DTU Wind Energy
Section of Composite Materials
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Bio4self - bio-based and biodegradable self-reinforced composites

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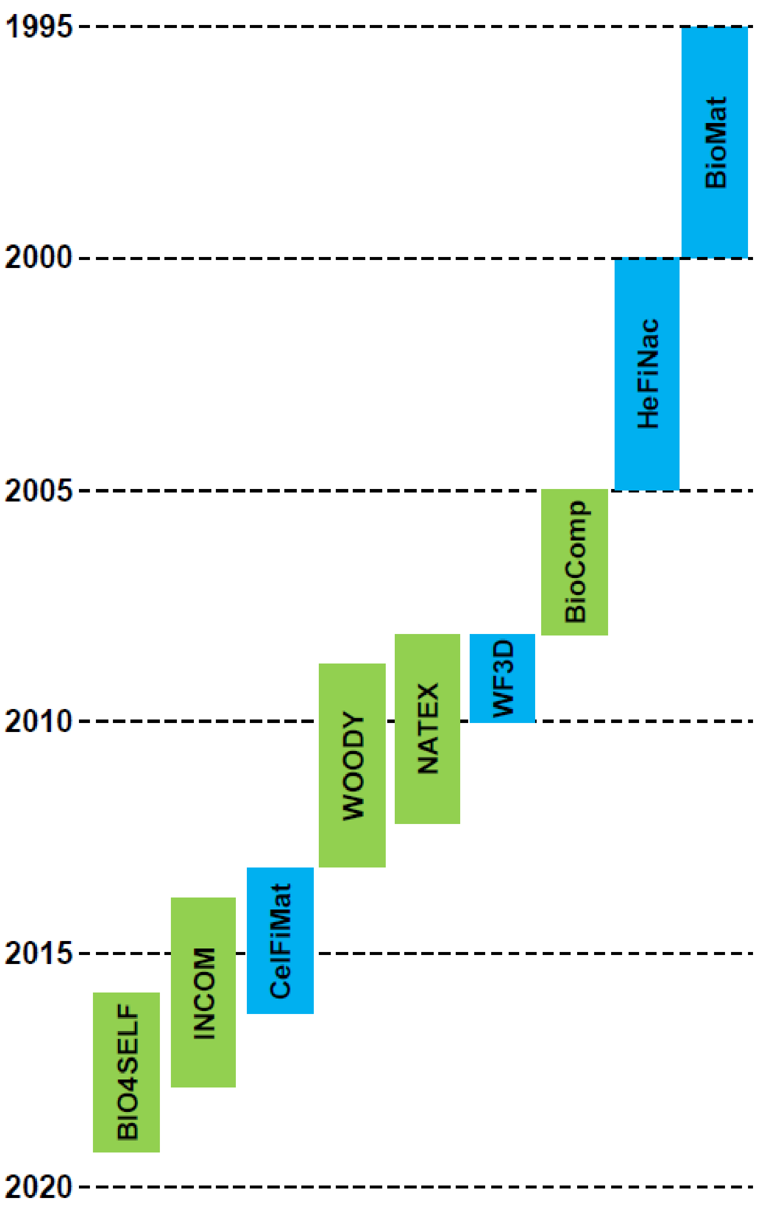
Biocomposite work

at

DTU Wind Energy

- "Characterisation and application of plant fibres for new environmentally friendly products" - **BioMat**
  Danish Research Council. 1995 - 2000
- "High performance hemp fibres and improved fibre network for composites" **HeFiNac**
  Danish Research Council. 2000 - 2005
- "New classes of engineering composite materials from renewable resources" **BioComp**
  EU 6th Framework Programme. 2005 - 2008
- "Structure-property relations of wood fibres: 3D characterisation and modelling" - **WOODFIBRE3D**
  Danish Research Council. 2008 - 2010
- "Natural aligned fibres and textiles for use in structural composite applications" - **NATEX**
  EU 7th Framework Programme. 2008 - 2012
- "Innovative advanced wood based composite materials and components"
  WOODY
  EU 7th Framework Programme. 2009 - 2012
- "High quality cellulosic fibres for strong biocomposite materials"
  CelFiMat
  Danish Research Council . 2013 - 2015
- "Industrial production processes for nanoreinforced composite structures" **INCOM**
  EU 7th Framework Programme. 2013 - 2017
- "Biobased self-functionalised self-reinforced composite materials based on high performance nanofibrillar PLA fibres" – **BIO4SELF**
  EU Horizon2020. 2016 - 2019



