Empa

Materials Science and Technology

Hochfeste Platten aus industriell hergestellter Bakteriencellulose – ein alternatives Basismaterial für Platinen?

Thomas Geiger

Cellulose & Wood Materials Laboratory, Empa

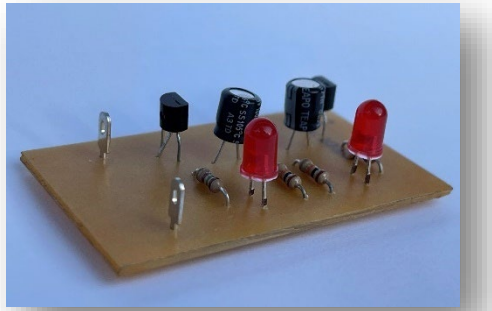
Coffee Lectures: Polymers for the Future - Herbstsemester 2022

12. Oktober 2022: Alternative und innovative Materialien

OST Ostschweizer Fachhochschule

Outlook

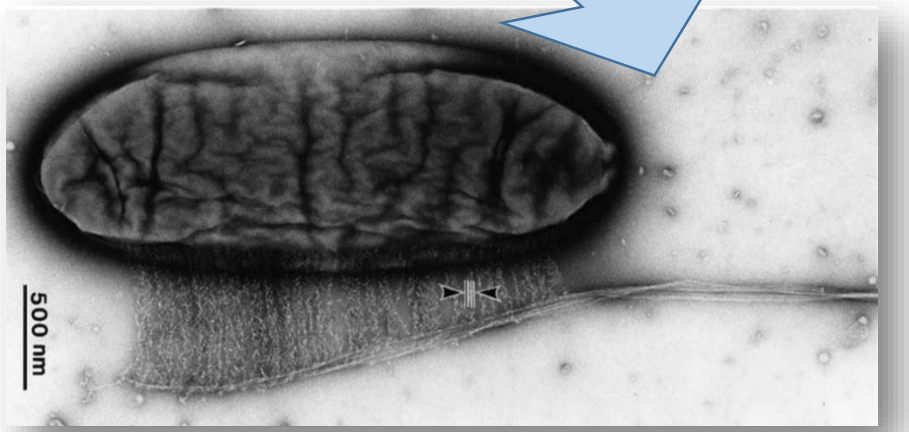
- Origin of industrial produced bacterial cellulose (BC)
- High-strength rigid boards from nano-celluloses
- Processing of high-strength rigid boards with BC
- Board properties
- Future applications – molded parts and PCBs



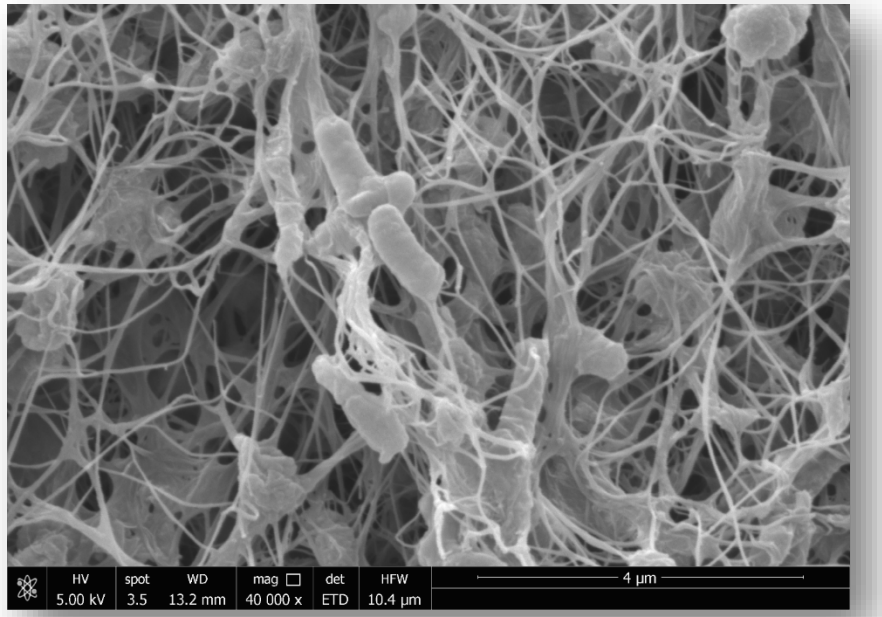
Origin of industrial produced bacterial cellulose

- Industrial waste products with a high sugar content: fruit peels, rotten fruit, **coconut water**, …

Glucose Peptone Yeast Extract Disodium Phosphate Citric Acid



T, pH



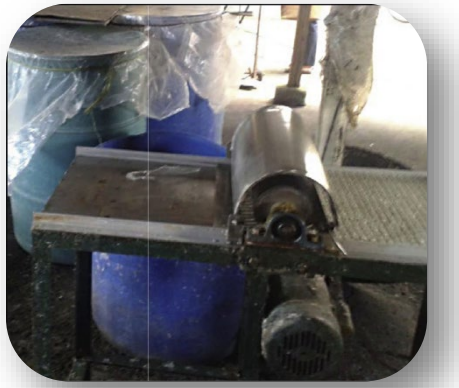
Acetobacter xylinum / Komagataeibacter xylinus bacteria
(Campano, C. et al. Cellulose **2016**, 23 (1), 57–91)

BC from coconut water: **Nata de Coco**

- fermenting tee (Kombucha): symbiotic culture of bacteria and yeast (SCOBY)
- fermenting alcoholic liquids to vinegar: Essigmutter (mother of vinegar)

Origin of industrial produced bacterial cellulose

Extraction of coconut milk or coconut water	Mixing of all ingredients	Boiling the prepared mixture	Transfer to plastic trays and cooling	Adding starter of Acetobacter xylinum	Incubating for 7 – 14 days at 23 – 32˚C	Separating the nata from spent liquor	scraping thin bacterial films off the nata surface	Storage by immersing the nata sheet in water




Ingredients: water, sugar, $(NH_4)_2SO_4$, coconut water

Phisalaphong, M. et al. Nata de Coco Industry in Vietnam, Thailand, and Indonesia in: Gama, M., Dourado, F., Bielecki, S., Series Eds.; Bacterial Nanocellulose: From Biotechnology to Bio-Economy; Elsevier Science Bv: Amsterdam, **2016**.

Origin of industrial produced bacterial cellulose

Industrial BC sheet
nata de coco compressed 1:10

- Production: Brazil, Philippines, Vietnam, Thailand, Indonesia …
- Market in Japan and the USA (2009 – 2011):
  6000 MT (Metric Tons) from the Philippines

- commercial applications:

Food and Food packaging

Cosmetics

Biomedical

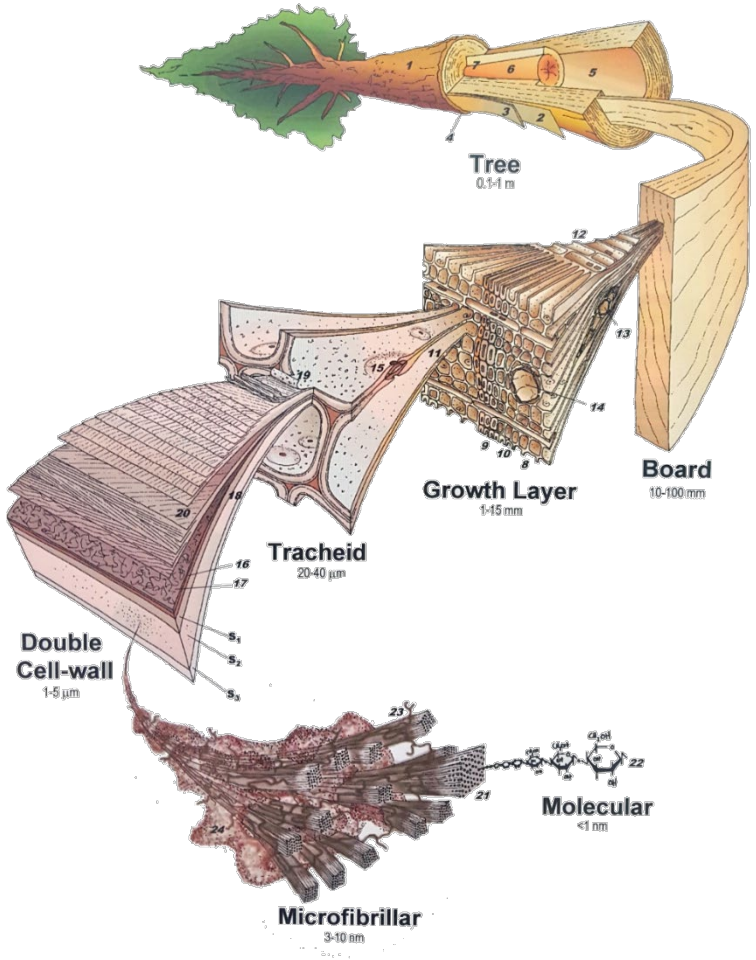
Electronics

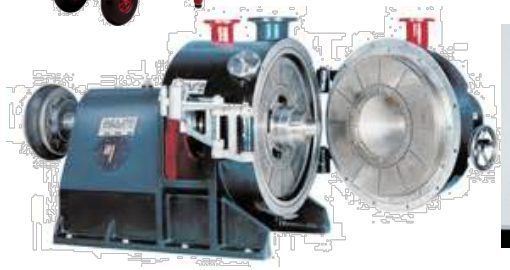
Hydrogels or thin films !

