Science 4 Technology – Poster Exhibition 2024

Department Polymer Engineering and Science

Chair of Composites and Design of Recycling

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Poster Exhibition 2024

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Compaction behaviour of textile reinforcements

Novel test-rig design and analysis of influencing factors

Starting point

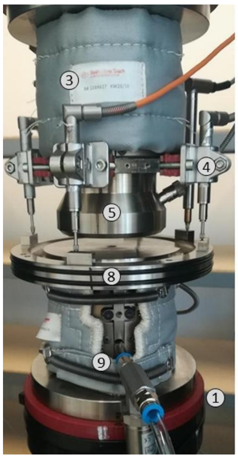
- Fibre reinforced composites are highly efficient, but expensive to manufacture and energy intensive
- To reduce waste and CO_2 emissions during production, we need to understand the material behaviour
- Available test methods do not mirror the most common manufacturing processes

Goal

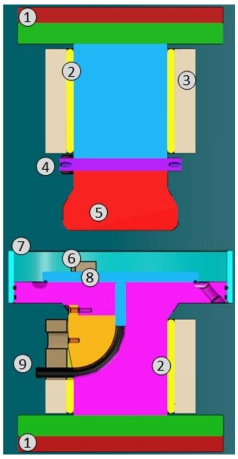
- Design a novel test-rig to match most common manufacturing processes (RTM, VARI)
- Develop a test method that saves time and materials
- Analyse the influence of:
    - Test fluid
    - Textile structure
    - Temperature and binder content

Test-rig design

- Lab-scale design integrated in UTM
- Easy all around access for specimen manipulation
- Active heating of test area up to 250 °C
- Combined test for dry and wet characterization
- Optional injection of fluids allows for in-situ impregnation of material samples

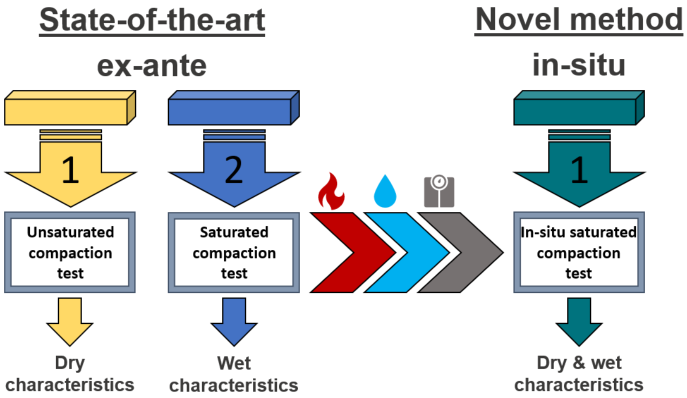


1) Insulation plate
2) Heating band
3) Insulation sleeve
4) 5 LVDTs
5) Stamp
6) Cover plate
7) Fluid barrier
8) Base plate
9) Fluid line



Test method development

- 50% reduced material consumption
- Reduced work load through high degree of automation



State-of-the-art

ex-ante

Novel method

in-situ

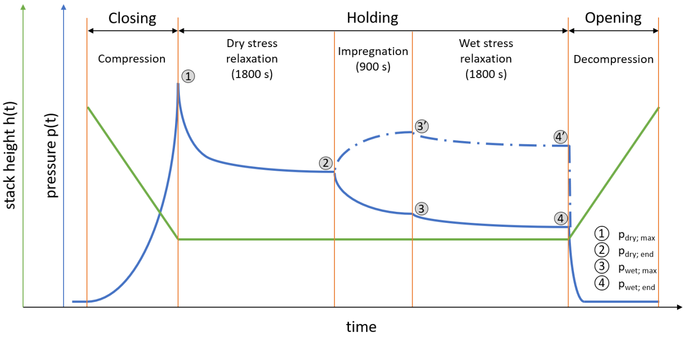
1 **Unsaturated compaction test** → **Dry characteristics**

2 **Saturated compaction test** → **Wet characteristics**

1 **In-situ saturated compaction test** → **Dry & wet characteristics**

	ex-ante		in-situ
$p_{dry; max}$	✓	–	✓
$p_{dry; end}$	✓	–	✓
$p_{wet; max}$	–	✓	×
$p_{wet; end}$	–	✓	✓

- Schematic result of stress relaxation during in-situ test



Future work

- Analyse the influence of
    - Temperature and binder content
- Develop material model for in-line process control