Biocomposite work

at

DTU Wind Energy

Bio4self project (EU H2020)

Bio4self aimed at self-reinforced composites, which are:

- ✓**Fully bio-based**
- ✓**Easily recyclable**
- ✓**Reshapable**
- ✓**Industrially biodegradable**

Targeting **structural applications**

Self-reinforced composites are produced using one type of biopolymer: **Poly(lactic acid), PLA**

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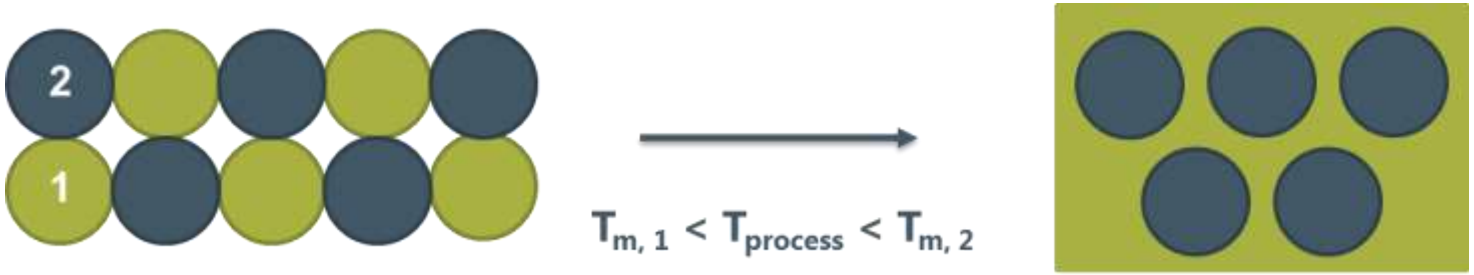
What are self-reinforced composites?

SRPC Self-reinforced polymer composite

SRPCs consist of reinforcement fibres and matrix made of the same material



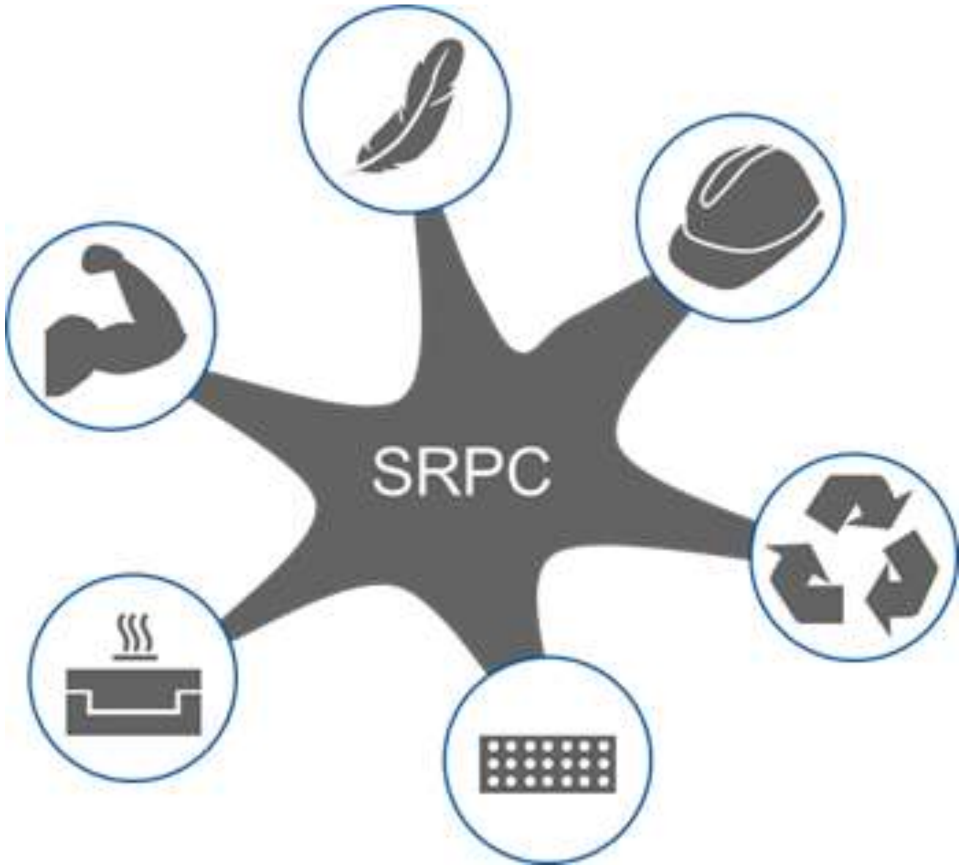
Production of these PLA SRPCs via combination of:

1. a low melting PLA grade
2. a **high stiffness, high melting PLA reinforcing fibre**

Why self-reinforced composites?

SRPCs offer a wide range of advantages

- **Lightweight:** high specific stiffness and strength
- **High impact resistance**
- Environmental friendly material due to **high recyclability** of mono material composite
- Excellent **fibre-matrix adhesion**
- Inherent **thermoformability**



Self-reinforced composites are having potential for a variety of structural applications

Automotive

– Door panels

– Underbody panels

Industrial equipment

– Machine cover

Sporting

– Body armour

– Canoes

Military

– Body armour

Current commercial SRPCs are fossil-based, typically polypropylene e.g. Curv®, Pure®; also polyester (COMFIL)

Bio4self approach

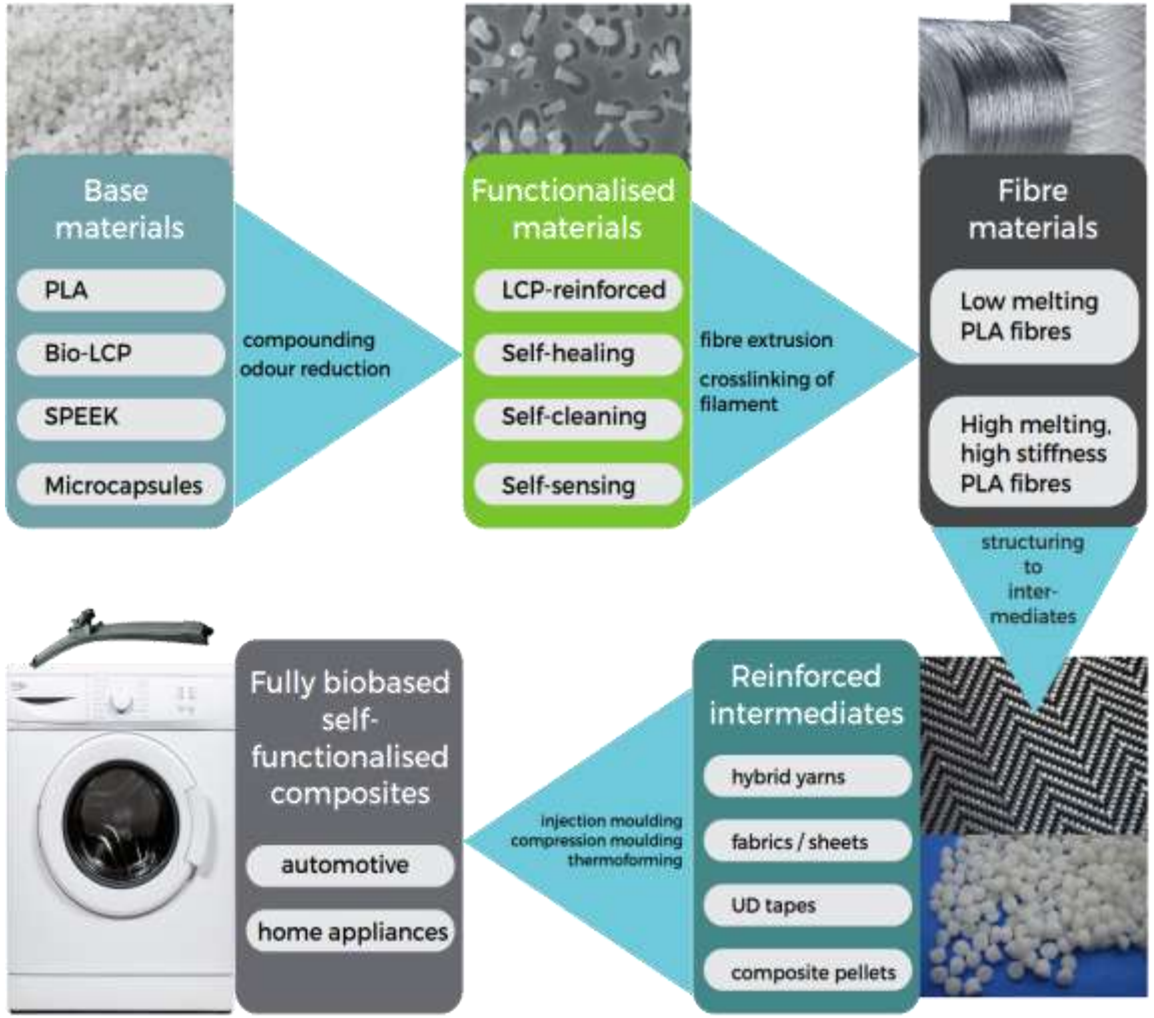
From PLA raw material to PLA self-reinforced composites

