The orientation of fibres in fine grain systems – numerical simulation and CT-analysis

Bianca Bund,
Wolfgang Breit,
Christian Heese (HS RheinMain)
Technische Universität Kaiserslautern
Fachgebiet Werkstoffe im Bauwesen

Email bianca.bund@bauing.uni-kl.de
www.bauing.uni-kl.de/fwb

Fibre reinforced cementitious fine grain systems

- Mechanical properties of concrete in hardened state like ductility and flexural strength are dependent on fibre distribution and orientation
- Fibre orientation depends on casting situation and rheological behaviour of the suspension

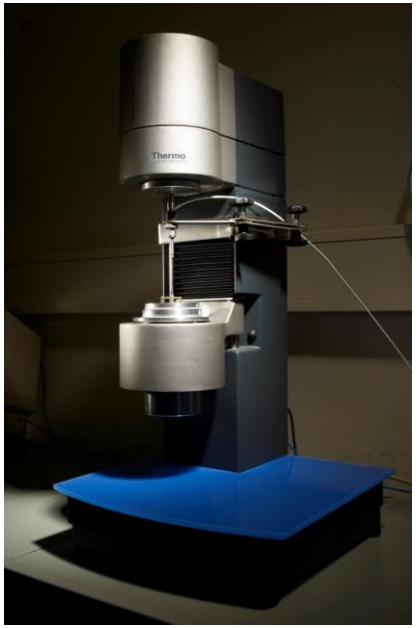
- Current practice:
  - Registration of flow behaviour
    → empirical tests

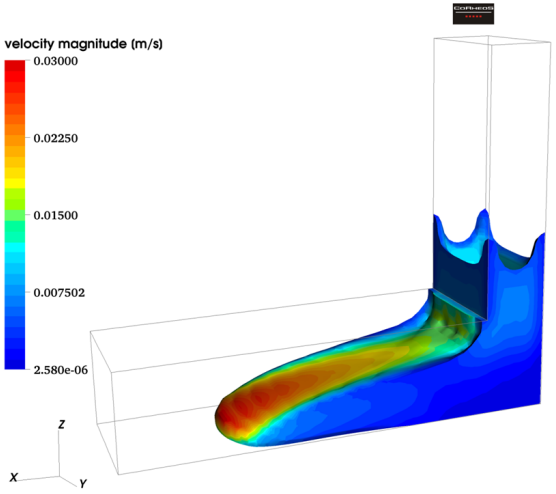
  - Determination of fibre orientation
    → destructive test procedures

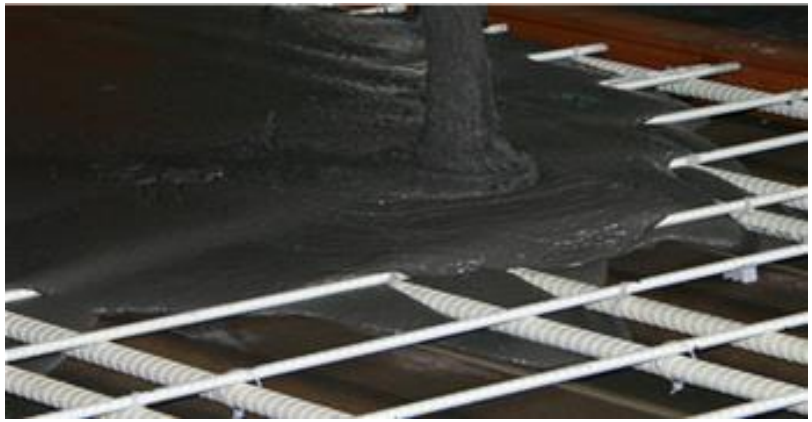
→ time consuming and expensive!

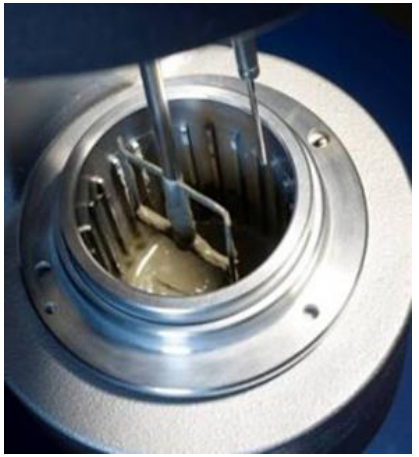
Aim of work

Numerical simulation of flow and form filling behaviour and the fibre orientation of fibre reinforced cementitious fine grain systems based on rheological characterisation with a rotational rheometer

