NEW INSIGHTS IN STRESSING LEATHER – MULTI-SCALE SIMULATION OF MACROSCOPIC STRUCTURE-PROPERTY RELATIONS

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0. Introduction – 1

- Situation:
  - Structural variations → anisotropies
  - Variable macroscopic properties

- Need:
  - General information on leather’s characteristics
  - Structure-related properties for specific leather applications

- Approach:
  - Leather‘s quality analyses by established testings
    → destructive, sum values only

0. Introduction – 2

Objectives

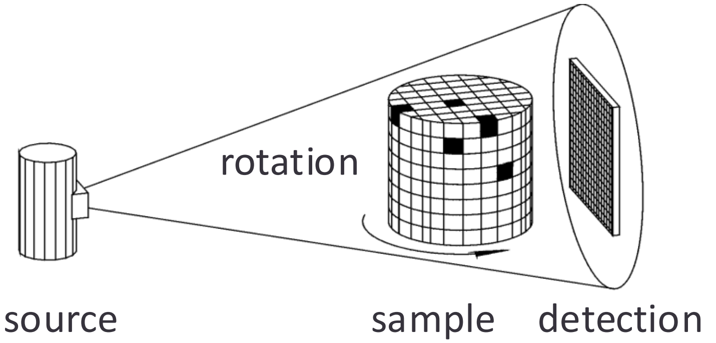
- Non-destructive leather qualification by 3D leather image analyses
- Quantification of leather total structure and structure elements
- Leather structure modelling

→ **Prediction of macroscopic leather properties by multi-scale simulation**

1. Review – 1

Computed Tomography in Principle

- Sample irradiation with X-ray
- Variety of cross-sectional images (= projections)
- Reconstruction of volume structure

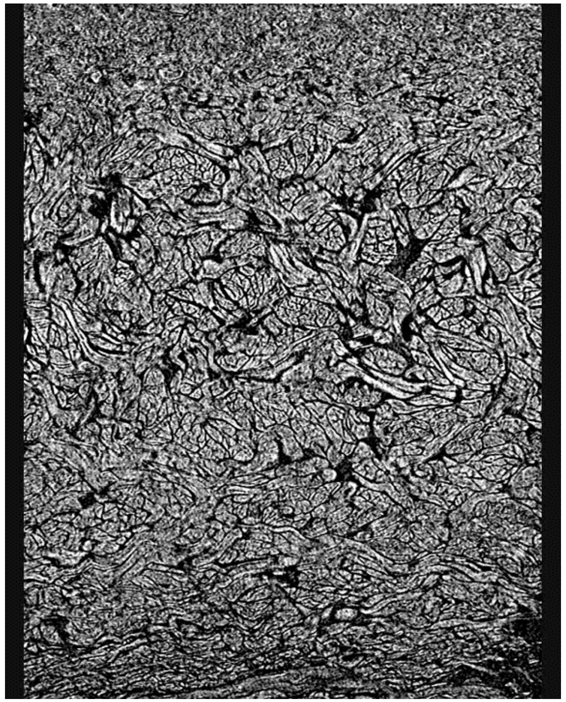


Settings CT

- Voltage 75 kV
- Detector $(2048)^2$ pixels
- 1200 shots in angular steps
- Irradiation time 4 x 1.0 s
- Pixel resolution ≈ 2…15 µm
- Window of measurement (6 x 6 x 5) mm

Structure Detection by µCT

- Reticular layer of FOC-leather
  → Grey level images



Grain side

Flesh side

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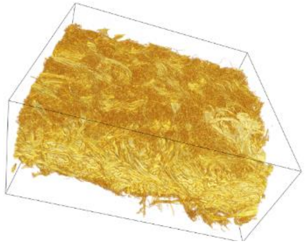
1. Review – 2

0.

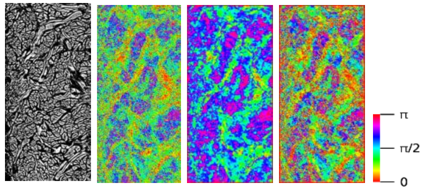
Vegatable-tanned split leathers

I.



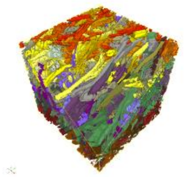
3D Imaging techniques, micro-computed tomography (µCT)

II.



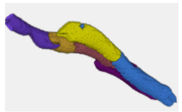
Data processing, image analyses

III.



