Parametric 3D Modelling of Nonwovens for Mechanical and Filtration Properties

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Motivation

*a2zbabybabydiapers.wordpress.com

**http://www.nonwovens-industry.com/

What does happen to nonwovens under tension and compression?

Does microstructure change?

Does this affect mechanical, filtration and absorption properties?

Outline

- Motivation
- Objectives
- Material and microstructure
- Experiments
- Tensile Performance
- Out-of-plane Loading
- A New Parametric 3D Computational Model
- Flow Simulations
- Summary and conclusions

Objectives

i. To predict tensile, compression and filtration performance of nonwovens with computational models.

ii. To develop a new 3D parametric model to simulate compression of nonwovens and its effects on flow properties.

iii. To optimize available nonwovens by means of this new parametric model to enhance filtration and absorption performances.

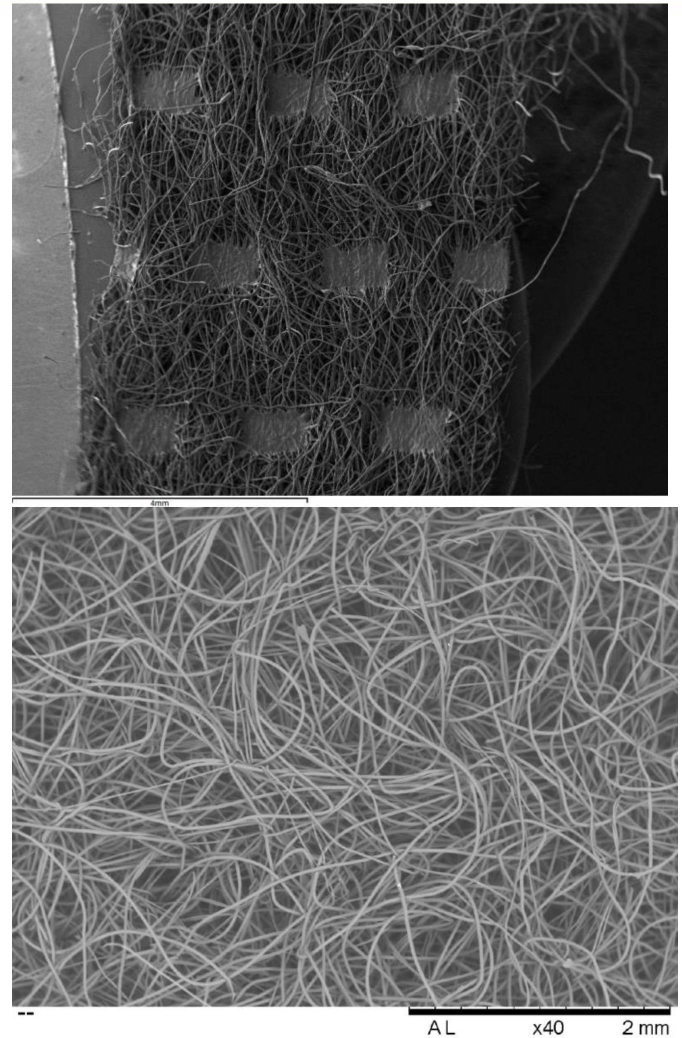
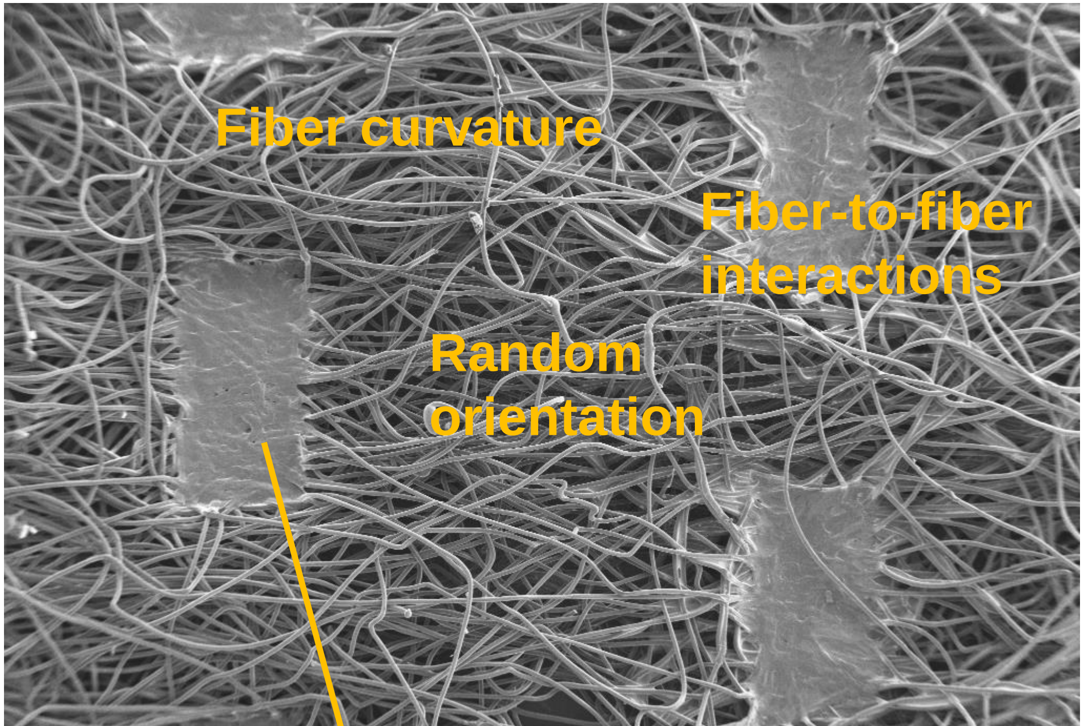