Marestoni, L. D. et al. Polímeros **2020**, 30 (4); https://www.bennetthealth.net/; Sony Corporation

High-strength rigid boards from nano-celluloses

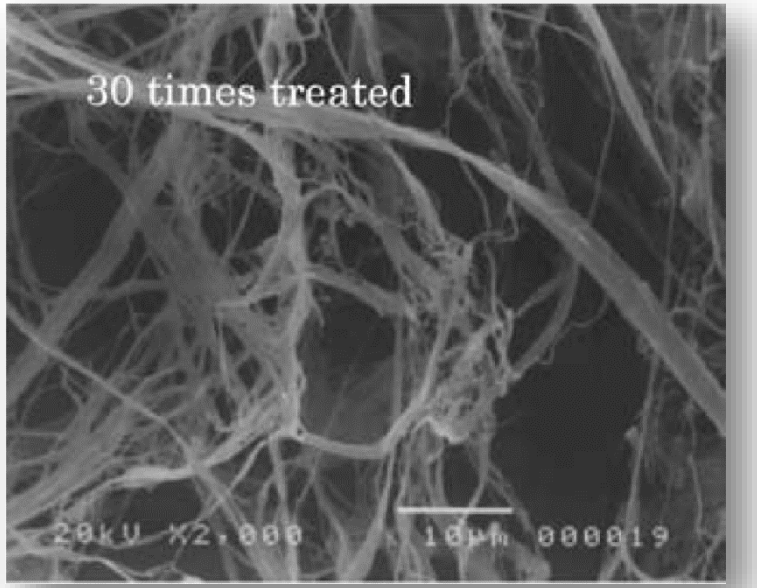
Cellulose nanofibrils (CNF)

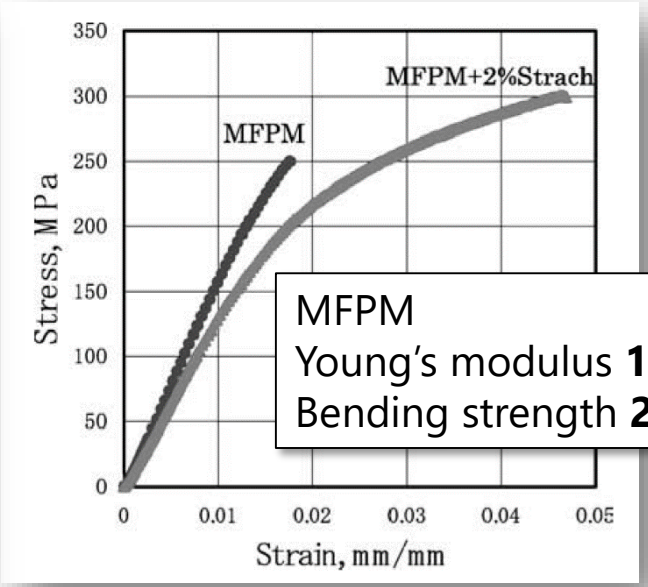




Energy

High-strength rigid boards from nano-celluloses





MFPM
Young's modulus **16 GPa**
Bending strength **250 MPa**

Microfibrillated kraft pulp (CNF 10 wt%) compressed to rigid board 40 mm × 8 mm × 1.5– 2.0 mm

a) Dewatering @ RT, 5 MPa (size 100 mm × 100 mm ×4 mm)
b) Drying @ 105 °C to 2 wt%
c) Hot-Pressing @ 100 MPa, 150 °C, 30 min
d) 3-point bending test (size 40 mm × 8 mm × 1.5– 2.0 mm)

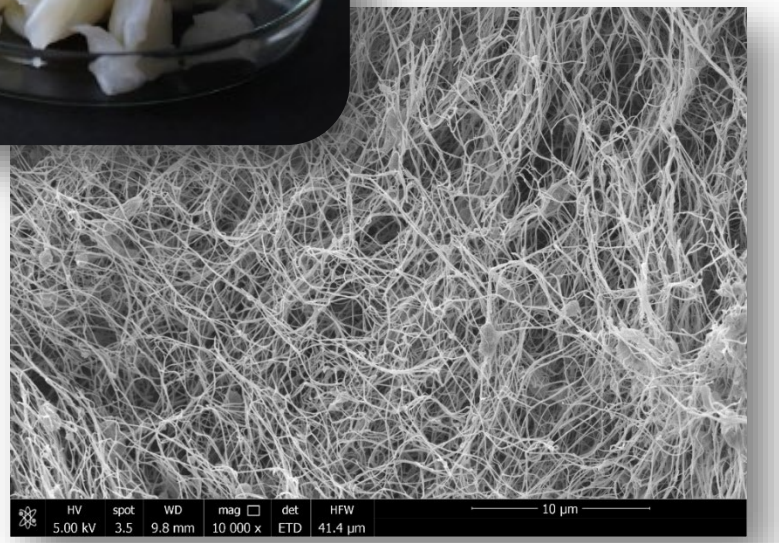
NCV (Nano Cellulose Vehicle) project

- Project launch 2016
- Materials: CNF, PP-CNF, Epoxy-CNF
- Bonnet made out of 100 % CNF

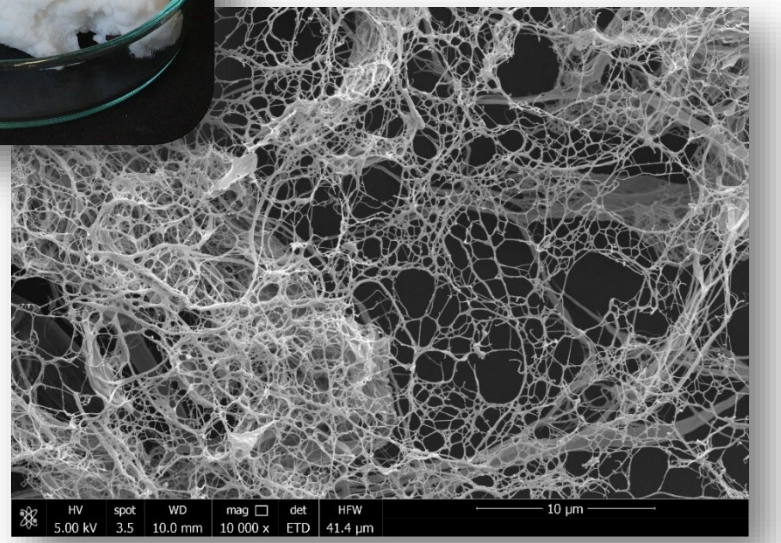
Yano, H. et al. Journal of Materials Science **2004**, 39 (5), 1635–1638; https://www.rish.kyoto-u.ac.jp/ncv/

High-strength rigid boards from nano-celluloses

Bacterial cellulose (BC)
Nata de coco



Cellulose nanofibrils (CNF)



- **BC-01** : raw nata de coco from 99 Gold Data Trading Co., Ltd. (Thành phố Hồ Chí Minh, Vietnam)
- **BC-02** : rinsed nata de coco
- **BC-03** : nata de coco bleached with NaOH and NaClO
- **BC-04** : BC sheets produced and purified by fzmb GmbH (Bad Langensalza, Germany)

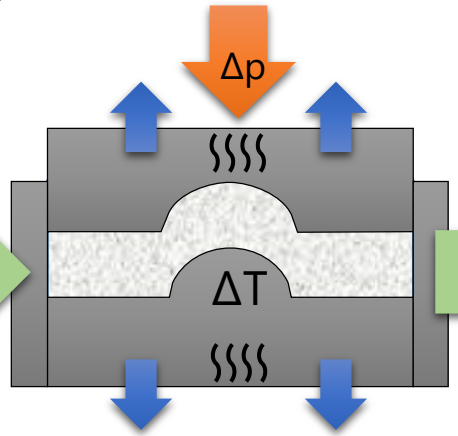
Processing of high-strength rigid boards with BC

