Leibniz-Institut für Polymerforschung Dresden

BICOMPONENT PP FIBERS FOR SUSTAINABLE MINERAL BONDED STRAIN HARDENING COMPOSITES

ICCM23, 30 July – 4 August, 2023, Belfast, Ireland

Mihaela-Monica Popa[1], Mirza Abdul Basit Beigh[2], Cesare Signorini [2], Viktor Mechtcherine[2], Christina Scheffler[1]

[1] Leibniz-Institut für Polymerforschung Dresden e. V. (IPF), Dresden, Germany
[2] Technische Universität Dresden, Institute of Construction Materials, Dresden, Germany

Motivation

- existing reinforced concrete structures reveal low resistance to impact loading, such as shock, collision, or explosion

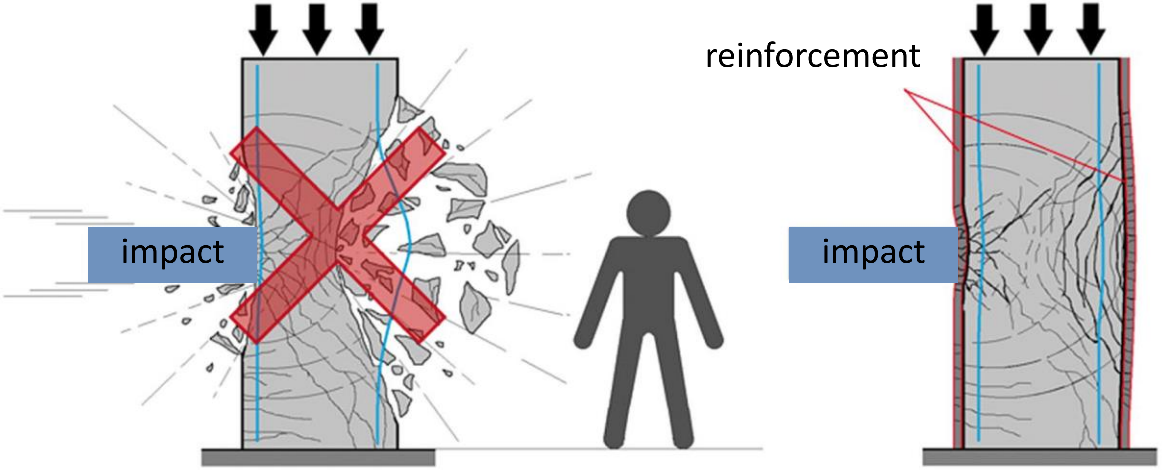
Glenwood Canyon, 2004, Foto: Colorado Department of Transportation. https://coloradogeologicalsurvey.org

Beirut residents after port explosion in 2020, https://edition.cnn.com

[1] Kim, K., & Lee, J. (2020). Fragility of bridge columns under vehicle impact using risk analysis. Advances in Civil Engineering, 2020, 1-14.
[2] https://www.nbmcw.com/article-report/infrastructure-construction/transportation-metrorail-airways-waterways/effects-of-blast-loading-on- engineering-structures-an-overview.html

Research Target

- application of thin layers of strengthening material using innovative, mineral-bonded composites
- economically and ecologically approach



Research Training Group

Mineral-bonded composites for enhanced structural impact safety

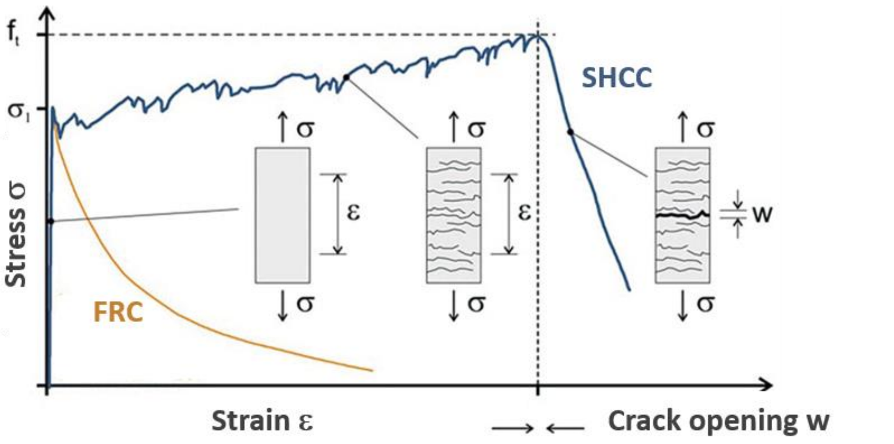
https://www.grk2250.de/

CUROSU, Iurie, et al. Mineral-bonded composites for enhanced structural impact safety: material level investigations. BETON-UND STAHLBETONBAU, 2021, 116. Jg., Nr. 1, S. 45-57.

