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Direct measurement of the cohesive strength of protein gel in contact with NaOH by wire cutting experiments

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Institut für Naturstofftechnik

Introduction

Main objective

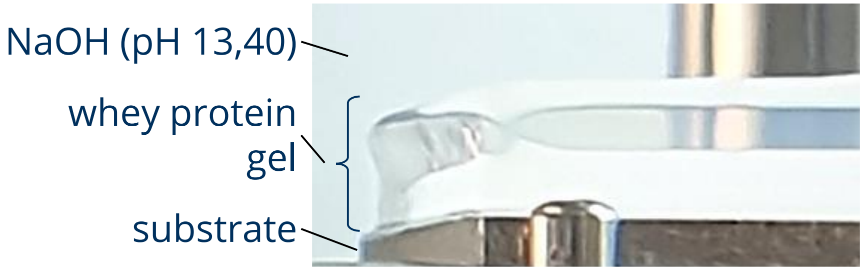
- for optimization of cleaning process and for parameter setting of process models

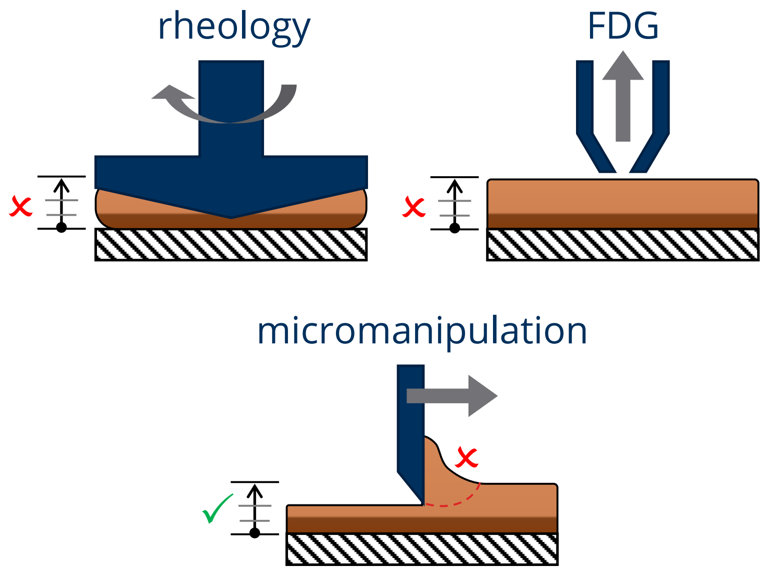
Needs

- determination of interaction of a soiling with a cleaning fluid
- knowledge of a shift of the force balance between cohesive and adhesive binding forces due to the action of the cleaning fluid is one aspect to reach the objective

Methods

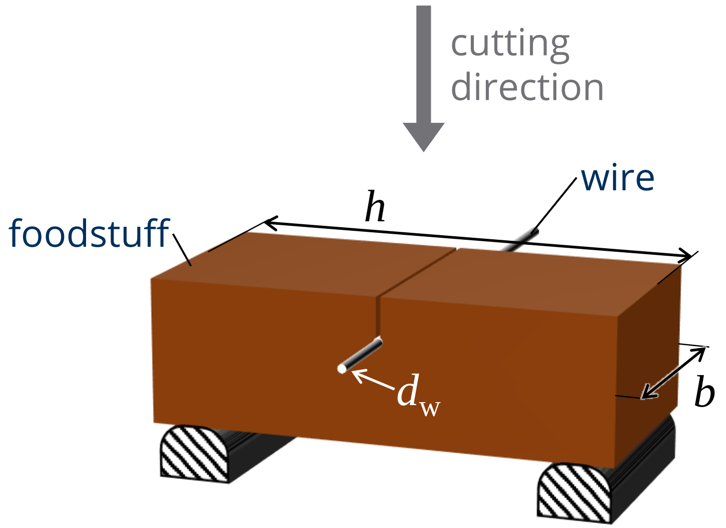
- rheology and FDG can not investigate material properties in different layer positions
- clear determination of binding forces with micromanipulation technique is not readily possible because of the influence of material deformation or displacement





