AN INTRODUCTION TO COMPOSITES SUSTAINABILITY

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YOUR HOSTS

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- 2023 holder of the FRQNT B3X postdoctoral award
- Ph.D. & B.Eng. in Mechanical Engineering from McGill University
- 10 years of experience in composites manufacturing and sustainability
- Research website: www.smithcomposites.com
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

Knowledge in Practice Centre (KPC)

Knowledge
- Introduction to composites
- Foundational Knowledge
- Systems Knowledge
- Systems Catalogue
- Practice
- Case Studies
- Perspectives

Practice

https://compositeskn.org/KPC/A1
PAST WEBINAR RECORDINGS AVAILABLE

Today’s Webinar will be posted at:
https://compositeskn.org/KPC/A339
TODAY’S Topic:

An Introduction to Composites Sustainability
PERCEPTION vs. REALITY
PERCEPTION vs. REALITY
WHAT IS

LINEAR ECONOMY

EXTRATION MANUFACTURING DISTRIBUTION USE

OVERCONSUMPTION OF RESOURCES

WASTE & POLLUTION

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WHAT COULD BE

2.1 INTENSIFY PRODUCT USE
- Sharing economy
- Short term renting

2.2 EXTEND THE LIFE OF PRODUCTS AND COMPONENTS
- Maintenance and repair
- Donating and reselling
- Refurbishing
- Performance economy

2.3 GIVE RESOURCES A NEW LIFE
- Industrial ecology
- Recycling and composting
- Energy recovery

CIRCULAR ECONOMY

1. RETHINK
REDUCE RESOURCE CONSUMPTION AND PRESERVE ECOSYSTEMS
- Ecodesign
- Responsible consumption and procurement
- Process optimization

EXTRACTION > MANUFACTURING > DISTRIBUTION > USE

Resources → Components → Products

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AN INTRODUCTION TO COMPOSITES SUSTAINABILITY

STEPS TOWARD CIRCULARITY - RETHINK

Rethink

Process Focused

- Material Waste
- Energy Consumption
- Emissions & Pollution

Product Focused

- Service Life
- Repairability
- Recyclability

MSTE Manufacturing Process Flow

Material

Energy Consumption

Service Life

Repairability

Recyclability

Equipment

Shape

Process

Tooling & Consumables

https://compositeskn.org/KPC/A208
STEPS TOWARD CIRCULARITY - RETHINK

Vacuum Bag Only Out-of-Autoclave Manufacturing

Resin-rich area(s)  Dry fibre tow  Interlaminar void

Micro-CT image courtesy of McGill MECH 544 Course Notes – 2015. Pascal Hubert

Material Waste  Energy Consumption

Waste  Consumed Energy  Emissions & Pollution

Waste  Consumed Energy  Emissions & Pollution

Service Life  Repairability  Recyclability

STEPS TOWARD CIRCULARITY - RETHINK

Rethink

Process Focused

Product Focused

Material Waste  Energy Consumption

Waste  Consumed Energy  Emissions & Pollution

Service Life  Repairability  Recyclability

Recyclability
AN INTRODUCTION TO COMPOSITES SUSTAINABILITY

STEPS TOWARD CIRCULARITY - RETHINK

Rethink

<table>
<thead>
<tr>
<th>Process Focused</th>
<th>Product Focused</th>
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<tr>
<td>Material Waste</td>
<td>Energy Consumption</td>
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<td>Emissions &amp; Pollution</td>
<td>Service Life</td>
</tr>
<tr>
<td>Repairability</td>
<td>Recyclability</td>
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</tbody>
</table>

Thermoplastic Matrix Composites

https://www.compositesworld.com/articles/compositeworlds-top-ten-articles-from-our-focus-on-design-column
AN INTRODUCTION TO COMPOSITES SUSTAINABILITY