State of the art

- strain-hardening concrete composites = polymer fibers (2 vol.-%) + concrete matrix
- fiber diameter 10-20 µm, widely used PVA, HDPE, PP

micro-crack bridging for high energy absorption



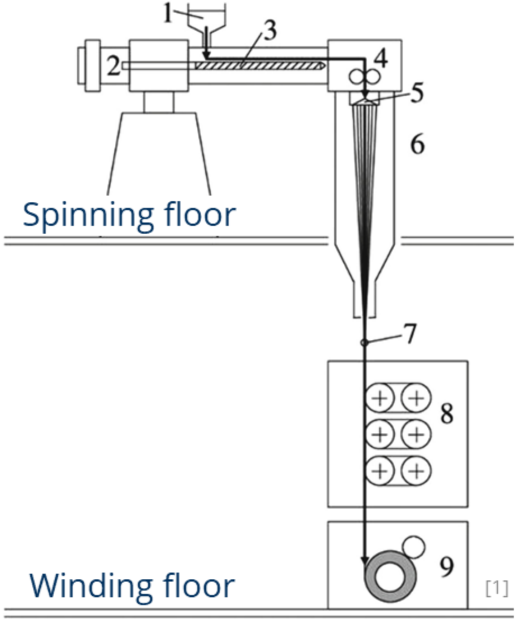
CUROSU, Iurie, et al. Mineral-bonded composites for enhanced structural impact safety: material level investigations. BETON-UND STAHLBETONBAU, 2021, 116. Jg., Nr. 1, S. 45-57.

Approach

Polypropylene fibers (PP):

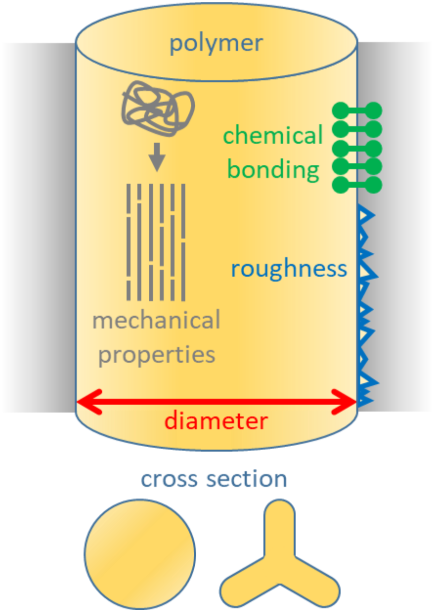
- high availability, cost-effective
- alkali-resistant
- production process can use recycled PP

Melt spinning



[1] Brünig, H. Adv Polym Sci (2018) 282: 1–34

Fundamental research on tailored fibers

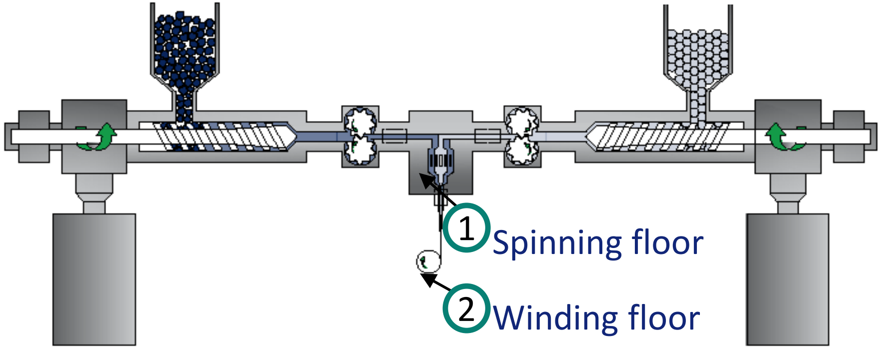


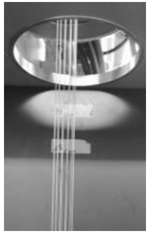
Wölfel, E., Brünig, H., Curosu, I., Mechtcherine, V., & Scheffler, C. (2021). Dynamic single-fiber pull-out of polypropylene fibers produced with different mechanical and surface properties for concrete reinforcement. Materials, 14(4), 722.

