A new FEM simulation method of paper materials by using gasket model

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Introduction ——Research Background

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Paper cutting

Paper counting

Paper folding

- Mechanical behaviour of paper
- Through-thickness direction

Traditional printing

Book binding

Paper creasing

Paper calendering

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Introduction —— Paper Models

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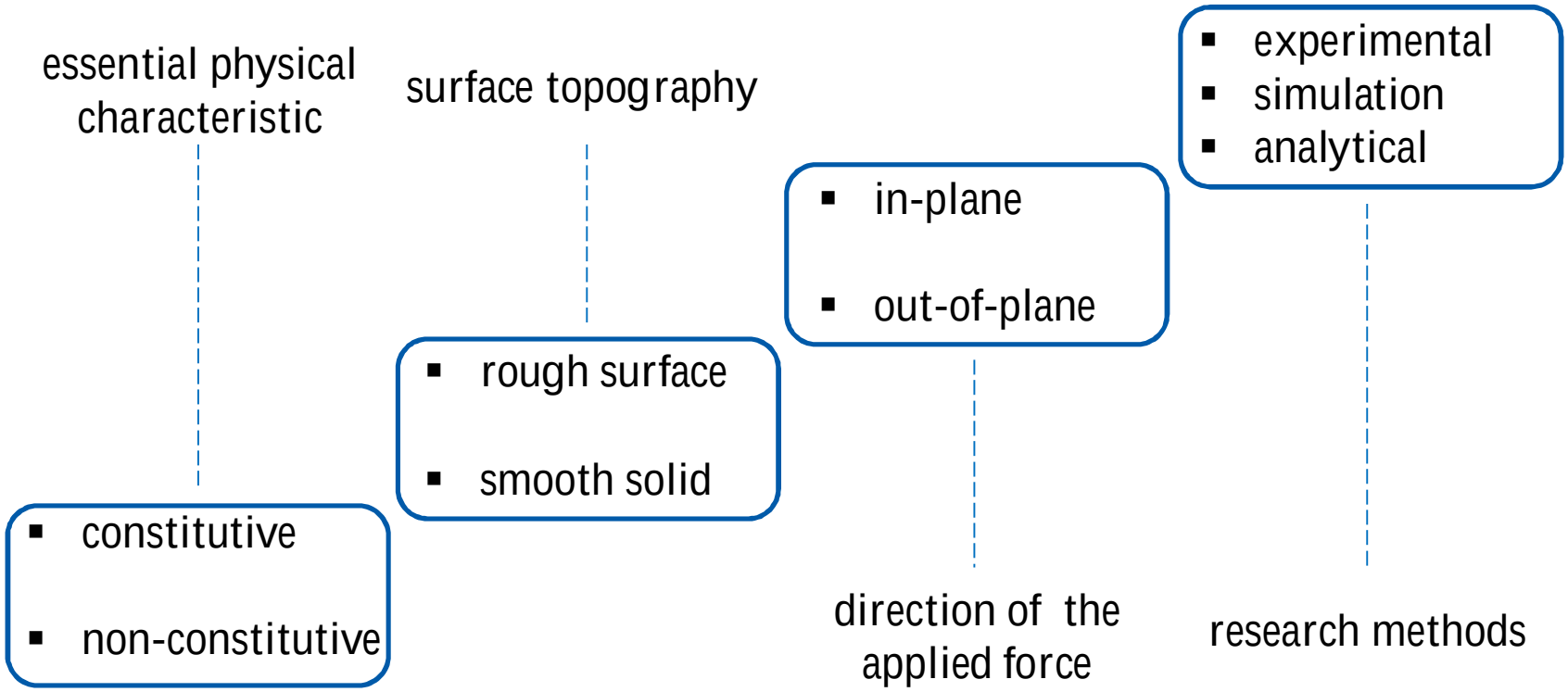
According to different classification criteria, the paper models can be classified into various groups.