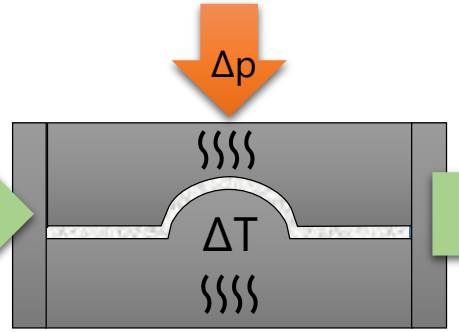
Material
BC (7 wt.%) and water

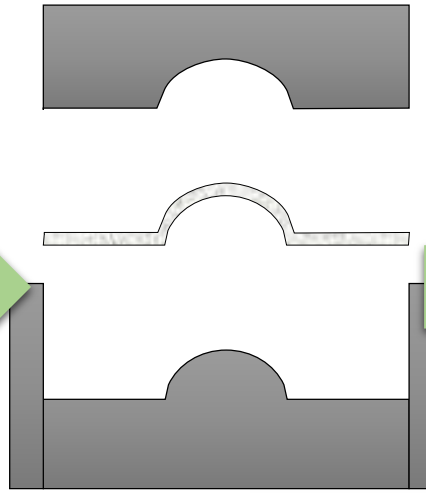
Dewatering & Molding

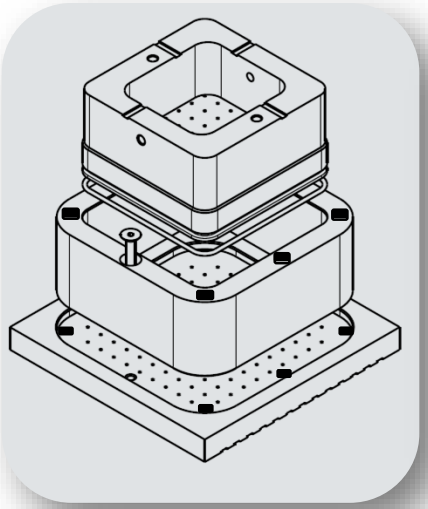
Demolding

Finalization



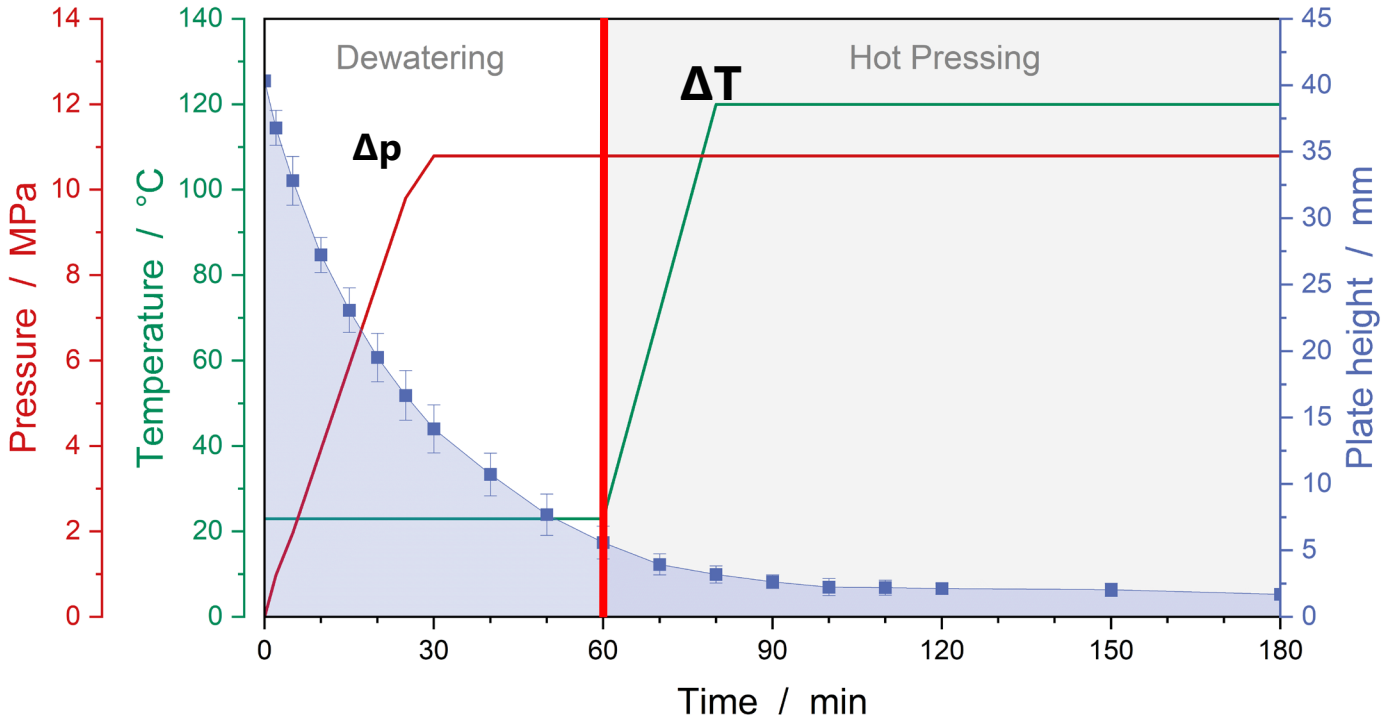


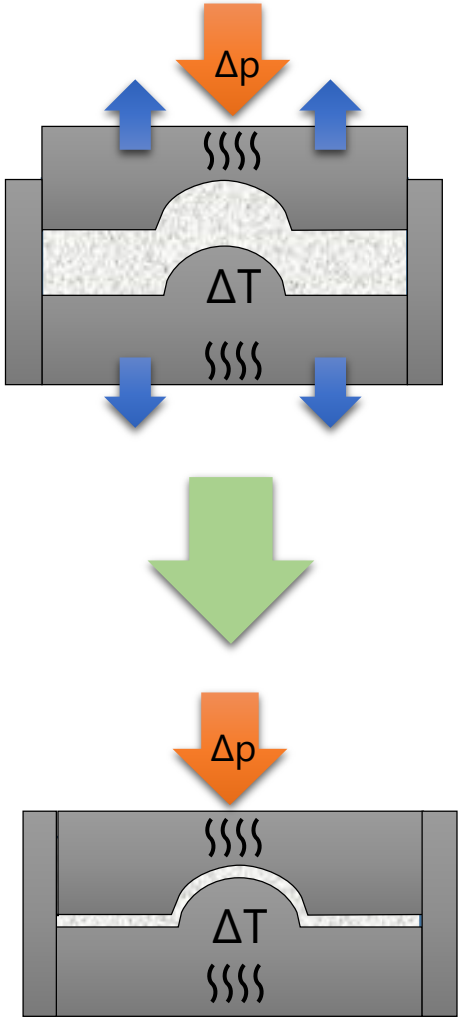




Processing of high-strength rigid boards with BC

Process optimization with BC-02 (7 wt.%) and water

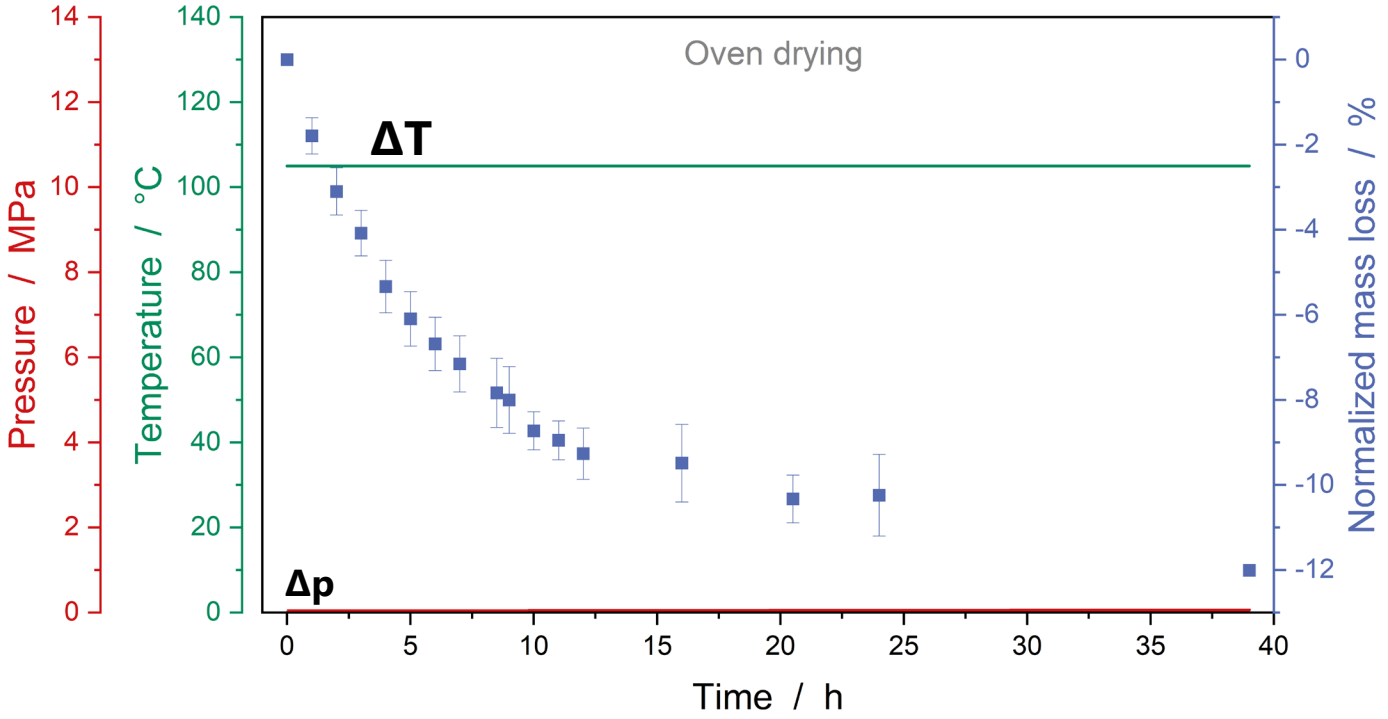


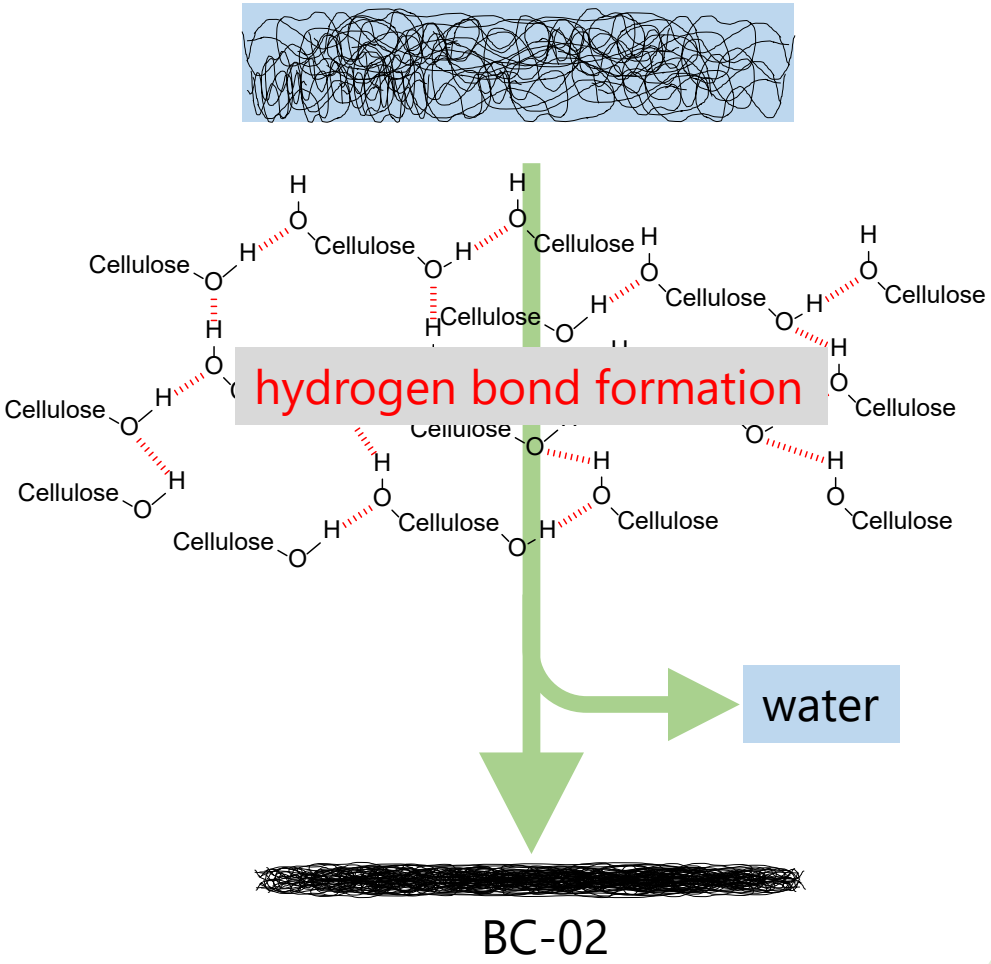


Geiger, T.; Hoffmann, K.G.; Nyström, G., oral presentation and proceeding, ECCM20, Lausanne, Switzerland, June 26-30, 2022

