Bacterial Cellulose Based Biodegradable Nanocomposites Prepared via Film Stacking

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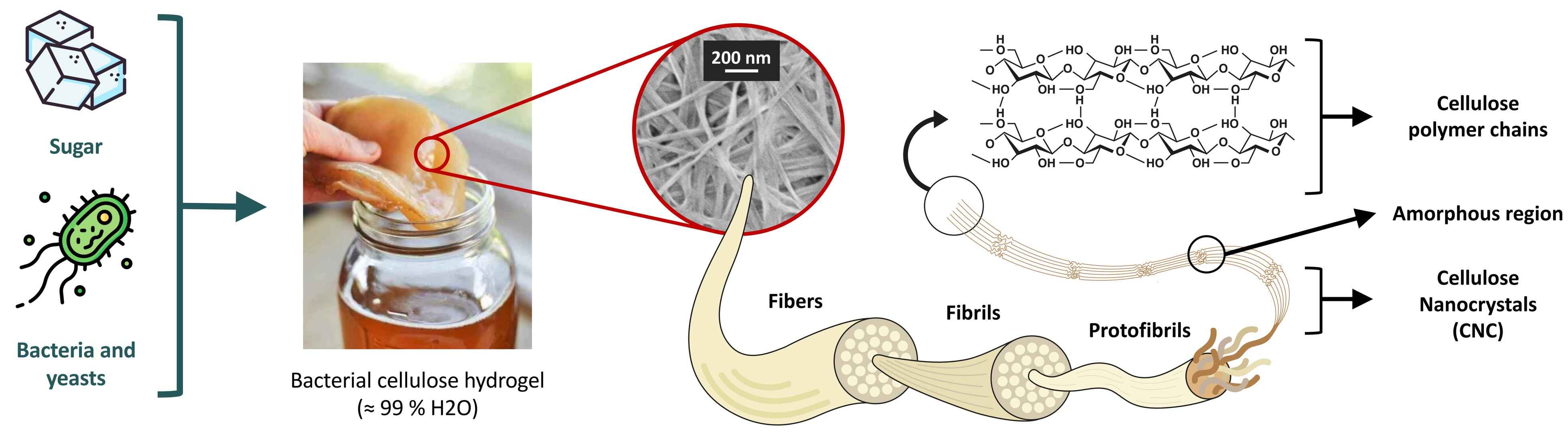
with the contribution of FONDAZIONE VRT

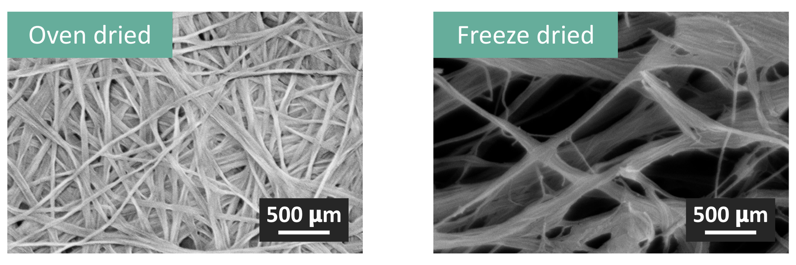
Introduction

Bacterial cellulose (BC)

Cellulose fibers organize in a **hierarchical structure,** constituting an interwoven **network**[1]. The mean cellulose ribbon diameter is equal to 86 ± 25 nm.