FDG ... fluid dynamic gauging

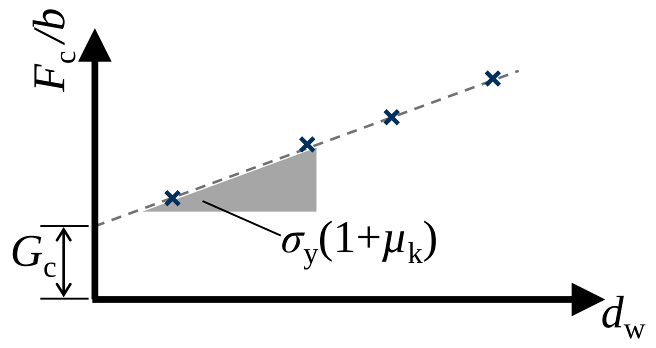
Introduction
Approach wire cutting experiment



- common method for determining the cohesive strength of foodstuffs
- the ratio h/d_w was usually greater than 100
- Luyten (1988) and Kamyab et al. (1998) noted that the normalized cutting force F_c/b is proportional to the wire diameter

$$\frac{F_c}{b} = \sigma_y(1+\mu_k)d_w + G_c$$

- determination of the cohesive strength G_c by linearly extrapolation to zero diameter
- slope: deformation energy (yield stress σ_y) and friction of the wire (kinetic coefficient of friction μ_k)

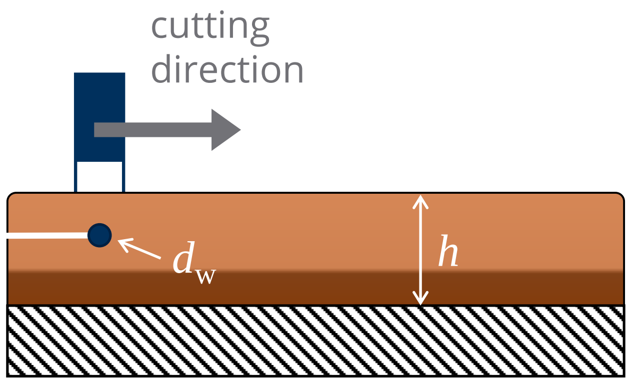


Luyten, H., 1988.
The rheological and fracture properties of Gouda cheese.
PhD thesis, Wageningen Agricultural University

Kamyab, I., Chakrabarti, S., Williams, J.G., 1998.
Cutting cheese with wire. J. Mater. Sci. 33, 2763-2770.

Introduction
Aim of this study

— investigation of the suitability of the wire cutting method
  - for the determination of the cohesive strength in different layer positions
  - of thin soil layers (h/d_w = 5 .. 30)



— changes in the mechanical behavior of a whey protein gels (WPG)
  - depending on a penetration front of a cleaning fluid
  - will be determined and compared with the initial *virgin* gel-properties