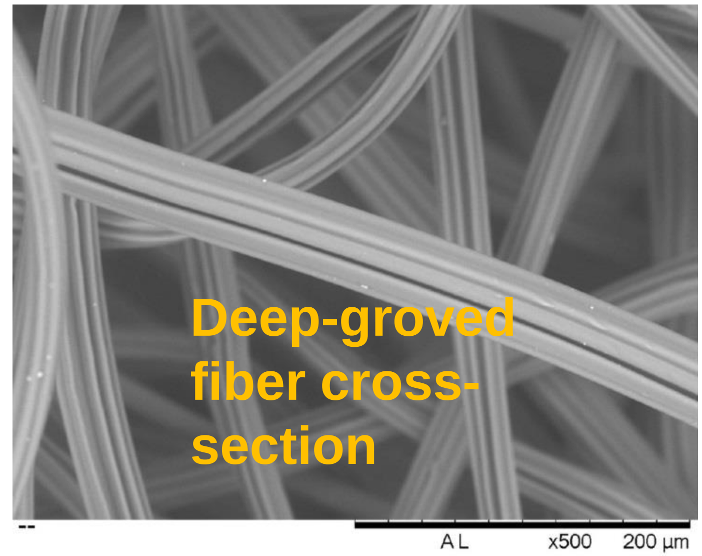
Figure 1: Thermally bonded nonwovens

Material and Microstructure



200µm

Bond point

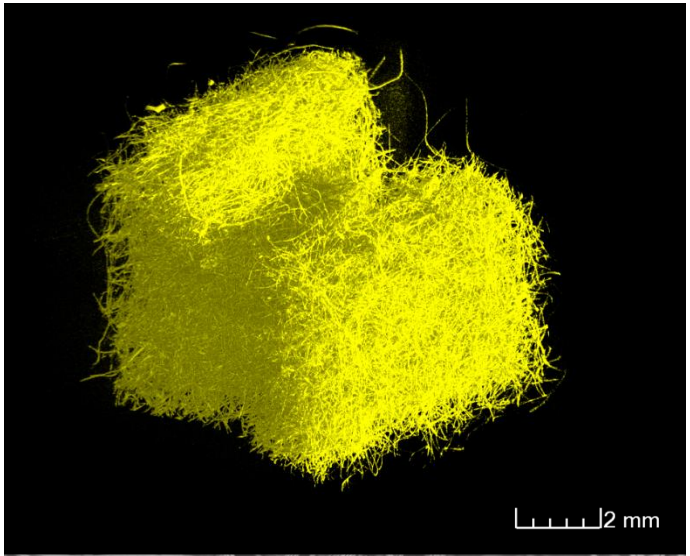


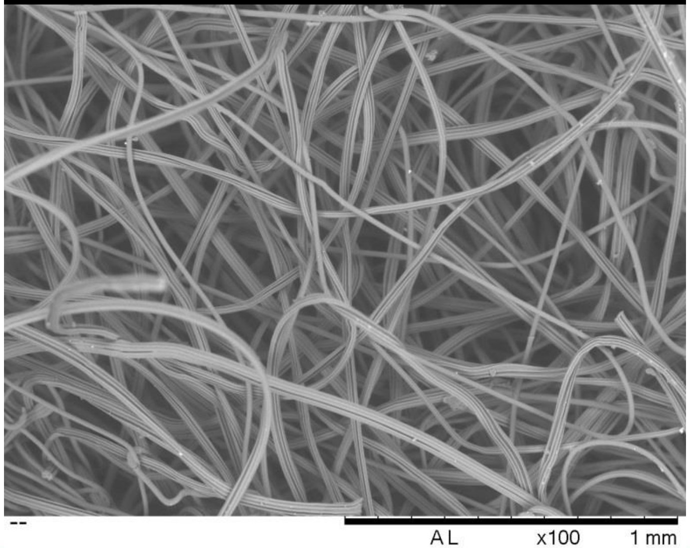
- Highly complicated materials due to material and microstructural properties