Processing of high-strength rigid boards with BC

Process optimization with BC-02 (7 wt.%) and water

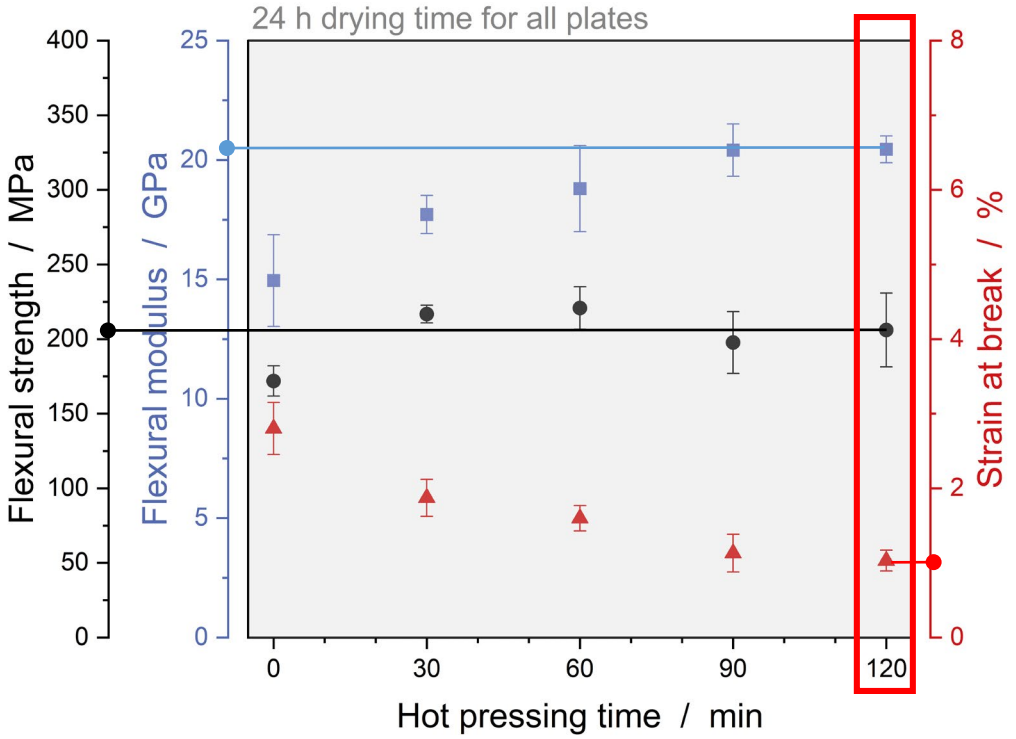




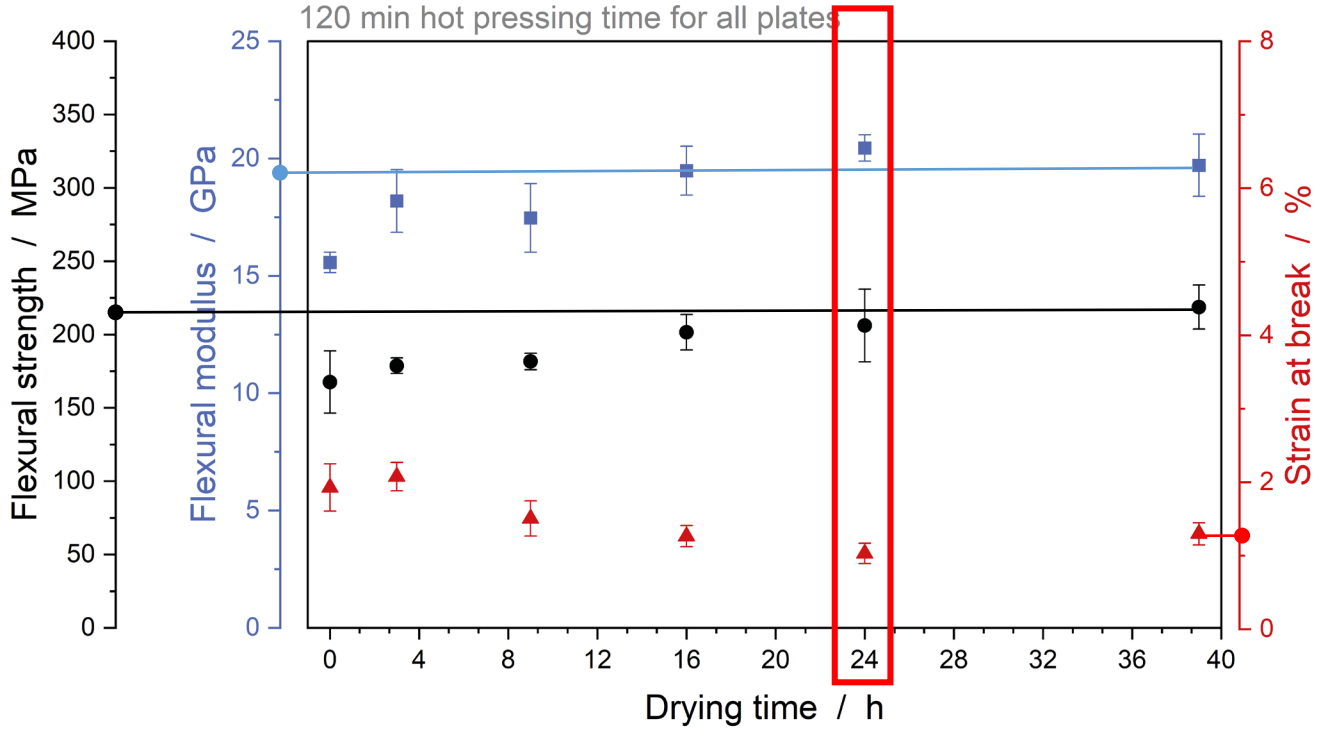
Geiger, T.; Hoffmann, K.G.; Nyström, G., oral presentation and proceeding, ECCM20, Lausanne, Switzerland, June 26-30, 2022

Processing of high-strength rigid boards with BC

Process optimization with BC-02 (7 wt.%) / water



@ 120min

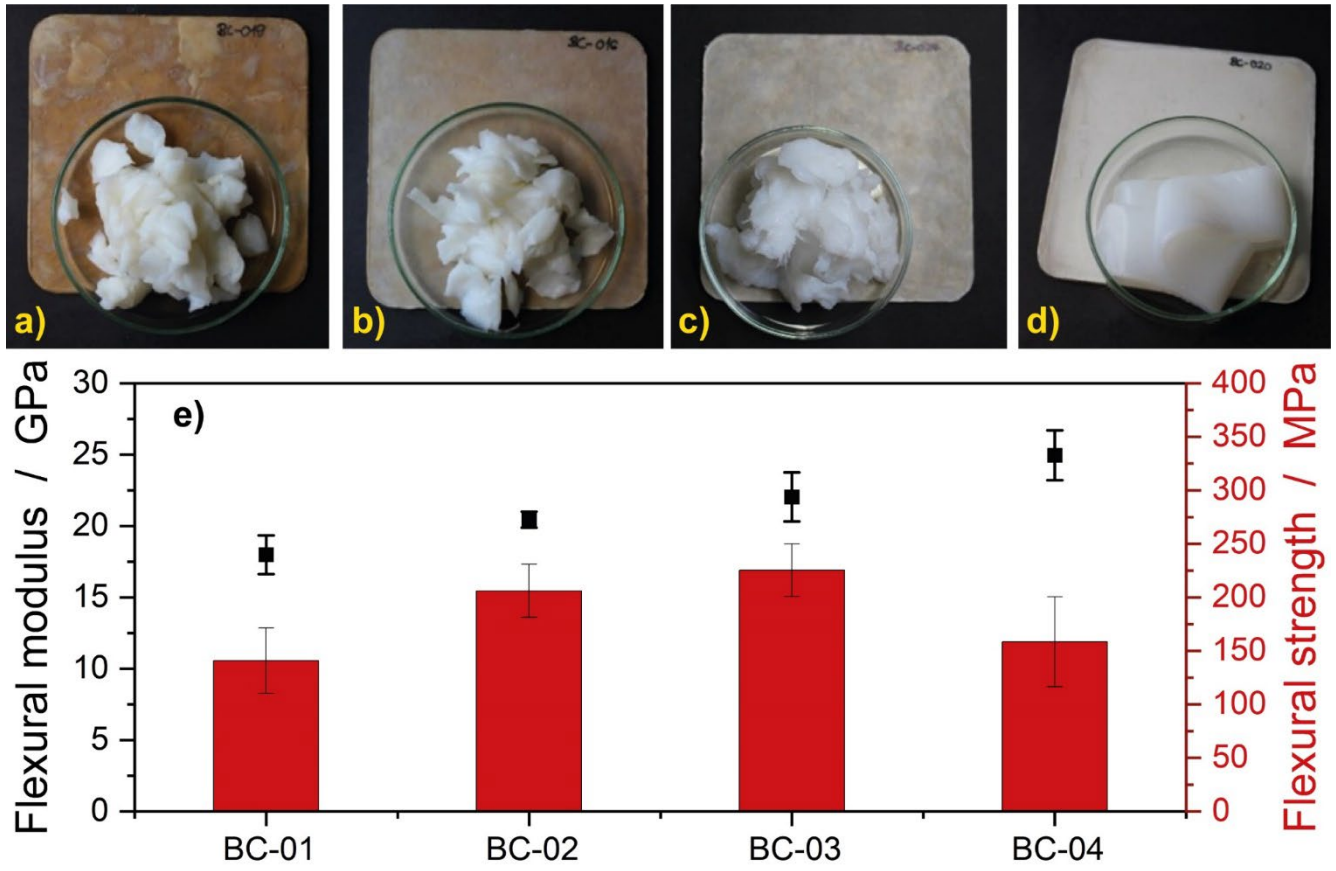


@ 105°C

Optimization: **pressing time of 120 min at 11 MPa and a drying time of 24 h at 105 °C**

Geiger, T.; Hoffmann, K.G.; Nyström, G., oral presentation and proceeding, ECCM20, Lausanne, Switzerland, June 26-30, 2022