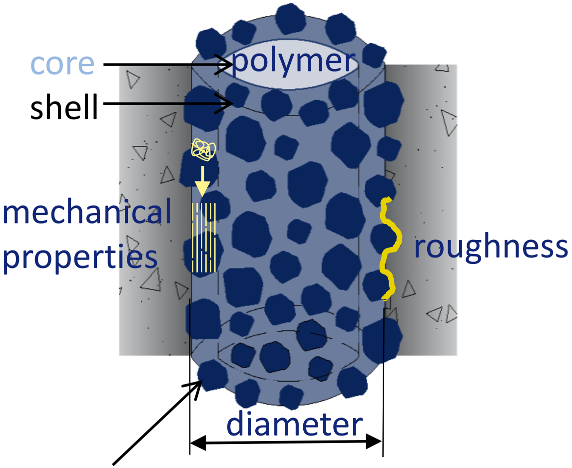
Approach

- Aim: Improvement of mechanical interlocking combined with high tensile strength
- → Development of bicomponent PP-fibers with increased surface roughness

Shell material: PP + $CaCO_3$ Core material: pure PP

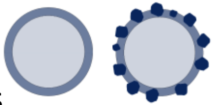




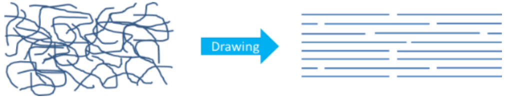


CaCO3 particles
average size – 2 µm

- **Spinneret**
  Eleven holes



- **Online drawing**
  Enhanced mechanical properties

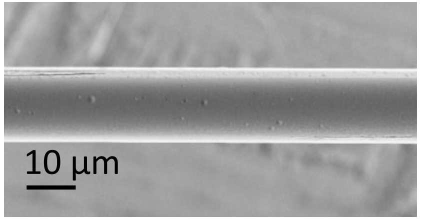


- **Chamber size**
  Endless fibers
- **Spin finish**
  Favisan UF 1625: 90% water
  + 10% Tenside composition

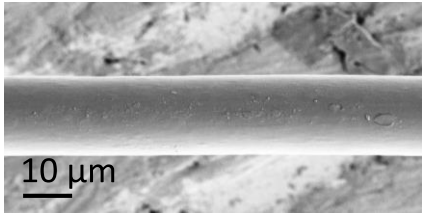
Experimental plan

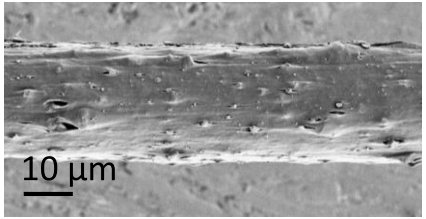
- core/shell ratio 75/25
- incorporating $CaCO_3$-particle content
- dies size 0.3 x 0.6 mm
- v = 2400 m/min
- drawing ratio DR=3

Commercial PP-fiber (mono), d = 19.8 µm

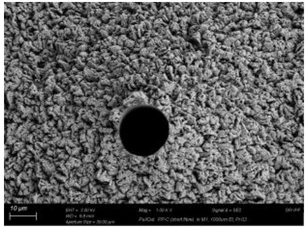


PP + PP, d=27.61 µm



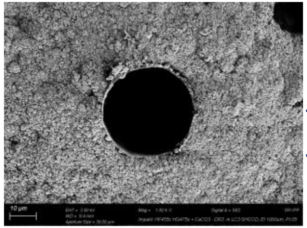


PP + 10 vol.% $CaCO_3$, d=28.37 µm



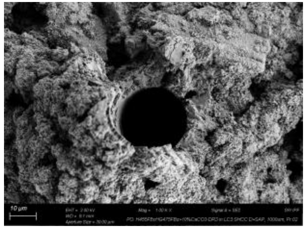
M1 matrix

GRK2250/I
– basis model mix
– high strength matrix
(Dr. Curosu I. 2016)



FRLC3 matrix

Optimized model mix
– ↑ sustainability
– LC3: lower CO_2 emissions,
↑ micro-mechanical properties



