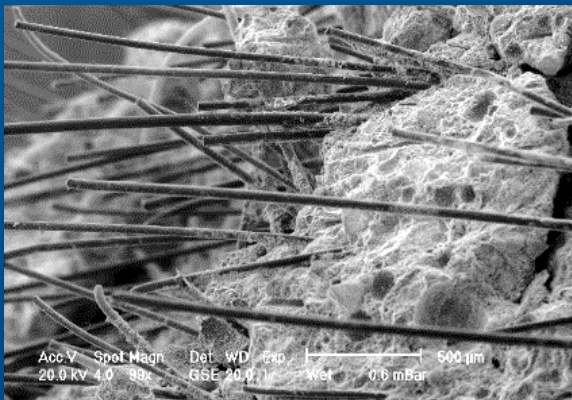


The International Inorganic-Bonded Fiber Composite Conference (IIBCC)  
Colombo, Sri Lanka, November 20 – 21, 2024

Viktor Mechtcherine

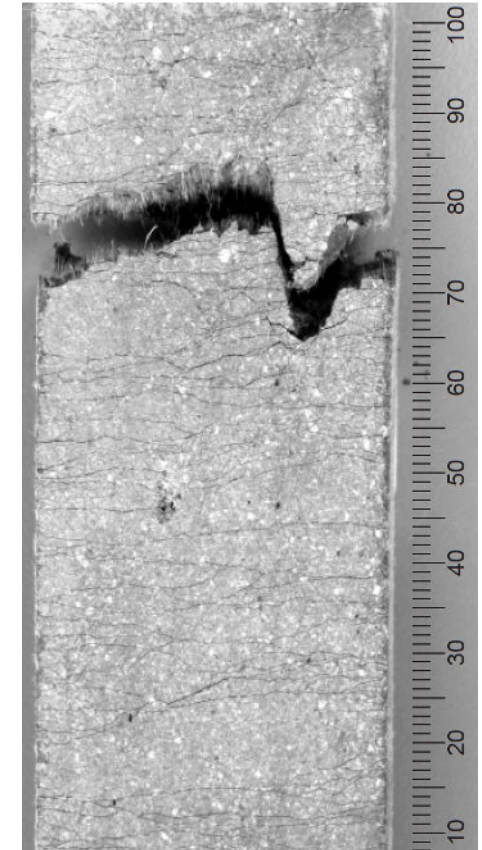
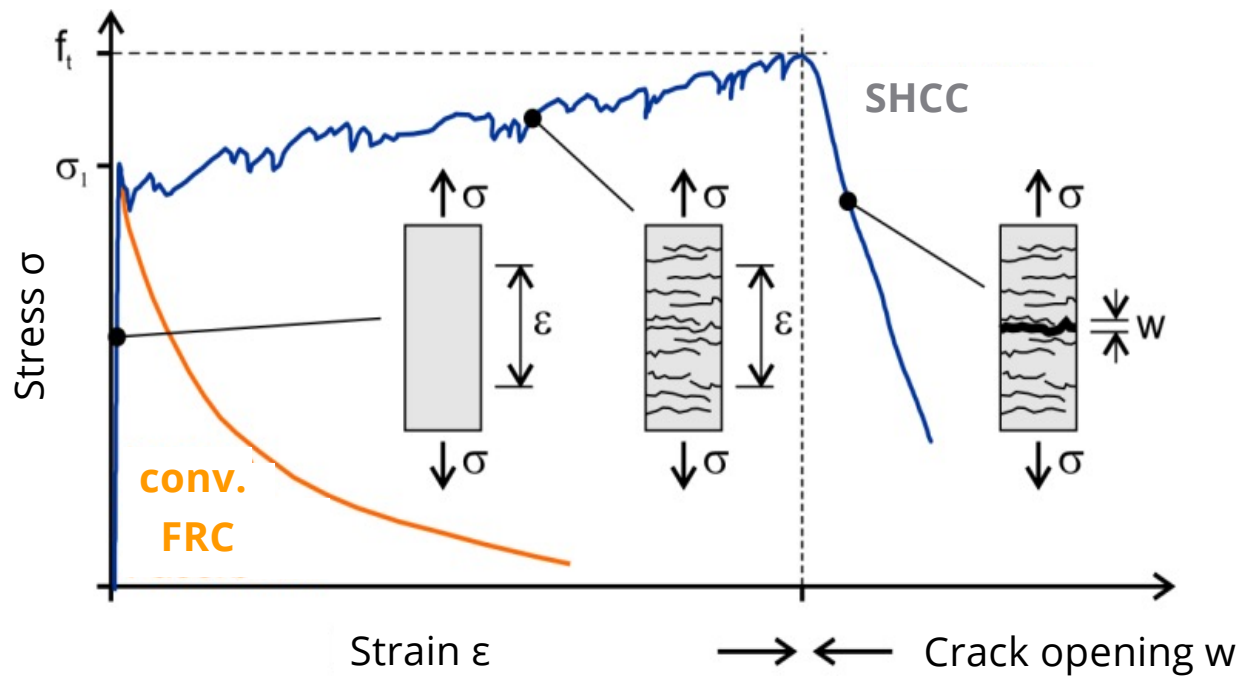
Novel inorganic-bonded fiber composites and digital manufacturing technologies: A path to sustainable construction



© Viktor Mechtcherine, email: [mechtcherine@tu-dresden.de](mailto:mechtcherine@tu-dresden.de)

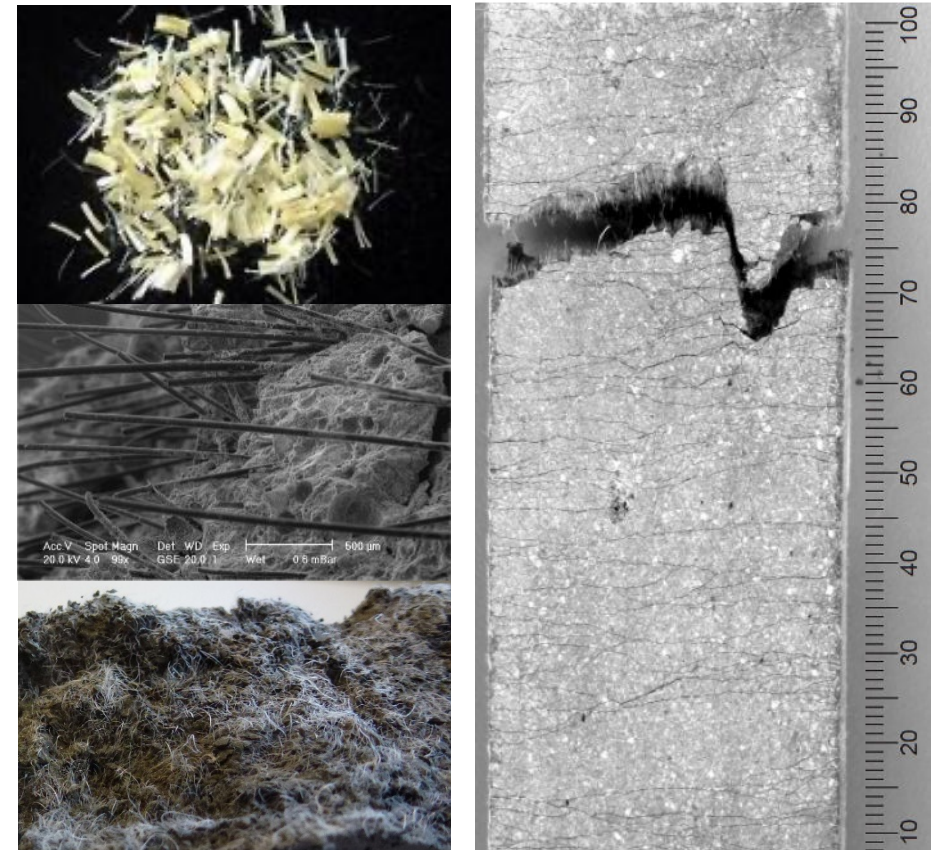
# Novel Materials: Strain-hardening Cement-based Composite (SHCC)

Behavior under uniaxial tensile loading



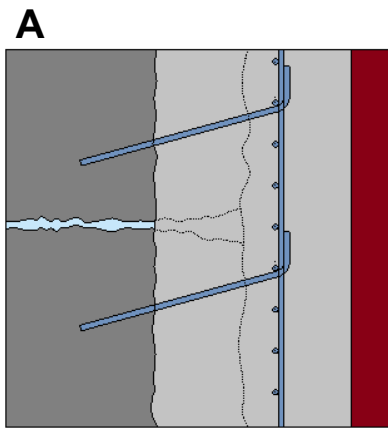
# Novel Materials: Strain-hardening Cement-based Composite (SHCC)

Constituent	SHCC	LC3-SHCC
	[kg/m <sup>3</sup> ]	
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)

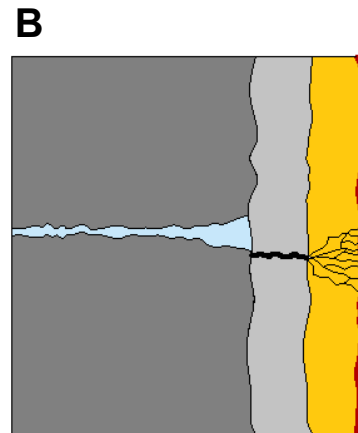


Wang, Rehman, Curosu, Zhu, Beigh, Liebscher, Chen, Tsang, Hempel, Mechtcherine, *Cement and Concrete Research* 144 (2021) 106421

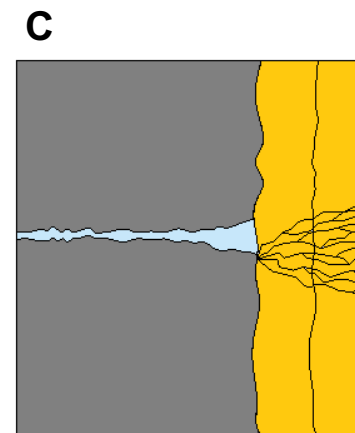
# Use of SHCC for Rehabilitation of Concrete Structures



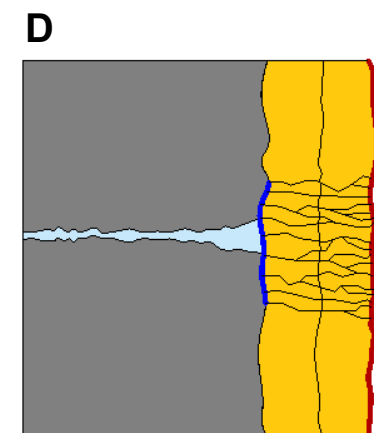
- steel reinforced concrete
- finishing layer



- 1 layer shotcrete
- 1 layer SHCC
- fine finish



- 2 layers SHCC
- fine finish



- local decoupling
- 2 layers SHCC
- fine finish

Müller, Mechtcherine, *ICCRRR 2018*, doi:10.1051/mateconf/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

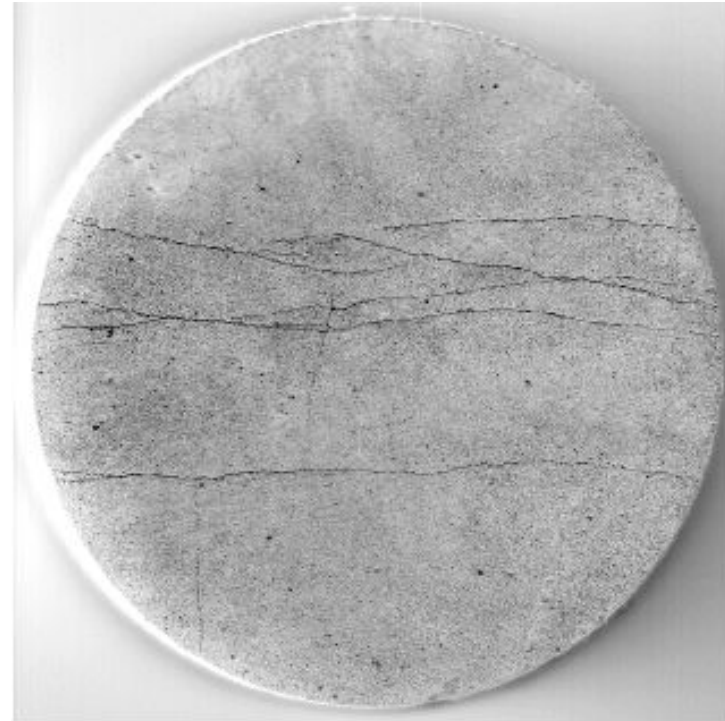


# Use of SHCC for Rehabilitation of Concrete Structures

## Water storage power plant in Hohenwarte, Germany



Crack in concrete substrate



Distributed fine cracks in SHCC

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

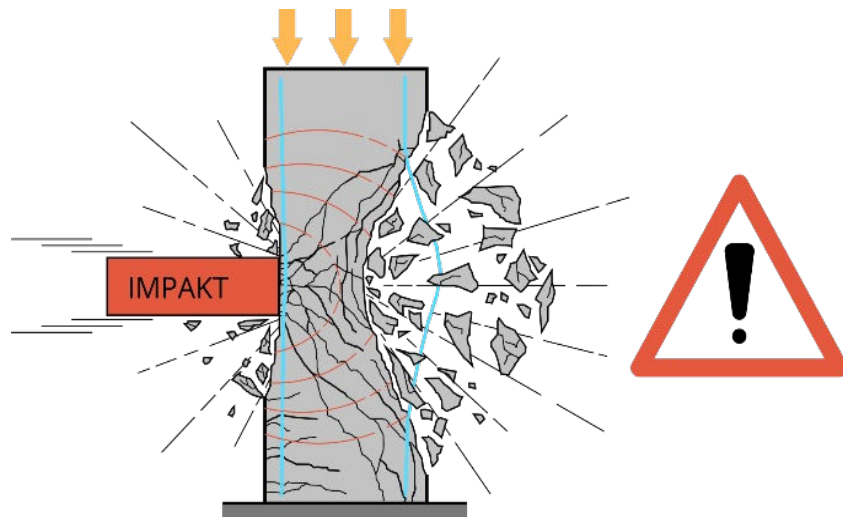
# Concrete Structures under Impact Loading



