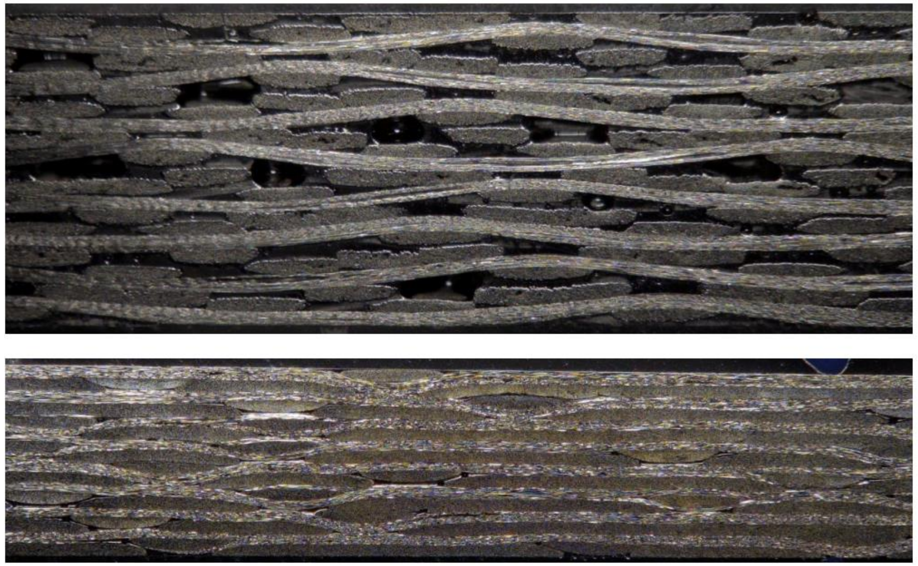
# BULK FACTOR

- Bulk factor, $\beta$ is the ratio of the initial thickness, $t_i$ to the final thickness, $t_f$:

$$\beta = \frac{t_i}{t_f}$$

- A partially impregnated fibre bed and EVaCs result in higher bulk factor
- This change in thickness is attributed to the compaction of voids and to the fibre tow impregnation by the resin[1]
- A higher bulk factor can make laminate consolidation more difficult with complex geometries

[1]



**Top:** prior to debulk ($t_i$)
**Bottom:** after 3 atm debulk (~ $t_f$)

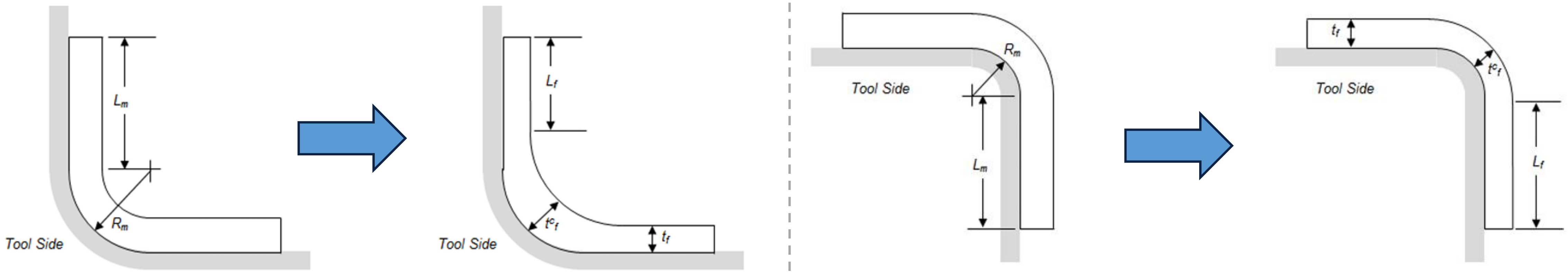
[1] T. Centea, L.K. Grunenfelder, S.R. Nutt, "A review of out-of-autoclave prepregs – Material properties, process phenomena, and manufacturing considerations," *Composites Part A*, Vol. 70, 2015, pp. 132–154.

# BULK FACTOR

In corner regions, curvature changes how the material compacts compared to flat areas:

- **Interply friction** can stop plies from fully conforming to the mould, limiting local compaction and leaving thicker sections
- **Reaction stresses** vary between corners and flats, causing uneven compaction and thickness variation

[1]




A) Female tool - initial    B) Female tool - final    C) Male tool - initial    D) Male tool - final

[1] Pascal Hubert, Timotei Centea, Lessa Grunefelder, Steven Nutt, James Kratz, et al.. Out-of-Autoclave Prepreg Processing. Comprehensive Composite Materials II, 2, Elsevier, pp.63-94, 2018

# WHAT MAKES AN OOA PREPREG AN OOA PREPREG

Partially-impregnated, “breathable” prepregs + tuned resin rheology + compatible fibre architecture = the material trio that lets vacuum-only OoA curing match autoclave quality.[1]

| | Aspect | What is desireable? | Why it’s critical in vacuum bag only cure? |
|---|---|---|---|
|  | **Prepreg** Partial impregnation | Built-in dry tow cores or stitched channels for **self-venting (EVaCs)** | Enables extraction of air & volatiles before resin flows |
|  | **Resin** Dual-window viscosity | • High at room-temp → no **cold-flow** *<br>• Low at 80-120 °C → tow wet-out<br>• Post-cure @ 180 °C | Balances evacuation first, impregnation second; mismatch = sealed vents **or** dry tows → voids |
|  | **Fibre bed** Permeable & low-moisture | UD or low-crimp fabrics, pre-dried | Maintains high in-plane K (~$10^{-14}$ m$^2$) during Stage I; moisture or tight weaves choke flow and spawn gas-voids |

* the premature migration of uncured resin under gravity at room temperature, which can create dry or resin-poor areas before the cure cycle begins.