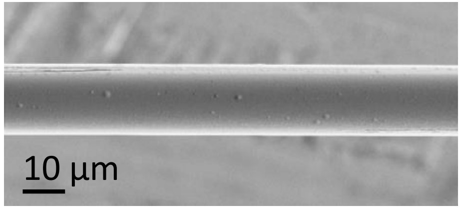
FRLC3 +SAP matrix

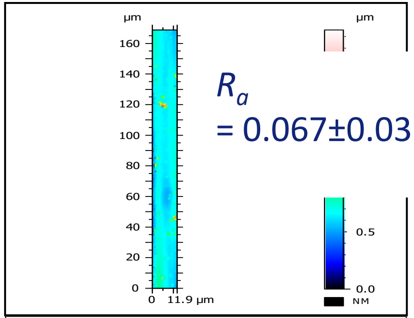
Superabsorbant polymer
– ↑ porosity →
↑ strain-hardening effect

Results – Fiber spinning trials

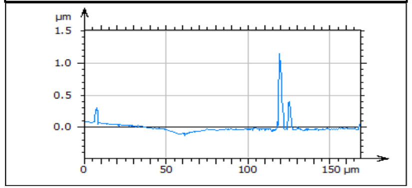
Analysis of surface morphology and roughness

Commercial PP-fiber (mono),

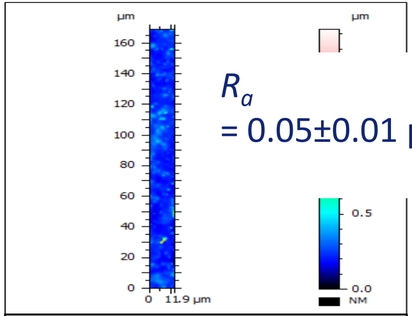




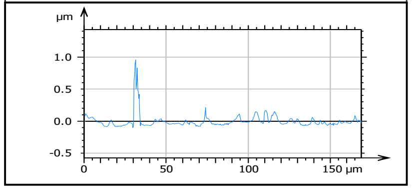
R_a = 0.067±0.036 µm



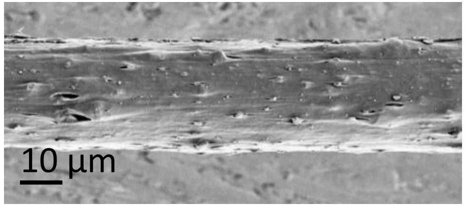
PP + PP_DR3

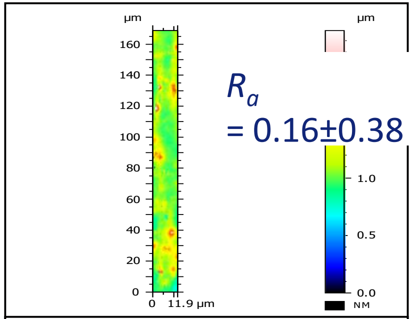


R_a = 0.05±0.01 µm

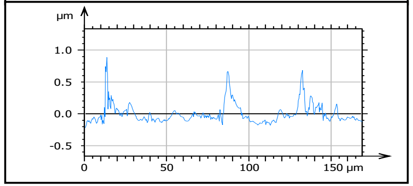


PP + 10 vol.% $CaCO_3$_DR3





R_a = 0.16±0.38 µm



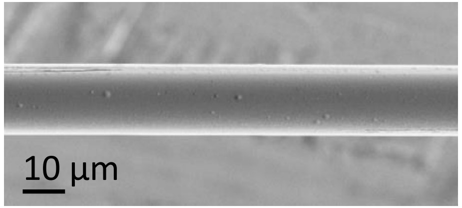
Confocal Microscope
(µSurf expert, Nanofocus AG)