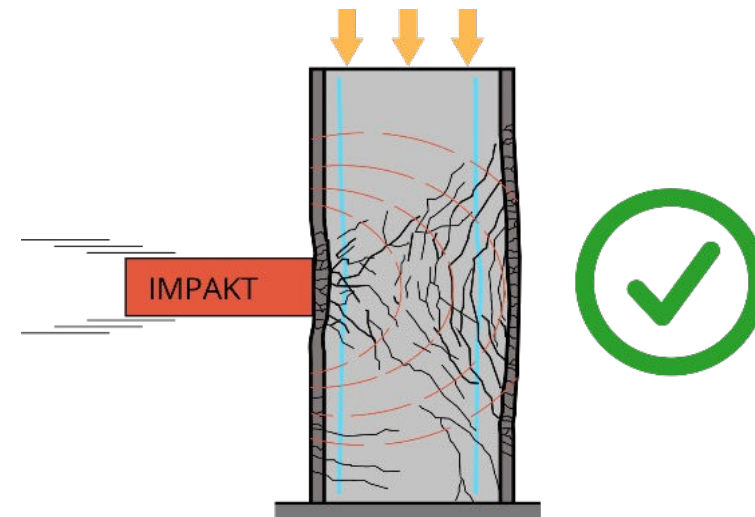
„A dollar spent on mitigation saves society an average of \$4.“



# Strengthening of Concrete Structures Subject to Impact Loading

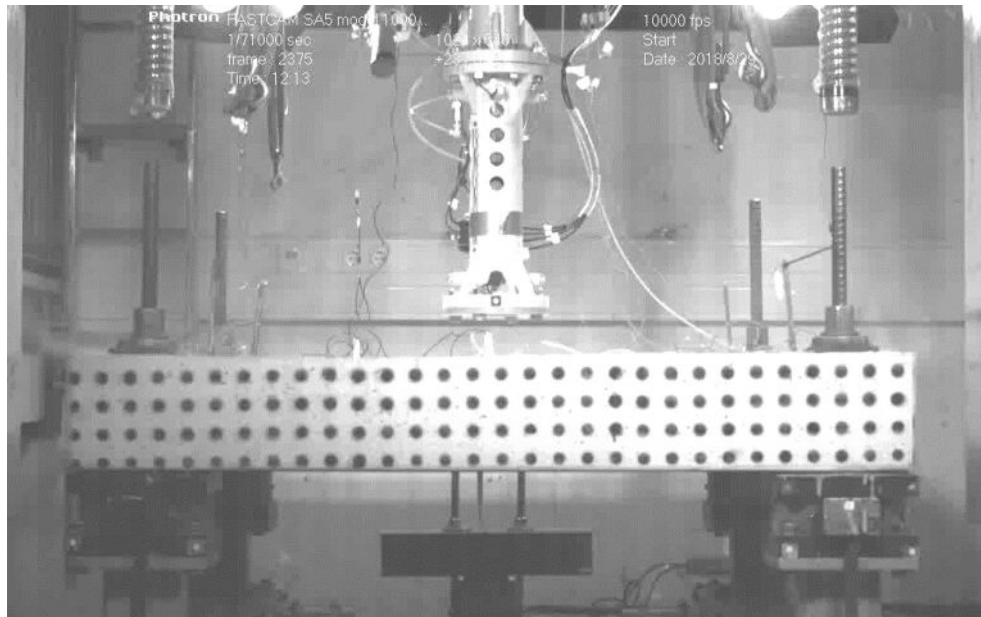


Steel reinforced concrete



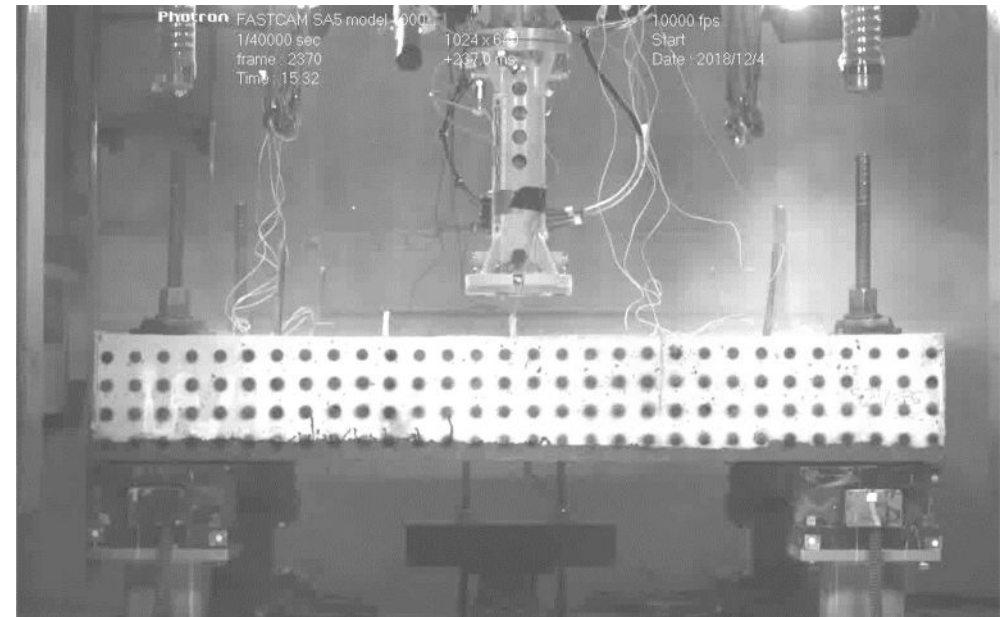
Strengthened with a mineral-based composite

# 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

OTAT



# Novel Technologies: Extrusion-based 3D Concrete Printing

• higher productivity • lower spatial resolution • coarser aggregates



TU Dresden, 2022



TU Dresden, 2020

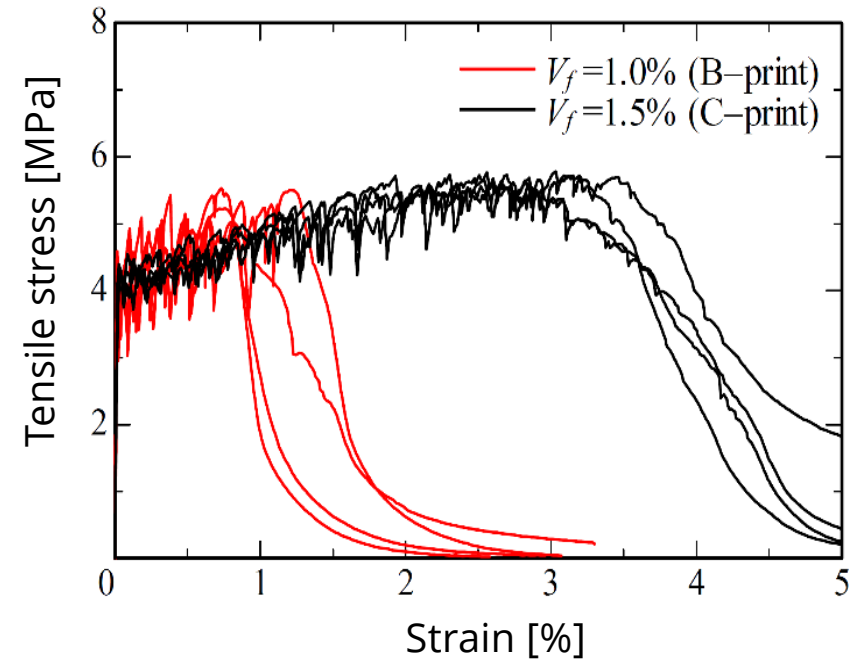
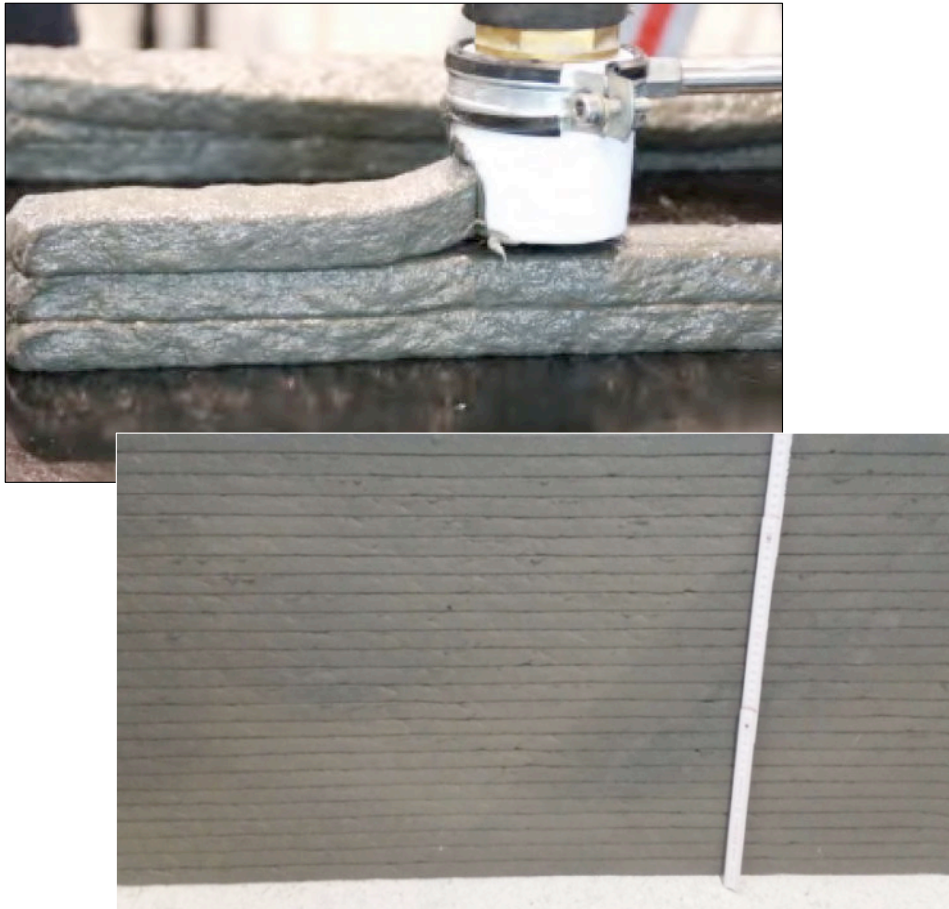


TU Dresden, 2019



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)

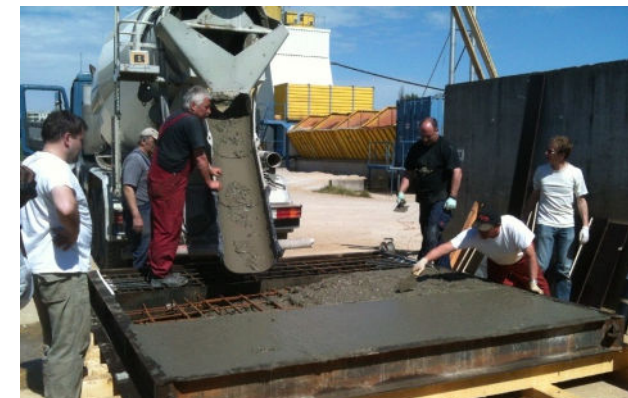
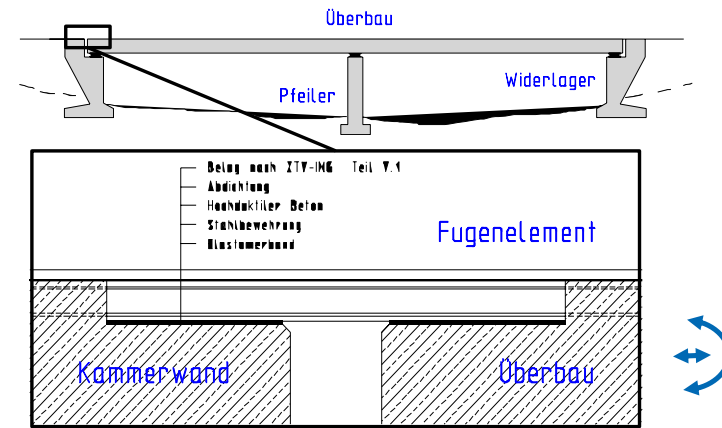