Board properties

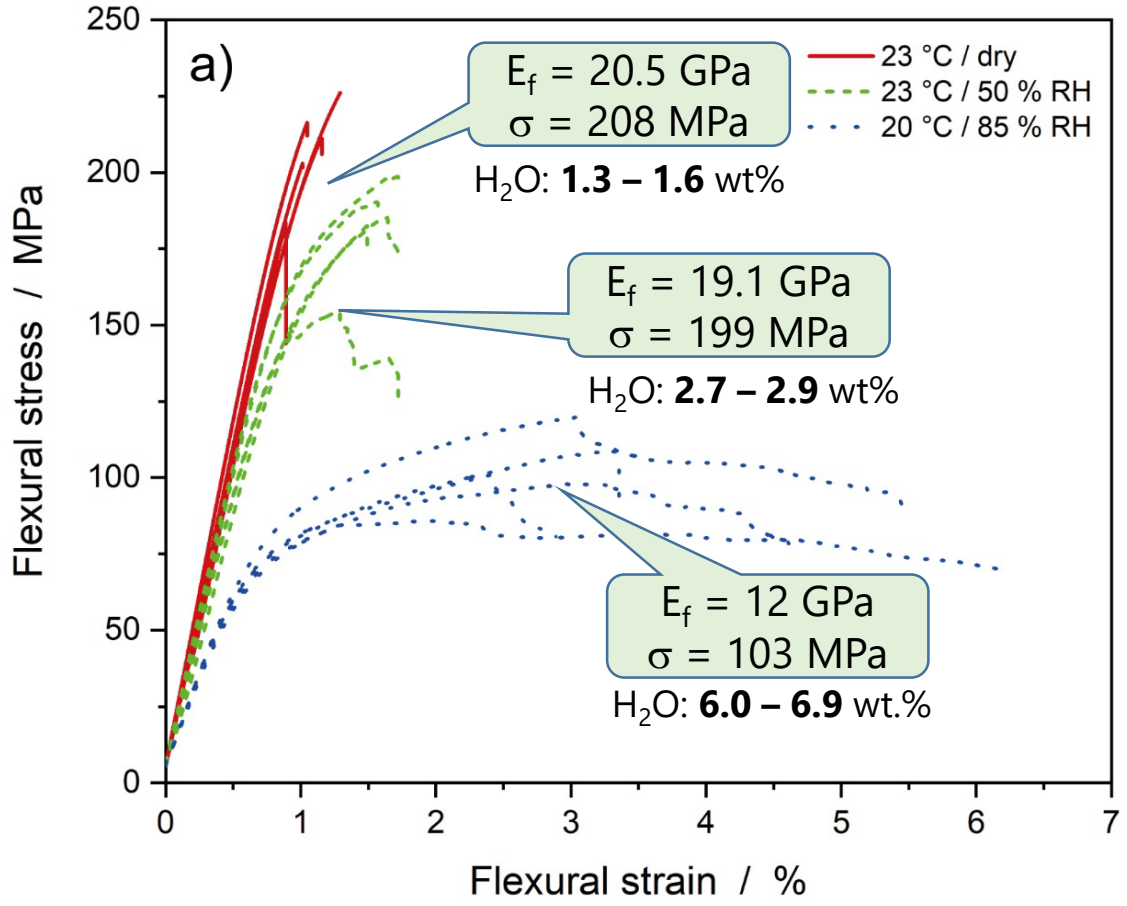


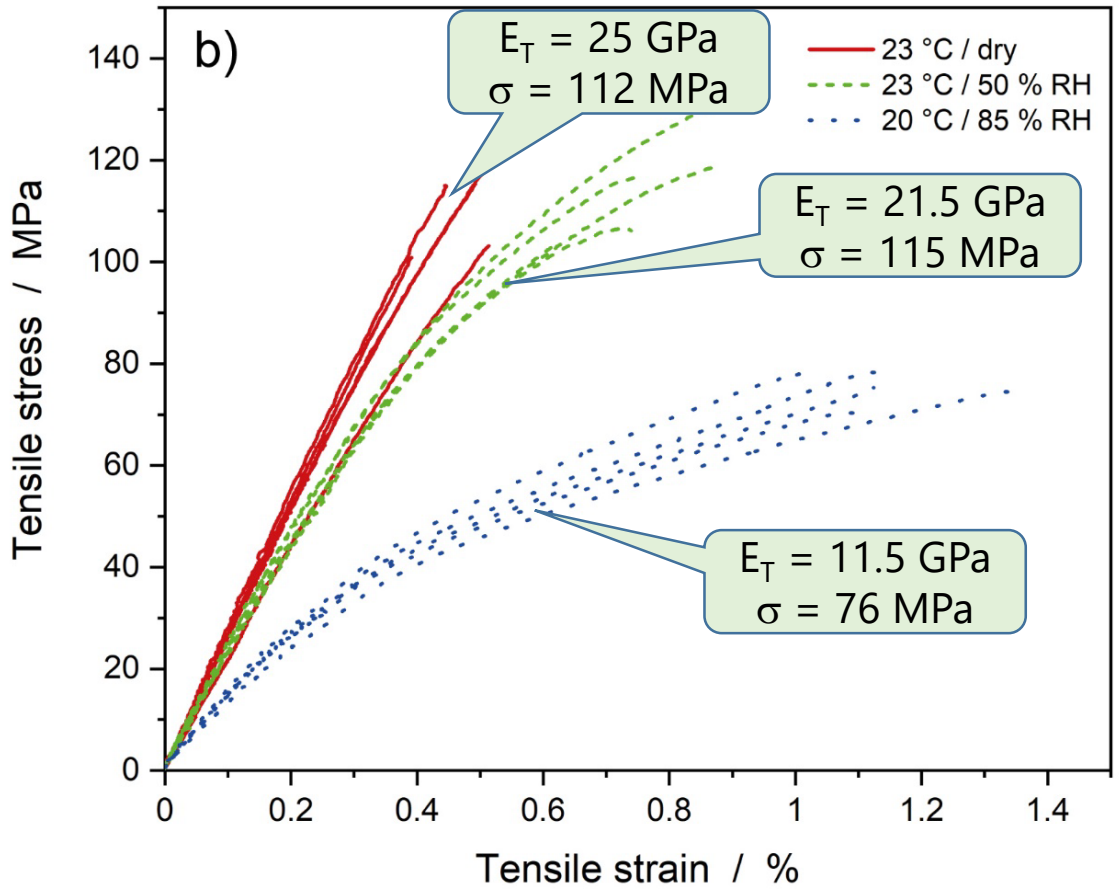
- **BC-01** (a) :
  raw nata de coco
  from 99 Gold Data Trading Co., Ltd. (Vietnam)
  → cheapest, but low performance
- **BC-02** (b):
  rinsed nata de coco
  → cheap, good performance
- **BC-03** (c):
  nata de coco **bleached** with NaOH and NaClO
  → not sustainable, good performance
- **BC-04** (d):
  BC sheets produced and **purified** by
  fzmb GmbH (Bad Langensalza, Germany)
  → high price product

Geiger, T.; Hoffmann, K.G.; Nyström, G., oral presentation and proceeding, ECCM20, Lausanne, Switzerland, June 26-30, 2022

Board properties

Mechanical tests of rigid boards made of BC-02



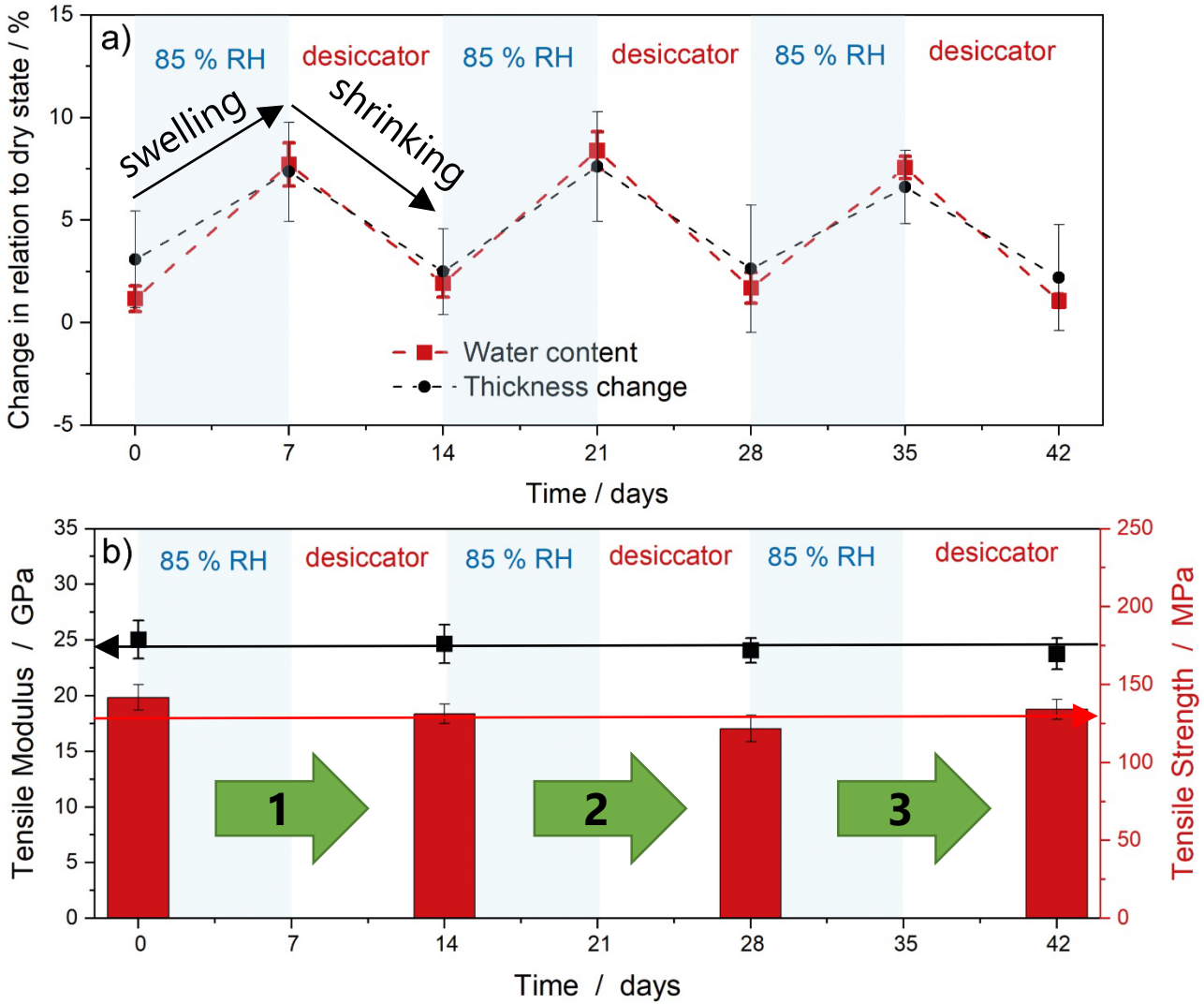


Geiger, T.; Hoffmann, K.G.; Nyström, G., oral presentation and proceeding, ECCM20, Lausanne, Switzerland, June 26-30, 2022

