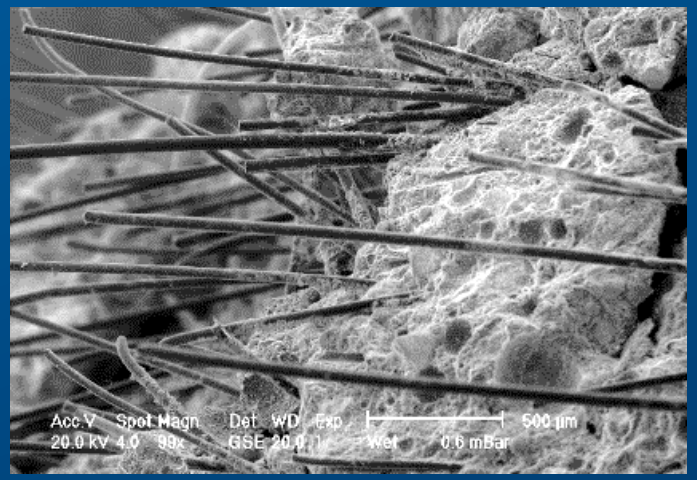
TECHNISCHE UNIVERSITÄT DRESDEN

ifb

Online Lecture at Ecole Polytechnique Fédérale de Lausanne, December 3, 2024

Viktor Mechtcherine

Novel inorganic-bonded fiber composites and digital manufacturing technologies: A path to sustainable construction



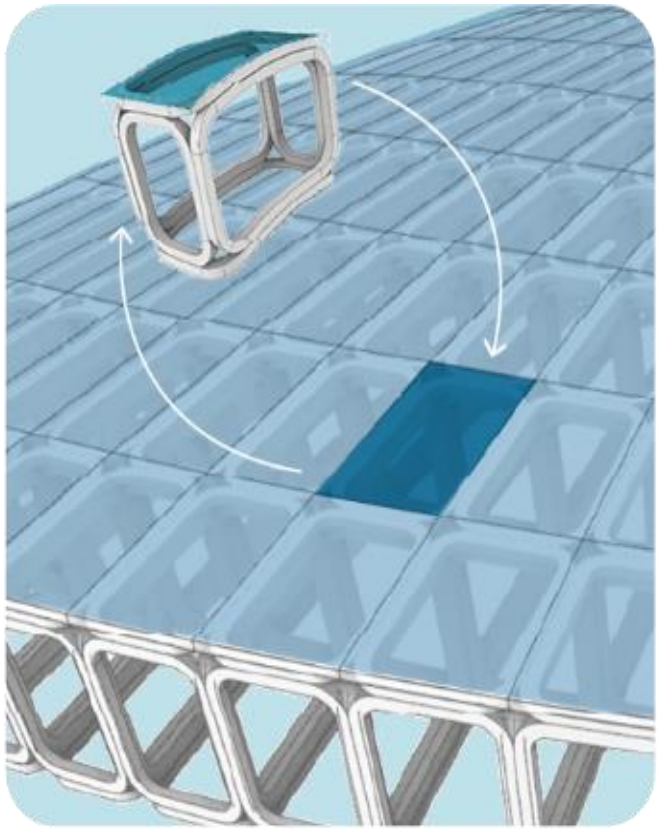
Construction sector is responsible for

- 25% of climate-damaging greenhouse gases
- 40% of energy consumption
- 50% of material resources consumption

[McIntosh]

Toward Recourse-Efficient Structures

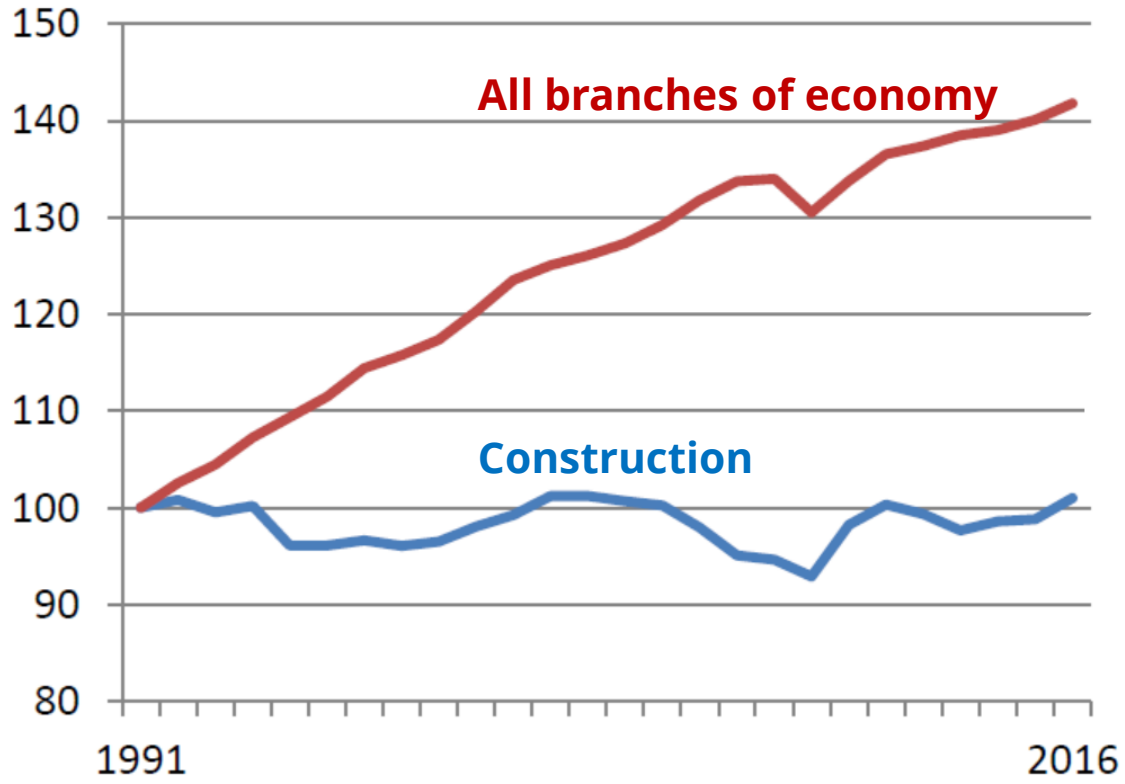
Structural Design



[https://flic.kr/p/9RV48w]

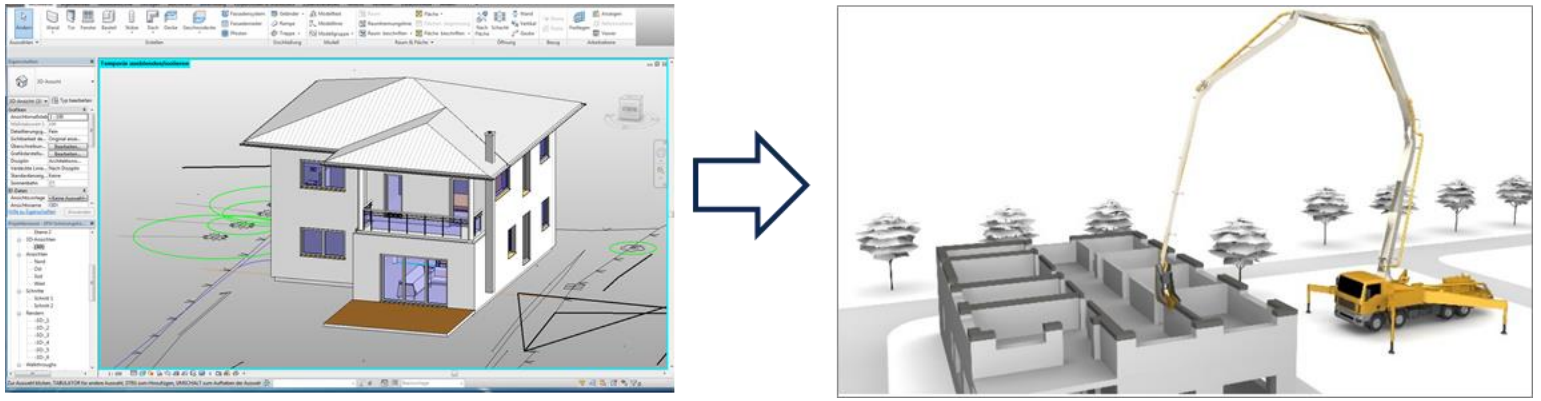
Productivity and Scarcity of Skilled Labor

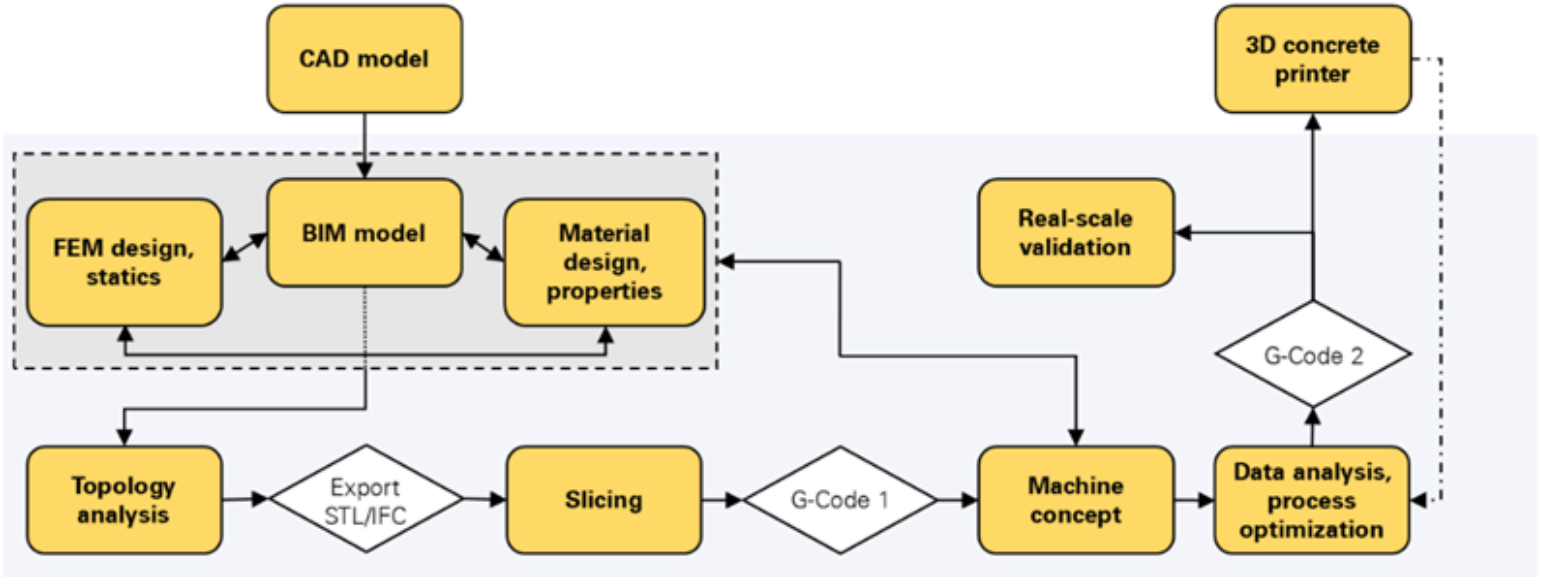
Productivity per labor hour



[VGR Destatis]

Toward Digital Fabrication

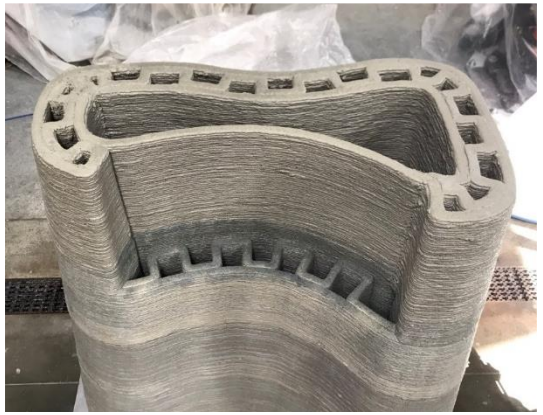




Mechtcherine, Nerella, *Bautechnik* 95 (2018] 275-287

Novel Technologies: Extrusion-based 3D Concrete Printing

higher productivity • lower spatial resolution • coarser aggregates



TU Dresden, 2022

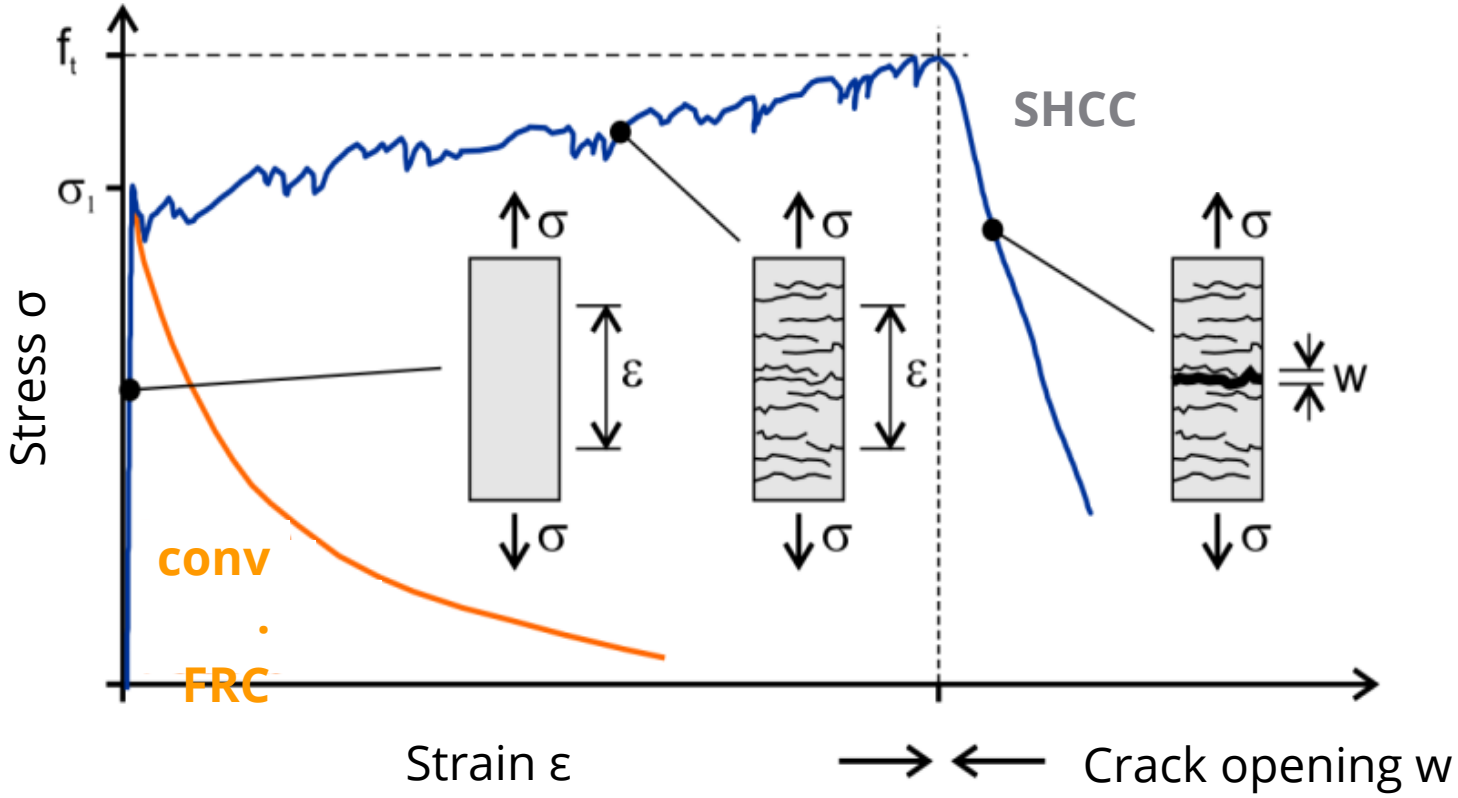
TU Dresden, 2020

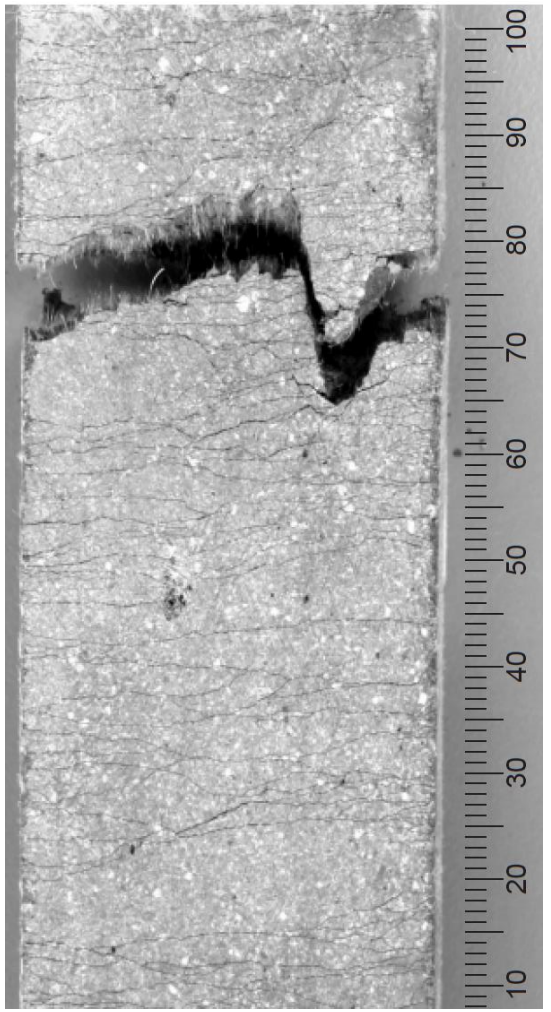
TU Dresden, 2019

TU Dresden, 2019

Novel Materials: Strain-hardening Cement-based Composite (SHCC)

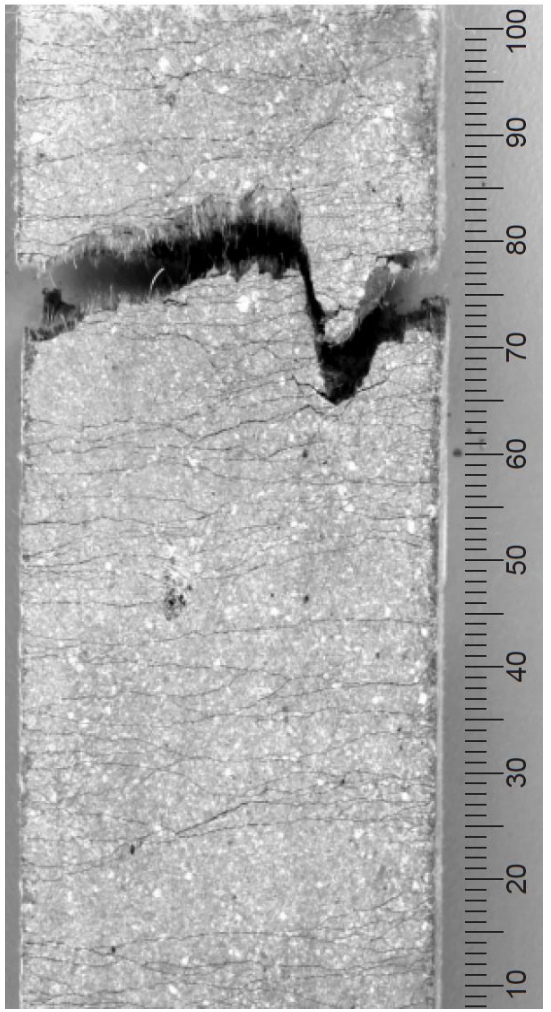
Behavior under uniaxial tensile loading





Novel Materials: Strain-hardening Cement-based Composite (SHCC)