Shimzu Corporation, Japan

# SHCC: Further Application Examples



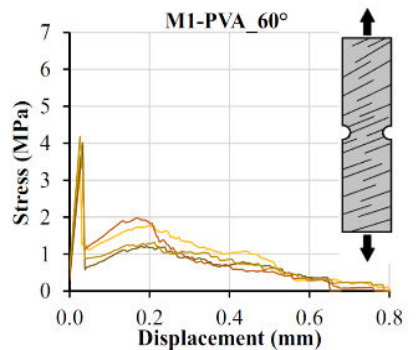
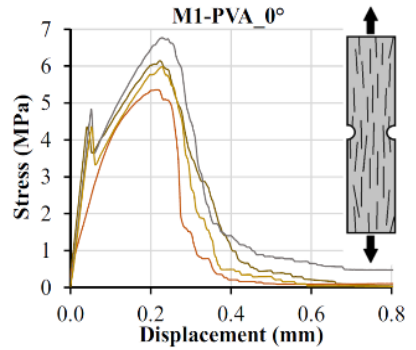
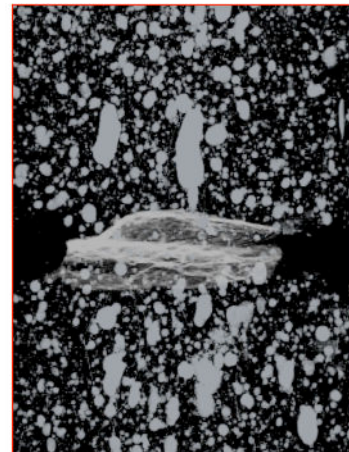
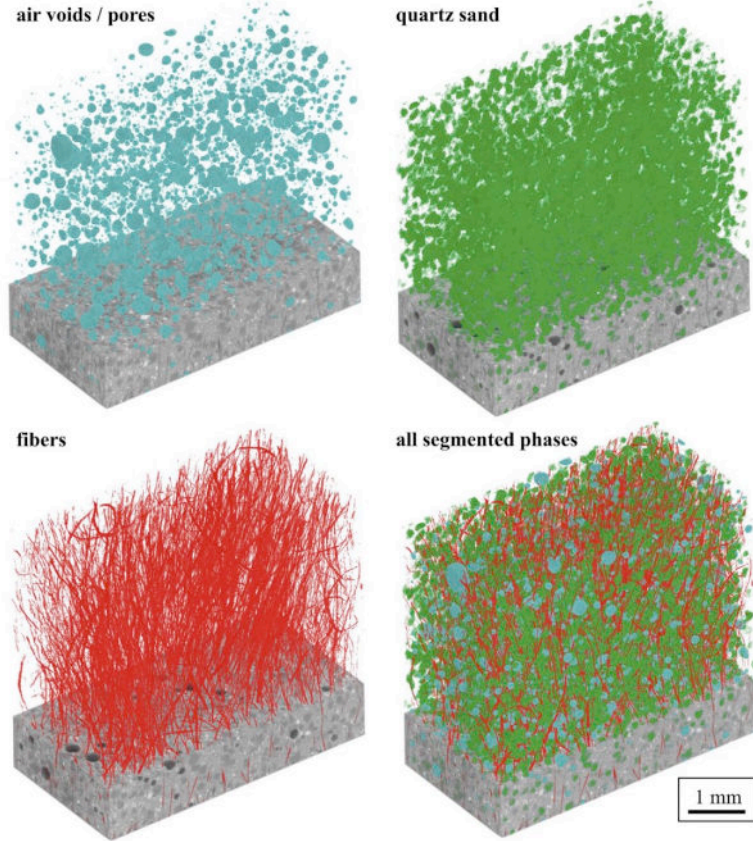
Mueller, Ranjbarian, Mechtcherine, *Structural Concrete* 20 (2019) 1231-1242



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      Segmented pores, cracks and fibers in SHCC under tensile load

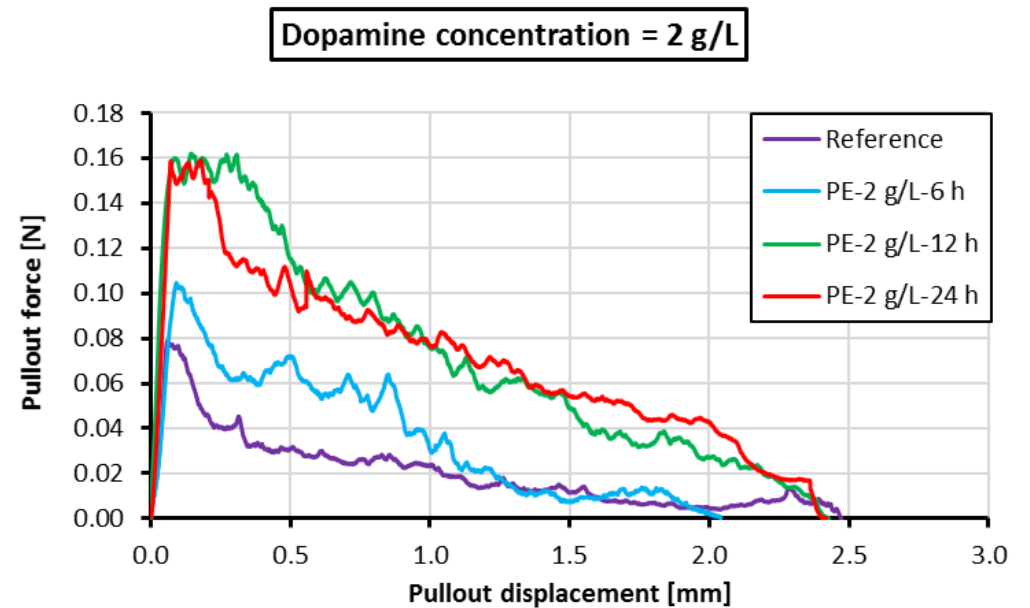
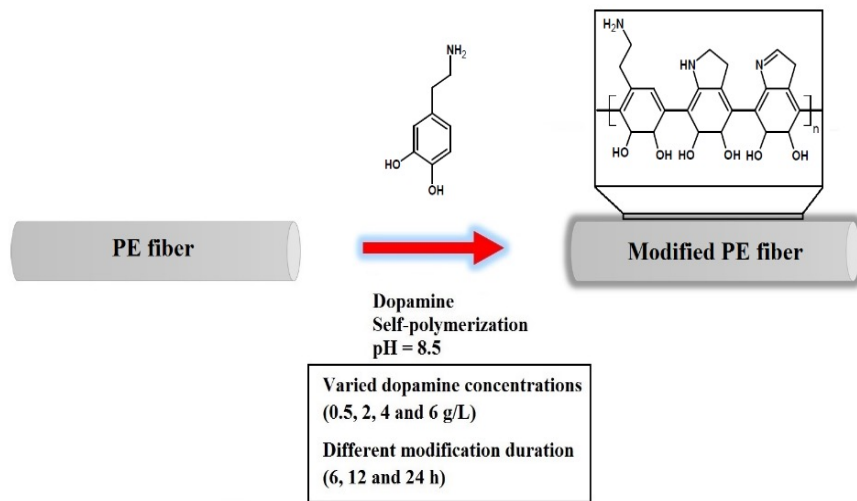


Lorenzoni, Curosu, Paciornik, Mechtcherine, Oppermann, Silva, *CCR* 139 (2020) 103551

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

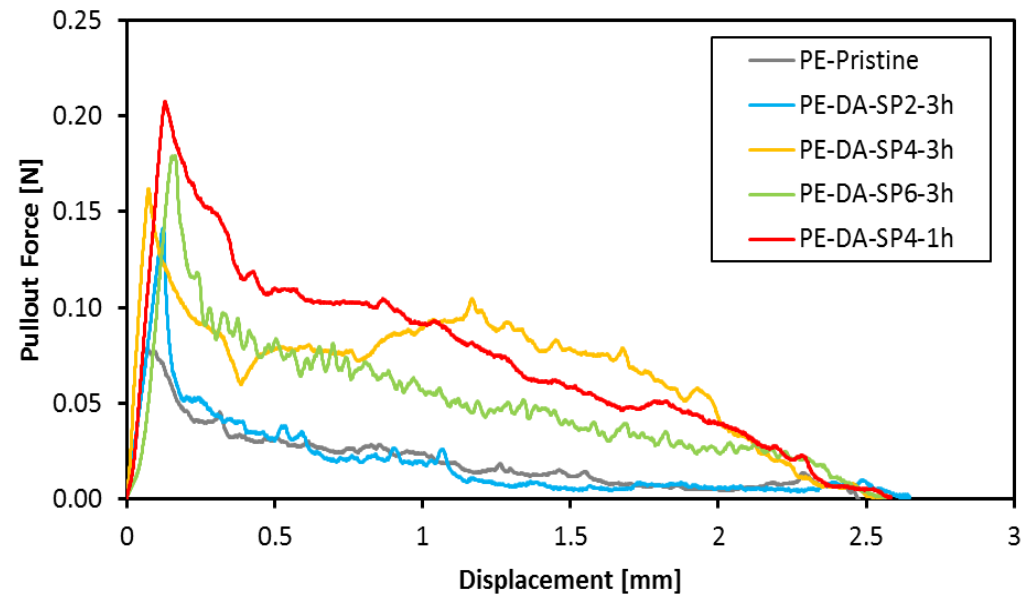
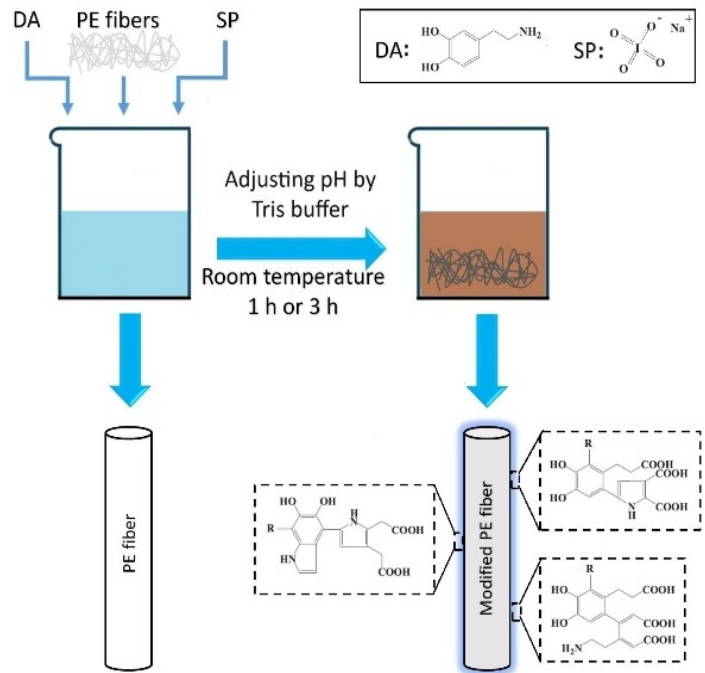


# SHCC: Bond Enhancement by Dopamine Modification



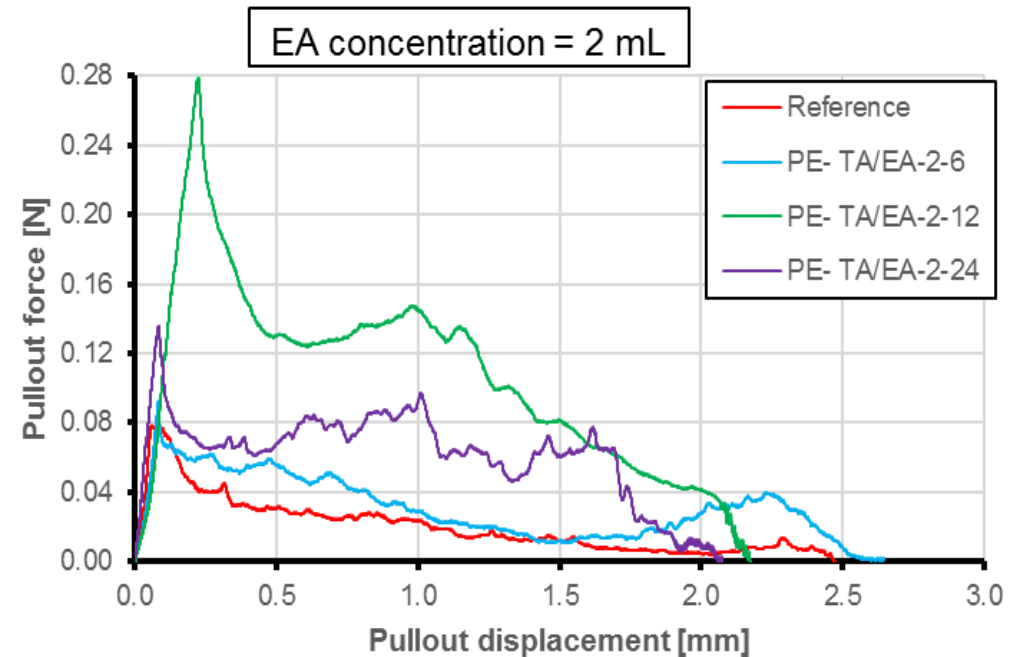
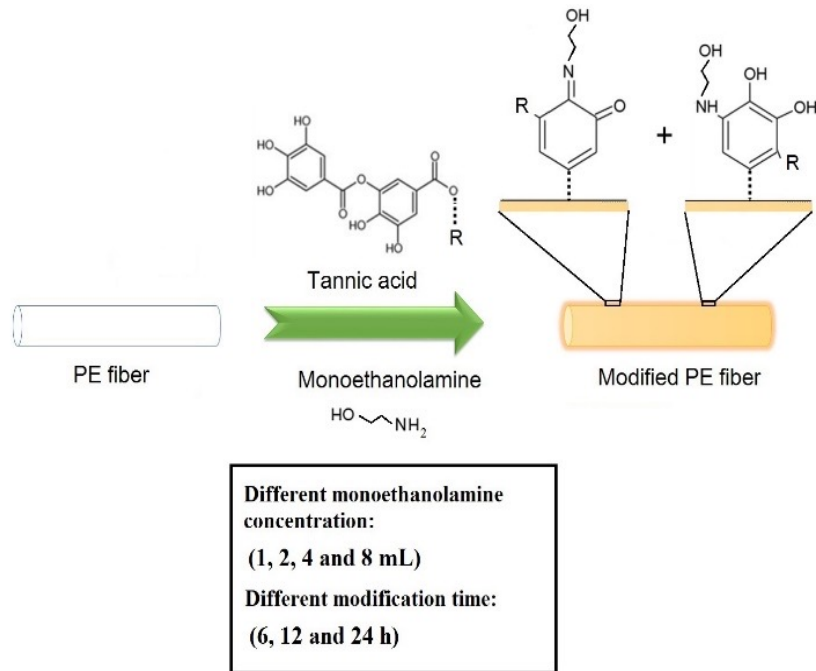
Bashiri Rezaie, Liebscher, Ranjbarian, Simon, Zimmerer, Drechsler, Frenzel, Synytska, Mechtcherine, *Composites Part B: Engineering* 217 (2021) 108817