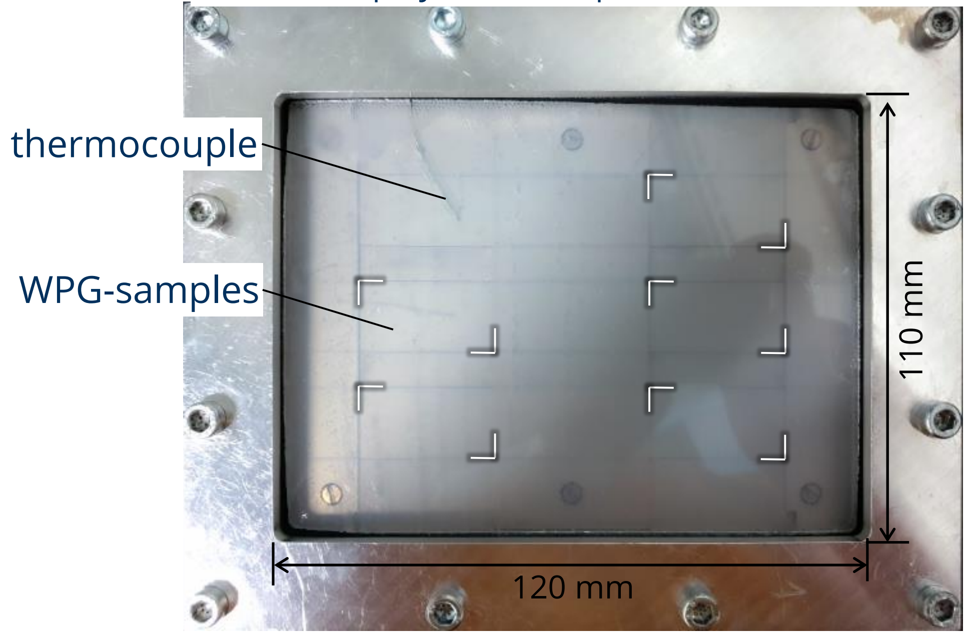
Materials and Methods
Soiling procedure

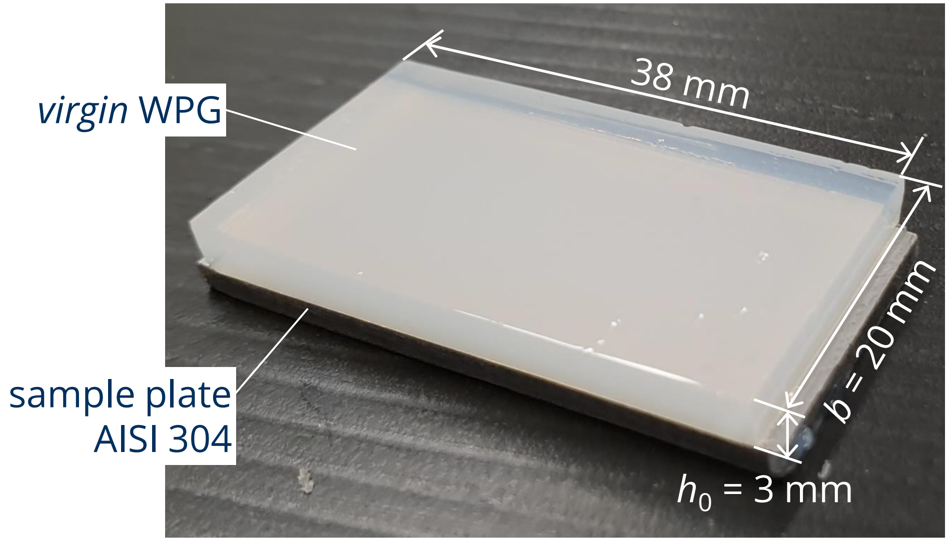
Whey protein gel (WPG)

— 30 g whey protein isolate (WPI) dissolved into 170 g deionized water

— heat-induced gelation with a aluminium mould
  - denaturation by a temperature profile in an oven
  - storing in a fridge for at least 12 hours

— sample plates were cut out in a defined pattern and removed from the mould
  - WPG layer with an initial height h_0 of 3 mm