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Introduction —— Paper Simulation

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Research status of paper simulation:

- Still no material model provided which could directly be used for paper simulation.
- Only very few previous works attempt to establish a simulation model.
- Constitutive models require a large number of difficult to measure parameters.
- Extension to multiple sheets is difficult.

Is it possible to do the simulation of paper materials in a much easier way?

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Introduction —— Gasket Simulation

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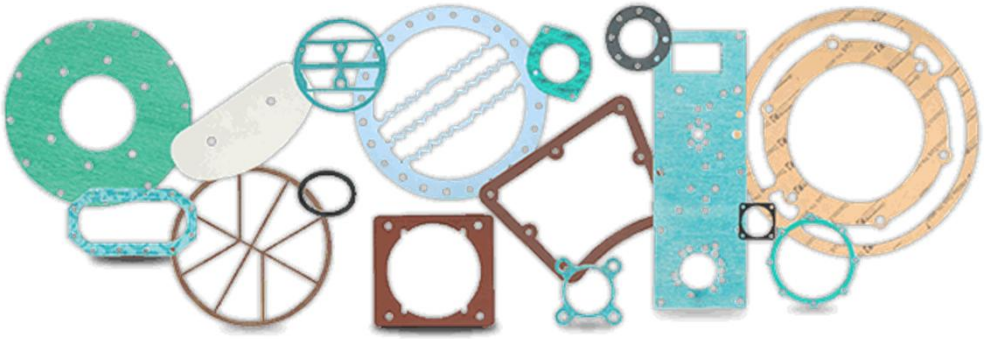
Characteristics of gaskets:

- Thin in one direction, but through-thickness behaviour is most important.
- The mechanical behaviour of gasket in the through-thickness direction is similar to paper materials.
- Gasket elements are offered in FEM software.



How to realize the simulation of paper materials by the gasket model.

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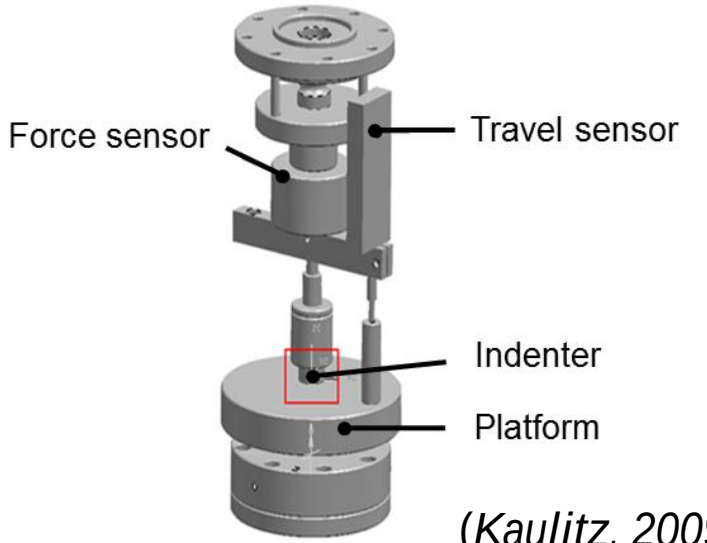
Material and Method —— Experimental Setup

The air-conditioned laboratory of the Institute of Printing Science and Technology (IDD) is equipped with the universal testing machine Zwick Z050.