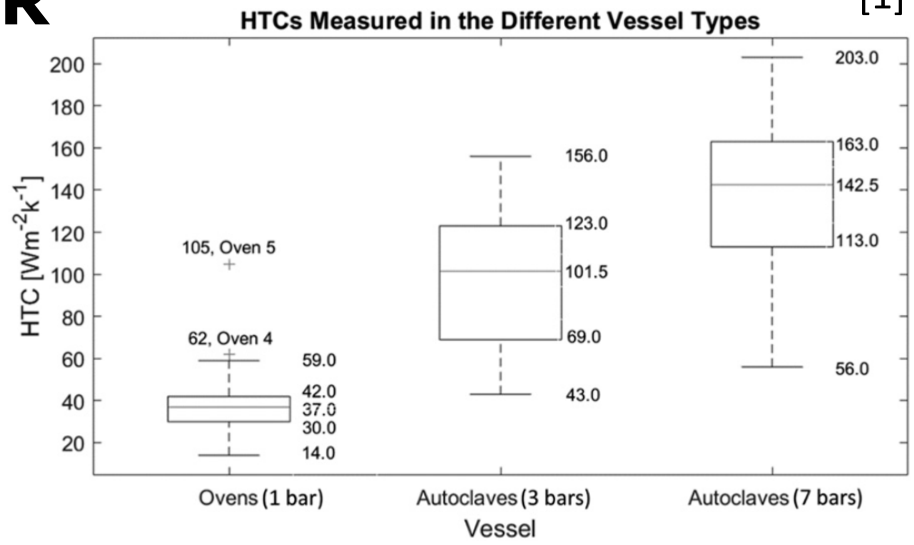
**Key take-away:** Materials systems are designed to accommodate: **Stage I** (vacuum hold) air evacuation, **Stage II** (heat-up) complete impregnation, and **Stage III** (final cure) autoclave-level quality achieved – without autoclave pressure.

[1] Centea, T., Grunenfelder, L. K., & Nutt, S. R. (2015). A review of out-of-autoclave prepregs – Material properties, process phenomena, and manufacturing considerations. Composites Part A: Applied Science and Manufacturing, 70, 132–154.

# HEAT TRANSFER

- In composite processing, the **heat transfer coefficient (HTC)** governs how quickly and uniformly heat reaches the laminate — impacting resin flow, air evacuation, and cure quality.[1]
- ***Autoclaves have higher HTC, which allows for more control of the cure***

[1]




| | Autoclave (3-7 bar) | Oven (1 bar) |
|---|---|---|
| **HTC Range** | 60–200 W/m²·K | 15–50 W/m²·K |
| **Flow Mechanism** | Forced convection + pressurized gas | Forced convection only |
| **Spatial Variation** | **High** (turbulent flow, inlet/outlet effects) | **Low** (flatter, more uniform flow field) |
| **Pressure Effect** | HTC increases with pressure (↑ convective force) | No pressure boost — atmospheric only |
| **Thermal Response** | Fast heat-up, but can be uneven across part surface | Slower ramp, but more consistent across part |

[1] Adam Fisher, Arthur Lévy, James Kratz. Effects of heat transfer coefficient variations on composite curing, Journal of Composite Materials, 2022

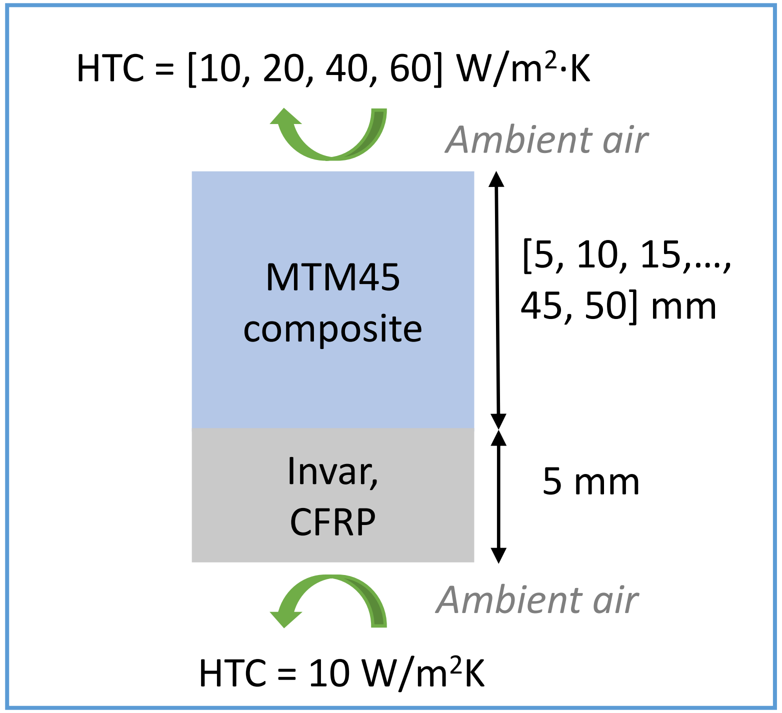
# THERMAL MANAGEMENT CASE STUDY

| Thickness | High HTC (Autoclave) | Low HTC (OoA Oven) |
|---|---|---|
| Thin | Minimal lag, low exotherm | Slight lag, mild exotherm |
| Medium | Short lag, moderate exotherm | Longer lag, stronger exotherm |
| Thick | Lag managed, but local overshoots possible | Risk of core overheating, long lag |