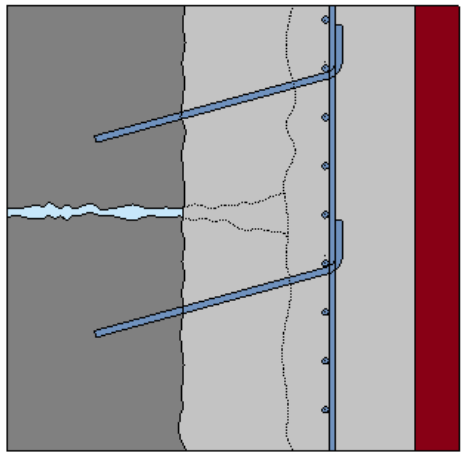
Constituent	SHCC	LC3-SHCC
	[kg/m³]	
Cement	505	599
Fly ash	621	-
Calcined clay	-	379
Limestone powder	-	190
Quartz sand 0.06/0.2	536	536
Water	338	359
Superplasticizer PCE	10	11
Stabilizer UWC	4	-
Fiber 12 mm	29 (PVA)	20 (HDPE)



Wang, Rehman, Curosu, Zhu, Beigh, Liebscher, Chen, Tsang, Hempel, Mechtcherine, *Cement and Concrete Research* 144 (2021) 106421

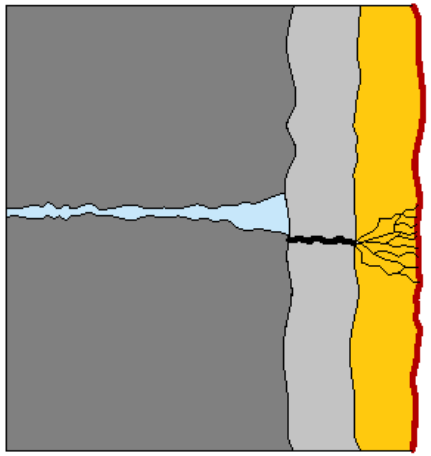
Use of SHCC for Rehabilitation of Concrete Structures

A



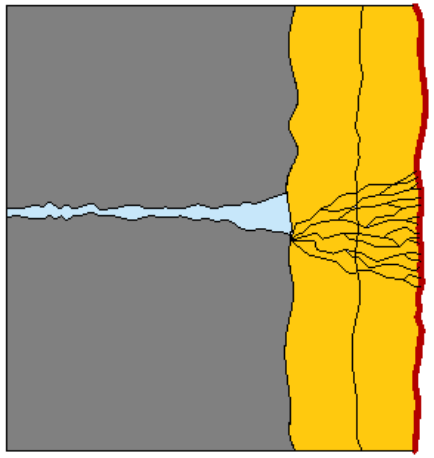
- steel reinforced concrete
- finishing layer

B



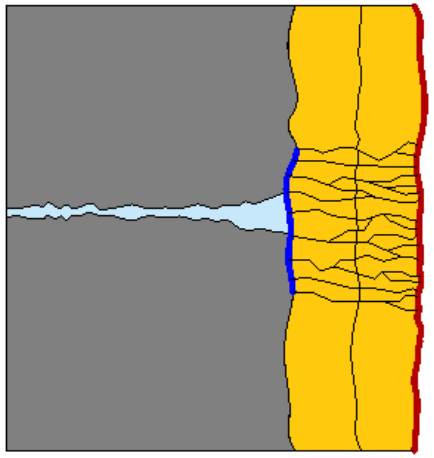
- 1 layer shotcrete
- 1 layer SHCC
- fine finish

C



- 2 layers SHCC
- fine finish

D



- local decoupling
- 2 layers SHCC
- fine finish

Müller, Mechtcherine, *ICCRRR 2018*, doi:10.1051/matecconf/201819909006

Use of SHCC for Rehabilitation of Concrete Structures

Water storage power plant in Hohenwarte, Germany

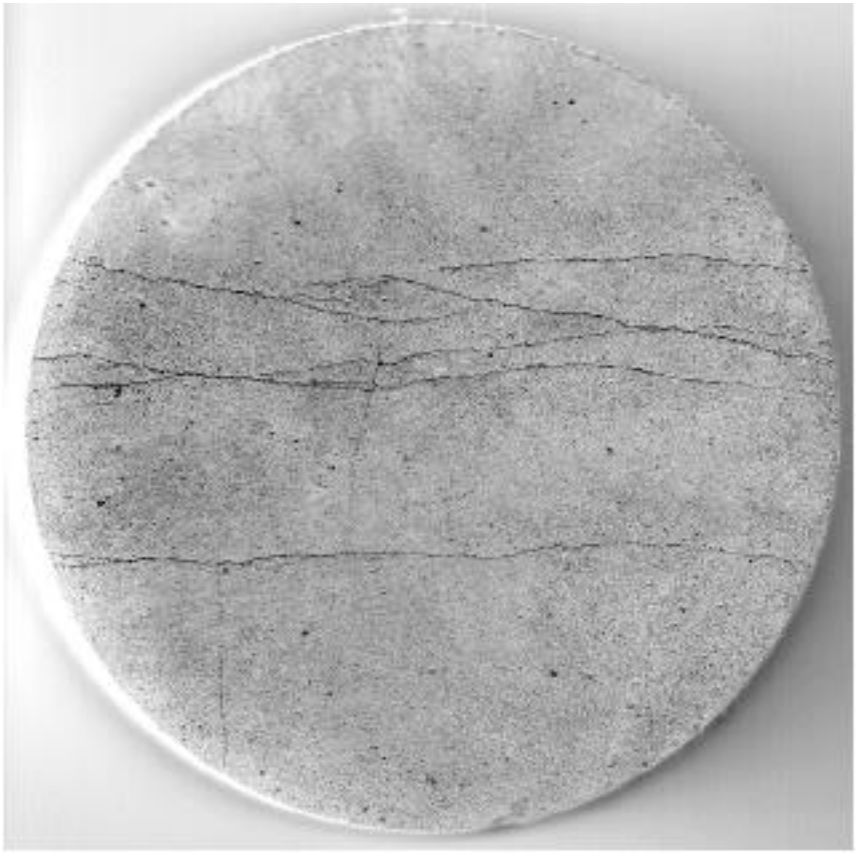
Use of SHCC for Rehabilitation of Concrete Structures

Water storage power plant in Hohenwarte, Germany

Use of SHCC for Rehabilitation of Concrete Structures

Water storage power plant in Hohenwarte, Germany

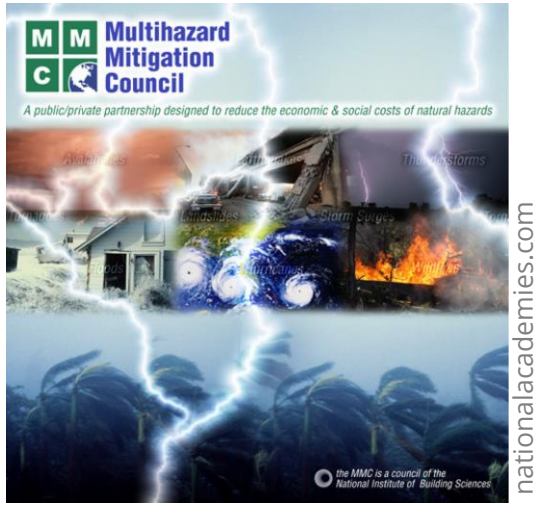
Crack in concrete substrate



Distributed fine cracks in SHCC

Müller, Mechtcherine, *ICCRRR 2018*, doi:10.1051/matecconf/201819909006

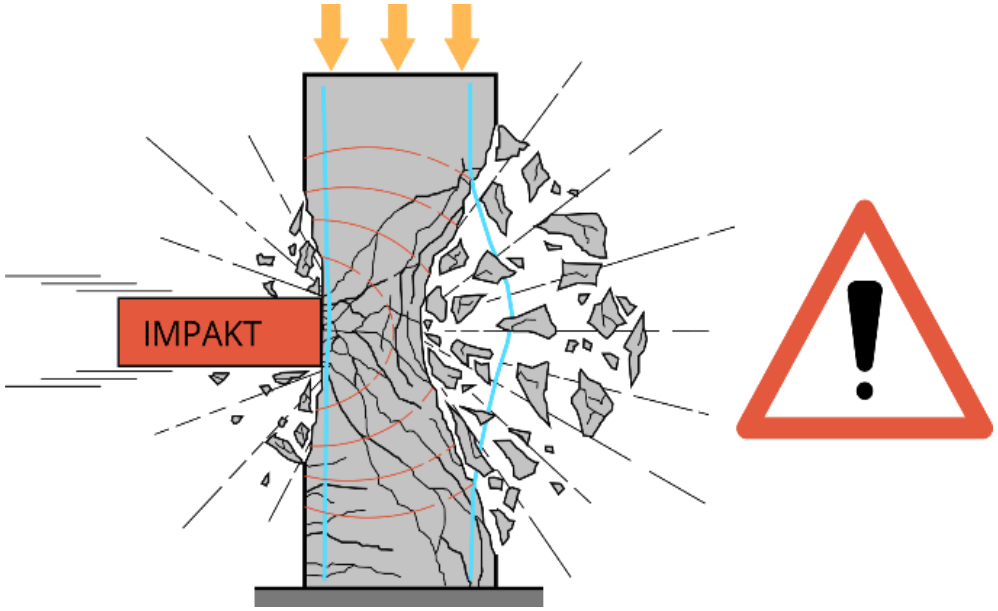
Concrete Structures under Impact Loading



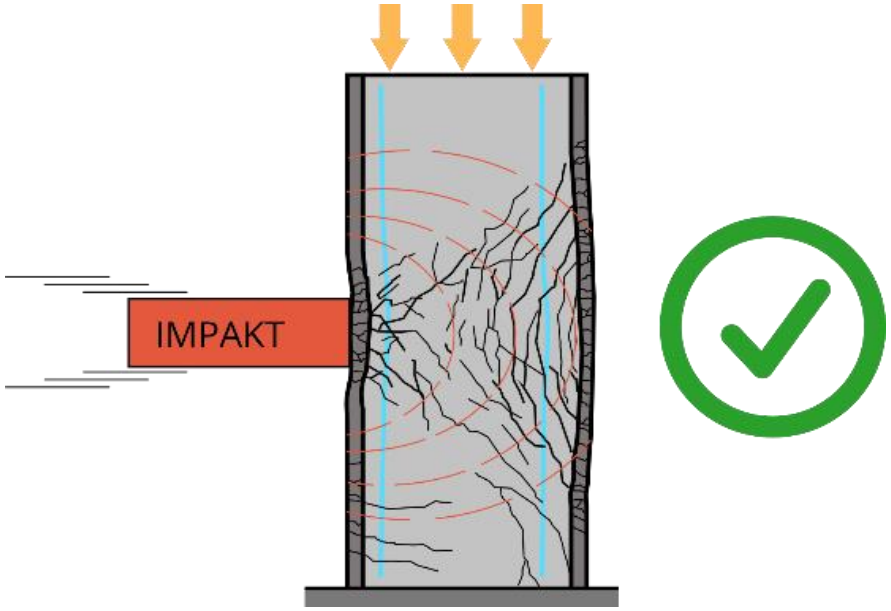
nationalacademies.com

„A dollar spent on mitigation saves society an average of $4.“

Strengthening of Concrete Structures Subject to Impact Loading

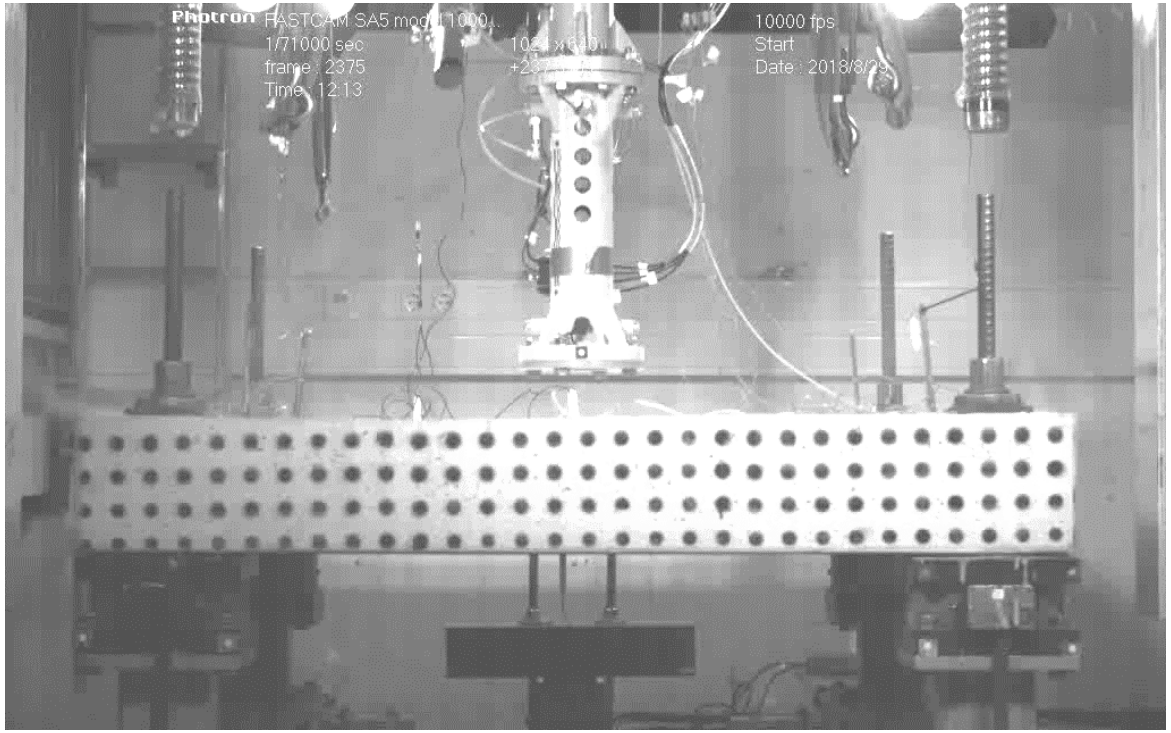


Steel reinforced concrete

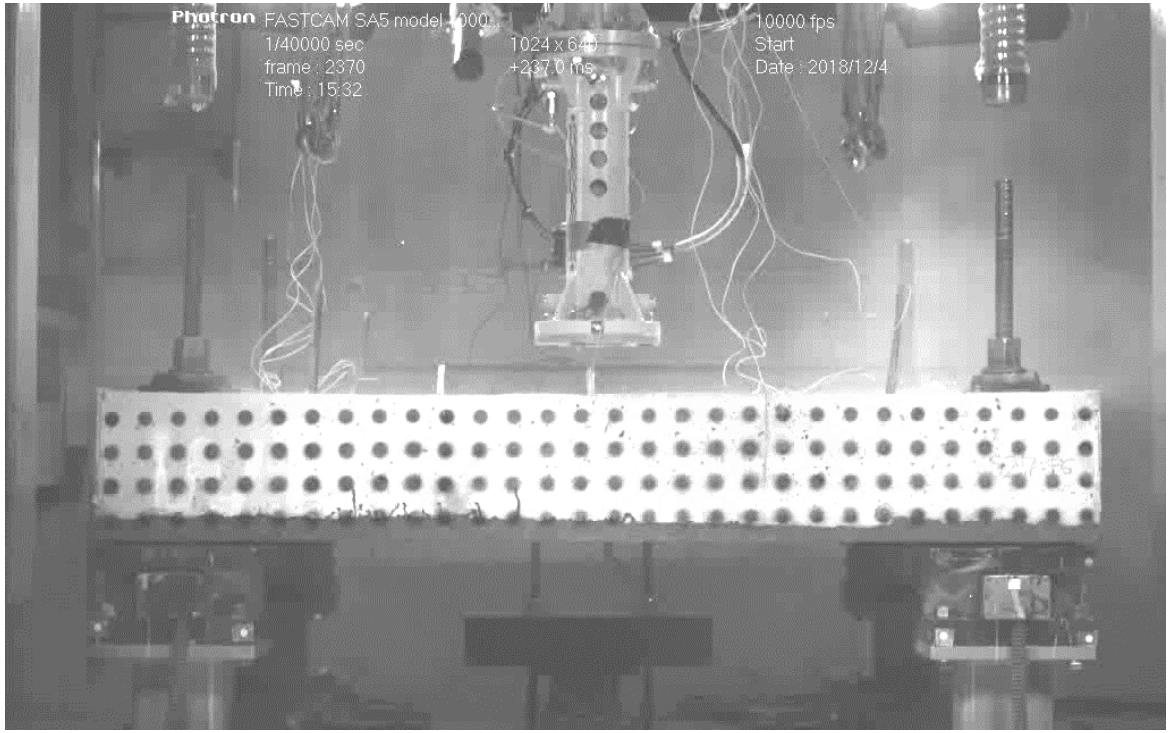


Strengthened with a mineral-based composite

Strengthening of Concrete Structures Subject to Impact Loading



PL122 53.9 m/s without strengthening



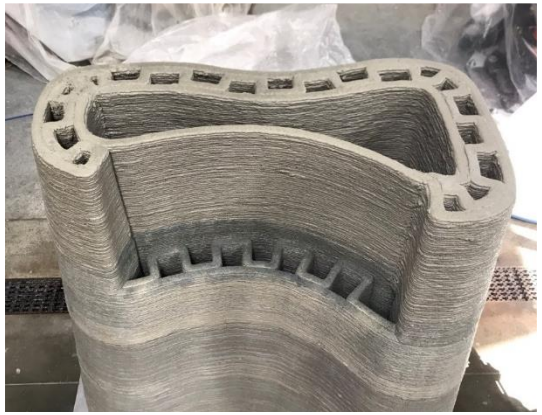
PL128 54.1 m/s with SHCC + carbon textile

Signorini, Bracklow, Hering, Butler, Leicht, Schubert, Beigh, Beckmann, Curbach, Mechtcherine: *Journal of Building Engineering* 80 (2023) 108037


mdr HD

Novel Technologies: Extrusion-based 3D Concrete Printing

higher productivity • lower spatial resolution • coarser aggregates



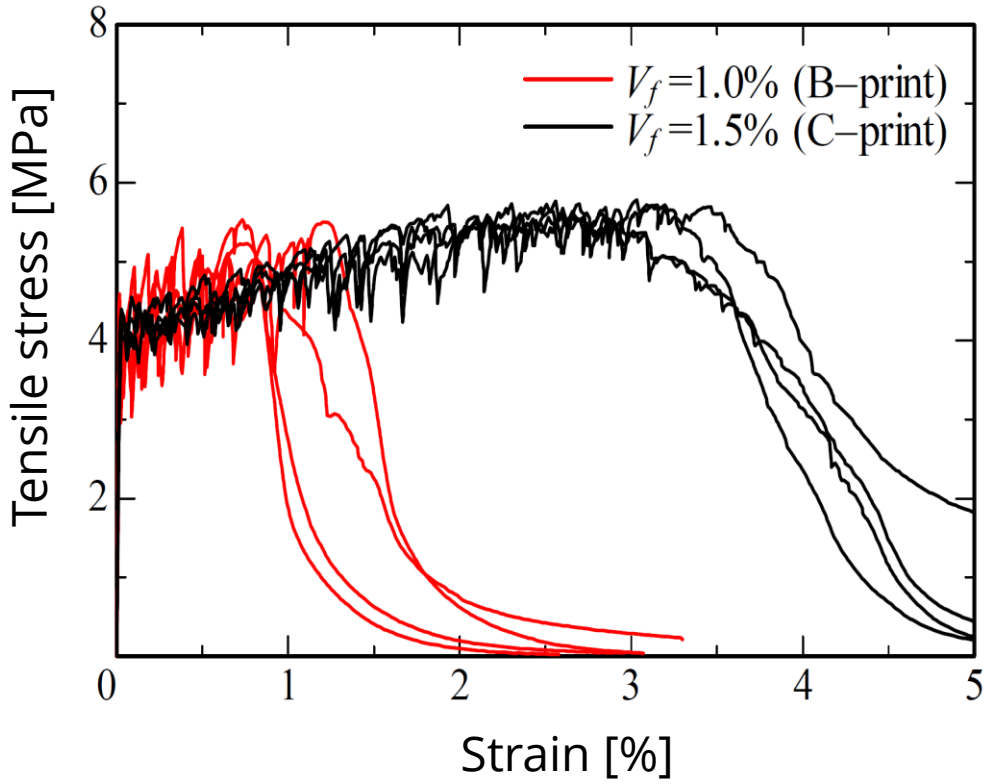
TU Dresden, 2022

TU Dresden, 2020

TU Dresden, 2019

TU Dresden, 2019

3D Printing with Strain-hardening Cement-based Composite (SHCC)



