Solutions for Zero Waste Composite Prepreg Processing

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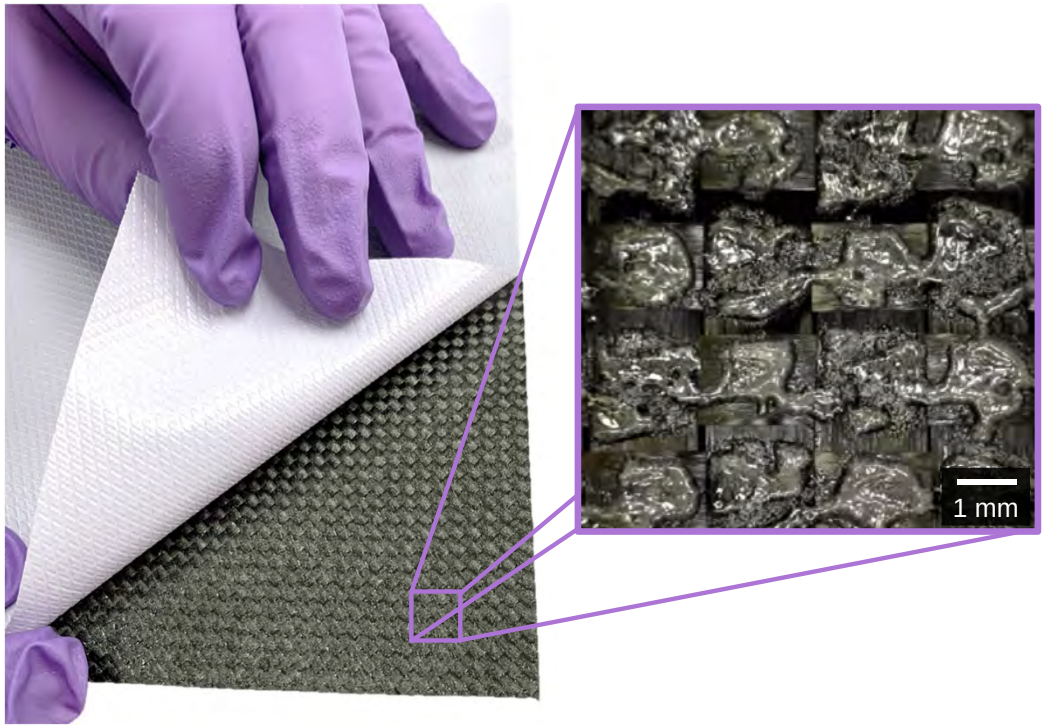
McGill
Structures & Composite Materials Laboratory

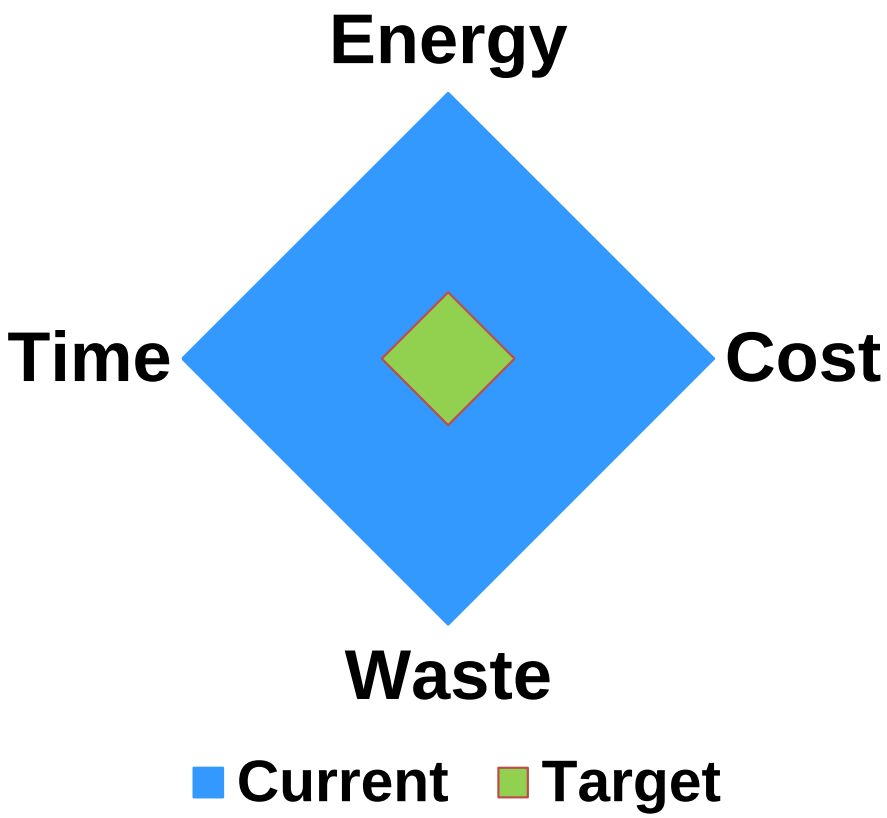
CREPEC
Research Center for High Performance Polymer and Composite Systems

Autoclave prepreg manufacturing



Top Right: "At Boeing's 777X wing factory, robots get big jobs", Seattle Times (2016), Bottom Right: "New Images of 777X Highlight Massive Composite WIng" Airlineratings..com (2020)

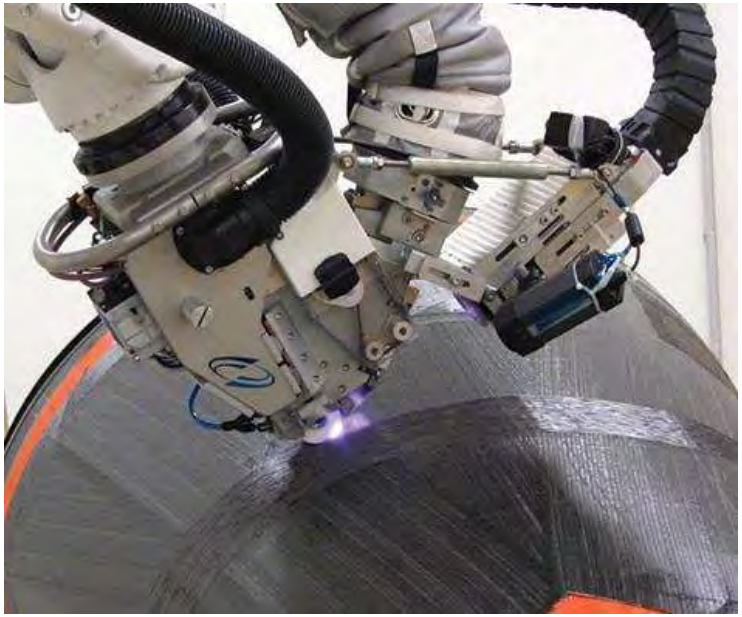
Composites manufacturing challenges



Composite prepregs

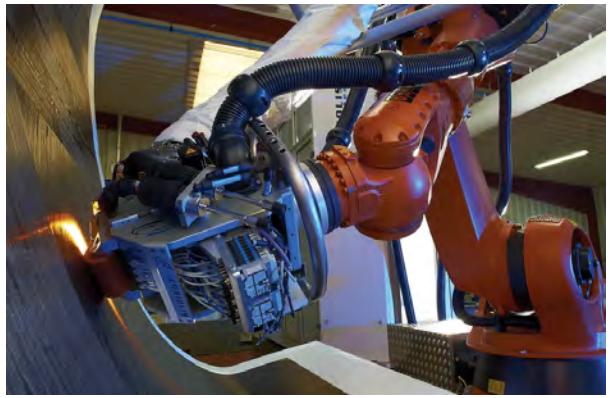
https://www.materialstoday.com

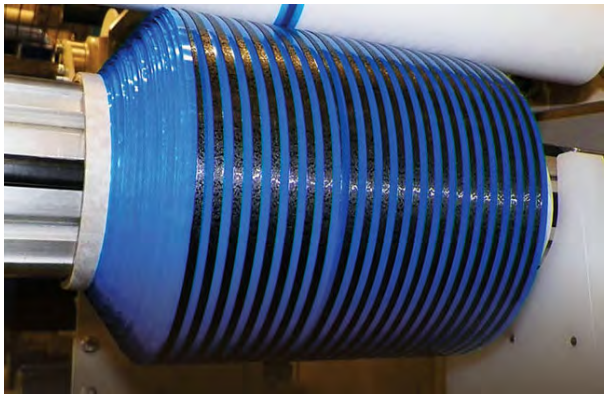
http://www.talkcomposites.com



https://www.compositesworld.com

Composites manufacturing waste

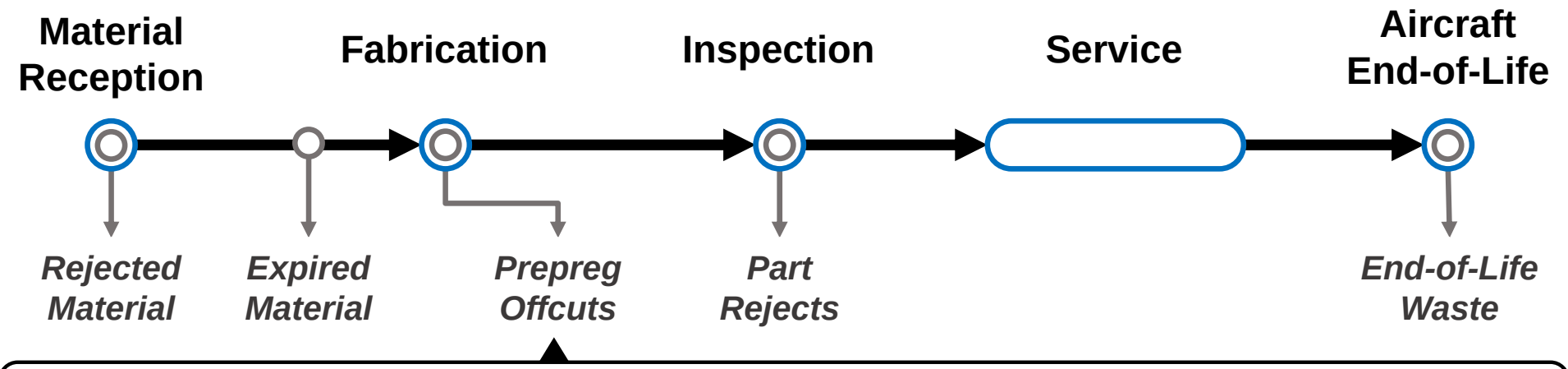


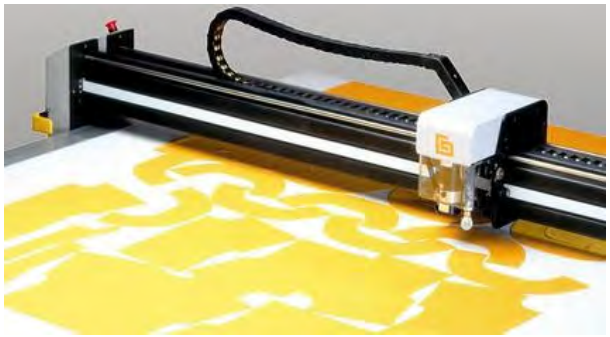


courtesy of Marsh 2011

courtesy of www.aerodefensetech.com

Uncured prepreg offcuts





- ***Pristine fibre and matrix***
- ***Known history & composition***
- ***Limited contamination***
- ***Increasing disposal cost***

Bottom Left: www.gerbertechnology.com/gerbercutters/

Thermoset composites recycling

Thermochemical Fibre Reclamation

- **Degrade fibre interface**
- **Disregard value of uncured resin**
- **Require large infrastructure**