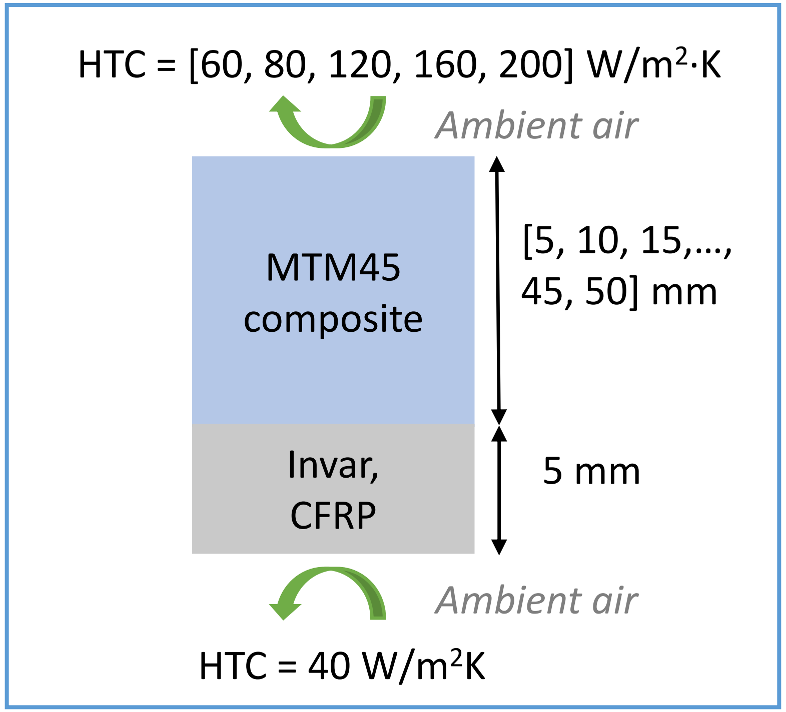
Variables:

- Part Thickness,
- Top HTC,
- Tooling Material

**Oven**




**Autoclave**



# THERMAL MANAGEMENT CASE STUDY

Tooling Legend

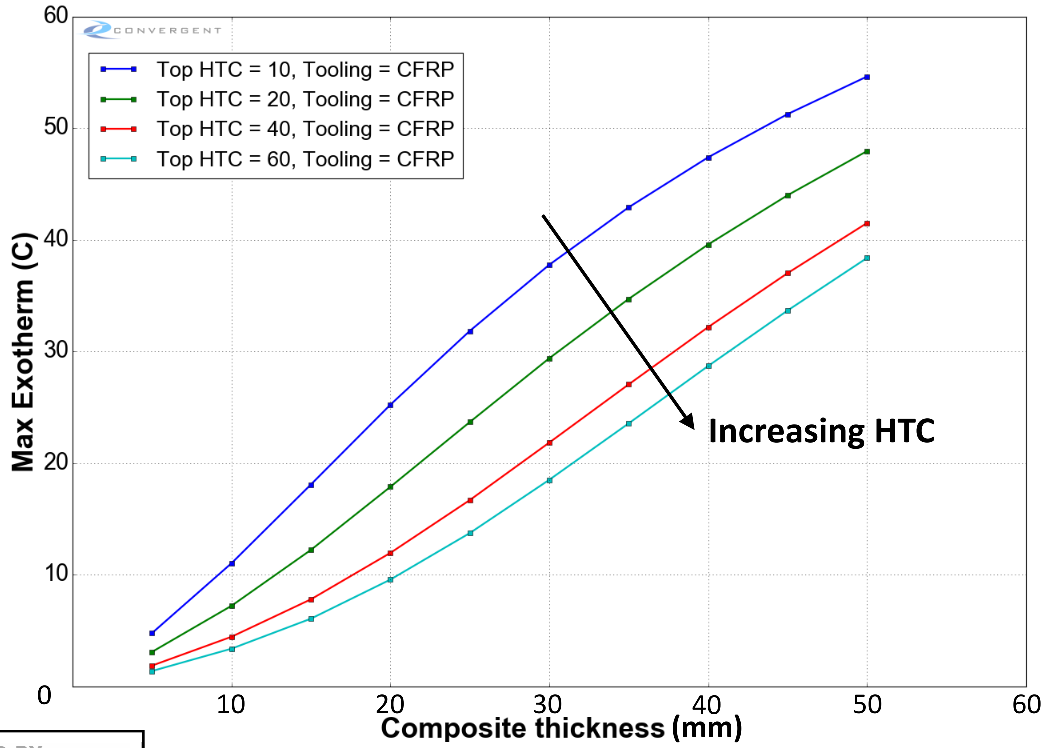
—— CFRP

## Raven: Parametric Study

- Variables: Part Thickness, Top HTC, Tooling Material

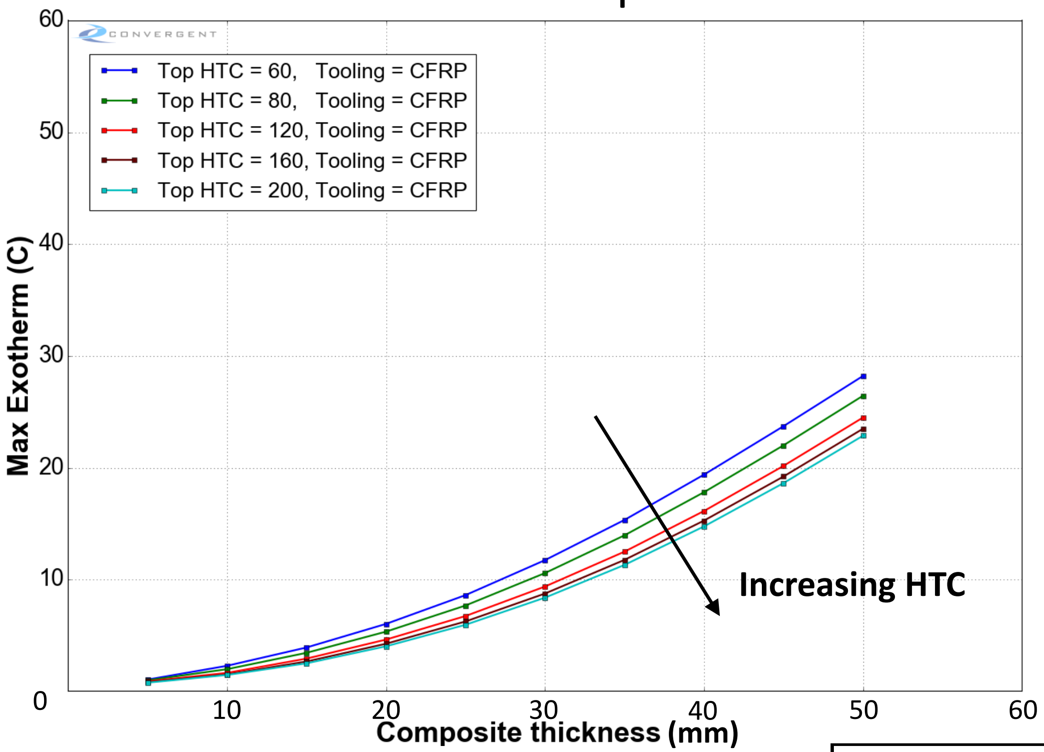
**Oven**

Max Exotherm vs Composite Thickness




**Autoclave**

Max Exotherm vs Composite Thickness



# THERMAL MANAGEMENT CASE STUDY

Tooling Legend

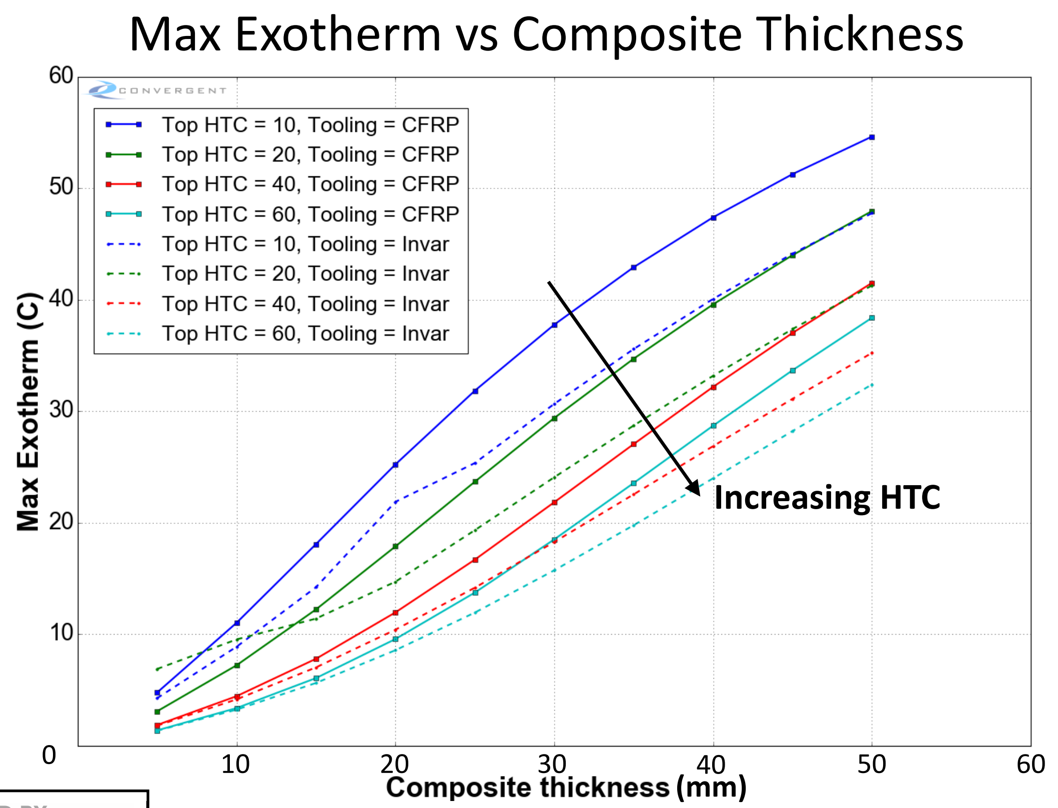
—— CFRP

- - - Invar

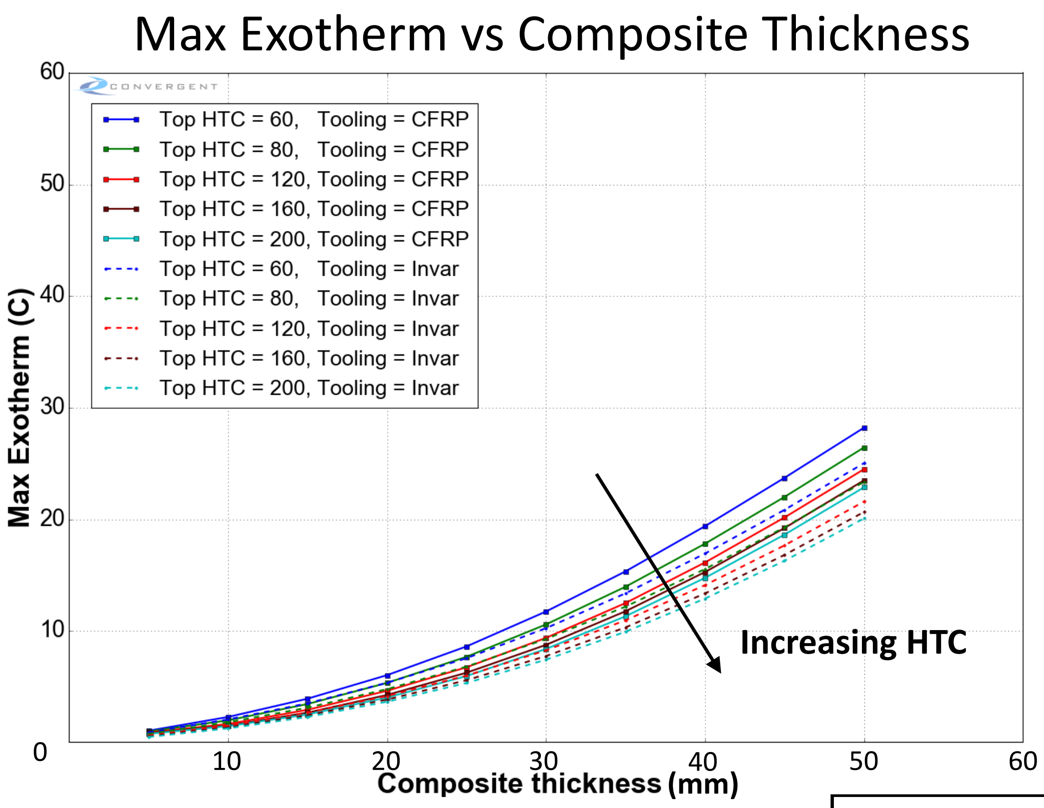
## Raven: Parametric Study

- Variables: Part Thickness, Top HTC, Tooling Material

**Oven**




**Autoclave**

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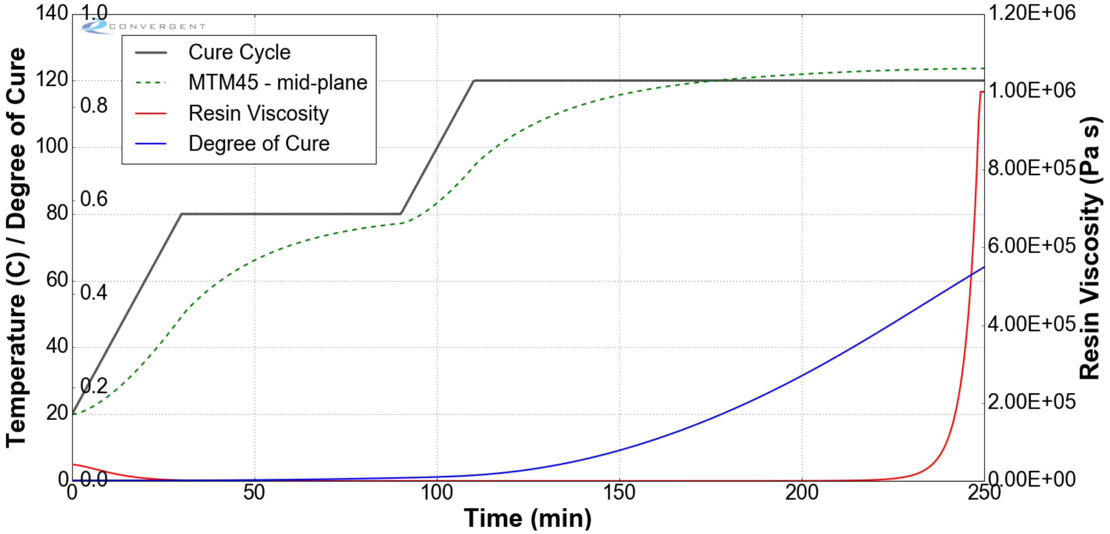
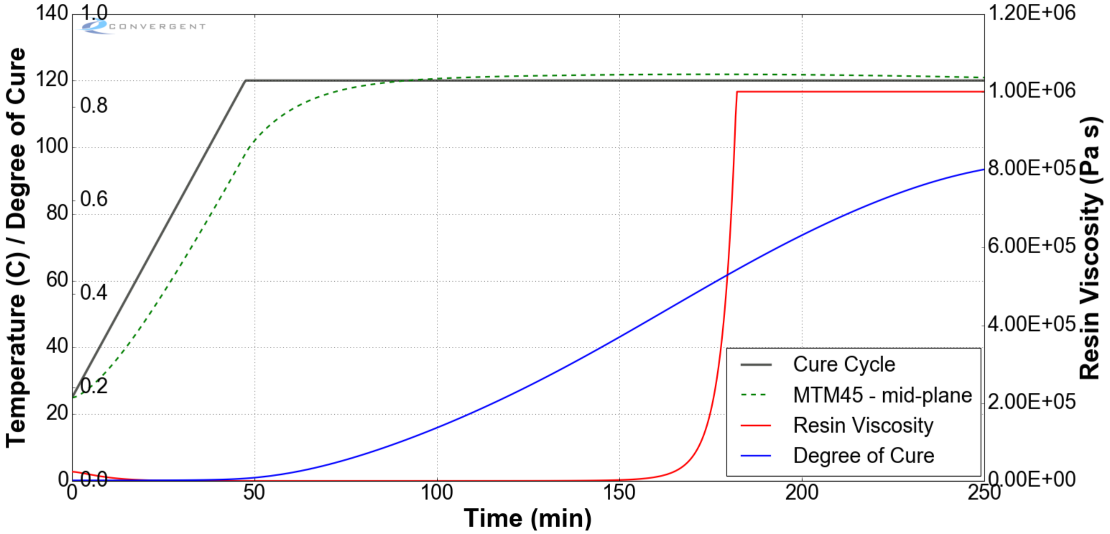
# MRCC COMPARISON - MTM45

Using HTCs to define equipment, and cure cycle specified in MTM45 Data Sheet (excl post-cure)

OVEN




AUTOCLAVE




- **Initial dwell**: Oven holds at ~80 °C before ramp; allow for further air/volatile extraction.
- **Viscosity drop**: Autoclave viscosity falls into its flow window earlier; Oven's drop is delayed.
- **Cure onset:** Degree-of-cure curve rises sooner in the Autoclave; Oven remains flat until its main dwell.