Compounds
- Hydrolysis stabilised compounds

Fibres
- High stiffness reinforcement yarns
- Low melting matrix yarns

Textile intermediates
- Hybrid yarns via comingling
- Fabrics

Composite manufacturing & Prototyping
- Filament winding
- Thermoforming



Requirements for self-reinforced PLA composites

Thermoformed suitcase by Samsonite

Materials requirements:

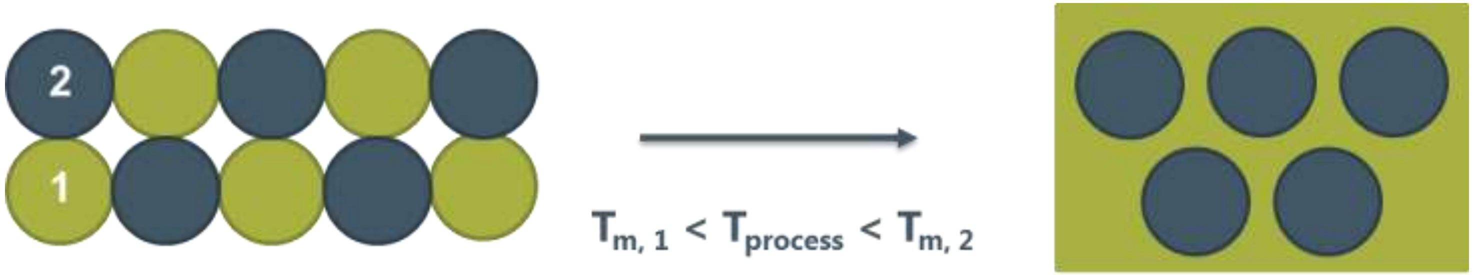
- Low weight – Area weight < 1500 g/m^2
- Stiffness / Tensile modulus ≥ 3.2 GPa
- Impact properties: Passing the Samsonite suitcase test serie

Samsonite

Some key results

Manufacturing challenge

Consolidation temperature: Both of the PLA filament (matrix and reinforcement) can melt, therefore the processing temperature $\mathbf{T_{process}}$ should be carefully adjusted in order not to melt the reinforcement.