Mechanical Comminution

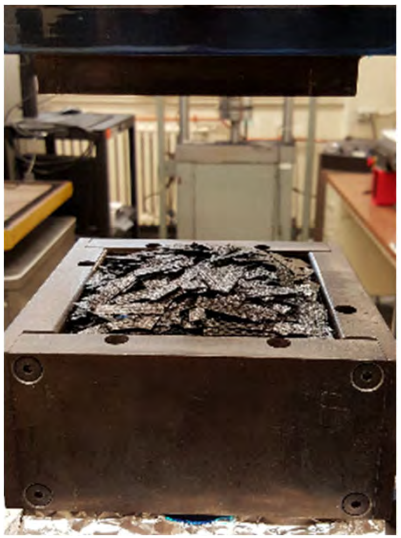
- **Degrade fibre properties**
- **Low value recyclates**
- **Poor fibre recovery rates**

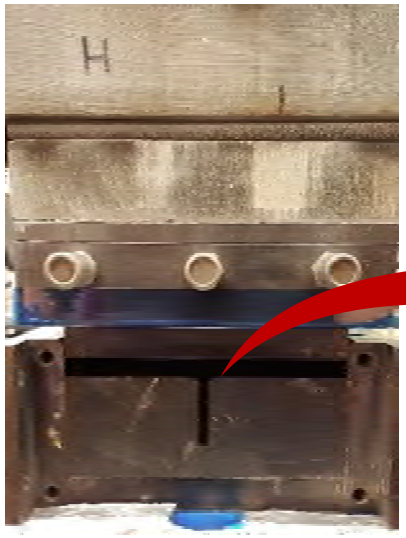
Incineration

- **Energy recapture only**
- **Not universally considered recycling**

Prepreg recycling challenge

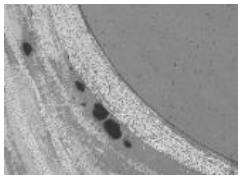
Compression Moulding Compound





Resin-fibre separation

Poor internal quality



Long cure times

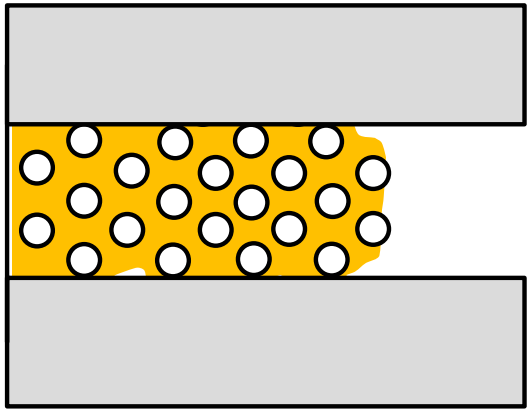
Difficult handling

Mechanisms of flow-compaction

Fibre

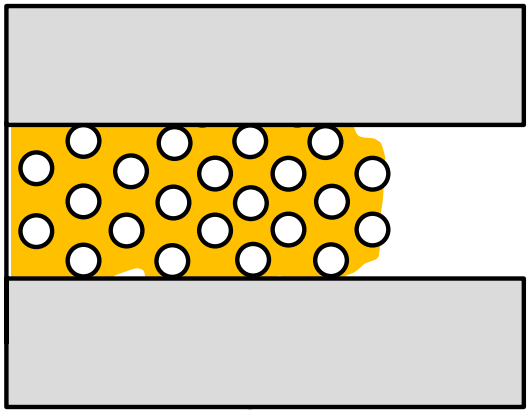
Resin

Percolation (Autoclave)



Low viscosity
Long cure time

Shear (Compression Moulding)



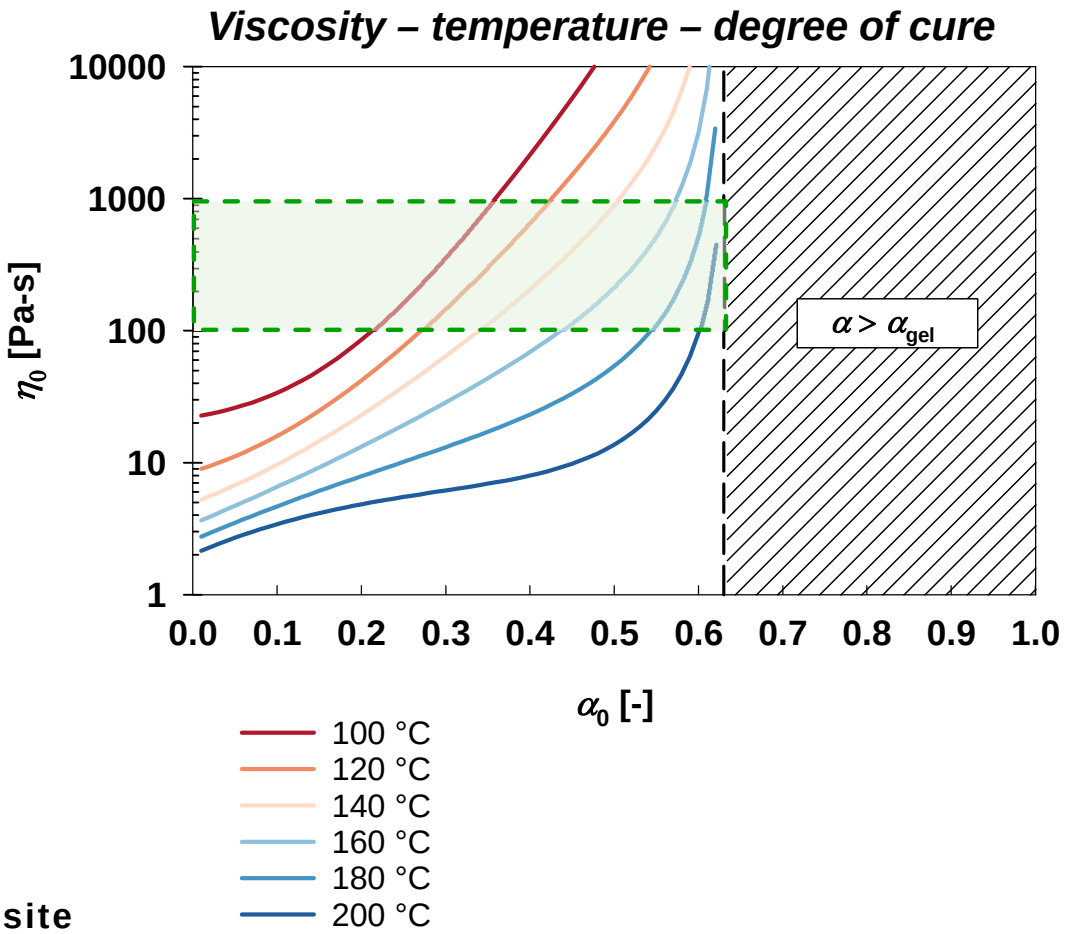
High viscosity
Short cure time

Effect of resin viscosity

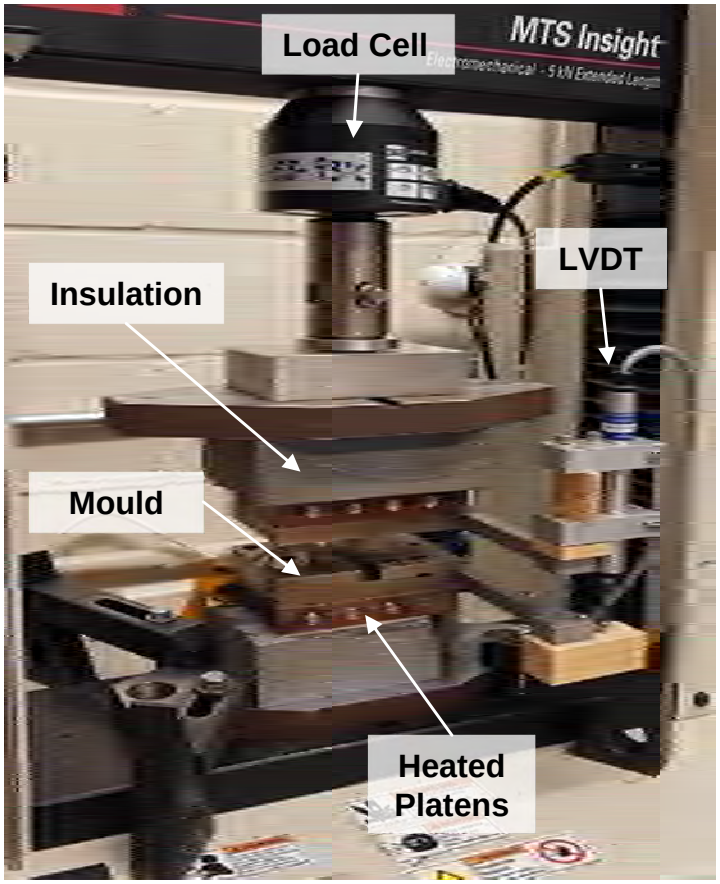
Resin System	Processing Viscosity
PEEK	300 – 650 Pa-s
PEKK	500 – 1000 Pa-s
Cycom® 5276-1	~ 5 Pa-s
Hexcel 8552	2 – 10 Pa-s
Hexcel 3501-6	0.1 – 1 Pa-s

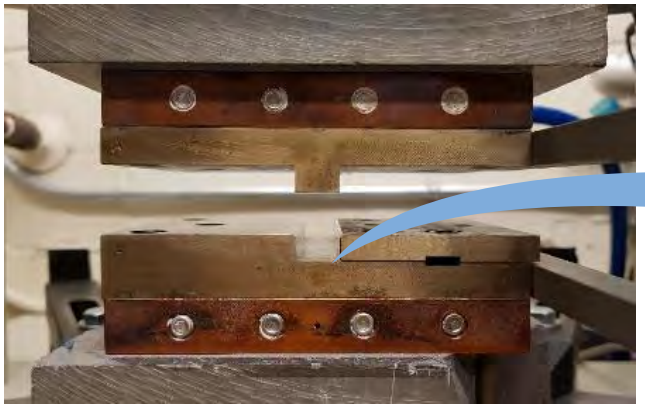
Compression Moulding

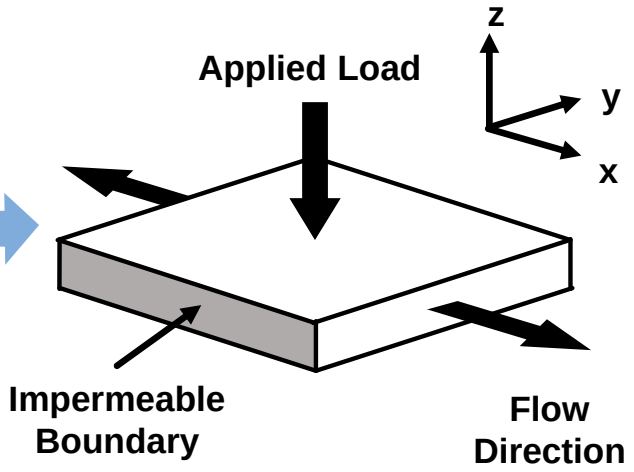
Autoclave



1-D flow-compaction (1/4)