- **Exotherm effect:** Oven mid-plane shows a clear exotherm overshoot; Autoclave's higher HTC suppresses internal temperature spikes.

# MECHANICAL COMPARISON CASE STUDY 1

*NASA Study: Comparison of Autoclave and Out-of-Autoclave Composites* [1]

**Objective:** Assess laminate quality and mechanical performance of OoA and autoclave prepregs under both **fresh** and **extended out-life** conditions

## Materials & Setup

- Autoclave systems: IM7/8552-1 & IM7/977-3
- OoA systems: IM7/MTM45-1 & T40-800b/5320
- All layups used **32-ply quasi-isotropic** to replicate structural laminates
  - OoA panels were cured under **vacuum-only conditions**
  - Autoclave panels cured under **85 psi**
  - Slow ramp ~2 °F/min (~1 °C/min) to 350 °F (180 °C) hold for 2 hours

Fibre property comparison

| Property | IM7 | T40-800B |
|---|---|---|
| Tensile Modulus (GPa) | ~276 | ~294 |
| Tensile Strength (MPa) | ~5600 | ~5660 |
| Density (g/cm³) | ~1.78 | ~1.80 |

Note: **Out life** refers to accumulated time out of the freezer before the part is cured

[1] Sutter, J. K., Kenner, W. S., Pelham, L., Miller, S. G., Polis, D. L., et al. (2011). Comparison of autoclave and out-of-autoclave composites. NASA.

