OPTIMIZING A PRESS MOULDING PROCESSING

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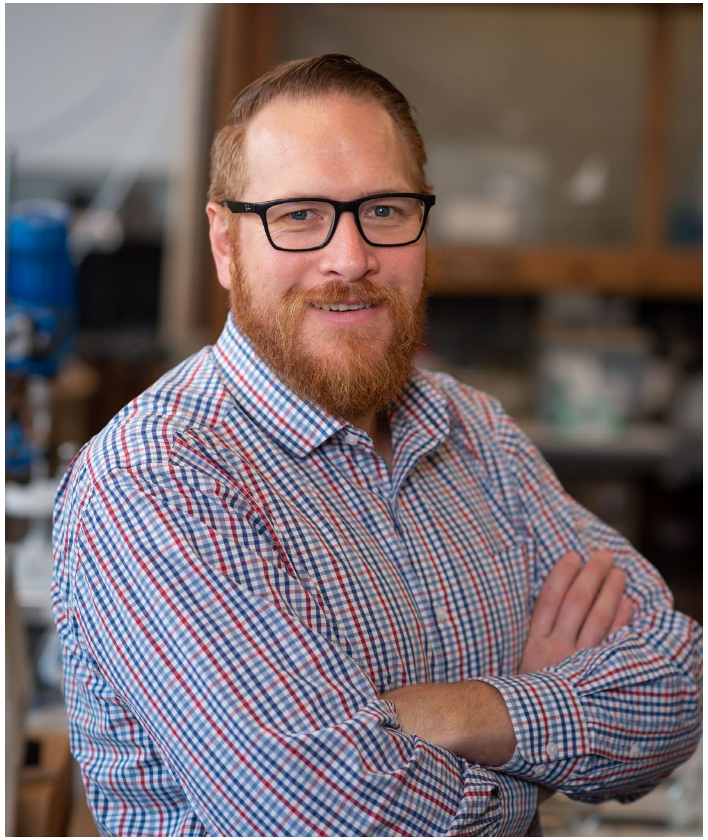


Casey Keulen, Ph.D, P.Eng.
Assistant Professor of Teaching, University of British Columbia
Co-Director of Advanced Materials Manufacturing MEL Program, UBC
Director of Knowledge in Practice Centre, CKN

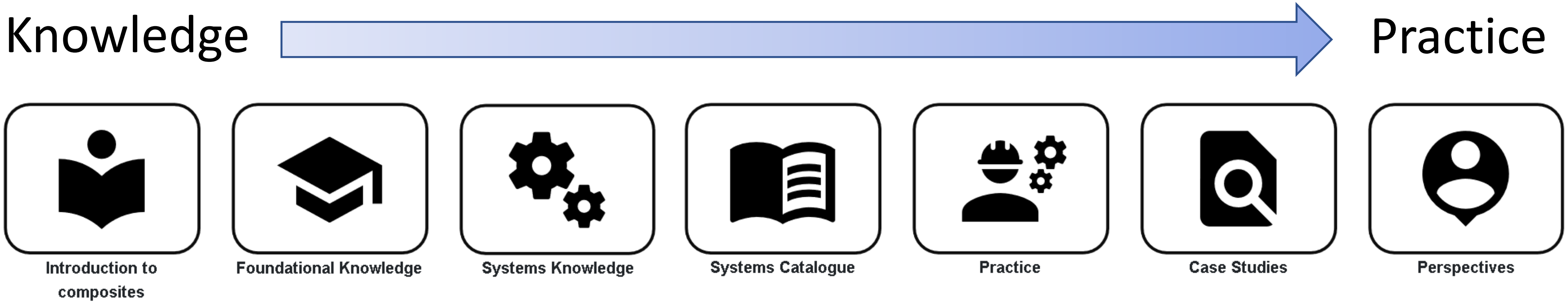
- Ph.D. and M.A.Sc. in Composite Materials Engineering
- Over 15 years experience in industry and academia working on polymer matrix composites in aerospace, automotive, marine, energy, recreation and others
- Experience working with over 150 companies from SME to major international corporations
- Expertise in liquid composite moulding and thermal management

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



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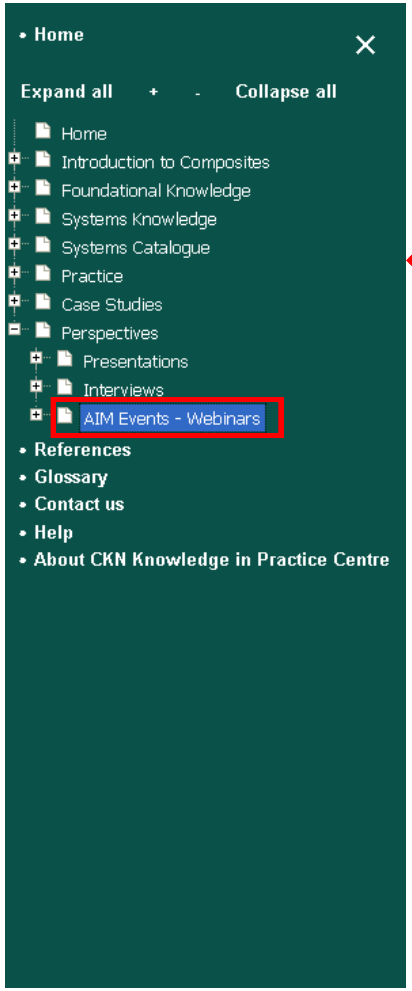

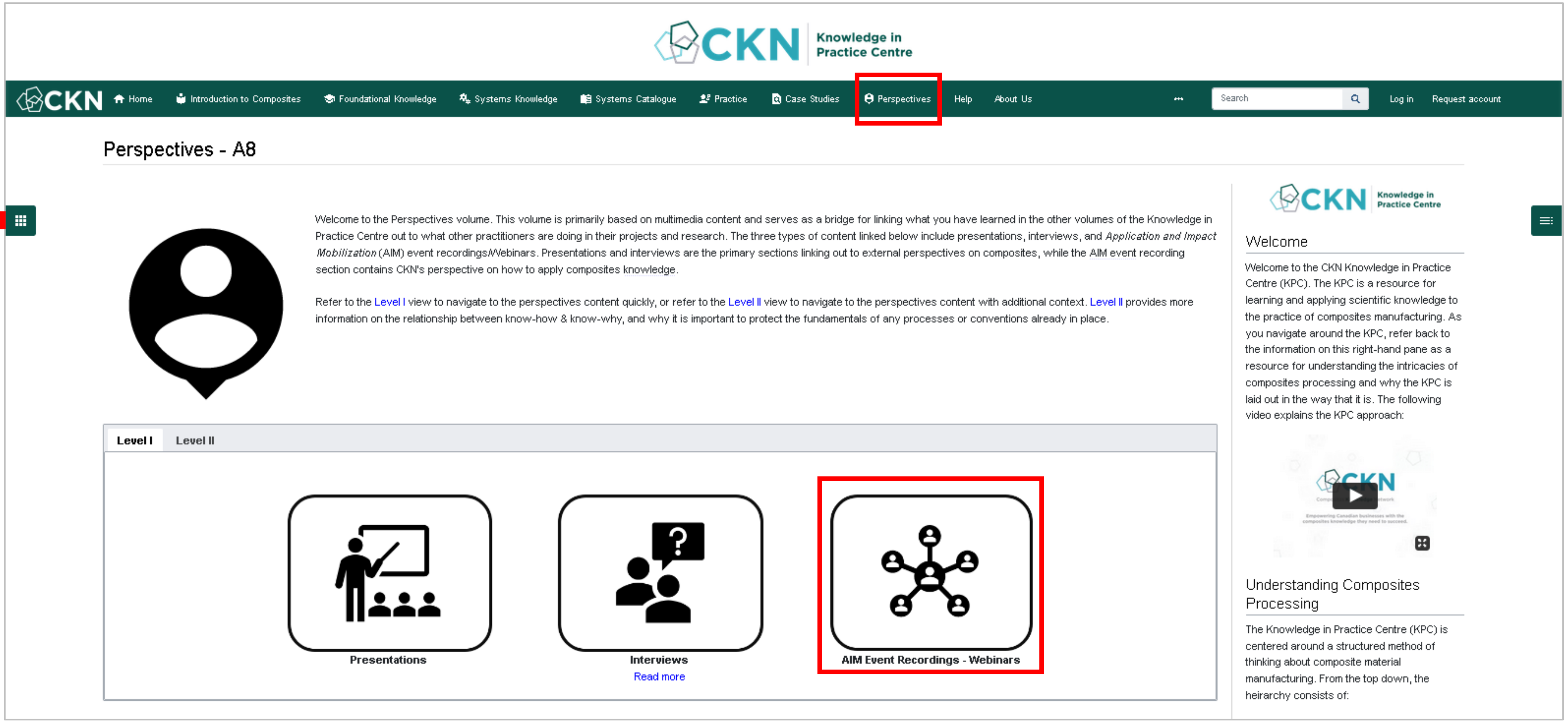

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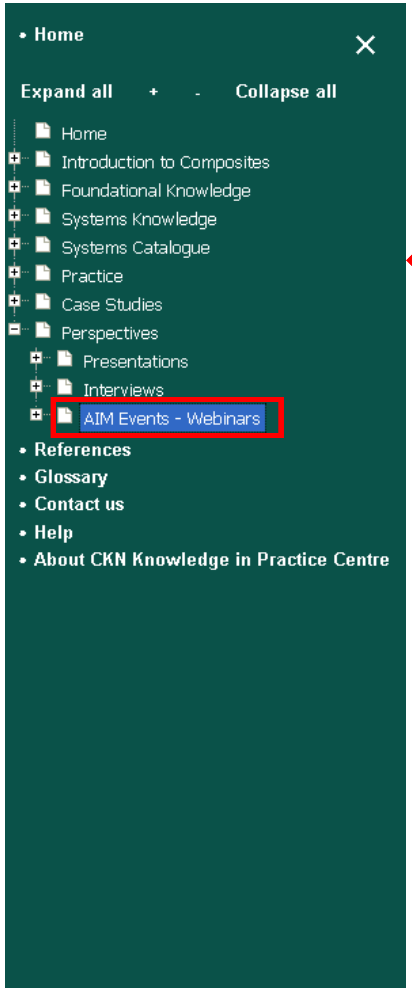