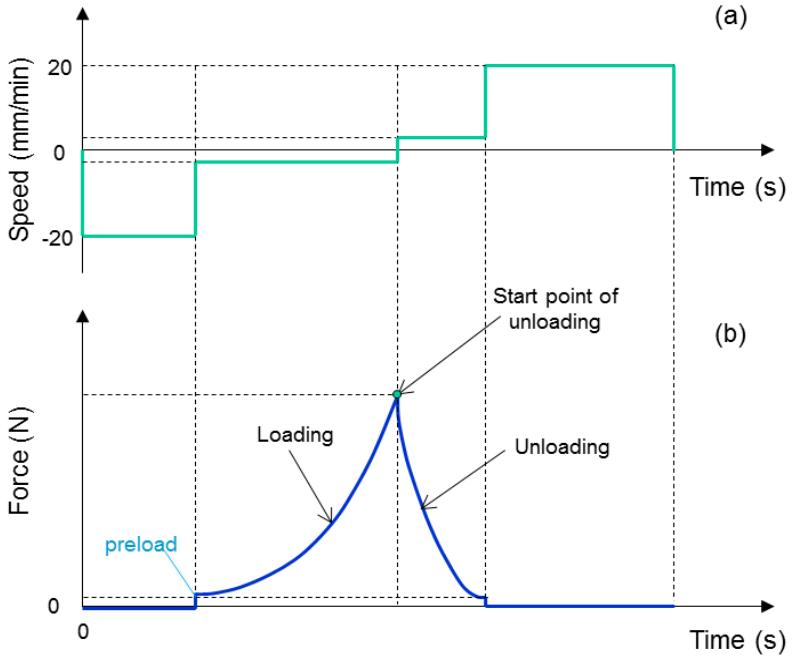


(*Kaulitz, 2009* [1])

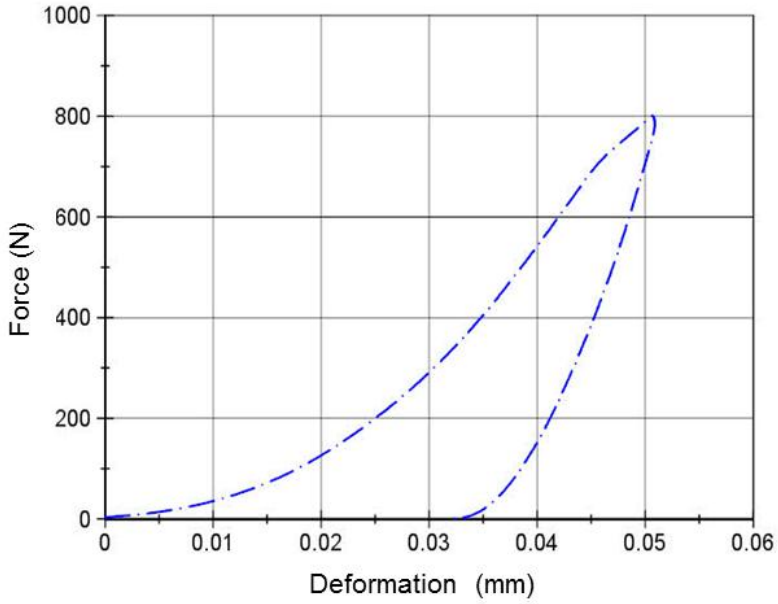
Test equipment for determining force deformation behaviour of paper

- Air-conditioned laboratory of IDD:
  - temperature: 23 ± 0.5°C
  - relative humidity: 50 ± 1.5%
- Parameters of the sample :
  - grammage: 80 g/m2
  - average thickness: 102µm
- Precision accuracy of Zwick machine :
  - cross head speed: 0.0005 – 2 000 mm/min
  - position repetition accuracy: ± 2 µm

Experimental Method



Schematic of the applied speed and force in the loading cycle



A typical force-deformation curve of paper

Simulation Process——Fundamental Theory

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The definition of the material properties:

- the loading process
- the unloading process

Compressibility model for synthetic gasket material (*Jorwekar, 2006* [2]):

$$y = a \cdot \left(1 - e^{-\left(x/b\right)}\right) + c \cdot \left(1 - e^{-\left(x/d\right)}\right) + u \qquad [1]$$

Slope:

$$\frac{dy}{dx} = \left(a/b\right) \cdot e^{-\left(x/b\right)} + \left(c/d\right) \cdot e^{-\left(x/d\right)} \qquad [2]$$