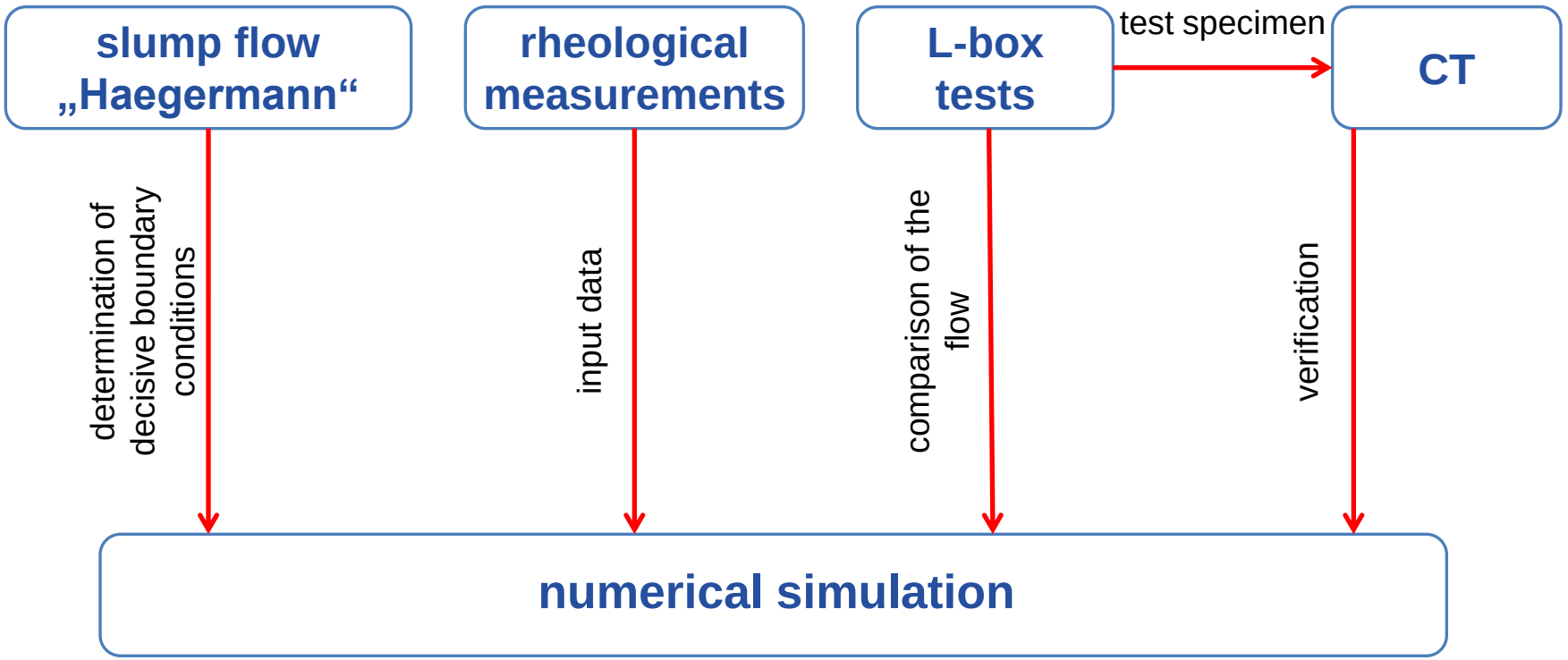








Design of experiments

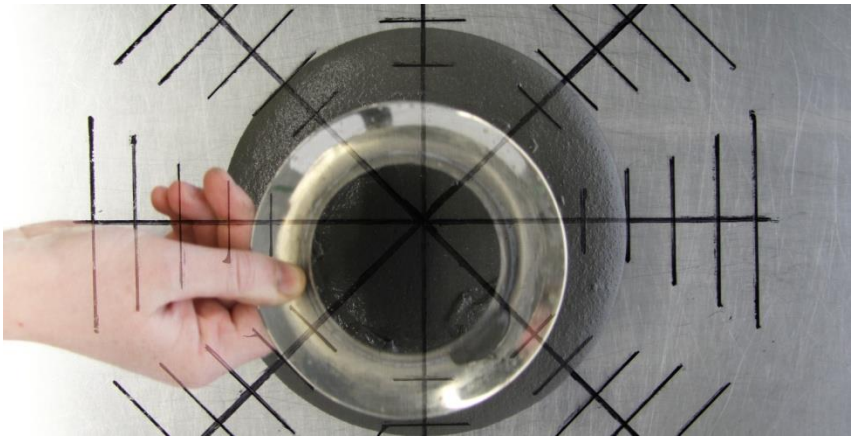


Mixing process

- Fine grain concrete was mixed with intensive mixer with a horizontal pan (Eirich R02E)
- Mixture has volume of 4 litres
- Maximum grain size: < 1 mm
- Fibres: l = 6 mm, Ø 0,175 mm
- Fibres not considered in volumetric calculation ➟ keep basic mix and its rheological behaviour constant
- Cooled raw materials, plasticizer room temperature
- Total mixing time: 9 min, fibre addition in last minute of mixing

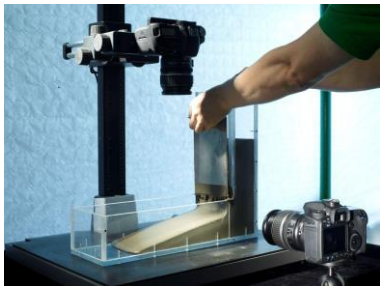
Slump Flow test

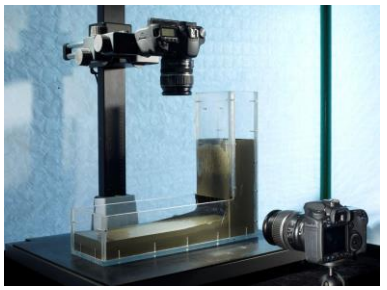
- Slump flow test with Haegermann cone according to EN 1015-3
- Slump flow of fine grain concrete without fibres tested for calibration of the numerical simulation



L-box test

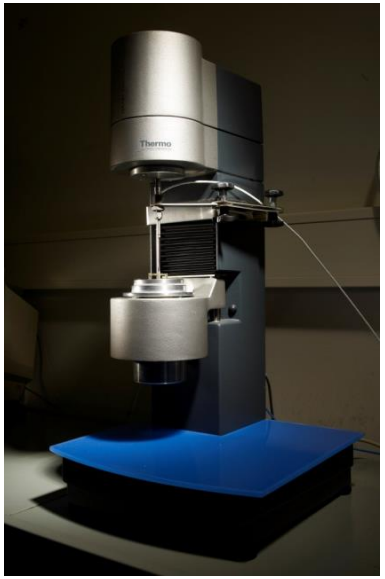
- Started simultaneously to slump flow test