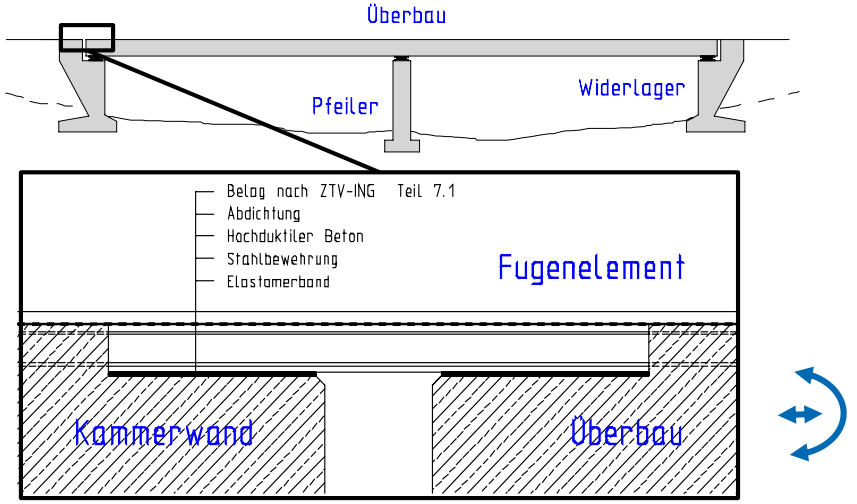
Ogura, Nerella, Mechtcherine, *Materials* 11 (2018) 1375

3D Printing with Strain-hardening Cement-based Composite (SHCC)

Shimzu Corporation, Japan

SHCC: Further Application Examples

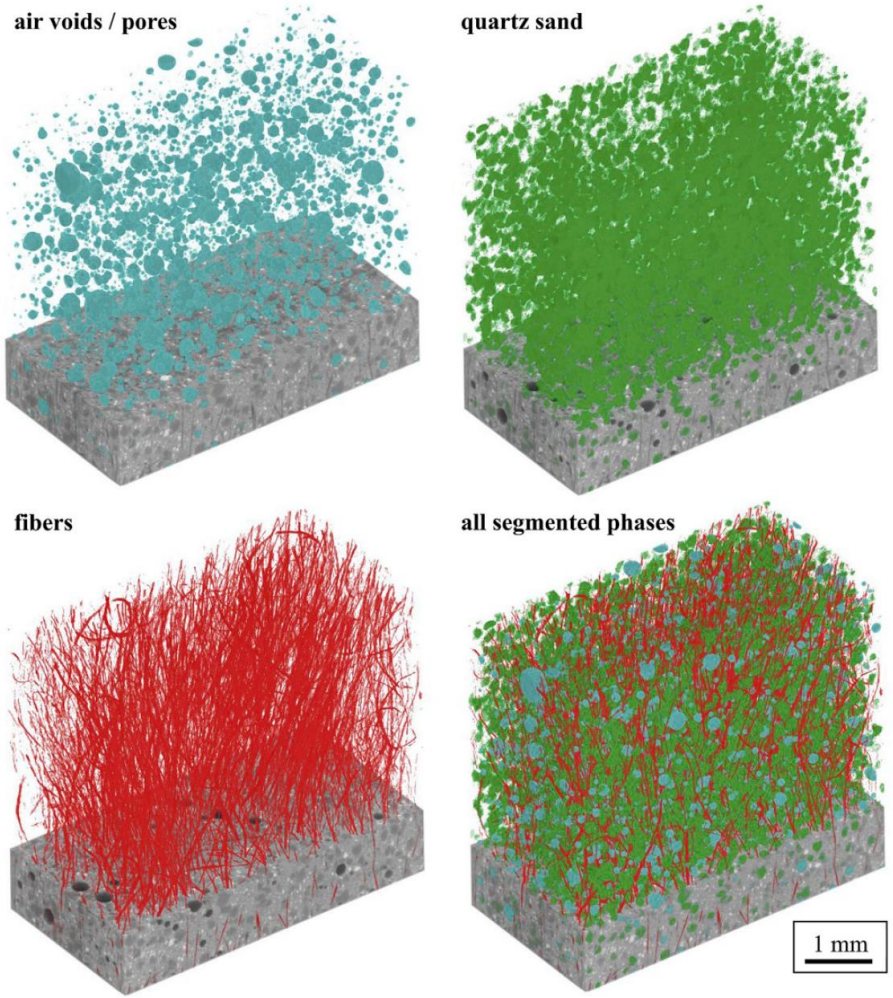
Mueller, Ranjbarian, Mechtcherine, *Structural Concrete* 20 (2019) 1231-1242



Mündecke, Mechtcherine, *Beton- und Stahlbetonbau*, Heft 3 (2015) 220-227

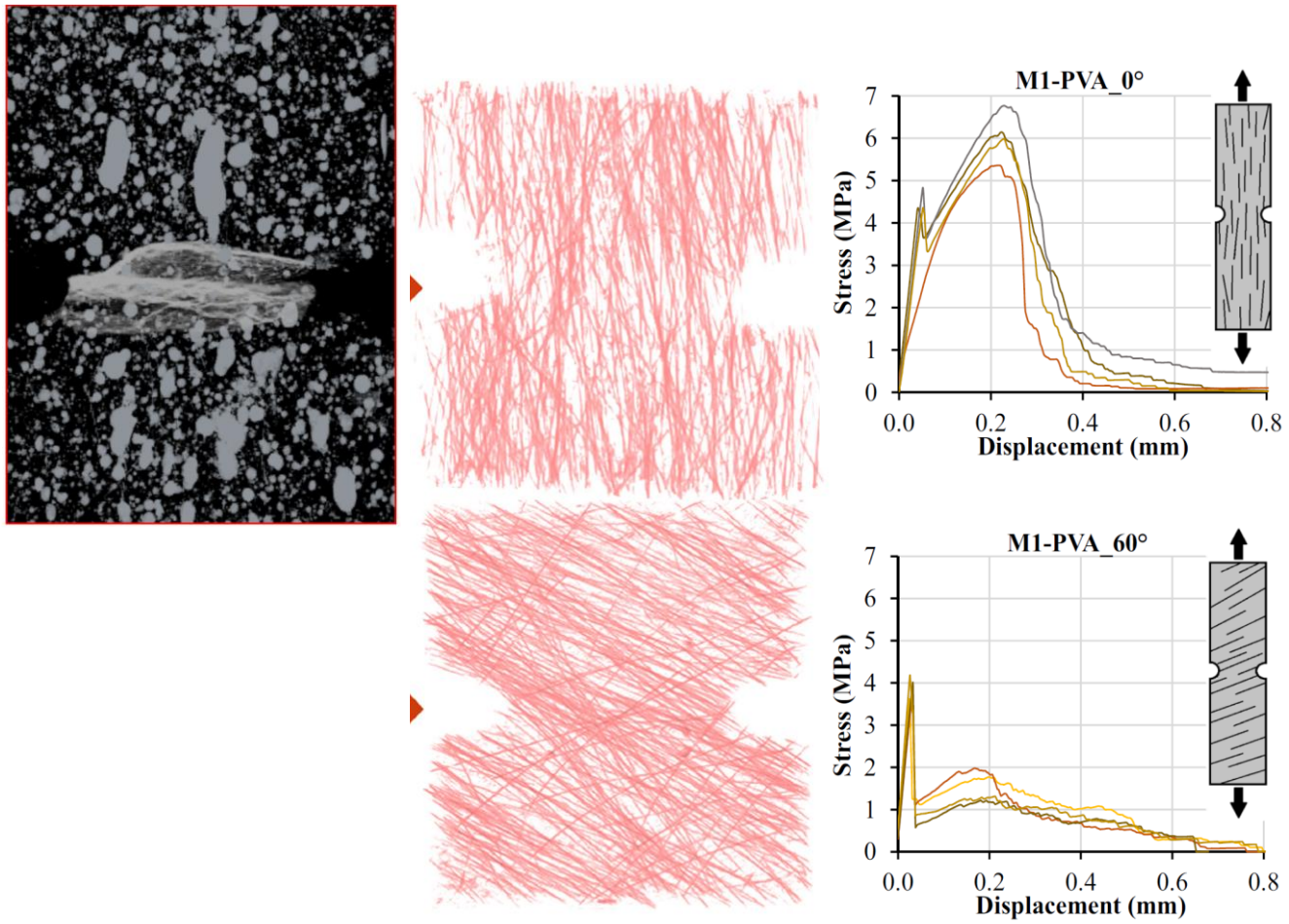
SHCC: Quantitative Analysis of the Composite‘s Microstructure

3D images of SHCC segmented by Deep Learning



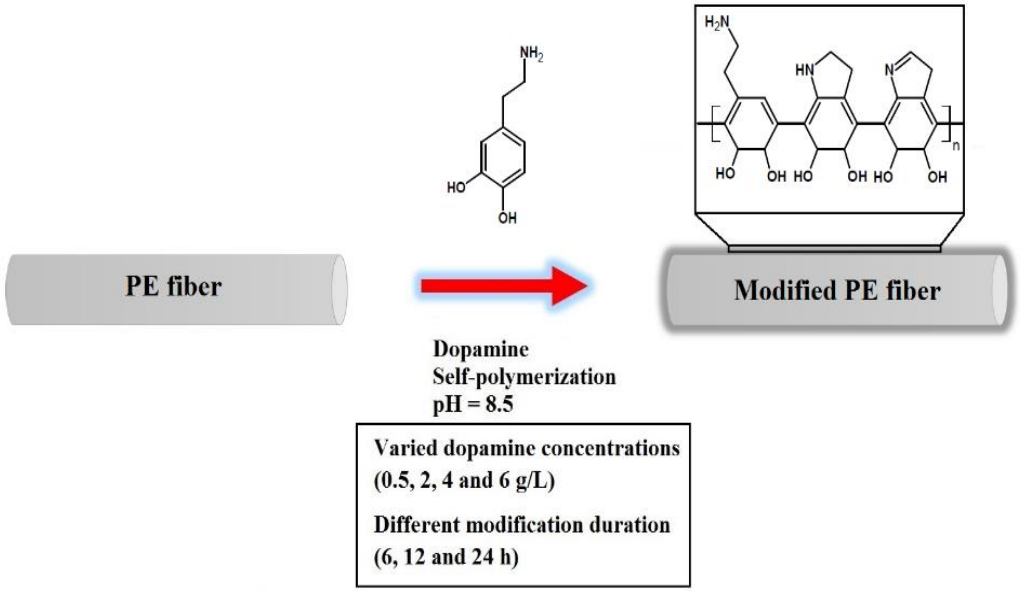
Lorenzoni, Curosu, Paciornik, Mechtcherine, Oppermann, Silva, *CCR* 139 (2020) 103551

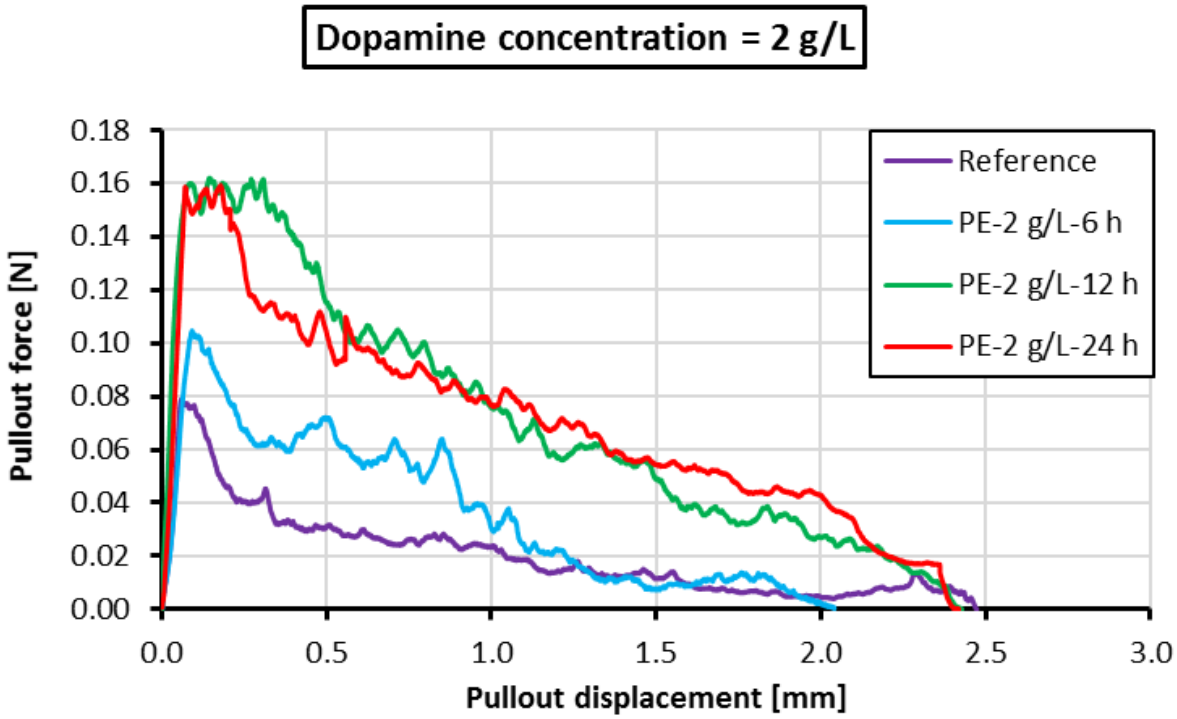
Segmented pores, cracks and fibers in SHCC under tensile load



Curosu, Muja, Ismailov, Ahmed, Liebscher, Mechtcherine, *CCR* 152 (2022) 106650

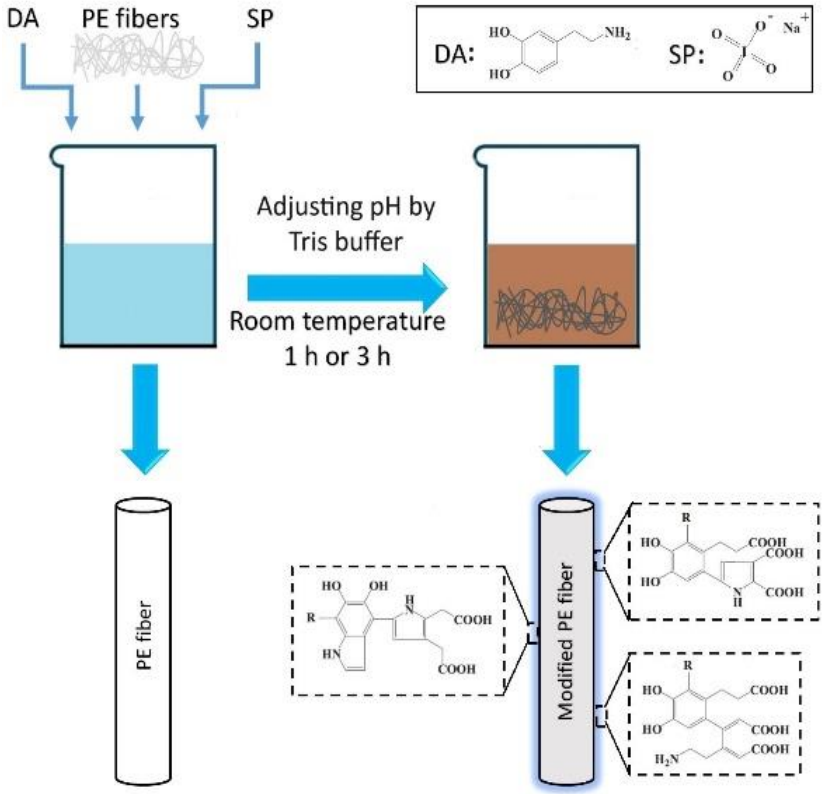
SHCC: Bond Enhancement by Dopamine Modification

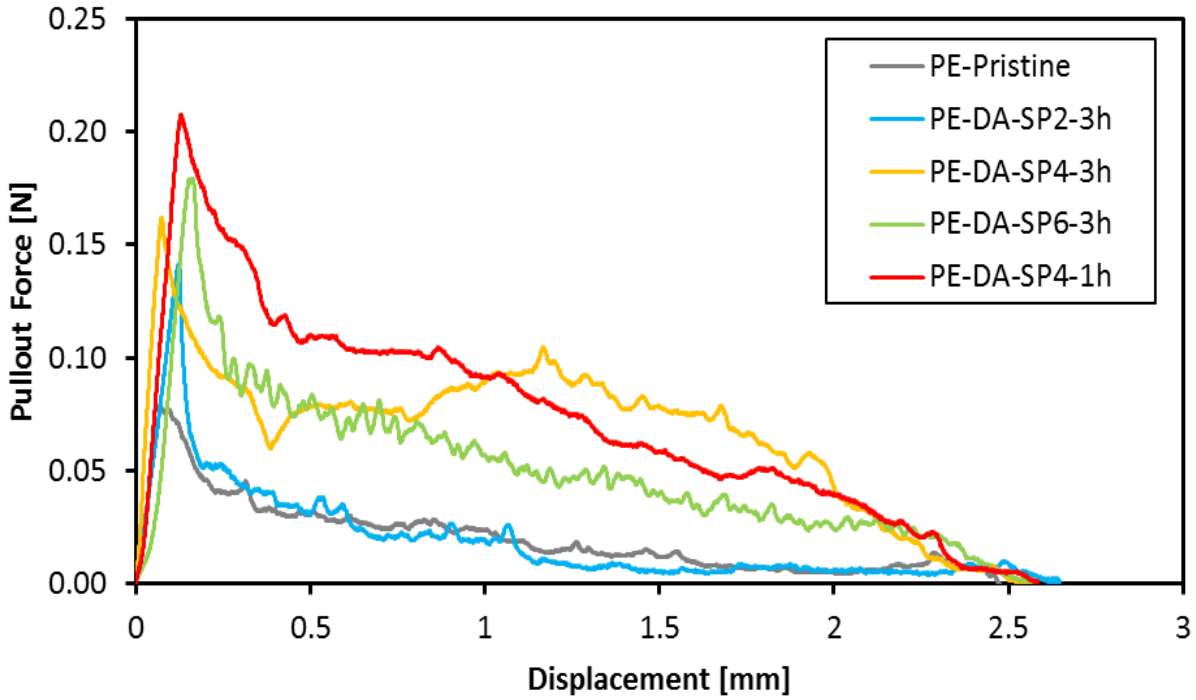




Bashiri Rezaie, Liebscher, Ranjbarian, Simon, Zimmerer, Drechsler, Frenzel, Synytska, Mechtcherine, *Composites Part B: Engineering* 217 (2021) 108817