Unloading curve function (due to the unrecoverable strain):

$$u(z) = a \cdot \left(1 - e^{-\left(z/b\right)}\right) + c \cdot \left(1 - e^{-\left(z/d\right)}\right) - \left[a' \cdot \left(1 - e^{-\left(z/b'\right)}\right) + c' \cdot \left(1 - e^{-\left(z/d'\right)}\right)\right] \qquad [3]$$

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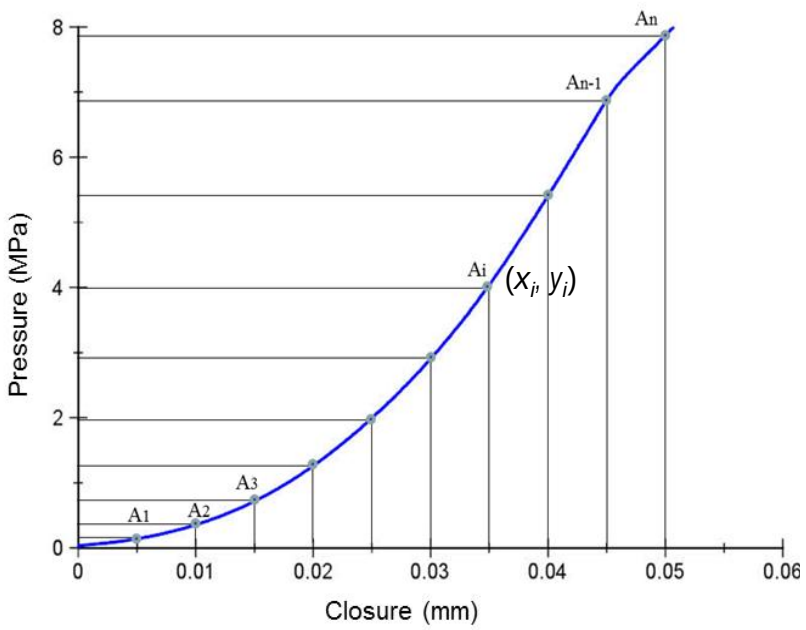
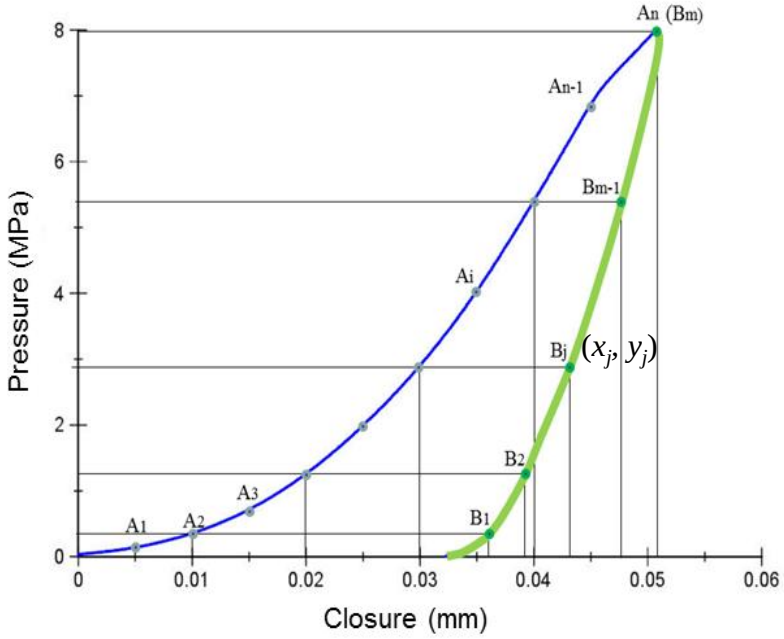
Simulation Process ——Defining Material Properties