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Composite manufacturing processes (RTM, VARI)

Thesis topic:
Transversal compaction behaviour of textile reinforcements

With support from:
TEIJIN

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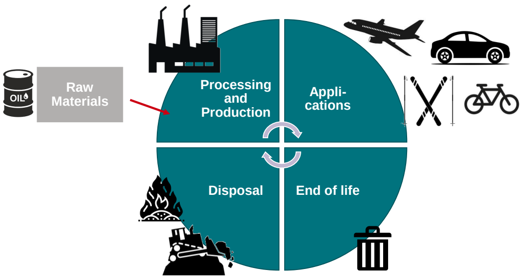
Bio-based Composites in Circular Economy

QB3R - Quality assured manufactured high-performance components based on 100% **b**io-based **r**aw materials with high **r**epair and **r**ecycling potential

Composites and their challenges

- Composites exhibit low weight to high strength and stiffness ratio
- Energy intensive manufacturing causes high environmental impact
- Thermoset polymer matrix impedes recycling



How to improve Sustainability and material circularity ?

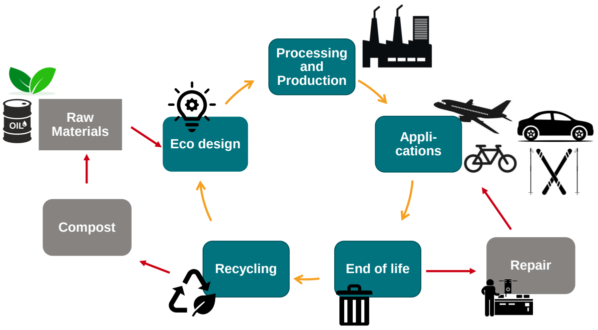
- Substituting conventional materials by materials from renewable resources

Synthetic fiber → Natural fiber

Fossil based polymer → Bio-based polymer

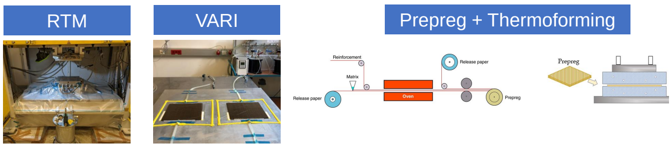
- Integrating vitrimeric functionality contributes to material circularity such as repair and recycle.

Objective: Advancing circularity and sustainability by using renewable resources and considering R-strategies
1) smarter product, manufacture/processing (rethink),
2) life extension strategies (repair), and
3) creative material application (recycle).



Processing

- Processing of natural fiber and bio-based matrix are intricate.
- Processing focus on aspects such as manufacturing technique, methodology and material properties

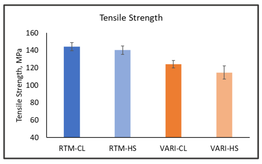


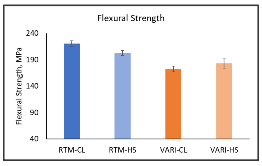
Preliminary results:
Processing of bio-epoxy

Manufacturing technique
RTM and VARI

Configuration

CL - 60° C at 180 mins
HS - 100° C at 30 mins

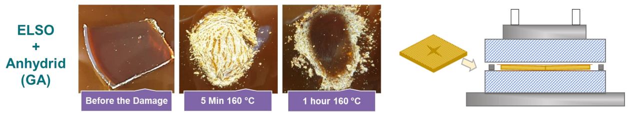




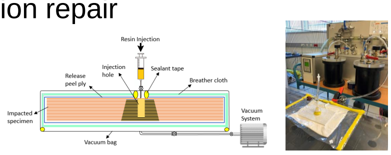
Repair

- Developing cost-effective repair strategies for restoring damaged bio-based composites are crucial:

Self healing (Vitrimeric function) repair

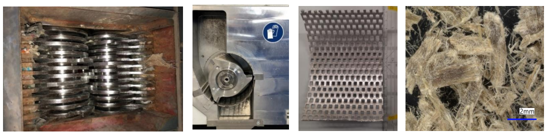


Reinfiltration repair



Recycling

- Surplus / Eol bio-based composites are recycled and integrated into a different composite component by means of eco design i.e. sandwich composite.