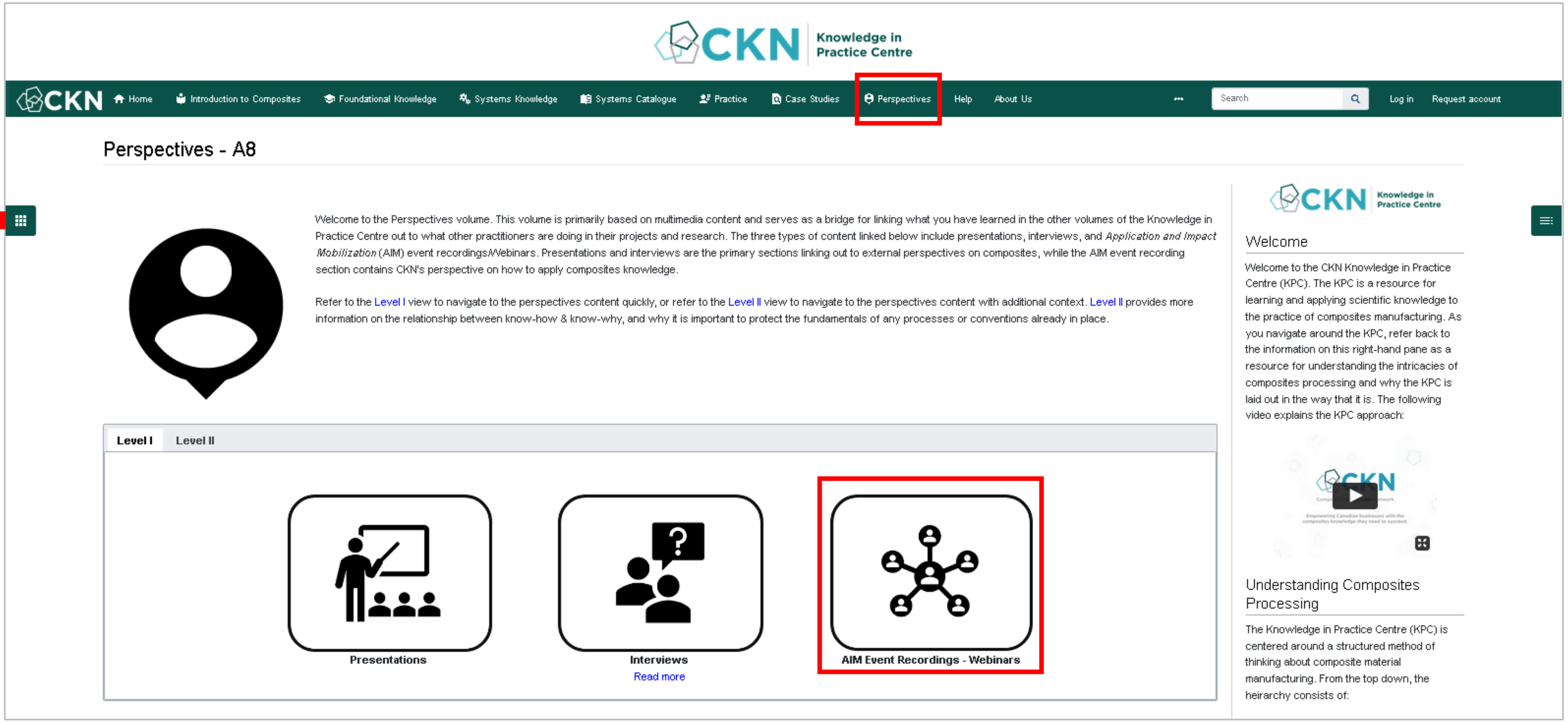

Today's Webinar will be posted at:
https://compositeskn.org/KPC/A324

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TODAY'S TOPIC:

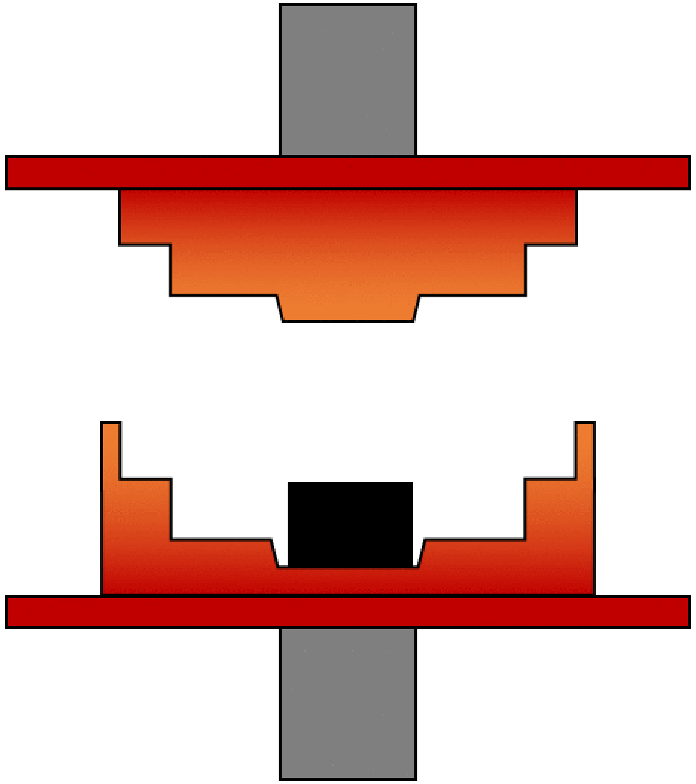
Optimizing a Press Moulding Process

OUTLINE

- Overview of hot press processing
- Set the scene for the hypothetical 'optimization project' in terms of MSTEP
- Layout the workflow:
  - Material characterization
  - Process characterization
  - Model validation
  - Process optimization
  - Optimized process validation
- Conclusion

PRESS MOULDING PROCESSING

- Press moulding uses two matched mould halves that close to form a cavity in the shape of the part
- Material charge is loaded into mould, mould is closed and held at pressure/temperature, opened and part is removed
- Advantages:
  - Suitable for high volume production
  - Good temperature/pressure control
  - Good surface finish and dimensional control
  - Potential for high fibre volume fraction
  - Complex part shapes possible
- Limitations:
  - High initial investment
  - Challenge removing entrapped gases/volatiles
  - Applied pressure may not be uniform across part surface
  - Scalability is challenging/costly



- Compression moulding page: [A302](A302)
- Hot press page: [A176](A176)

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Society of Manufacturing Engineers: https://www.youtube.com/watch?v=Gd1dkrX8JFU

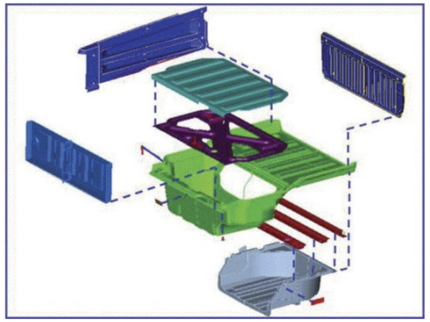
PRESS MOULDING PROCESSING

- Fraunhofer Innovation Platform for Composites Research, London Ontario
  - 2500 tons
  - 3 X 2 m bed

https://www.eng.uwo.ca/fraunhofer/facilities/index.html

PRESS MOULDING PROCESSING - COMMON APPLICATIONS

- Aerospace
  - Overhead bins
  - Sidewalls
  - Coverings
- Automotive
  - Tailgates
  - Body panels
- Industrial
  - Enclosures, doors, etc.
  - Man hole covers



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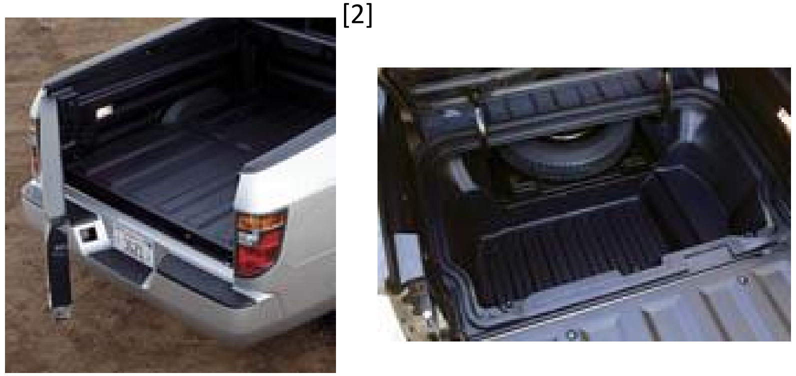

[2]

[3]

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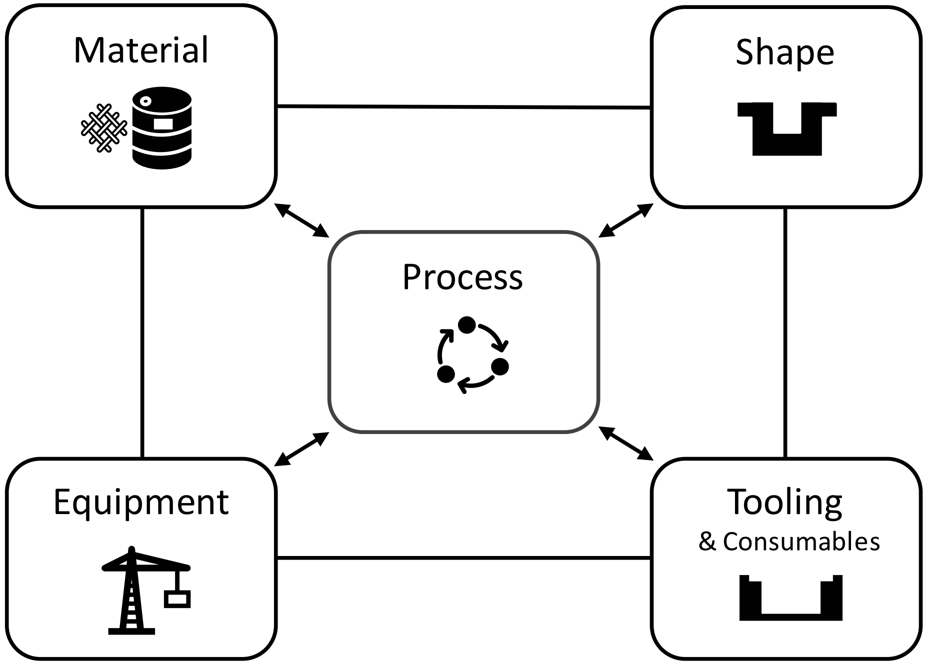
[1] http://www.reinforcedplastics.com/view/3883/smc-has-plenty-of-road-to-run-in-automotive-applications/
[2] http://www.compositesworld.com/articles/inside-the-box-thinking-pays-off-for-honda
[3] https://www.toraytac.com/products/parts-and-services/compression-molded-parts
[4] https://www.azom.com/article.aspx?ArticleID=10665

SETTING THE SCENE

- We have a process currently setup and running
  - No major issues
- Would like to increase rate without increasing cost – what can be done?
  - *Decrease time press/mould is occupied*
- Recall the MSTEP approach, in our case:
  - Material is fixed
  - Part geometry is fixed
  - Tooling is fixed –> more tooling = more cost
  - Equipment is fixed –> more equipment = more cost
- *This leaves the process to focus on*