R_a = arithmetic mean deviation of the surface

Results – Fiber spinning trials

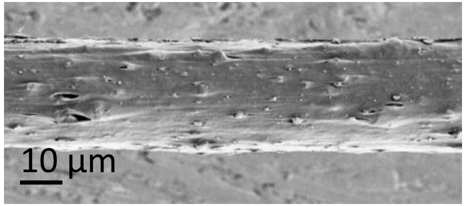
Analysis of mechanical properties

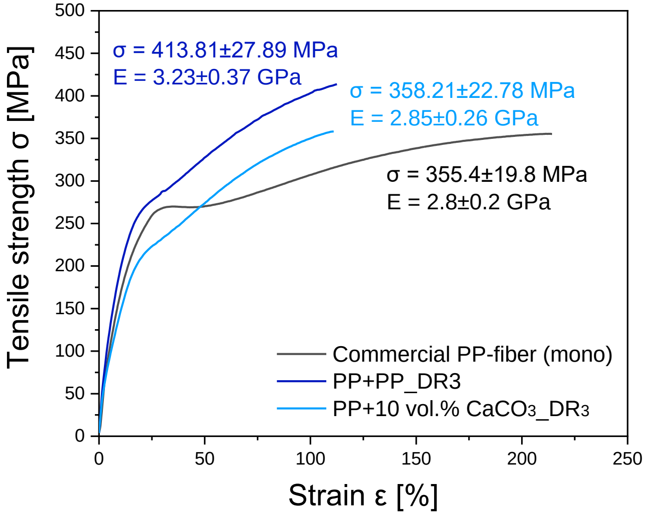
Commercial PP-fiber (mono),



PP + PP_DR3

PP + 10 vol.% $CaCO_3$_DR3



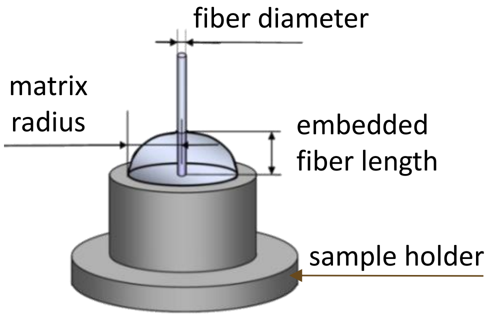


FAVIMAT+ (Textechno)

- Clamping length (10 mm)
- Velocity (5 mm/min)

Single fiber pull-out test (SFPO)

Sample preparation



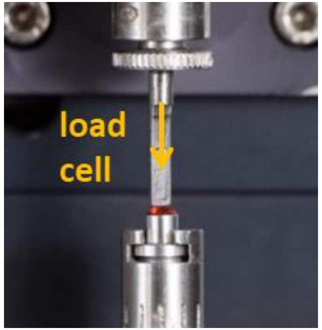
computer assisted embedding, l_e = 1000 µm

FRLC3 (normal strength m...	...3
Beigh B.A.M. et al.	
CEM I 52,5 R-SR3/NA (2) (Holc...	
Limestone (Saxodol 90 LE)	
Clay (Liapor)	
Gypsum (D) (Fluka (Honeywell))	
Quartz sand 0.06–0.2 mm (BCS 41...	
H2O	...,4716
FM MG ACE 460 (BASF)	0,0081
VMA (SIKA)	0,0037

FRLC3 + SAP

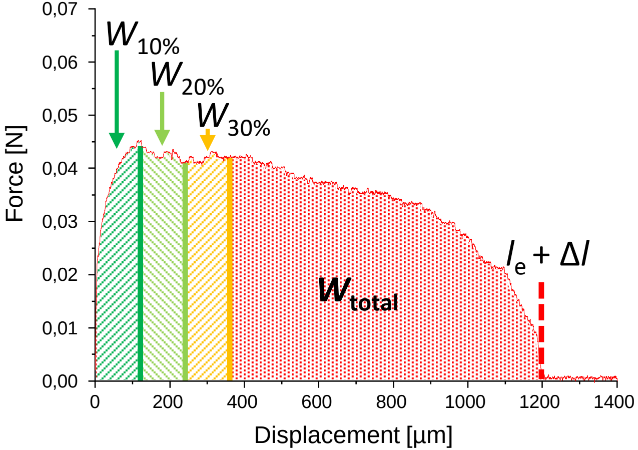
Testing

quasi-static, v=1,000 µm/s



dynamic, v=10,000 µm/s

Evaluation



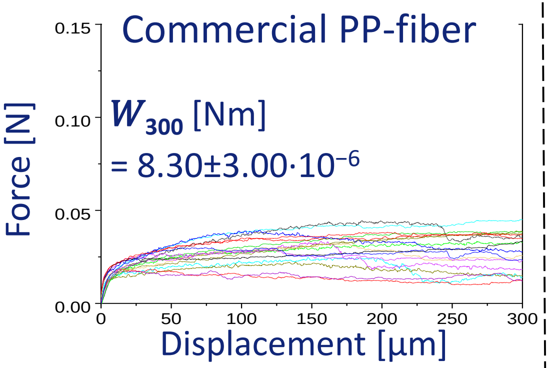
$$W_{total} = W_{chemical\ bond} + W_{friction} + W_{fiber\ elongation} + W_{fiber\ surface\ deformation}$$

Curosu, I.; Mechtcherine, V.; Millon, O. Effect of Fiber Properties and Matrix Composition on the Tensile Behavior of Strain-Hardening Cement-Based Composites (SHCCs) Subject to Impact Loading. Cem. Concr. Res. 2016, 82, 23–35.