Board properties

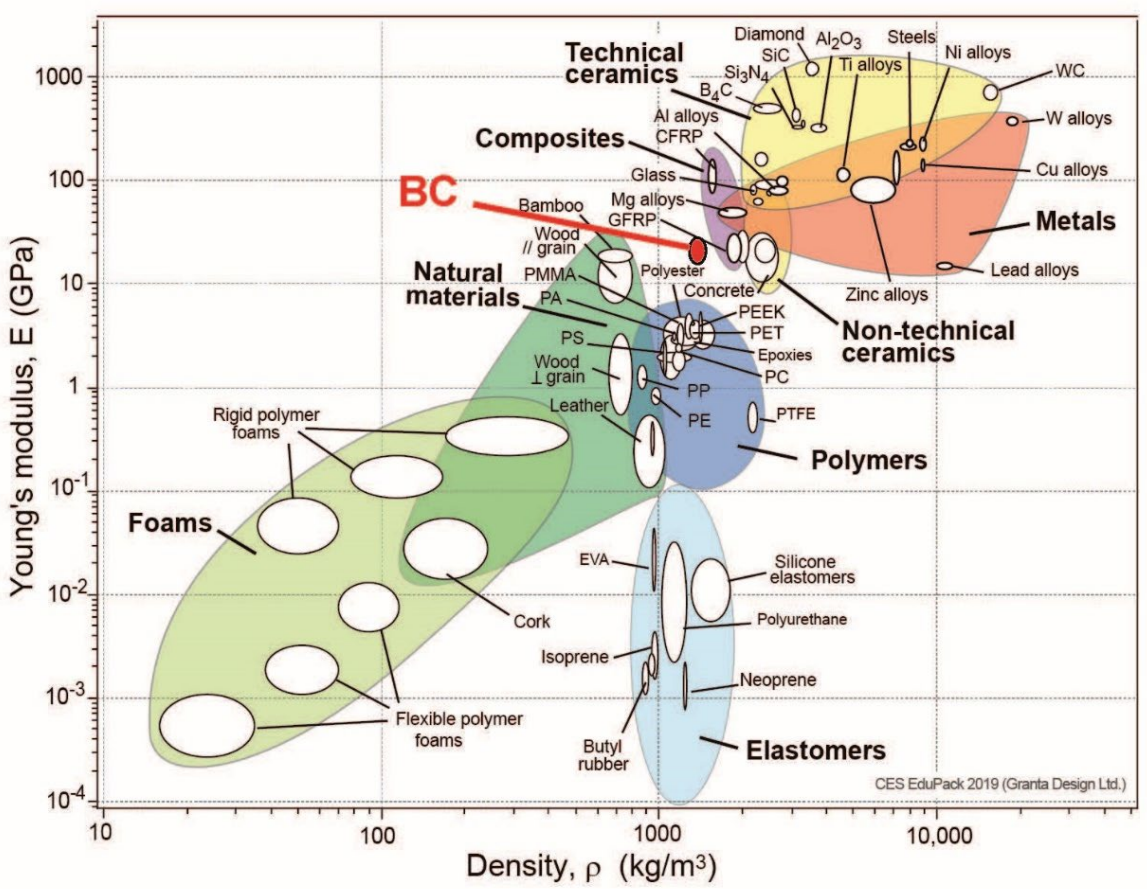
Cycles of wetting and subsequent drying (BC-02)

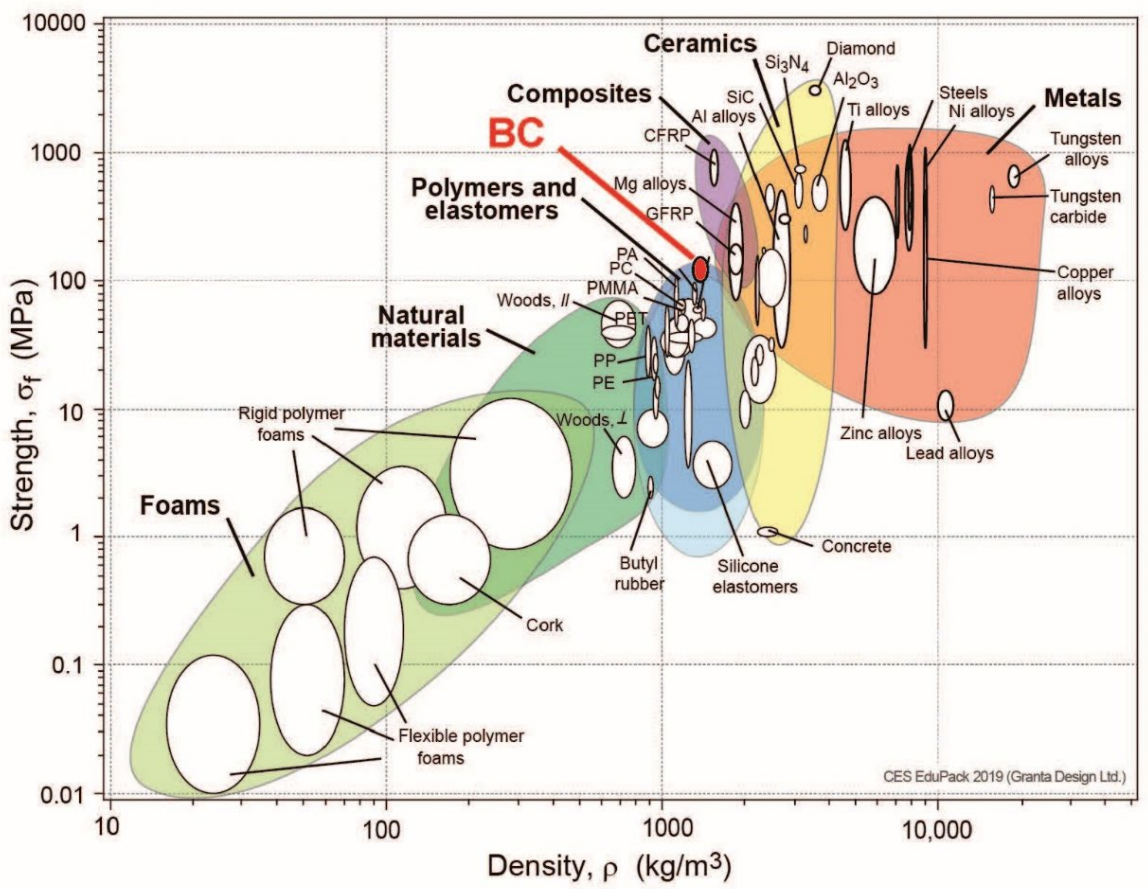
- incorporation of water is reversible
- original mechanical properties are regained



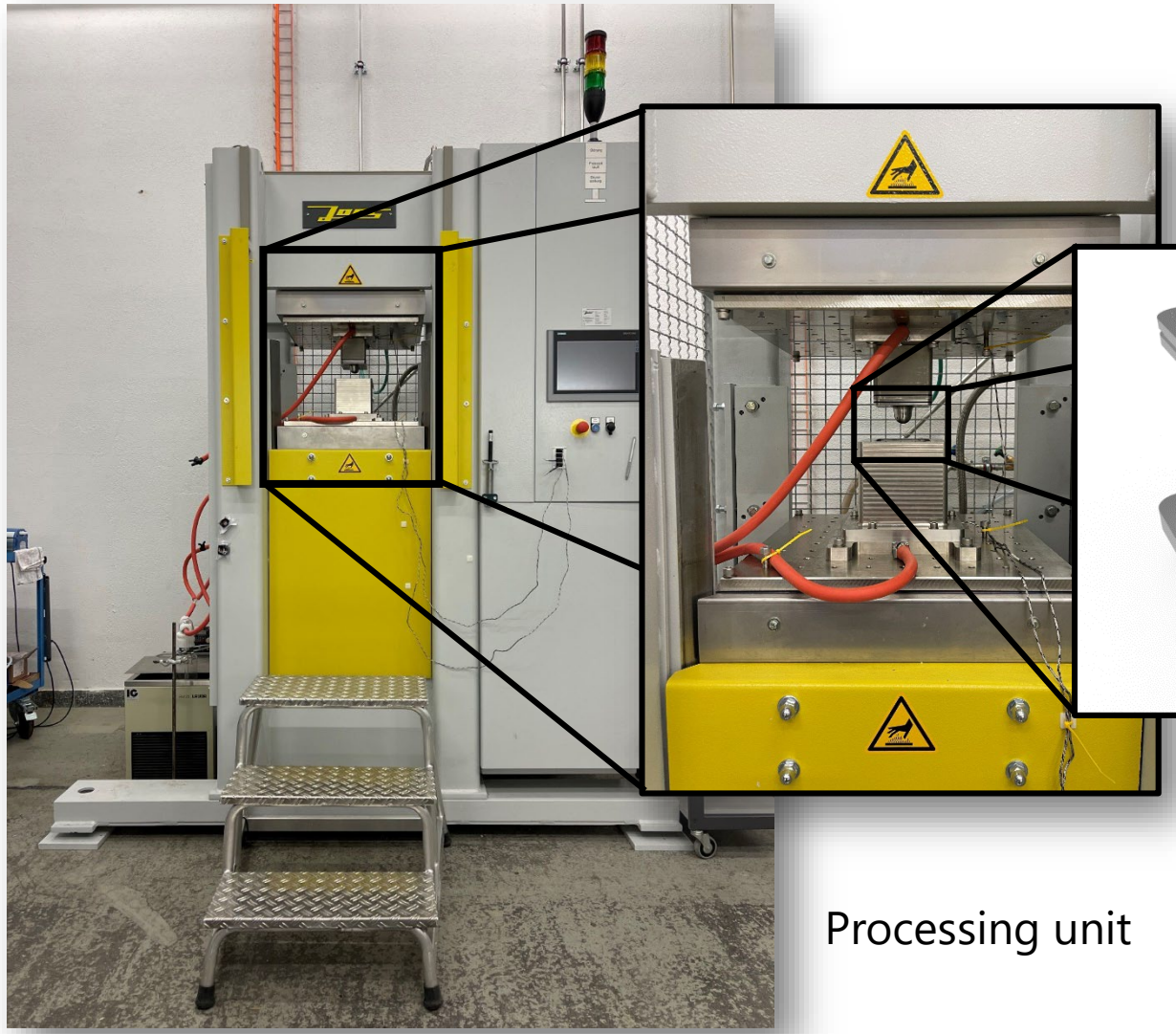
Geiger, T.; Hoffmann, K.G.; Nyström, G., oral presentation and proceeding, ECCM20, Lausanne, Switzerland, June 26-30, 2022