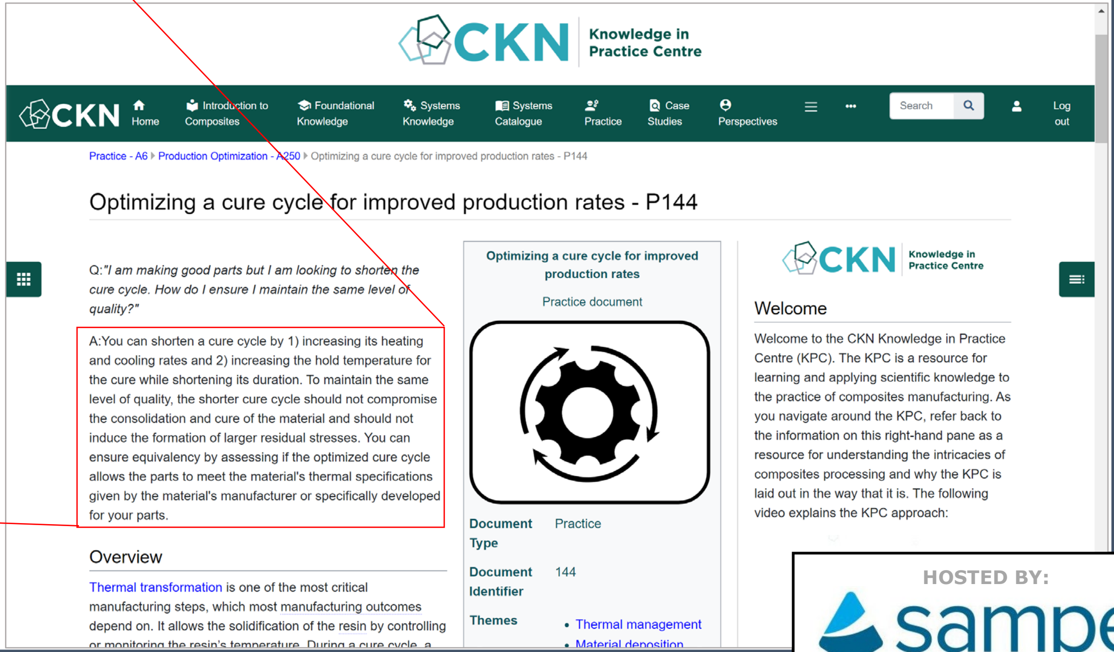


MSTEP Approach: A230

LET'S SEE WHAT THE KPC SAYS

- Within the Practice Volume we find:
  - Optimizing a cure cycle for improved production rates – P144

A:You can shorten a cure cycle by 1) increasing its heating and cooling rates and 2) increasing the hold temperature for the cure while shortening its duration. To maintain the same level of quality, the shorter cure cycle should not compromise the consolidation and cure of the material and should not induce the formation of larger residual stresses. You can ensure equivalency by assessing if the optimized cure cycle allows the parts to meet the material's thermal specifications given by the material's manufacturer or specifically developed for your parts.



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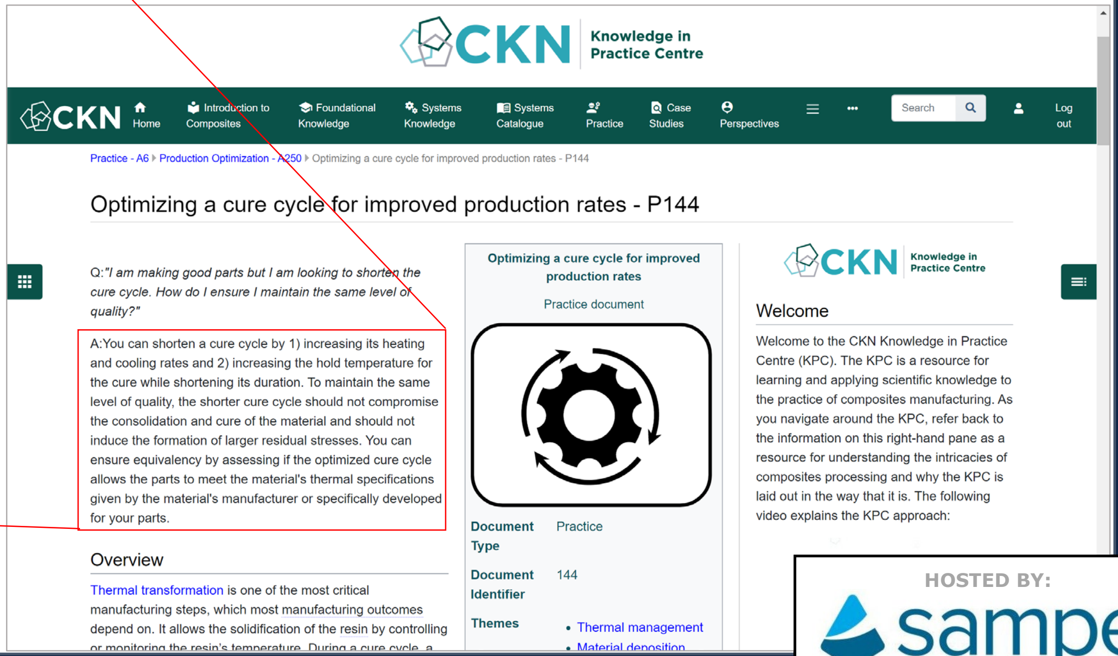

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Increase hold temperature

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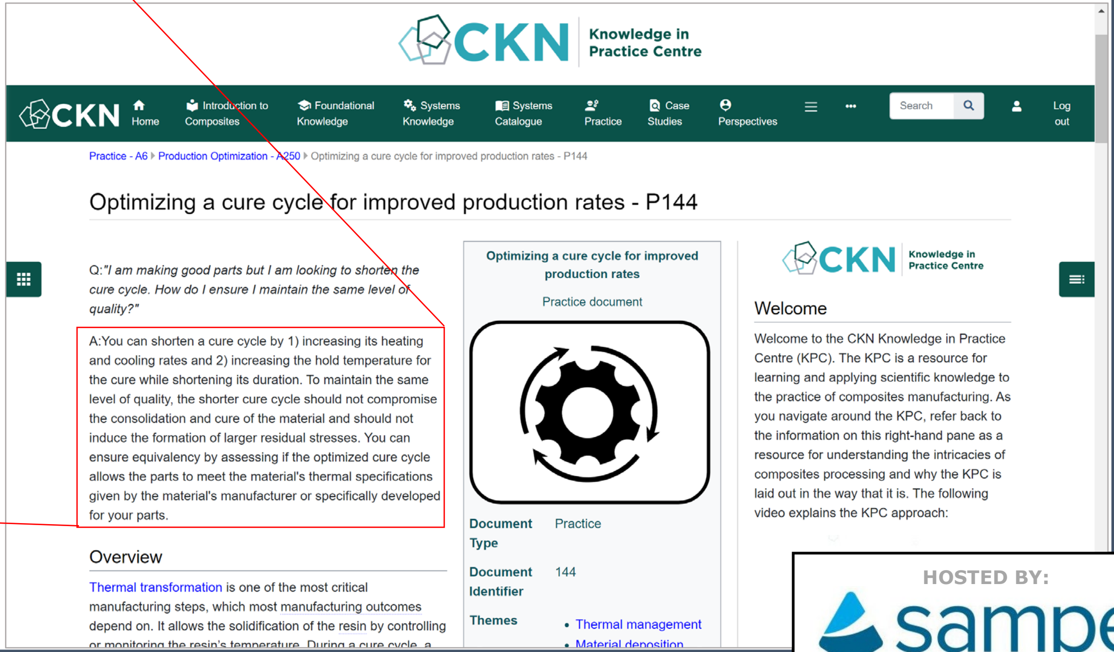

LET'S SEE WHAT THE KPC SAYS

- Within the Practice Volume we find:
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Increase hold temperature

Should not compromise consolidation and/or cure or induce unacceptable residual stresses

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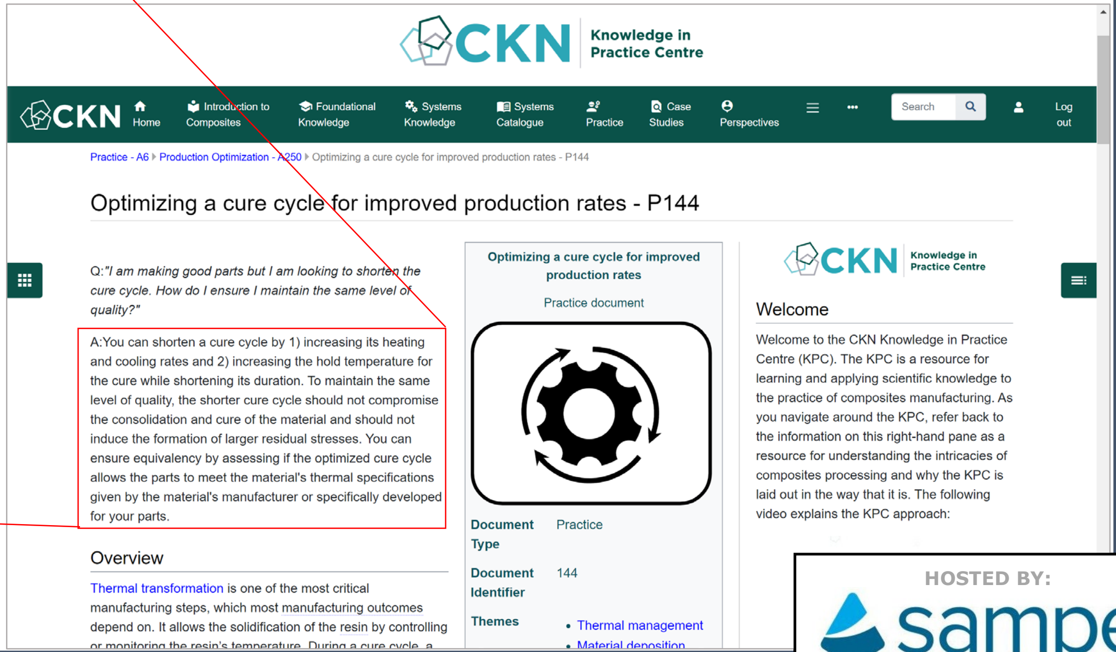
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Practice - A6 ▸ Production Optimization - A250 ▸ Optimizing a cure cycle for improved production rates - P144

Optimizing a cure cycle for improved production rates - P144

Q:"I am making good parts but I am looking to shorten the cure cycle. How do I ensure I maintain the same level of quality?"

A:You can shorten a cure cycle by 1) increasing its heating and cooling rates and 2) increasing the hold temperature for the cure while shortening its duration. To maintain the same level of quality, the shorter cure cycle should not compromise the consolidation and cure of the material and should not induce the formation of larger residual stresses. You can ensure equivalency by assessing if the optimized cure cycle allows the parts to meet the material's thermal specifications given by the material's manufacturer or specifically developed for your parts.