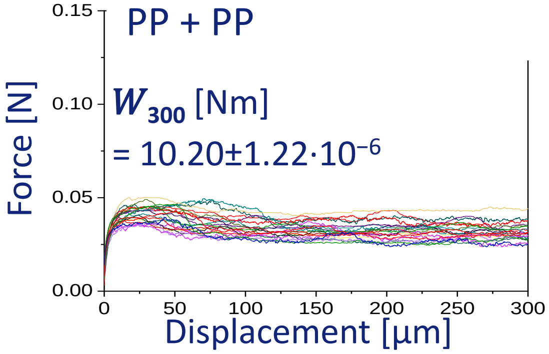
ipf

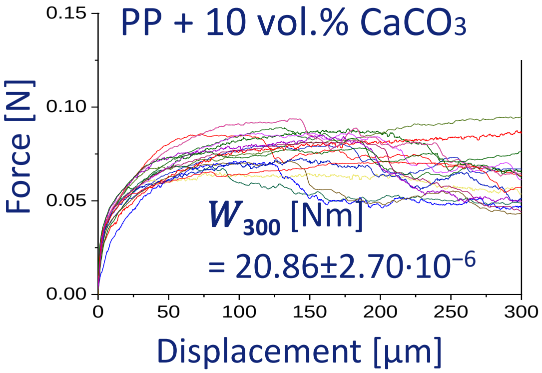
Results – Quasi-static single fiber pull-out test (Q-SFPO)