Material circularity within bio-based composites uphold sustainability and reduce environmental impact

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Research Focus:

Bio-based Composite; Processing; Repair; Recycle

Funding

Project QB3R (project no. FO999889818) provided by the Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology within the frame of the FTI initiative "Kreislaufwirtschaft 2021", which is administered by the Austria Research Promotion Agency (FFG)

Project Partners:

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Potential contribution of bio-based materials to climate protection?

Discussion using the example of fiber-reinforced polymer composites

Fiber-reinforced polymer (FRP) composites and their environmental challenges

- *High-performance materials in various applications*
- *In terms of sustainability, several challenges:*
  - Based on fossil resources
  - Limited recyclability of the material
  - Processing and manufacturing processes
  - Emissions and environmental impacts

Bio-based FRP composites for circular economy

? Actual contribution to climate change? ?

➜ Quantification using Life Cycle Assessment

Methodological parameters

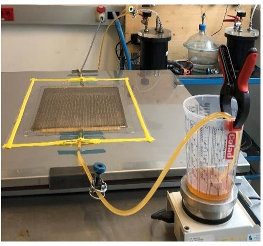
→ ***Goal:*** *compare* **bio-based** *with* **petrochemical** *FRP*

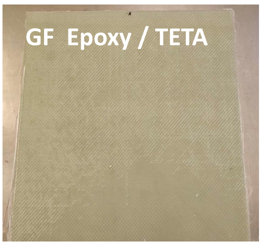
		Bio-based	Petrochemical
Materials	**Textile**	Flax fiber	Glass fiber
	Resin	Epoxidized linseed oil	Epoxy resin (fossil)
	Hardener	Itaconic acid anhydride (IA)	Amine (TETA)
Processing	**Process**	Vacuum assisted resin infusion (VARI)	Vacuum assisted resin infusion (VARI)
	Infusion	7 min @ 80°C	3 min @ 120°C
	Curing	20 h @ 120°C	0.25 h @ 120°C
EoL	**Process**	Incineration with energy recovery	Incineration with energy recovery
	Efficiency	η_{el}: 15 %, η_{th}: 70 %	η_{el}: 15 %, η_{th}: 70 %
	Heating value	23,9 MJ/kg	13,8 MJ/kg

→ ***Functional unit:*** manufactured composite of equivalent geometry → ***equal functionality assumed***

→ ***System boundaries:*** Cradle-to-grave

Materials & VARI process





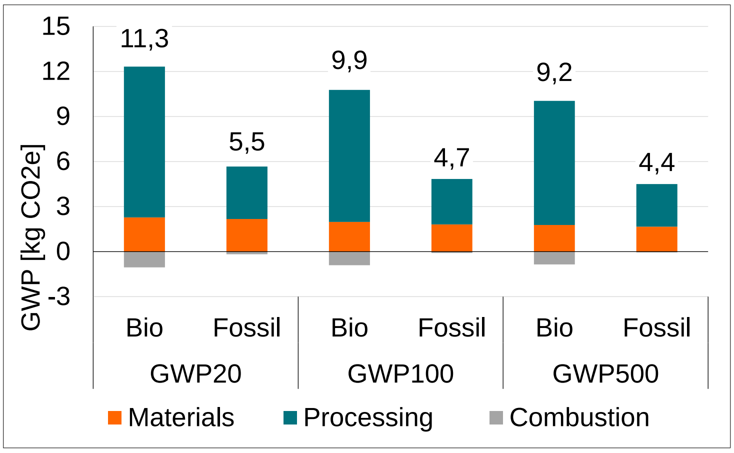
→ ***Inventory data:*** measured, literature, ecoinvent 3.9.1

→ ***LCIA method:*** IPCC 2021 (without SLCF)

→ ***Software:*** OpenLCA v2.0, BrightWay25

→ ***Allocation:*** Economic, cut-off

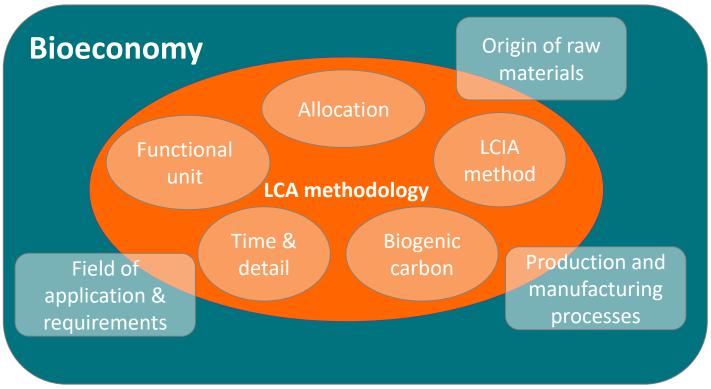
Global warming potential (GWP)