Interfibril Hornification: Irreversible **hydrogen bonds** between nanofibrils **upon drying,** producing a **brittle** BC sheet with **low fracture resistance.**



1. **High purity** (free from lignin and hemicellulose)
2. **High crystallinity** (compared to plant cellulose)
3. **Mechanical properties** (tensile strength and stiffness)
4. **Biocompatibility and Non-Toxicity**
5. **Biodegradability**

Film stacking of PLA and BC (+PEG)

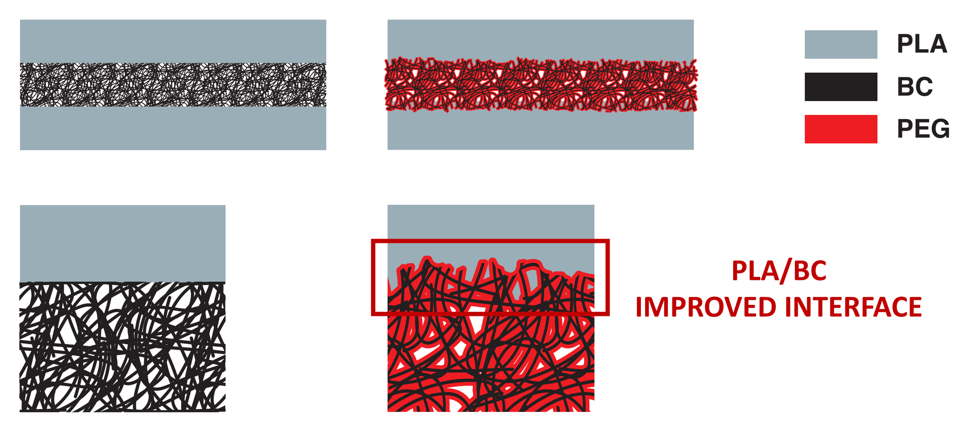
The properties of BC can be **tailored** by modifying the culture conditions during its production or by incorporating various **additives**, making it versatile for a wide range of **applications.**

BC as nano-reinforcement

- Mechanical properties ↑
- Gas barrier ↑
- High specific surface area

PEG impregnation

- BC plasticization (fiber sizing)
- PLA penetration
- PLA/BC adhesion ↑



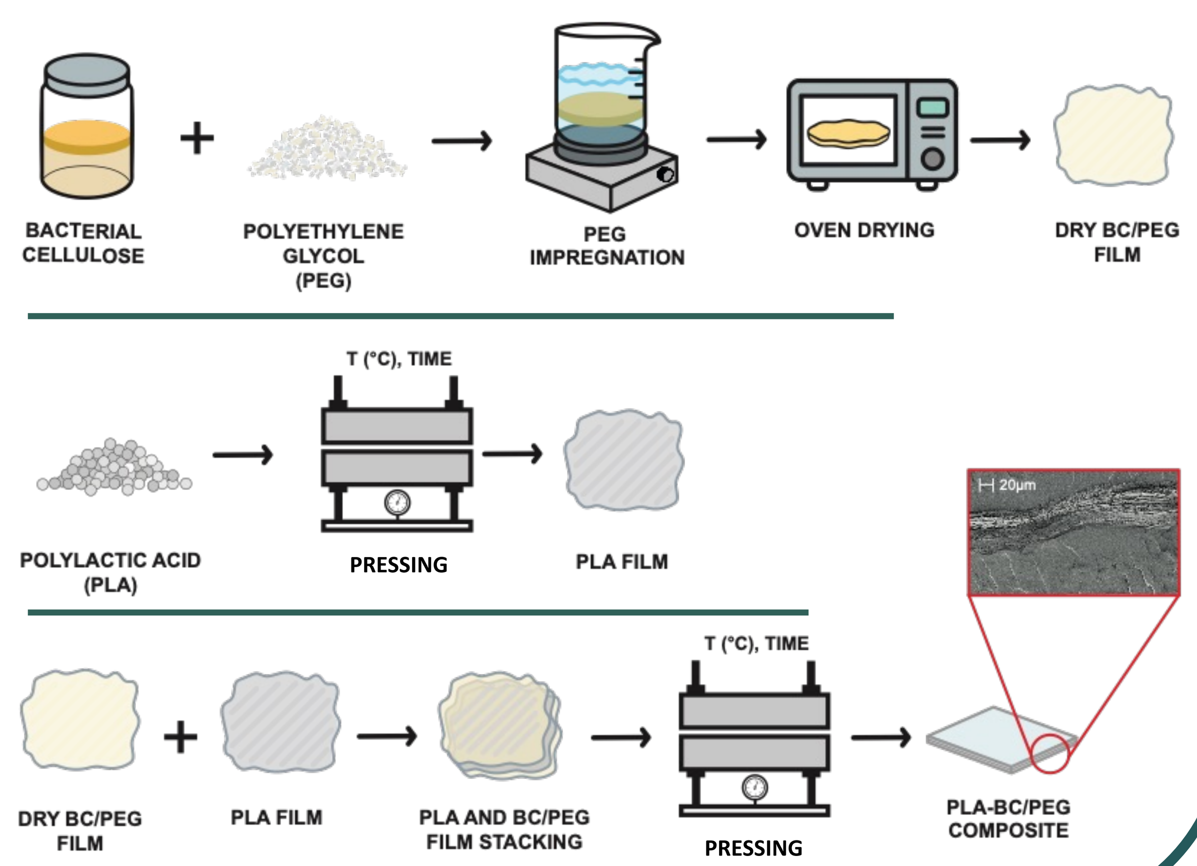
PLA = poly(lactic acid), BC = bacterial cellulose, PEG = poly(ethylene glycol)