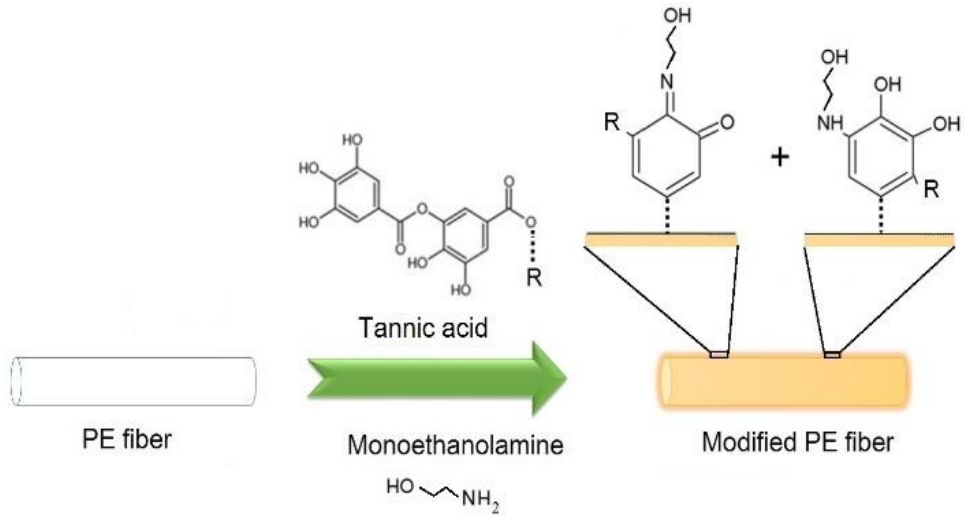
SHCC: Bond Enhancement by Fast Dopamine Modification

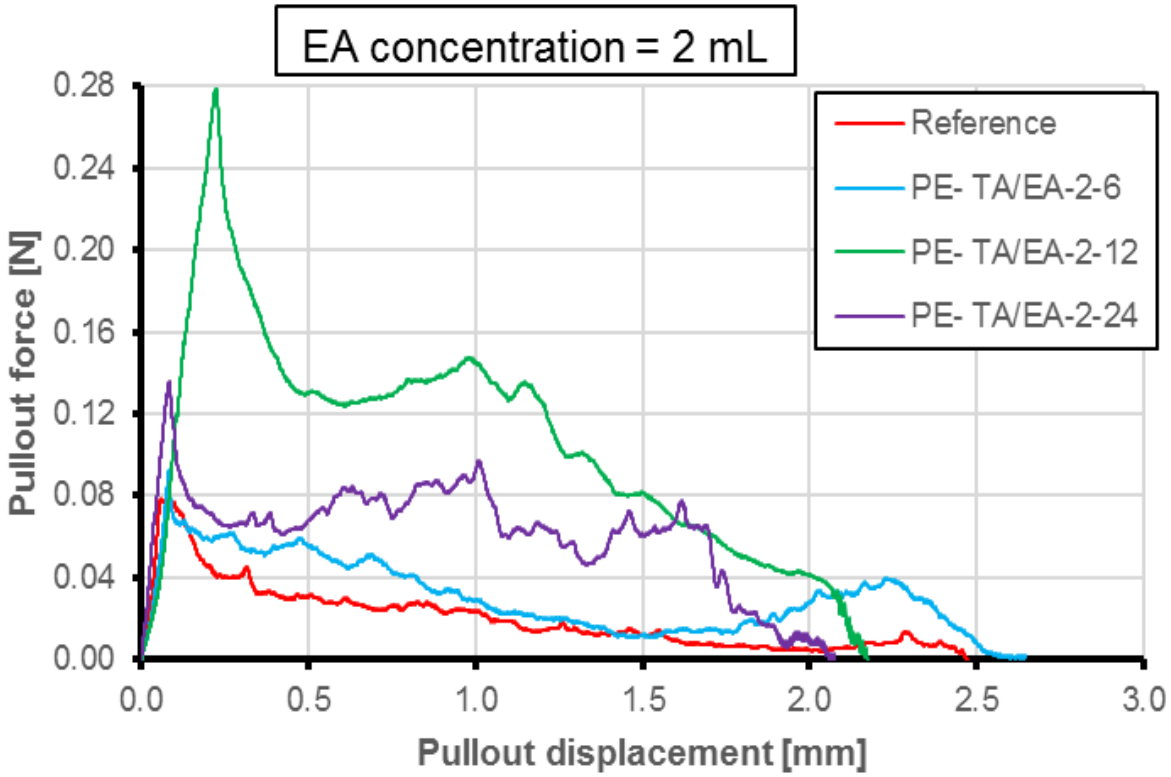




Bashiri Rezaie, Liebscher, Mohammadi, Drechsler, Frenzel, Synytska, Mechtcherine, *Cement and Concrete Composites* 152 (2024) 105601

SHCC: Bond Enhancement by Tannic Acid Modification





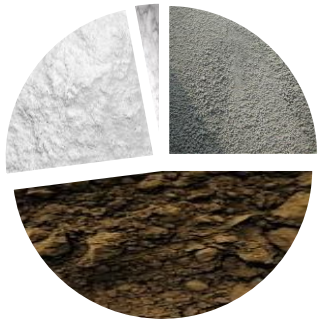
Bashiri Rezaie, Liebscher, Drechsler, Synytska, Mechtcherine, *Cement and Concrete Composites* 131 (2022) 104573

SHCC: Low-clinker, Low-cost Compositions

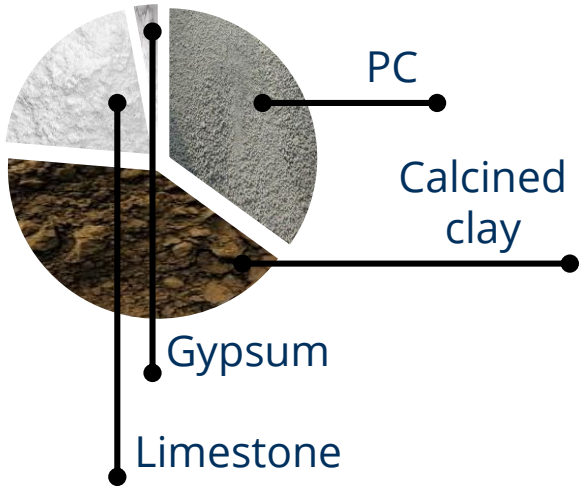
Low-clinker matrix

LC³-50
PC:LC³=50:50

LC³-25
PC:LC³=25:50



LC³-35
PC:LC³=35:50



Low-cost and recyclable fibers

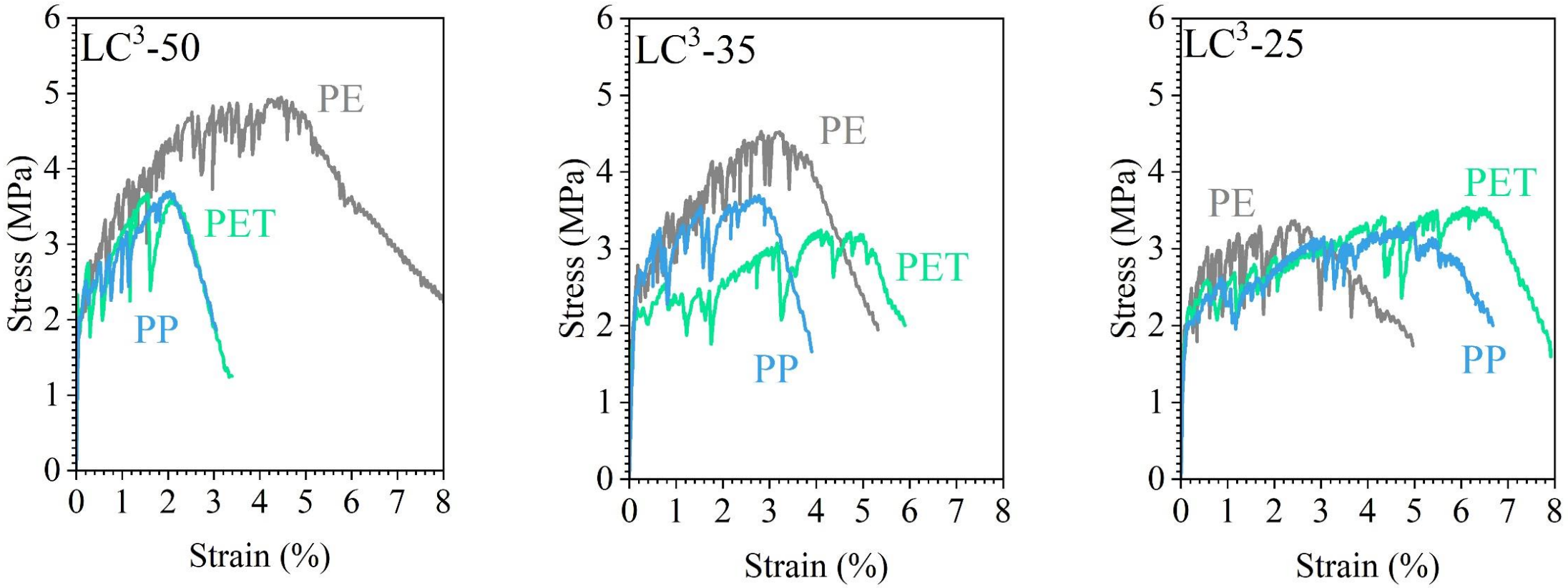
Polyethylene (PE)

Polyethylene terephthalate (PET)

Polypropylene (PP)

Ahmed, Nune, Liebscher, Köberle, Willomitzer, Noack, Butler, Mechtcherine, *Journal of Cleaner Production* 428 (2023): 139438

SHCC: Low-clinker, Low-cost Compositions



Ahmed, Signorini, Chikhradze, Liebscher, Butler, Mechtcherine, *Construction and Building Materials* 438 (2024) 137166

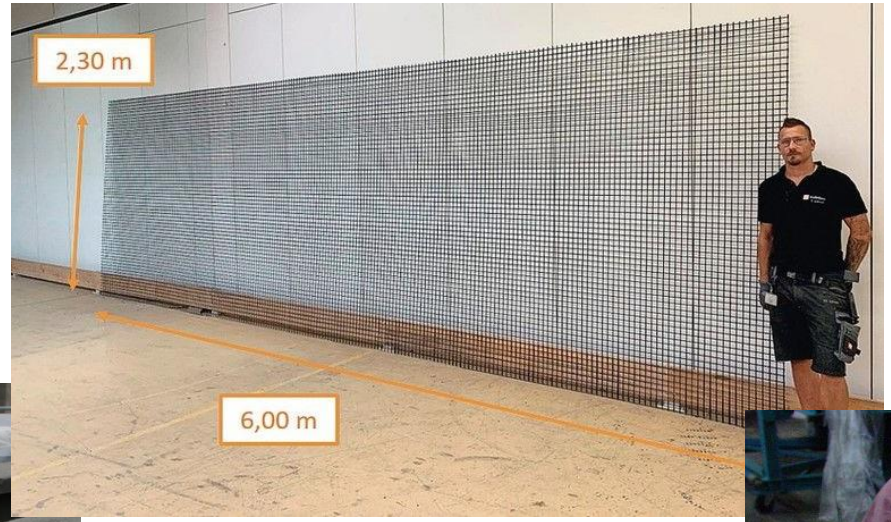
Novel Materials: Use of Carbon Concrete Composites

Strengthning / Repair / Rehabilitation

New construction

Carbon Concrete Composites: Stiffness of the Textile Reinforcement

Moderate stiffness
(e.g. impregnation with styrene butadiene rubber)

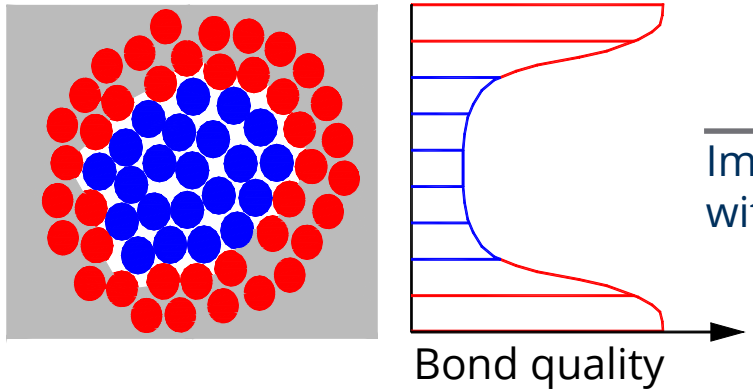


High stiffness
(e.g. impregnation with epoxy resin)

High flexibility
(no impregnation)
“The gift of water” by Jackie Brookner, NY

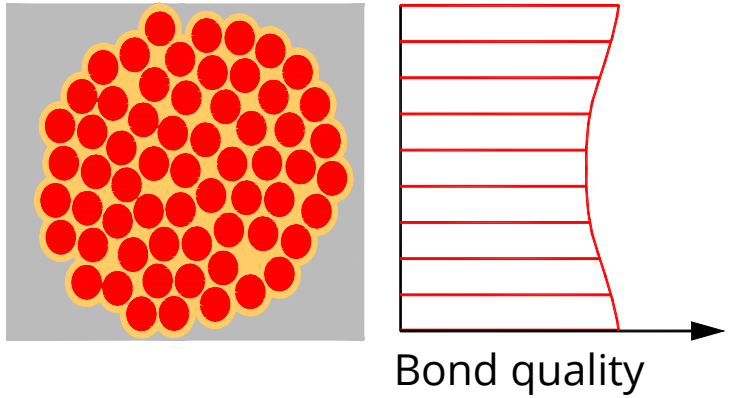
Carbon Concrete Composites: Impregnation of Textile and Bond Behavior

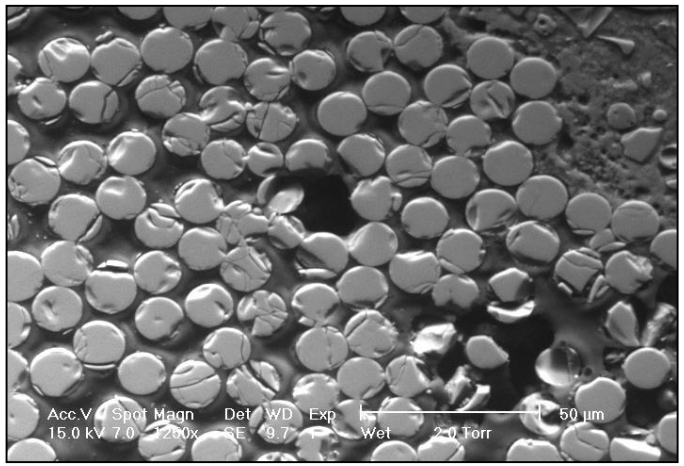
Yarn without polymer



Impregnation with polymers

Yarn with coating/impregnation

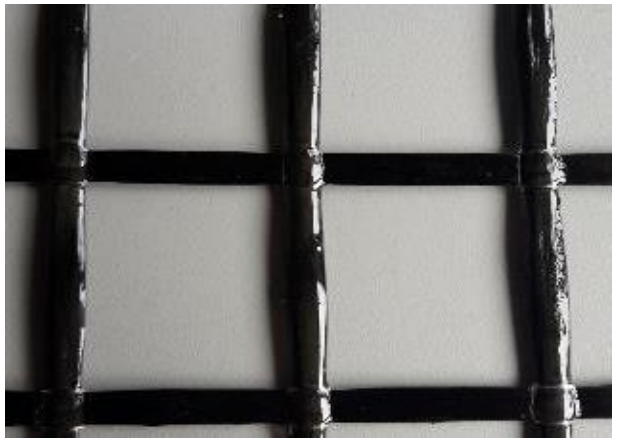




- better bond between the filaments
  → *higher strength and strain capacity*
- easier handling of textile
- additional protective film
  → *prevention of fiber damage*
  (→ enhanced durability, e.g. for basalt)

Why Looking for Alternatives to Polymer Impregnation?

- Lower temperature dependence of mechanical performance
  → larger spectrum of applications
- Better bond to cement-based matrices
- Higher durability and sustainability
- Easier processability and higher flexibility in production
- Lower costs



Source: TU Dresden, IfB

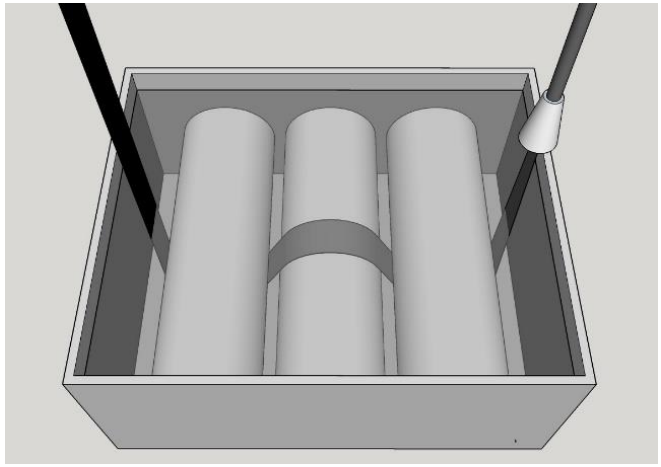
Source: bz-berlin.de, 11.09.2017

Source: TU Dresden, IfB

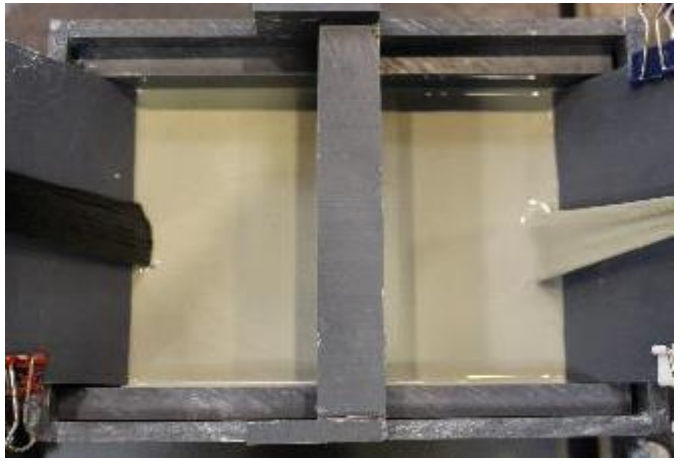
→ Solution: Mineral-bonded carbon fiber reinforcement

Mineral Impregnated Carbon Fiber Composite Reinforcement (MFC)

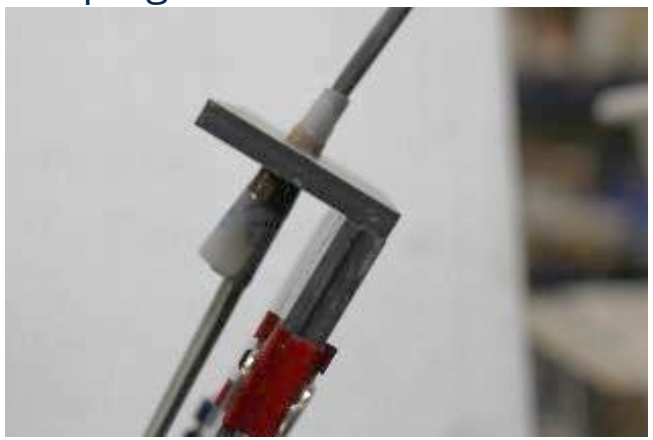
Three-roll-padder



Impregnation



Shaping

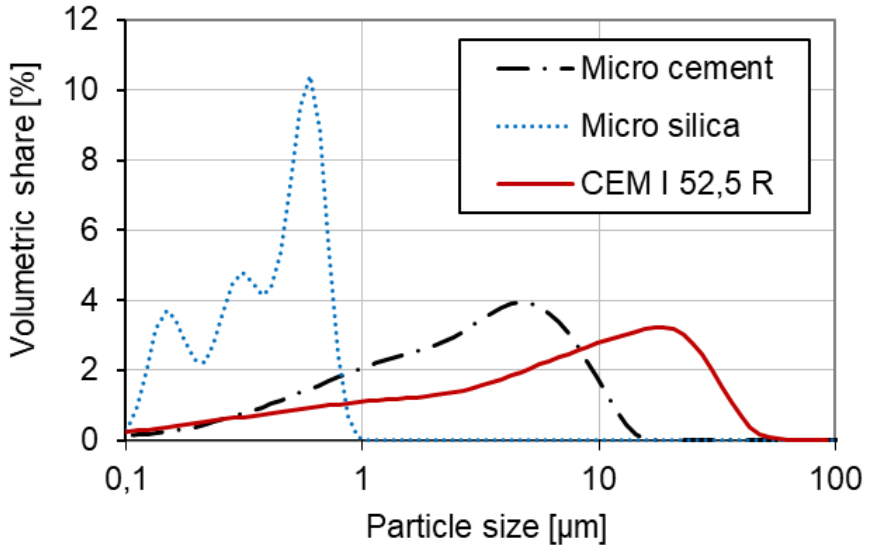


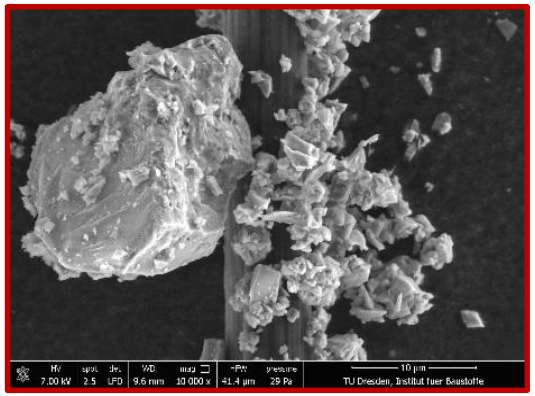
3 mm bar

Schneider, Michel, Liebscher, Terreri, Hempel, Mechtcherine, *Cement and Concrete Composites* 97 (2019) 68-77