STEPS TOWARD CIRCULARITY - RETHINK

Rethink

Process Focused

Material Waste

Energy Consumption

Emissions & Pollution

Product Focused

Service Life

Repairability

Recyclability

Process Simulation & Virtual Testing

https://www.imperial.ac.uk/structural-integrity-health-monitoring/research/structural-integrity-and-failure-analysis/virtual-testing/

https://compositeskn.org/KPC/A283
STEPS TOWARD CIRCULARITY - OPTIMIZE

Optimize

Intensify Product Use
- Product Sharing

Extend Product Life
- Repair
- Certification Extension

Resource New Life
- Recycling
- Energy Recovery
COMPOSITE WASTE TYPES

- Reinforcement
- Composite Structure
  - Sandwich Core
  - Polymer Matrix

AN INTRODUCTION TO COMPOSITES SUSTAINABILITY
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COMPOSITE WASTE TYPES

**Pre-Manufacturing**
- Prepreg Edge Trim
- Prepreg Rejects (Quality)
- Consolidated Plate Offcuts
- Resin Batch End
- Etc.

**Manufacturing**
- Textile Offcuts
- Part Trim/Rejects
- Expired Thermosets
- Core Offcuts
- Etc.

**End-of-Life**
- Wind Turbine Blades
- Decommissioned Aircraft
- Boats
- Composite Tooling
- Etc.
OPTIMIZE – RESOURCE NEW LIFE

Recycling
- Fibre Reclamation
- Mechanical Transformation
- Other

Re-Manufacturing
- Liquid Composite Moulding
- Wet-Layup
- Compression/Injection Moulding
- (Semi)Direct Reuse
- Filler/Feedstock
- Reforming (Thermoplastic)
Optimize – Resource New Life

**Recycling**
- Fibre Reclamation
- Mechanical Transformation
- Other

**Recycled Product**

**Re-Manufacturing**
- Liquid Composite Moulding
- Wet-Layup
- Compression/Injection Moulding
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- Filler/Feedstock
- Reforming (Thermoplastic)
RECYCLING – FIBRE RECLAMATION

Objective
Separate reinforcing fibre from polymer matrix, while maintaining fibre length

Challenge
Separate the unseparable!

N. Krumenacker PhD, McGill (2018)
MEC786 Course Notes, ÉTS (2023)
RECYCLING – FIBRE RECLAMATION

- Carbon fibre (807 GJ/tonne) vs. Steel (13.63 GJ/tonne)
- 62,000 tonnes of carbon fibre present in composite waste estimated in 2020

A.W. Smith, PhD, McGill (2021)
Liddell et al. (2017), Jamison et al. (2015), Witik et al. (2013)
RECYCLING – FIBRE RECLAMATION

• 53,094 TJ – enough to power **50,000** Tesla Model 3s for **100 years** (EV Database).

FIBRE RECLAMATION – PYROLYSIS

• Thermal decomposition of polymer matrix in the absence of oxygen (250 – 800 °C)
• Products include, solid, liquid and gaseous phases

https://www.youtube.com/watch?v=-ZQzfwdHf1I&ab_channel=VDizentrumRessourceneffizienz
3:30 to 5:45

Cooney and Wiles 1989
FIBRE RECLAMATION – PYROLYSIS

- Thermal decomposition of polymer matrix in the absence of oxygen (250 – 800 °C)
- Products include, solid, liquid and gaseous phases

Clean fibre
Char residue from polymer decomposition

FIBRE RECLAMATION – FLUIDISED BED

• Thermal-oxidative decomposition of polymer matrix (450 – 550 °C)
• Material sorting by elutriation and subsequent cyclone
• Developed at the University of Nottingham for continuous operation

Fig. 7. Fibre product recovered from SMC feed.

FIBRE RECLAMATION – FLUIDISED BED

- Thermal-oxidative decomposition of polymer matrix (450 – 550 °C)
- Material sorting by elutriation and subsequent cyclone
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Fig. 13. SEM of veil containing reclaimed fibres.