Aim of the work: preparation and characterization of **PLA/BC/PEG composites** produced by **film stacking** of **PLA** and **PEG-impregnated BC** films.

Sample preparation

Prepared samples: **PLA/BC** or **PLA/BC+PEG** composites with 1 or «X» layer of BC as reinforcement.

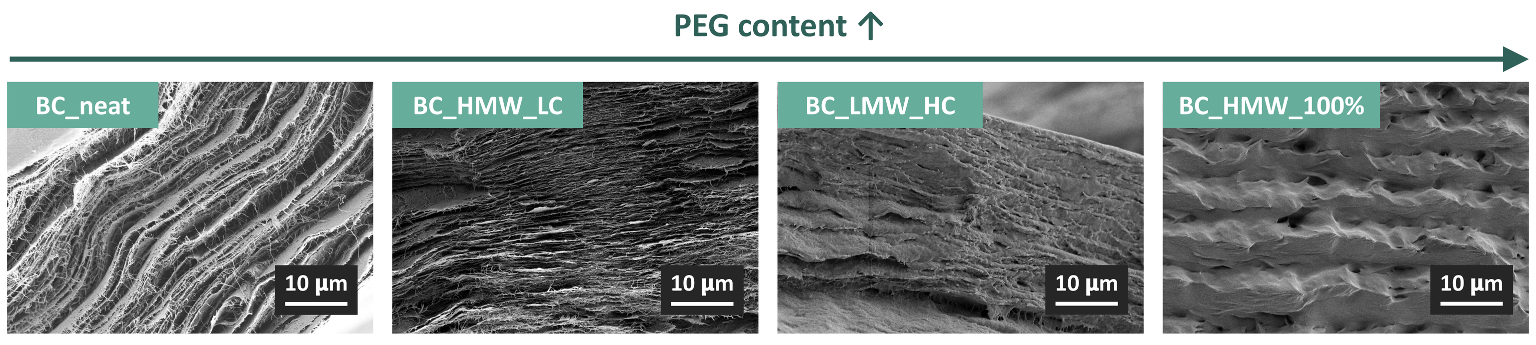
1. BC PEG-impregnation
2. PLA film production
3. Film stacking



Characterization of PEG-impregnated BC films

PEG impregnation: PEG with different MW (HMW or LMW) and concentrations (100%, HC or LC)