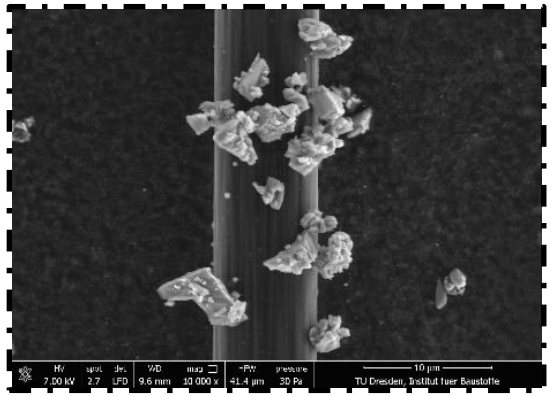
Mineral Impregnated Carbon Fiber Composite Reinforcement (MFC)

Mineral components of the suspension

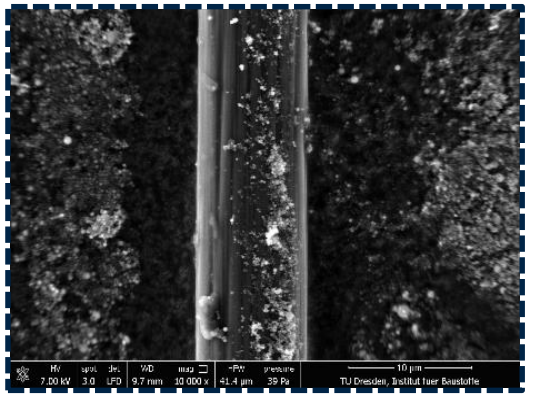




CEM 52.5



micro-cement with D95 < 9 µm

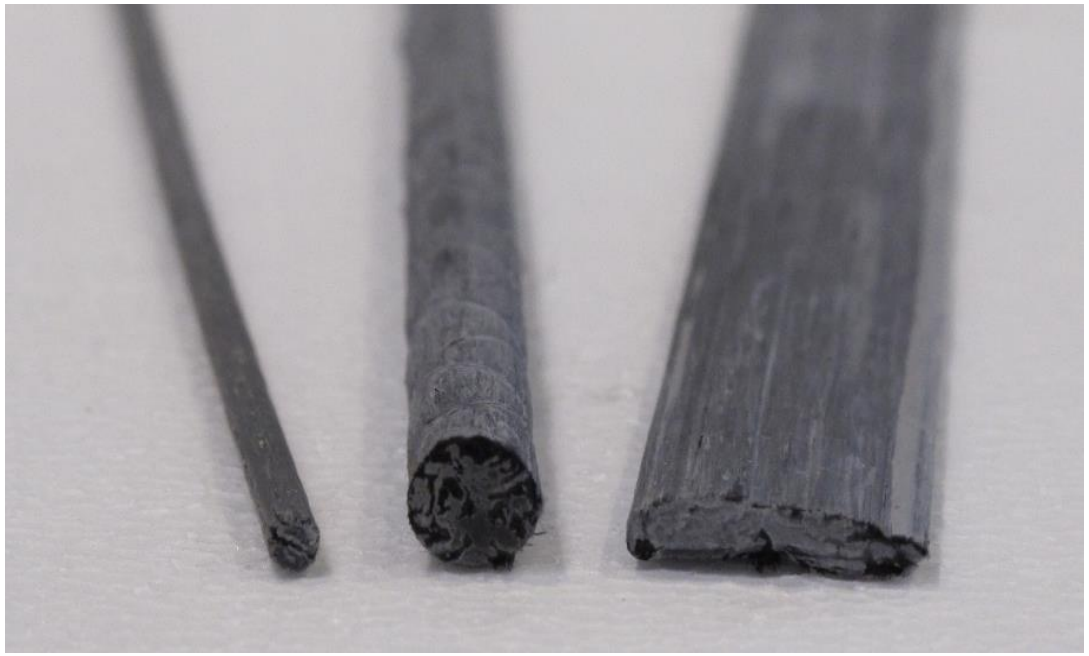


micro-silica

Schneider, Michel, Liebscher, Terreri, Hempel, Mechtcherine, *Cement and Concrete Composites* 97 (2019) 68-77

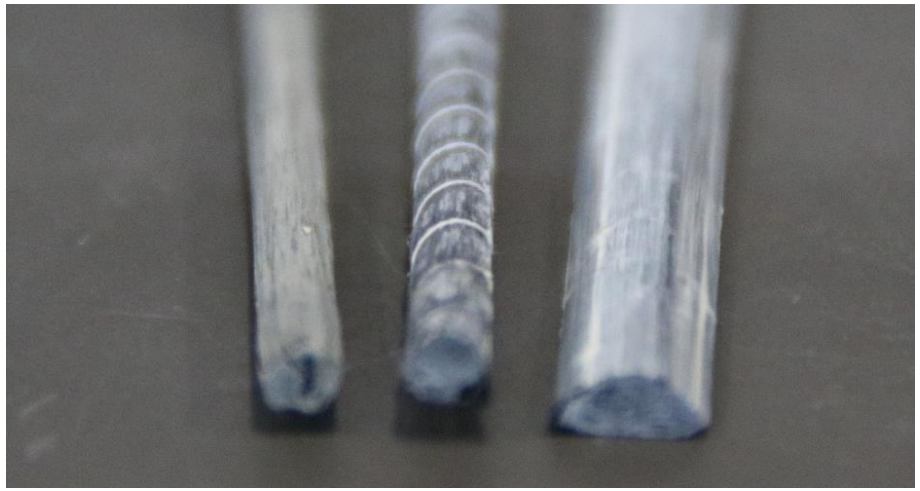
Mineral Impregnated Carbon Fiber Composite Reinforcement (MFC)

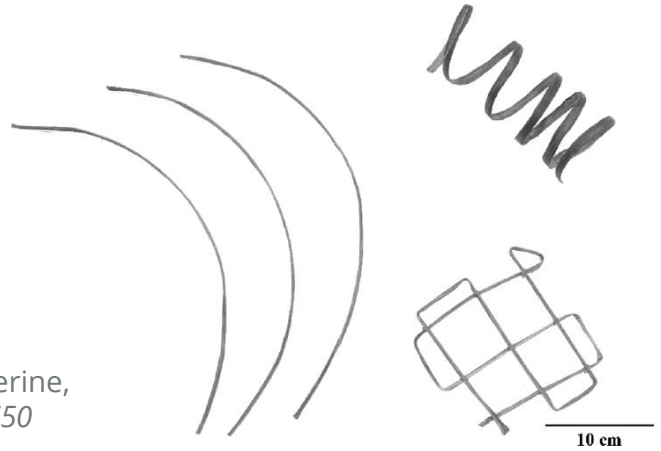
Microcement bonded



Mechtcherine, Michel, Liebscher, Schneider, Großmann,
Automation in Construction 110 (2020) 103002

Geopolymer bonded, treatment by ohmic heat

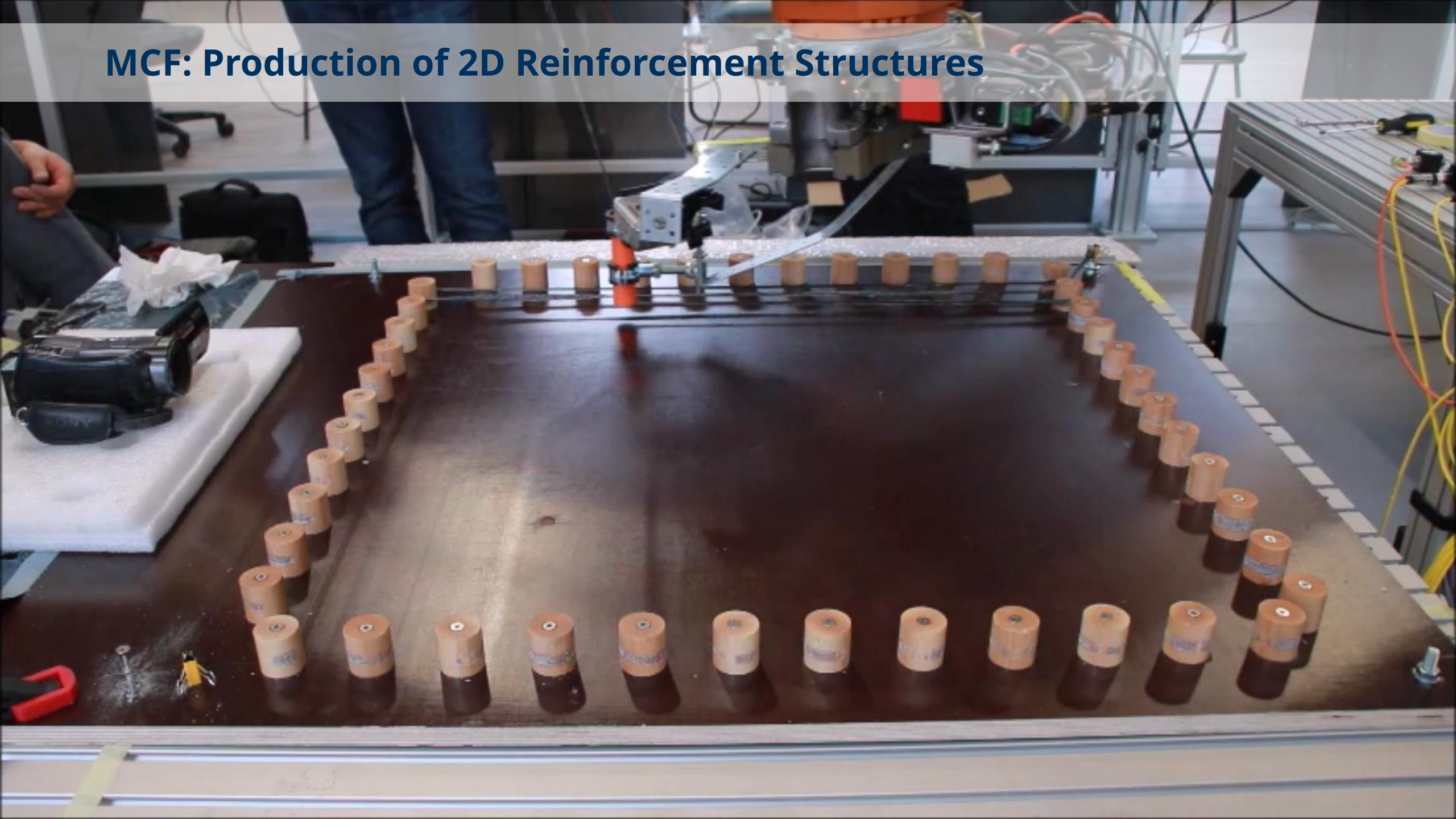




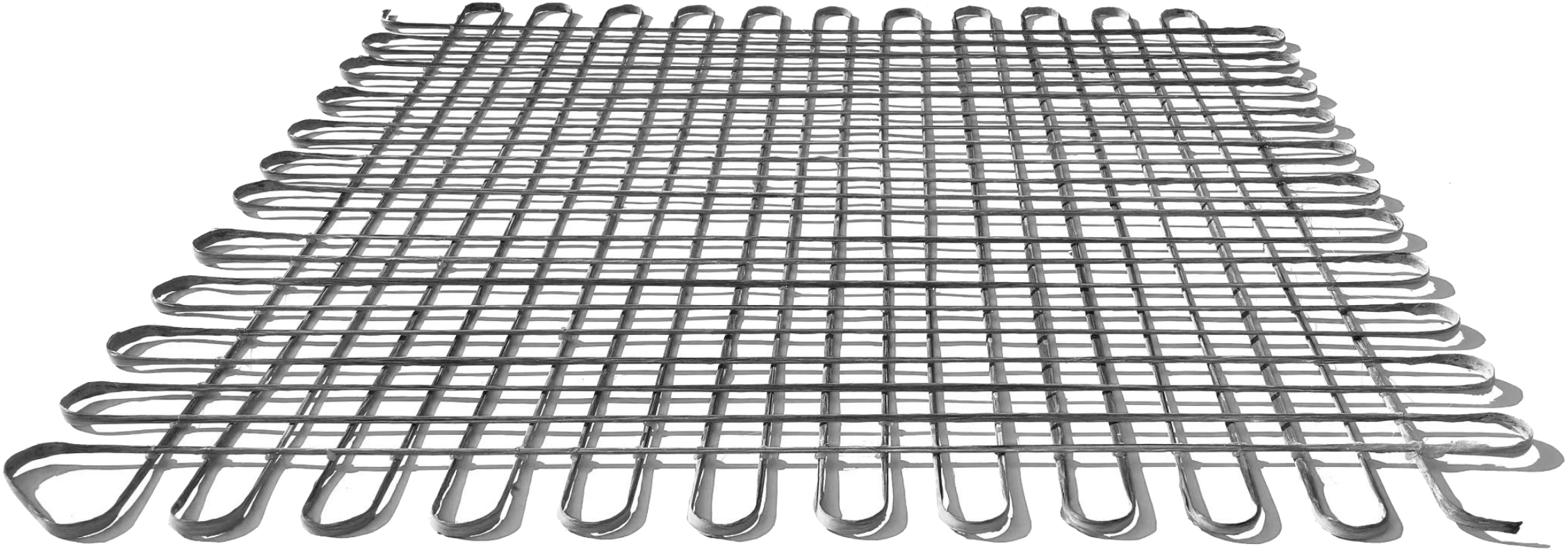
Junger, Liebscher, Zhao, Mechtcherine,
Composites: Part A 153 (2022) 106750