Overview

Thermal transformation is one of the most critical manufacturing steps, which most manufacturing outcomes depend on. It allows the solidification of the resin by controlling

Optimizing a cure cycle for improved production rates

Practice document

Document Type: Practice

Document Identifier: 144

Themes:
- Thermal management
- Material deposition

CKN Knowledge in Practice Centre

Welcome

Welcome to the CKN Knowledge in Practice Centre (KPC). The KPC is a resource for learning and applying scientific knowledge to the practice of composites manufacturing. As you navigate around the KPC, refer back to the information on this right-hand pane as a resource for understanding the intricacies of composites processing and why the KPC is laid out in the way that it is. The following video explains the KPC approach:

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LET'S LAYOUT OUR WORKFLOW

Material Characterization

- Thermal stability (TGA)
- Cure kinetics (DSC)

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- Mould temperature
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- Final degree of cure (DOC)

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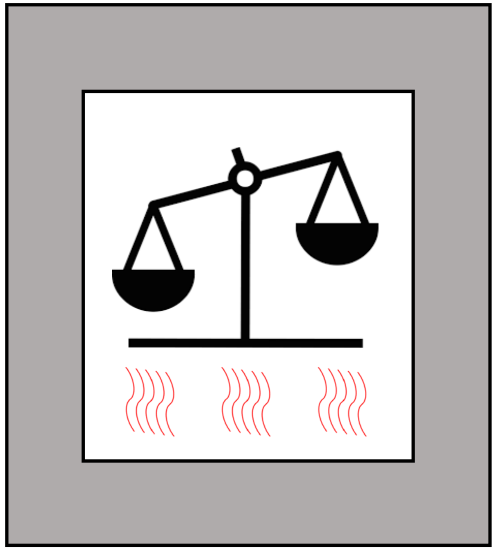
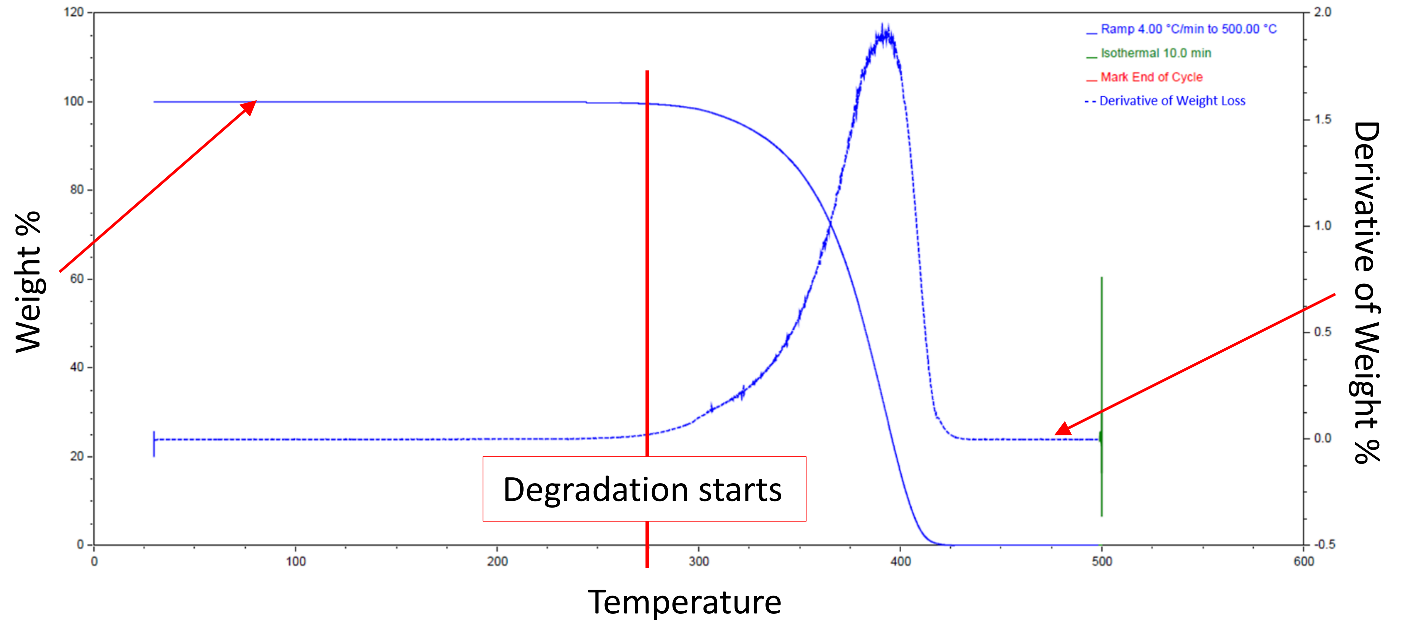
- Degree of cure
- Dimension
- Mechanical performance

MATERIAL CHARACTERIZATION – THERMAL STABILITY

- Start out by understanding the limits of the material
- We can use a thermo-gravimetric analysis (TGA) to understand this better
  - https://compositeskn.org/KPC/A329



TGA Instrument

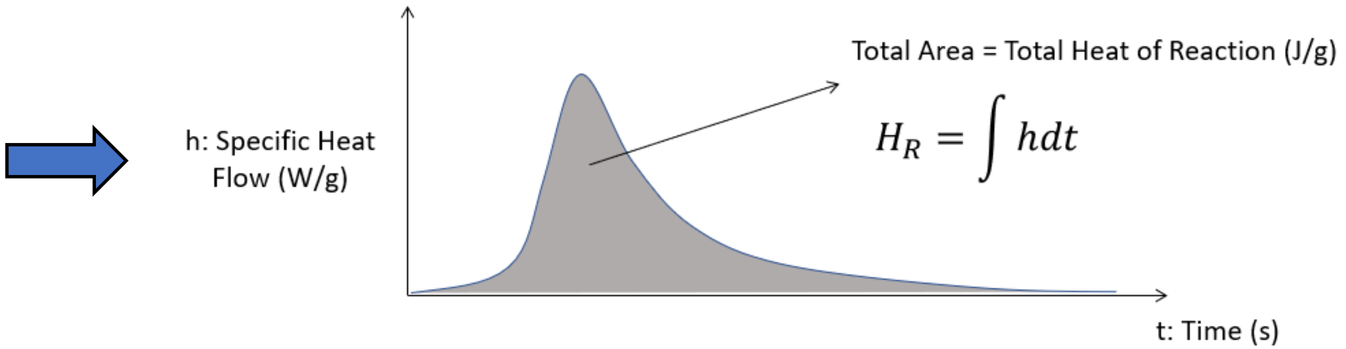


MATERIAL CHRACTERIZATION – CURE KINETICS

- Now we can characterize the material and build a model that we will use for simulation
  - Degree of cure: A104
  - Heat of reaction: A114

DSC Instrument

Raw Material



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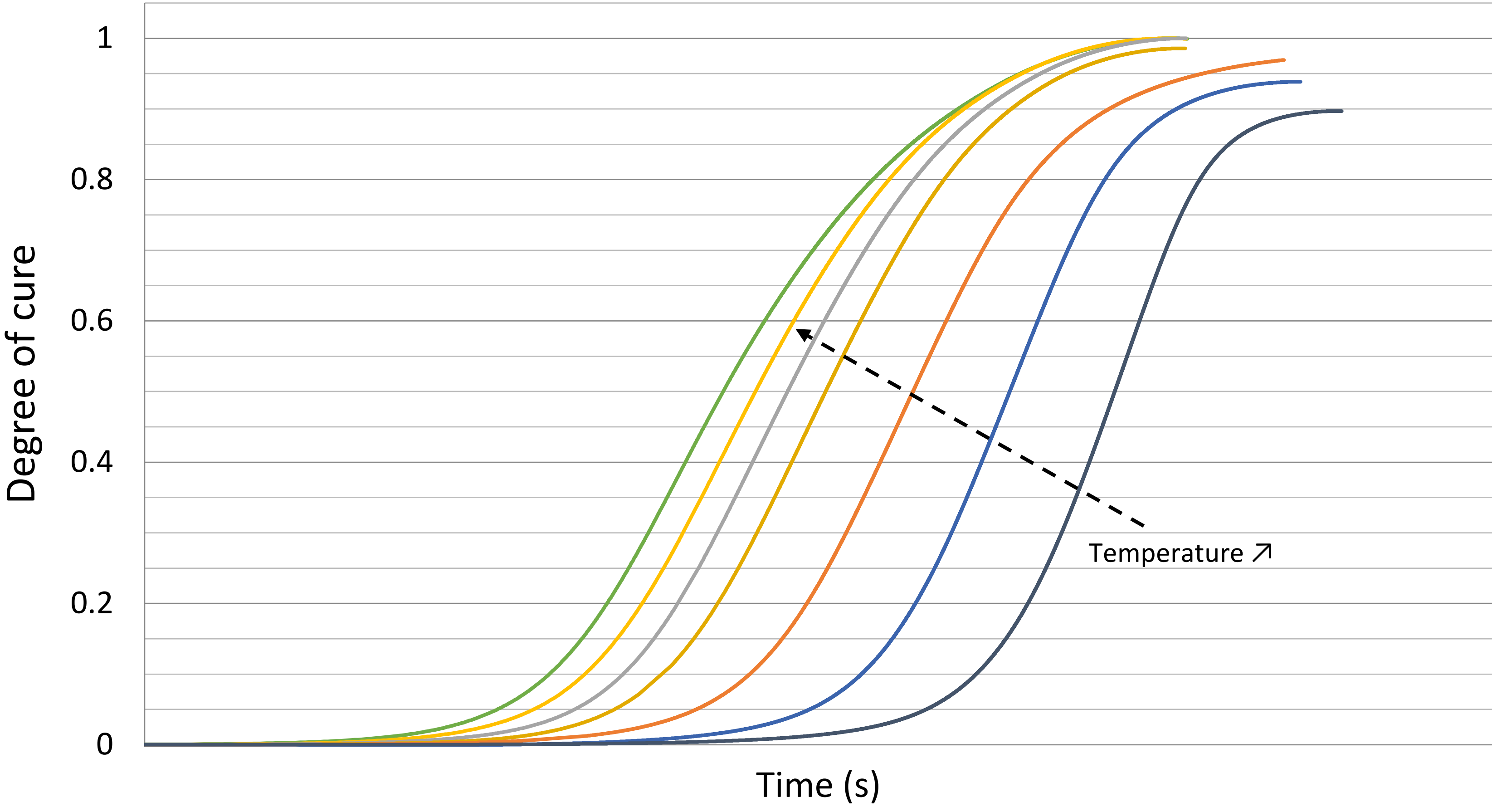