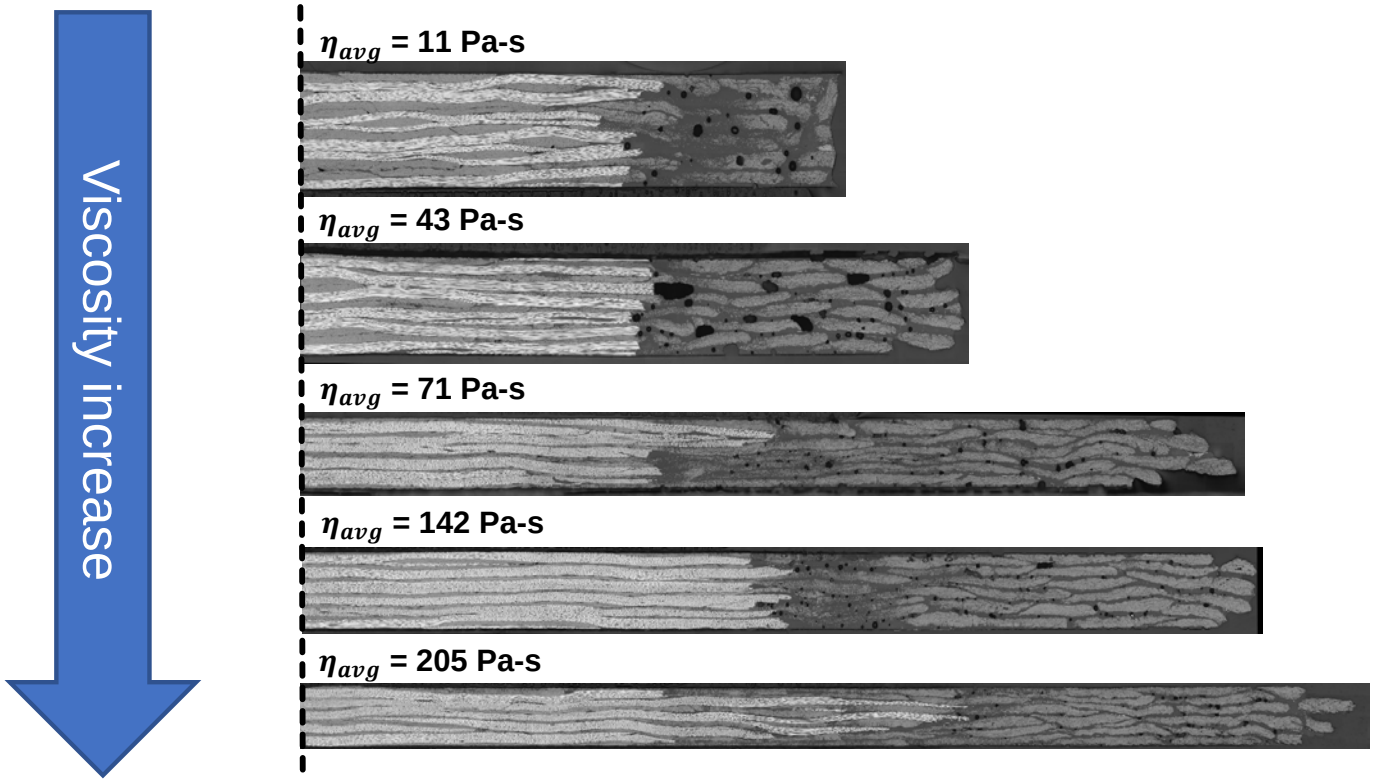






- ***Cure Temperature: 140 °C***
- ***Testing load: 1 kN***
- ***Specimen size: 12.7 mm x 12.7 mm x 6 layers***
- ***Mould closure rates: 0.01, 0.1, 1.0 mm/s***

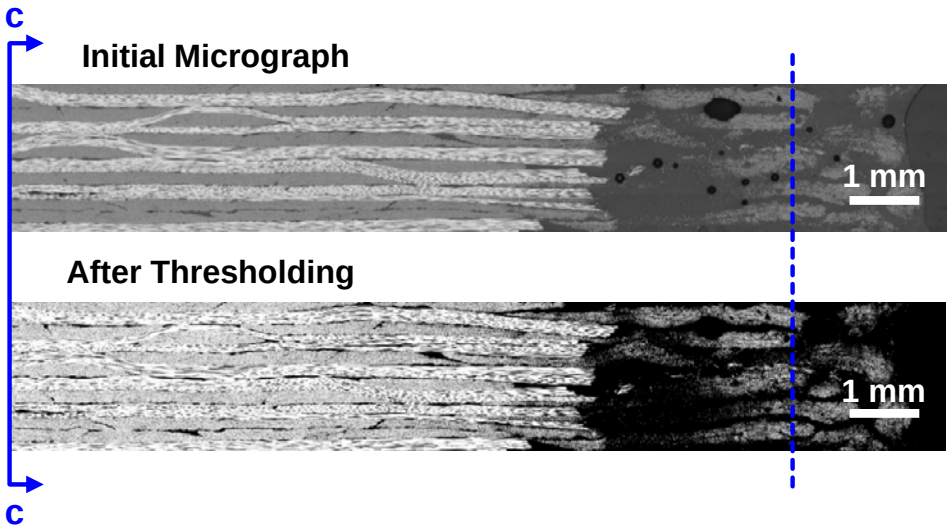
1-D flow-compaction (2/4)

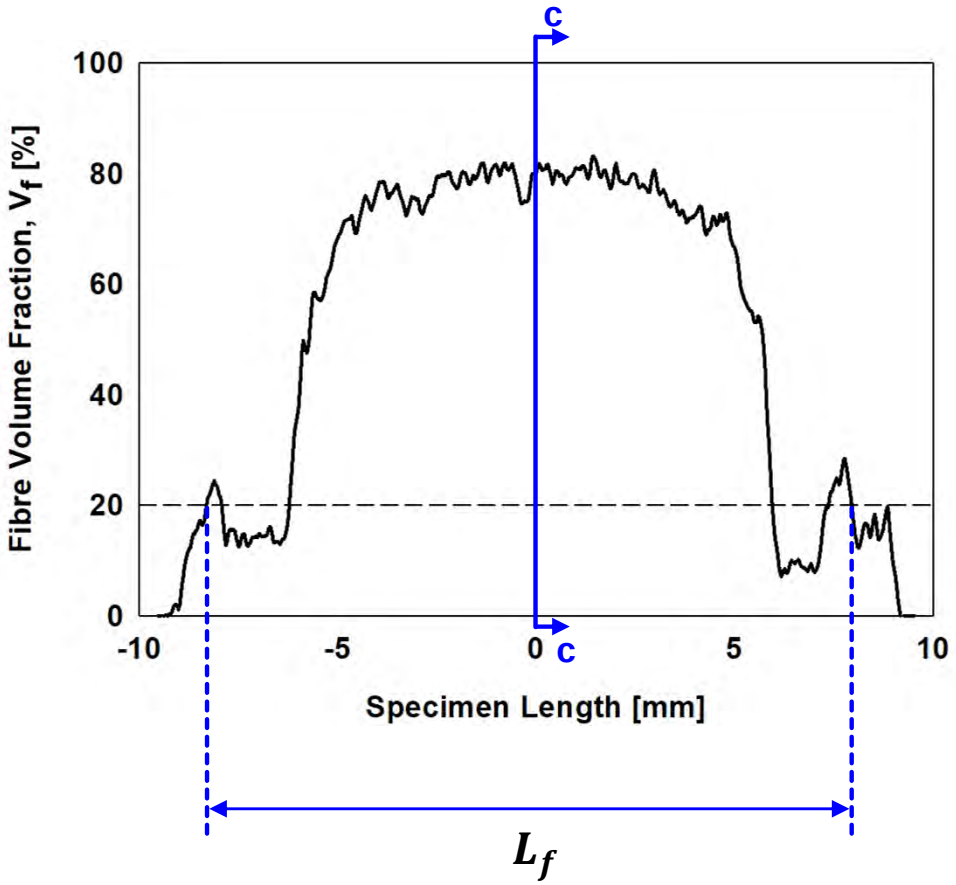


1-D flow-compaction (3/4)