MCF: Production of 1D Reinforcement

MCF: Production of 2D Reinforcement Structures

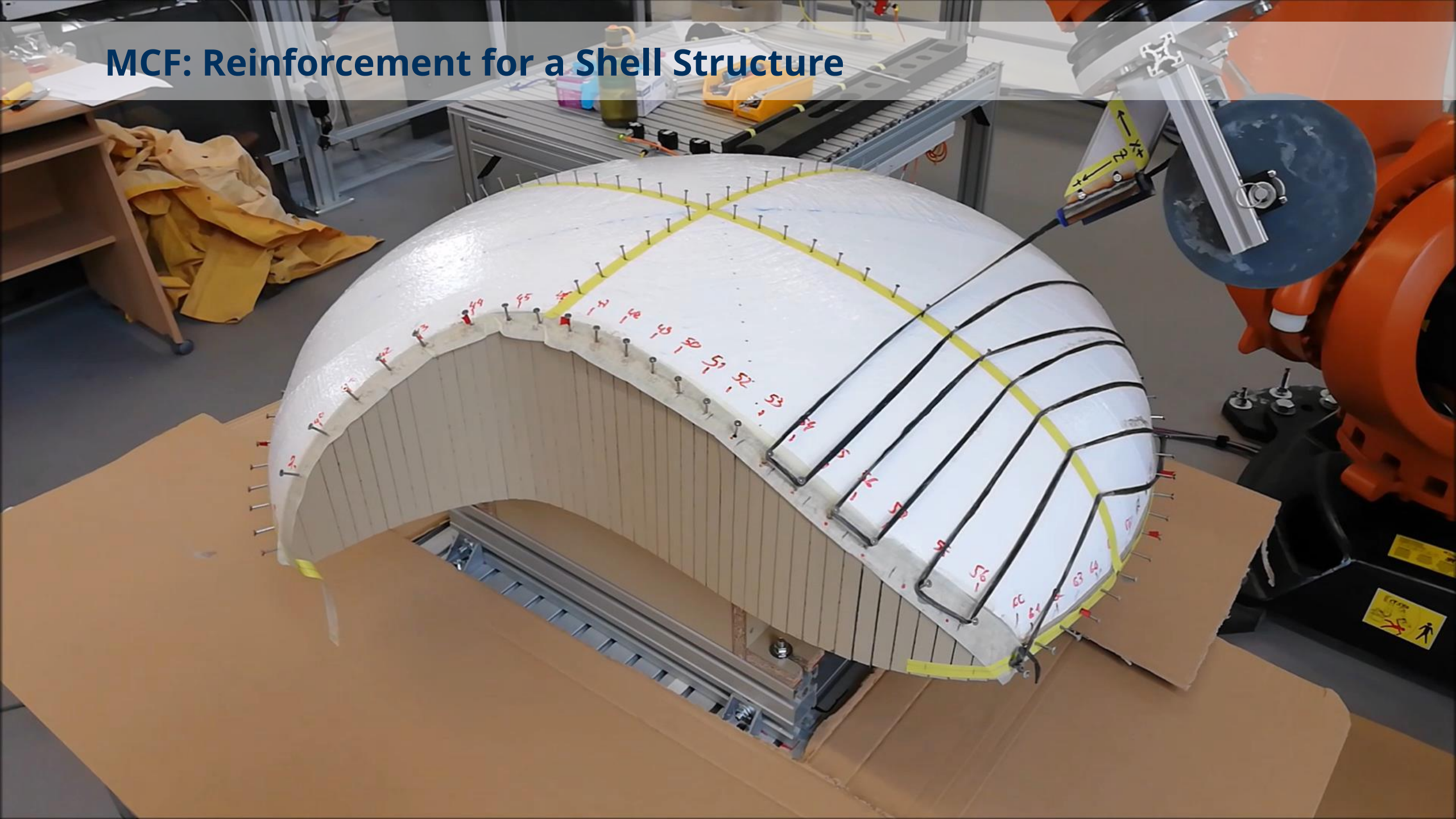


MCF: Completed 2D Reinforcement Structure

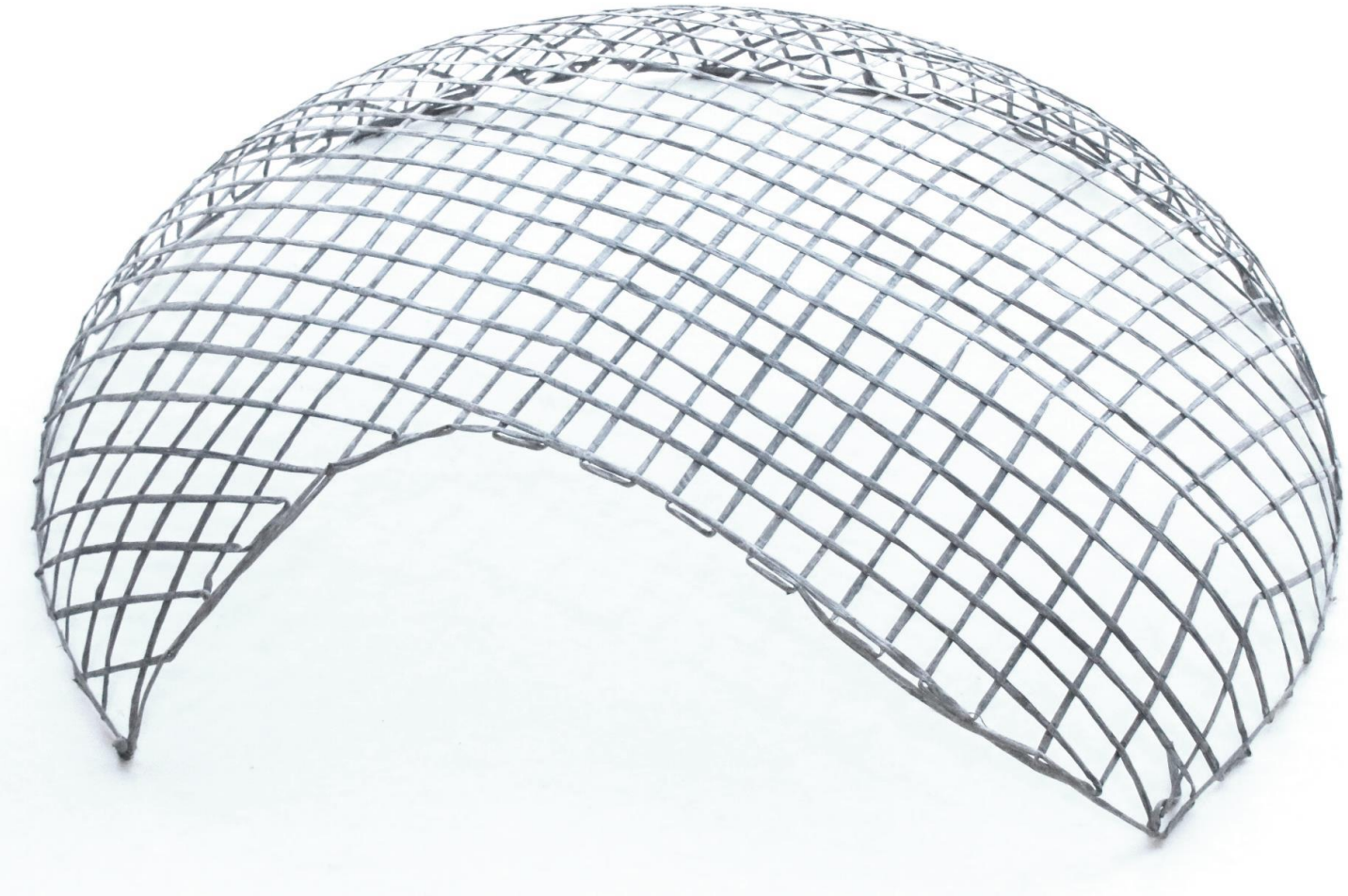


Mechtcherine, Michel, Liebscher, Schneider, Großmann, *Automation in Construction* 110 (2020) 103002

MCF: Reinforcement for a Shell Structure

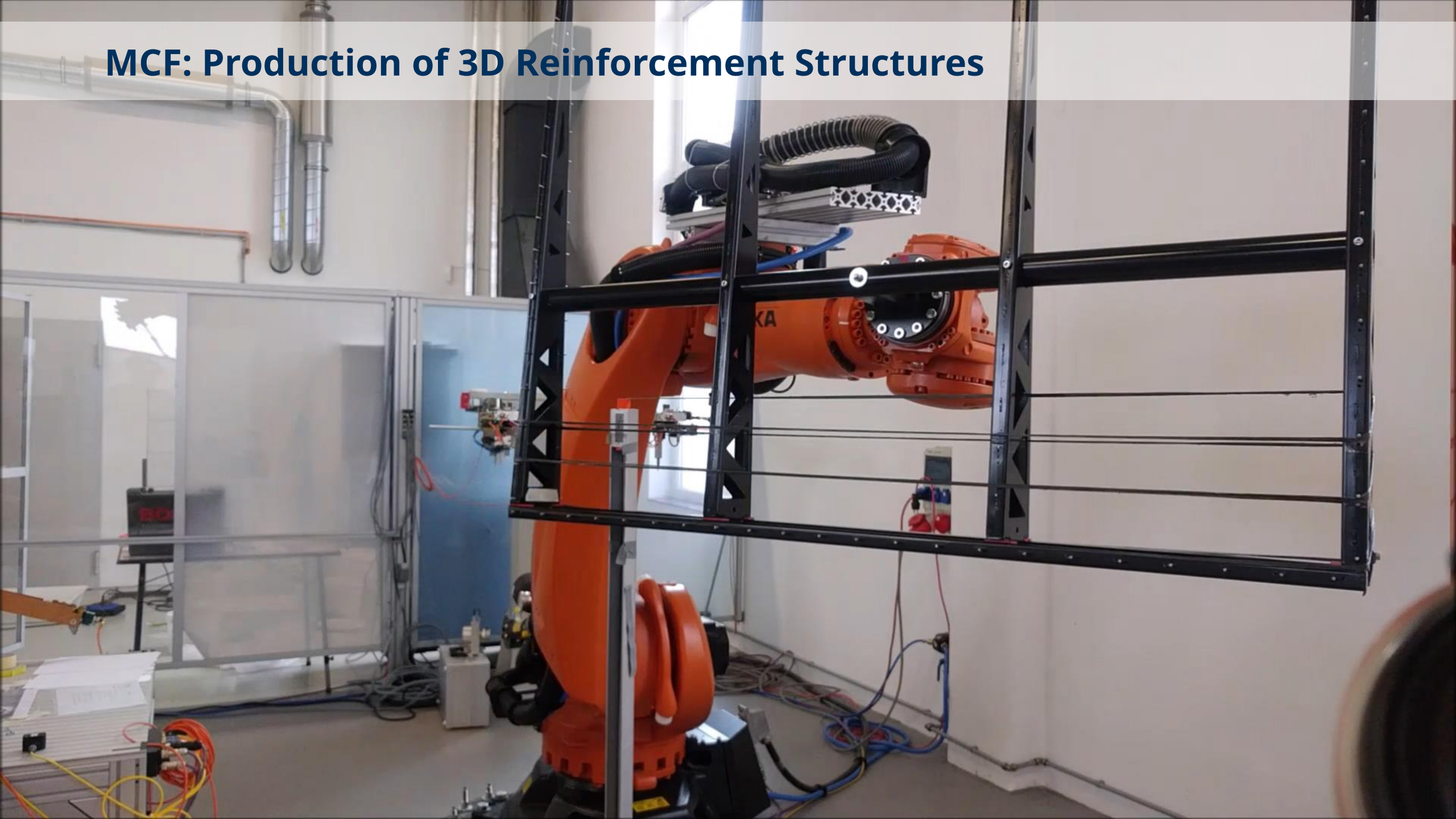


MCF: Reinforcement for a Shell Structure

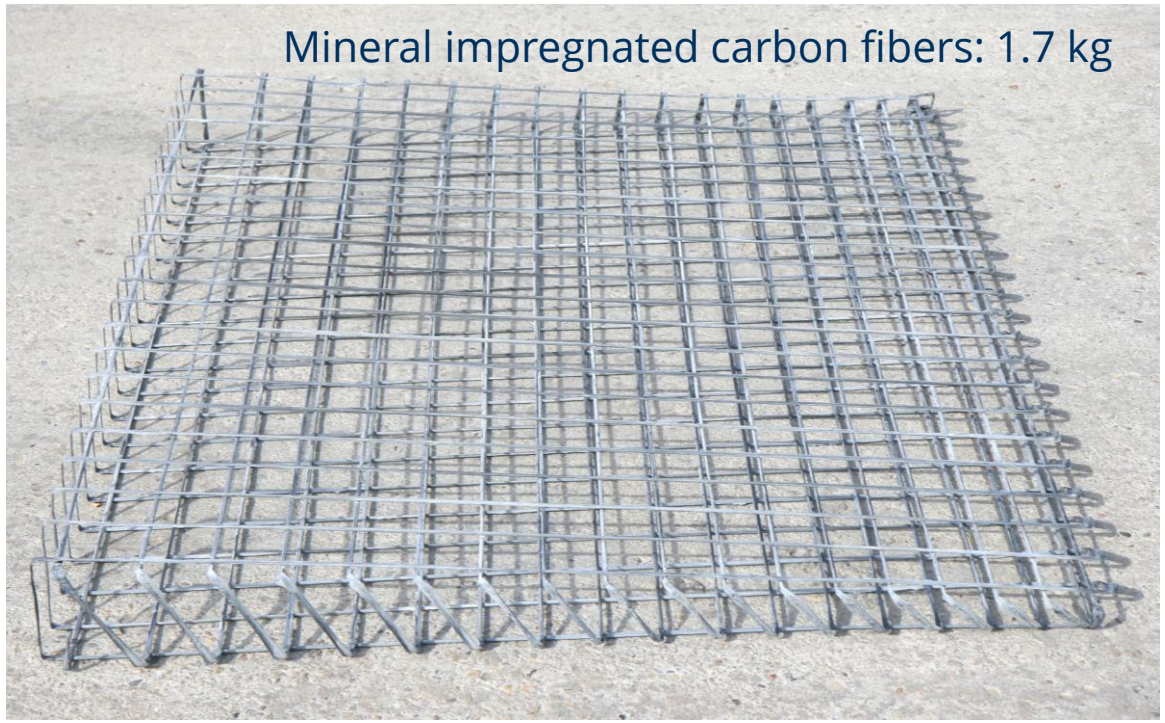


Mechtcherine, *Construction Printing Technology* 1 (2019) 11-16

MCF: Production of 3D Reinforcement Structures

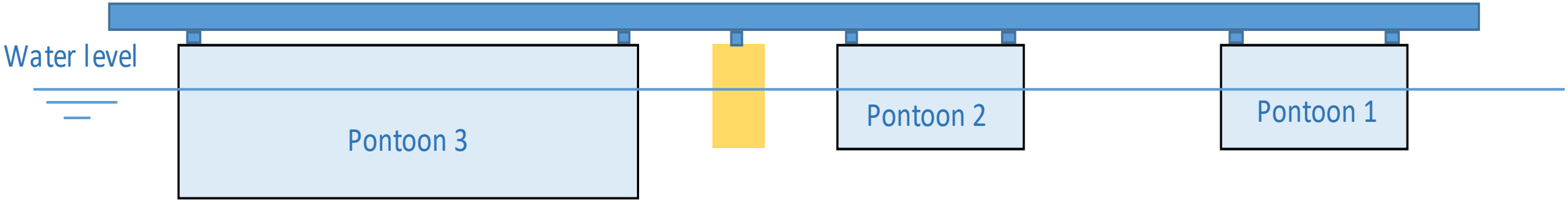


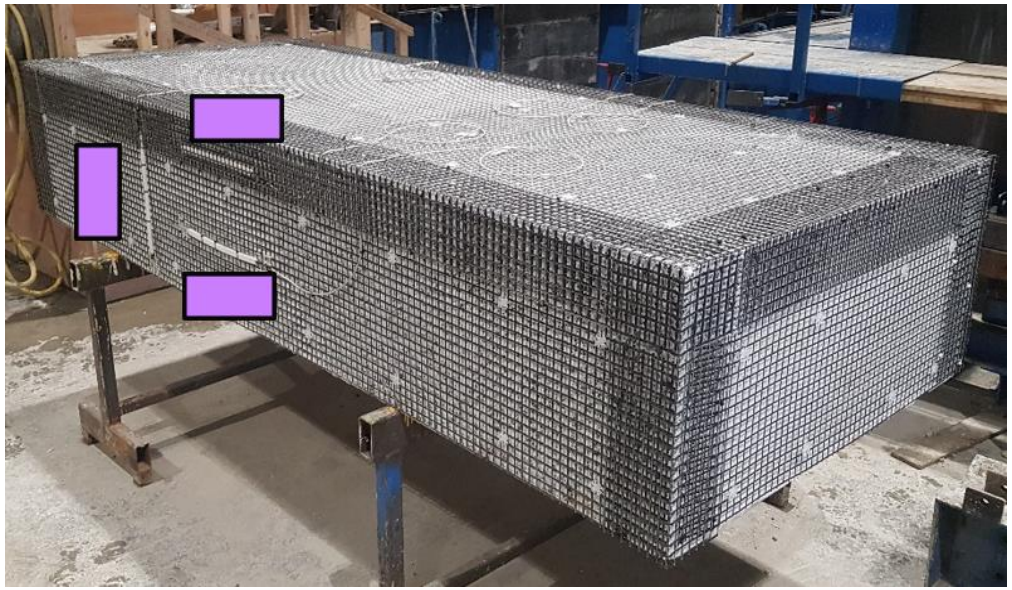
MCF: Completed 3D Reinforcement Structure for a Balcony Slab



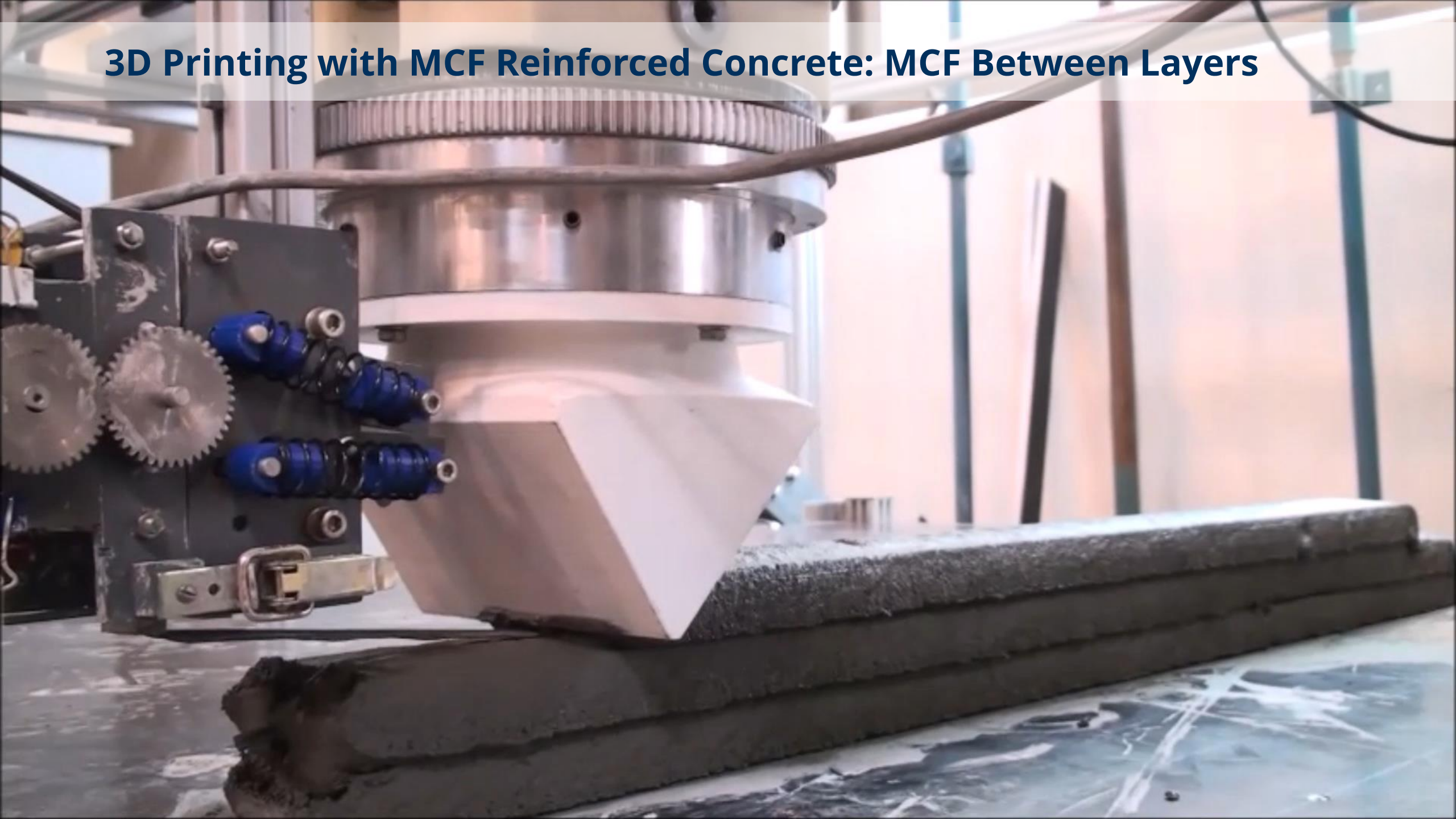
Mechtcherine, Michel, Liebscher, Schneider, Großmann, *Beton- und Stahlbetonbau* 114 (2019) 947-955

Pontoon Made with MCF Reinforcement





3D Printing with MCF Reinforced Concrete: MCF Between Layers



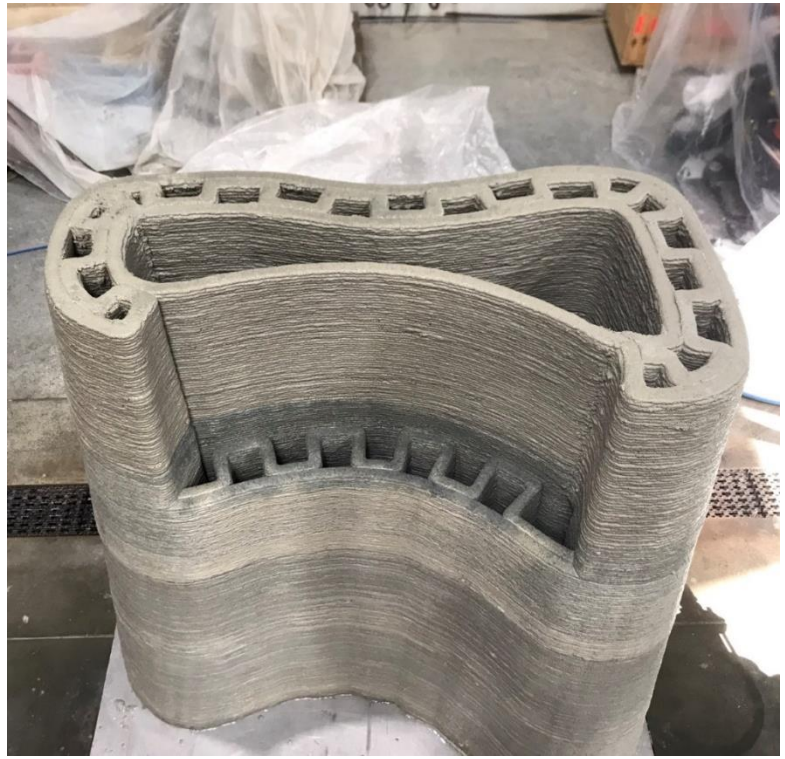
3D Printing with MCF Reinforced Concrete: Into the Layers