Loughborough University

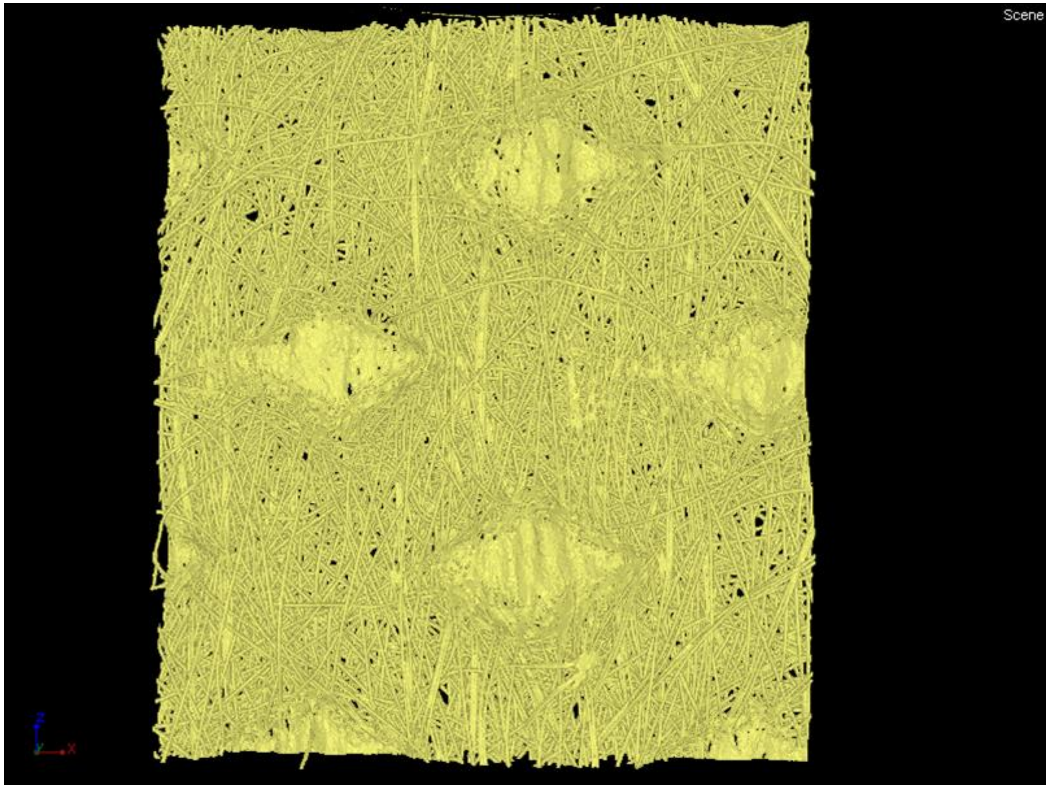
Experiments

Test	Instrument	Outcome
Scanning electron microscopy (SEM)	Carl Zeiss, Leo, 1530VP FEGSEM	Fabric characteristics (bond pattern, shape…etc.)
X-ray micro computed tomography (CT)	XTEK XT-H 160Xi	3D image, ODF, bond pattern, shape and dimensions…etc.
Fiber tensile tests	Instron Micro Tester 5848	Elastic properties and rate-dependent flow curve