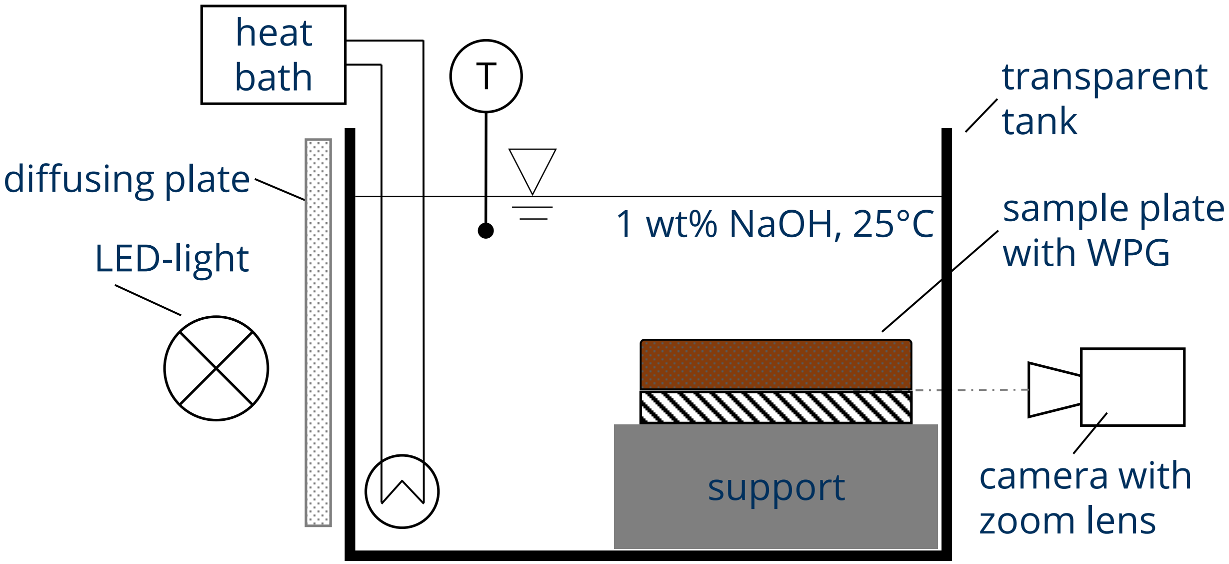




Materials and Methods
Swelling measurements

- to define the position of the horizontal cutting level
- to record the reaction of the layer a camera with a zoom lens looks sideways through a transparent tank at the sample

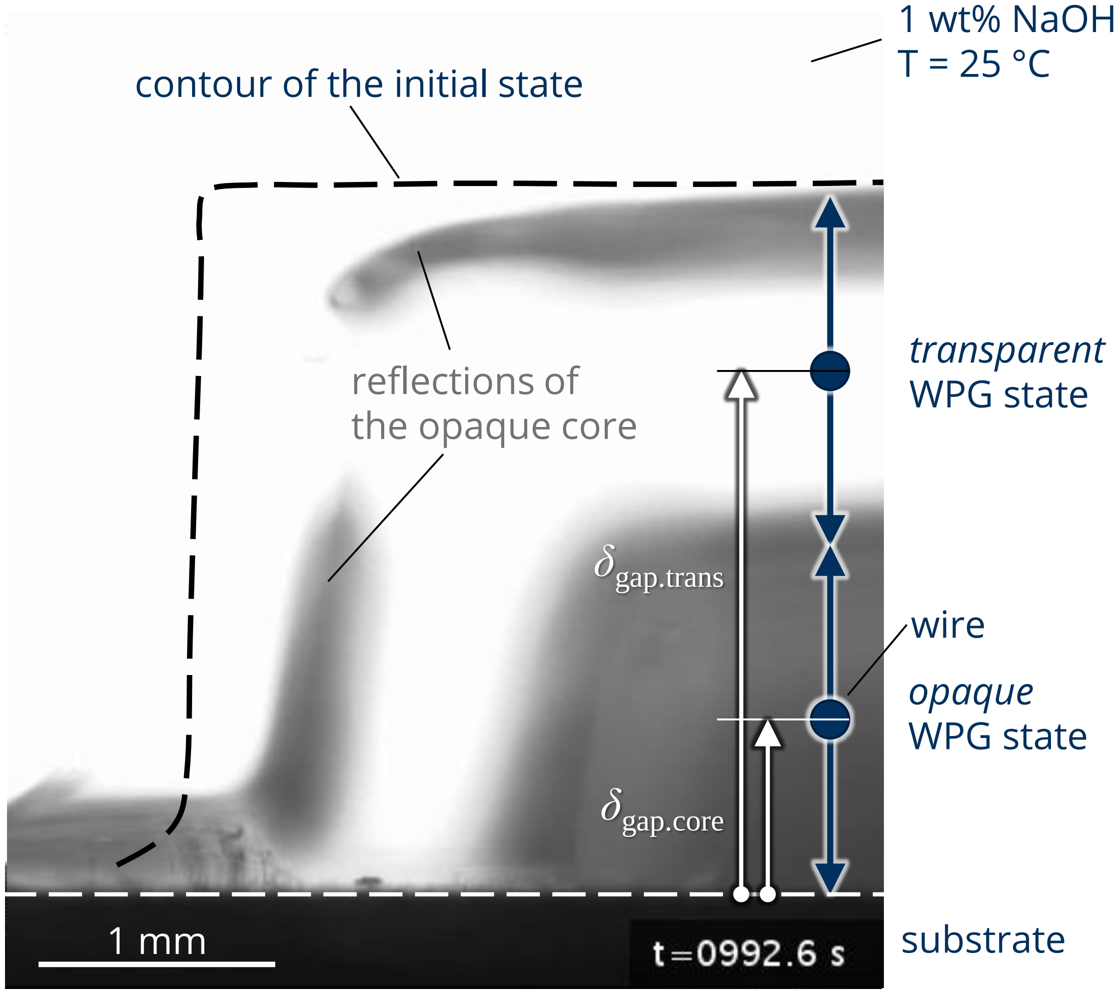
- cleaning solution for all experiments was 1.0 wt% NaOH at 25 °C (pH = 13.40)