Board properties

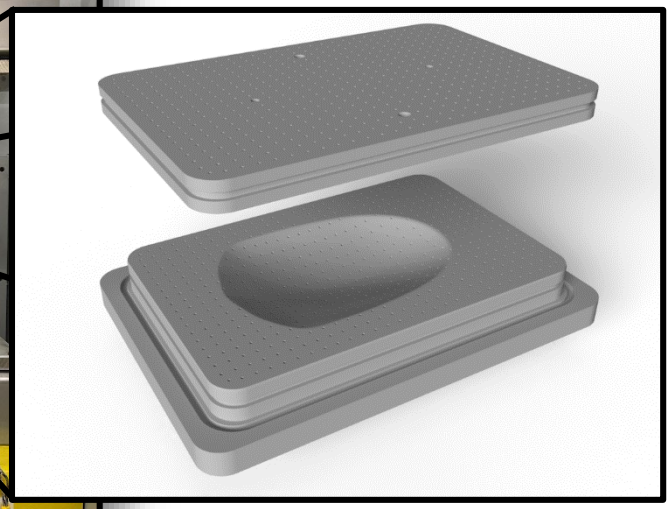




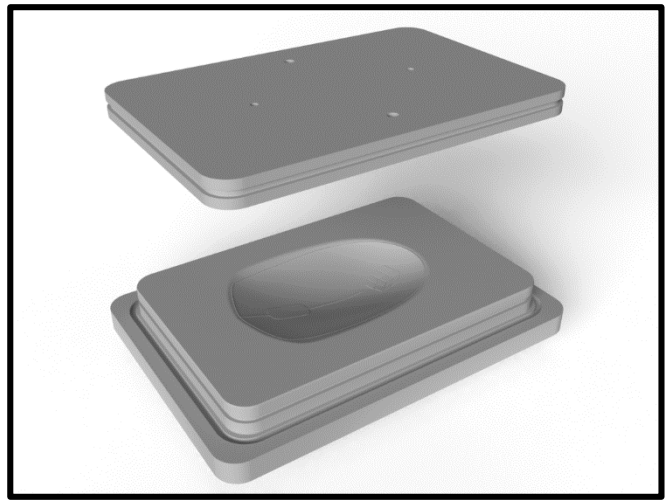
Future applications – molded parts



Processing unit



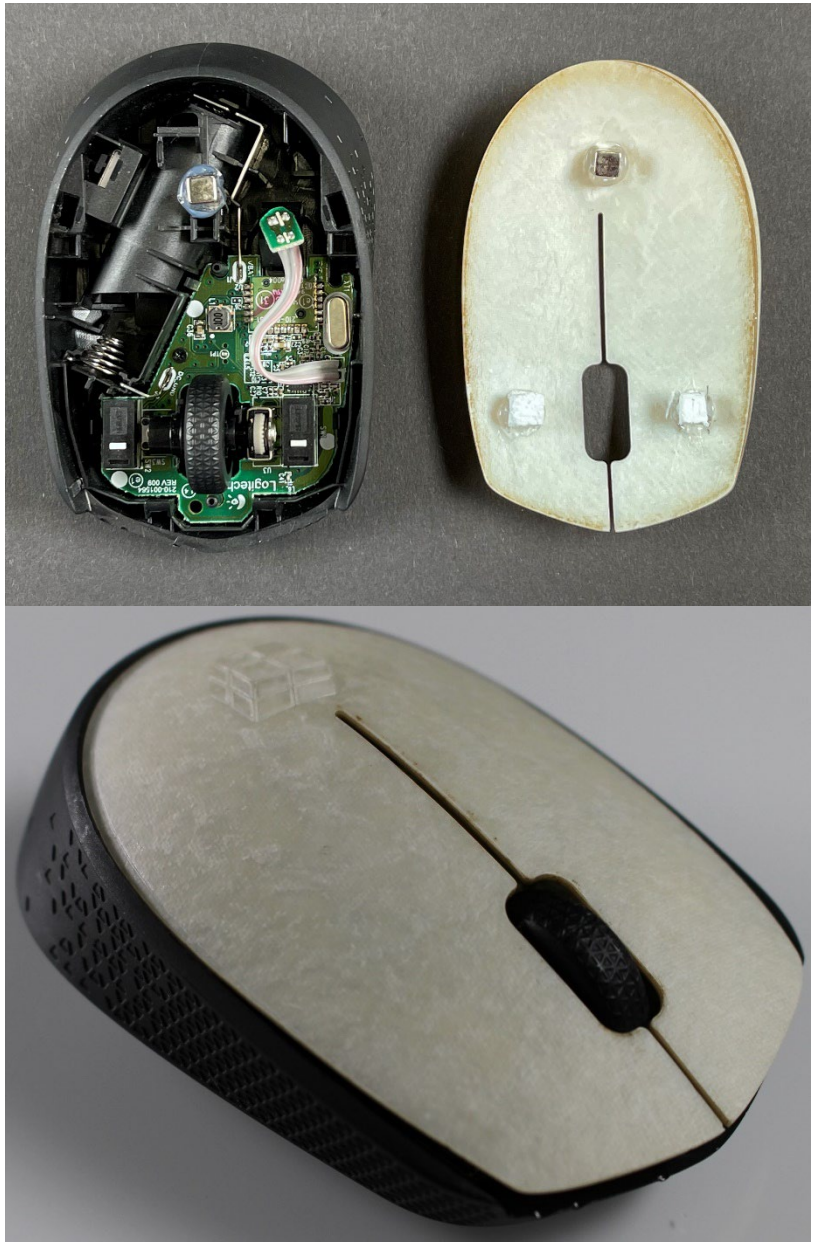
Mold for dewatering



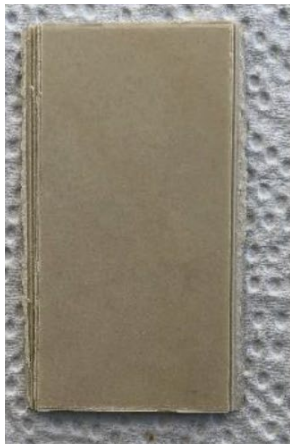
Mold for surface finish

Future applications – molded parts

CNF BC Fiber

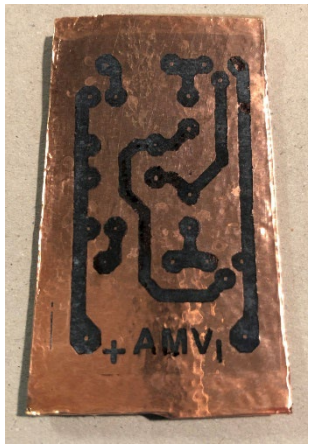


Future applications – PCBs



NFC or BC board

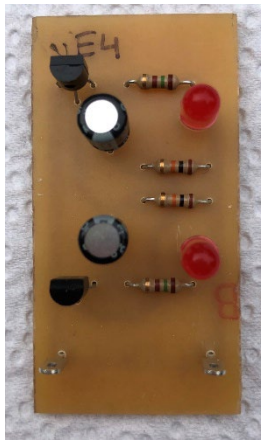
copper foil



masking

aqueous etching

drilling



placement

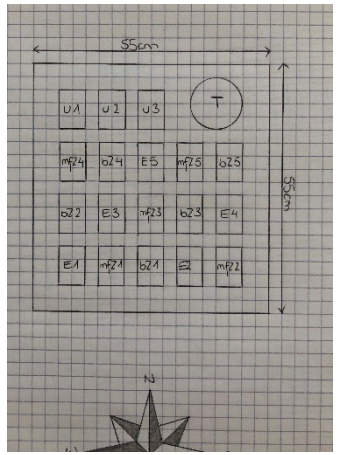
soldering

regenerative circuit (astable multivibrator)

C. K. Geiger «Cellutronic - The circuit board of the future» maturity graduation work, cantonal school Zürich Nord (2021)
Geiger, T.; Geiger, C.K.; Hoffmann, K.G.; Nyström, G., poster presentation and proceeding, ECCM20, Lausanne, Switzerland, June 26-30, 2022

Future applications – PCBs

compost preparation



sample preparation

home composting for 5 months

sample collection

ecoPCB

Epoxy-PCB

C. K. Geiger «Cellutronic - The circuit board of the future» maturity graduation work, cantonal school Zürich Nord (2021)
Geiger, T.; Geiger, C.K.; Hoffmann, K.G.; Nyström, G., poster presentation and proceeding, ECCM20, Lausanne, Switzerland, June 26-30, 2022