# 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

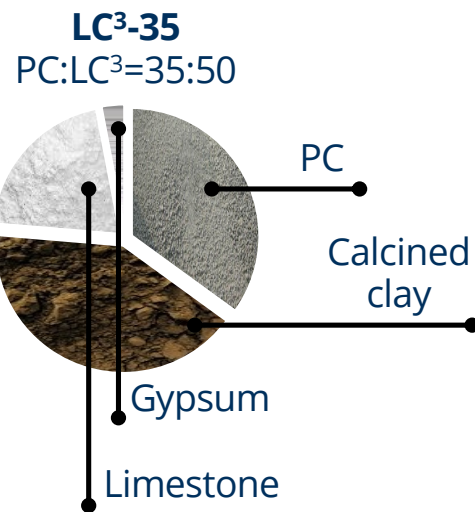
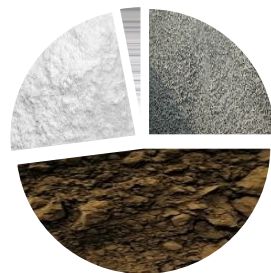
# SHCC: Low-clinker, Low-cost Compositions

## Low-clinker matrix

**LC<sup>3</sup>-50**  
PC:LC<sup>3</sup>=50:50



**LC<sup>3</sup>-25**  
PC:LC<sup>3</sup>=25:50



## Low-cost and recyclable fibers

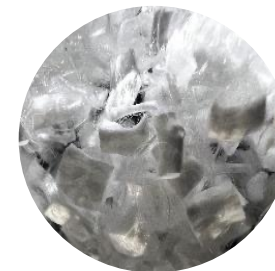
Polyethylene (PE)



Polyethylene terephthalate (PET)

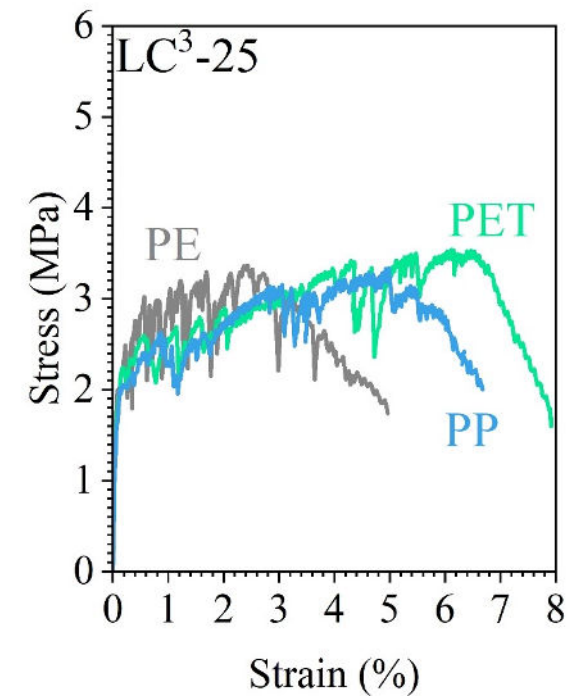
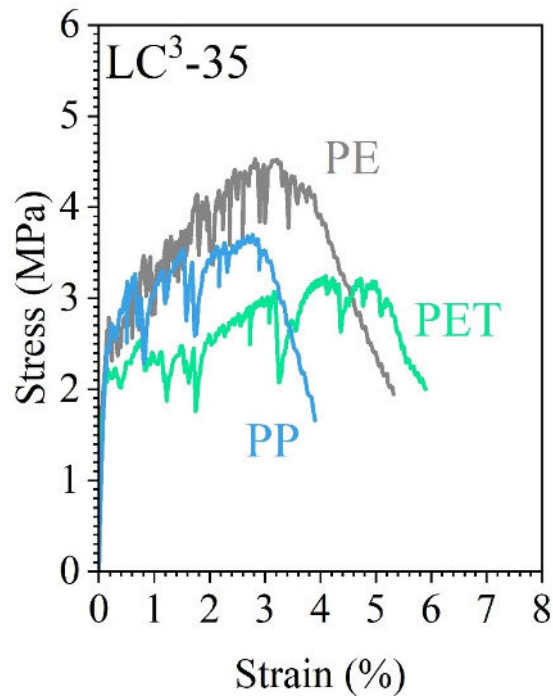
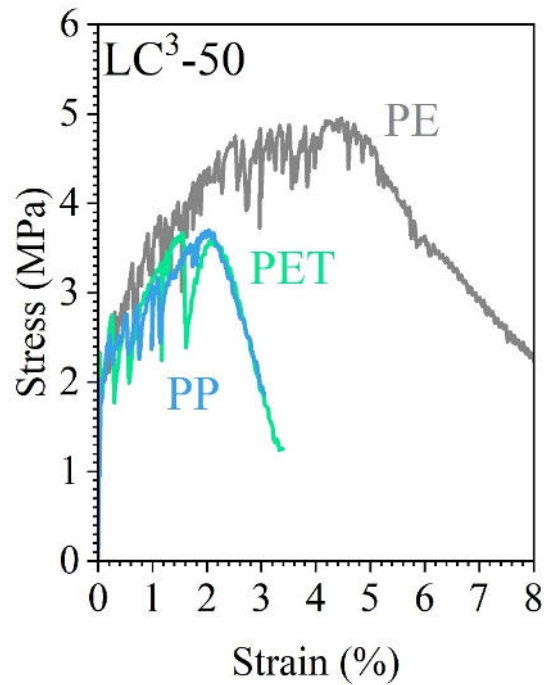


Polypropylene (PP)



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

# Use of Carbon Concrete Composites



Strengthening / Repair / Rehabilitation

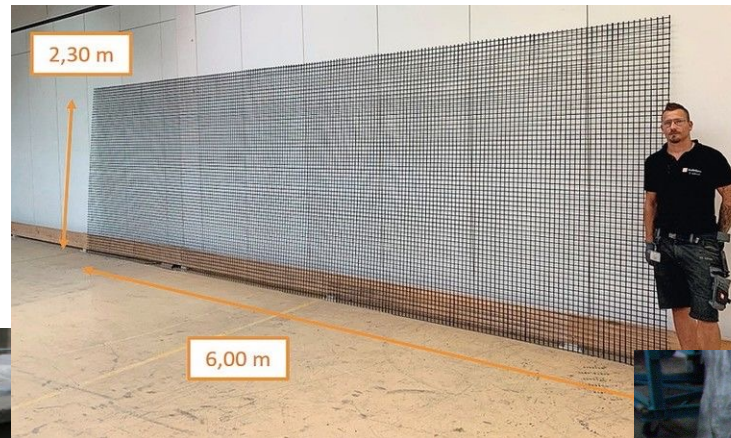


New construction

# 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)

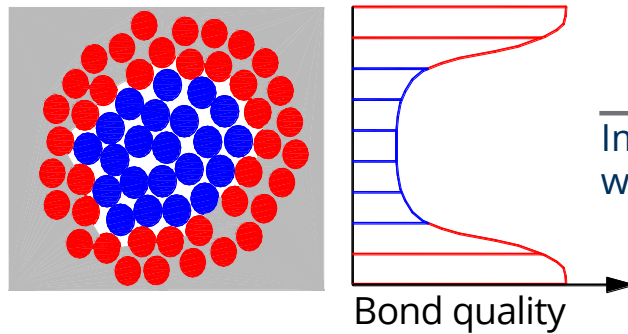
## High flexibility

(no impregnation)  
"The gift of water" by Jackie Brookner, NY

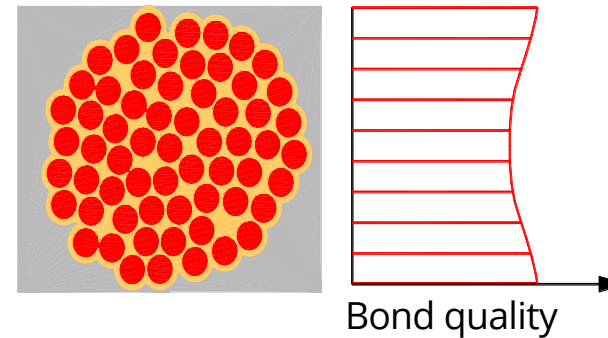


# Carbon Concrete Composites: Impregnation of Textile and Bond Behavior

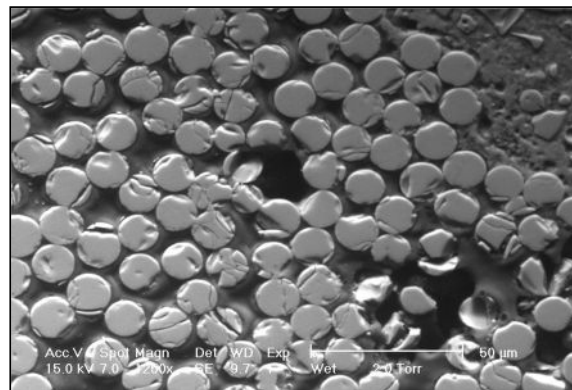
## Yarn without polymer



## Yarn with coating/impregnation



Impregnation with polymers



- 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



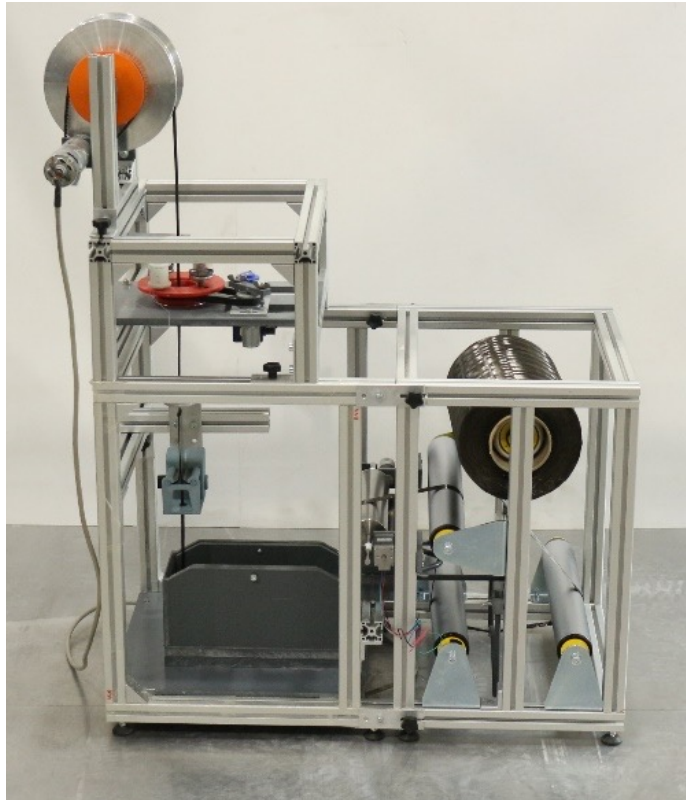
Source: bz-berlin.de, 11.09.2017



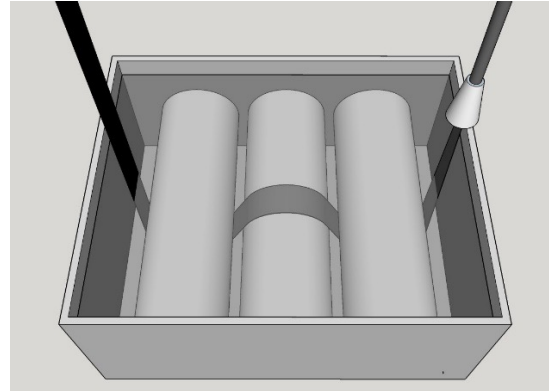
Source: TU Dresden, IfB

→ **Solution: Mineral-bonded carbon fiber reinforcement**

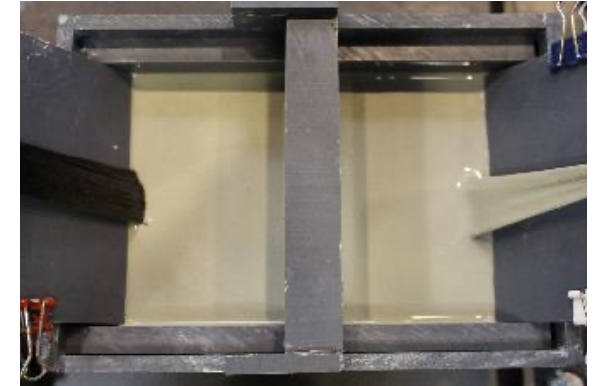
# Mineral Impregnated Carbon Fiber Composite Reinforcement (MFC)



Three-roll-padder



Impregnation



Shaping



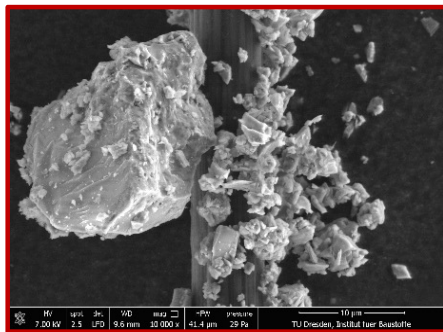
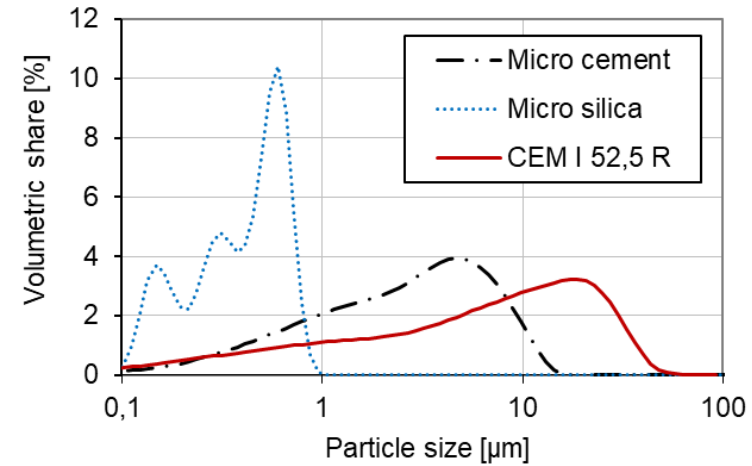
3 mm bar



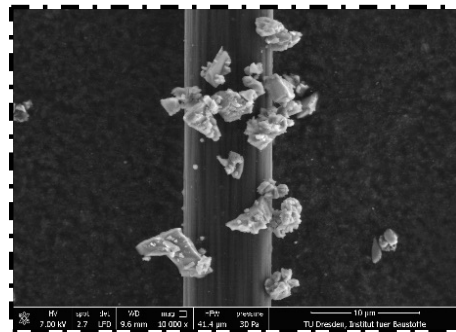
Schneider, Michel, Liebscher, Terreri, Hempel, Mechtcherine, *Cement and Concrete Composites* 97 (2019) 68-77