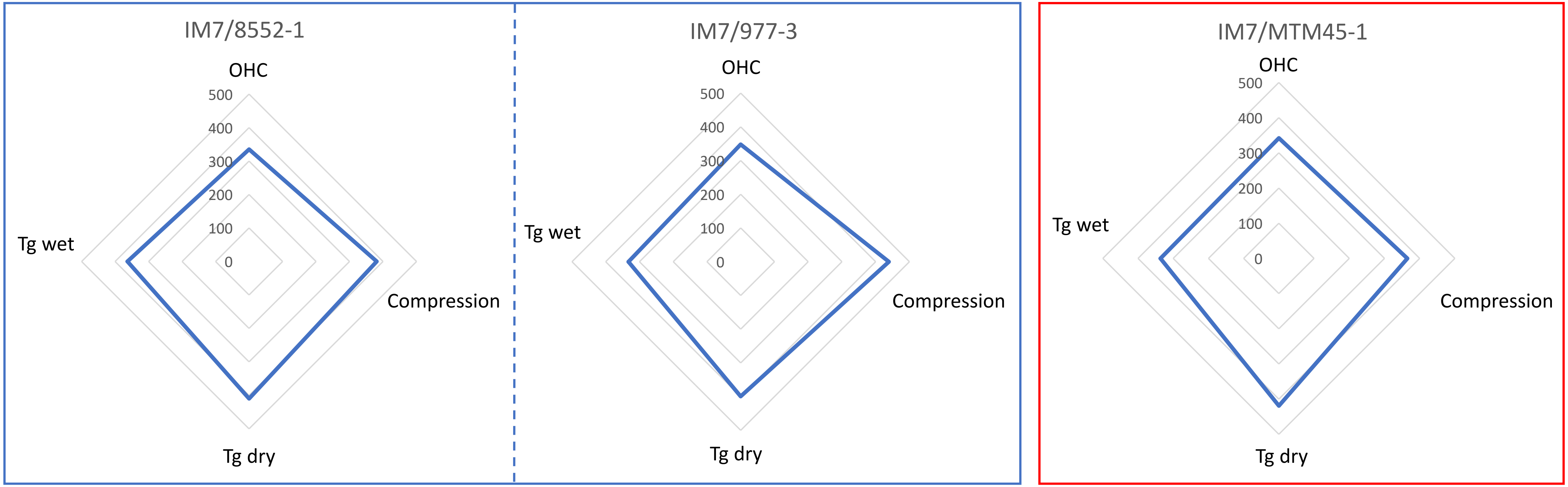
# MECHANICAL COMPARISON CASE STUDY 1

*NASA Study: Comparison of Autoclave and Out-of-Autoclave Composites* [1]

Fresh Prepreg

**Autoclave** Prepreg

**Out-of-Autoclave** Prepreg

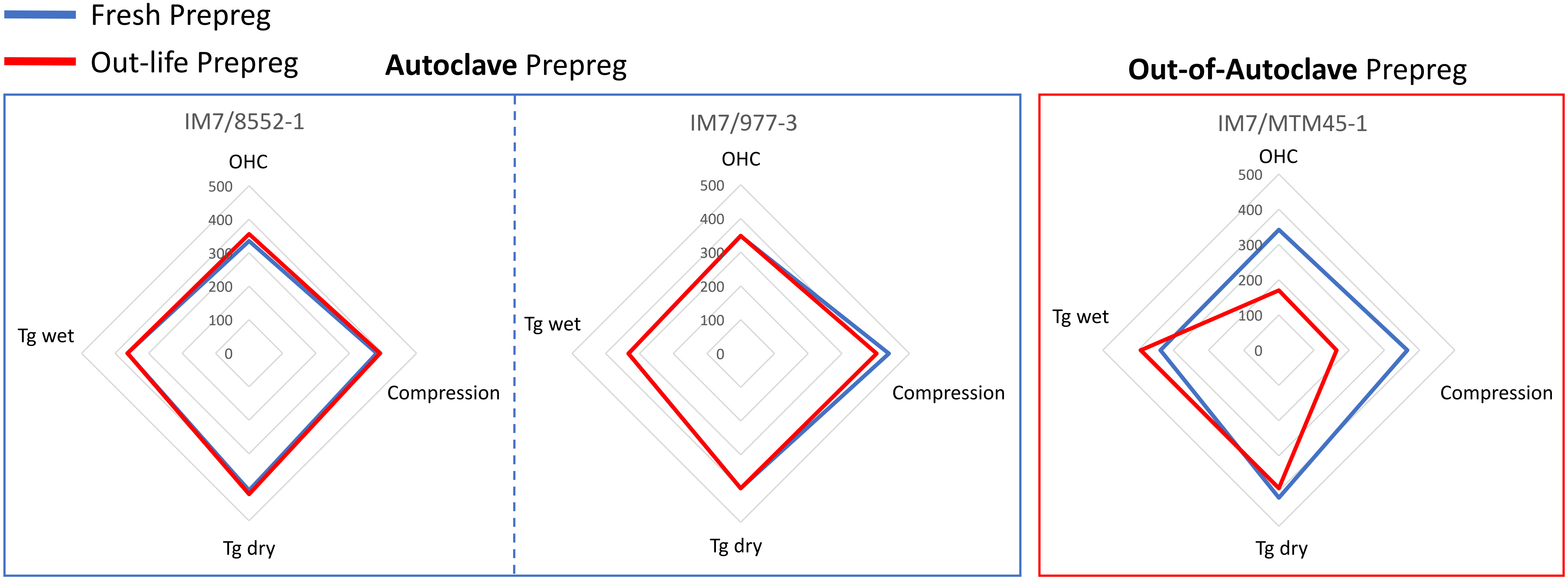



***Note**: According to the study, the T40-800B/5320 batch may have experienced off-nominal prepregging, reportedly leading to accelerated tack degradation. As a result, the out-life condition of the panels was inadequate for open-hole compression (OHC) and compression testing.*

[1] Sutter, J. K., Kenner, W. S., Pelham, L., Miller, S. G., Polis, D. L., et al. (2011). Comparison of autoclave and out-of-autoclave composites. NASA.

