Cellulose nanocomposite core in sandwich composite panels

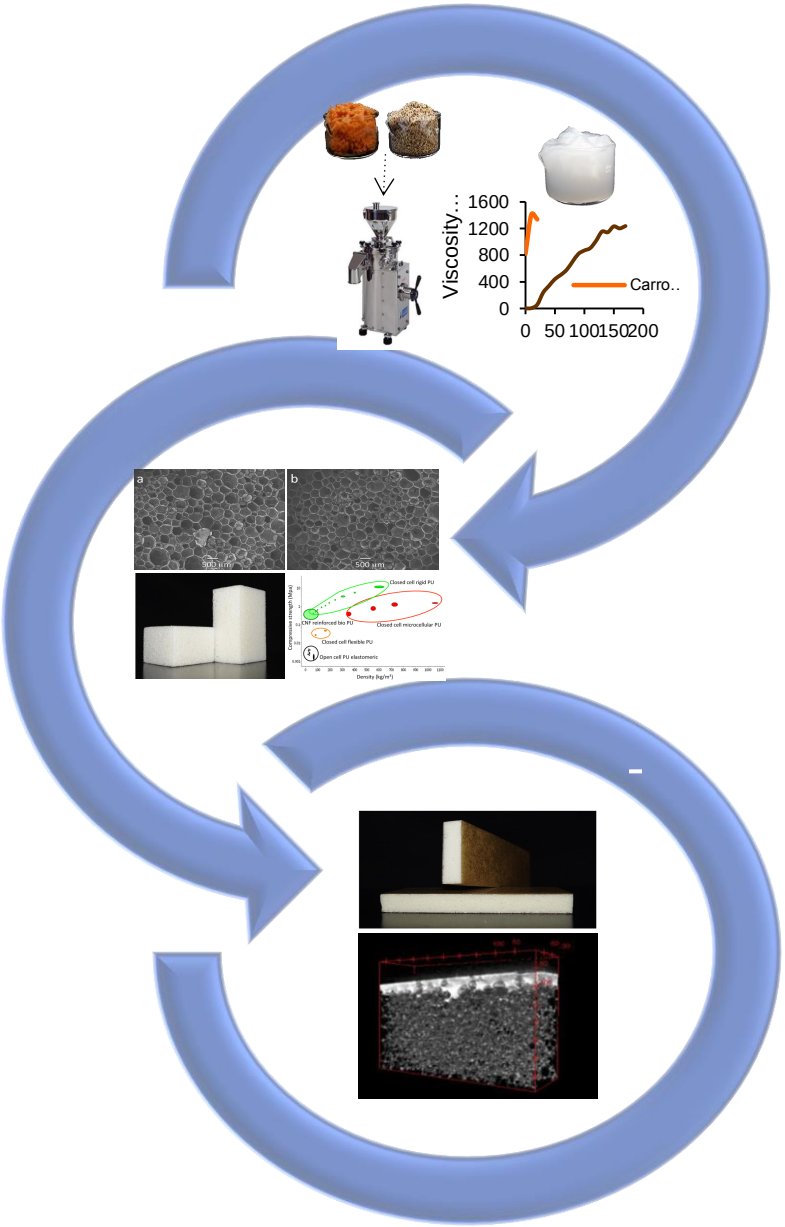
Nikolina Frisk, Xiaojian Zhou, Linn Berglund, Yvonne Aitomäki, Mohini Sain, Kristiina Oksman

Division of Materials Science
Luleå University of Technology, Sweden

Introduction

- INCOM project EU FP7 2013-2017
- The overall goal have been Industrial scale light-weight composite materials development
- Our goals have been production of cellulose nanofibers with low energy (<2 MWh/ton), use of low cost raw material and large scale production
- Development of core material with low density <50 kg/m^3 using Bio-PU foams reinforced with cellulose nanomaterials
- Use the foams as a core in composite laminates
- I'm presenting some of the results reached in the project