# Mineral Impregnated Carbon Fiber Composite Reinforcement (MFC)

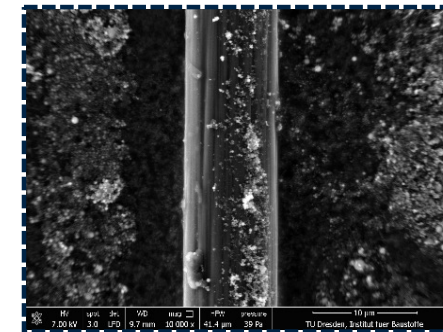
## Mineral components of the suspension



CEM 52.5



micro-cement with D95 < 9 µm

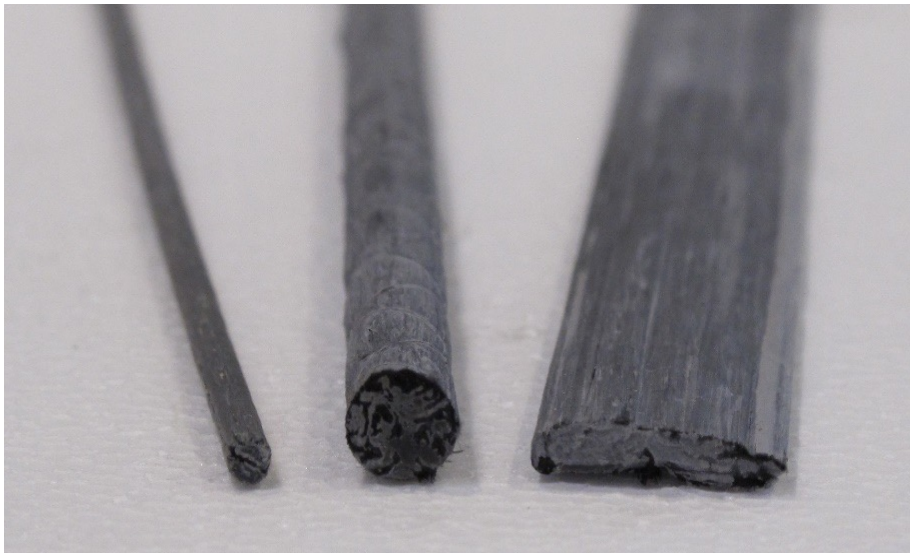


micro-silica

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

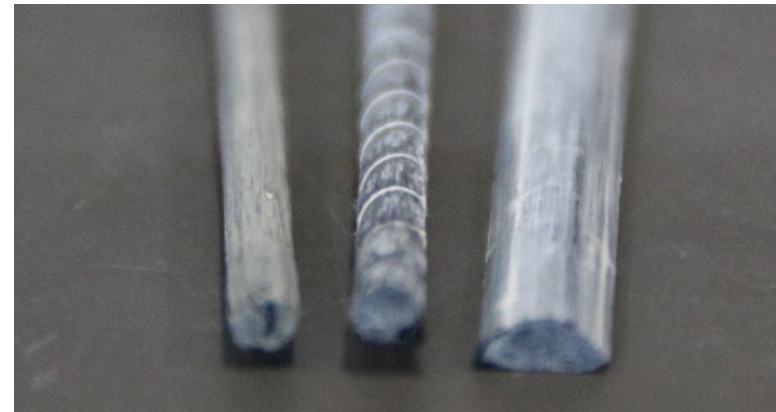
# Mineral Impregnated Carbon Fiber Composite Reinforcement (MFC)

Microcement bonded

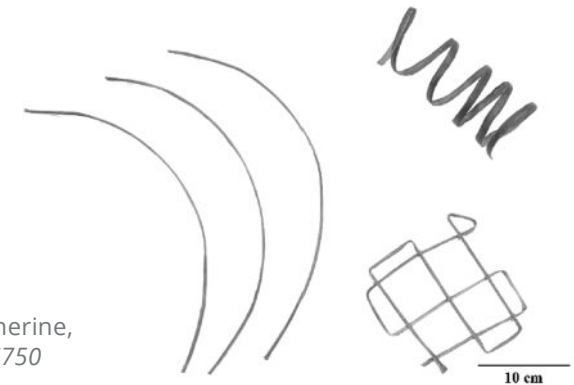


Mechtcherine, Michel, Liebscher, Schneider, Großmann,  
*Automation in Construction* 110 (2020) 103002

Geopolymer bonded, treatment by ohmic heat



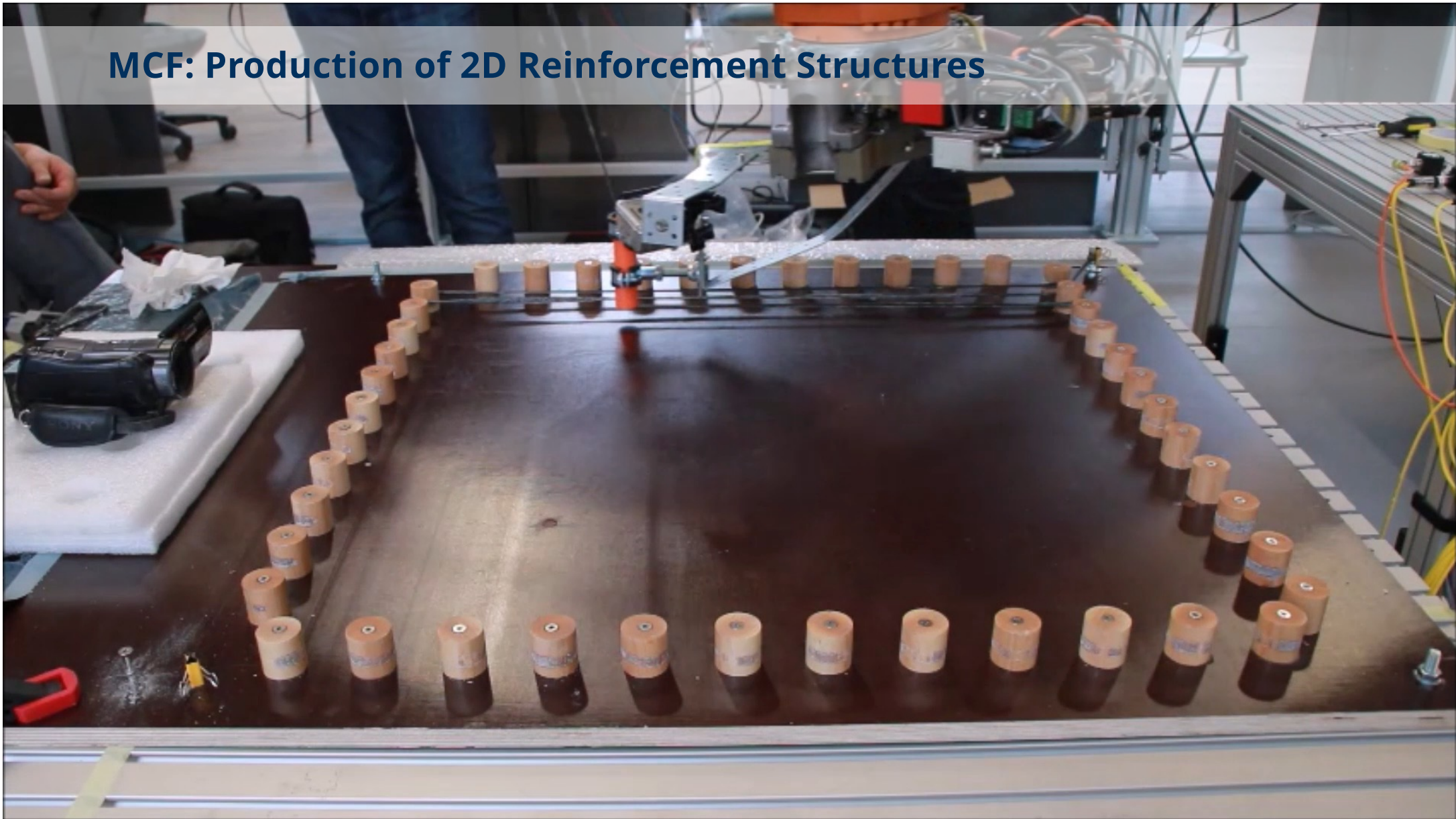
Junger, Liebscher, Zhao, Mechtcherine,  
*Composites: Part A* 153 (2022) 106750



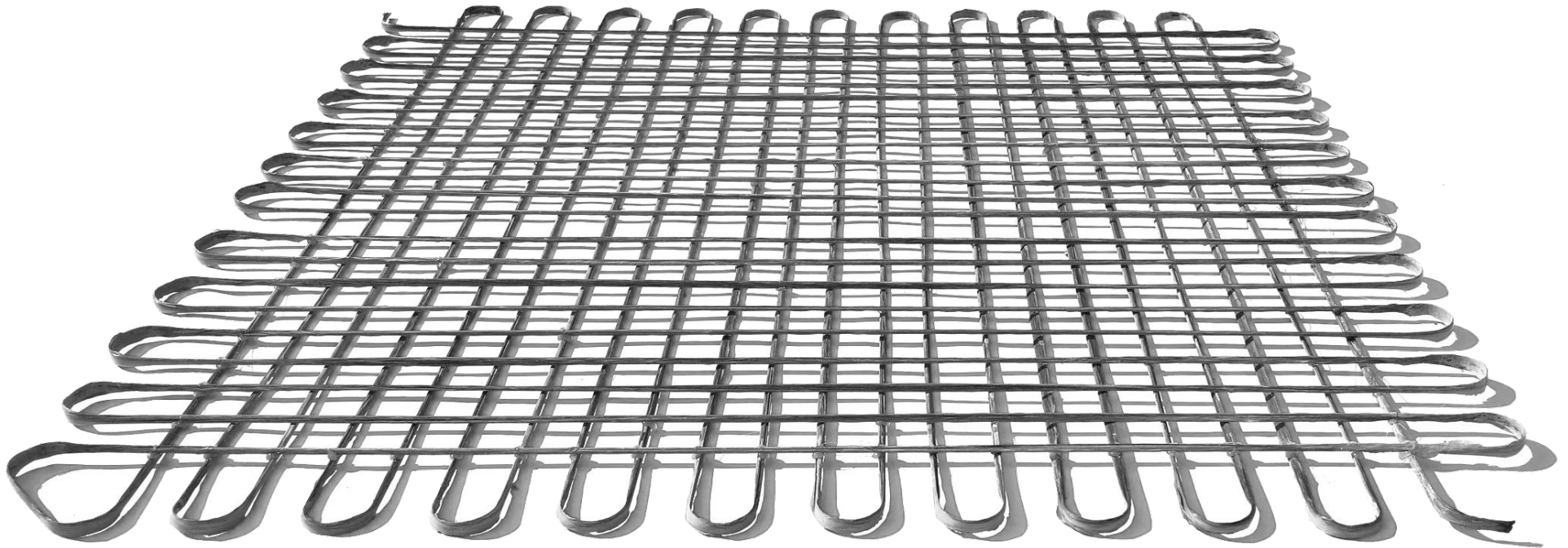
## MCF: Production of 1D Reinforcement



## MCF: Production of 2D Reinforcement Structures



## MCF: Completed 2D Reinforcement Structure



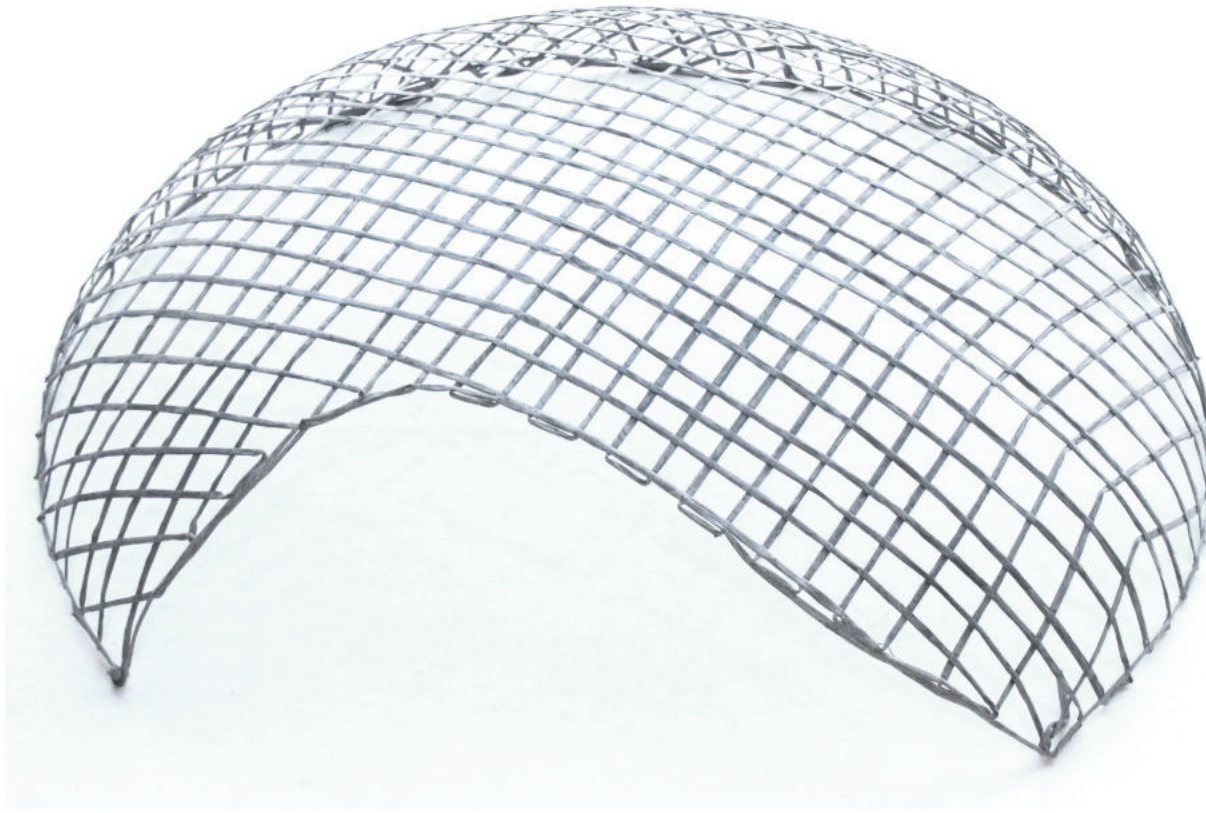
Mechtcherine, Michel, Liebscher, Schneider, Großmann, *Automation in Construction* 110 (2020) 103002