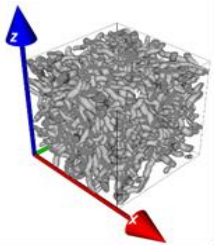
Structure segmentation

IV.



Structure elements parametrization

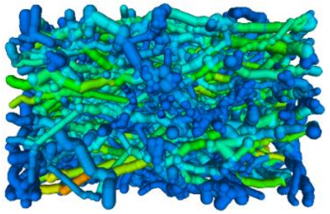
V.



3D geometric modelling

Alteration

VI.



Simulation

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1. Review – 3

Leather Tanning

- Vegetable-tanned (FOC), split leathers

Leather Types

- Simmentaler breed (Leather 1+2, FILK)
- Zebu breed (Leather 3, FILK)
- References (Leather 4-6, industry)

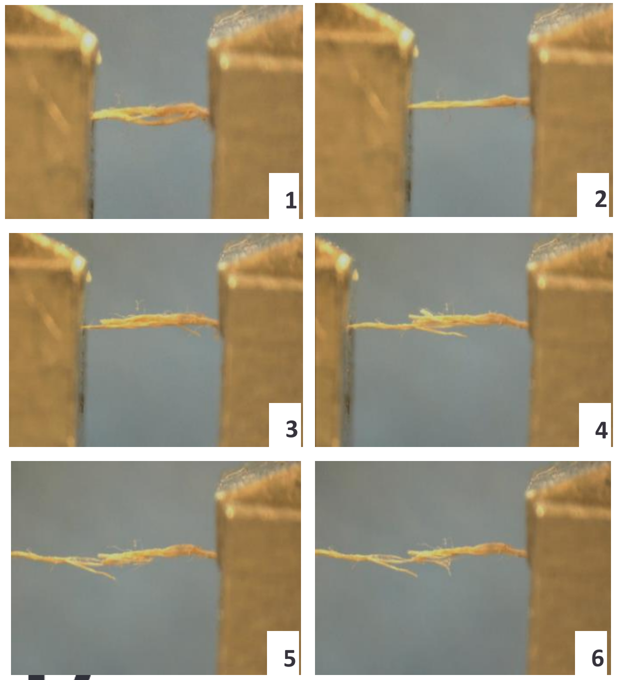
Macroscopic Input Parameter

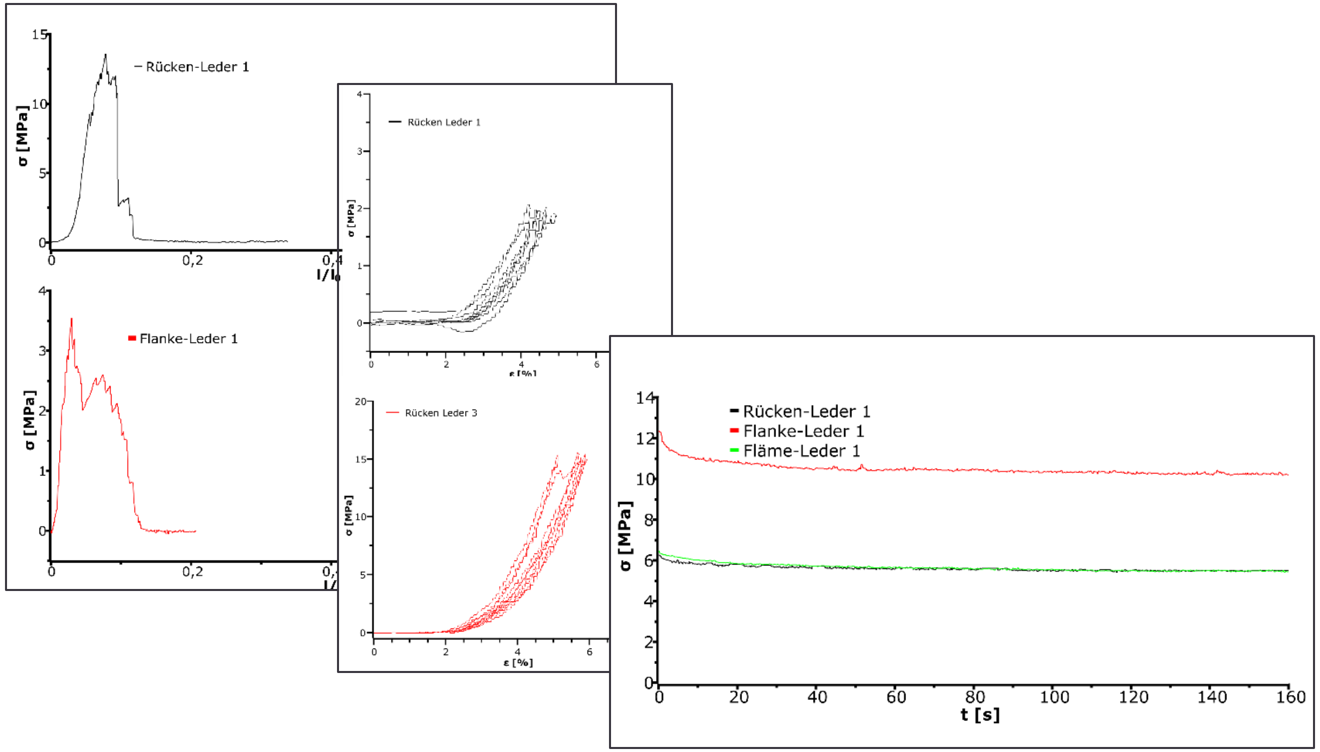
- Density
- Thickness
- Tensile test
- Stress-strain properties (extension set)
- Microscopy (LiMi, REM)