Content

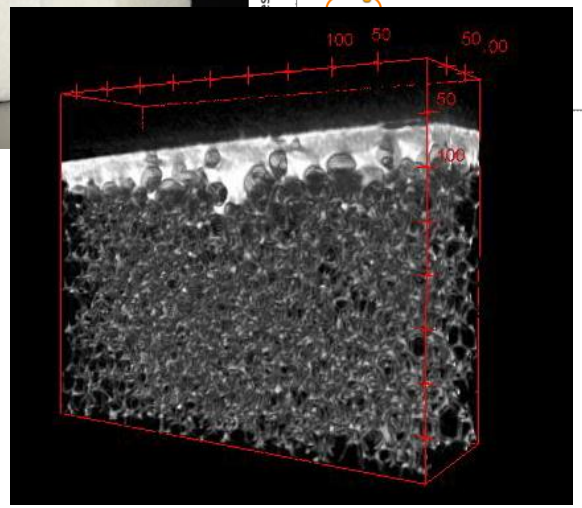


Carrot residue, process & quality

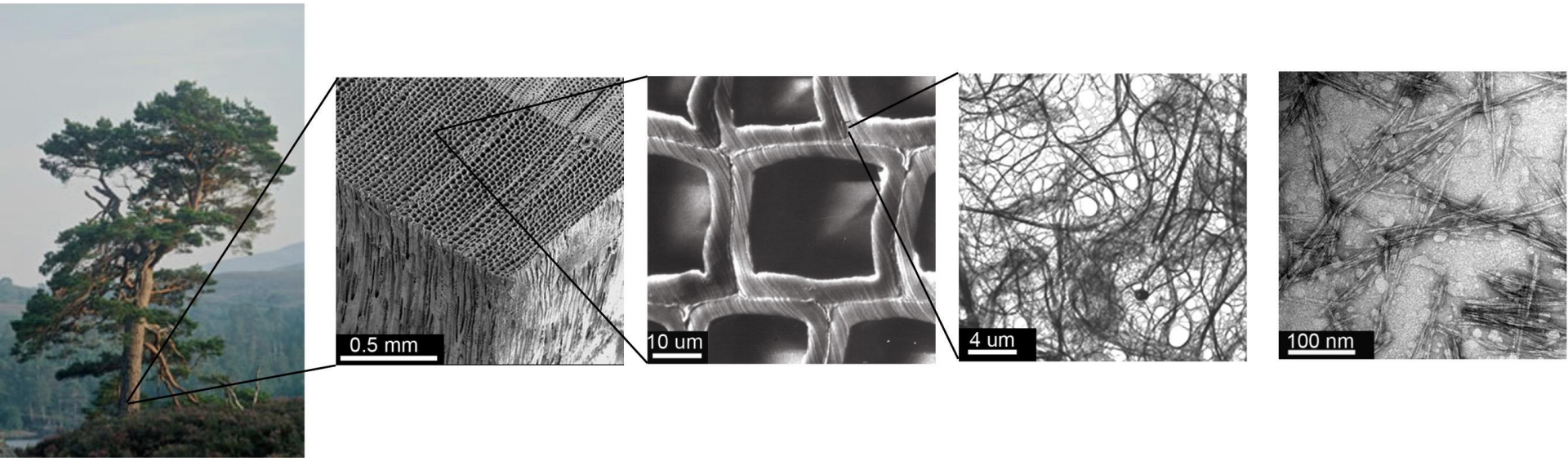
Bleaching

Foams reinforced with nanofibers

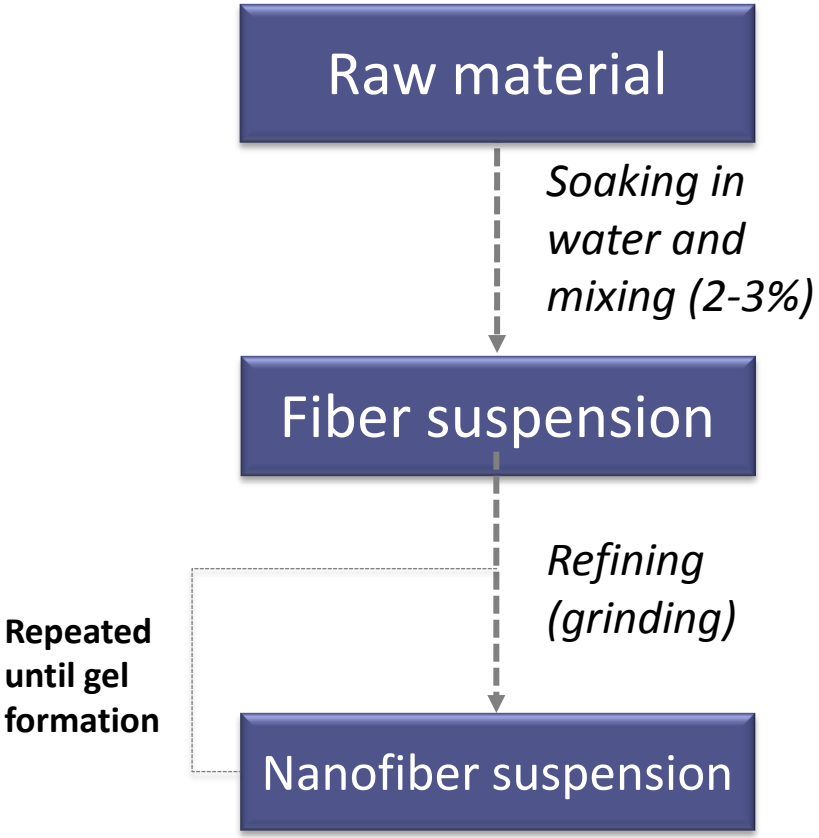
Sandwich laminates with CNF reinforced BioPU core

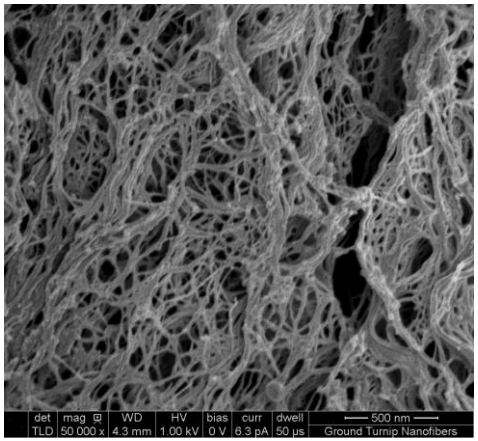


What is meant with nanocellulose?