	Bio-composite	Fossil composite
Materials	Often lab scale, non-optimized	Industrial scale, optimized
Processing	Long (>20 h)	Short (< 1h)
	Detailed data from lab experiments	
Incineration	Greater amount, higher calorific value	Glass fibers inert, lower calorific value

Conclusion

Contribution of biogenic materials to climate protection depends on LCA methodological & technical factors



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Research Focus:
Life Cycle Assessment of potential options to decrease environmental impacts associated with fiber-reinforced polymer composites

Funding

Project QB3R (project no. FO999889818) provided by the Austrian Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology within the frame of the FTI initiative “Kreislaufwirtschaft 2021”, which is administered by the Austria Research Promotion Agency (FFG)

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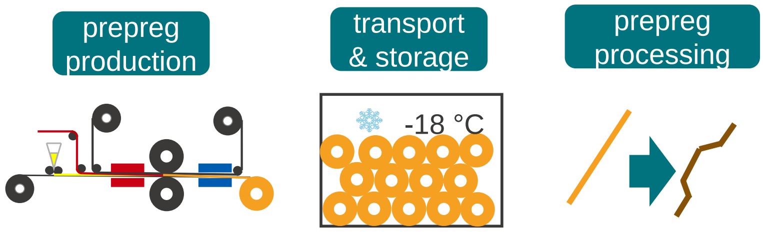
Spectroscopic Analysis of Prepregs (SAPP)

Quality assurance by means of inline monitoring

Project aim: quality assurance and improved process stability along prepreg value chain by inline monitoring using NIRS:



Degree of cure (or related parameters, e.g. T_G)

Mixing ratio

Resin content

Near Infrared Spectroscopy (NIRS):

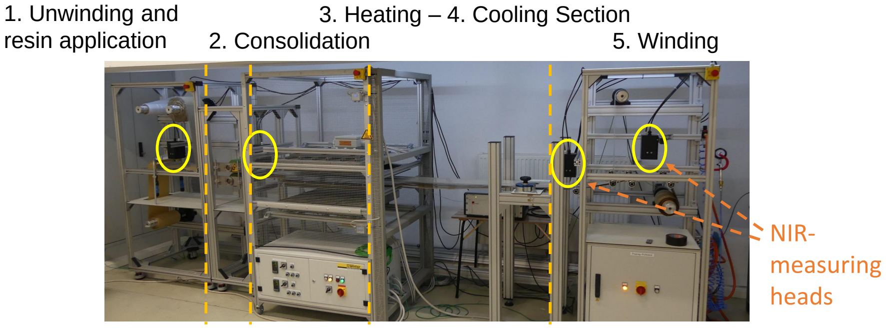
	Visible light	Near-Infrared	Infrared
Wave length λ [nm]	400	780 2500	25.000
Spectroscopy:	UV/Vis-	NIRS-	IR-

NIRS allows for the determination of concentration depending parameters:

- ✚ fast (< 1s)
- ✚ contactless
- ✚ without sample preparation
- ✚ use of optical fibers allow positioning of the spectrometer in a safe environment

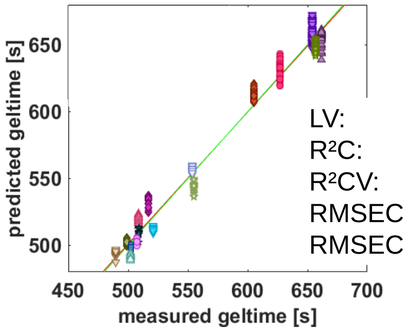
Applications of NIRS in prepreg production

Self constructed prepreg testrig



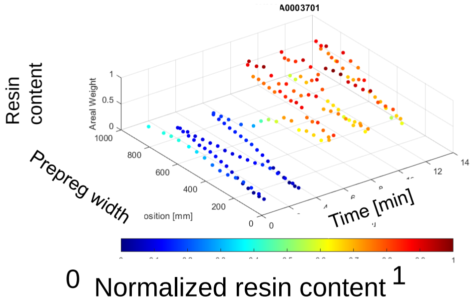
- ➢ Allows full control over all processing parameters and flexible adaption to experimental requirements

Geltime determination by NIRS:



LV: 6
R^2C: 0.991
R^2CV: 0.982
RMSEC: 6 s
RMSECV: 9 s

Resin content during process startup phase:



Project results:

- ➢ NIRS is a powerful technology to monitor various process parameters during prepreg production inline with high accuracy
- ➢ Along the whole value chain of prepregs possible applications for NIRS have been demonstrated using different types of spectrometers

Portrait of the author

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Automated Tape Placement of Carbon-Fiber Reinforced Thermoplastic Tapes

Influence of Flashlamp Heating on Bonding Strength

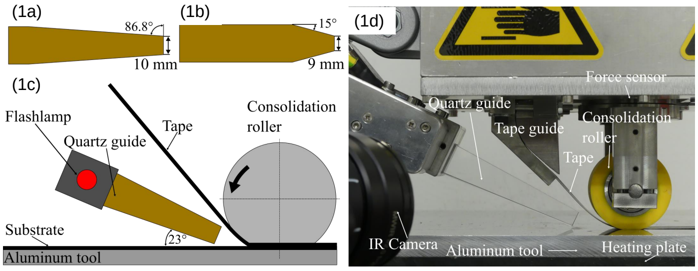
Motivation and Goal

- Automated Tape Placement can be used to manufacture lightweight and high-performance composite structures in a single-step process
- Flashlamp heating systems can bridge the gap between hot-gas-torch and laser heating systems in terms of safety, cost, response time and energy density
- **Goal:** Investigation of the influences of flashlamp heating process parameters on the bonding strength of the composite

Experimental Setup and Methodology

- The energy of the flashlamp system is defined by voltage, pulse width and frequency
- Pulse width and frequency are varied to investigate each parameter influence on the bonding strength
- The influence of moisture is analyzed by comparing dried and non-dried samples (before the placement)
- Thermogravimetric Analysis (TGA) is used to determine the onset of degradation
- Differential Scanning Calorimetry (DSC) is used to study thermophysical properties of the polymer
- The bonding quality is determined by wedge peel tests

Test Rig



(1a) Quartz with one radiating surface (1b) Quartz with three radiating surface (1c) Schematic of the flashlamp system placement within the ATP system (1d) ATP setup used in this study.

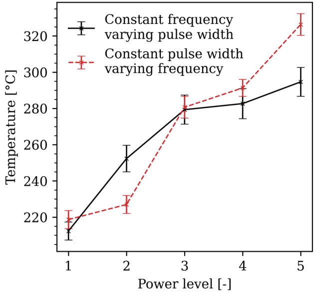
Results

Influence of the quartz guide

- The quartz guide in Figure 1b) accumulates significant amount of matrix from the tape on the chamfered sides, resulting in a reduction in heating and bonding strength

Temperature evolution

- The flashlamp settings with constant pulse width and varying frequency result in higher temperature at higher power levels (Figure 2)



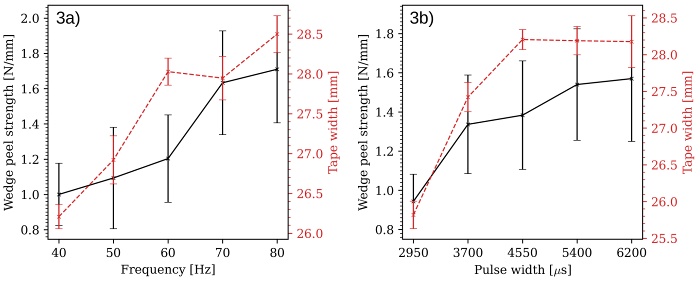
(2) Process temperature for all power levels used in this study for constant frequency with varying pulse width (- curve) and constant pulse width and varying frequency (- - curve)

TGA and DSC tests

- The TGA measurements reveal an onset of degradation at 361.8°C for CF/PA6
- DSC tests indicate no sign of change in the thermophysical properties of the polymer

Peel Strength

- Moisture in the samples can double the peel strength, but affects other mechanical properties negatively
- Higher frequencies while keeping the pulse width constant yield a higher peel strength at higher power levels compared to constant frequency and varying pulse width



(3a) Effects of the frequency on the wedge peels strength and the tape width (3b) Effects of the pulse width on the wedge peels strength and the tape width

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Research focus:

- Automated Tape Placement
- Fiber reinforced composites with carbon and natural fibers and thermoplastic matrix
- Process characterization
- Mechanical testing of fiber reinforced composites