## MCF: Reinforcement for a Shell Structure



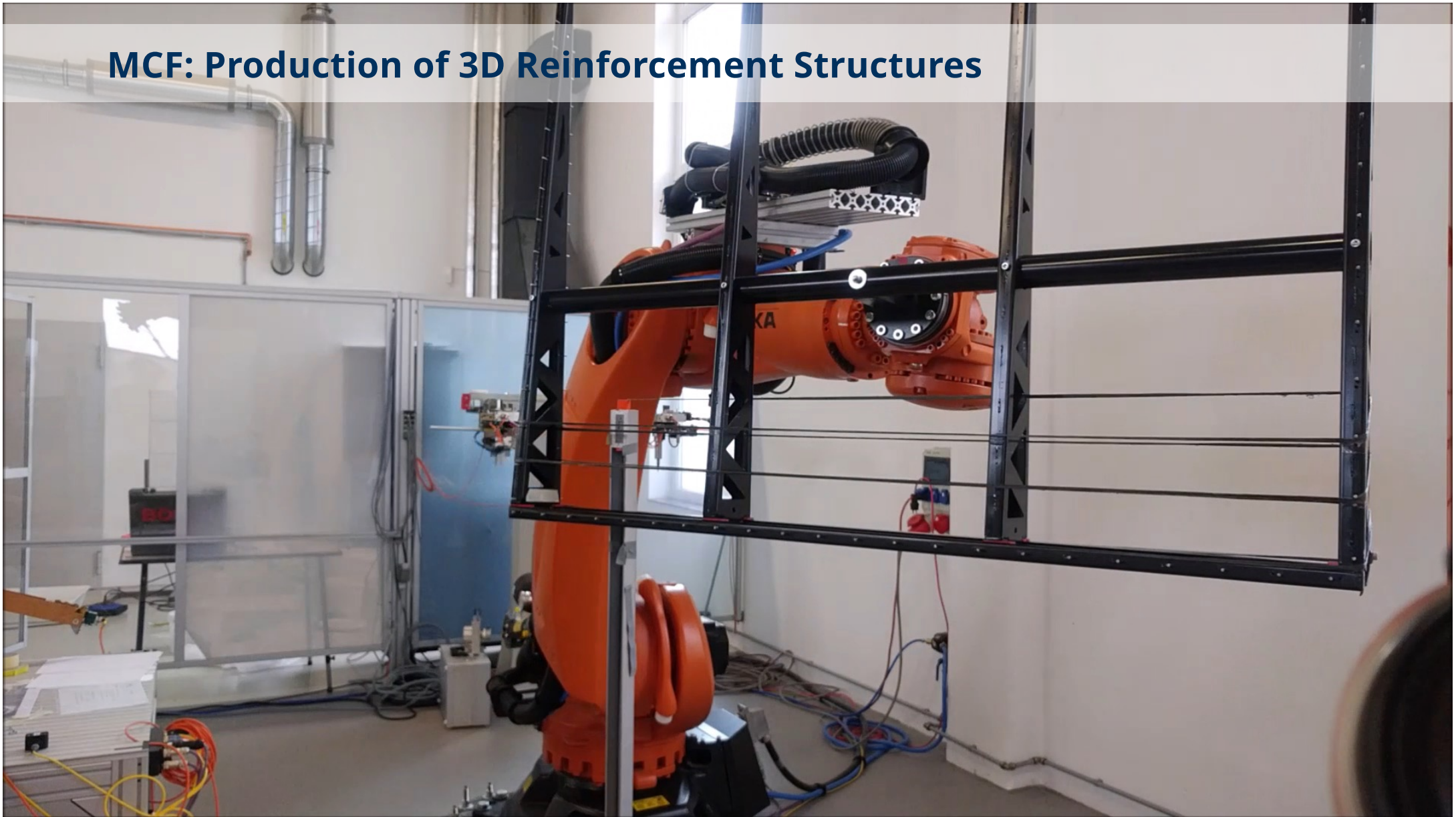


## MCF: Reinforcement for a Shell Structure

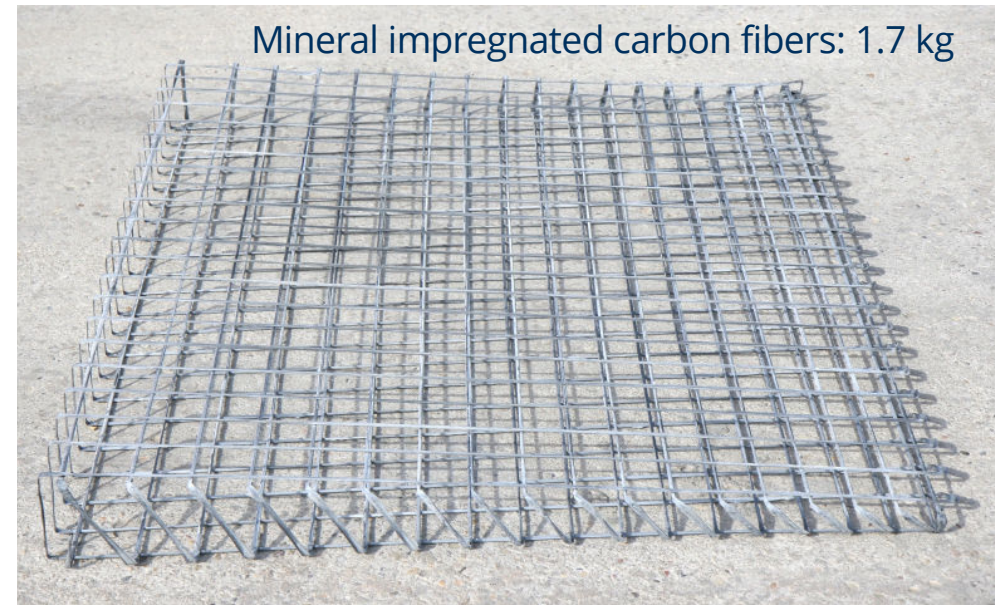


Mechtcherine, *Construction Printing Technology* 1 (2019) 11-16

## MCF: Production of 3D Reinforcement Structures

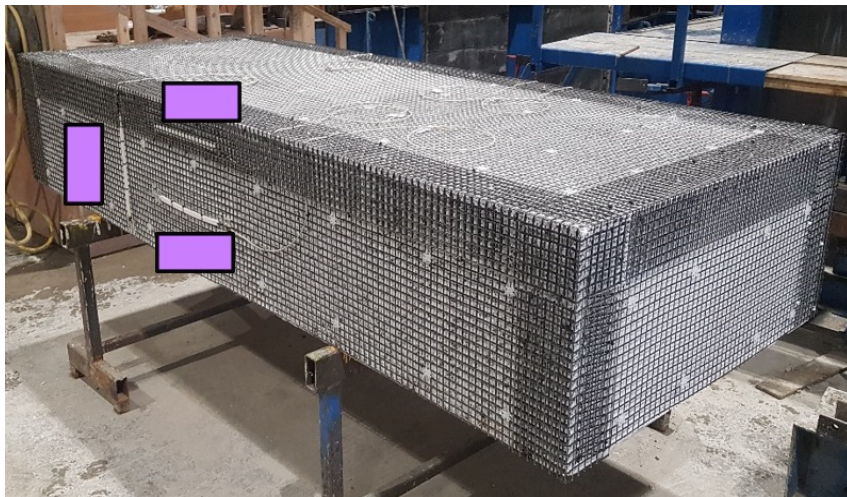
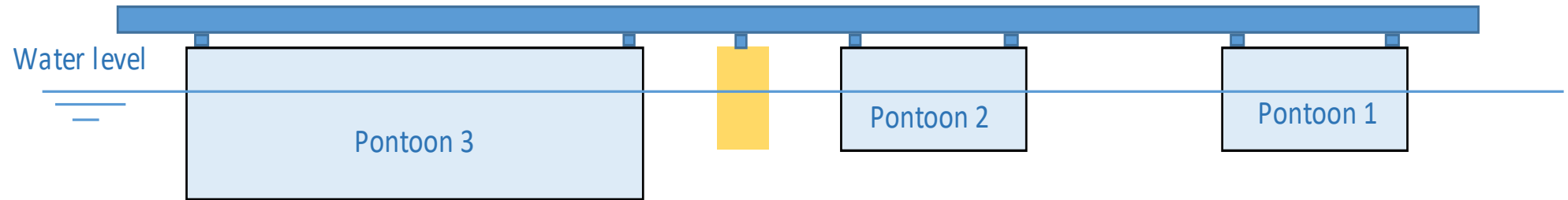


## MCF: Completed 3D Reinforcement Structure for a Balcony Slab

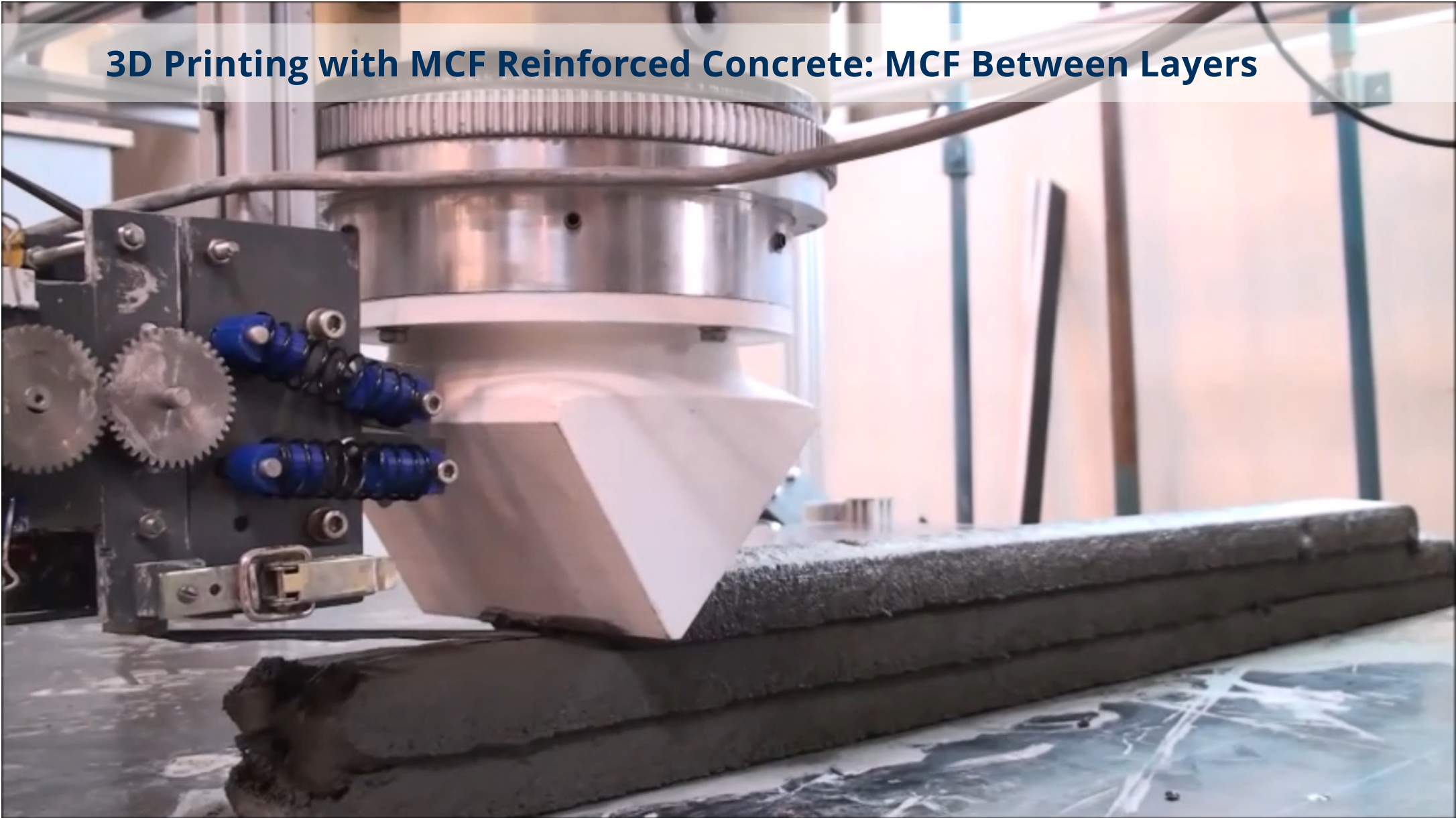


Mechtcherine, Michel, Liebscher, Schneider, Großmann, *Beton- und Stahlbetonbau* 114 (2019) 947-955