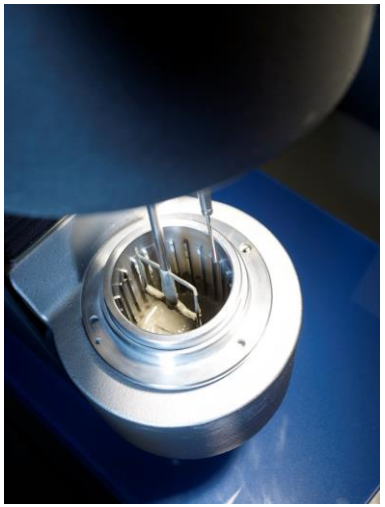


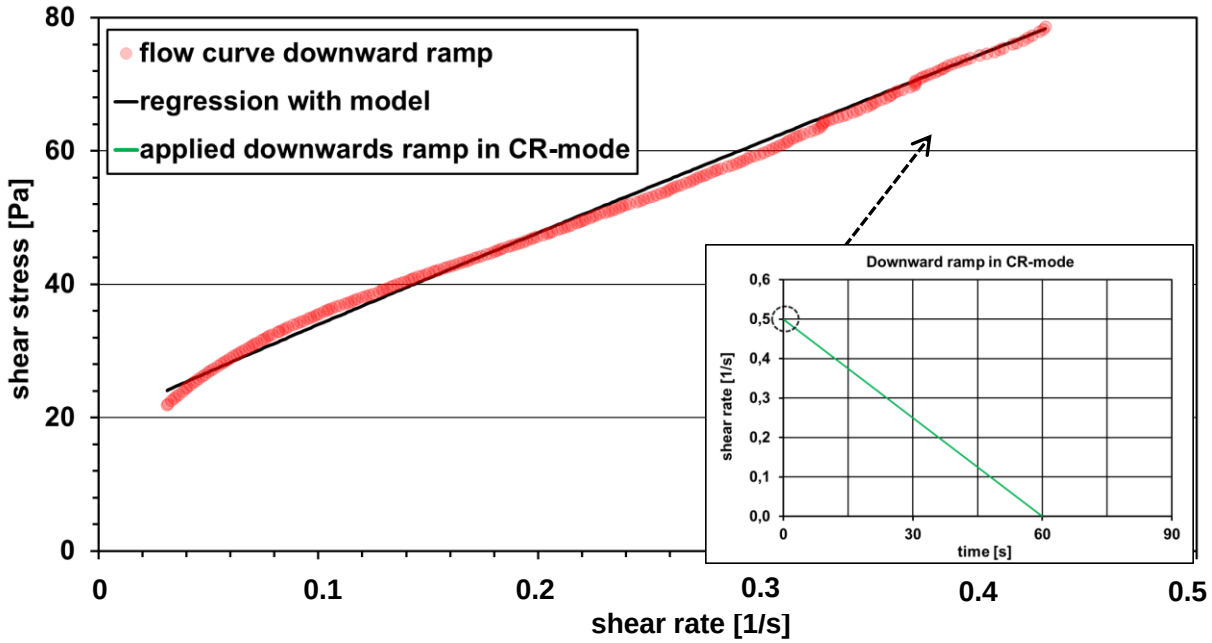


Rheological measurement

- Started simultaneously to slump flow and L-box test
- Measuring program: linear downward ramp in controlled rate (CR)
- Obtained shear rate vs. shear stress curve
  ➡ create an initial fit for model in numeric simulation

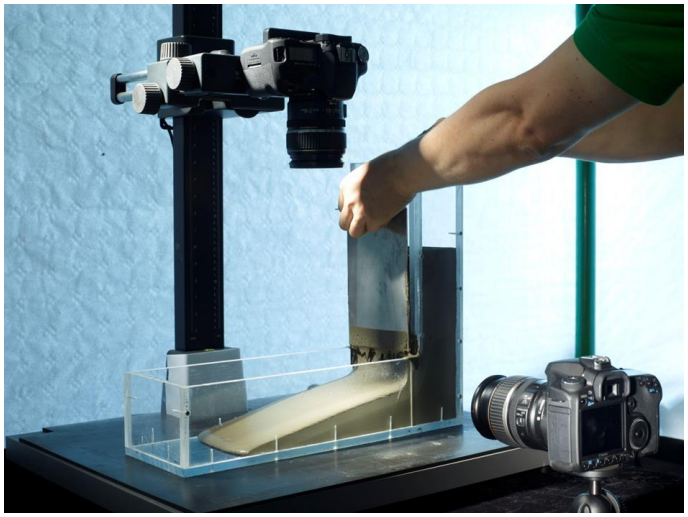


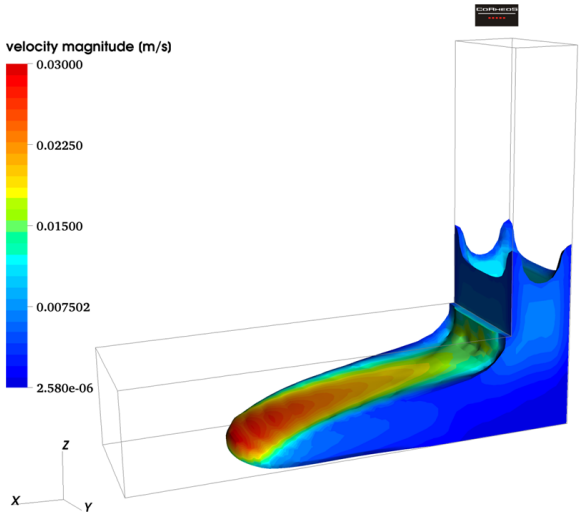




Simulation with **Co**mplex**Rheo**logy**S**olver (CoRheoS)