1. Review – 4

Micro-Structural Input Parameter

- Tensile test on leather fibres
  - (A) Tensile test
  - (B) Hysteresis
  - (C) Relaxation





Uniaxial Tensile Test		Fmax [mN]	σ [N/mm²]	E-Modulus [MPa]	Elongation at break [%]
Leather 1	Back	258.00	13.58	**304.14**	7.90
	Flank	45.30	3.54	**209.98**	2.90
	Axilla	3.50	0.21	**4.96**	6.26
Leather 2	Back	51.70	6.46	**307.71**	5.20
	Flank	44.40	6.22	**263.58**	4.50
	Axilla	33.50	27.69	**517.25**	2.38
Leather 3	Back	130.90	7.11	**215.95**	6.44
	Flank	434.30	30.80	**233.31**	11.79
	Axilla	341.80	30.25	**235.27**	3.34
Leather 4	Back	652.15	23.67	**294.48**	14.565
	Flank	730.8	26.02	**189.82**	20.16
	Axilla	323	12.80	**129.60**	50.68

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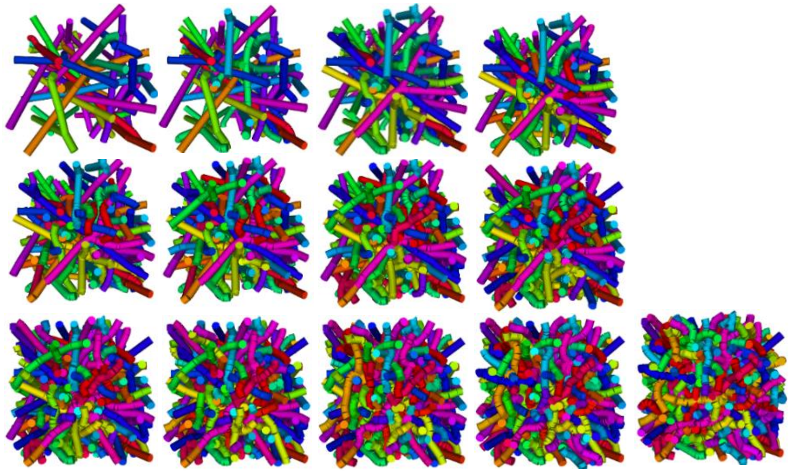
1. Review – 5

Modelling the Leather Structure

- Macrostructure modelling:
    - Fibre bundle of circular form, no differences in cross-sectional thickness
    - Fibre bundle length >> sample edge length
    - Increasing fibre volume fraction (10 – 85 %)
    - Various types of contacts