Creep tests	Instron Micro Tester 5848	Viscous properties
Relaxation tests	Instron Micro Tester 5848	Viscous properties
Fabric tensile tests	Hounsfield Benchtop Tester	Mechanical response



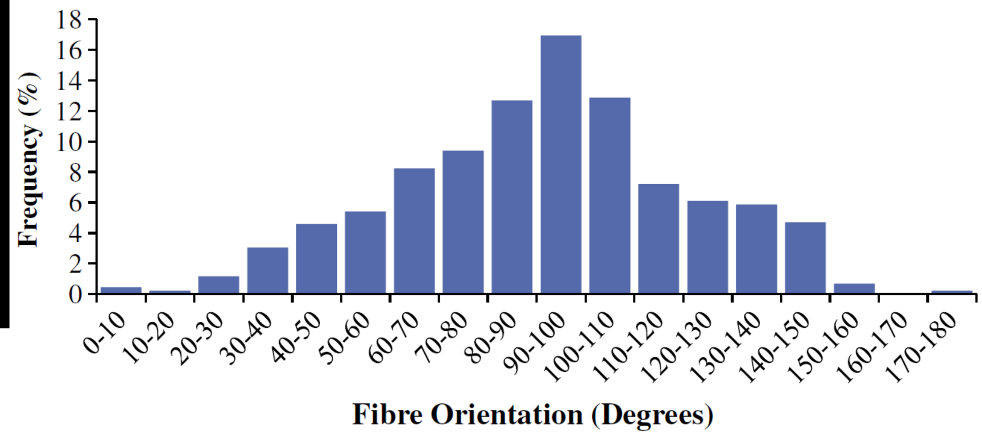


Experiments- Fiber Orientation Distribution



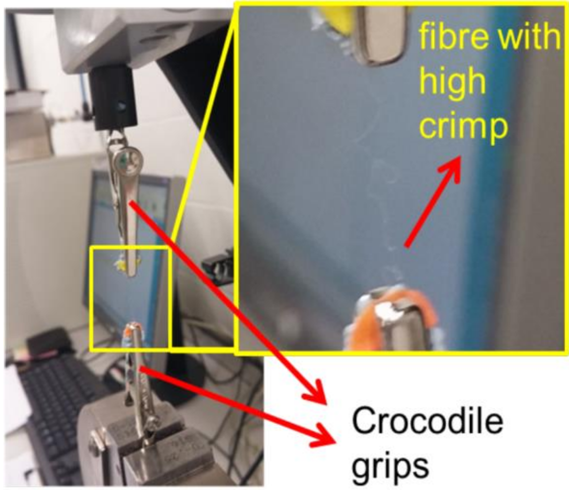
Fiber Orientation Distribution:

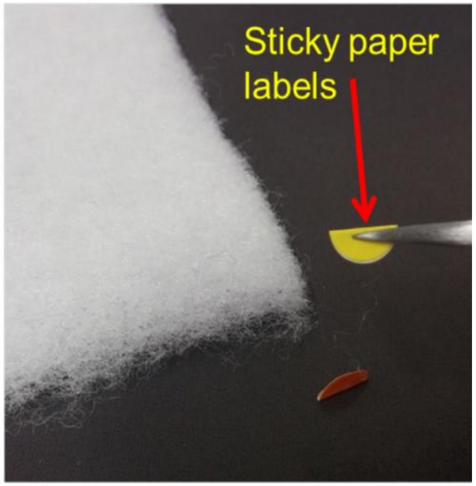
- Grey-scale 2D images using a Hough-transform-based image processing algorithm



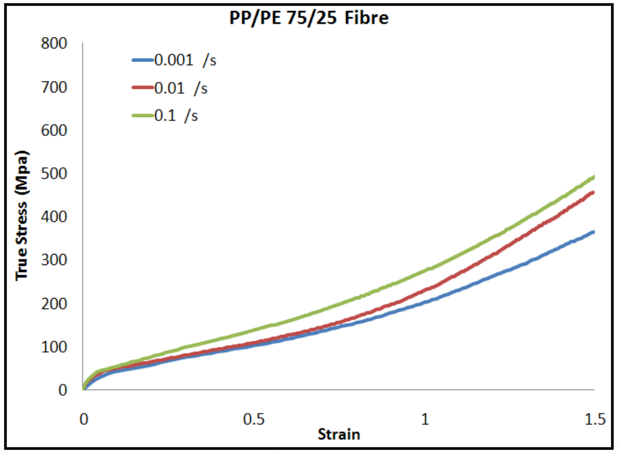
(Demirci, 2011)