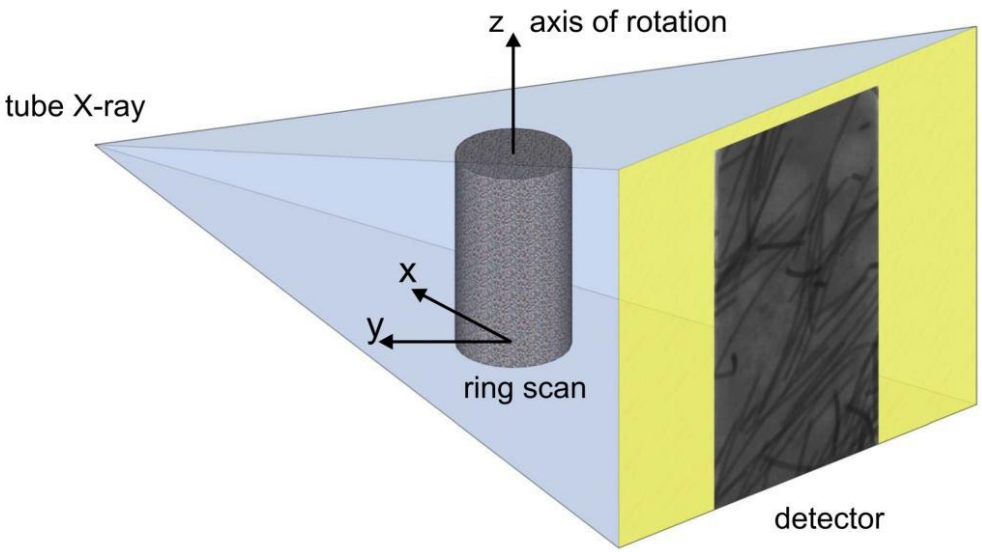
- CoRheoS ⟶ software system for simulation of complex fluids developed by Fraunhofer ITWM
- Fine grain system (UHPC) ⟶ Bingham-like fluid behaviour described by simple Herschel Bulkley model
- Prediction of the fibre orientation ⟶ Folgar Tucker model
- Simulation of fibre reinforced fine grain concrete performed by coupling of fibre orientation state with the flow variables

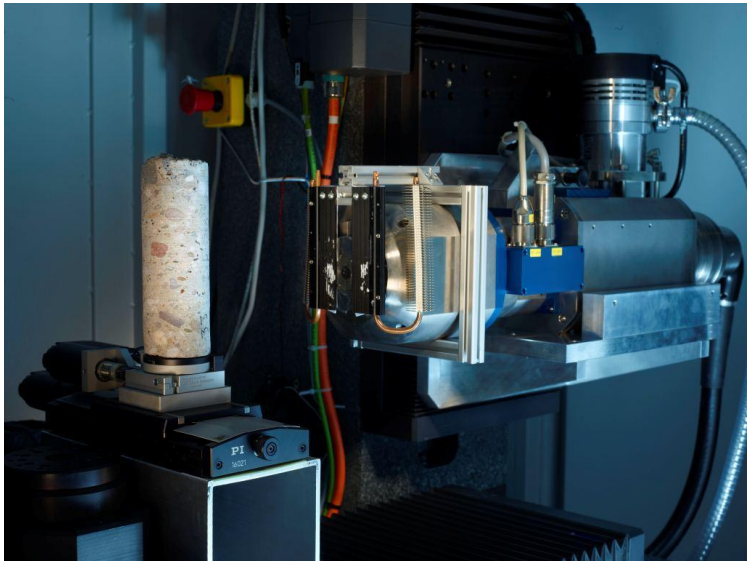




Computed Tomography

- CT ⟶ validation of L-box simulation results of the fibre orientation
- Hardened core samples from L-box test were analysed