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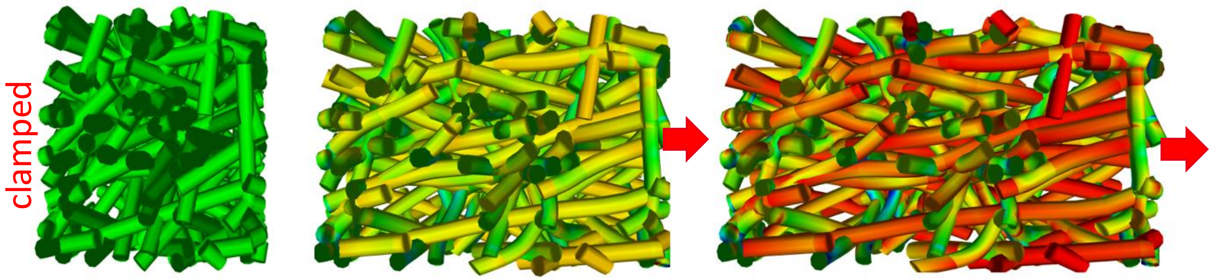
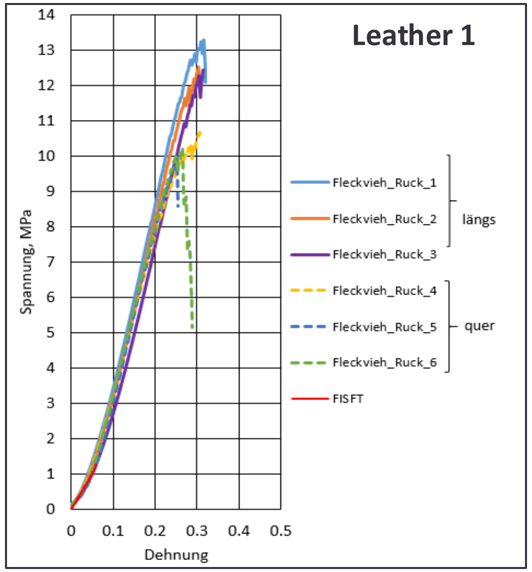
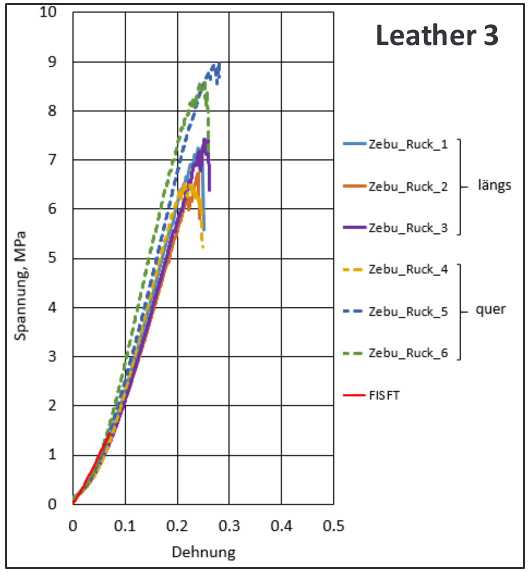
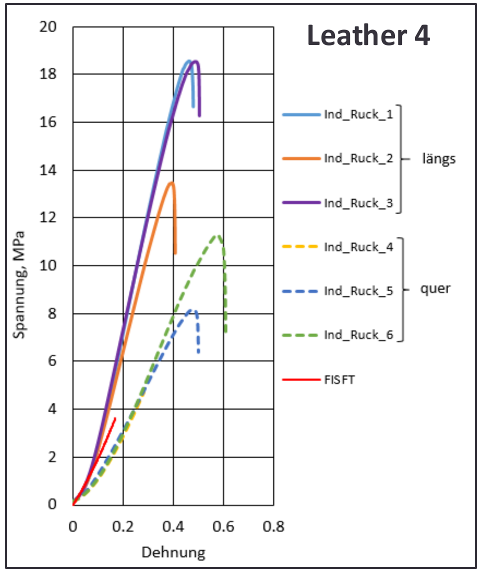
1. Review – 6

Prediction of Macro-Structural Elastic and Visco-Elastic Properties









Parameter/ Animal	Experim. Fiber volume fraction	Experim. E-Modulus [MPa]	Simulated Leather E- Modulus [MPa]
Leather 1	0.612	49.39	49.8
Leather 3	0.626	39.86	39.9
Leather 4	0.656	34.26	24,7

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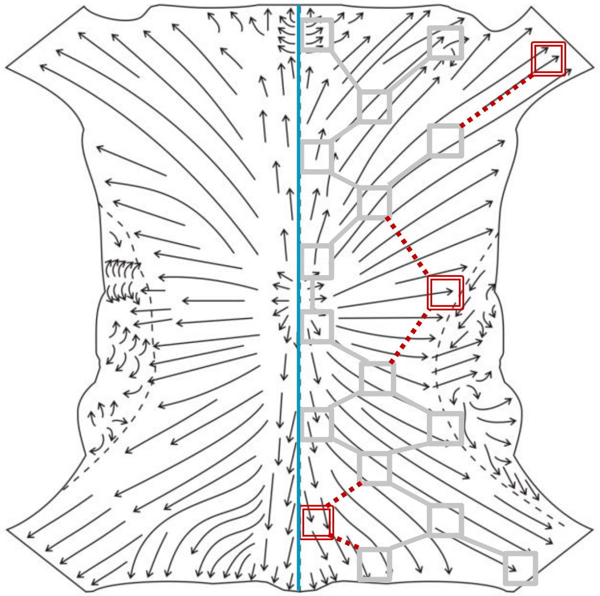
2. Status