Results

Swelling measurements – reaction of WPG in contact with NaOH

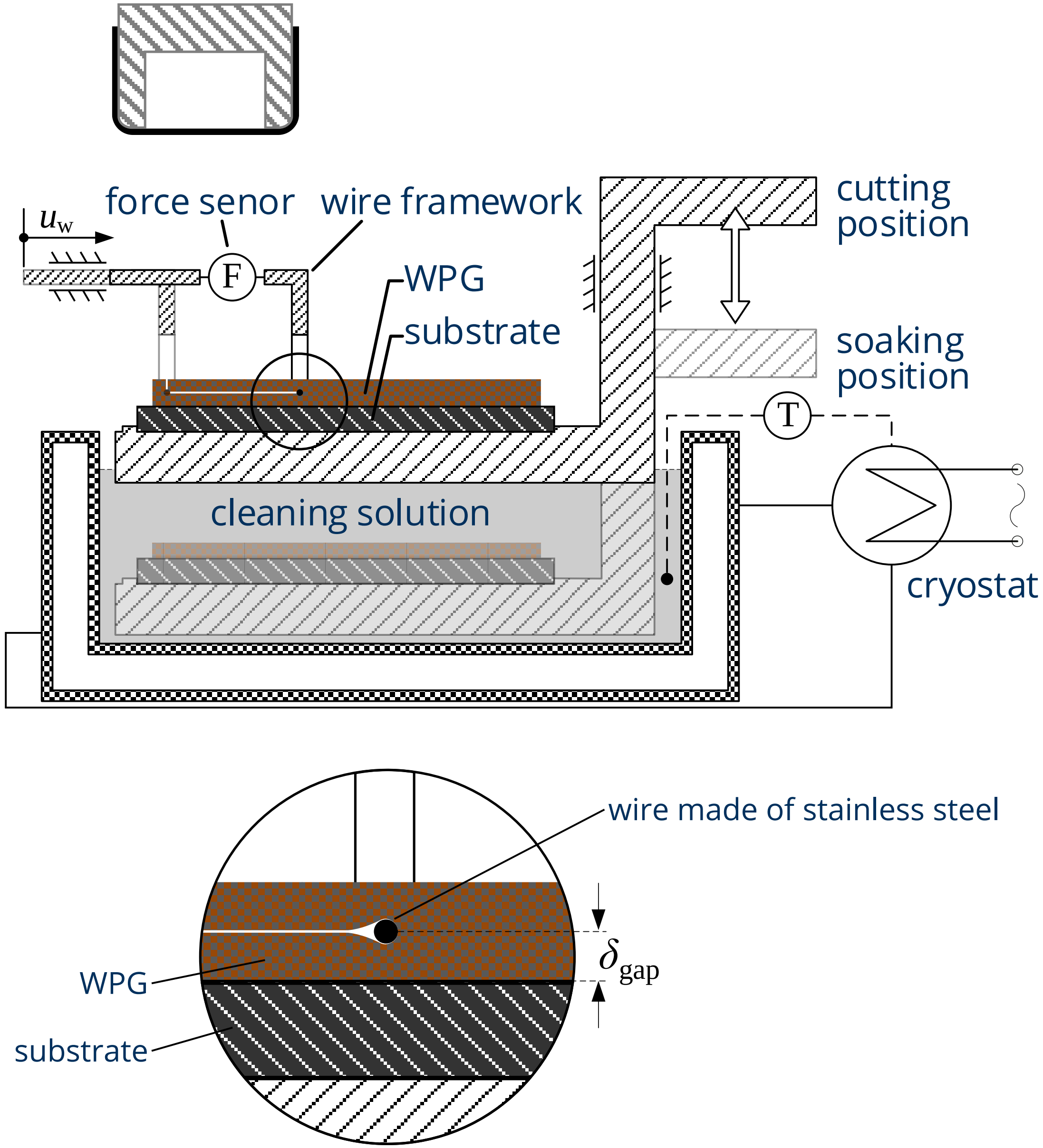
- whey protein gel (WPG) in contact NaOH
- initial increase in soil thickness
- progressive penetration front leads to the formation of two states within the WPG: *opaque* core and *transparent* state
- the total soil height decreases with soaking time
- height of both states could be identified by image processing tools
- both state have the same layer thickness after soaking time of 990 s