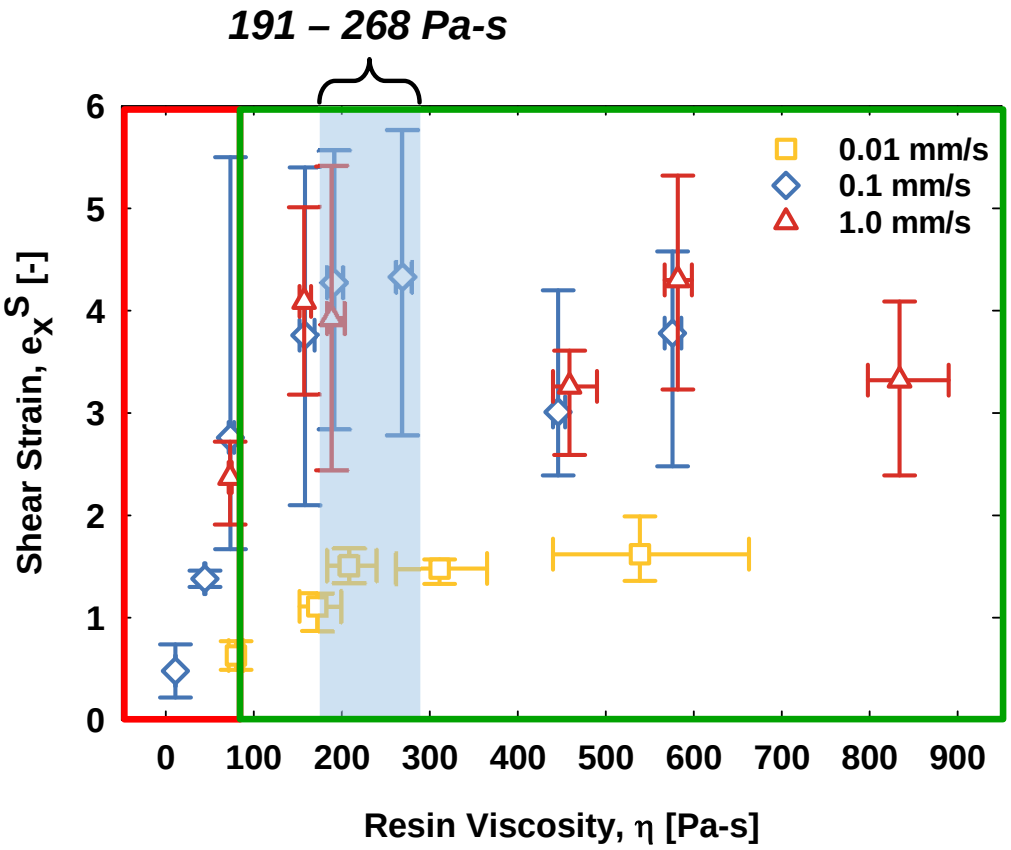
Green Strain Tensor

$$e_x^S = \frac{1}{2}\left[\left(1 + \frac{L_f - L_0}{L_0}\right)^2 - 1\right]$$

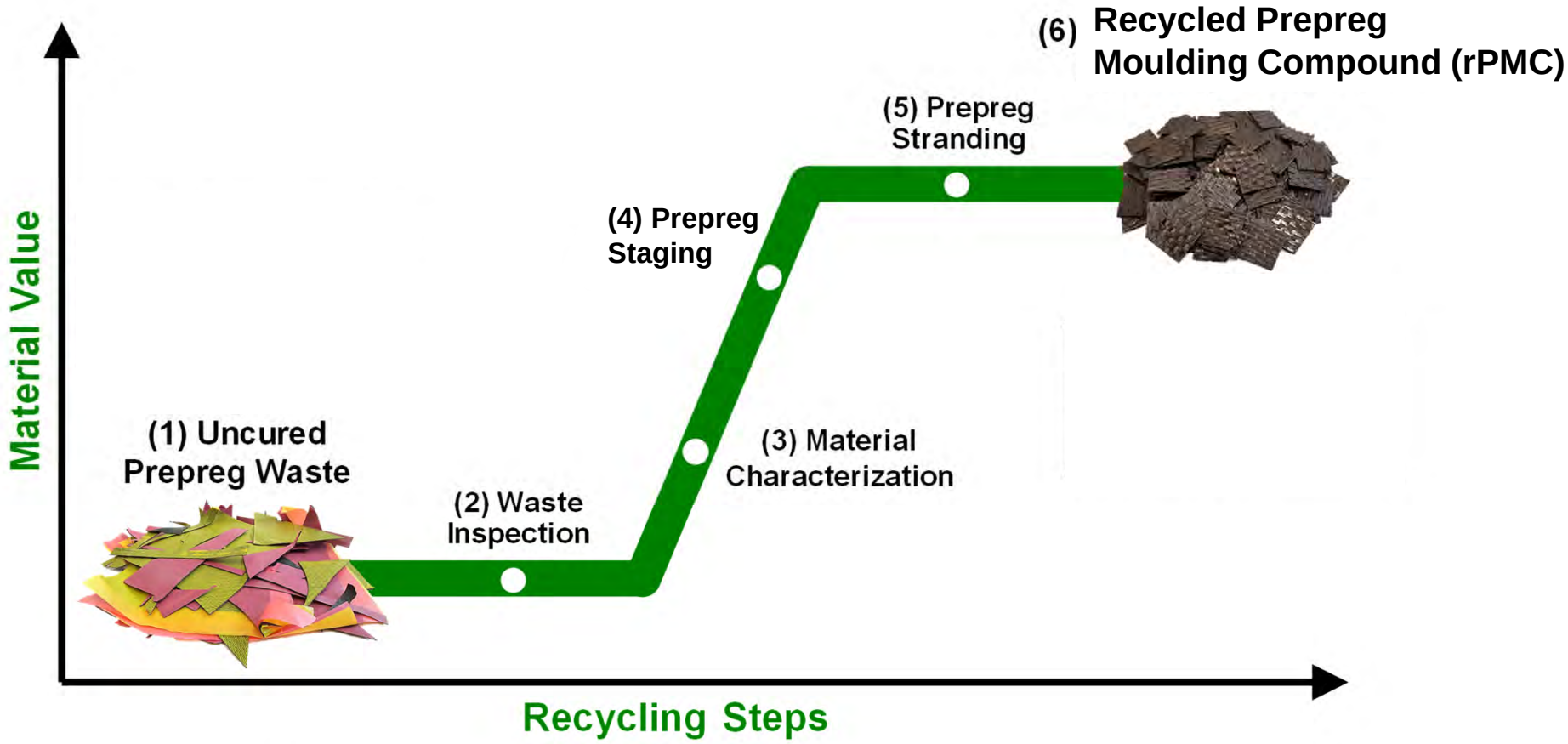




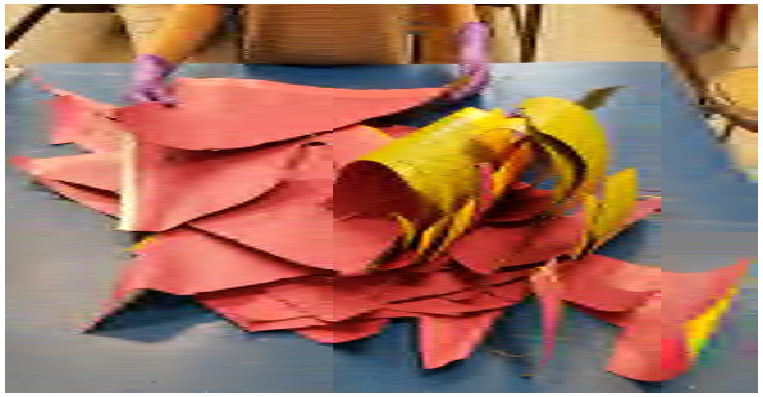
1-D flow-compaction (4/4)



Prepreg recycling framework

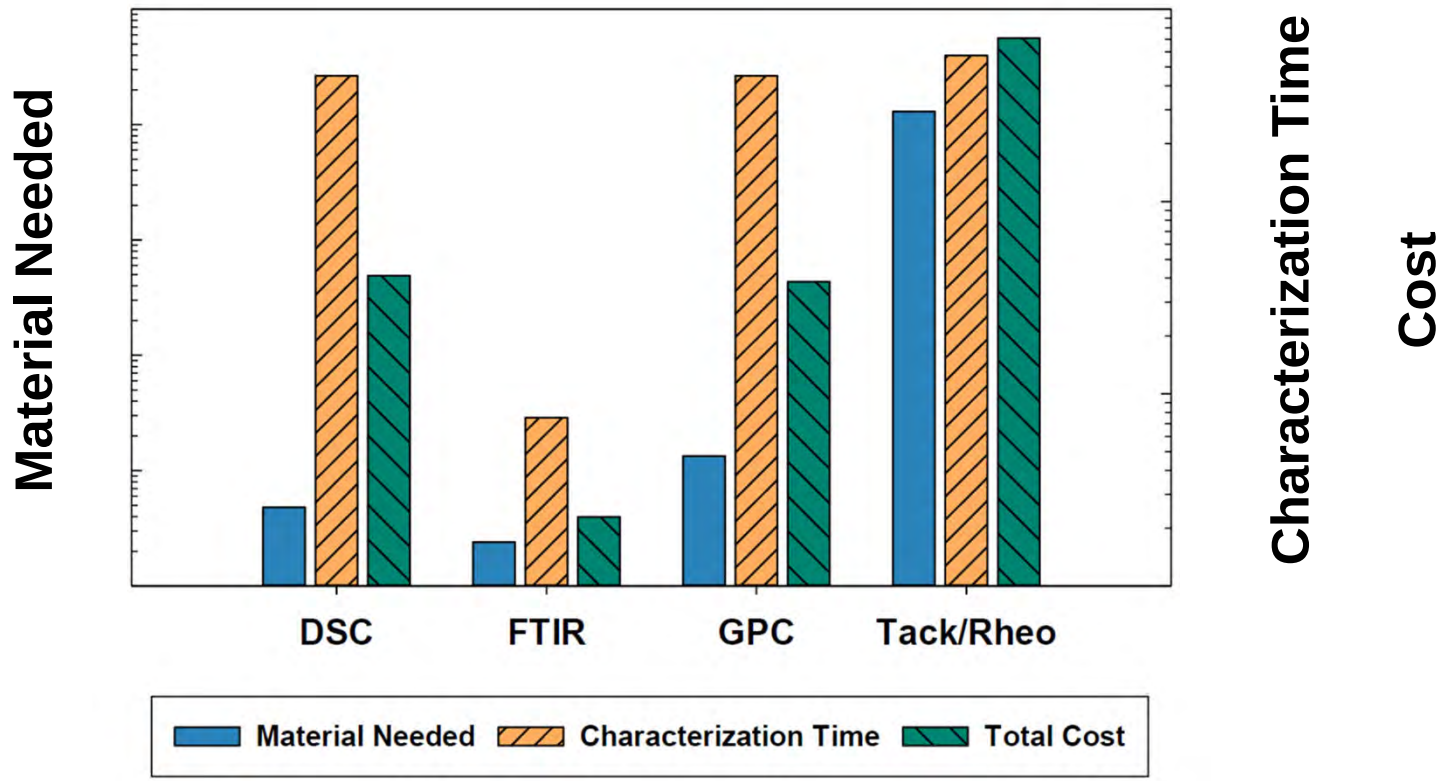


Step 1 - Recovered offcuts



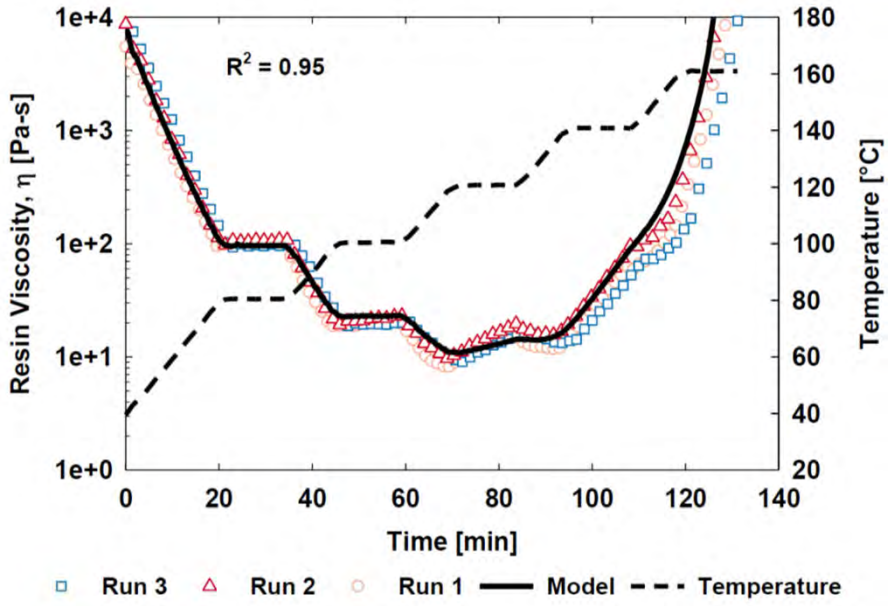
Specification	Prepreg A	Prepreg B
Resin	Cycom 5276-1 Epoxy	
Fibre	Thornel T650 – PAN	
Tow Size	3K	
Architecture	Plain weave (PW)	8 harness satin (8HS)
Resin Content	36 % wt	42 % wt
Areal Weight	312 gsm	370 gsm
Out-life	N/A	15 days
Shelf Life	N/A	6 months