Experiments - Single Fiber Tests

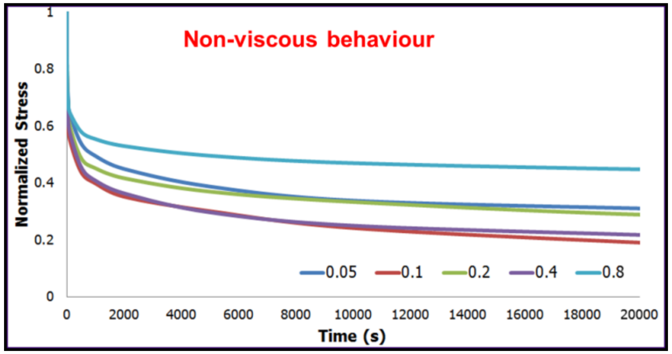




- Tensile tests with various strain rates



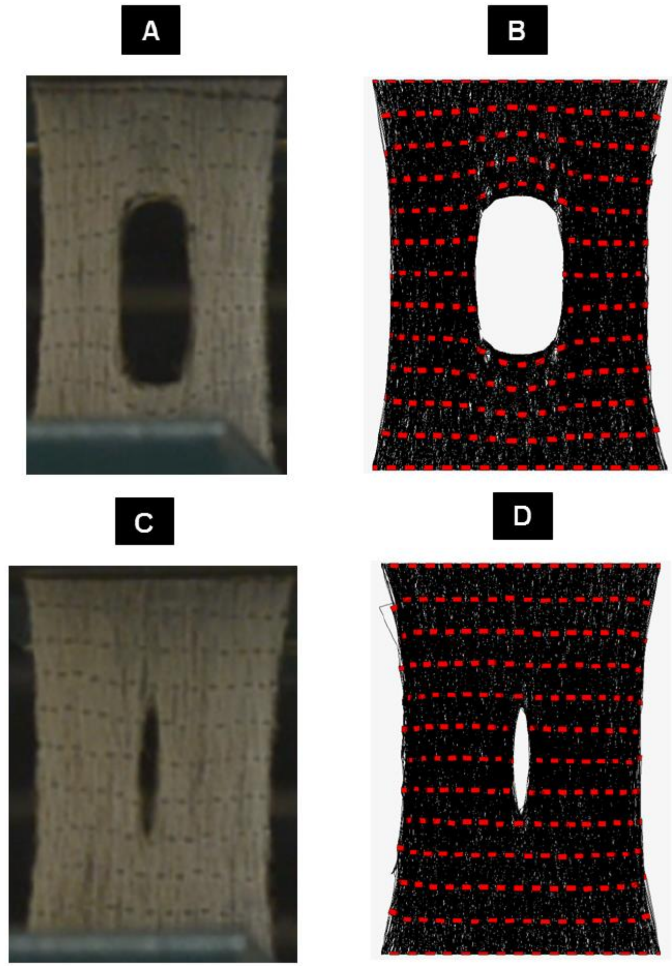
- Relaxation tests



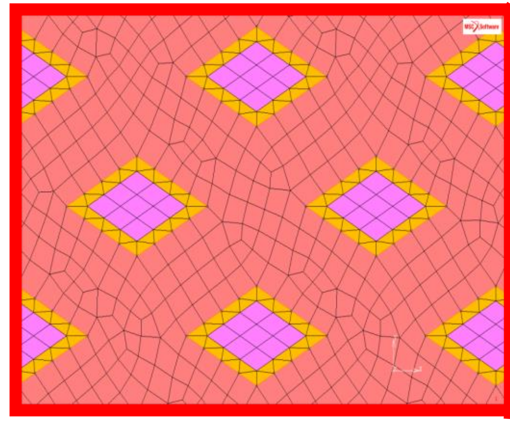
- Individual fibers extracted from nonwovens and tested under a tensile tester with a ±5N load cell
- Fibers exhibit highly time-dependent material behaviour.

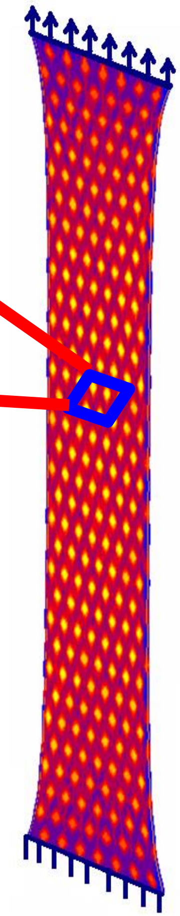
Tensile Performance - Deformation and Damage Mechanisms