- **Melting temperature of low Tm PLA** / matrix material: 155°C
- **Melting temperature of high Tm PLA** / reinforcement: 177°C

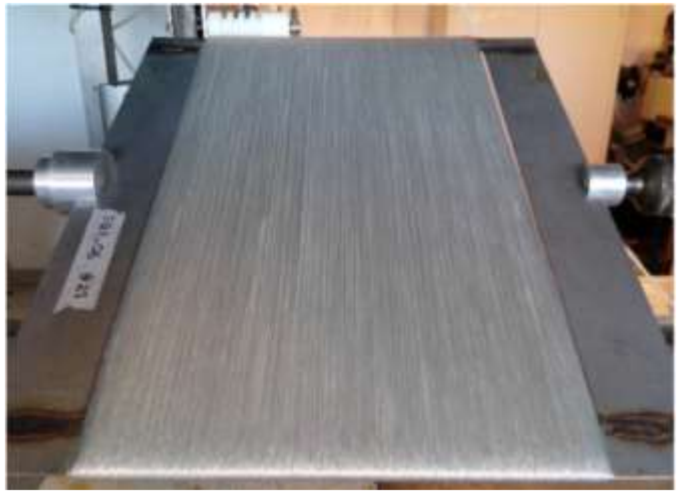
Some key results

Plan:

– Manufacture UD fiber composites using different consolidation temperature: **155, 160, 165 and 170°C**

Filament winding

- Unidirectional fibre composite – 2 mm thick
- Drying overnight in vacuum chamber at 35°C



Press consolidation

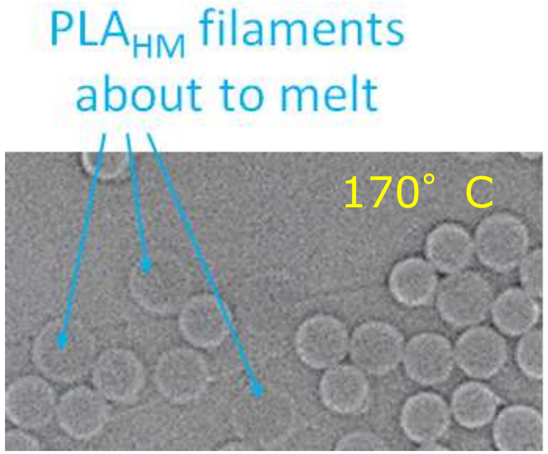
- Heating: 10 min at selected temperature under vacuum
- Pressing : 1 min at 30°C - Pressure: 2 MPa