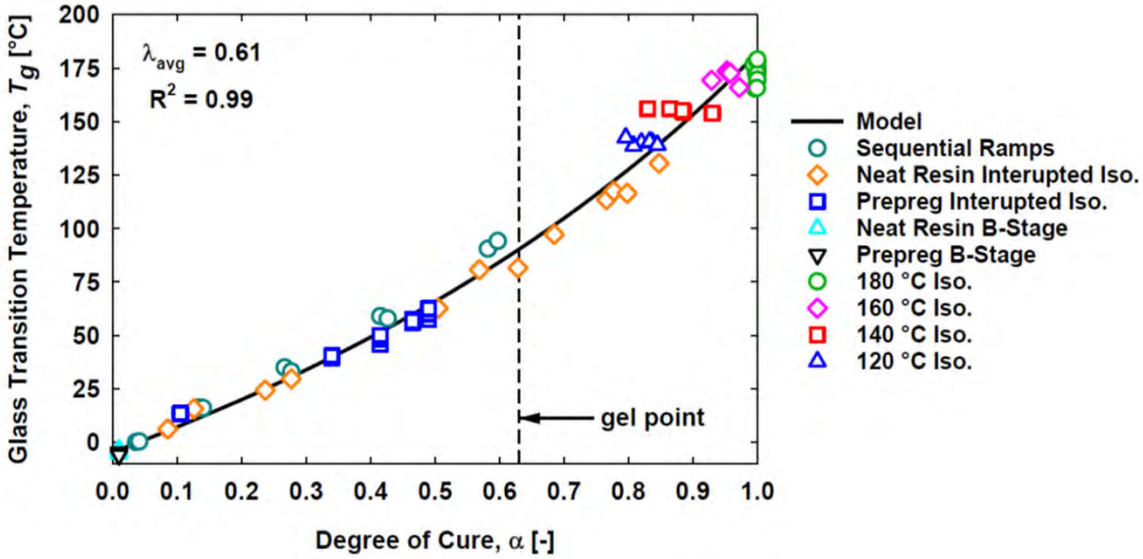
Step 2 – Waste inspection



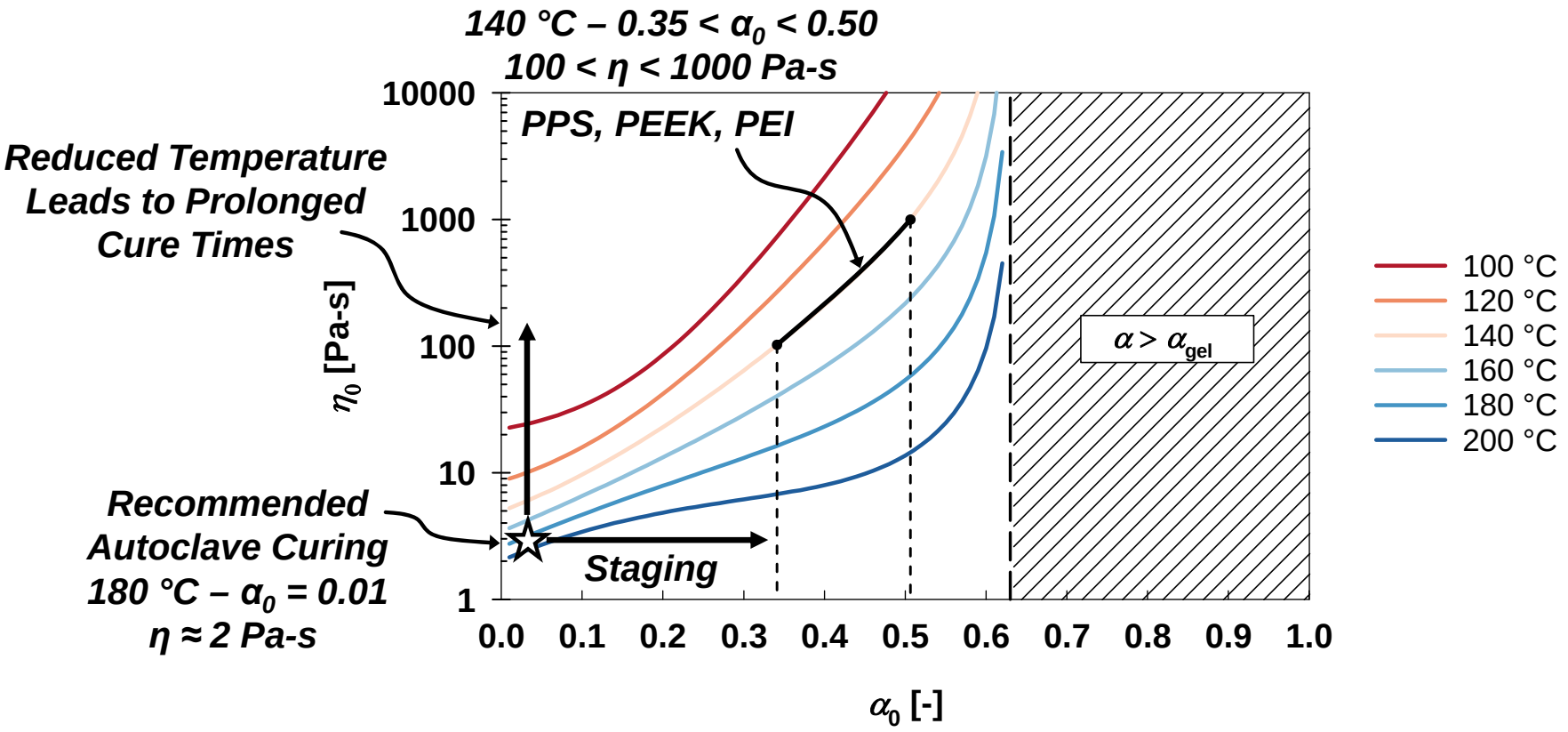
Step 3 - Material characterization

- Cure kinetics and vitrification
- Viscosity





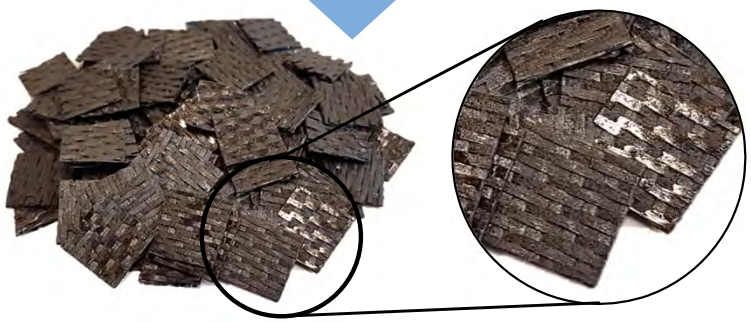
Step 4 - Prepreg staging

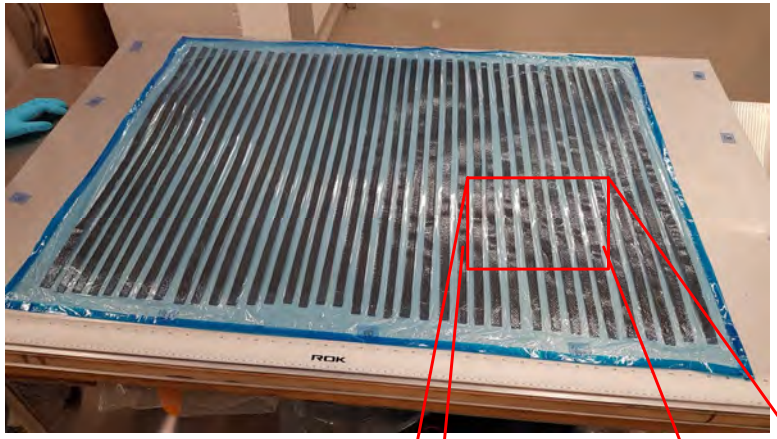


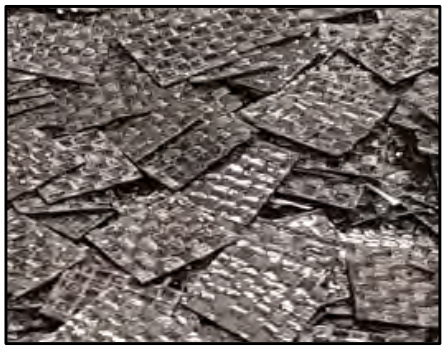
Step 5 – Prepreg stranding

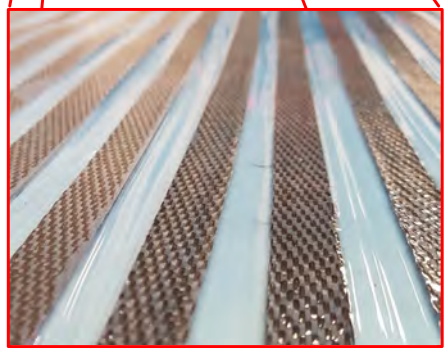
Procedure

1. Offcut Slitting (12.7 mm)
2. Oven Staging at 120 °C
3. Rapid Cooling
4. Stranding (12.7 mm)