Challenges

- Leather structure insight: high resolution µCT-analyses
- "sample cutting“ for µCT-analyses caused breakage of scaffold → fibres in meshes shorter → loss of hierachical structure information = more isotropy
- Simulation limited by maximum fiber bundle strain

→ **Extension of methodological approach for global anisotropy analyses by integration of wider leather structure areas**



Nach Covington, T., Tanning Chemistry, RSC Publishing Cambridge 2009

3. Objectives

Development of a simulation tool for the prediction of partial macro-mechanical properties within a leather area as well as entire macro-mechanical properties of complete leather batches

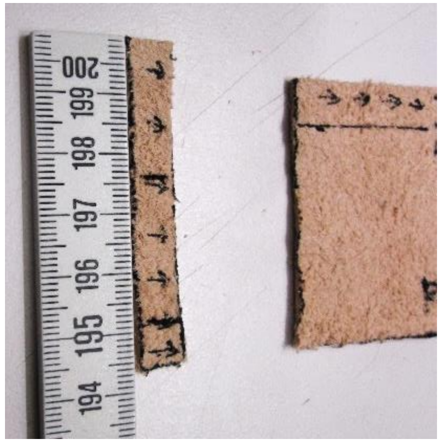
→ Tool for optimization of leather selection and processing (e.g. leather trimming of components)

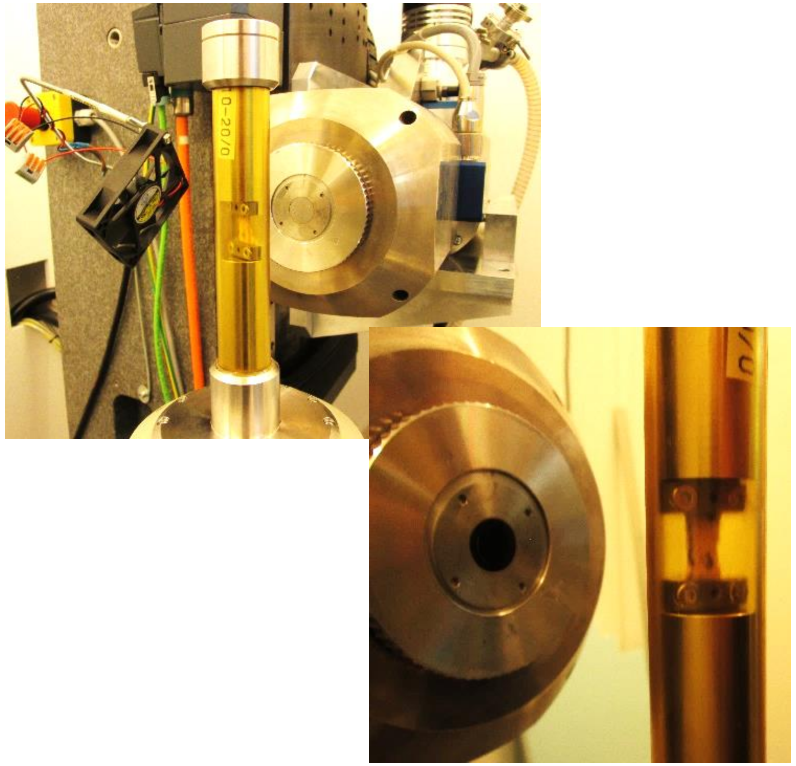
- Expanding findings for micro-mechanical leather structure modelling and simulation from separate leather hide areas to entire leather hides
- Further development of non-destructive leather structure imaging by using modified µCT technologies
- Development of a representative tissue network model for the entire leather skin, including complex branching structures

4. Progress

Adapted µCT-analyses

- Preparation modified: leather samples of larger size
- Window of measurement (10 x 10 x 2) mm, embedded in larger structural network
- ***In-situ* structure detection under load (tension of 100 N)**





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Acknowledgement

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Haiko Schulz

Renate Meyndt

Martin Strangfeld

Fraunhofer ITWM

Julia Orlik

Katja Schladitz

Michael Godehardt

David Neusius

Olga Lykhachova

AiF

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Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

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