FIBRE RECLAMATION – SOLVOLYSIS

- Chemical decomposition of polymer matrix into low molecular weight components
- Solvents used include benzylalcohol, formic acid, acetone, water, etc.
- Reaction rate accelerated by agitation and temp-pressure manipulation

From: High performance recycled CFRP composites based on reused carbon fabrics through sustainable mild solvolysis route

Illustration of separated CF layers after partial immersion in formic acid.
• Environmental concerns
• Scaling challenges
• Supercritical water possible « green » alternative
  • 22.1 – 35 MPa
  • 400 – 650 °C

Eckert et al., (1996)
Morin et al. (2013). https://hal.science/hal-00695025
MECHANICAL TRANSFORMATION

Objective
Reduce solid waste size via mechanical action to produce uniform recyclate(s)

Challenges
Health & safety, fibre damage, sorting & dismantling

Fibre Rich  Resin Rich

[Images of mechanical equipment and raw materials]
OTHER – ELECTRODYNAMIC FRAGMENTATION

- Rapid breakdown of the fibre-matrix interface due to high voltage micro pulses


OTHER – (RE)CERTIFICATION

- Re-life procedure for expired thermoset prepreg rolls
- Prepreg patching and ultrasonic scanning

OTHER – CHEMORHEOLOGY MANIPULATION

• Changing the curing and flow behaviour of prepreg offcuts
• Create a strand-based compression moulding compound
AN INTRODUCTION TO COMPOSITES SUSTAINABILITY

RECYLING-WASTE MAP

- Technical Difficulty
- Contamination
- Energy Required
- Cost

Waste Volume

Recycling Difficulty

(Pre)Manufacturing

- Tooling
- Testing Specimens
- Part Trimmings
- Uncured Prepreg Offcuts
- Thermoplastic Prepreg Waste
- Expired Prepreg Rolls

Dry fibre offcuts

Thermoplastic

End-of-Life

Wind Turbine Blades

Infrastructure

Boats

Cars

Aircraft

Sports Equipment

Thermoplastics

Thermosets
OPTIMIZE – RESOURCE NEW LIFE

Recycling
- Fibre Reclamation
- Mechanical Transformation
- Other

Recycled Product

Re-Manufacturing
- Liquid Composite Moulding
- Wet-Layup
- Compression/Injection Moulding
- (Semi)Direct Reuse
- Filler/Feedstock
- Reforming (Thermoplastic)
RE-MANUFACTURING – FIBRE RECLAMATION

Reinforcement + Matrix (Polymer) = Combined Composite

https://compositeskn.org/KPC/A215
RE-MANUFACTURING – FIBRE RECLAMATION

Reclaimed Reinforcement (Mat/Discontinuous) + Matrix & Sizing (Optional) = Recycled Composite

- Vacuum Bag (Oven/Autoclave)
- Infusion
- Compression Moulding

https://compositeskn.org/KPC/A215
RE-MANUFACTURING – MECHANICAL TRANSFORMATION

REFORMING (THERMOPLASTICS)
LEARNING OUTCOMES

✓ Expanded view of sustainability and the impact of early decision making « RETHINK »
✓ Different waste types and characteristics
✓ Summary knowledge of composites recycling and re-manufacturing techniques
✓ Appreciation for the complexity of sustainability – one size does not fit all
ADDITIONAL REFERENCES

- Slide 6
  - https://www.nasa.gov/topics/moonmars/features/ccm.html
  - https://www.compositesworld.com/articles/composites-end-markets-pressure-vessels-2023
  - https://www.pinterest.ch/pin/468726273696529748/

- Slide 7
  - https://www.reinforcedplastics.com/content/features/recycling-composites-commercially-part-1

- Slide 16
  - https://cen.acs.org/environment/recycling/companies-recycle-wind-turbine-blades/100/i27
  - https://breton.it/products/technologies/ultrasonic-cutting

- Slide 29
  - CaronteFX
  - Thermoplastic Composites Research Center (https://tprc.nl/)
  - Changzhou Doing Machine Co.
Thank you for joining us!

Keep an eye out for upcoming AIM events:

*Introduction to Tooling for Composite Materials Processing*
*Hosted by Dr. Casey Keulen*
*September 27, 2023*
[https://compositeskn.org/KPC/A340](https://compositeskn.org/KPC/A340)

And don’t forget to visit the KPC for more information:
[https://compositeskn.org/KPC](https://compositeskn.org/KPC)

*Today’s Webinar will be posted at:*
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