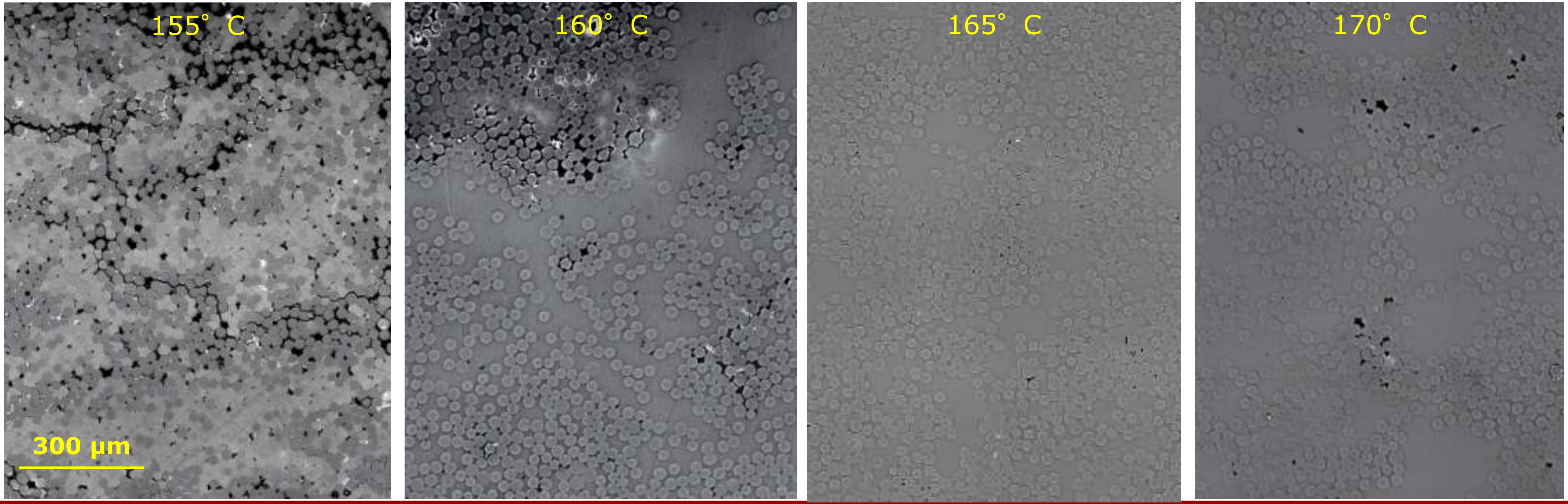
Some key results

Composite manufacturing and performance

Characterization – Microstructure

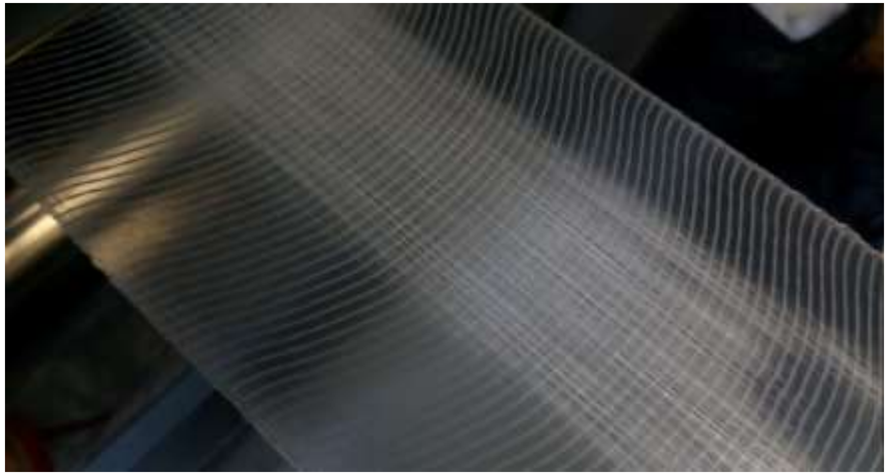
- 165°C is the optimal temperature





Some key results

OK temperature



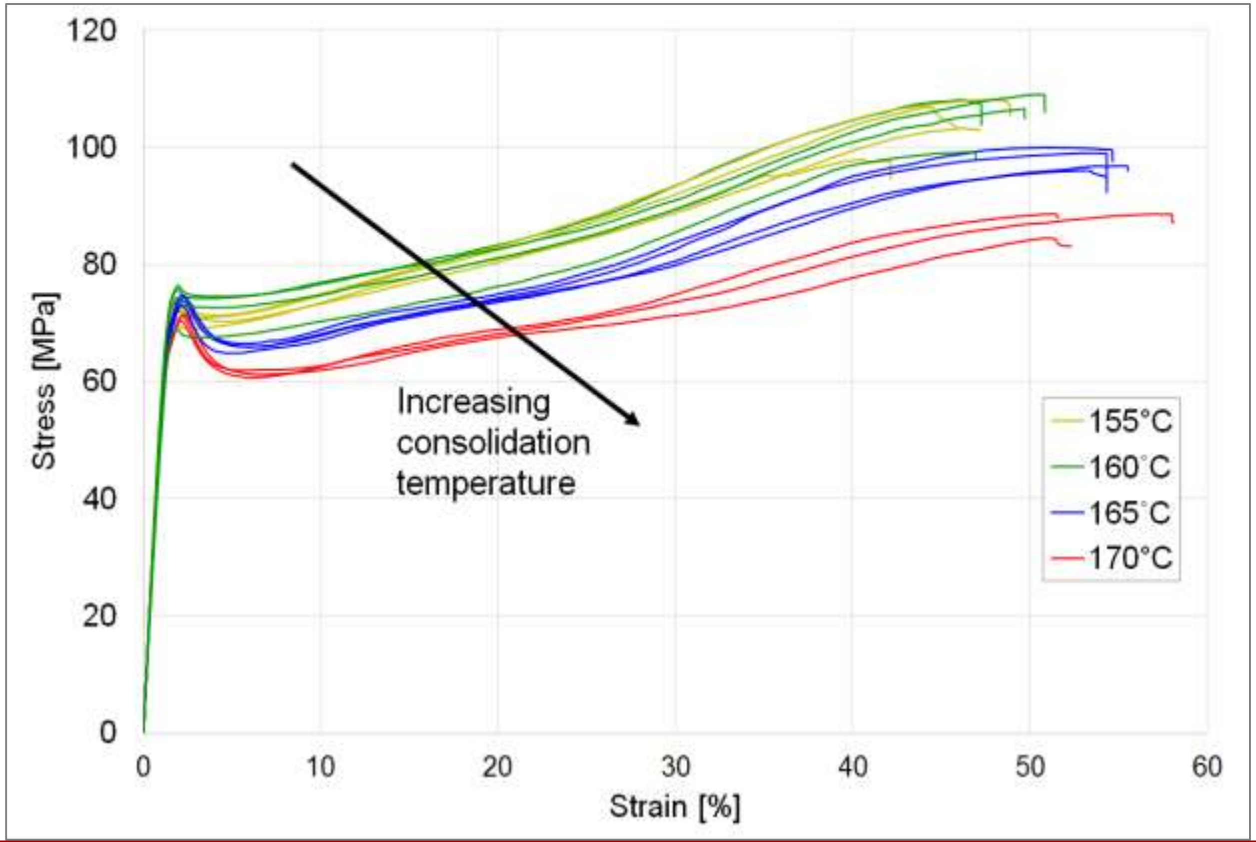
Too high temperature

Some key results

Characterization – Static tensile test 0˚

- E-modulus as expected