Materials and Methods
Wire cutting experiment

— works similar to the micromanipulation technique
— soaking of the WPG sample in cleaning solution
— vertical lift of the sample against the wire
— horizontal cutting movement of the wire through the WPG layer
— force sensor measuring cutting force *F*

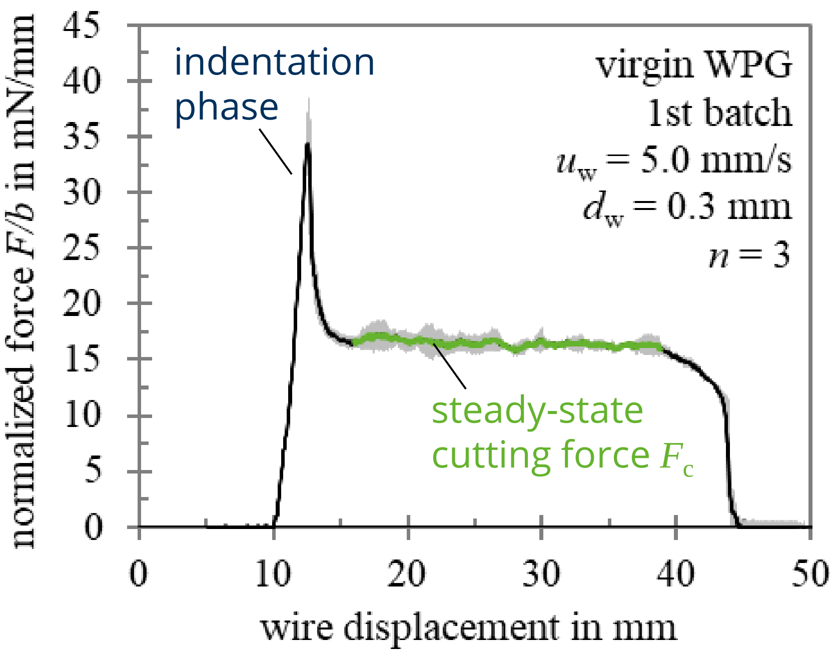
— wires:
- made of stainless steel AISI 304
- diameters d_w of (0.1, 0.15, 0.2 and 0.3 ± 0.0015) mm
- the preload of the wire was adjusted before each cutting measurement