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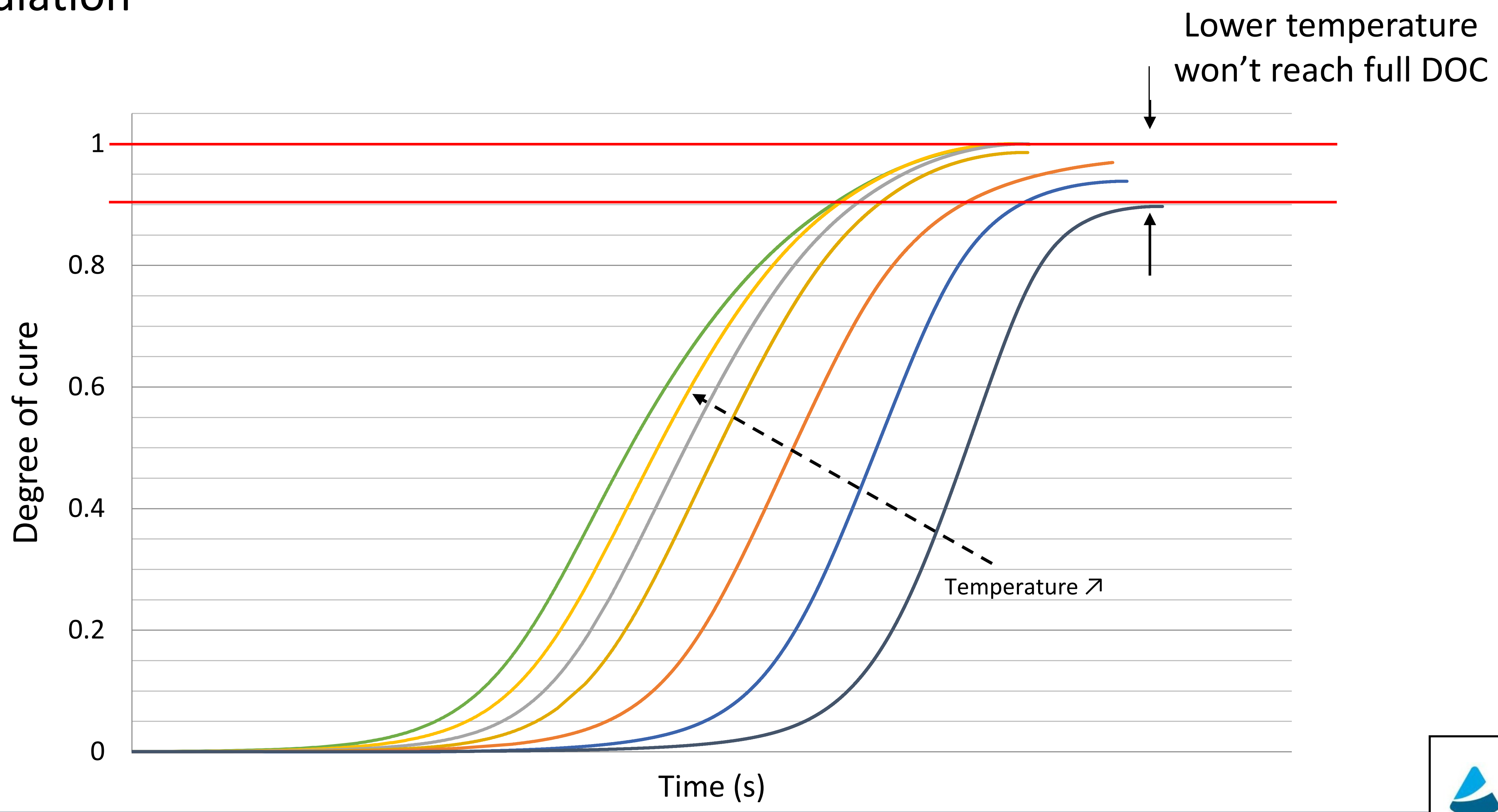

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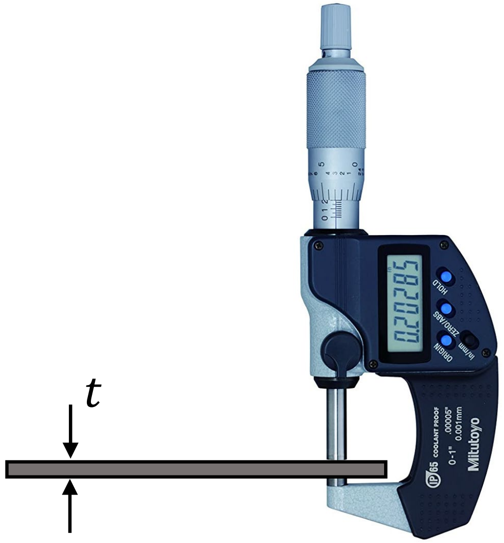
PROCESS CHARACTERIZATION - CONSOLIDATION

- Start out by investigating and benchmarking the material consolidation of the existing parts
  - Flow and Consolidation Management theme: A158
- Common fibre volume fraction measurement methods: M109
  - Matrix burn-off or digestion
  - Thickness measurement

Background on Vf: A213

Matrix burn-off or digestion
ASTM D3171



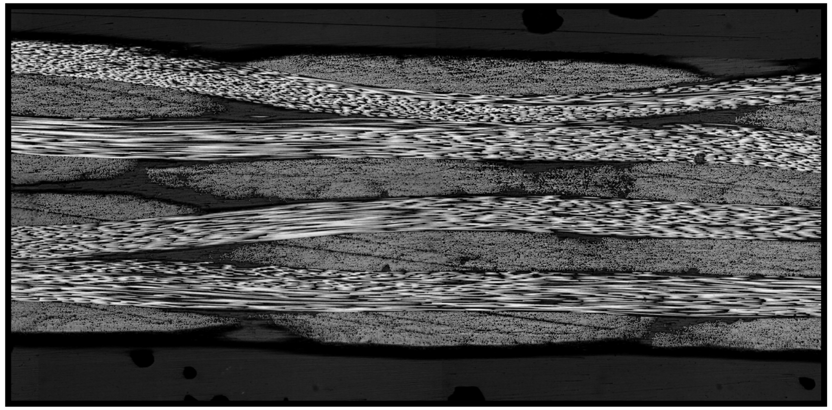
Thickness measurement

$$V_f = \frac{FAW}{\rho_f t}$$

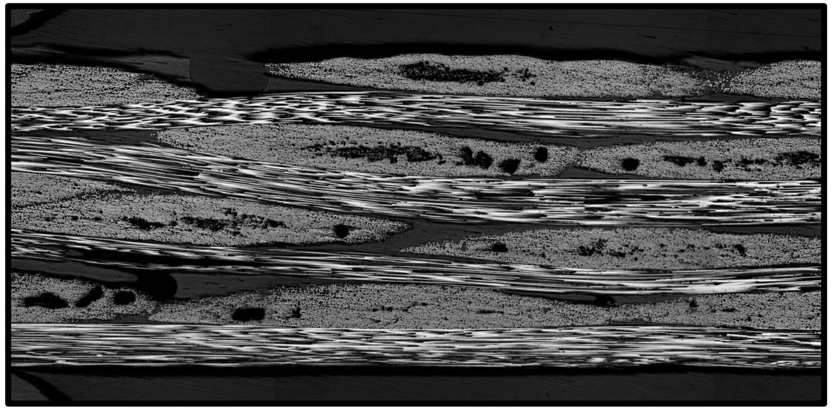
FAW = fibre areal weight
ρ_f = fibre density
t = thickness

PROCESS CHARACTERIZATION - CONSOLIDATION

- Microscopy can be used to inspect and characterize porosity



Example of low/no porosity



Example of moderate porosity

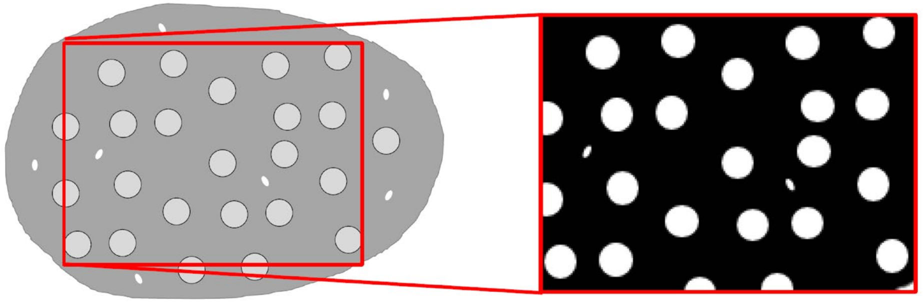
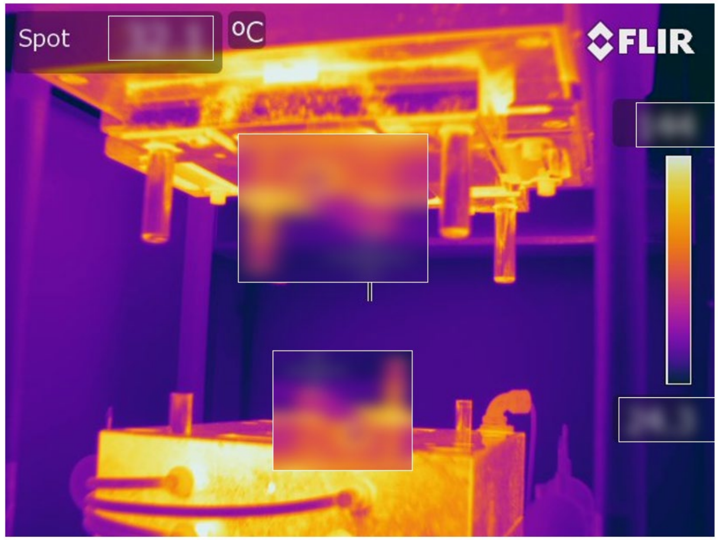
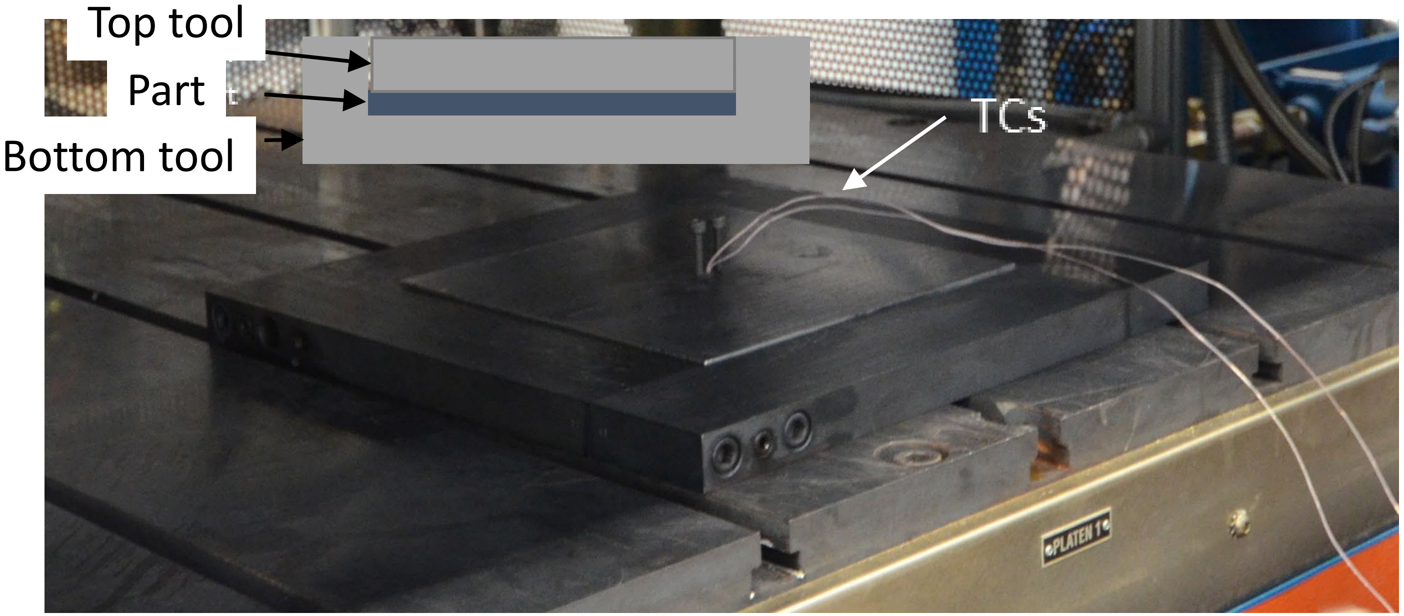