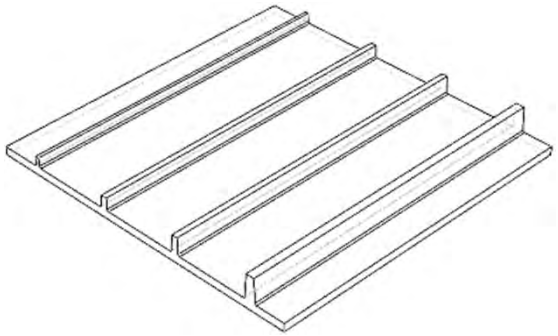




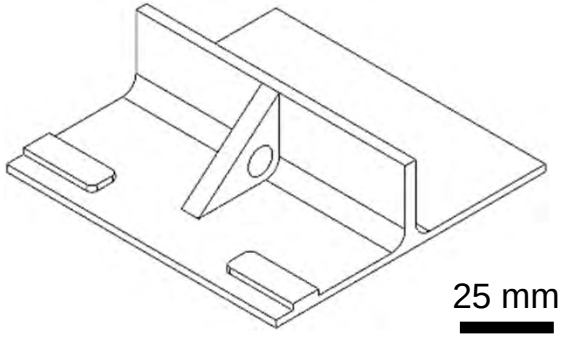


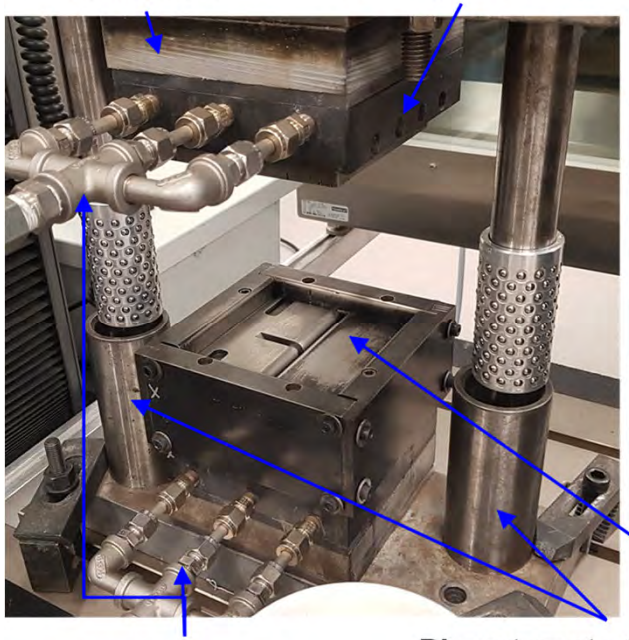
Step 6 – rPMC moulding

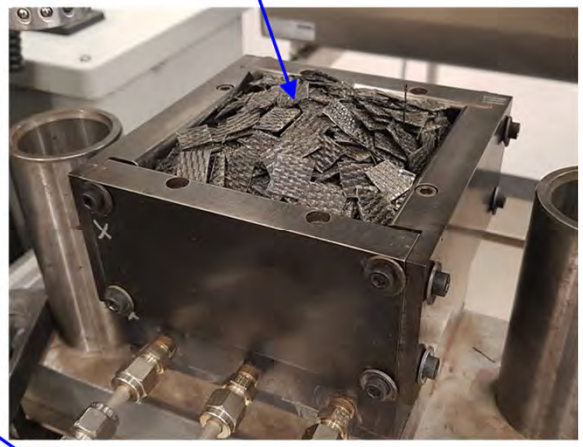
Multi-ribbed Panel



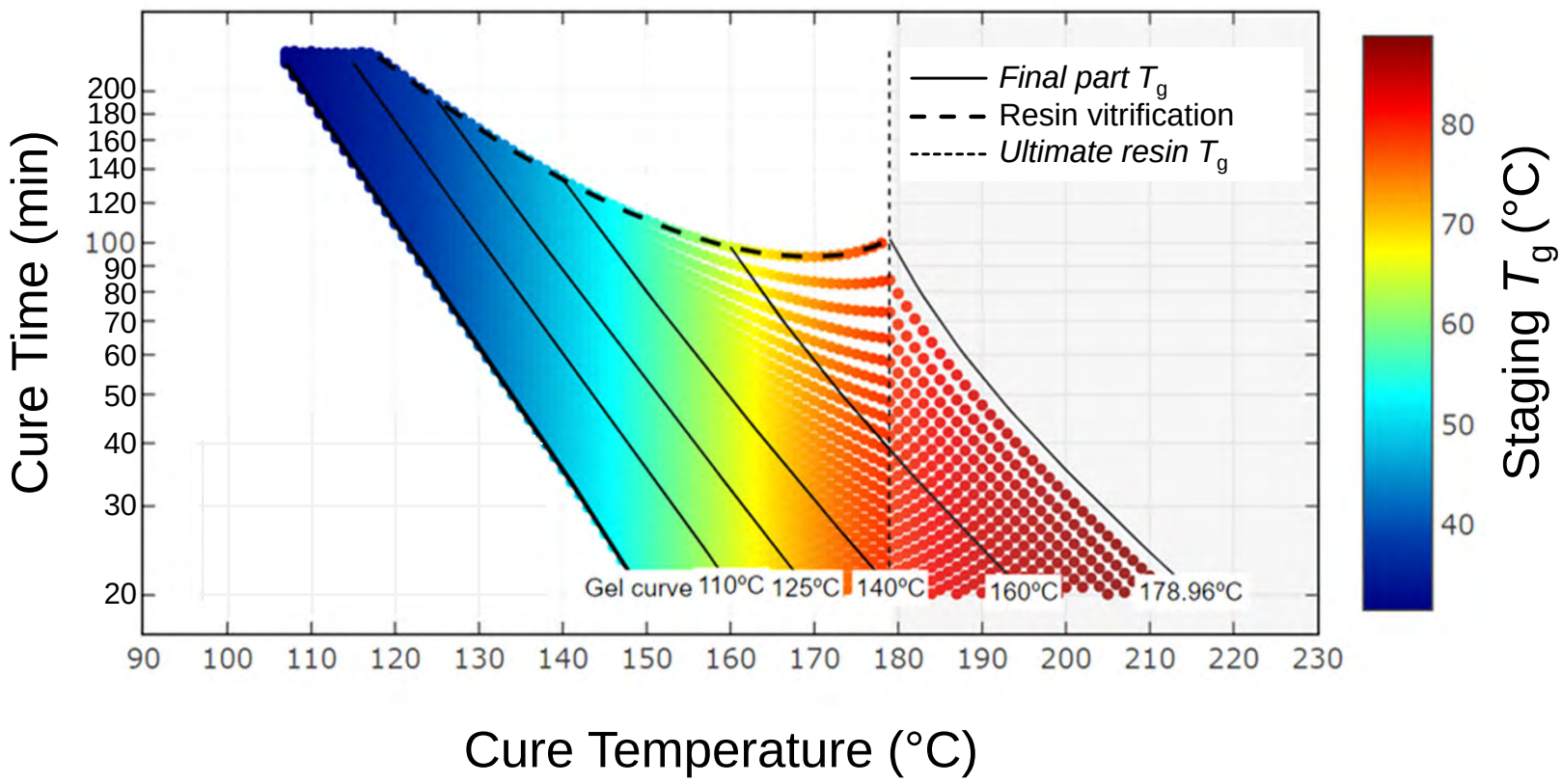
Compound T-Bracket







Manufacturing software tool



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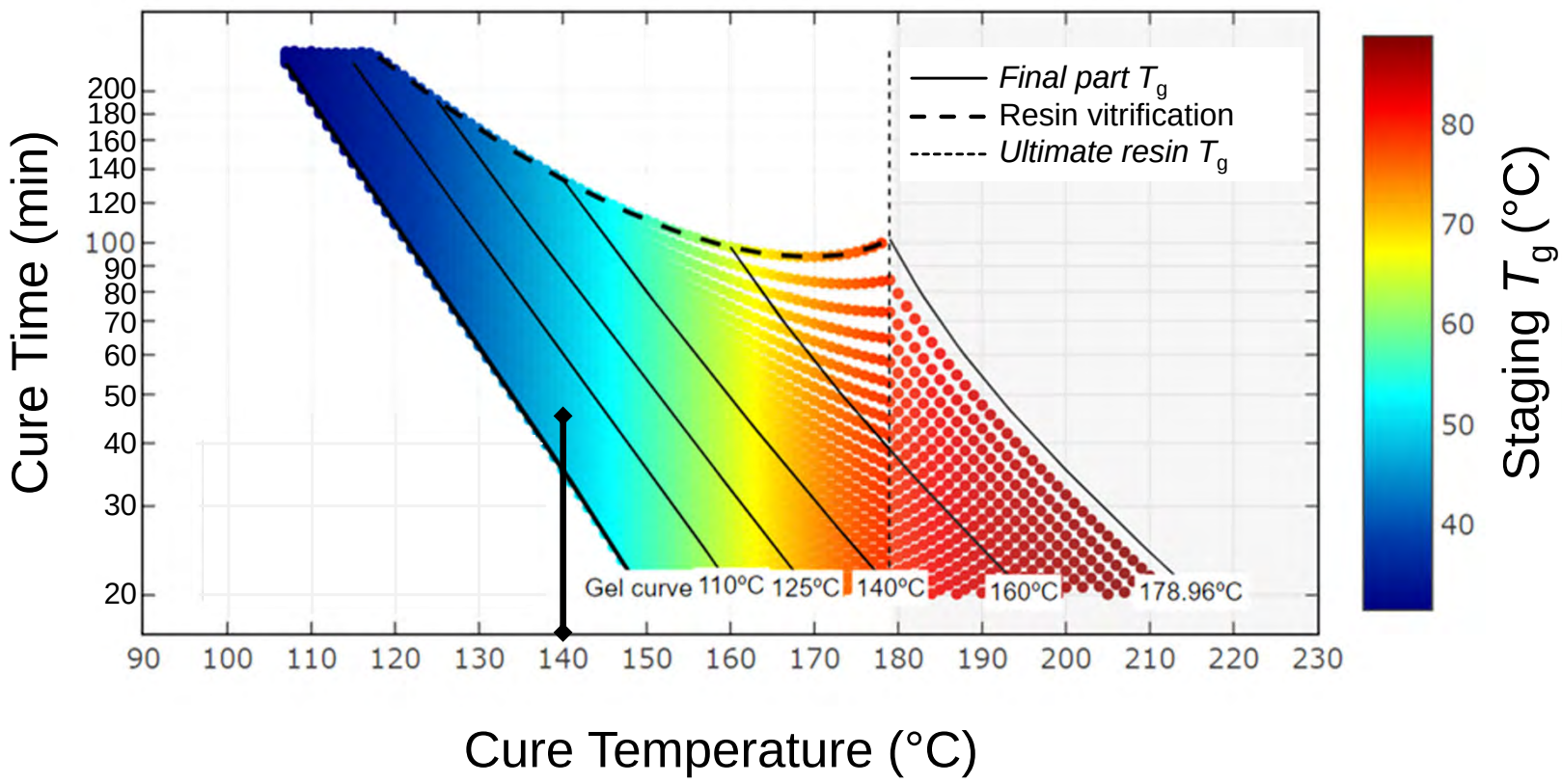

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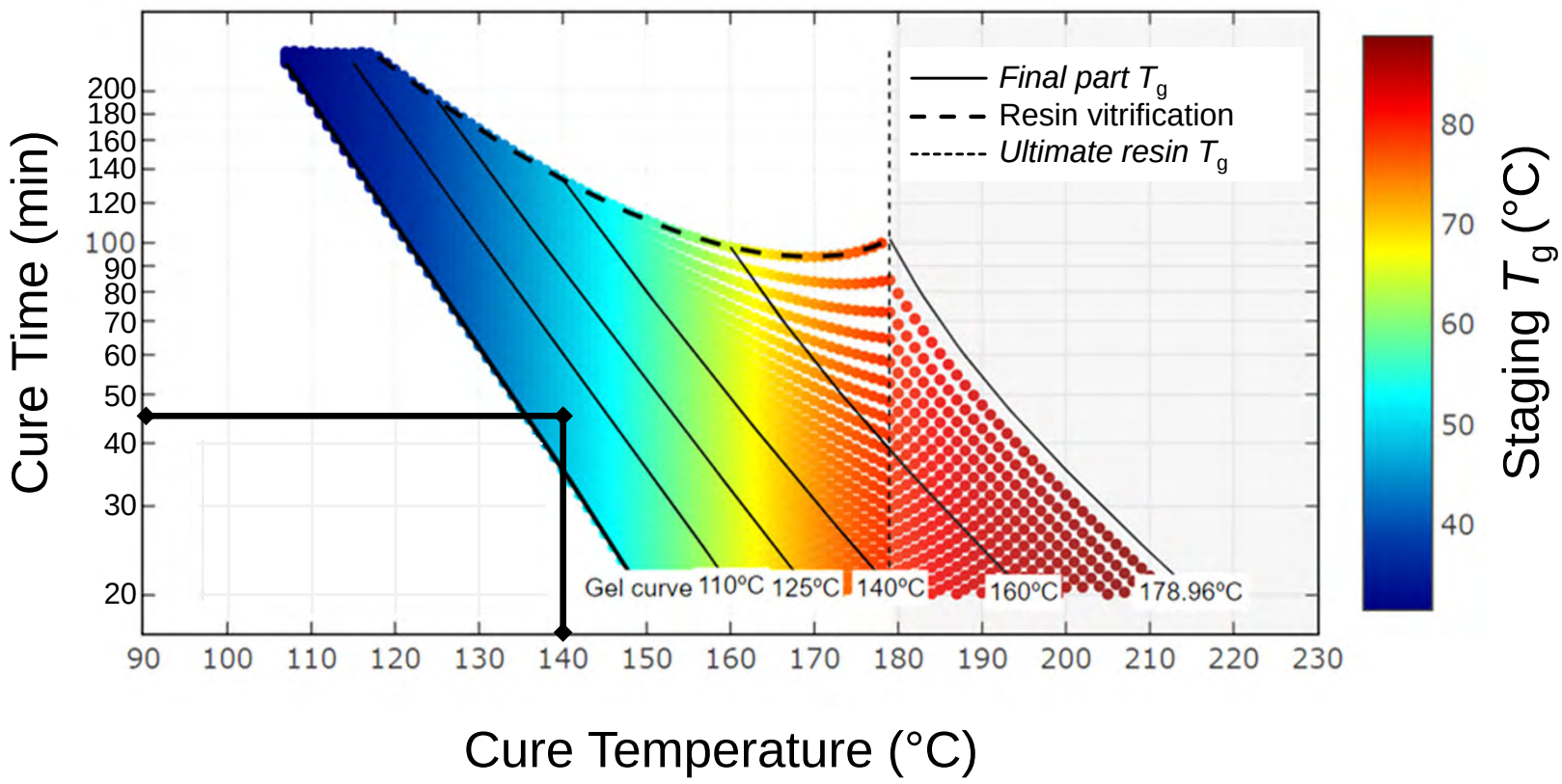