Mechanical separation of cellulose nanofibers

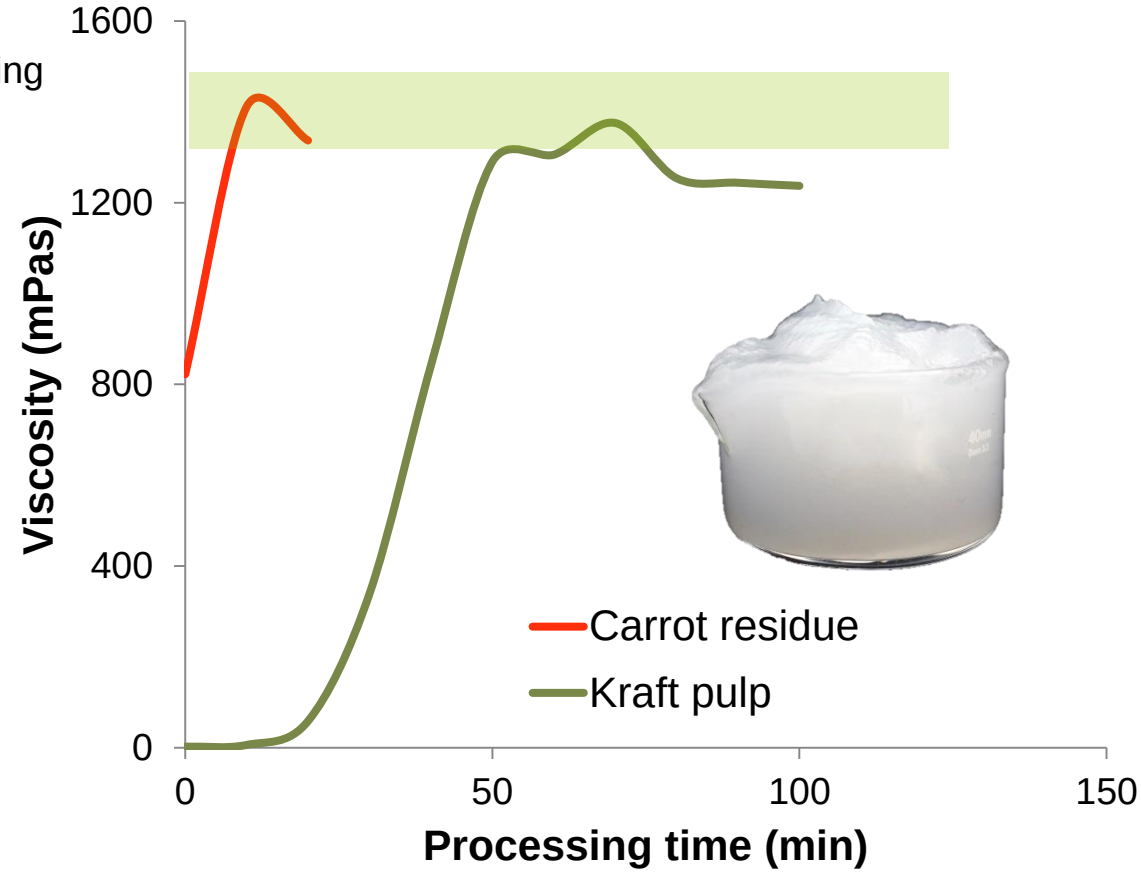




Efficient production of cellulose nanofibers from industrial residues

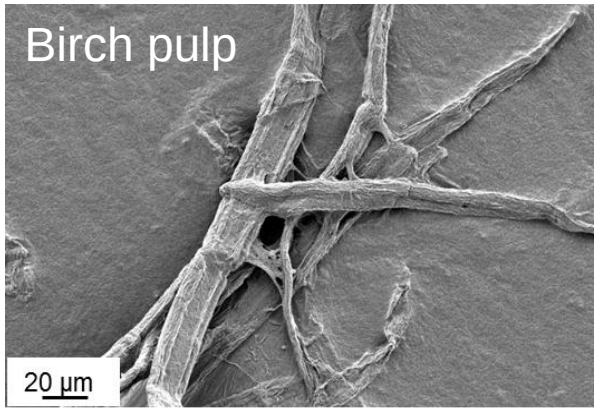
Bleaching

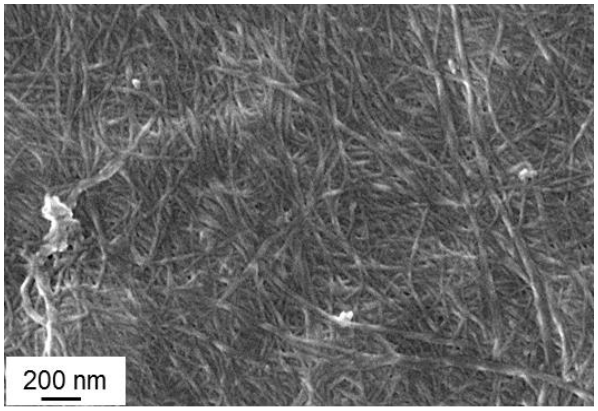
Ultrafine grinding

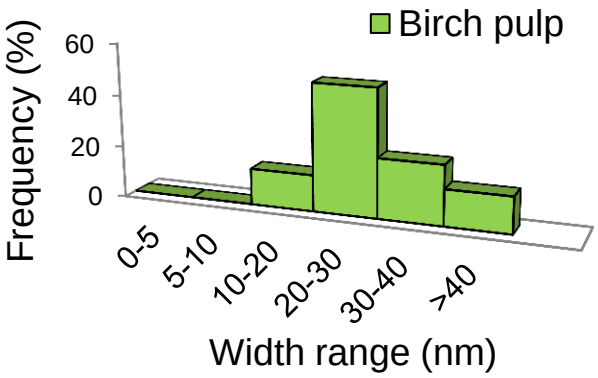


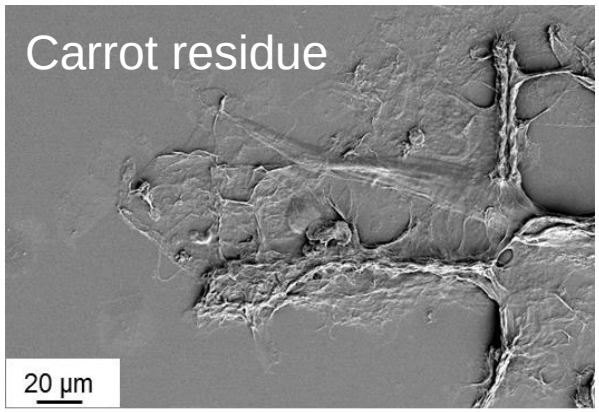
L Berglund et al Industrial Crops and Prod 92 (2016)