# 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

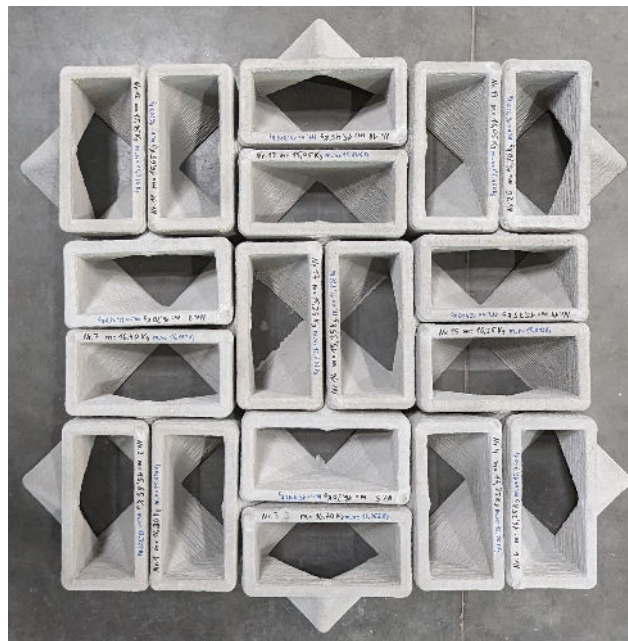


Neef, Müller, Mechtcherine, *Materials and Design* 239 (2024) 112794

# Integration of MCF into 3D Concrete Printing



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

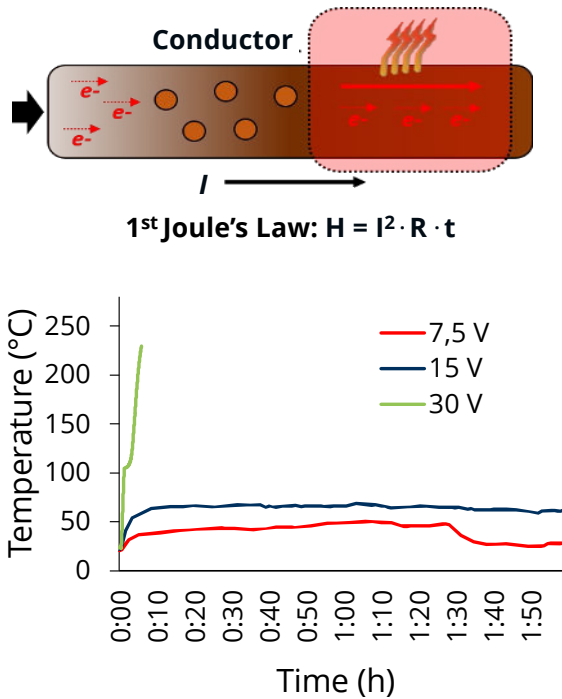


Neef, Goertzen, Niemeyer, Mechtcherine, *Beton- und Stahlbetonbau* 119 (2024) – DOI: 10.1002/best.202400061

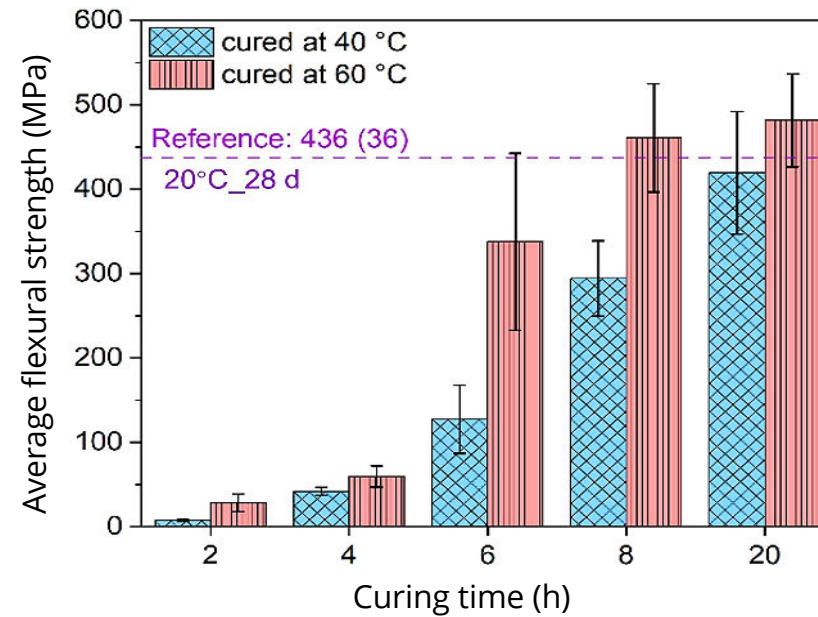




# Fast Setting MCF Reinforcements by Defined Joule Heating

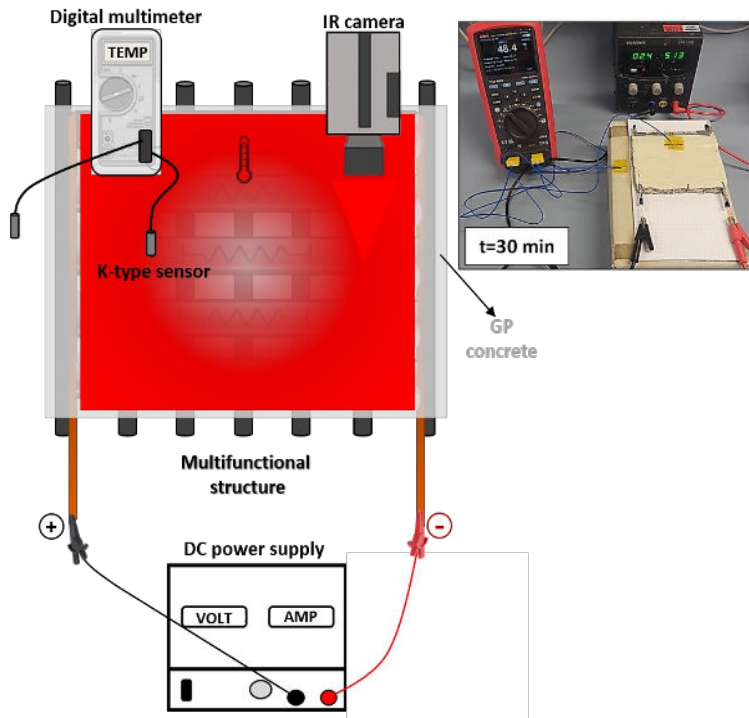


Junger, Liebscher, Zhao, Mechtcherine, *Composites Part A: Applied Science and Manufacturing* 153 (2022) 106750

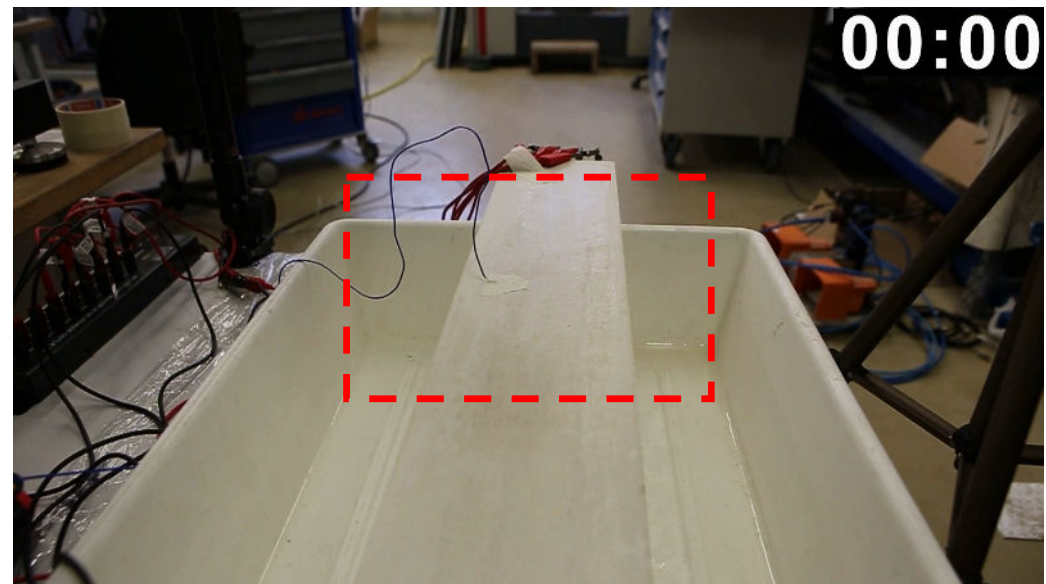


Zhao, Ahmed, Liebscher, Karalis, Saif, Butler, Mechtcherine, *Cement and Concrete Composites* 154 (2024) 105766

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



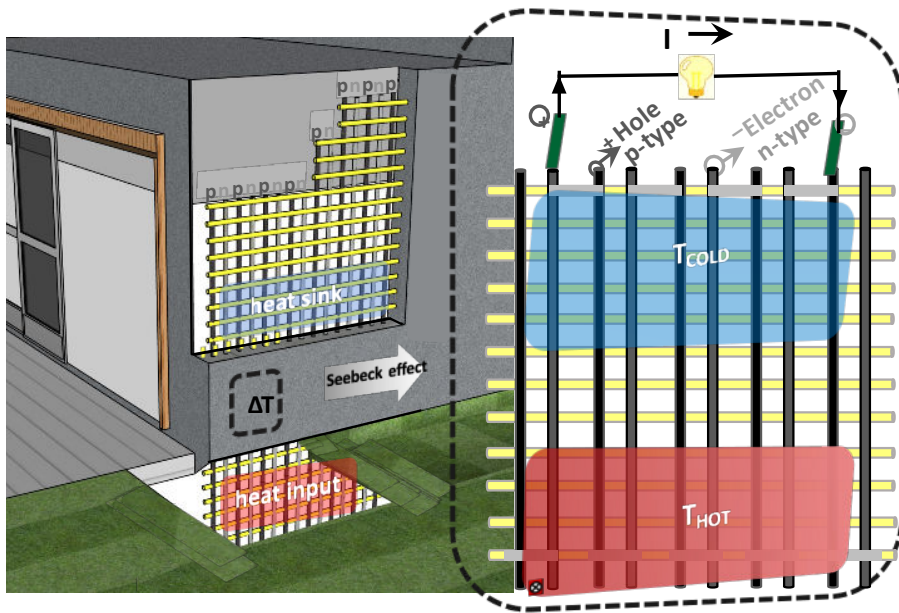
Setup of MFC grids as Joule heater device



De-icing by MFC reinforced concrete layer

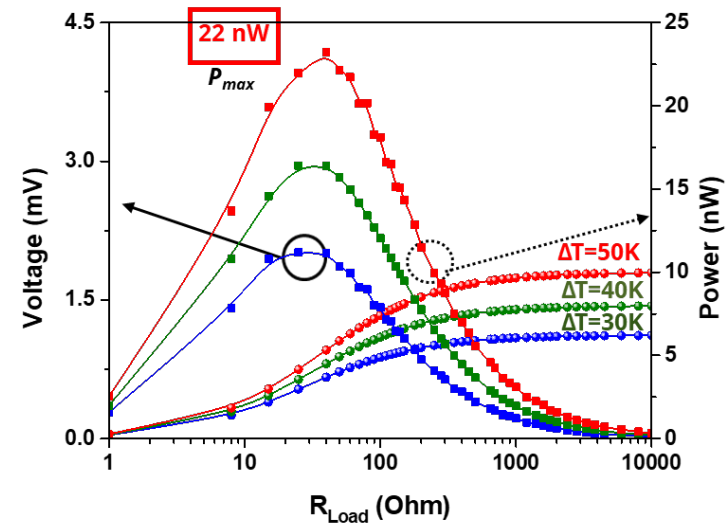
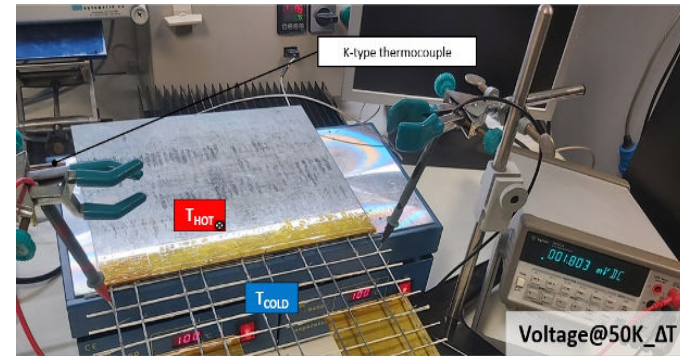
Karalis, Zhao, Liebscher, May, Wollny, Dong, Köberle, Tzounis, Mechtcherine, *Carbon* 222 (2024) 118898

# MCF-GP Composites for Thermal Energy Harvesting

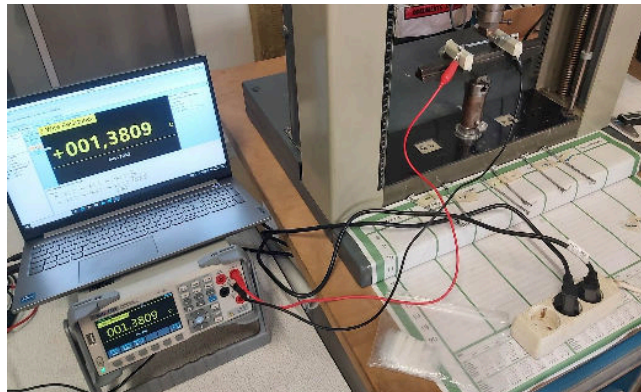
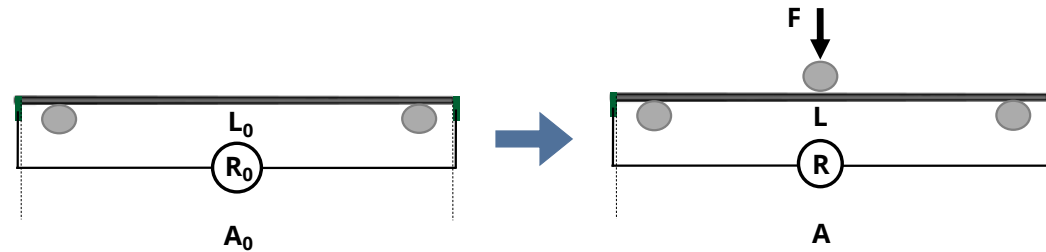
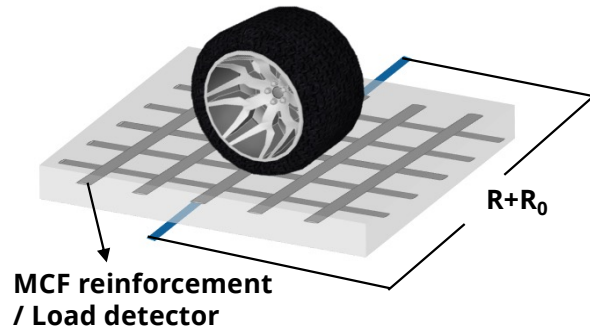