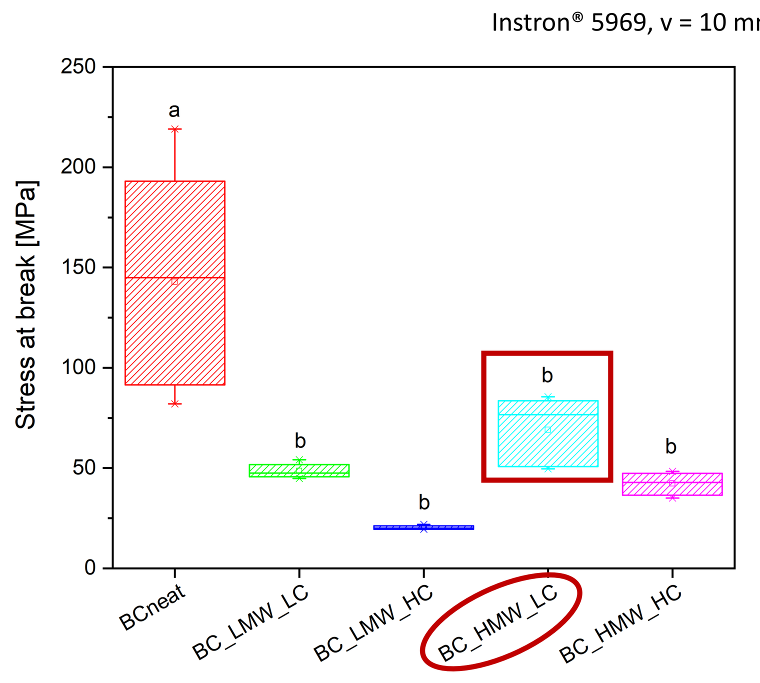
Microstructure – SEM micrographs (5.00 KX)



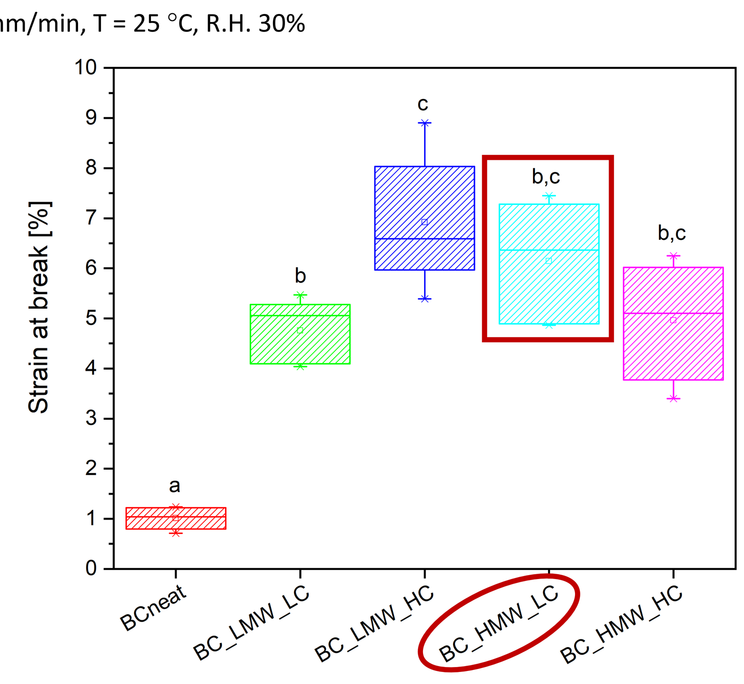
100 % PEG impregnation → too high PEG content (complete immersion of BC fibers inside PEG matrix

Quasi-static tensile tests (ASTM D882, 10 mm/min)

Instron® 5969, v = 10 mm/min, T = 25 °C, R.H. 30%



BC + PEG → σ_b ↓ (neat BC)
Higher σ_b for HMW_LC



BC + PEG → ε_b ↑ (neat BC)
Higher ε_b for LMW_HC

ANOVA and Tukey's post hoc tests were performed on the data. Equal letters indicate that the difference of the means is not significant at the 0.05 level.