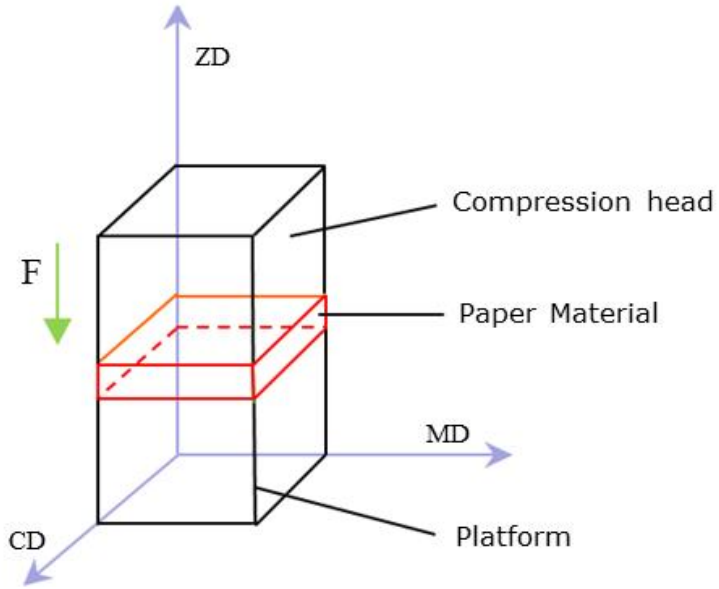


The data selected for defining the loading process



The data selected for defining the unloading process

Simulation Process——Modeling and Simulation



Schematic representation of the simulation model

i. Defining the material properties

ii. Building the simulation model

iii. Meshing the elements

iv. Defining the constraint conditions

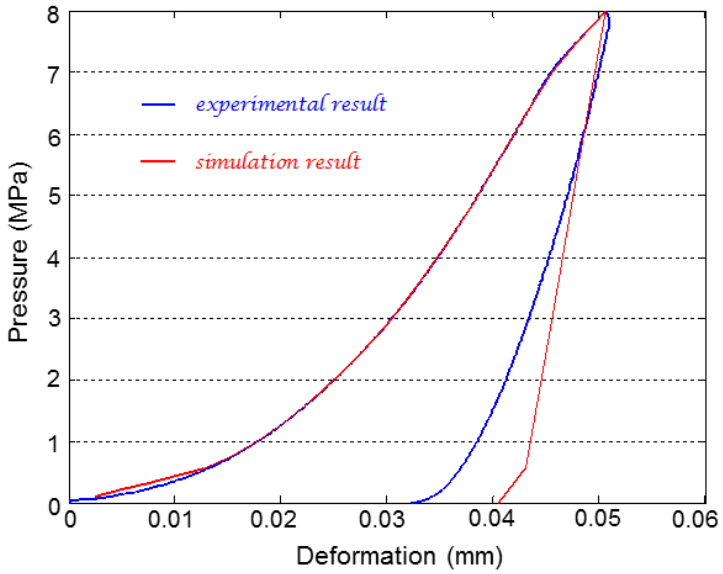
v. Imposing the force

vi. Outputting the results

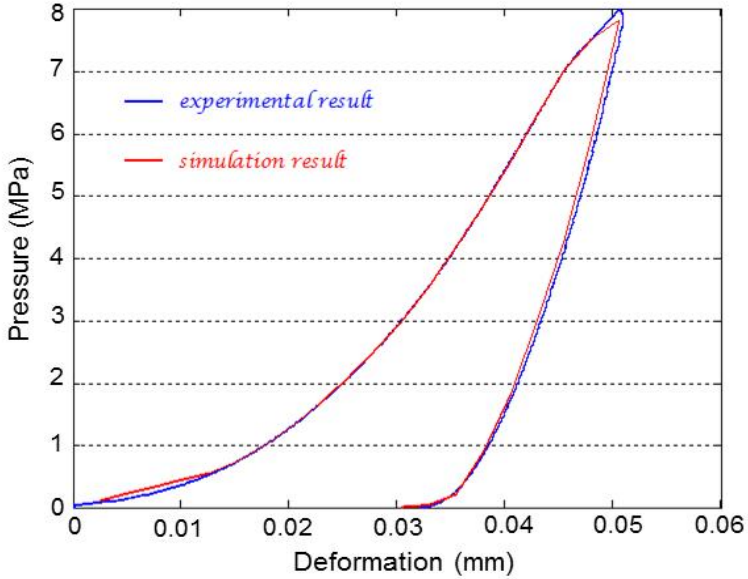
Results and Conclusions
—— Paper Simulation under a Defined Force