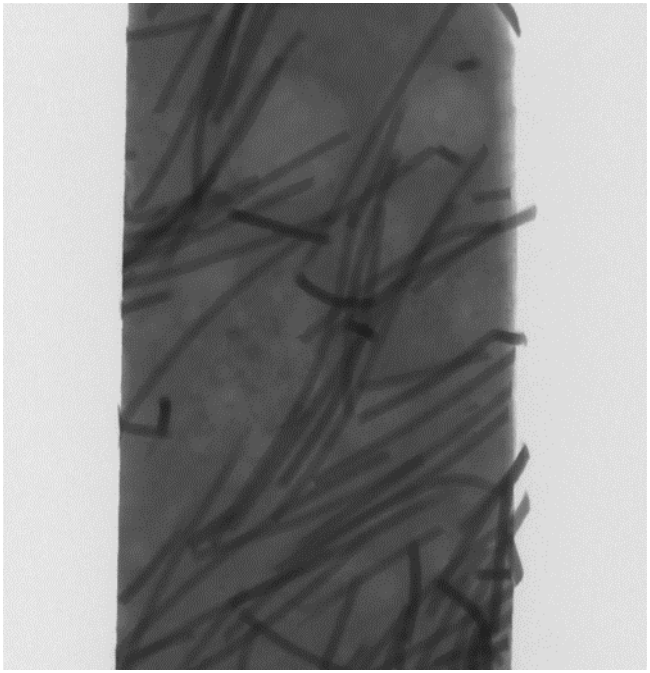




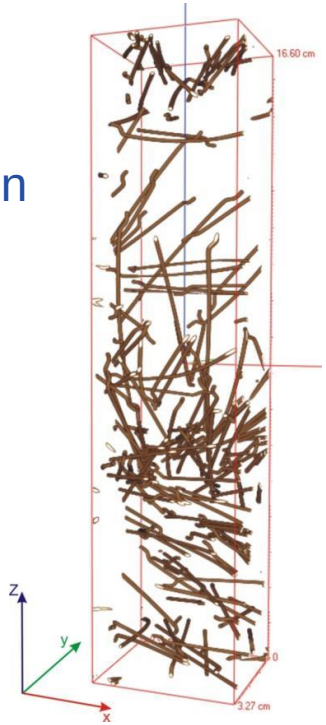
Computed Tomography

- Analysis and image processing of CT-images with MAVI, software developed at Fraunhofer ITWM
- Fibre orientation tensors determined with MAVI for chosen volume
- Fibre orientation tensors in x-, y- and z-direction were evaluated and compared with simulation results

tomographic reconstruction

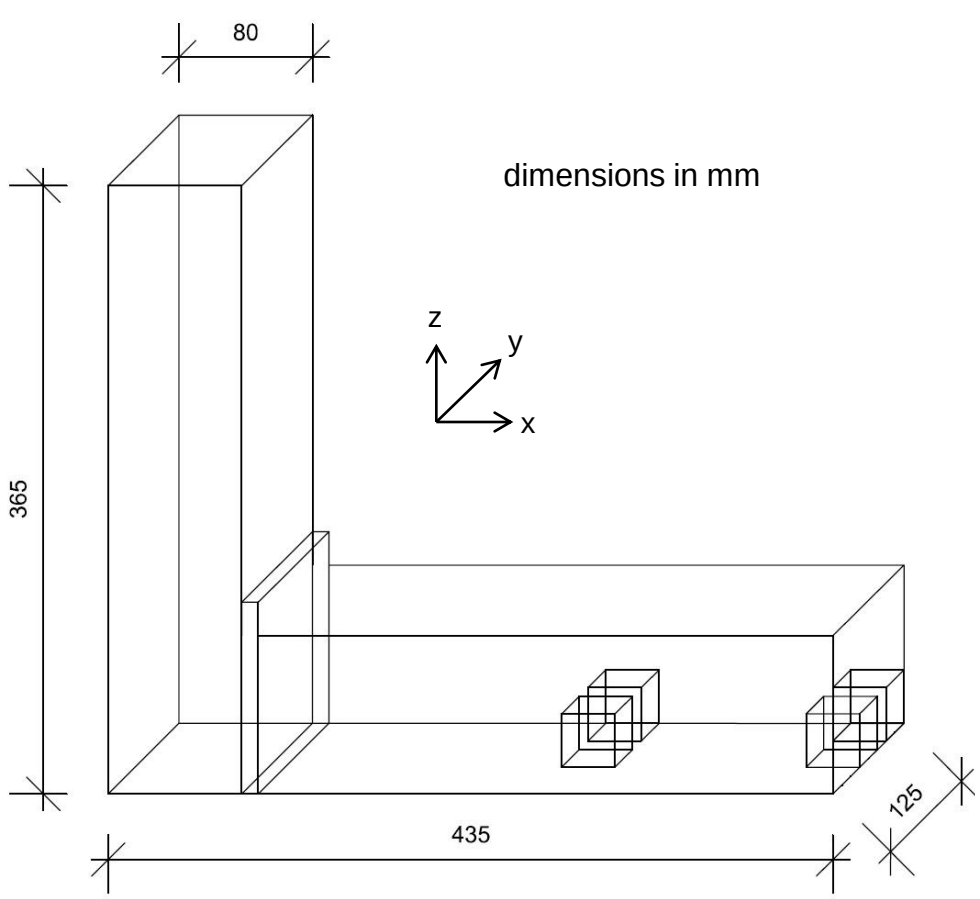


3D-visualisation

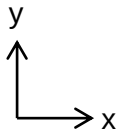


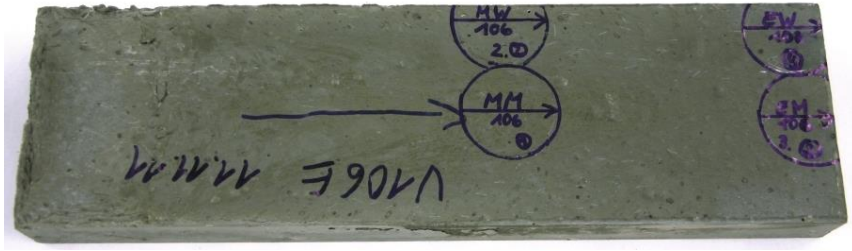
Simulation results – L-box test

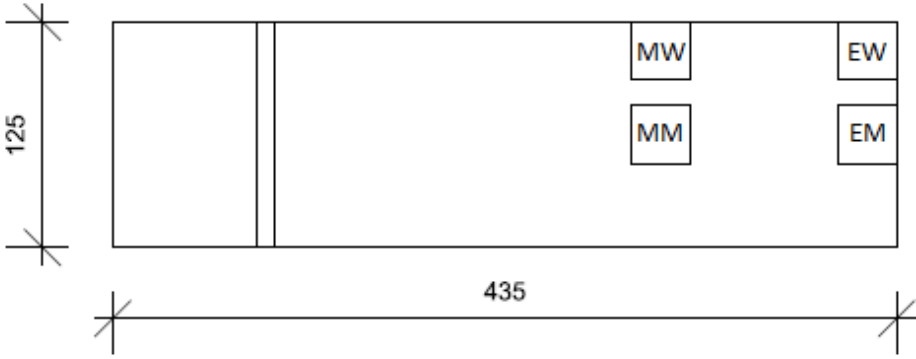
- Dimensions of the L-box and positions of the analysed areas