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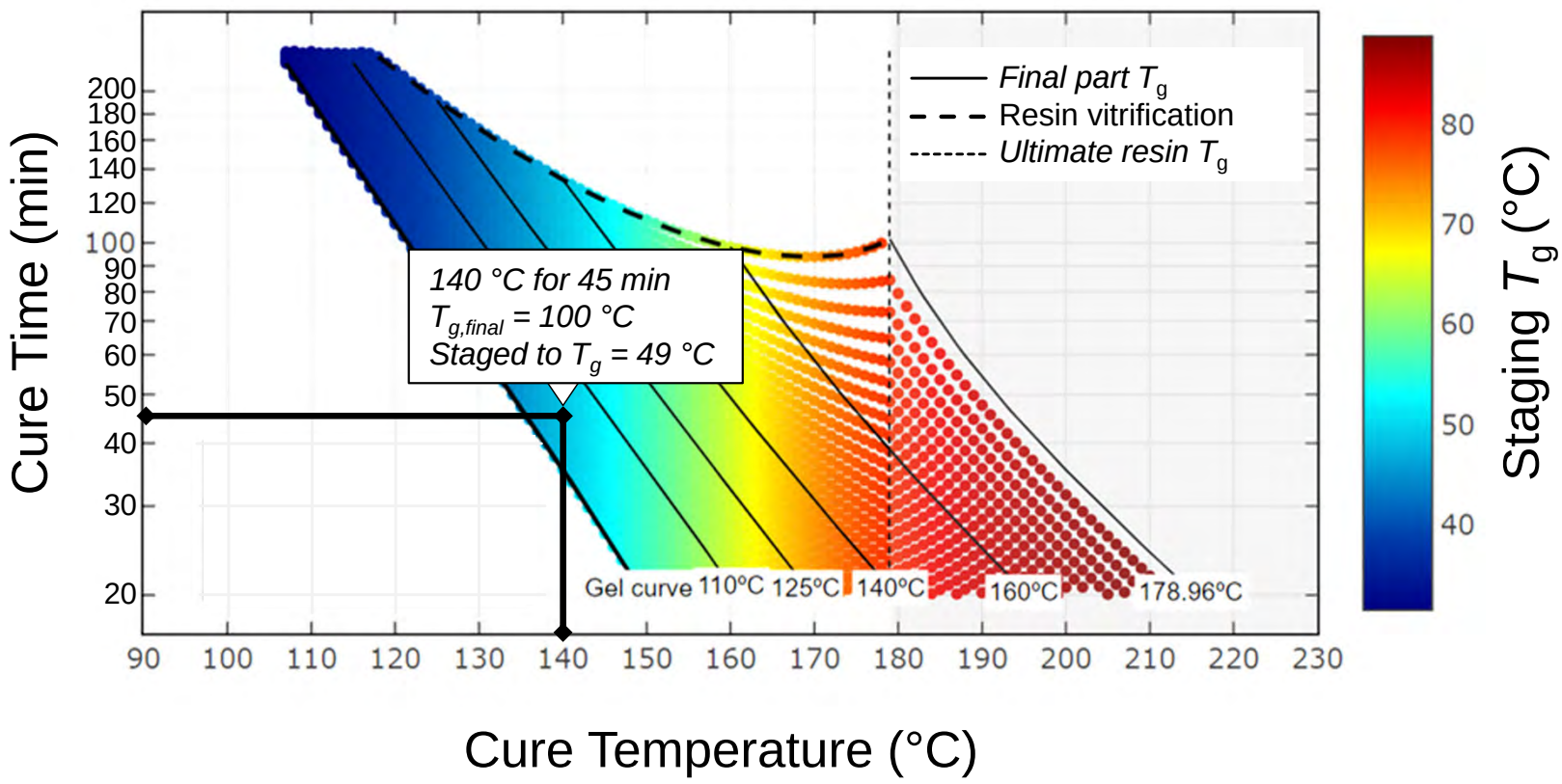
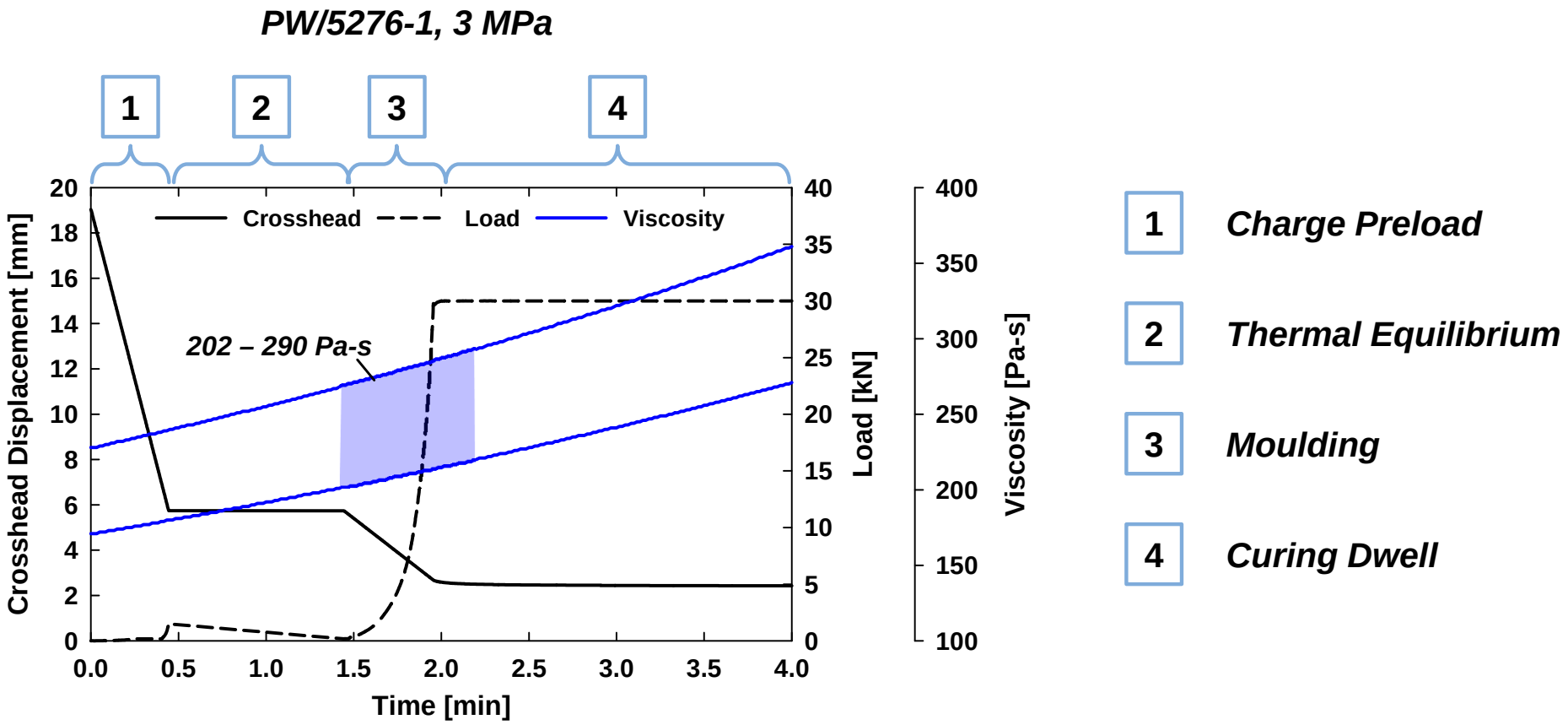