– in M1 matrix

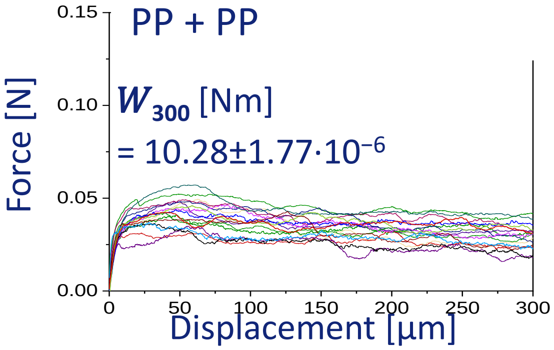


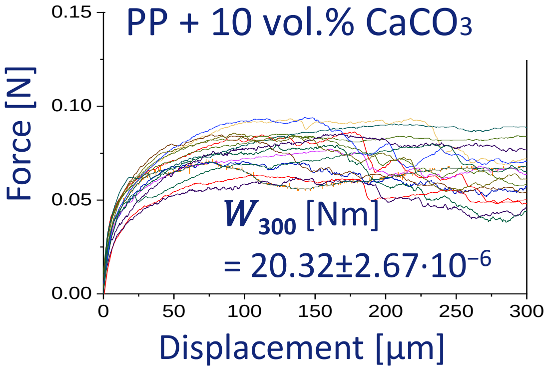
– in FRLC3 matrix





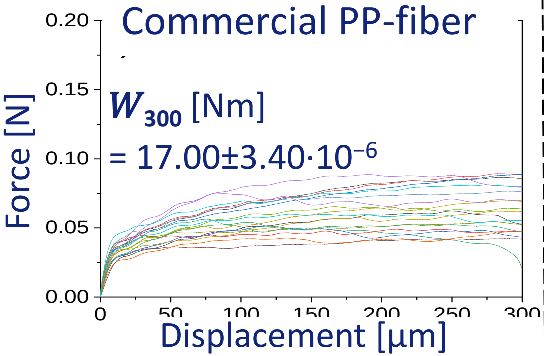
– in FRLC3+SAP matrix



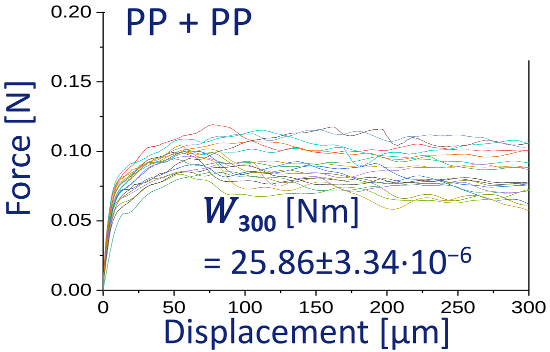


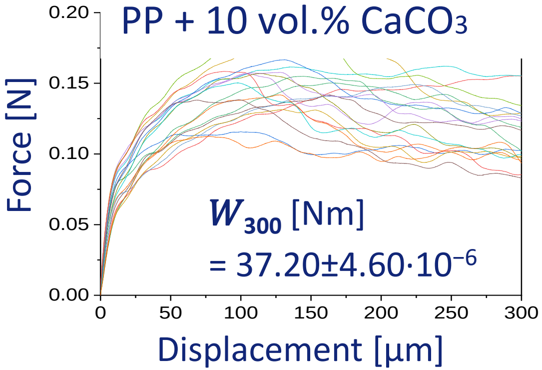
Results – Dynamic single fiber pull-out test (D-SFPO)

– in M1 matrix



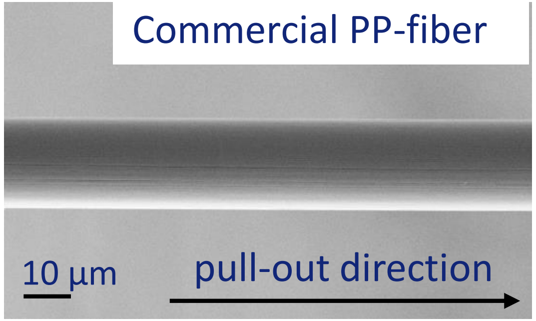
– in FRLC3 matrix



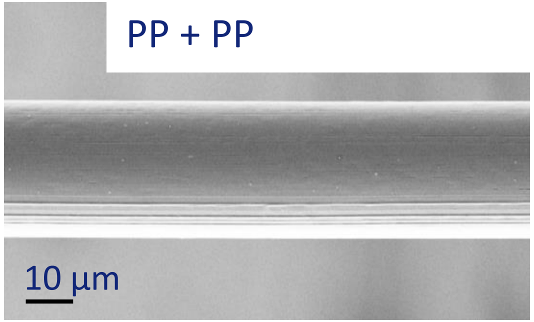


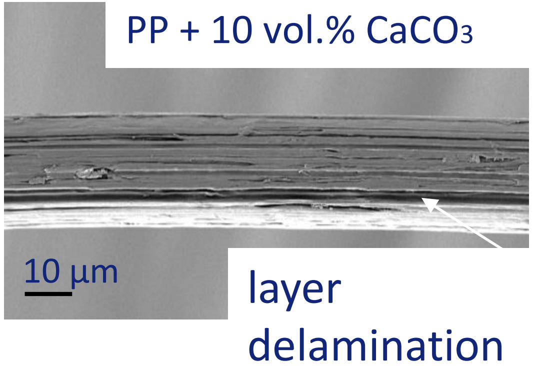
Results – Surface morphology after Q-SFPO