The simulation of paper material finished here:

- the linear unloading simulation
- the non-linear unloading simulation



The linear unloading simulation result



The nonlinear unloading simulation result

(A pressure of 8 MPa corresponds to about 800 N)

Results and Conclusions
—— Simulation under Variable Maximum Forces

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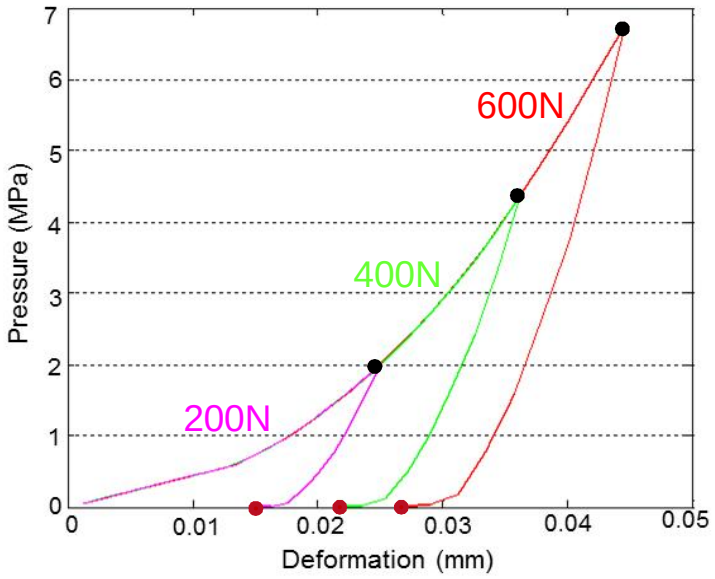
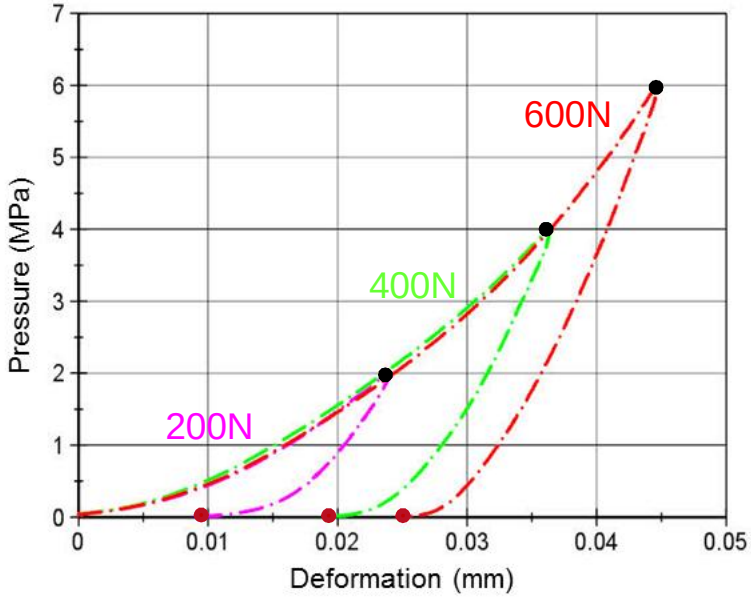
Three groups of simulations were implemented:

- the respective maximum forces applied are 200 N, 400 N and 600 N.