Image analysis for measuring porosity

PROCESS CHARACTERIZATION – PROCESSING TEMPERATURE

- Measure mould and part during processing
- Common methods:
  - Thermocouples
  - Infrared (IR) camera





Tool and part in hot press

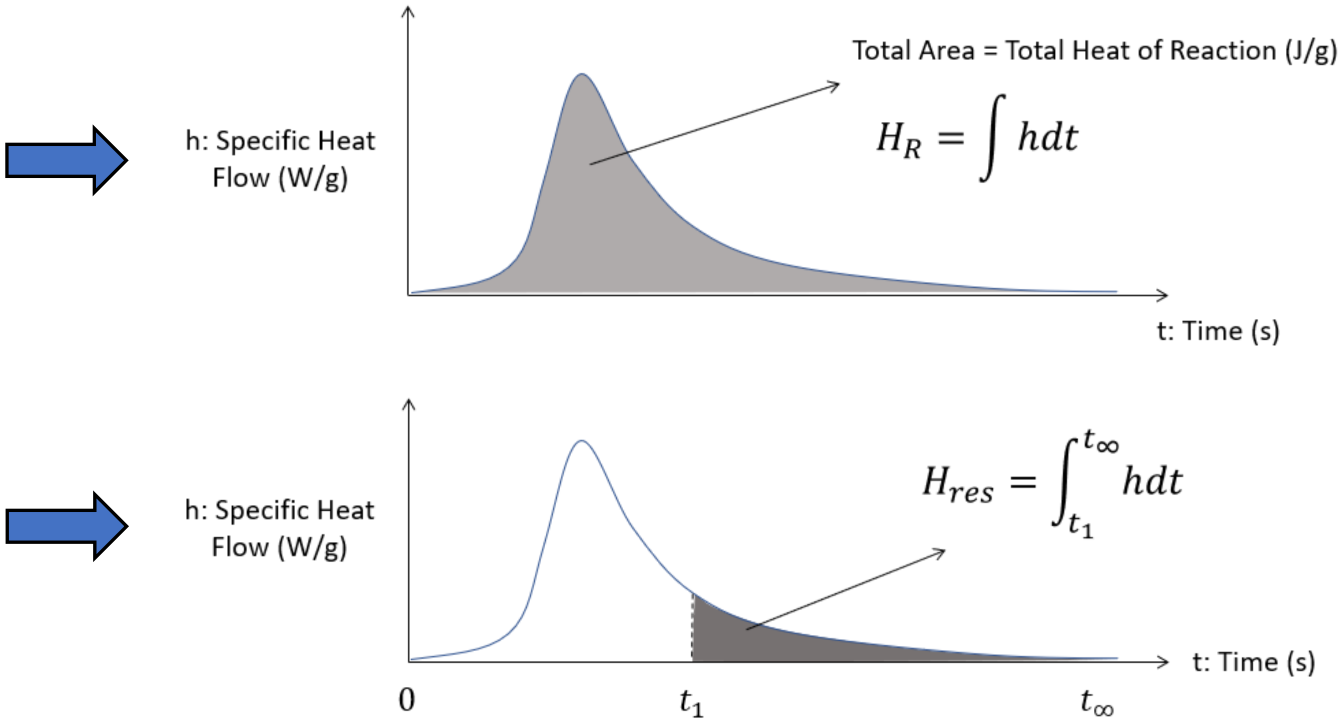
PROCESS CHARACTERIZATION – PART DOC

- How do we measure the DOC of a part?

DSC Instrument

Raw Material

Processed Part



$$\alpha = 1 - \frac{H_{res}}{H_R}$$

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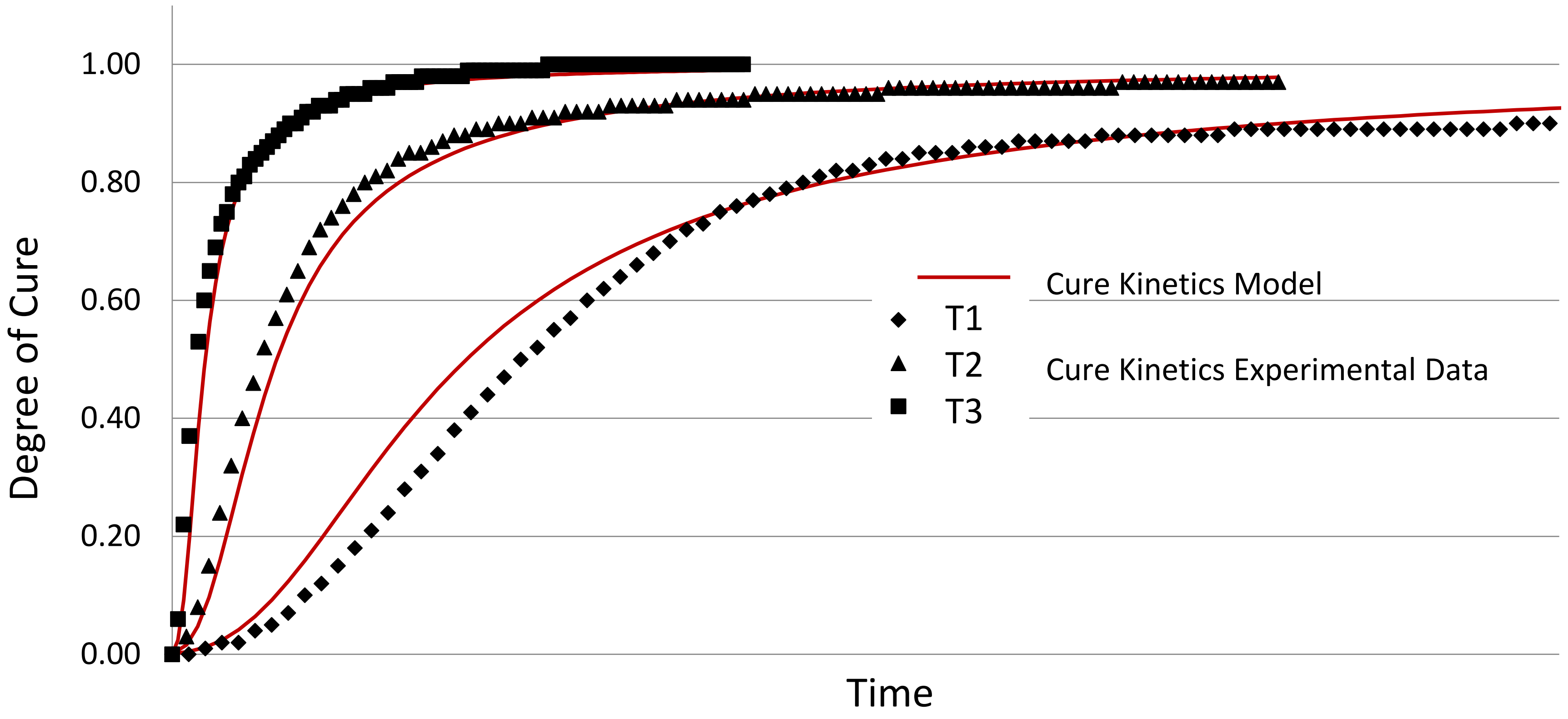
MODEL VALIDATION – CONFIRM EXPECTED DOC

- Measure DOC and compare to simulation



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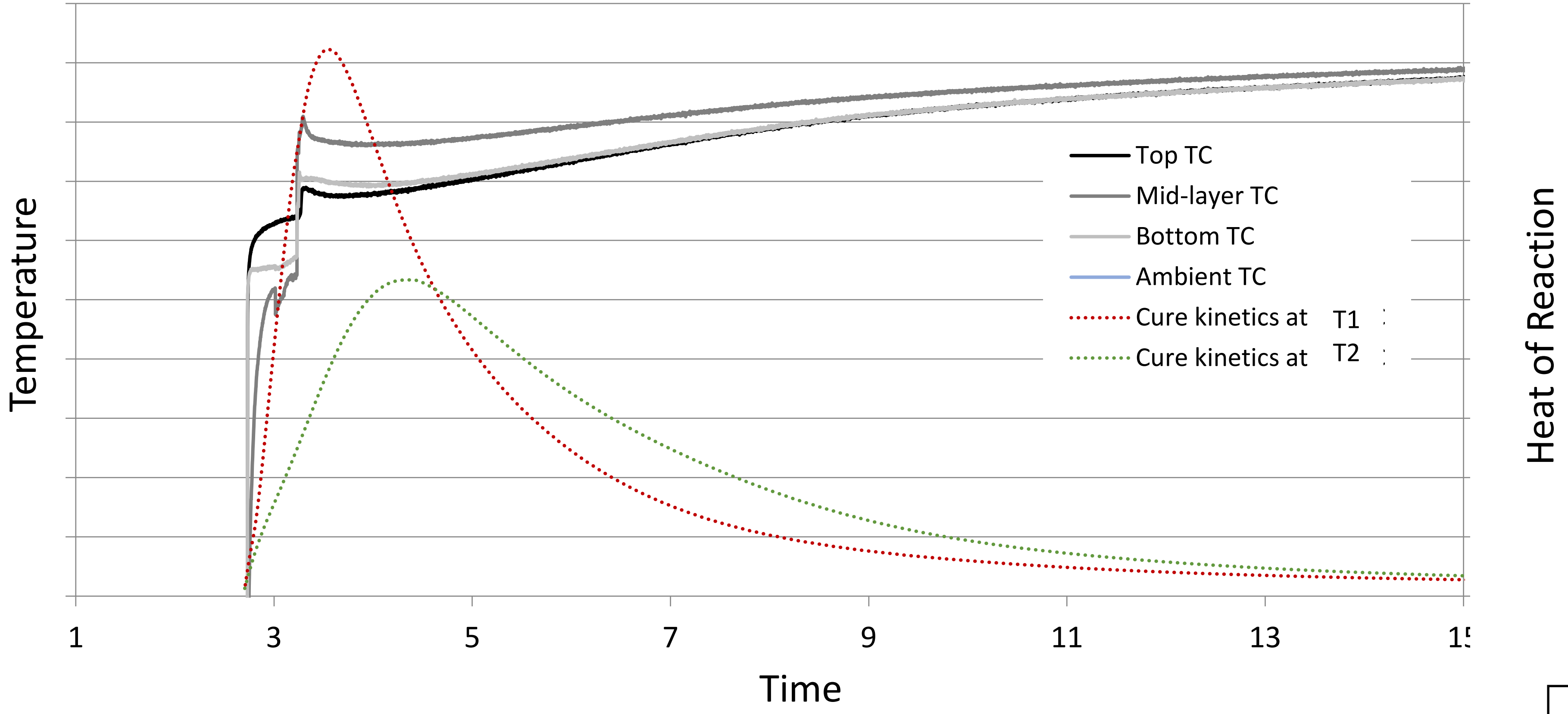
MODEL VALIDATION – SIMULATE EXISTING PROCESS