Vision of p- & n-type MCF thermoelement grid

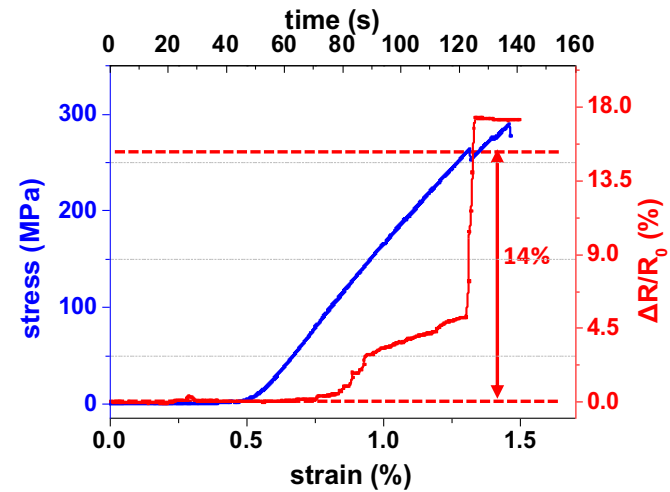
Zhao, Karalis, Liebscher, Tzounis, Köberle, Fischer, Simon, Aiti, Cuniberti, Mechtcherine, *Energy and Buildings* 298 (2023) 113564



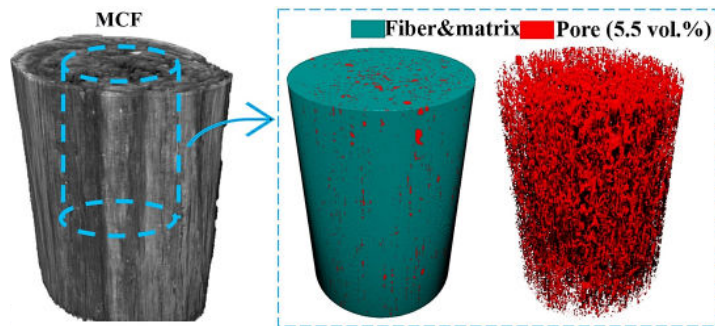
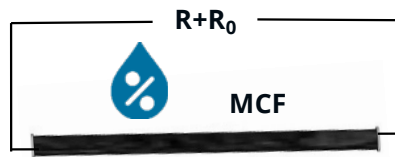
# MFC Reinforcements as Load Sensor



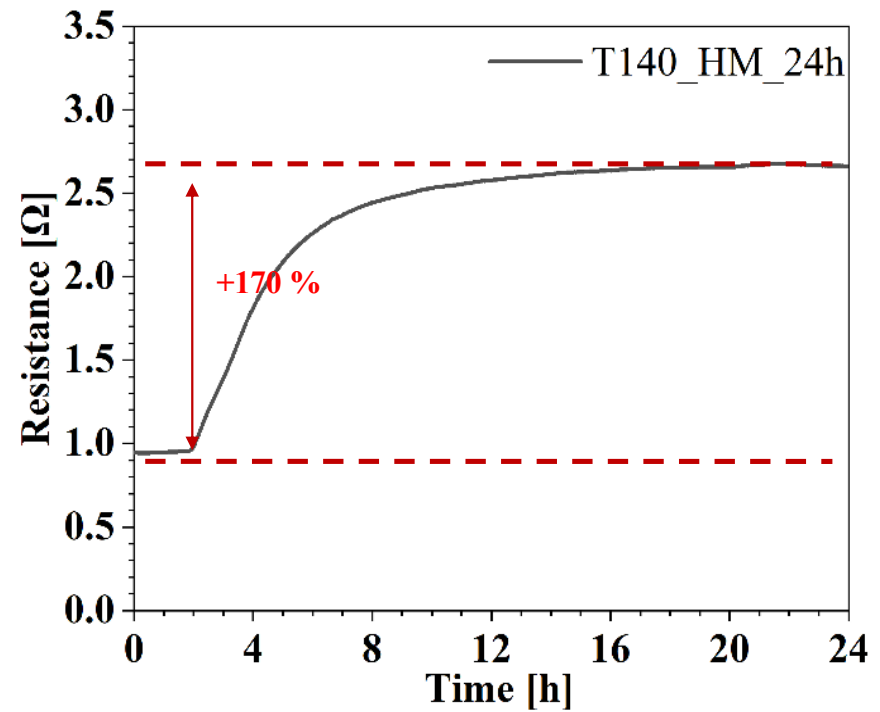
Test setup of MFC under static flexural loading



# MFC Reinforcements as Moisture Sensor



Segmented  $\mu$ CT images of microstructure of MCF



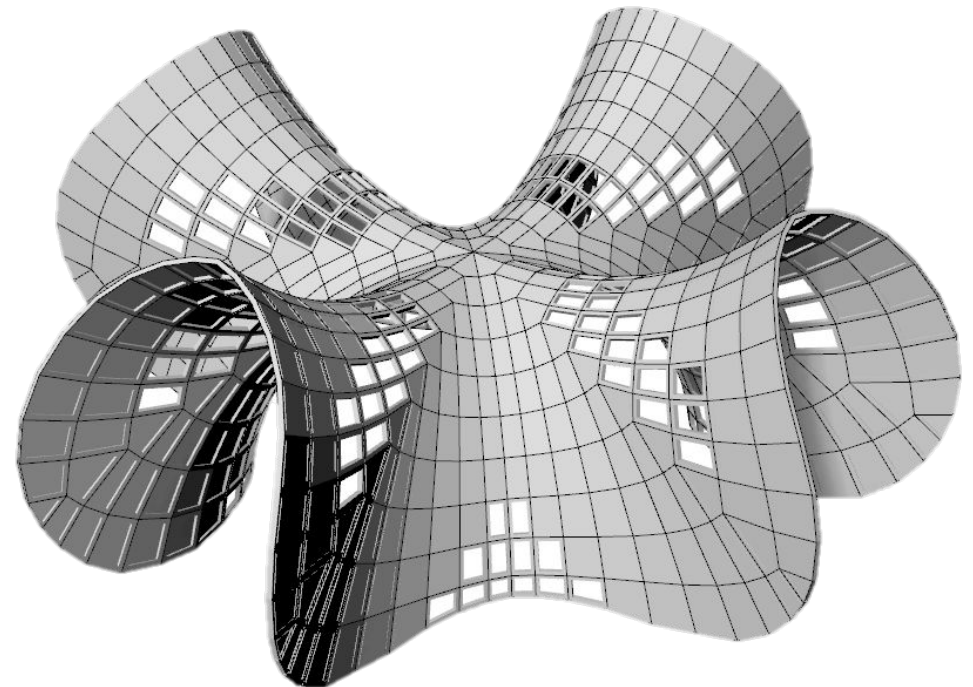
# Adaptive Concrete Diamond Construction (ACDC) of Shell Structures

Conventional fabrication using formwork



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

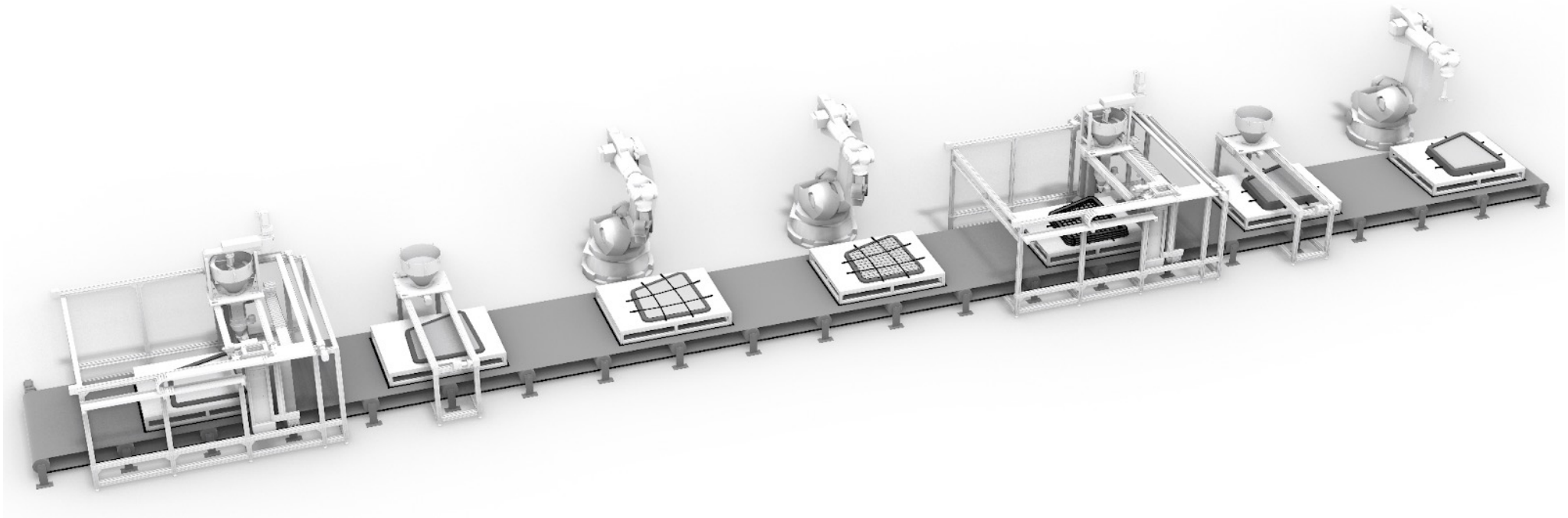
Shell structure made of prefabricated modules



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)

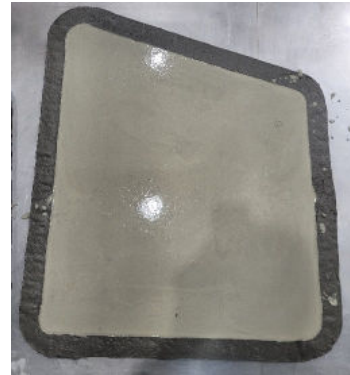


Ivaniuk, Tošić, Müller, Lordick, Mechtcherine, *Automation in Construction* 166 (2024) 105591

# 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)

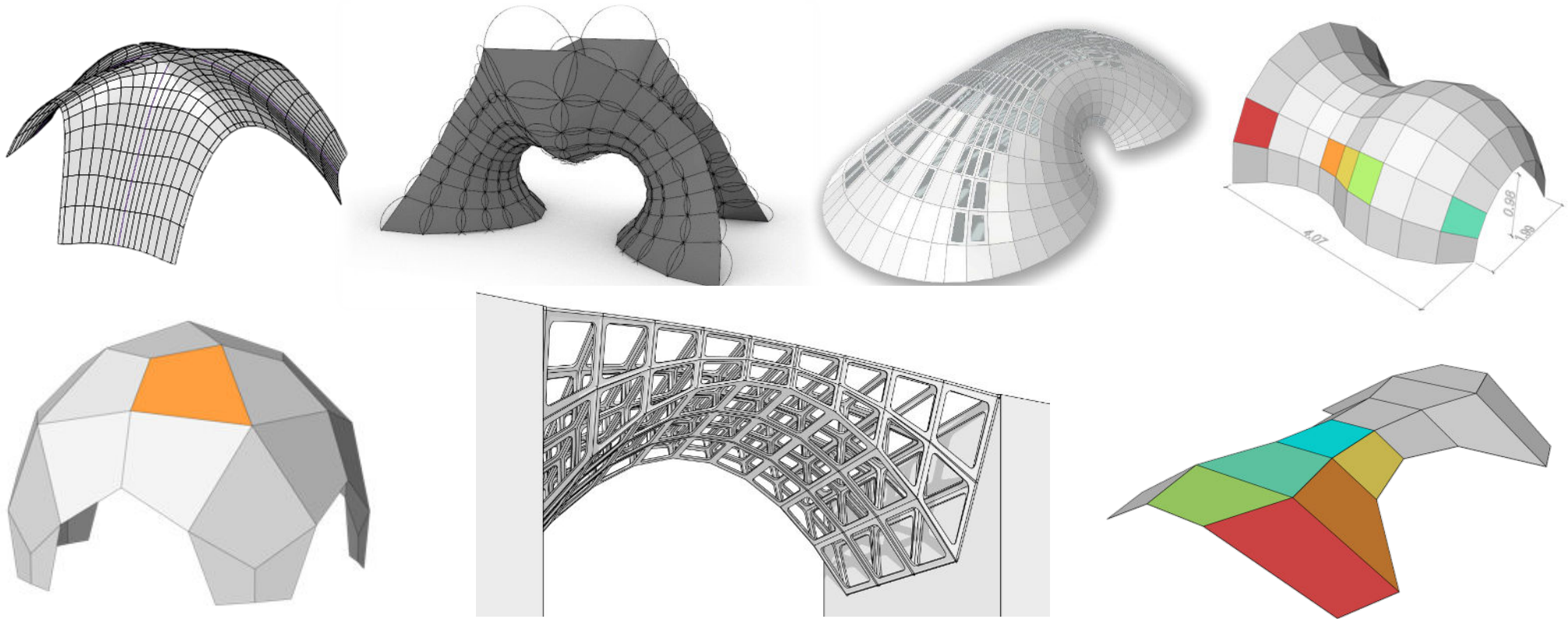


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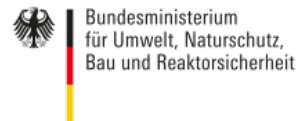
Ivaniuk, Eichenauer, Tošić, Müller, Lordick, Mechtcherine, *Materials and Design* 219 (2022) 110757

# Adaptive Concrete Diamond Construction (ACDC) of Shell Structures



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

# Acknowledgements



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Novel inorganic-bonded fiber composites and digital manufacturing technologies: A path to sustainable construction  
The International Inorganic-Bonded Fiber Composite Conference (IIBCC), Colombo, Sri Lanka, November 20 – 21, 2024

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