Conclusions

The **PEG-impregnation** has positive effects on **BC** and **BC/PLA** composites:

- ✓ BC **brittleness** ↓
- ✓ BC **optical transparency** ↑
- ✓ **Adhesion** between BC and PLA ↑
- ✗ BC **gas barrier** properties ↓

The preparation of **PLA/BC/PEG composites** is effective in improving **PLA**:

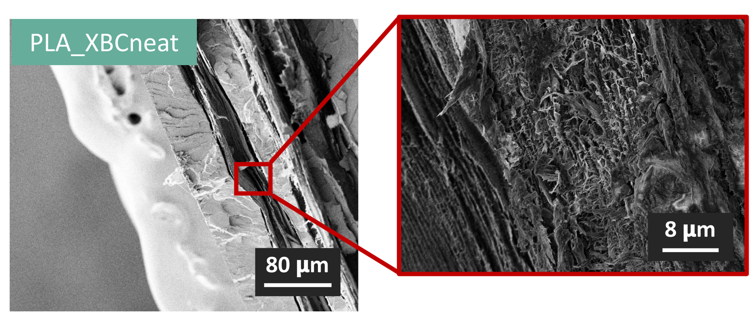
- ✓ Quasi-static **tensile properties** ↑
- ✓ **Gas barrier** properties ↑
- ✓ **UV barrier** properties ↑
- ✗ **Impact** properties and **toughness** ↓

Results and discussion

Characterization of PLA/BC/PEG composites

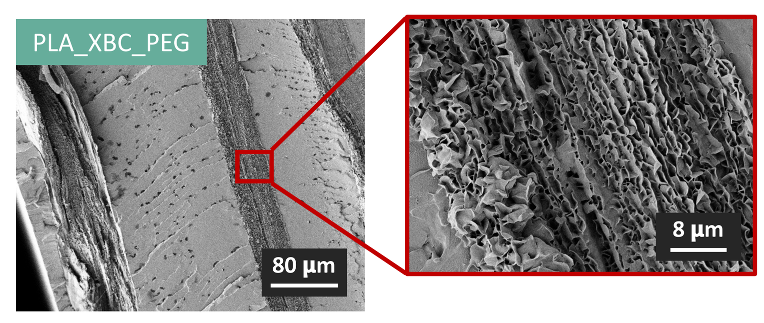
Microstructure – SEM micrographs (500 X, 5.00 KX)

PLA and BC neat



- Poor interfacial **adhesion**
- **Fracture** propagation along **different planes** (PLA and BC)

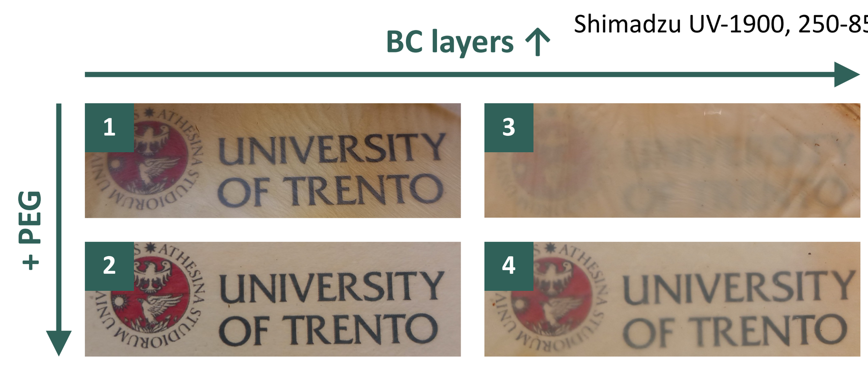
PLA and BC + PEG



- PEG → PLA/BC **adhesion** ↑
- **Fracture** propagation along **the same plane** (PLA and BC)

UV-vis spectroscopy

Shimadzu UV-1900, 250-850 nm



1. PLA_1BCneat, 2. PLA_1BC_PEG, 3. PLA_XBCneat, 4. PLA_XBC_PEG

Sample	T [%] at 600 nm	T [%] at 300 nm
BCneat	87	16
PLA_Neat	100	75
BC_PEG	98	73
PLA_1BCneat	88	9
PLA_XBCneat	69	1
PLA_1BC_PEG	93	11
PLA_XBC_PEG	87	2

