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

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**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
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 \( \sigma_y \)) and friction of the wire (kinetic coefficient of friction \( \mu_k \))

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 \((h/d_w = 5 \ldots 30)\)

— 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

\[ F_c \text{ (normalized force-displacement curve)} \]

\[ \text{indentation phase} \]

\[ \text{steady-state cutting force } F_c \]

\[ \text{wire framework} \]

\[ \text{wire} \]

\[ \text{virgin WPG} \]

\[ u_w = 5.0 \text{ mm/s} \]

\[ d_w = 0.3 \text{ mm} \]

\[ n = 3 \]

\[ \text{cutting direction} \]
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
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
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Thank you for your attention «

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