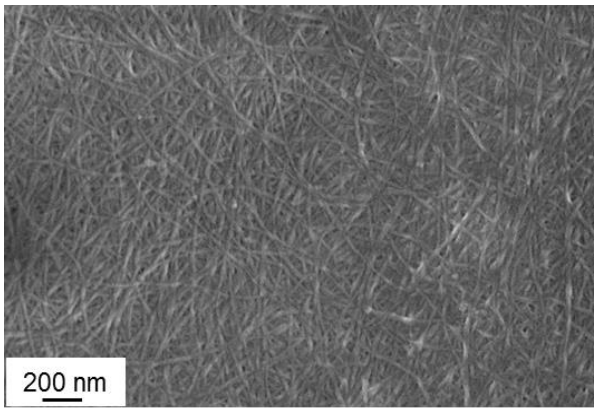
Characterisation of the nanofibers

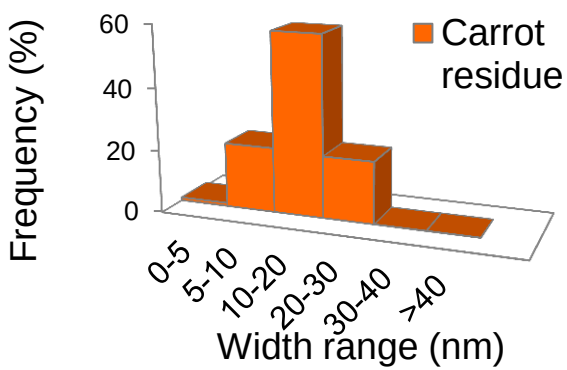








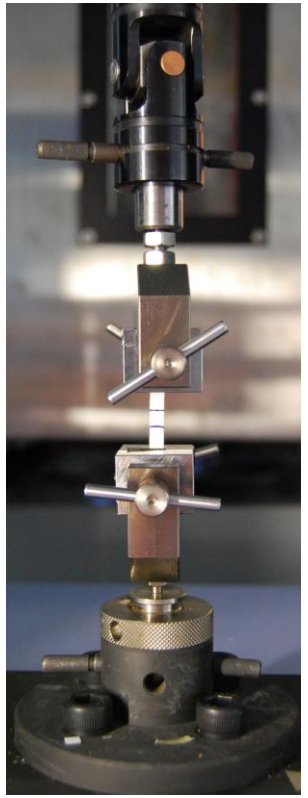




Mechanical properties of the nanofiber networks

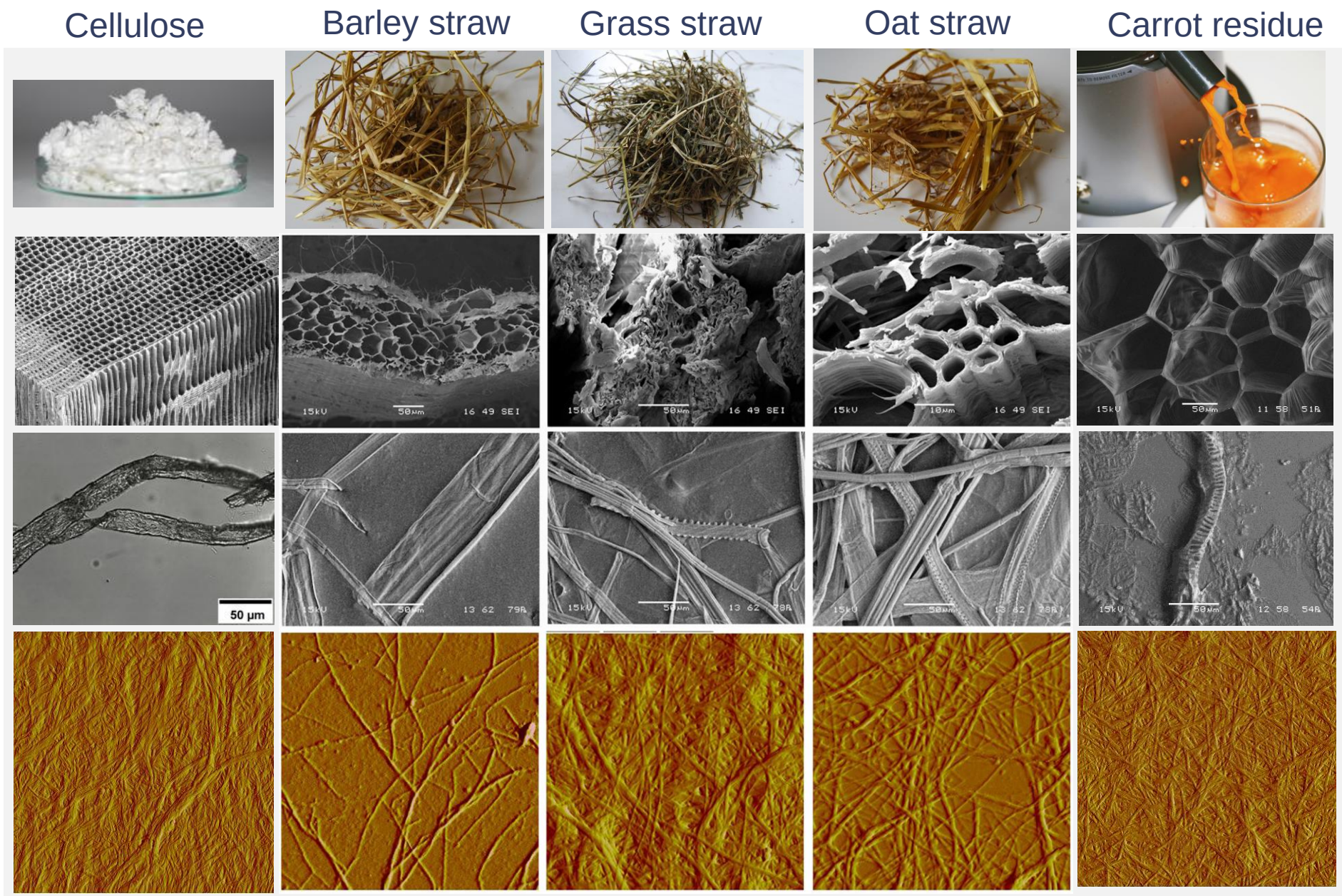
Nanopaper is prepared by vacuum filtration and pressing

	E-Modulus (GPa)	Strength (MPa)	Strain (%)	Energy (MWh/t)
$Birch_{nanofiber}$	9.9	190	6	13
$Carrot_{nanofiber}$	12.5	210	6	1

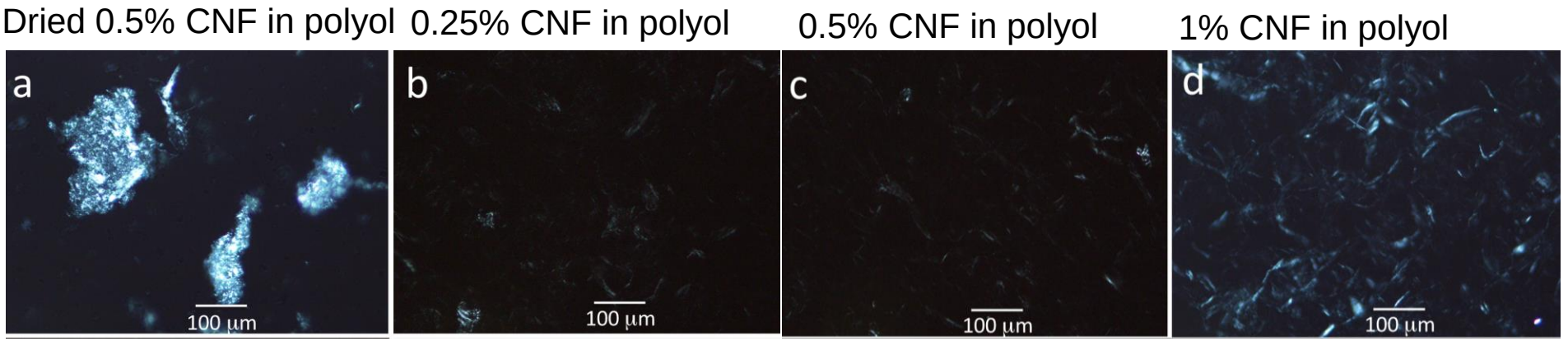


- Carrot nanopaper have better properties
- Probably because of even fiber size
- Reduced fiber size → better network → better mechanical properties

Nanofibers from biobased residues



Development of biobased core materials
Dispersion of CNF

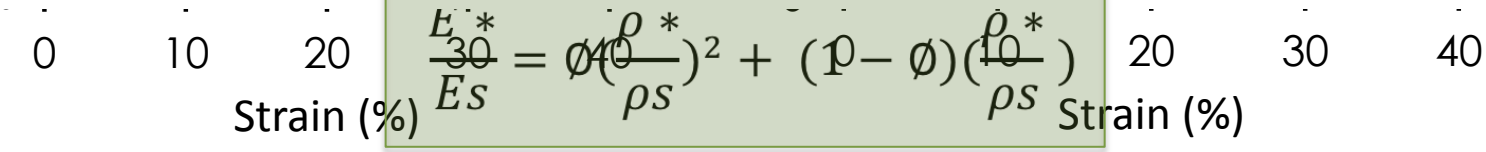


- Nanofibers are usually dispersed in water and are aggregating when drying
- Dispersion of the CNF into the polyol (castor oil) is difficult
- Nanofiber dispersion was mixed in polyol together with water & dioxane co-solvent which were removed by heating the mixture (evaporation)
- Resulted in well dispersed nanofibers