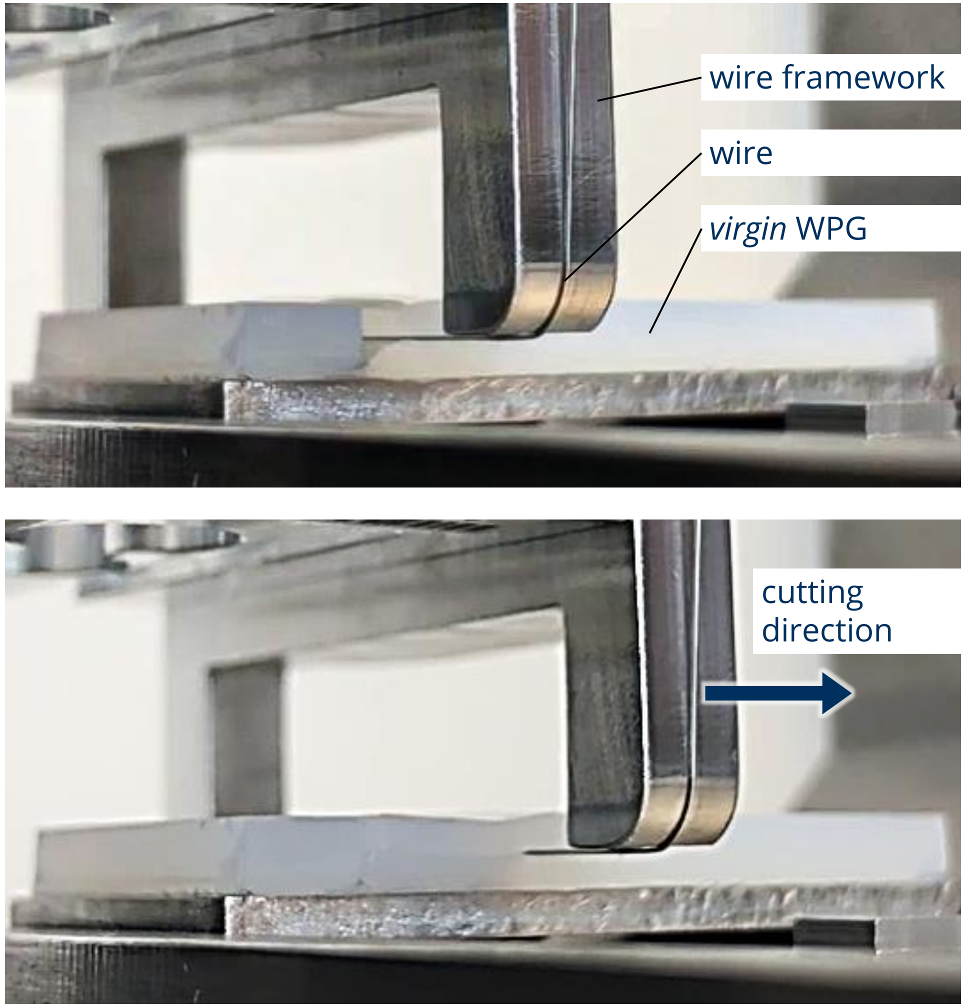


Results

Wire cutting experiment – determination of the steady-state cutting force F_c

— normalized force-displacement curve



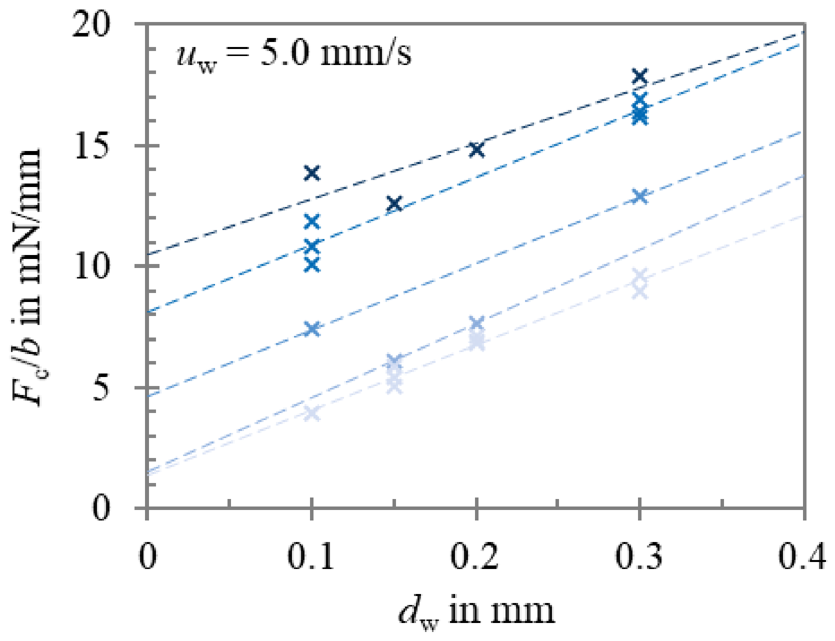


Results
Cohesive strength of *virgin* WPG

- steady state cutting force divided by sample width plotted against the wire diameter
- within a batch, the results show a good agreement with the approach used in the literature to determine cohesive strength

$$\frac{F_c}{b} = \sigma_y(1+\mu_k)d_w + G_c$$

- comparable slopes indicate similar material behavior upon cutting with the wire
- assumption: uneven formation of the microstructure of the gels during the preparation of the solution or during the heat treatment
  - clues: variations of pH and water-holding-capacity of the WPG