The simulation results under different forces



The experimental results under different forces

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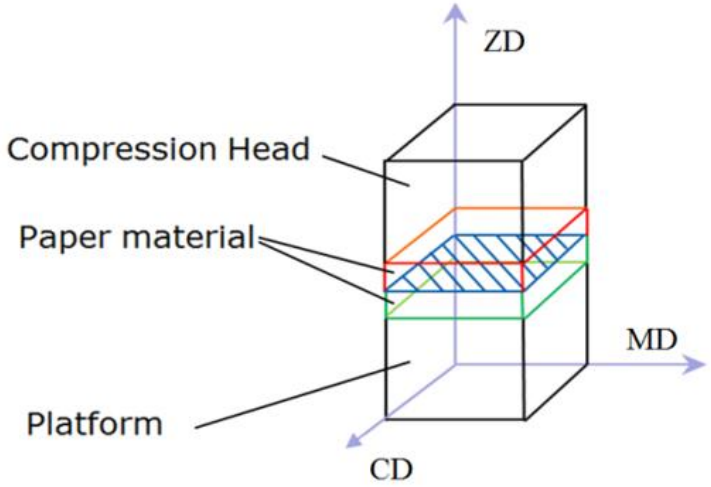
Comparisons between simulations and experiments

Force	200 N	400 N	600 N	800 N
Maximum Pressure (MPa)				
Simulation results	1.82	4.38	6.77	8.00
Experimental results	2.03	4.06	6.09	7.98
Deviation	10.3 %	-7.9%	-11.2%	-0.025%
Residual Strain (-)				
Simulation results	0.14	0.21	0.26	0.30
Experimental results	0.09	0.19	0.24	0.32
Deviation	-64.4 %	-13.5%	-7.7%	6.2%

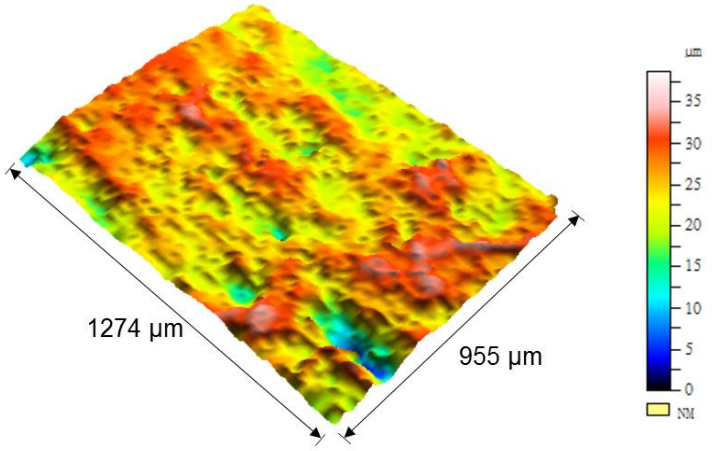
Conclusions:

- The accuracy of simulation under a specific force is very good.
- The gasket model could be perfectly used for paper simulation.
- To a certain degree, this simulation method could be used for simulations under other forces.

Outlook



One sheet ⟶ Two sheets



3D Surface topography of copy paper, the scan area is 1274 µm × 955 µm.

❑ Key problem:

- How to define the contact between paper layers.
- Establishing a model of paper which accounts for the surface topography.

Thanks for your attention!

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[1] Kaulitz, T., 2009. Bilden von Schneidlagen unter Ausnutzung des Nipinduzierten Effekts für die Druckweiterverarbeitung. (PhD dissertation, Darmstadt University of Technology)

[2] Jorwekar, P.P., Birari, Y.V. and Nadgouda, M.M., 2006. Cylinder head gasket contact pressure simulation for a hermetic compressor. International Compressor Engineering Conference at Purdue.

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