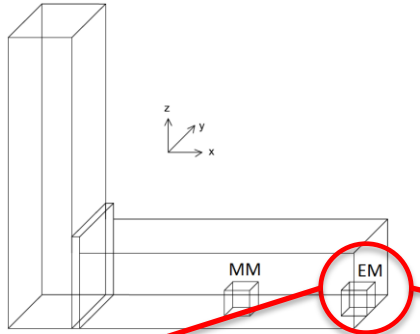
dimensions in mm

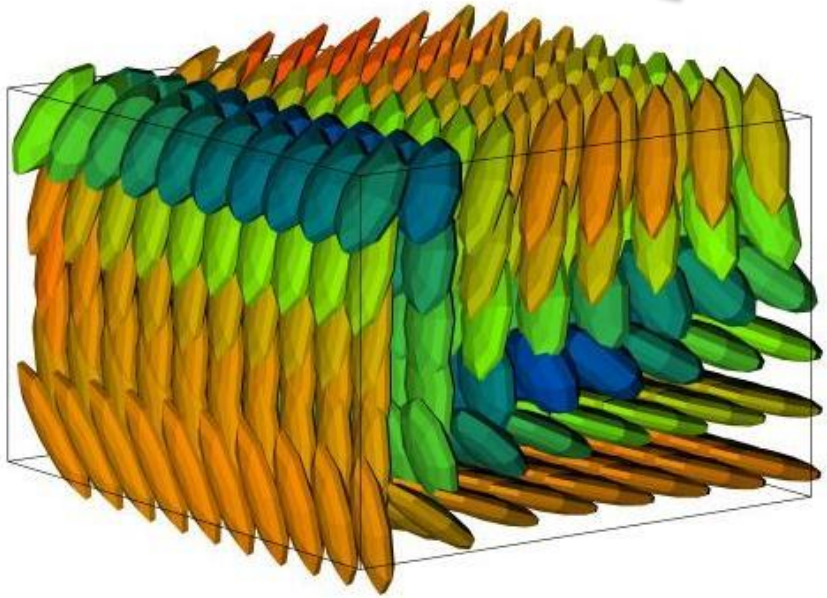


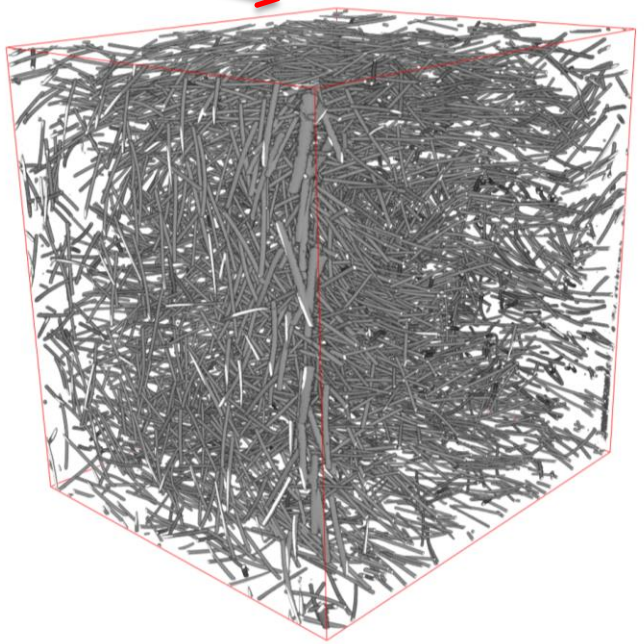




Simulation and CT results – L-box test



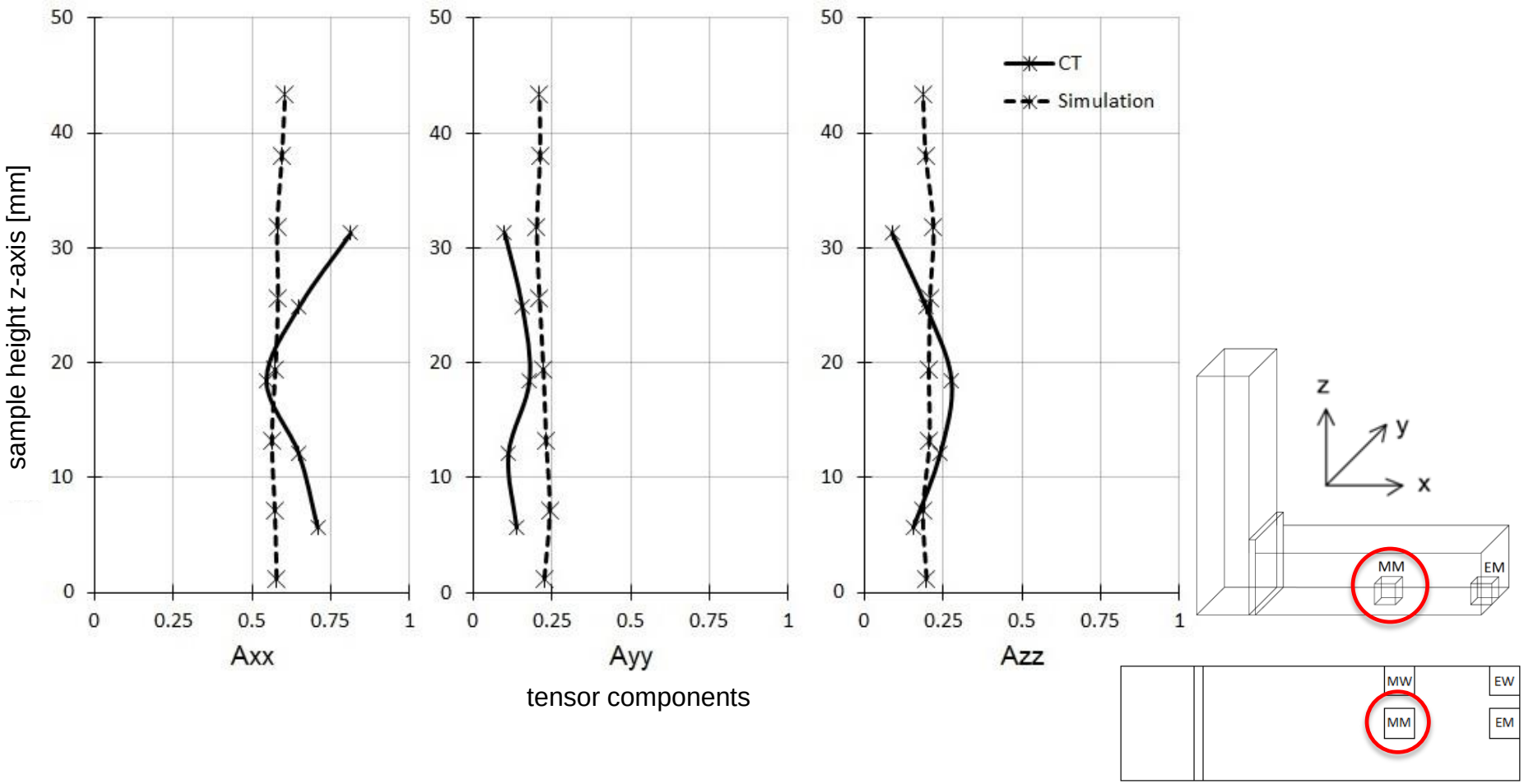




Fibre orientation ellipsoids of simulation at position EM

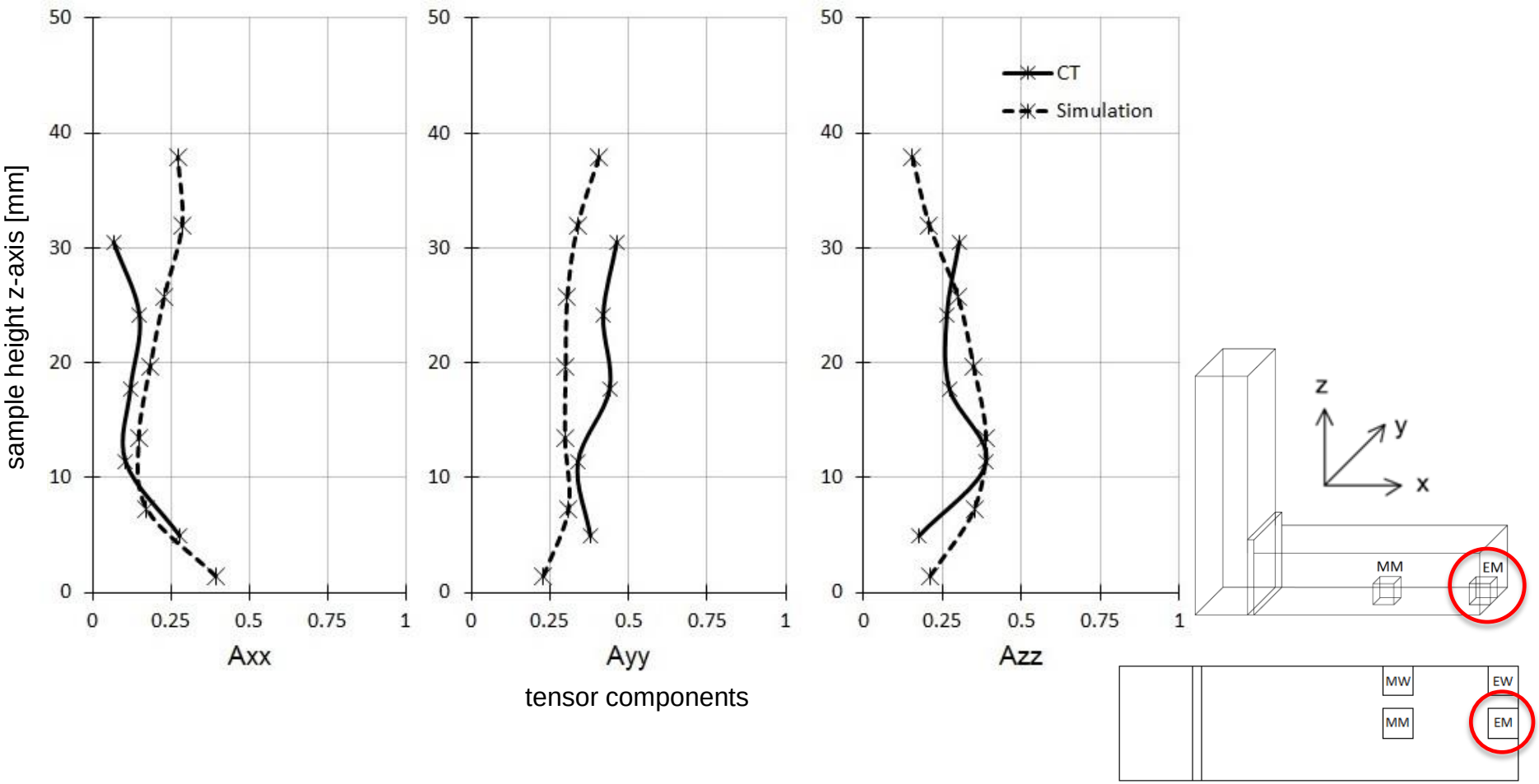
CT fibre visualisation at position EM

Simulation and CT results – L-box test - position MM



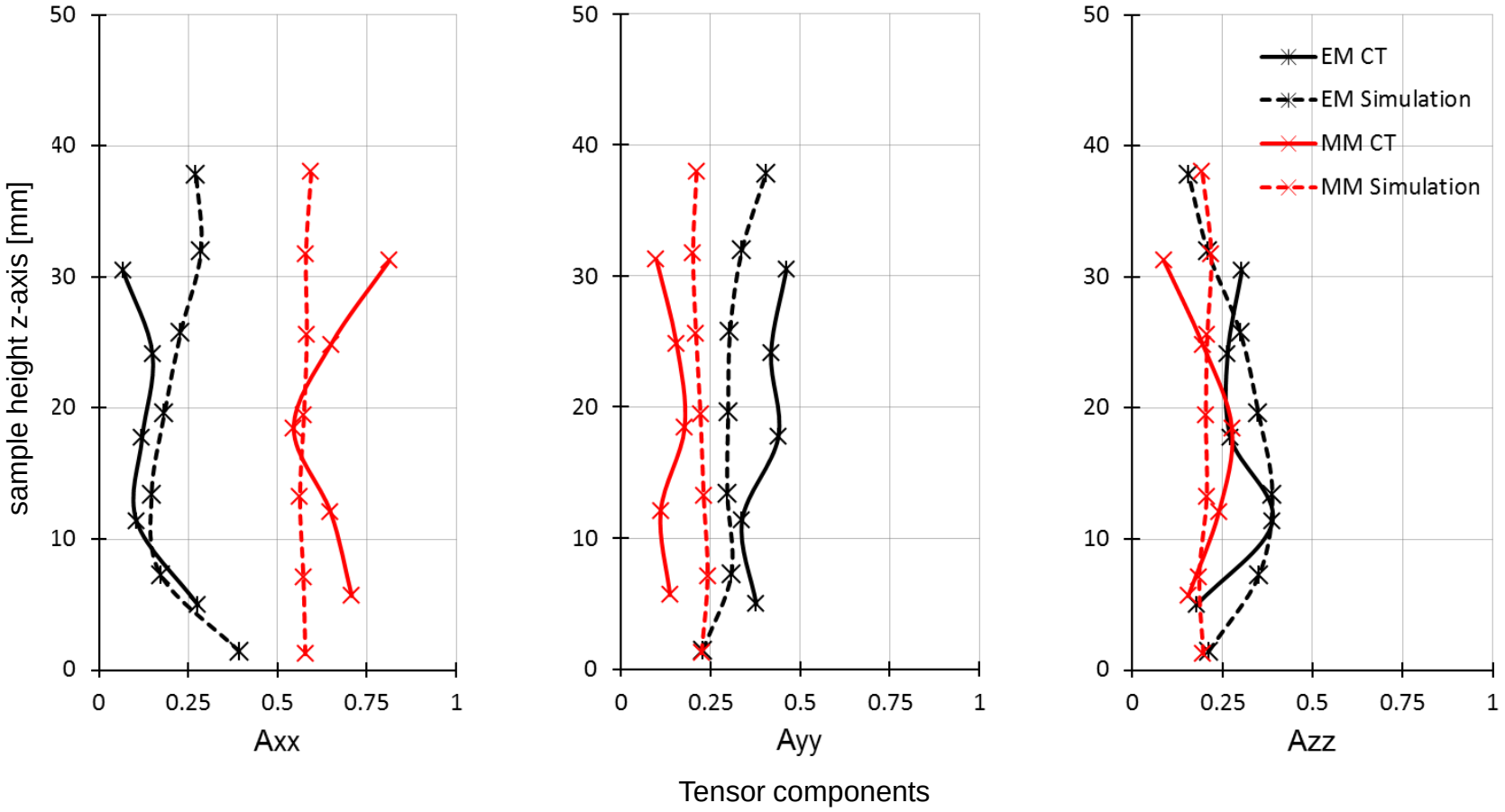
Comparison of simulation and CT results for fibre orientation tensor components Axx, Ayy and Azz in different sample heights (z-axis)

Simulation and CT results – L-box test - position EM



Comparison of simulation and CT results for fibre orientation tensor components Axx, Ayy and Azz in different sample heights (z-axis)

Simulation and CT results – L-box test - positions EM and MM



Simulation and CT results for fibre orientation tensor components Axx, Ayy and Azz at different positions EM and MM

Conclusion and outlook

- Presented simulation method for fibre reinforced cementitious fine grain systems achieves good results in the tested type of fibres and dosage concerning the fibre orientation
- Further development of the used model:
  - Adaption of the numerical boundary conditions
  - Inclusion of the time- and location dependant rheological behaviour of the fine grain system
  - More experiments with different fibre contents and types of fibres to verify the model

Thank you for your attention!

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