- Now that we know the cure kinetics and part/material temperature during the process we can simulate it



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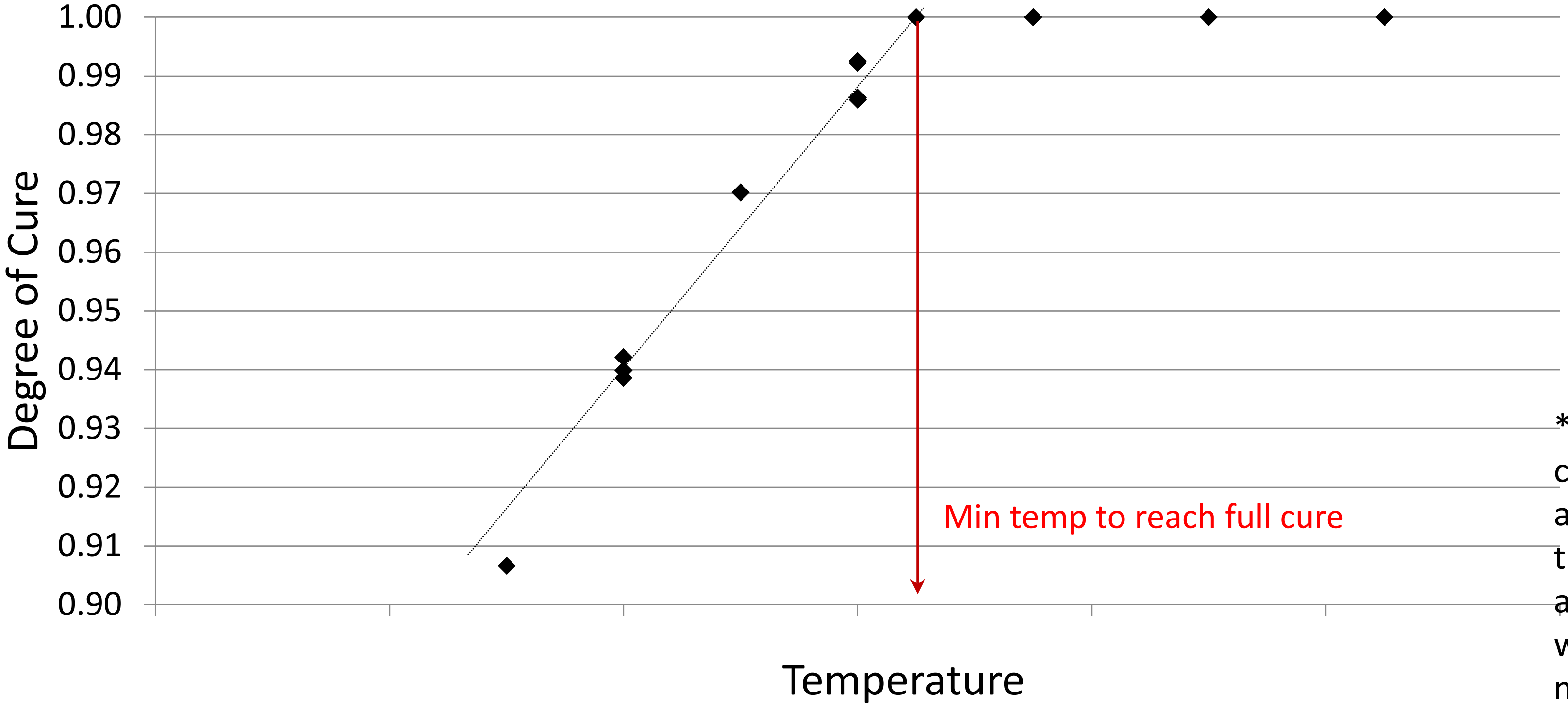
PROCESS OPTIMIZATION – CURE OPTIMIZATION

- Use simulation to ‘optimize’ the process
- Objective: minimize time in press by adjusting parameters within existing press capabilities



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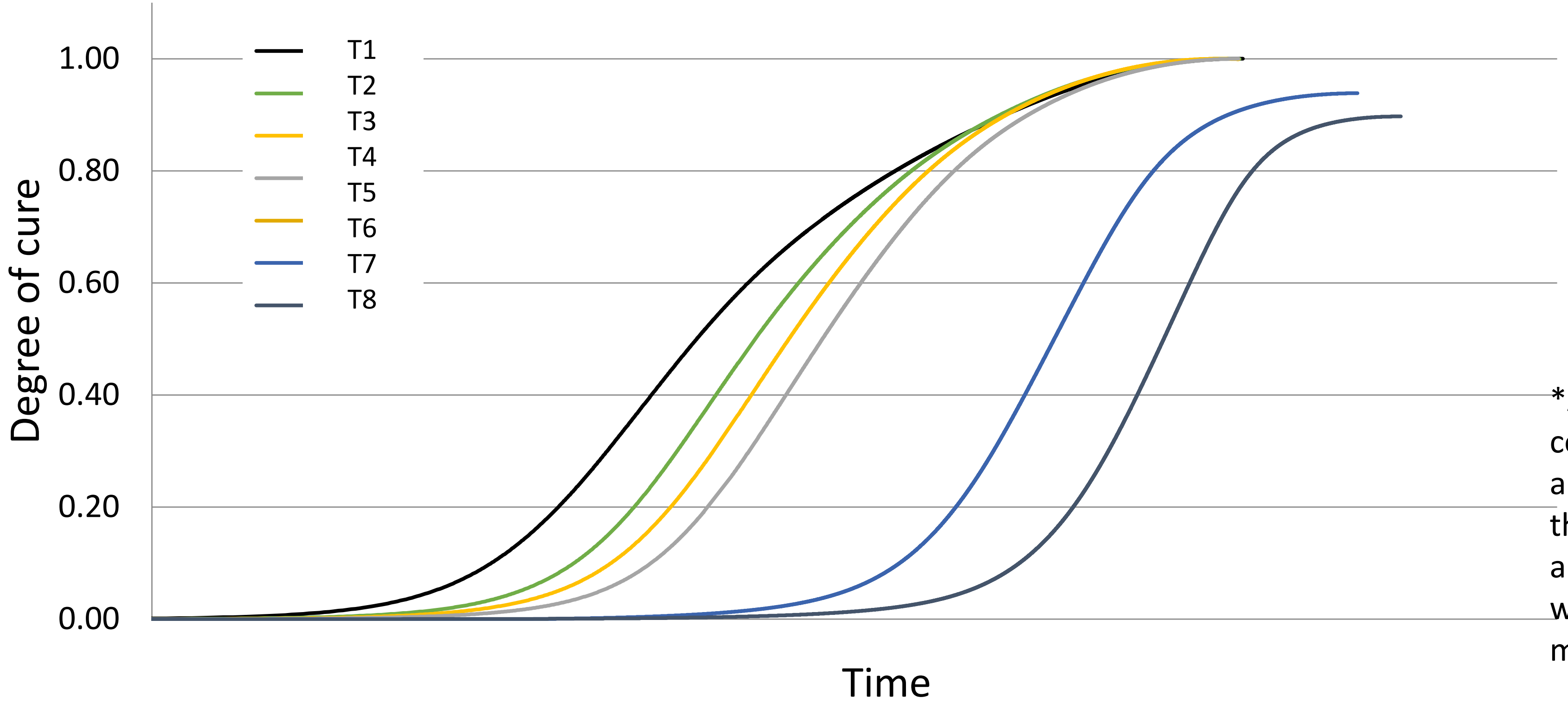

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PROCESS OPTIMIZATION – POST-CURE OPTIMIZATION

- What if we don't need to fully cure the part in the press?
- Approach:
  - Cure the part in the press enough that it can be demoulded
  - Batch post cure in a (lower cost) oven afterwards

Press Only		
Sample	Mold Temperature (°C)	Cure Cycle Time (min)
2	T1	9
3	T2	9
4	T3	8
5	T4	7

Press With Oven Post Cure				
Sample	Mold Temperature (°C)	Cure Cycle Time (min)	Oven Temperature (°C)	Post-Curing Time (min)
8	T5	2		
7	T6	3	*???*	
6	T7	4		
5	T8	5		

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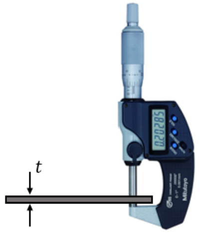
OPTIMIZED PROCESS VALIDATION

- Now that we've got our 'optimized' process, we can run some parts and validate that it is a viable process
- 'Rinse and repeat' some of the previous analysis

Matrix burn-off or digestion
ASTM D3171



Thickness measurement

$$V_f = \frac{FAW}{\rho_f t}$$

FAW = fibre areal weight
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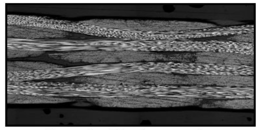
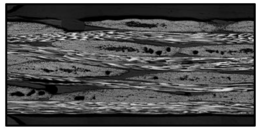
t = thickness

Measure Vf



Example of low/no porosity



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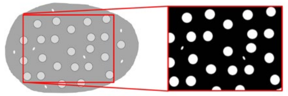
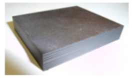