Future applications – PCBs

FR2 specifications - phenolic paper or phenolic cotton paper

NO	ITEM		UNIT	CONDITION AND METHOD	TYPICAL VALUE
1	SOLDER RESISTANCE(260^{0}C)		SEC	A	20-35
2	HEAT RESISTANCE		-------	150^{0}C30MIN	NO CHANGE
3	PEEL STRENGTH (35 Mm)		KGF/CM	A 280^{0}C10SEC	1.8-2.0
4	FLEXURAL STRENGTH	LENGTHWISE	KGF/MM^2	A	14-16
		CROSSWISE			13-14
5	VOLUME RESISTIVITY		W CM	C-96/20/65	1X10$^{13\sim14}$
6	SURFACE RESISTANCE	ADHESIVE SIDE	W	C-96/20/65	1X10$^{11\sim12}$
		LAMINATE SIDE			1X10$^{10\sim11}$
7	INSULATION RESISTANCE		W	C-96/20/65	1X10$^{11\sim12}$
8	CHEMICAL RESISTANCE		------	3%NaOH 40^{0}C 3 MIN	NO CHANGE
				BOILED IN TRICHLOROETHYLENE FOR 3 MIN	
9	WATER ADSORPTION		%	E-24/50+D-24/23	0.7~0.9
10	FLAMMABILITY		SEC	A UL94	AVG 3.0 MAX 8.0
11	DIELECTRIC CONSTANT (1MHZ)		-----	C-96/20/65	4.0-5.0
12	DISSIPATION FACTOR		------	C-96/20/65	0.025~0.035
13	CTI		V/	0.1%NH_4Cl UL746A	>600V
14	PUNCHING TEMPERATURE		^{0}C	A	AMBIENT70

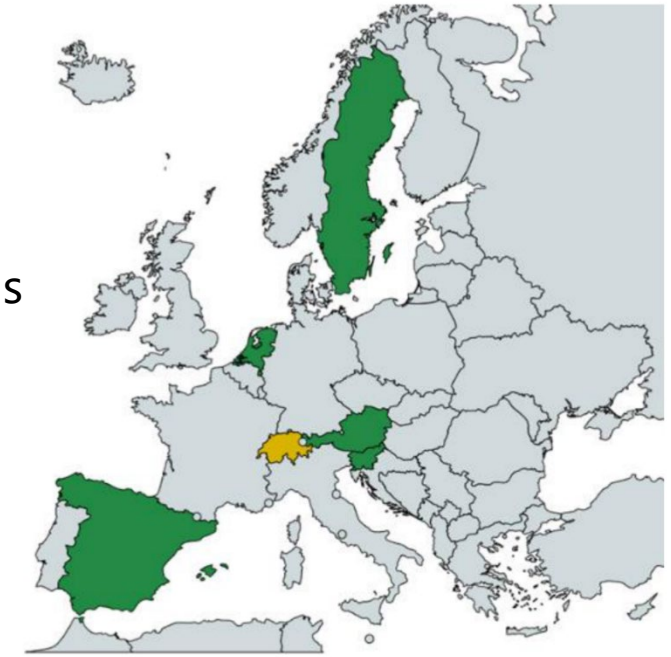
FR4 specifications - fiberglass impregnated with epoxy resin

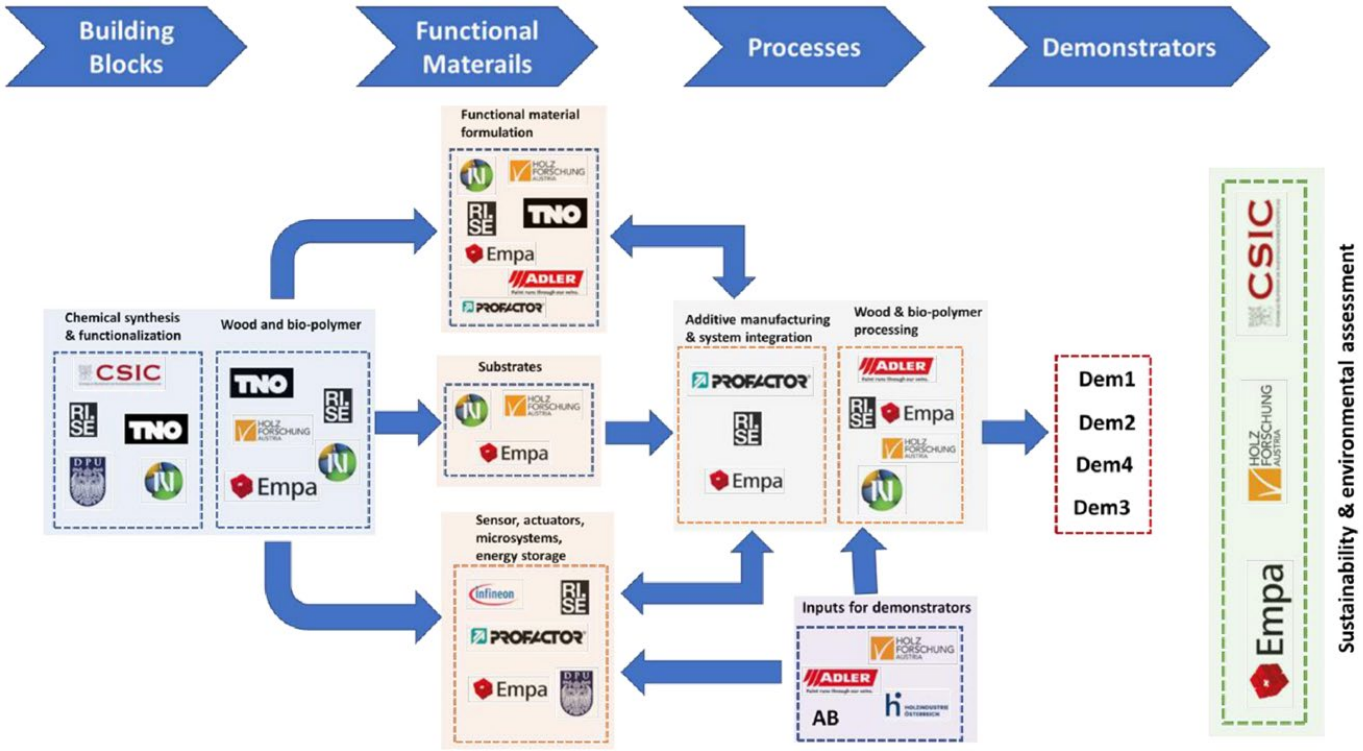
Parameter	Value
Specific gravity/density	1.850 g/cm^3 (0.0668 lb/cu in)
Water absorption	−0.125 in < 0.10%
[illegible]	140 °C (284 °F)
Thermal conductivity, through-plane	0.29 W/(m·K),[1] 0.343 W/(m·K)[2]
Thermal conductivity, in-plane	0.81 W/(m·K),[1] 1.059 W/(m·K)[2]
Rockwell hardness	110 M scale
Bond strength	> 1,000 kg (2,200 lb)
Flexural strength (A; 0.125 in) - LW	> 415 MPa (60,200 psi)
Flexural strength (A; 0.125 in) - CW	> 345 MPa (50,000 psi)
Dielectric breakdown (A)	> 50 kV
Dielectric breakdown (D48/50)	> 50 kV
Dielectric strength	20 MV/m
Relative permittivity (A)	4.4
Relative permittivity (D24/23)	4.4
Dissipation factor (A)	0.017
Dissipation factor (D24/23)	0.018
Dielectric constant permittivity	4.70 max., 4.35 @ 500 MHz, 4.34 @ 1 GHz
Glass transition temperature	Can vary, but is over 120 °C
Young's modulus - LW	3.5×10^6 psi (24 GPa)
Young's modulus - CW	3.0×10^6 psi (21 GPa)
Coefficient of thermal expansion - x-axis	1.4×10^{-5} K^{-1}
Coefficient of thermal expansion - y-axis	1.2×10^{-5} K^{-1}
Coefficient of thermal expansion - z-axis	7.0×10^{-5} K^{-1}
Poisson's ratio - LW	0.136
Poisson's ratio - CW	0.118
LW sound speed	3602 m/s
SW sound speed	3369 m/s
LW acoustic impedance	6.64 MRayl

EU-Project HyPELignum

Exploring wooden materials in hybrid printed electronics:
a holistic approach towards functional electronics with net zero carbon emissions

Start: October 2022





- RISE Research Institutes of Sweden AG (SE)
- RISE Innventia AG (SE)
- Profactor GMBH (AT)
- Kemijski Institut (SI)
- Agencia Estatal Consejo Superoir de Inverstigaciones Cientificas (ES)
- Adler-Werk Lackfabrik Johann Berghofer GmbH & Co KG (AT)
- TNO Nederlandse Organisatie Voor Toegepast Natuurwetenschappelijk Ondertoek (NL)
- Österreichische Gesellschaft für Holzforschung Verein (AT)
- Infineon Technologies Austria AG (AT)
- Danube Private University GmbH (AT)
- Association of the Austrian Wood Industries (AT)
- Empa (Dü and SG)

Conclusion

- Bacterial cellulose nata de coco (BC):
  -exceptionally homogeneous network of nanofibrils of high-purity cellulose

- BC: - produced on an industrial scale by fermentation
  - available in various processing forms as cut flakes or sheets

- BC: - optimized thermo-compression and subsequent drying
  - dewatering, resulting in mechanically very stable boards with several millimeter thickness

- BC: - removal of impurities from the fermentation by moderate bleaching with NaClO and NaOH
  - improvement of the mechanical properties (flexural modulus of 22 GPa).

- BC: - influence of moisture disturbs the hydrogen bond network (plasticization)
  - Flexural and tensile modulus as well as strength decrease.
  - incorporation of water is reversible - original mechanical properties are regained

- BC: - can be molded into 3D shapes during dewatering and drying
  - application: mouse cover and PCB

Acknowledgment

Christine K. Geiger (BC, CNF and PCB boards)
Katrin G. Hoffmann (BC and CNF boards, testing)
Anja Huch (SEM)
Walter Risi, Roman Elsener (mechanical testing)
Urs Hintermüller, Erwin Pieper (mold design and construction)

Thank you for your attention !!!

Contact

Thomas Geiger
(thomas.geiger@empa.ch)

Empa
Cellulose & Wood Materials
Überlandstrasse 129
CH- 8600 Dübendorf

www.empa.ch
www.empa.ch/cwmlab
www.empa.ch/web/gei

Empa
Materials Science and Technology