Video: TU Dresden

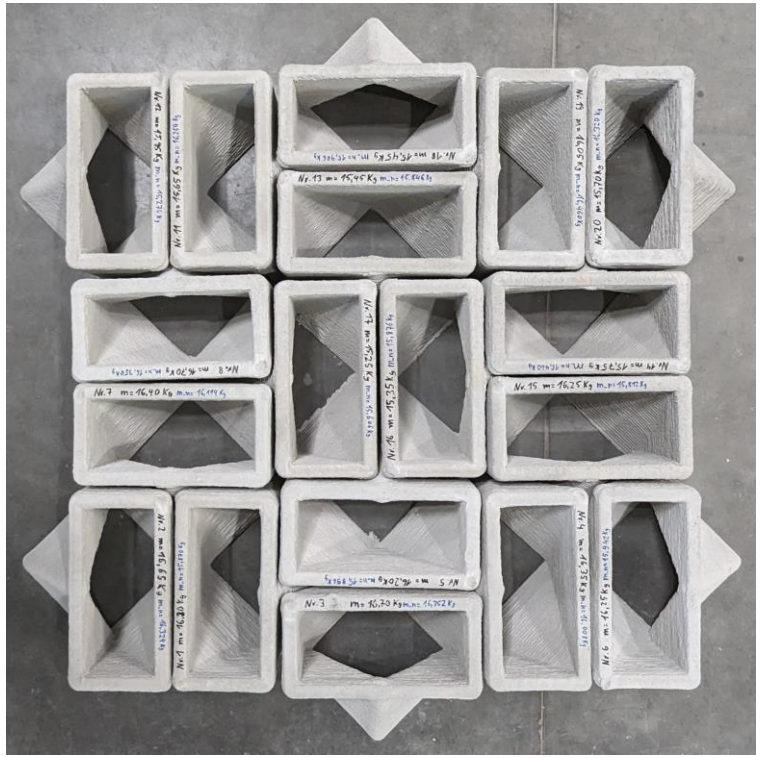
3D Printing with MCF Reinforced Concrete: Into the Layers

Neef, Müller, Mechtcherine, *Materials and Design* 239 (2024) 112794

Integration of MCF into 3D Concrete Printing

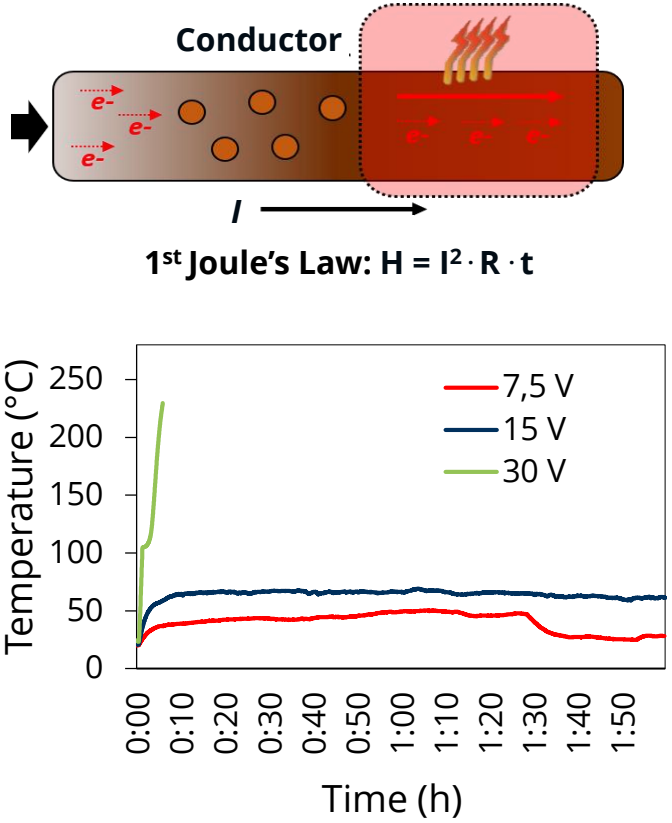


Neef, Mueller, Mechtcherine, *Materials and Design* 239 (2024) 112794

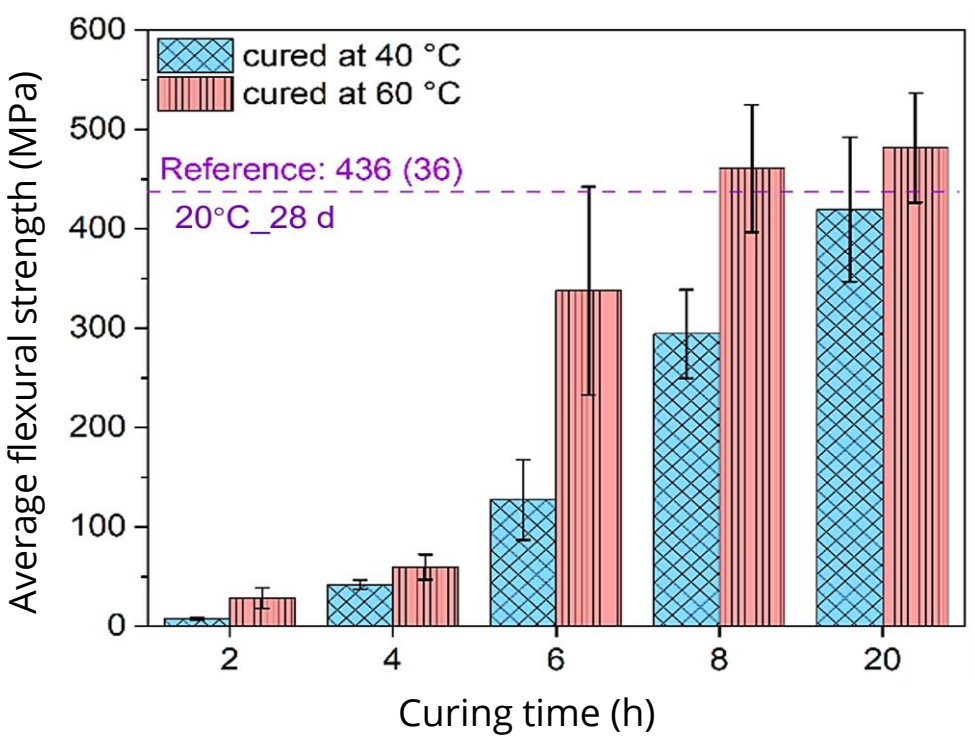


Neef, Goertzen, Niemeyer, Mechtcherine, *Beton- und Stahlbetonbau* 119 (2024) – DOI: 10.1002/best.202400061

Fast Setting MCF Reinforcements by Defined Joule Heating

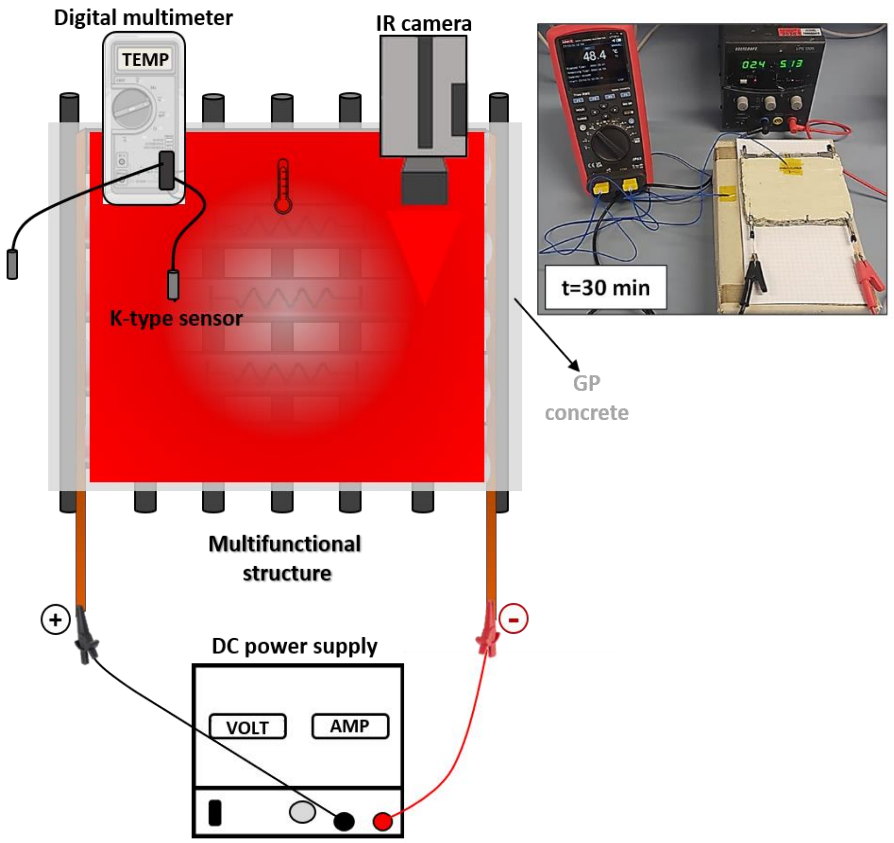


Junger, Liebscher, Zhao, Mechtcherine, *Composites Part A: Applied Science and Manufacturing* 153 (2022) 106750

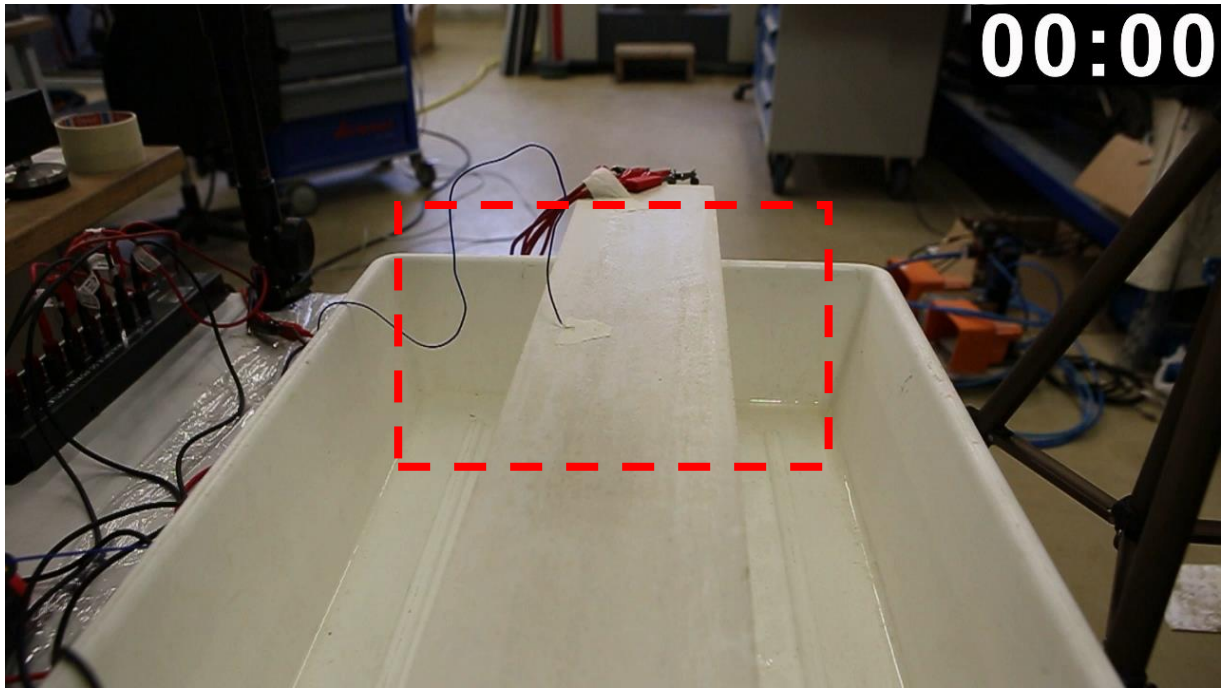


Zhao, Ahmed, Liebscher, Karalis, Saif, Butler, Mechtcherine, *Cement and Concrete Composites* 154 (2024) 105766

De-icing Capacity of MFC Reinforced Concrete Layer by Joule Heating



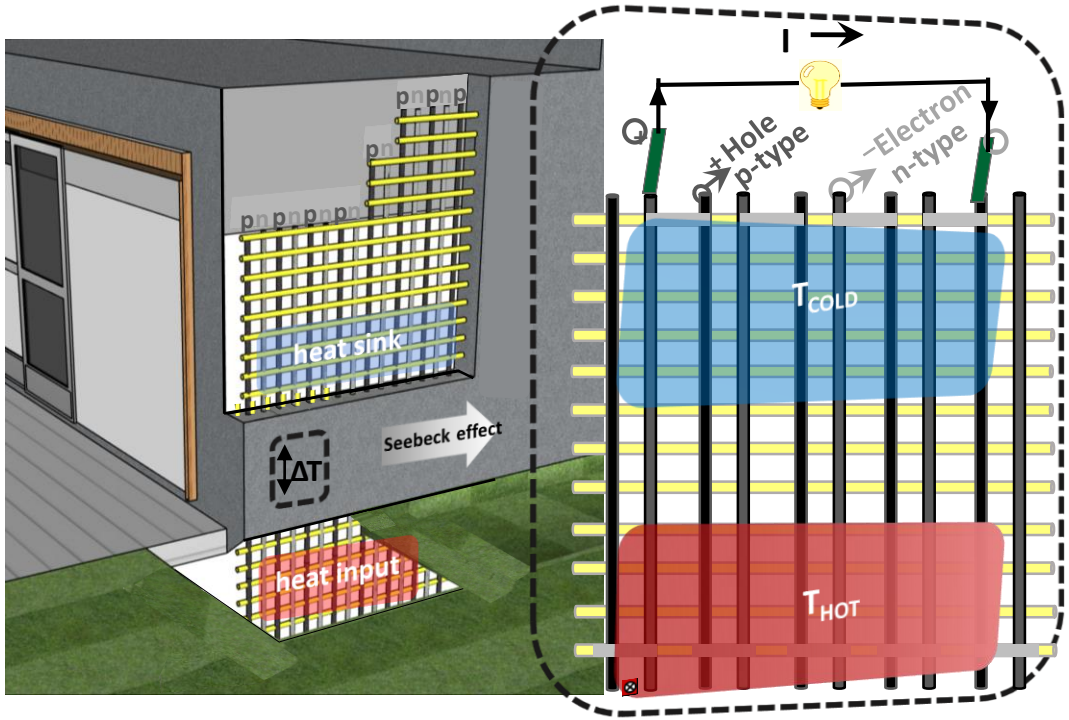
Setup of MCF grids as Joule heater device



De-icing by MCF reinforced concrete layer

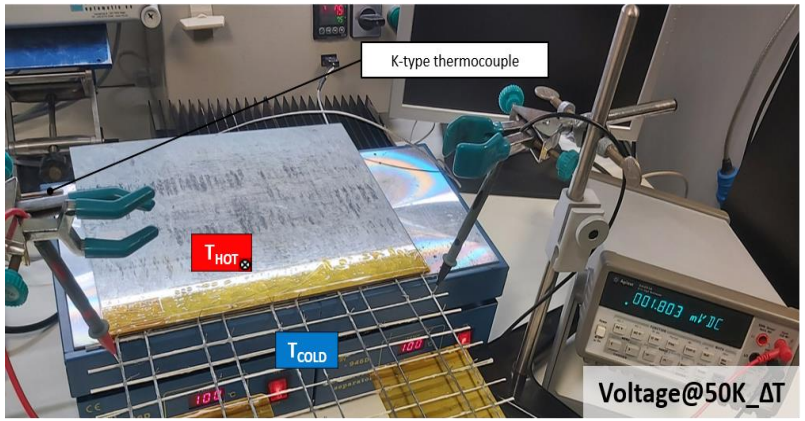
Karalis, Zhao, Liebscher, May, Wollny, Dong, Köberle, Tzounis, Mechtcherine, *Carbon* 222 (2024) 118898

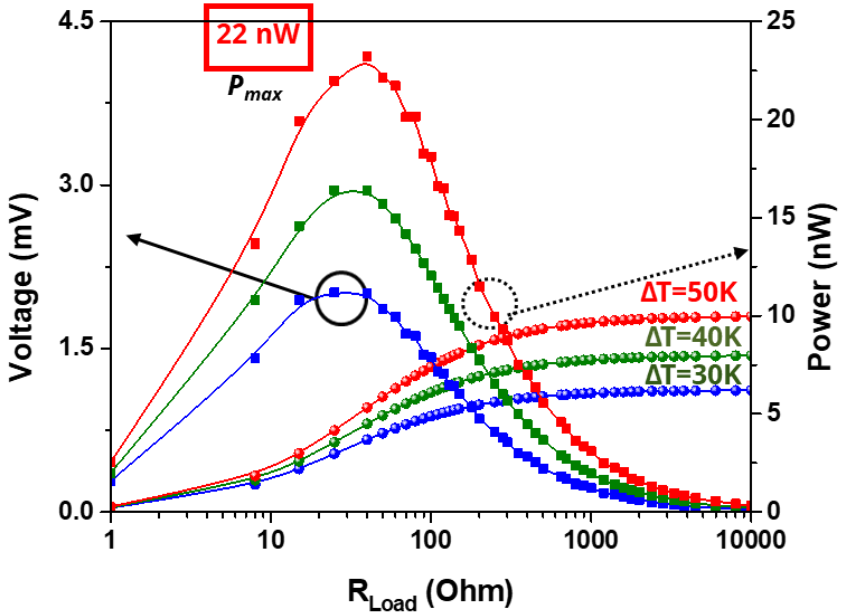
MCF-GP Composites for Thermal Energy Harvesting



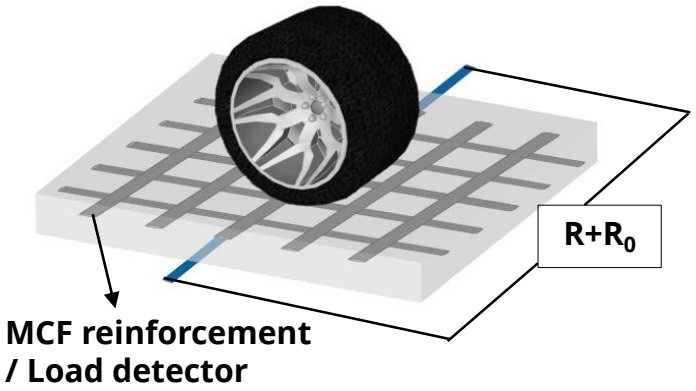
Vision of p- & n-type MCF thermoelement grid

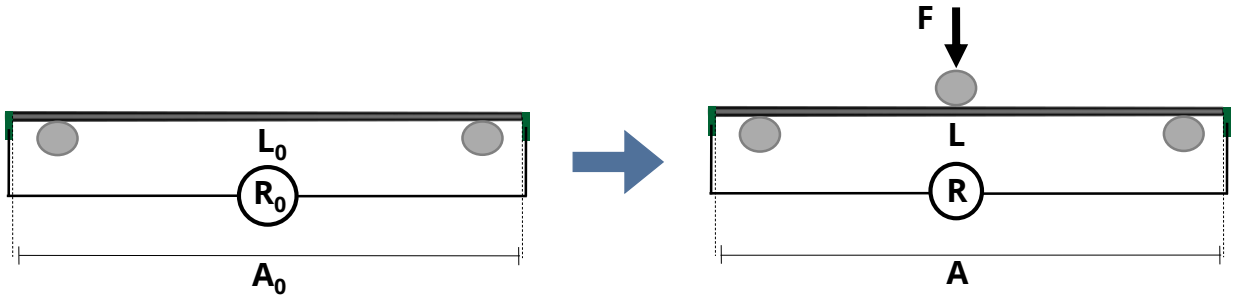
Zhao, Karalis, Liebscher, Tzounis, Köberle, Fischer, Simon, Aiti, Cuniberti, Mechtcherine, *Energy and Buildings* 298 (2023) 113564