× 5th batch $F_c/b = 23.06d_w + 10.49$

× 1st batch $F_c/b = 27.74d_w + 8.17$

× 3rd batch $F_c/b = 27.41d_w + 4.67$

× 4th batch $F_c/b = 30.59d_w + 1.54$

× 2nd batch $F_c/b = 26.79d_w + 1.44$

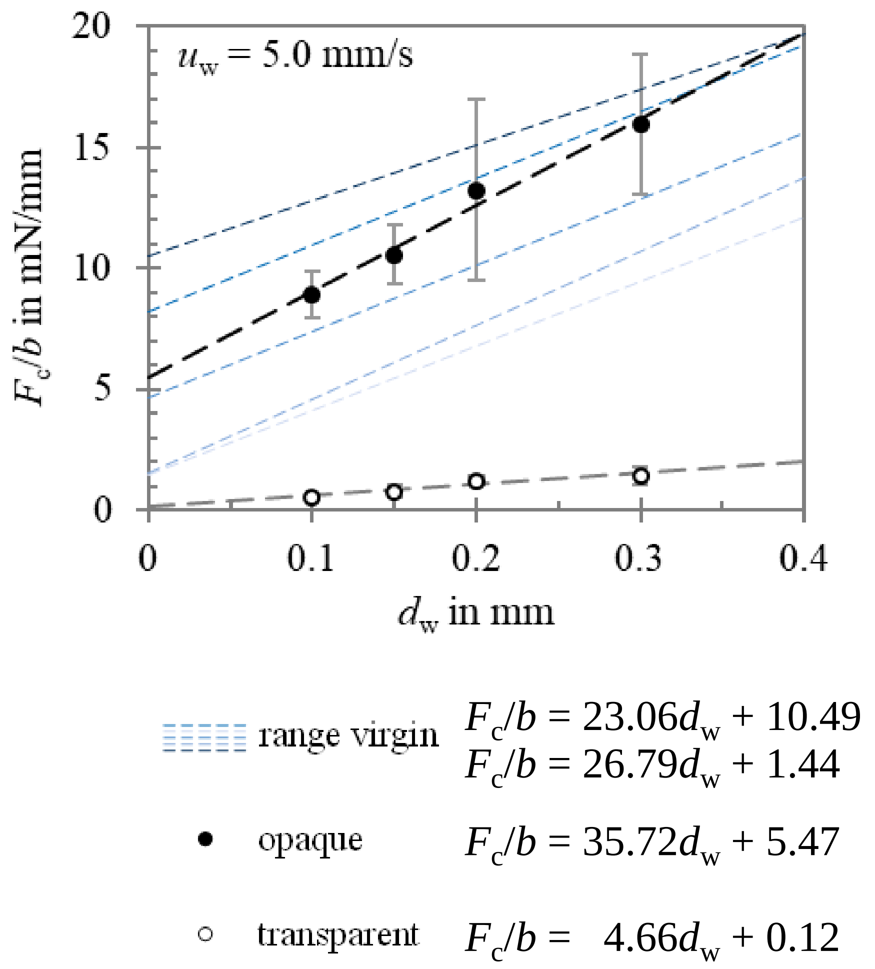
cohesive strength G_c

Results
Cohesive strength of *opaque* and *transparent* WPG states

- normalized steady-state cutting force of WPG after soaking in 1 wt% NaOH at 25 °C for 990 s

- cohesive strength of the opaque core can be placed in the range of the results of the virgin WPG
  - confirms the assumption of an unchanged gel structure of the WPG core

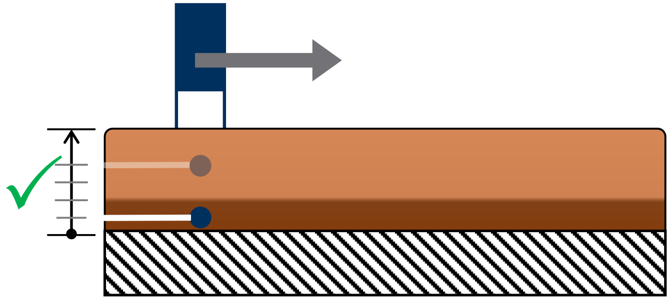
- the cohesive strength of the transparent state is significant reduced
  - underlines the breakdown of the disulphide bridges and non-covalent bonds due to the interaction with sodium hydroxide



Summary and conclusions

- the wire cutting method was used to investigate the cohesive strength of WPG after interaction with sodium hydroxide compared with the initial *virgin* state
- novelty: combination of the variation of the wire diameter and the adaption of the cutting position within the WPG layer to determine locally the cohesive strength
- cohesive strengths of the *opaque* core and the *virgin* WPG are similar
- significant reduction in the cohesive strength of the *transparent* state

➢ wire cutting method allows the local determination of cohesive strength without the influence of material deformation or displacement



- cons: cannot be used for very thin soil layer and high experimental effort due to variation of wire diameter
- in combination with the micromanipulation technique to investigate adhesive strength, it is a purposeful approach for measuring soil-specific cleaning properties

» Thank you for your attention «

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