# MECHANICAL COMPARISON CASE STUDY 1

*NASA Study: Comparison of Autoclave and Out-of-Autoclave Composites [1]*

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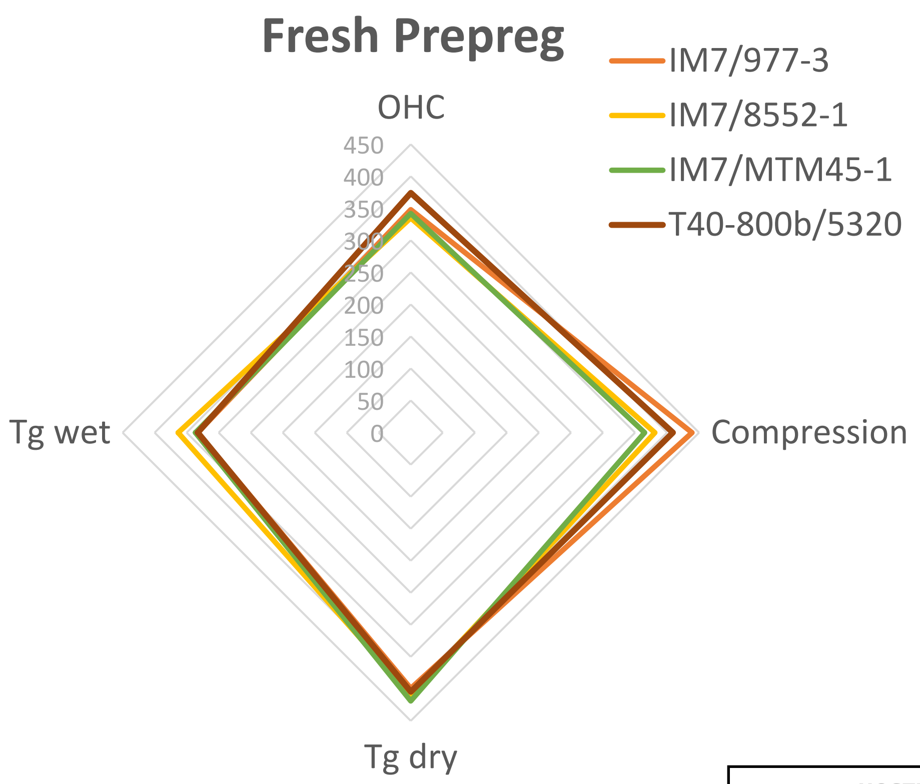
# MECHANICAL COMPARISON CASE STUDY 1

*NASA Study: Comparison of Autoclave and Out-of-Autoclave Composites [1]*

## Key Findings

- Fresh OoA prepregs matched autoclave systems in both mechanical and thermal performance
- All systems showed high panel quality when processed **within** recommended out-life
- Extended out-life severely degraded OoA performance:
  - **Tack loss**, causing poor ply adhesion
  - **Moisture uptake**, disrupting resin flow
  - **Increased voids**, especially in thicker parts
  - **Reduced strength** across all mechanical tests
- Autoclave systems maintained performance beyond vendor out-life limits
  - Tack, flow, and strength were largely preserved




[1] Sutter, J. K., Kenner, W. S., Pelham, L., Miller, S. G., Polis, D. L., et al. (2011). Comparison of autoclave and out-of-autoclave composites. NASA.

# MECHANICAL COMPARISON CASE STUDY 1

*NASA Study: Comparison of Autoclave and Out-of-Autoclave Composites* [1]

## Limitations

- Flat panel results may not reflect behavior in contoured or thick parts
- OoA sensitivity to thickness, tooling, and vacuum not fully captured
- Scaling up may introduce heat transfer and air evacuation issues
- Long-term durability and impact resistance not evaluated
- Resin-specific effects (e.g., flow, gel time) not isolated

## Takeaway

- OoA prepregs can match autoclave performance — but only when processed with strict control of out-time, tack life, and cure conditions.

[1] Sutter, J. K., Kenner, W. S., Pelham, L., Miller, S. G., Polis, D. L., et al. (2011). Comparison of autoclave and out-of-autoclave composites. NASA.

# MECHANICAL COMPARISON CASE STUDY 2

*Boeing Study: Mechanical Comparison of OoA Prepreg Part to Conventional Autoclave Prepreg Part* [1]

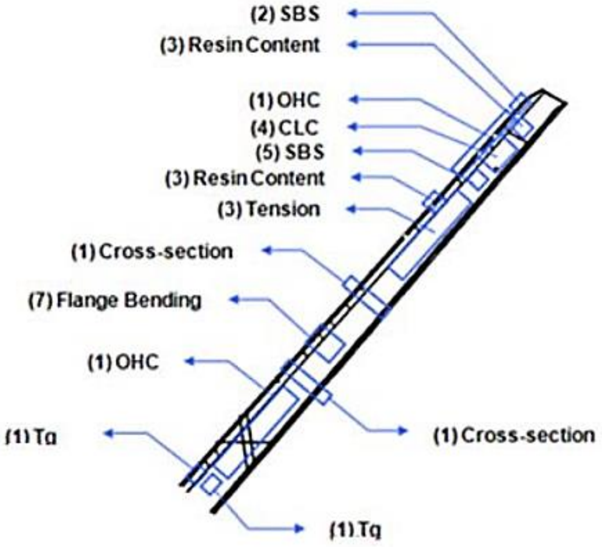
**Objective:** Assess whether an **OoA prepreg system** can match the **mechanical performance** of an **autoclave prepreg**, using the same full-scale part, layup, and processing conditions.