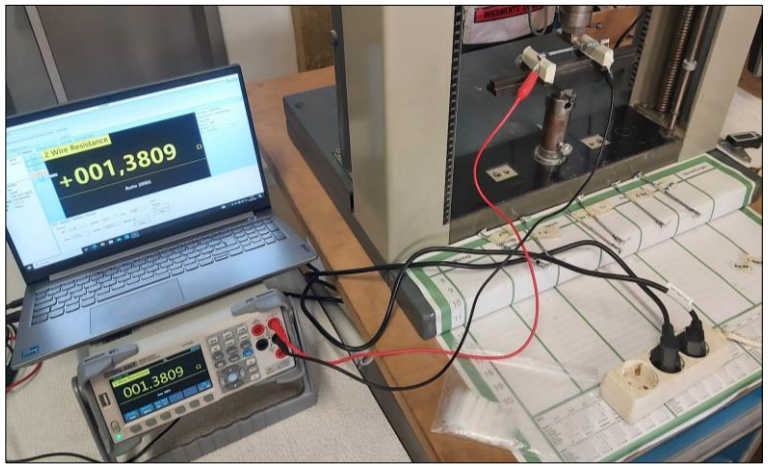




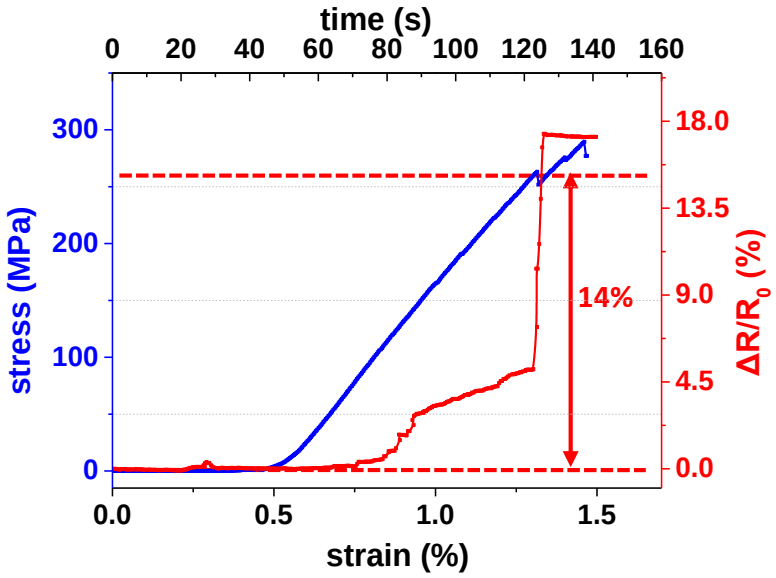
MFC Reinforcements as Load Sensor



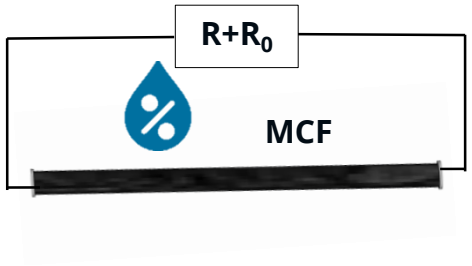


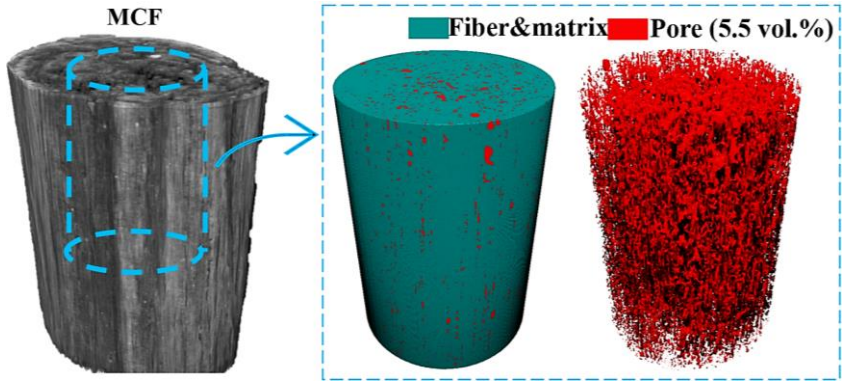


Test setup of MCF under static flexural loading

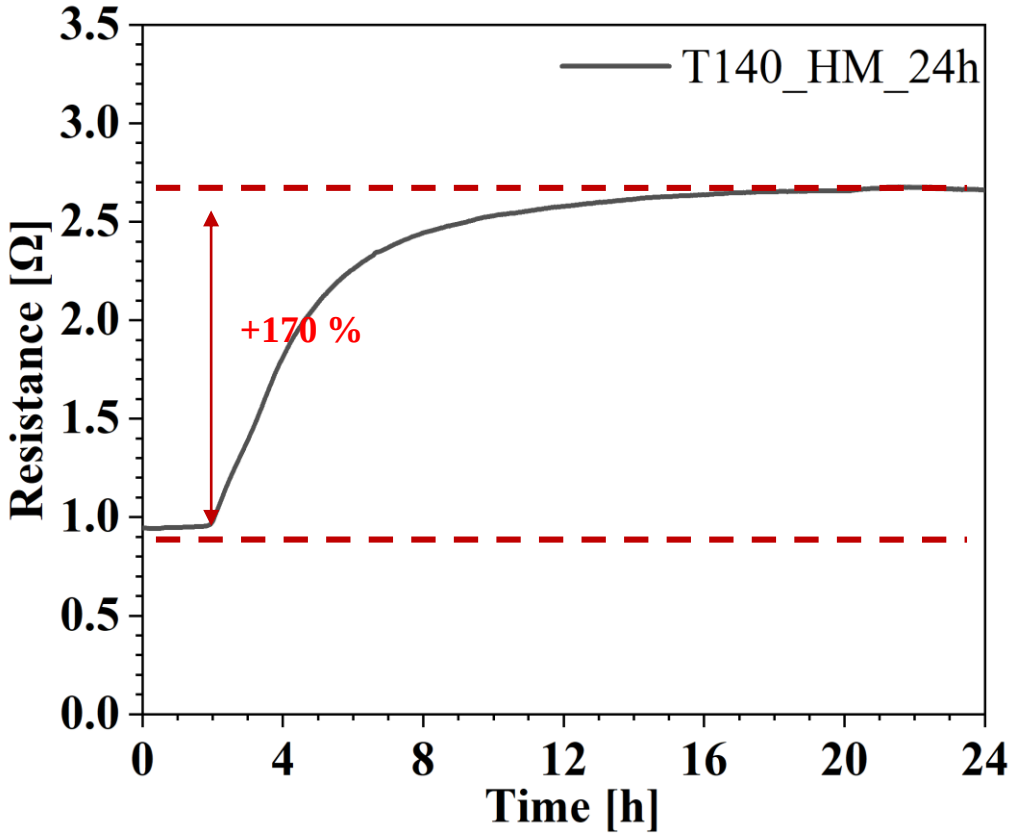


MFC Reinforcements as Moisture Sensor





Segmented µCT images of microstructure of MCF

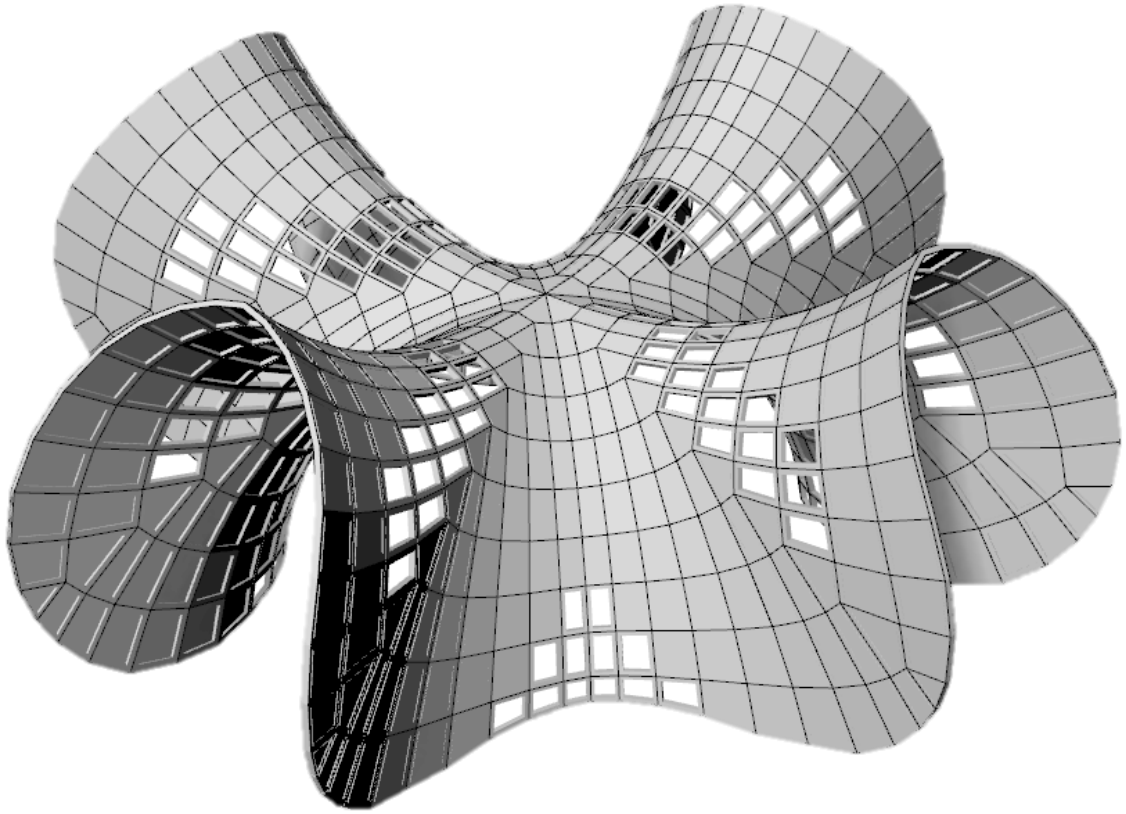


Adaptive Concrete Diamond Construction (ACDC) of Shell Structures

Conventional fabrication using formwork

https://customrodder.forumactif.org/t4351-chapel-lomas-de-cuernavaca-mexico-architect-felix-candela

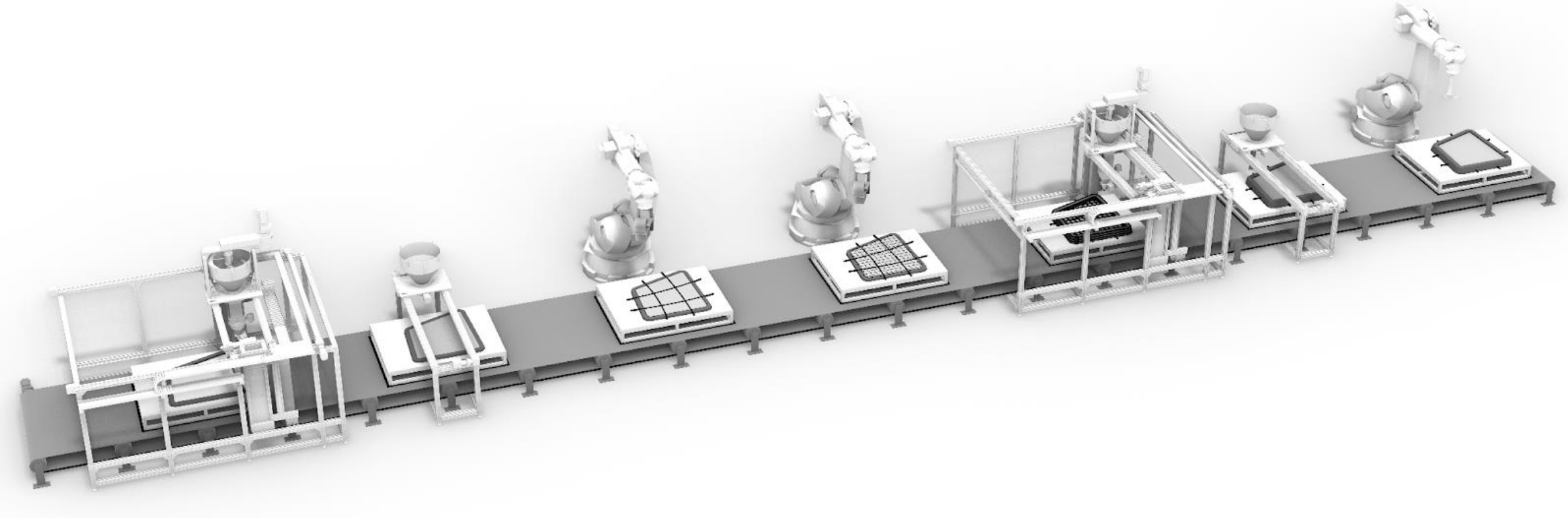
Shell structure made of prefabricated modules



Tošić, Eichenauer, Ivaniuk, Lordick, Krasić, Mechtcherine, *Automation in Construction* 141 (2022) 104432

SHCC and MCF in Hybrid Automated Fabrication of Modules

Adaptive Concrete Diamond Construction (ACDC)



Ivaniuk, Tošić, Müller, Lordick, Mechtcherine, *Automation in Construction* 166 (2024) 105591

SHCC and MCF in Hybrid Automated Fabrication of Modules

Step 1: 3D Printing

Step 2: Casting

Step 3: Placing cable

Step 4: Reinforcement

Step 5: 3D printing

Step 6: Casting

Robotische Verlegung von Carbongarn

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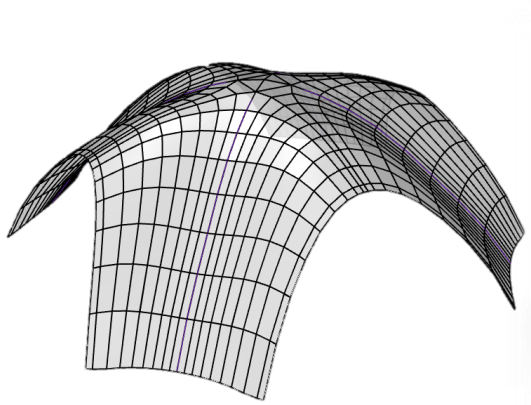
SHCC and MCF in Hybrid Automated Fabrication of Modules

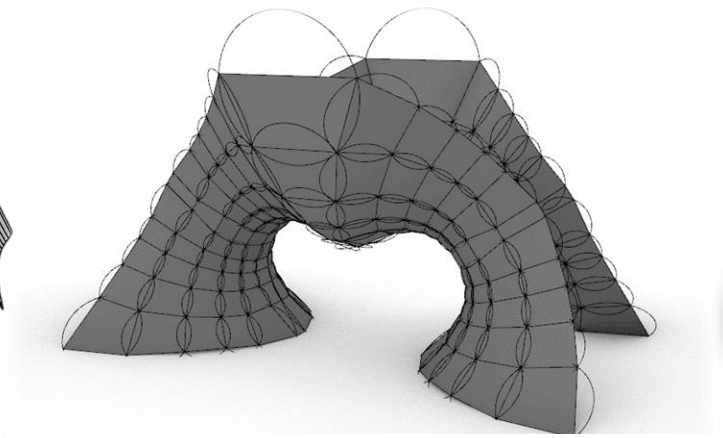
Adaptive Concrete Diamond Construction (ACDC)

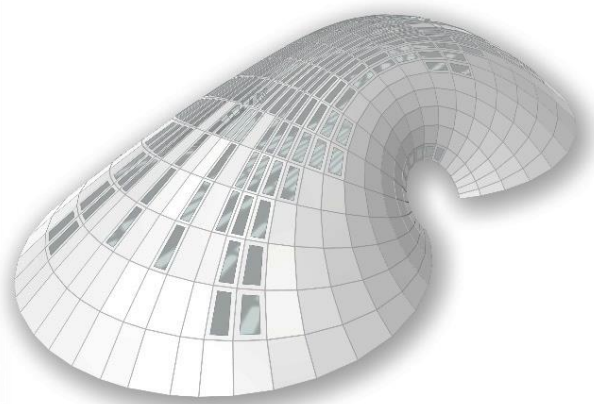
Ivaniuk, Tošić, Müller, Lordick, Mechtcherine, *Automation in Construction* 166 (2024) 105591

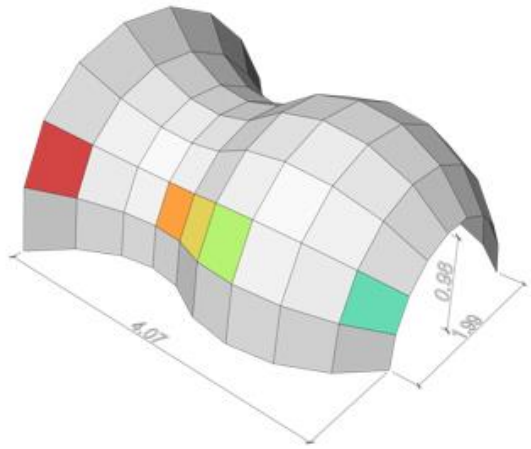
Ivaniuk, Eichenauer, Tošić, Müller, Lordick, Mechtcherine, *Materials and Design* 219 (2022) 110757

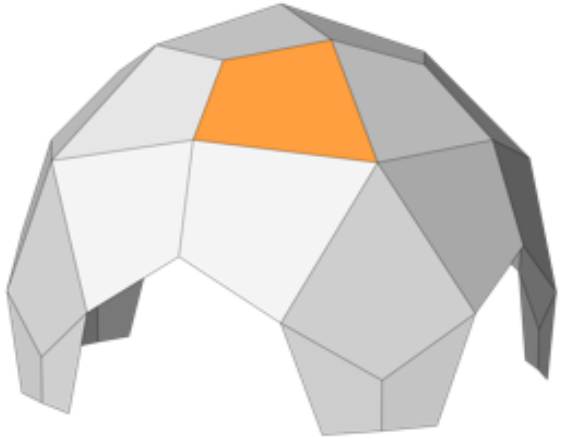
Adaptive Concrete Diamond Construction (ACDC) of Shell Structures

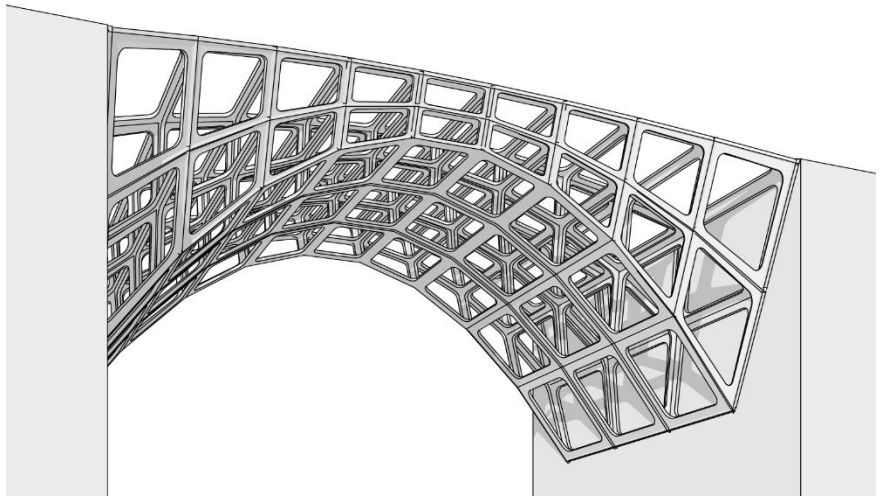


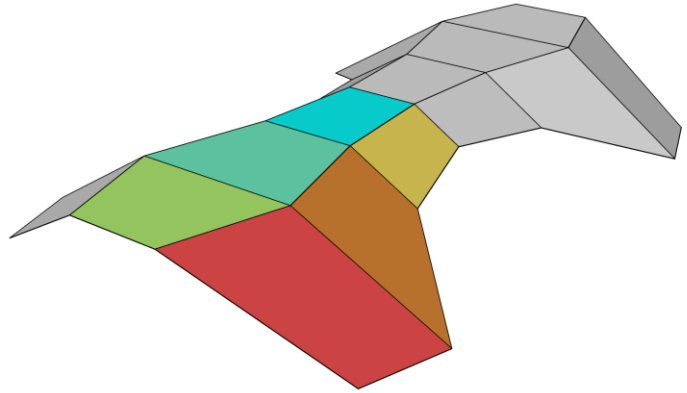












Tosic, Eichenauer, Ivaniuk, Lordick, Krasic, Mechtcherine, *Automation in Construction* 141 (2022) 104432

Acknowledgements

DFG Deutsche Forschungsgemeinschaft

Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit

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