Zhou et al Materials Design 110 (2016) 526-531

Effect of CNF on the mechanical properties

	Density (kg/m^3)	Porosity (%)	Foam Modulus (MPa)	Cell wall Modulus (MPa)
BPU	43 ±3	96	3.5	391
BPU 0.25CNF	43 ±2	96	4.3	460
BPU 0.5CNF	46 ±3	96	5.7	535
BPU 1CNF	49 ±3	95	4.4	386

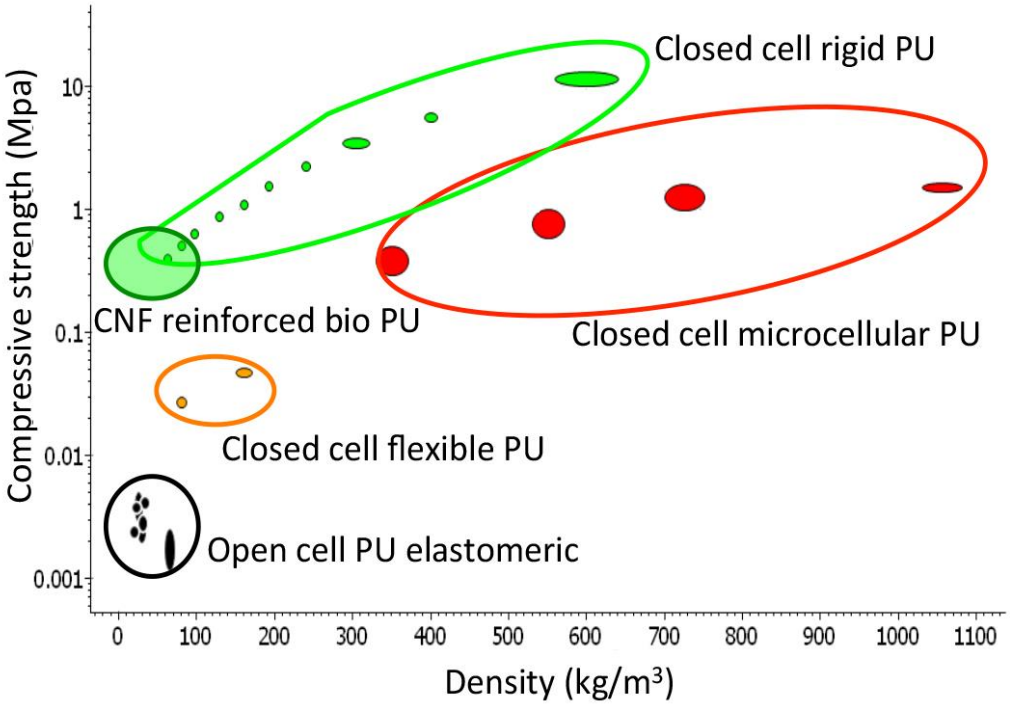


$$\frac{E^*}{Es} = \phi\left(\frac{\rho^*}{\rho s}\right)^2 + (1-\phi)\left(\frac{\rho^*}{\rho s}\right)$$

- Targeted foam density 45 kg/m^3
- Mechanical properties, compressive stress and modulus were improved up to 0.5 % CNF
- Estimated solid material modulus showed also improvement (Gibson and Ashby)

Zhou et al Materials Design 110 (2016) 526-531

Bio-PU core materials



- Bio based polyurethane foam can be reinforced with cellulose nanofibers (carrot)
- Improved mechanical properties to the level of commercial rigid PU foams

Zhou et al Materials Design 110 (2016) 526-531

Bio-PU foams with different densities using wet CNF

Foaming of Bio-PU foam (BPU) and CNF reinforced Bio-PU foam (CNF) for four different controlled densities

ρ=35 kg/m^3	ρ=40 kg/m^3	ρ=45 kg/m^3	ρ=50 kg/m^3

Vacuum infusing the foams into sandwich composites with Kraft paper skin and epoxy resin

ρ=35kg/m^3	ρ=40 kg/m^3	ρ=45 kg/m^3	ρ=50 kg/m^3

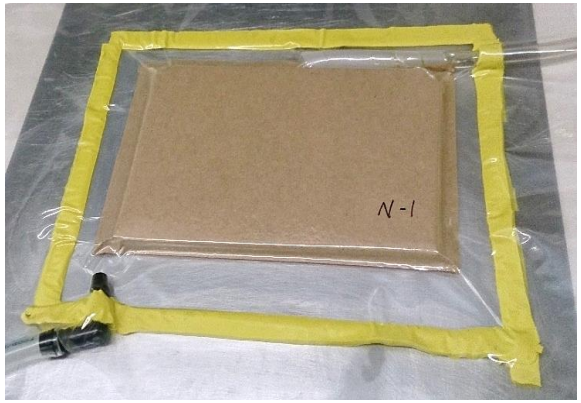
Characterizing and comparing the properties

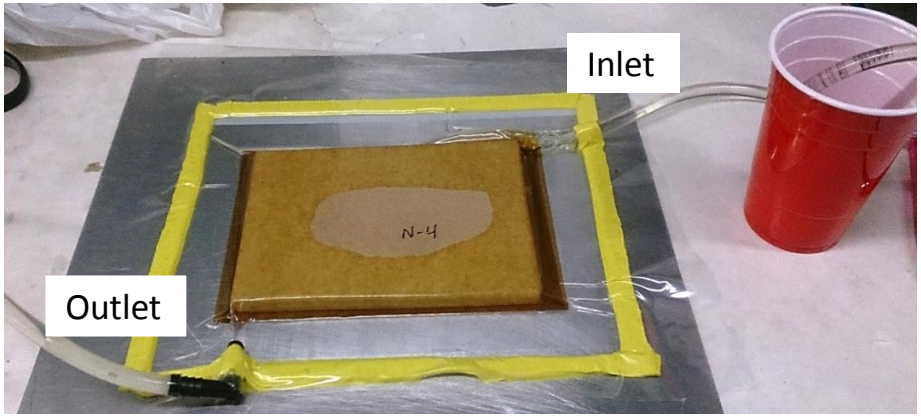
Microstructure	Foam properties	Composite laminate properties

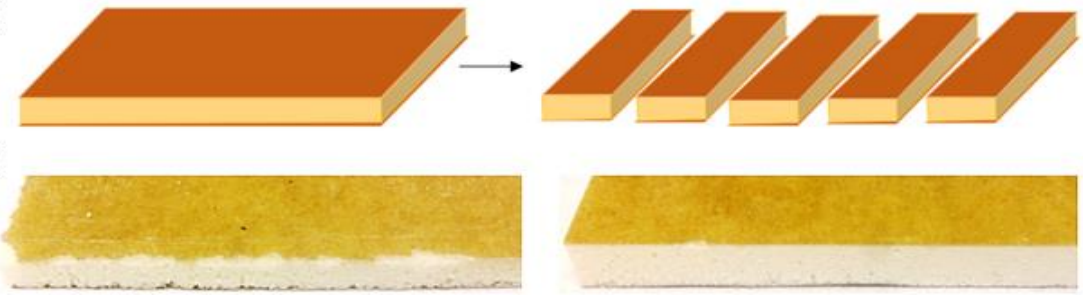
Material selection evaluation on mechanical properties based on merit indices