rPMC moulding process



1 *Charge Preload*

2 *Thermal Equilibrium*

3 *Moulding*

4 *Curing Dwell*

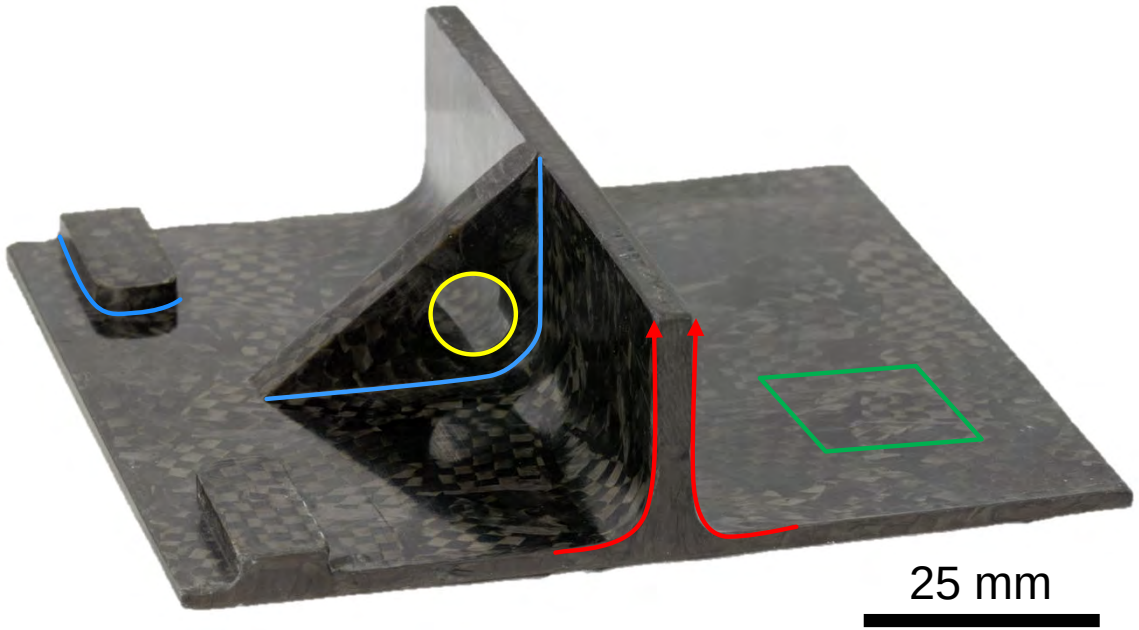
rPMC technology demonstrator

moulded hole

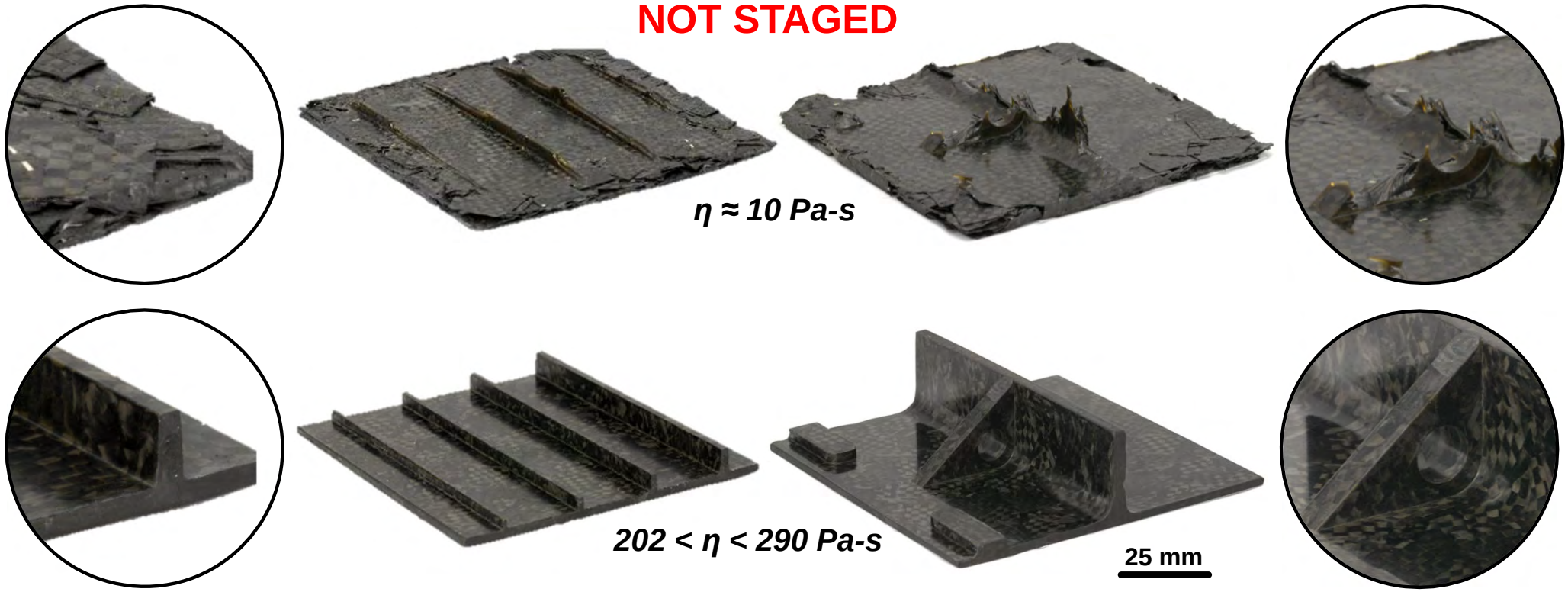
good surface finish

90° corner radii

~ 25 mm (1 in.) flow

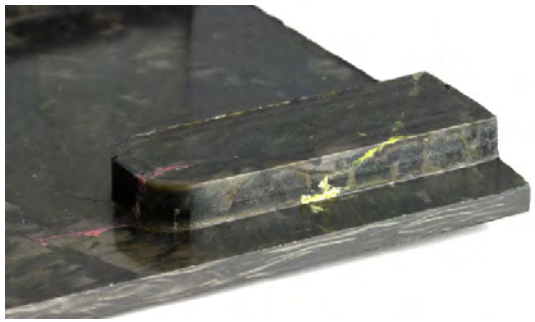


Prepreg staging validation

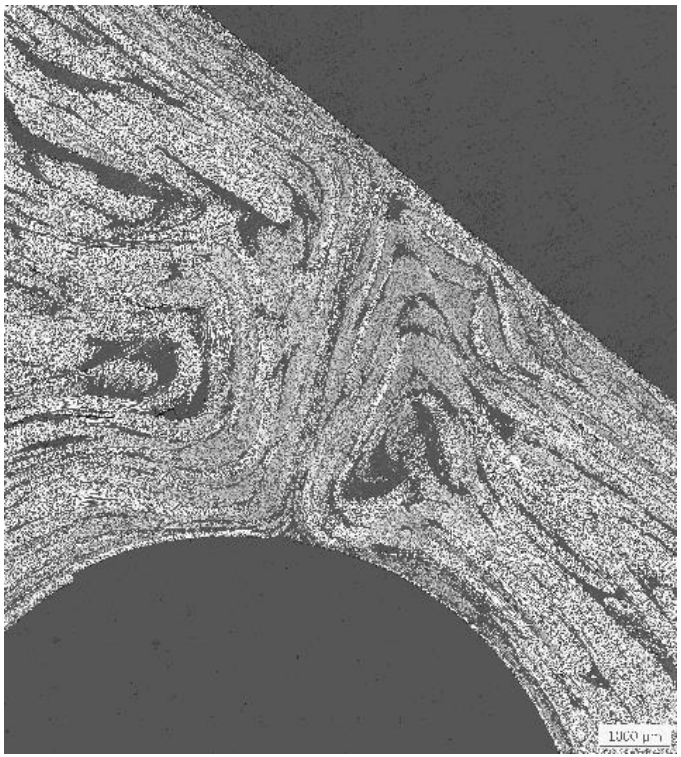


Observed defects

Entrapped Backing Film

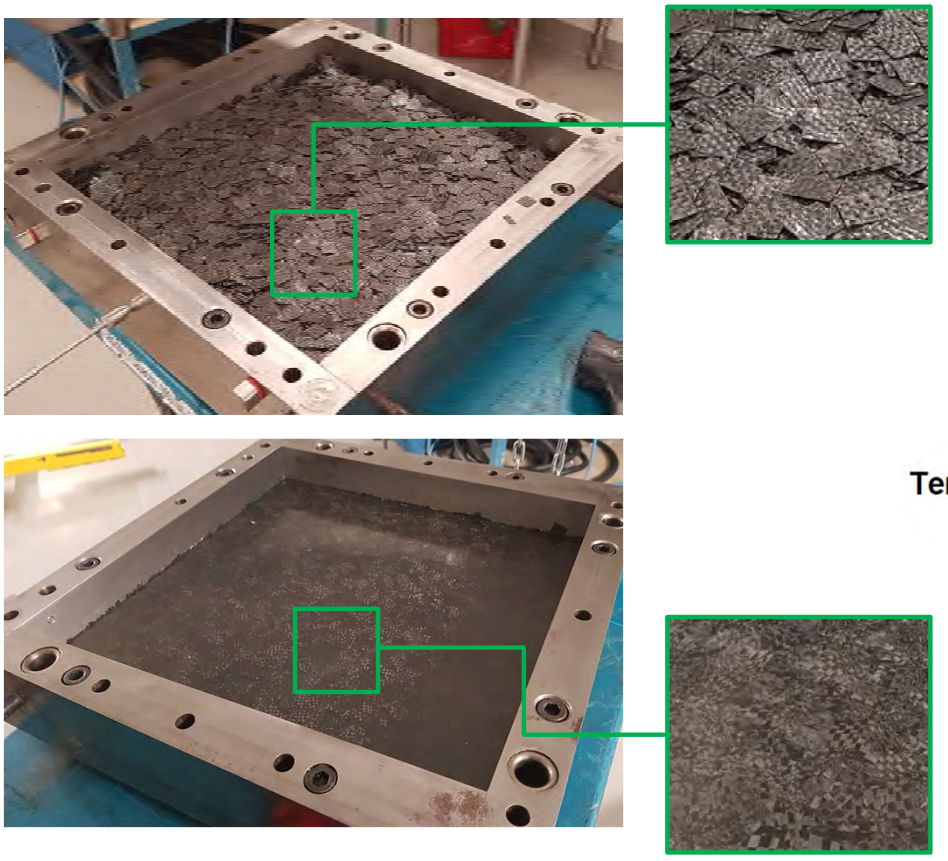


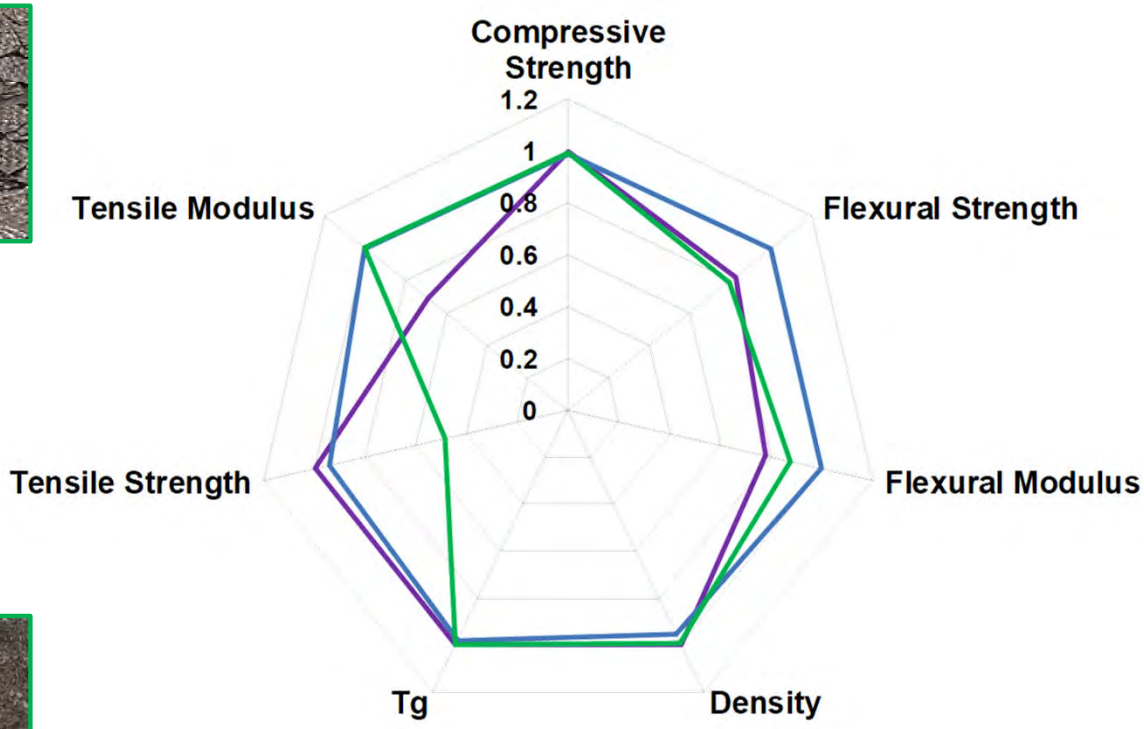
Knit Line Formation



A. Smith, 2021.

rPMC property comparison





rPMC PW/5276-1 (0.5” fibre length)

HexMC UT/M77 (2” fibre length)

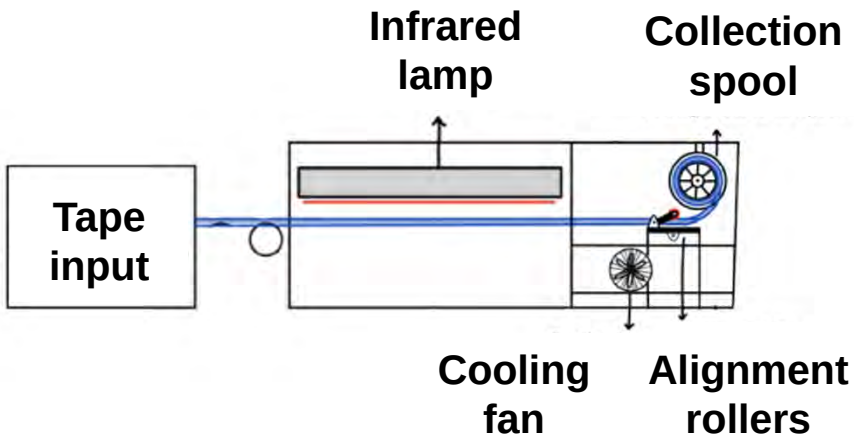
Quantum UT/AMC 8590 (1” fibre length)

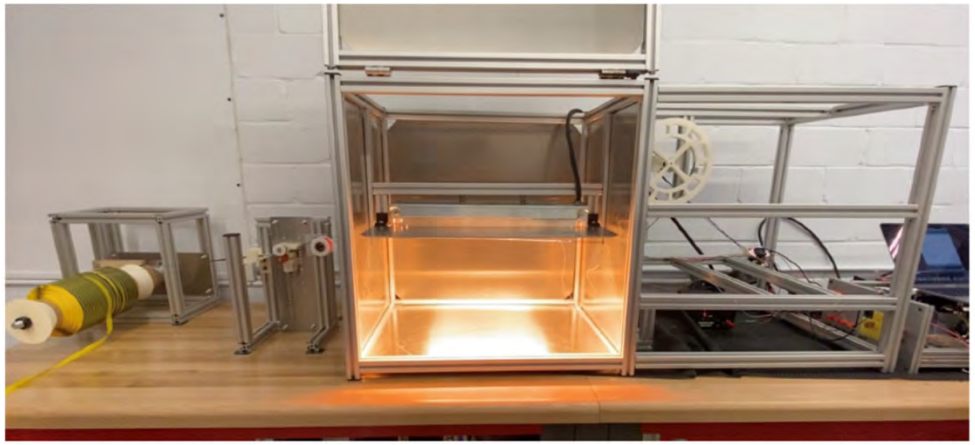
Conclusion

- Targeted changes to resin viscosity and curing time can be achieved through staging without added fillers or resins
- Flow-compaction mechanism excitation depends heavily on resin viscosity & mould closure rate
- Variations in prepreg degree of cure caused by room-temperature ageing have a significant impact on resin properties and requisite staging
- Specific mechanical performance of the recyclate developed are comparable to the properties of commercially available moulding compounds

Next steps and challenges

- Prepreg mixing
- Life cycle analysis of the process
- Automation of the process (inspection, prepreg handling, staging, stranding)





Acknowledgements

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Structures & Composite Materials Laboratory

Thank you

- https://www.mcgill.ca/composite/

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