Gas barrier properties

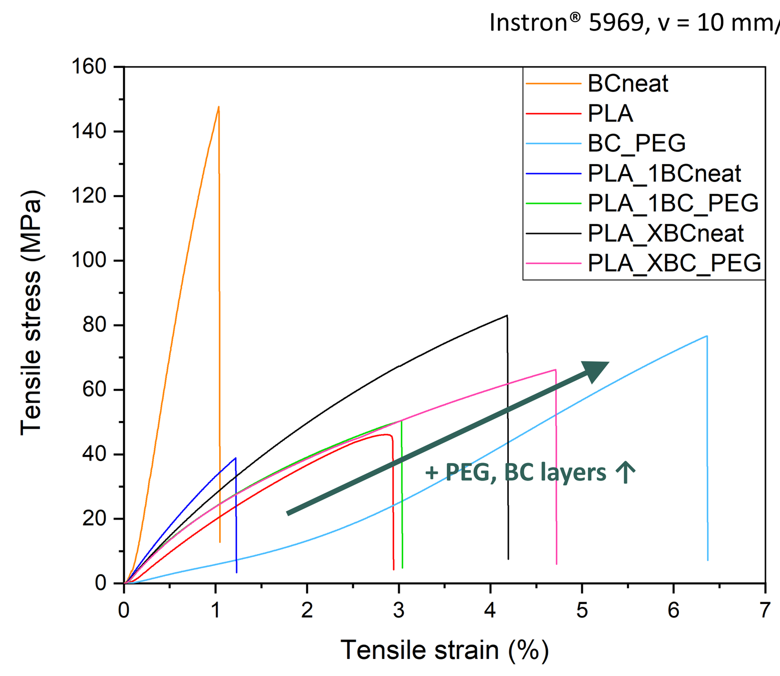
Sample	O_2 [barrer]	CO_2 [barrer]
PLA_Neat	0.33	1.20
BC_Neat	≈ 0.00	≈ 0.00
PLA_1BCneat	≈ 0.00	≈ 0.00
PLA_1BC_PEG	0.09	1.14

Gas permeability (O_2 and CO_2)
Mass spectrometer for gas permeability

BC → gas barrier ↑
PEG → gas barrier ↓
PLA + BC + PEG → gas barrier ↑

Quasi-static tensile tests (ASTM D882, 10 mm/min)