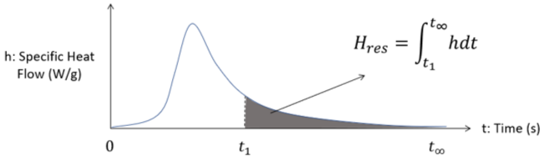
Image analysis for measuring porosity

Inspect Porosity

Consolidation



Processed Part

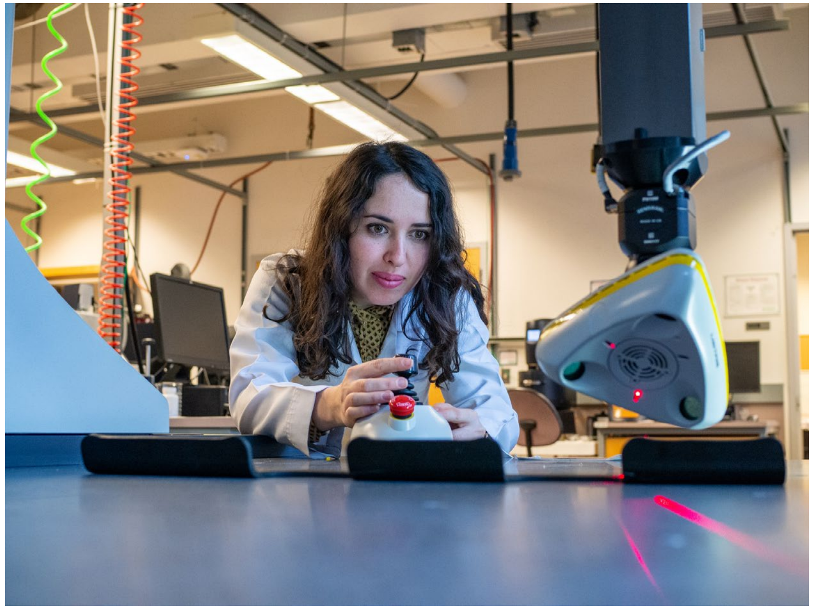


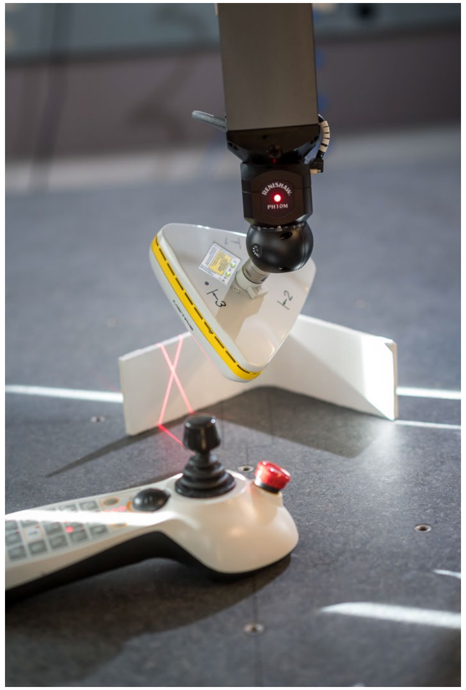
$$\alpha = 1 - \frac{H_{res}}{H_R}$$

Degree of Cure

OPTIMIZED PROCESS VALIDATION - DIMENSION

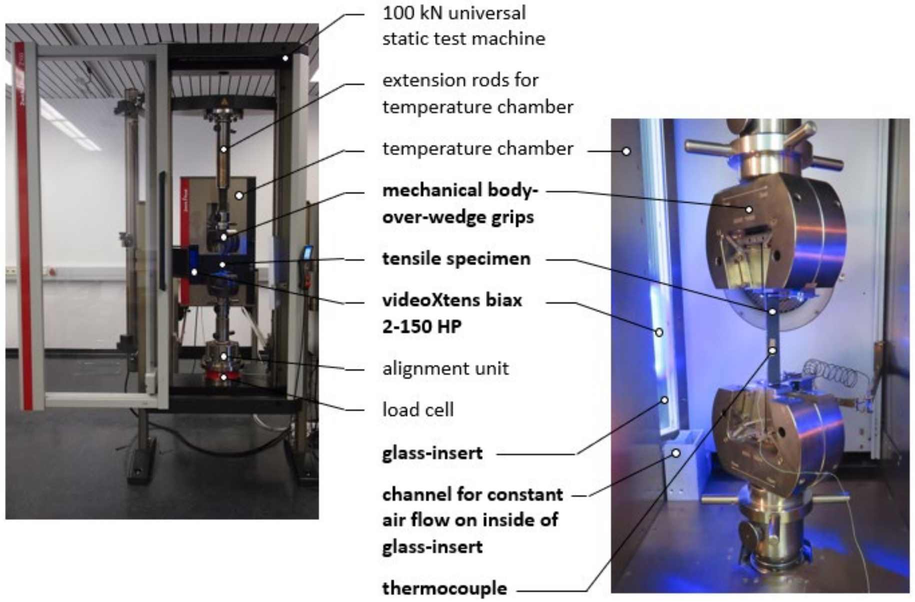
- Ensure that dimensional specifications are still met
  - Residual stress and dimensional control management: A165
- Coordinate measuring machine (CMM) commonly used



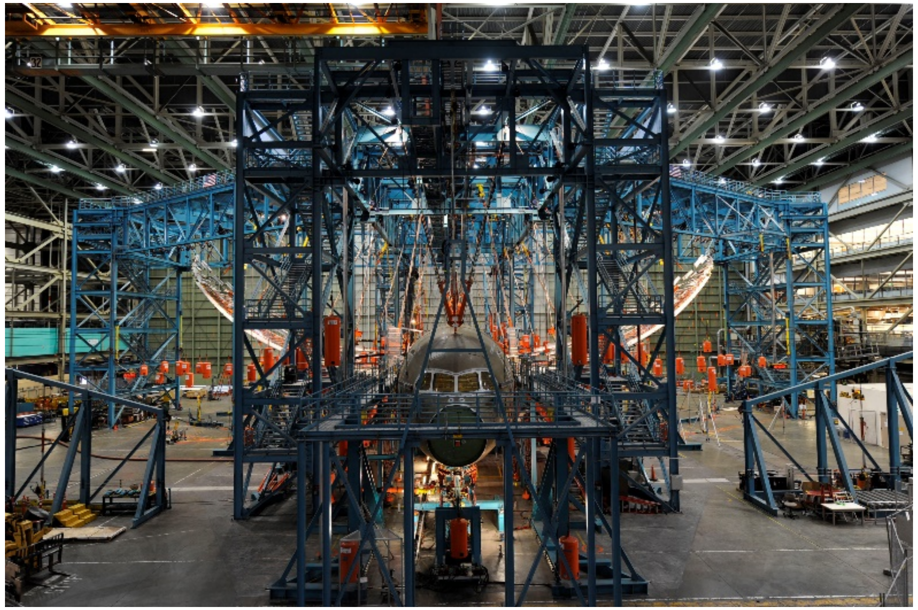


OPTIMIZED PROCESS VALIDATION – MECHANICAL PROPERTIES

- Ensure mechanical performance is met
- Mechanical component testing
  - AIM Event on testing: A131
  - AIM Event on effect of cure – Part I, Part II: A319, A320



Coupon testing

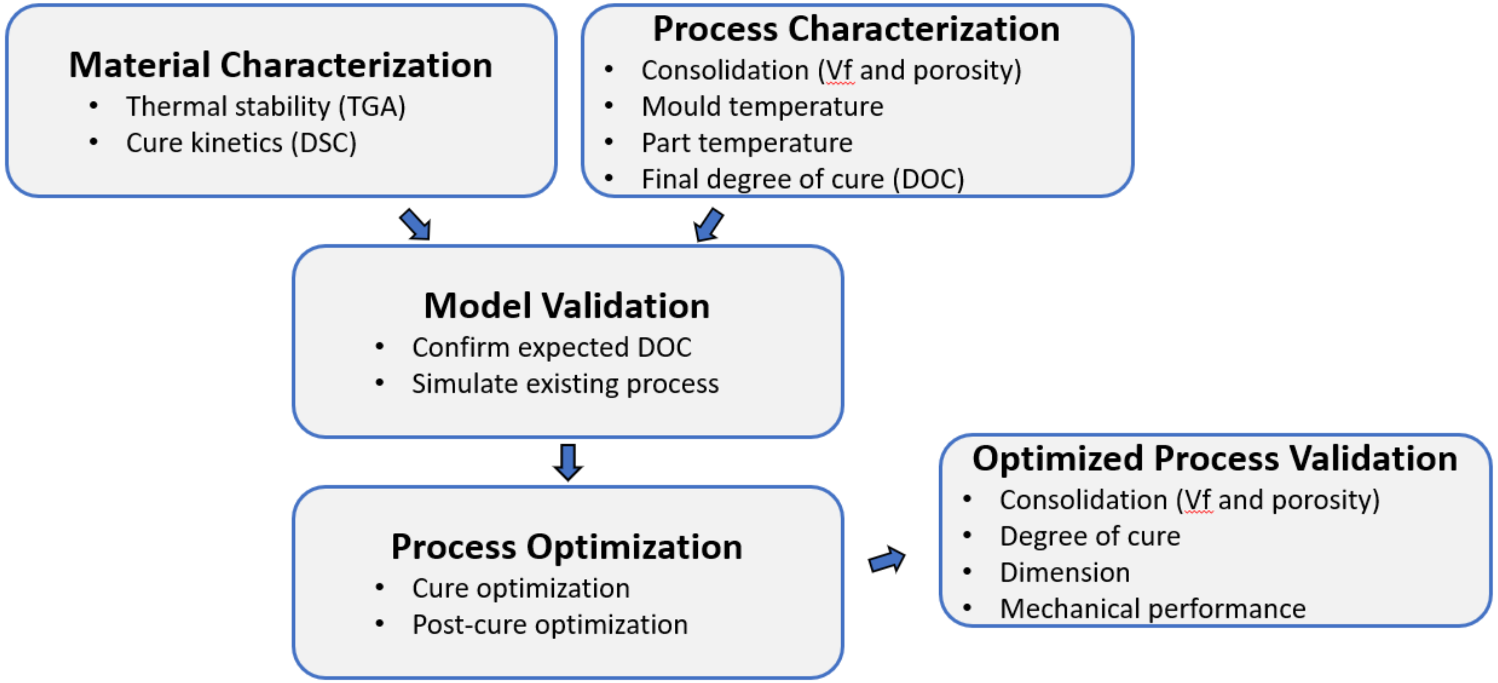


Component testing[1]

[1] https://www.wired.com/images_blogs/autopia/2010/03/index.jpg

RECAP AND CONCLUSIONS

- Systematic approach to improving on existing press moulding process
  - Not the only way to do it, other tools/techniques can be used



- Lots of background material on information presented here can be found on the KPC: https://compositeskn.org/KPC

Thank you for joining us!

Keep an eye out for upcoming AIM events:

Introduction to Sandwich Structures - Materials and Processing
Hosted by Dr. Casey Keulen
September 28, 2022
https://compositeskn.org/KPC/A327

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/A324