Frisk, Sain, Oksman. Ref Mod Matr Sci Matr Eng April 2017

Sandwich manufacturing using VI

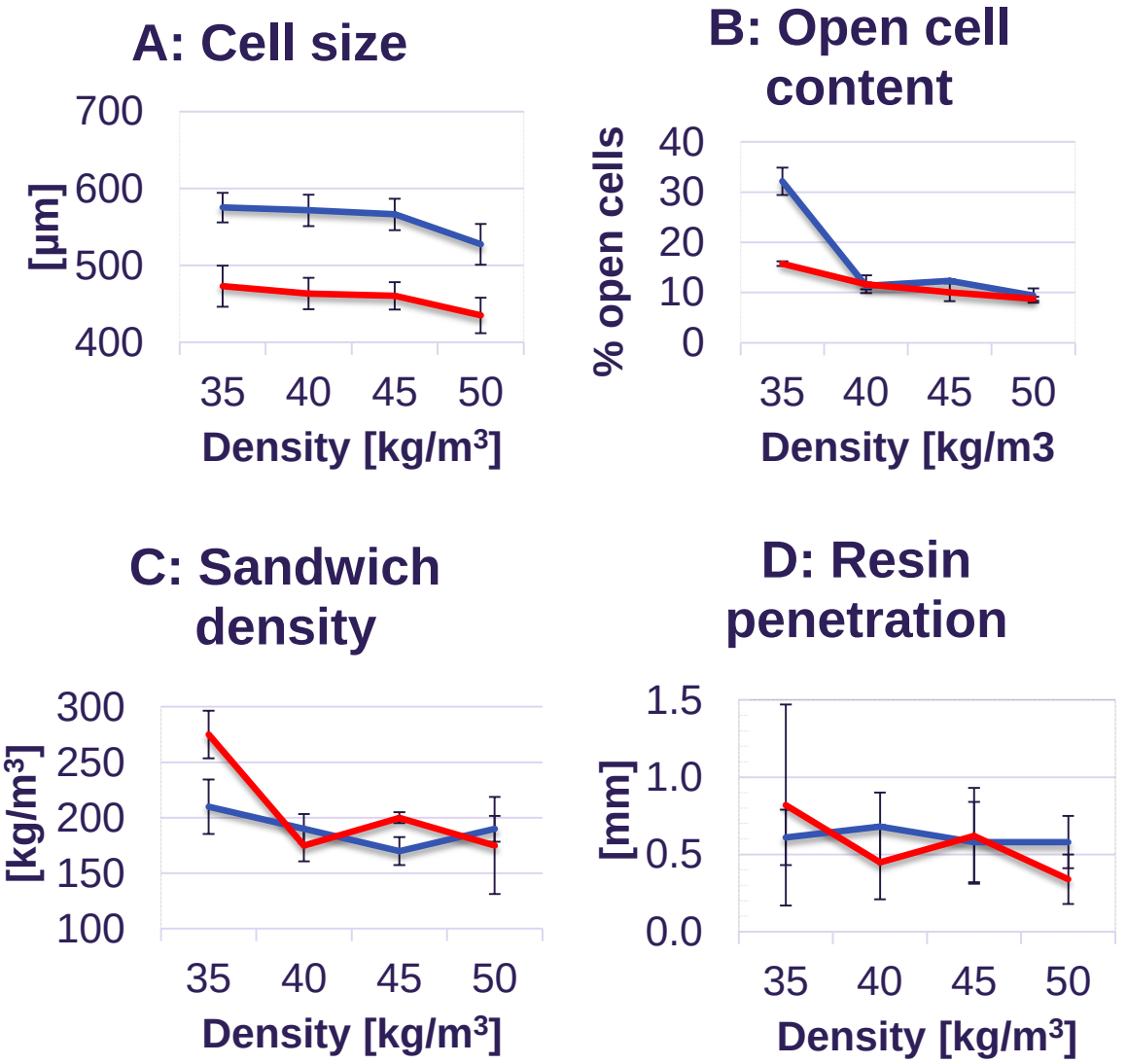






Resin: Low viscosity epoxy + slow hardener η = 725 cps at 22° C
Curing: Under vacuum bag for 24 h in RT Post curing: 72 h in RT

Materials characteristics



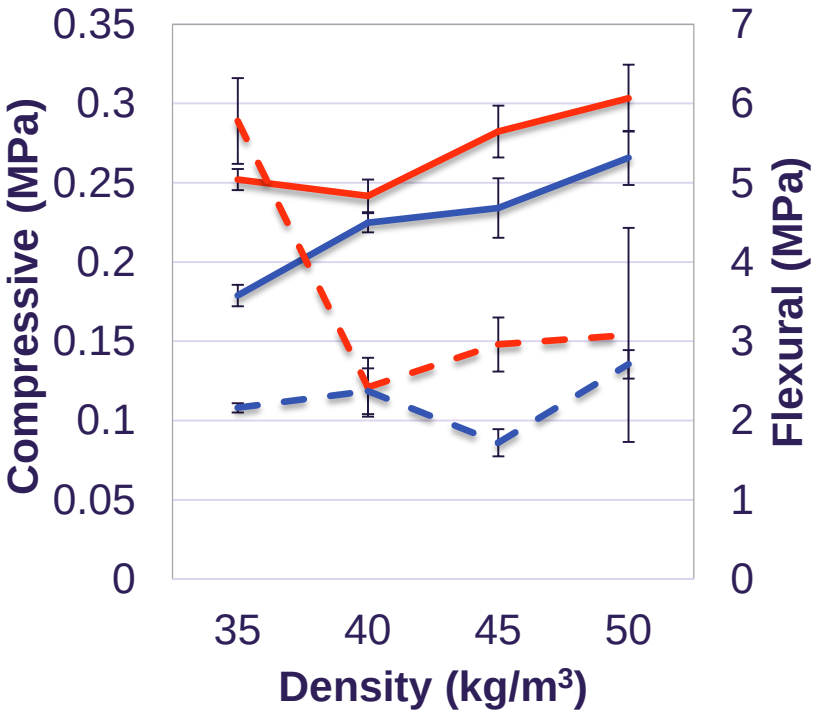
Addition of CNF decrease average cell diameter and open cell content