Instron® 5969, v = 10 mm/min, T = 25 °C, R.H. 30%

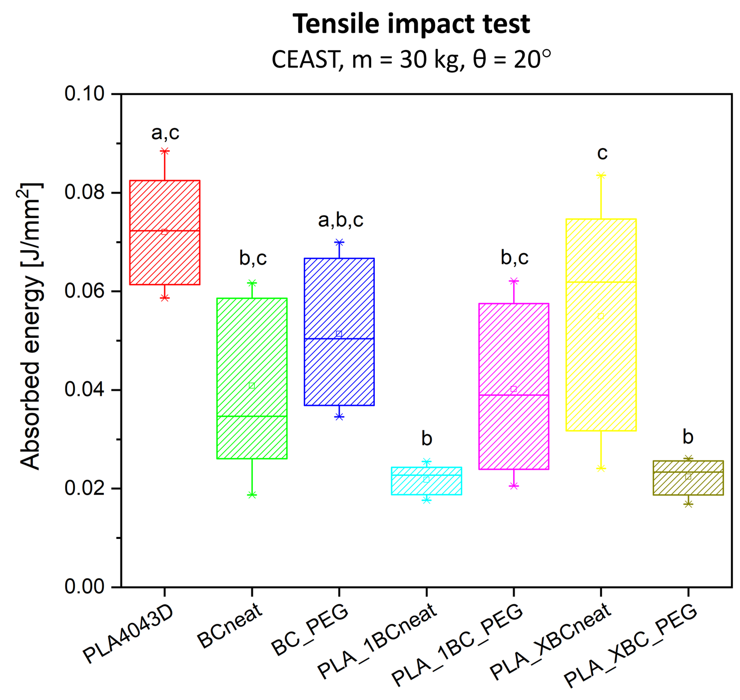


Sample	E (GPa)	σ_b (MPa)	ε_b (%)
PLA_Neat	3.2 ± 0.3	35.3 ± 9.0	2.7 ± 0.4
BC_Neat	23.5 ± 3.7	142.8 ± 54.4	1.0 ± 0.2
BC_PEG	2.1 ± 0.2	62.0 ± 15.3	6.1 ± 1.2
PLA_1BCneat	4.8 ± 0.2	33.1 ± 15.6	1.3 ± 0.5
PLA_1BC_PEG	4.0 ± 0.3	43.4 ± 8.3	3.0 ± 0.5
PLA_XBCneat	4.2 ± 0.2	74.1 ± 12.7	4.1 ± 0.8
PLA_XBC_PEG	3.9 ± 0.2	57.2 ± 9.0	4.5 ± 0.5

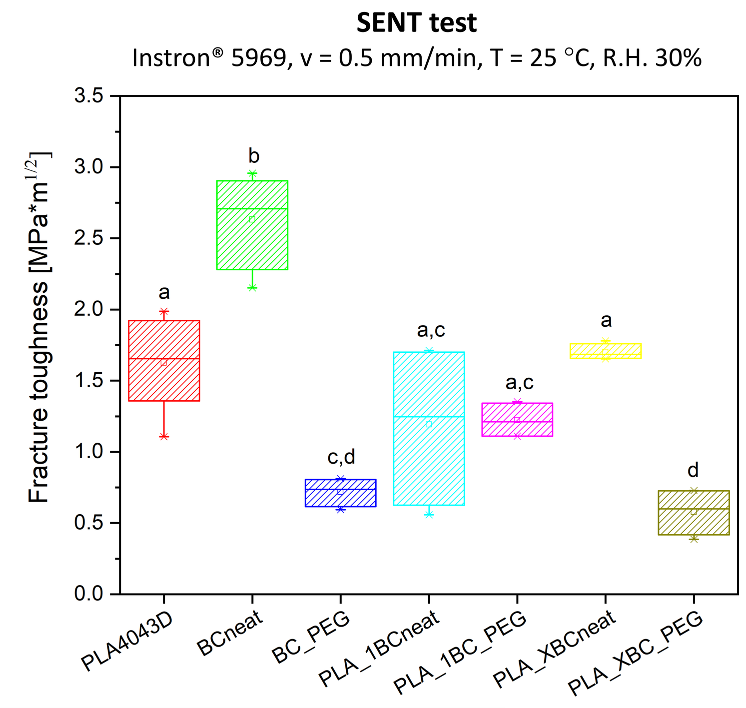
PLA + BC → E ↑, σ_b ↑, ε_b ↓
PLA + BC + PEG → E ↑, σ_b ↑, ε_b ↑
BC layers ↑ → σ_b ↑, ε_b ↑

Tensile Impact tests and SENT

Tensile impact test
CEAST, m = 30 kg, θ = 20°



SENT test
Instron® 5969, v = 0.5 mm/min, T = 25 °C, R.H. 30%



BC + PEG → impact **energy** ↑ but fracture **toughness** ↓ (neat BC)
BC layers ↑ → impact **energy** and fracture **toughness** ↑

References
[1] Dufresne, A., «Nanocellulose. From Nature to High Performance Tailored Materials», De Gruyter, 2013.

Acknowledgment
This work has been carried out thanks to the collaboration with Bioniks Srl, who synthesized and provided the bacterial cellulose (BC) and thanks to the financial support of Fondazione VRT. Erika Bordignon is gratefully aknowledged for the graphical collaboration.