## Materials & Setup

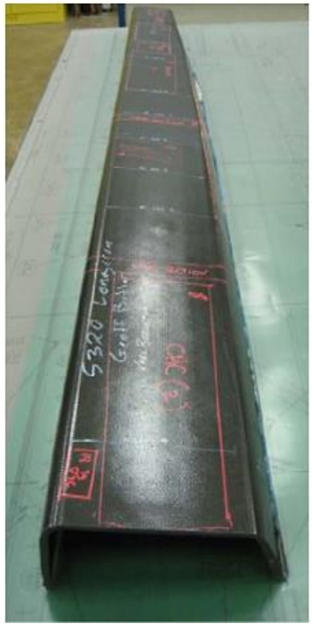
- OoA system: T40-800B/5320
- Autoclave control: IM7/8552
- Layup: 32-ply C-channel longeron (flight-qualified geometry)
- Tooling: Same ply table, hand lay-up on male tool
- Cure cycle:
    - Ramp: 1–5 °F/min → Hold: 250 °F for 1 h, then 350 °F for 2 h
    - OoA: full vacuum only, Autoclave: 90 psi

## Limitations

- Only one OoA part (12 ft vs full 14 ft length)
- Hand lay-up ⇒ not representative of automated production
- Resin migration observed in flange due to geometry
- Long-term durability and large-part performance not tested




[1]



[1]

[1] Dang, C., Bernetich, K., Carter, E. & Butler, G. (2011). Mechanical Comparison of Out-of-Autoclave Prepreg Part to Conventional Autoclave Prepreg Part (presented at the AHS 67th Annual Forum, May 3–5, 2011).

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# MECHANICAL COMPARISON CASE STUDY 2

*Boeing Study: Mechanical Comparison of OoA Prepreg Part to Conventional Autoclave Prepreg Part [1]*

## Performance Highlights of OOA

- **SBS**: up to 111% → strong interlaminar strength
- **Tension**: up to 104% → excellent fiber performance
- **CLC & OHC**: 92–99% → load-bearing capable
- **Tg**: 413–425 °F → exceeded 5320 spec (310 °F)
- **Web resin content**: ~32 wt% → nominal
- **Flange resin content**: ~27 wt% → likely tied to resin migration during cure in complex geometry

## Key Observations

- No excessive voids, wrinkling, or resin pooling
- Vacuum-only cure delivered autoclave-level quality
- Same ply table, no tooling changes production
- Minor sensitivity to resin distribution → process control matters

[1]

| Mechanical Properties | Coupon Set | (Control) IM7/8552 Al Plug 90 psig (%) | IM7/8552 HDF Test Part Comparison against Control (%) | 5320 Out-of-Autoclave Test Part Comparison against Control (%) |
|---|---|---|---|---|
| Open Hole Compression (ksi) | Flange at Ends | 100 | 98 | 99 |
| | Web | 100 | 85 | 92 |
| Short Beam Shear (ksi) | Flange at Ends | 100 | 100 | 108 |
| | Flange | 100 | | 109 |
| | Web Location 1 | 100 | 95 | |
| | Web Location 2 | 100 | 87 | 111 |
| Combined Loading Compression (ksi) | Flange | 100 | 90 | |
| | Web Location 1 | 100 | 99 | 95 |
| Tension (ksi) | Flange | 100 | 83 | |
| | Web | 100 | 96 | 104 |

| Physical Properties | Coupon Set | IM7/8552 Al Plug 90 psig Results MELR 09-791 | IM7/8552 HDF Test Longeron Results MELR 09-948 | 5320 Out-of-Autoclave MELR 10-1322 |
|---|---|---|---|---|
| Glass Transition (ºF) | Flange | 451 / 438 | 445 / 434 (2.4) /3 | 418 / 413 (0.9) /3 |
| | Web | 449 / 439 | 450 / 449 (0.5) /3 | 425 / 421 (1.0) /3 |
| Resin Content (wt %) | Flange | 35.0 /34.4 | 35.5 / 35.2 (0.9) /3 | 27.2 /26.3 (3.3) /3 |
| | Web | 36.0 /35.8 | 35.3 / 35.1 (1.3) /3 | 31.5 / 32.3 (5.4) /3 |

[1]

**Overall:** Boeing confirmed OoA 5320 as a viable structural alternative when process controls are maintained

[1] Dang, C., Bernetich, K., Carter, E. & Butler, G. (2011). Mechanical Comparison of Out-of-Autoclave Prepreg Part to Conventional Autoclave Prepreg Part (presented at the AHS 67th Annual Forum, May 3–5, 2011).

# SUMMARY

| ADVANTAGES | CHALLENGES |
|---|---|
| **Lower Cost**:<br>Avoids high capital and operating expenses of autoclaves | **No External Pressure**:<br>Requires ultra-precise resin rheology for consolidation and material handling |
| **Scalability**:<br>Enables production of large or low-volume parts | **Lower HTC**:<br>Demands longer, tightly controlled thermal cycles |
| **Simplified infrastructure**:<br>Uses ovens instead of pressure vessels | **Defect Sensitivity**:<br>Higher risk of porosity, wrinkling, resin-rich areas |
| **Potential for more widespread use:**<br>Lower barriers to entry can allow more use (potential for more vendors capable of OoA) | **Evacuation Constraints:**<br>Through-thickness venting remans limiting |

**Key takeaway:** OoA prepreg processing is a **viable alternative** to autoclave curing – validated by high-performance industry studies to deliver autoclave-quality parts – **when** its unique permeability, thermal, and consolidation constraints are **carefully managed**.

# Thank you for joining us!

***Keep an eye out for upcoming AIM events:***

*Flammability of Composite Materials*
*Hosted by Dr. Stephanie Feih*
*September 24, 2025*
https://compositeskn.org/KPC/A394

***And don't forget to visit the KPC for more information:***

https://compositeskn.org/KPC

***Today's Webinar will be posted at:***
https://compositeskn.org/KPC/A393

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