- Effect of consolidation temperature on strength properties

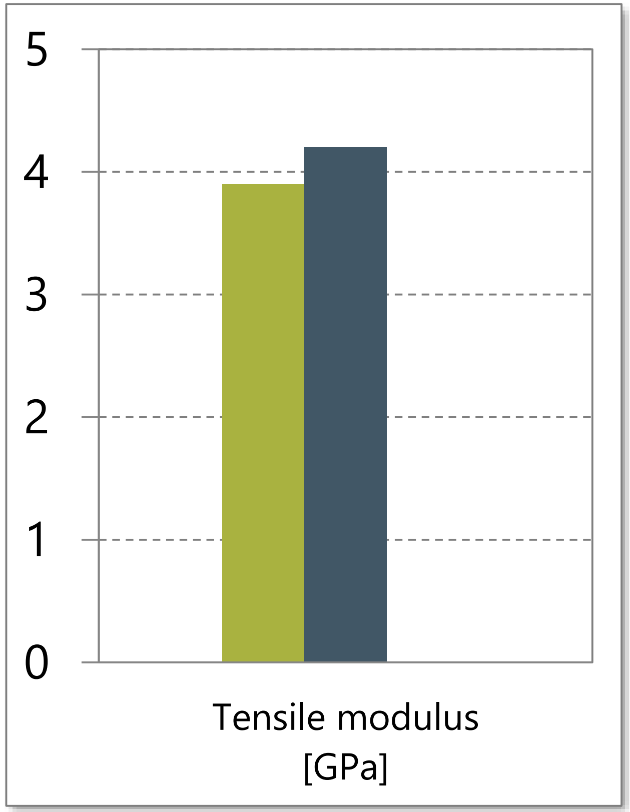
Consolidation temperature [˚C]	Stiffness [GPa]	Strength [MPa]
155˚C	6.3 ± 0.1	104 ± 5
160˚C	5.8 ± 0.2	106 ± 4
165˚C	5.9 ± 0.0	98 ± 2
170˚C	5.8 ± 0.1	84 ± 7



Some key results

	Tensile strength [Mpa]	E-modulus [GPa]	Area weight [g/m2]
UD composite	113 +/- 3	6.1 +/- 0.1	1341
Fabric composite	40 +/- 1	3.8 +/- 0.1	