Resin penetration and sandwich density linked but more random

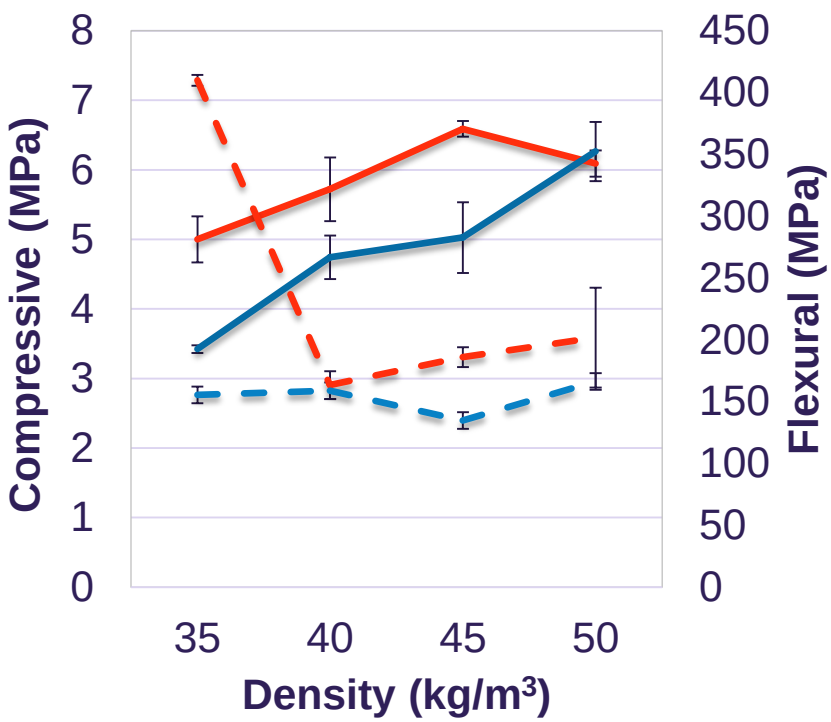
Frisk, Sain, Oksman. Ref Mod Matr Sci Matr Eng April 2017

Mechanical properties of the core and sandwich laminate

Strength comparison



Modulus comparison



BPU Compressive
BPU Flexural
CNF Compressive
CNF Flexural

Frisk, Sain, Oksman. Ref Mod Matr Sci Matr Eng April 2017

Facing strength

Strength between the kraft paper and the core

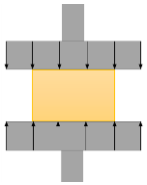
	Facing strength (MPa)	
Density (kg/m³)	BPU	CNF
35	6.1 ± 0.9	11.4 ± 0.3
40	6.4 ± 0.8	8.8 ± 0.7
45	6.1 ± 0.5	9.3 ± 0.5
50	8.8 ± 0.6	12.5 ± 0.7

- Significant improvement for all sandwich with CNF foam core
- Include relation between core and skin thickness

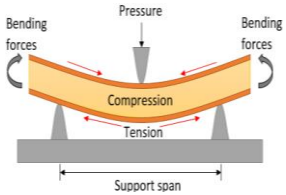
Frisk, Sain, Oksman. Ref Mod Matr Sci Matr Eng April 2017

Merit index ranking the foams and sandwich panels

Weight minimized for best performance



Foams



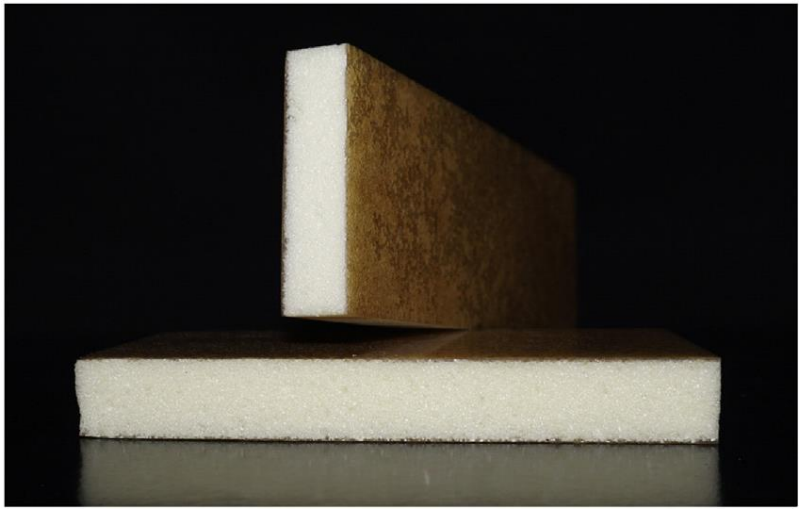
Sandwich

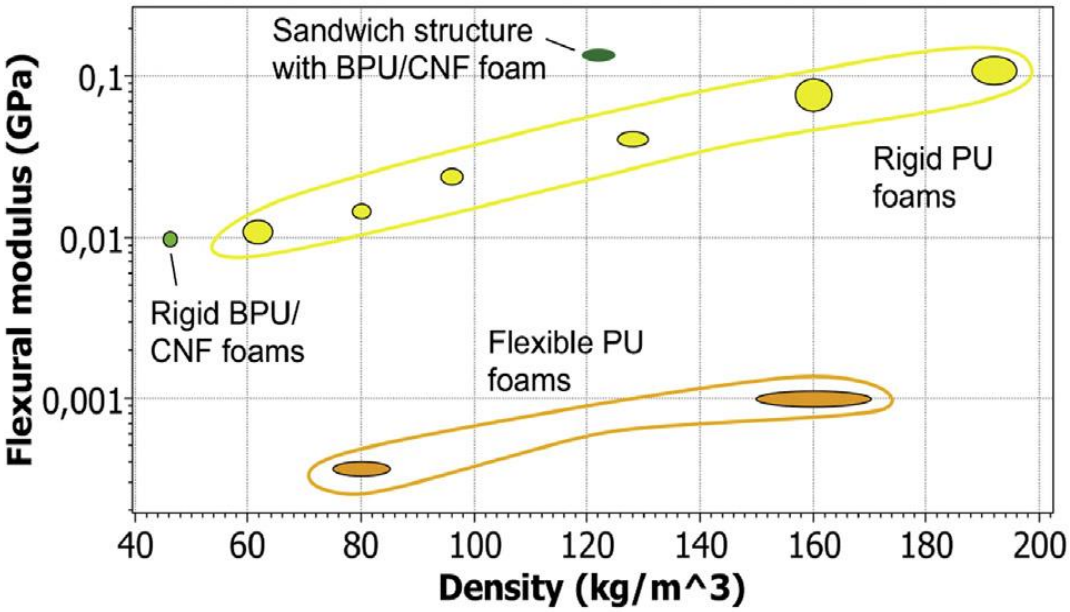
	M_1 ρ/σ		M_2 $\rho/E^{1/2}$		M_3 $\rho/\sigma^{2/3}$		M_4 $\rho/E^{1/2}$	
Density	BPU	CNF	BPU	CNF	BPU	CNF	BPU	CNF
35	19.6	13.9	18.9	15.7	125	86	16.8	13.7
40	17.8	16.5	18.4	16.7	107	97	15.0	13.7
45	19.2	15.9	20.1	17.5	117	98	14.4	14.8
50	18.8	16.5	20.0	16.4	99	83	14.9	12.3