– in M1 matrix

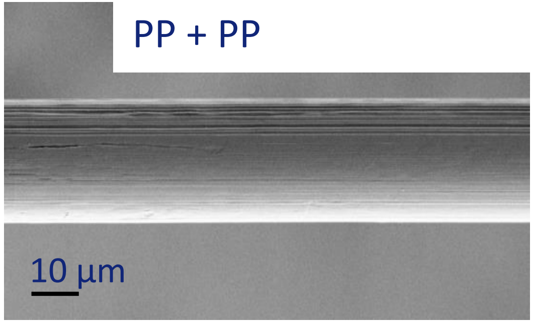


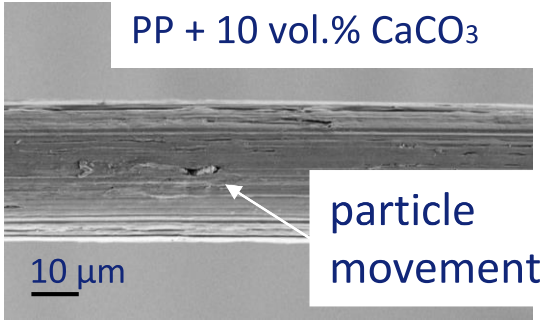
– in FRLC3 matrix





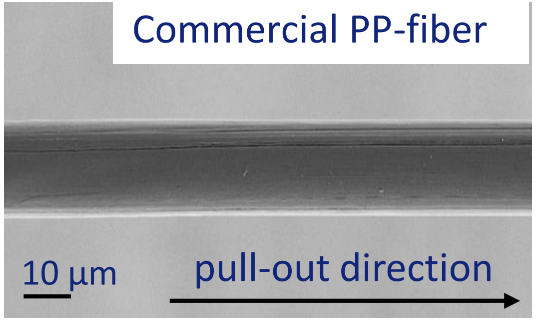
– in FRLC3+SAP matrix



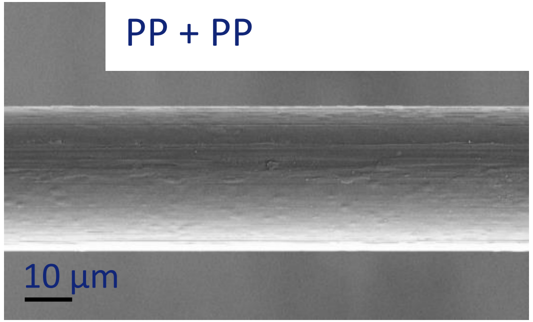


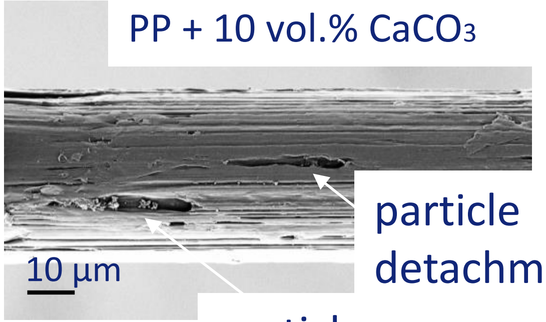
Results – Surface morphology after D-SFPO

– in M1 matrix



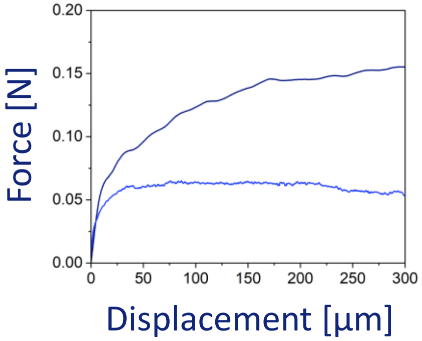
– in FRLC3 matrix





Summary and Outlook

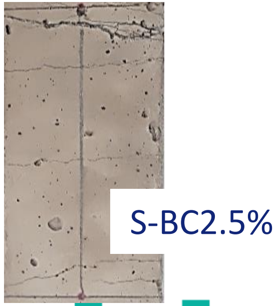
- enhanced energy absorption in FRLC$_3$ matrix and after SAP addition using rough PP bicomponent fibers compared to ‘smooth’ monocomponent PP fiber in M1 matrix
- no fiber bridging improvement after SAP addition compared to FRLC$_3$ regime
- ‘smooth’ bicomponent PP fibers showed slight bridging improvement in FRLC$_3$ matrix, even with SAP addition



Micro-scale analysis

Macro-scale analysis

- composites containing rough PP bicomponent fibers exhibit a propensity for strain-hardening behavior
- SAP utilization enhances the potential for stress transfer through multiple cracking
- rough fibers improve composite properties with less volume fraction



Leibniz-Institut
für Polymerforschung
Dresden

TECHNISCHE UNIVERSITÄT DRESDEN

GRK 2250/2

Thank you for your kind attention!

Deutsche Forschungsgemeinschaft (DFG—German Research Foundation) in the framework of the Research Training Group GRK framework 2250/2, project number 287321140

DFG
Deutsche Forschungsgemeinschaft

Contact

M.Sc. Mihaela-Monica Popa
Leibniz-Institut für Polymerforschung Dresden e. V.
Scientific Assistant

Work Group Fiber-Engineering

Phone: +49 351 4658 305
E-Mail: popa@ipfdd.de
Web: www.ipfdd.de/fiber-spinning