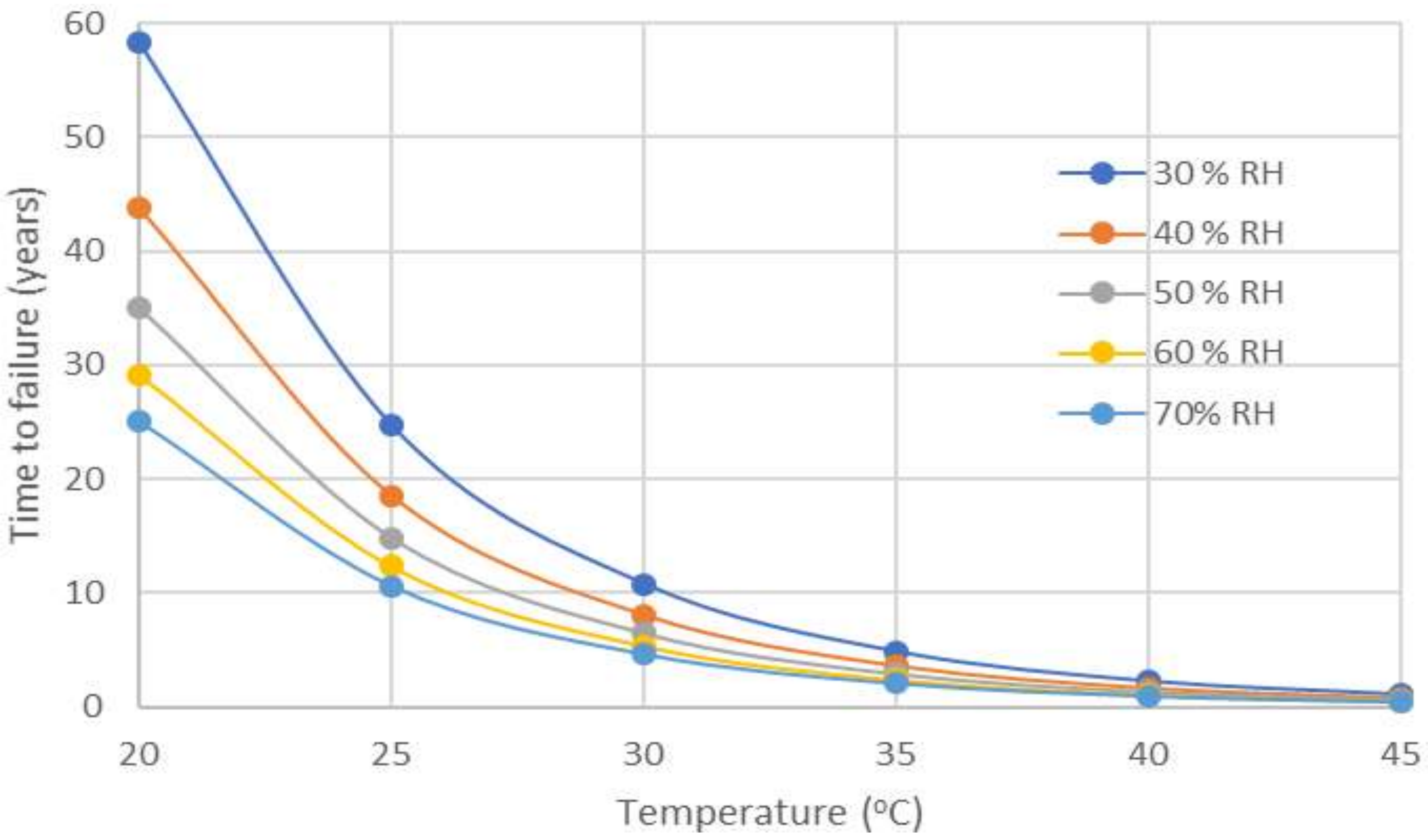
PLA self-reinforced composites compared industrial benchmark:



- Fabric based PLA composite
- Curv® self reinforced PP

Some key results

Life time predictions based on accelerated ageing tests



Prototypes

Transport box

- **Dimension (in mm):** 400 x 300 x 200
- **Weight:** 400 g
- **Manufacturing process:** The box consists of a combination of several plastic intermediates made via:
  - Extruded PLA foam process (inner foamed structure)
  - Thermoforming process (outer layer of consolidated sheets for protection)

DTU

Prototypes

Seat structure

- **Dimension (in mm):** 840 x 470 x 130
- **Weight:** 600 g
- **Manufacturing process:** In-mold hybridization. Thermoforming of consolidated PLA fabrics and overmolding (rib structures including the overmolding of metal inserts, which are used as load introduction elements).

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