- CNF increases performance of the foams and sandwich in ALL density categories (except M_4-ρ45)
- BPU-CNF foams are top ranked in all four merit index groups

Frisk, Sain, Oksman. Ref Mod Matr Sci Matr Eng April 2017

Biobased PU foams as core in lightweight sandwich composites





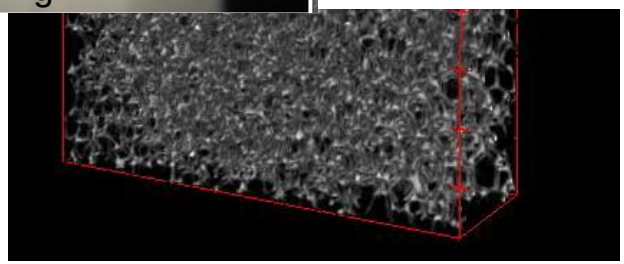
Some highlights of the presentation

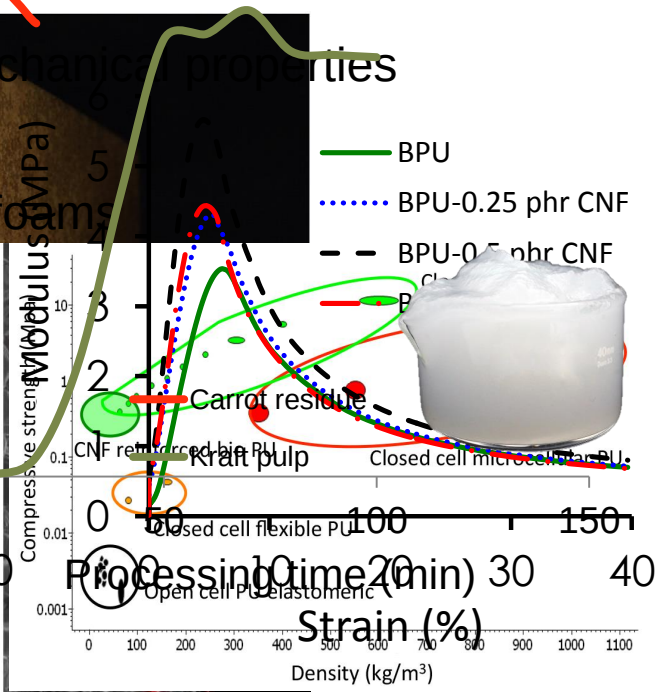
Bio PU core with CNF

Improved mechanical properties

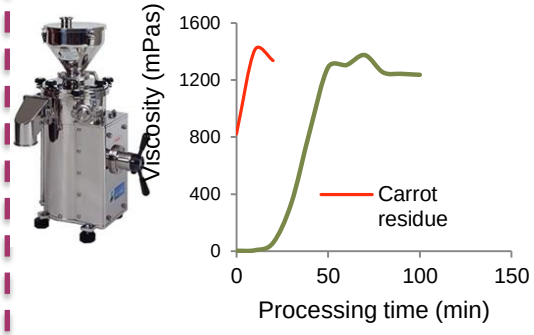
Bio PU foams

Ultrafine grinding

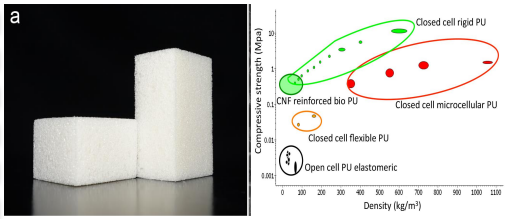




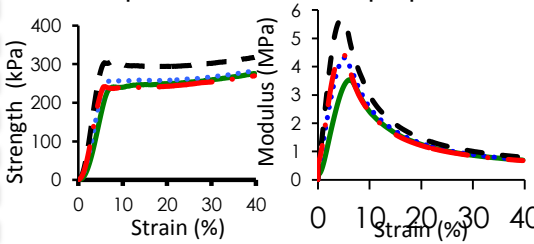
Fibrillation process nanofibers



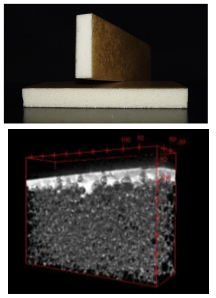
Bio PU foams



Improved mechanical properties



Bio-PU core with CNF



Conclusions

- The addition of CNF had a positive effect on foam properties
- Foams with lowest density showed highest impact

Property	35 kg/m³	40 kg/m³	45 kg/m³	50 kg/m³
Cell size	- 18 %	- 19 %	- 19 %	- 18 %
Open cell content	- 51 %	0 %	- 18 %	- 7 %
Compressive strength	+ 41 %	+ 8 %	+ 21 %	+ 14 %
Compressive modulus	+ 46 %	+ 21 %	+ 31 %	0 %
Flexural strength	+ 167 %	+ 2 %	+ 72 %	+ 14 %
Flexural modulus	+ 163 %	+ 3 %	+ 38 %	+ 21 %
Facing strength	+ 88 %	+ 37 %	+ 53 %	+ 42 %

Conclusions

- Carrot nanofibers with good quality can be separated with very low energy
- The addition of nanofibers are affecting the BPU foam properties positively even with very low concentration
- The increased mechanical properties of foam sandwich panels suggest a positive reinforcement behavior
  - Good dispersion of CNF at micro-scale
  - The used isocyanate is also reacting with OH groups on CNF leading to a CNF network within the BPU
- Merit indices for maximum performance indicates that all reinforced foams are superior or equal to their reference foam
- CNF-reinforced bio-PU foam has a great potential for use in commercialized products especially when light-weight is important

INCOM
7EC FP, 2013-2017
Grant agreement no: 608746

SurA Chemicals

bergius

UNIVERSITY OF TORONTO

VTT

Axon

2B

BRÄMHULTSJUICE

Technical University of Denmark DTU

Fraunhofer ISC

VMA-GETZMANN GMBH Verfahrensrtechnik

milliDyne Surface Technology

CSI Composite Solutions & Innovations Oy

DIEHL Aircabin

LULEÅ UNIVERSITY OF TECHNOLOGY

econcore economic core technologies