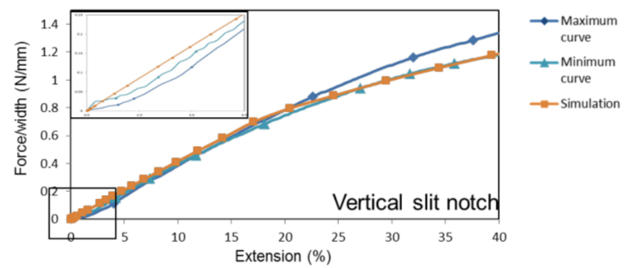
- Discontinuous models

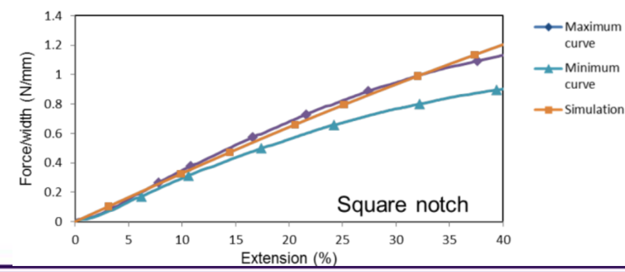


- Continuous models

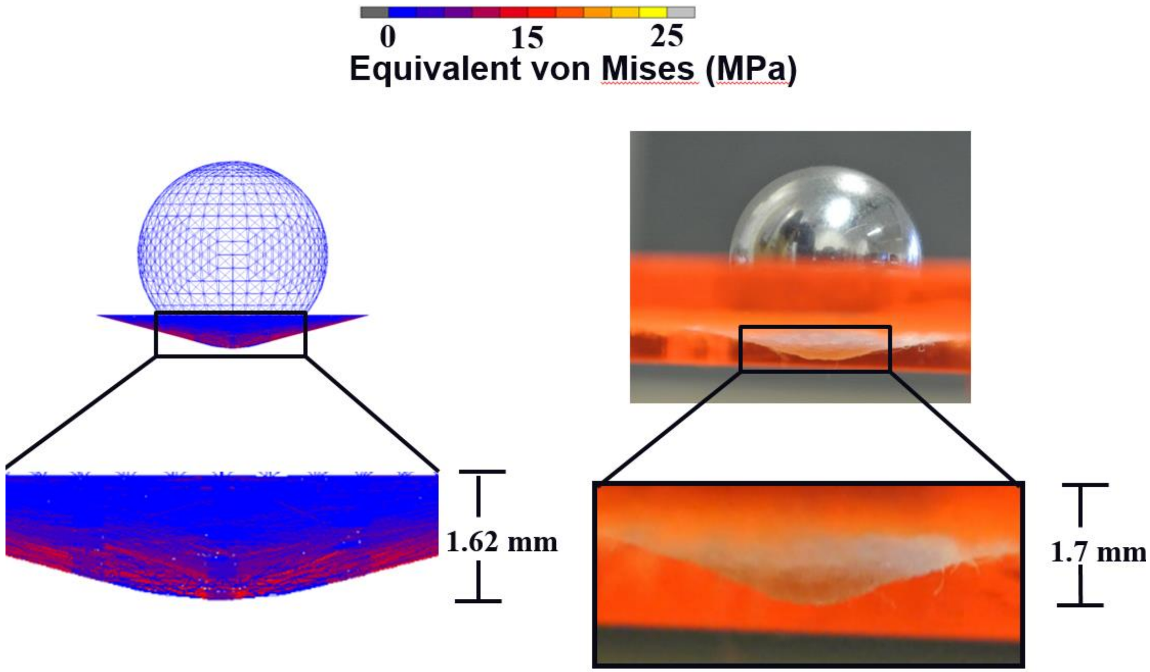


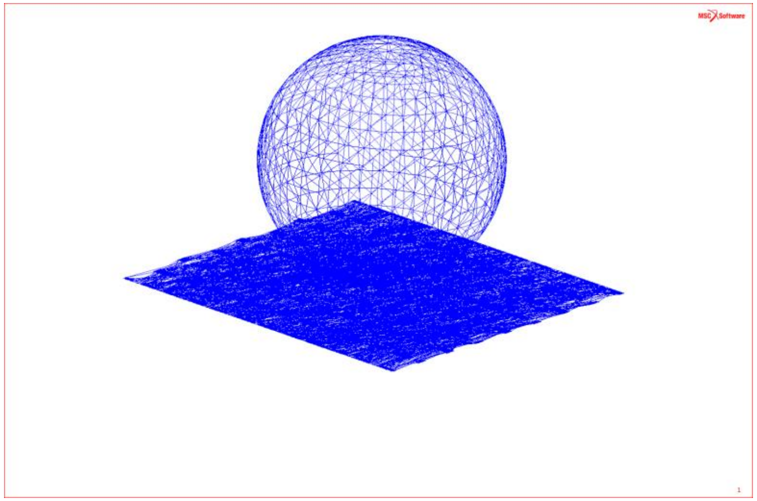


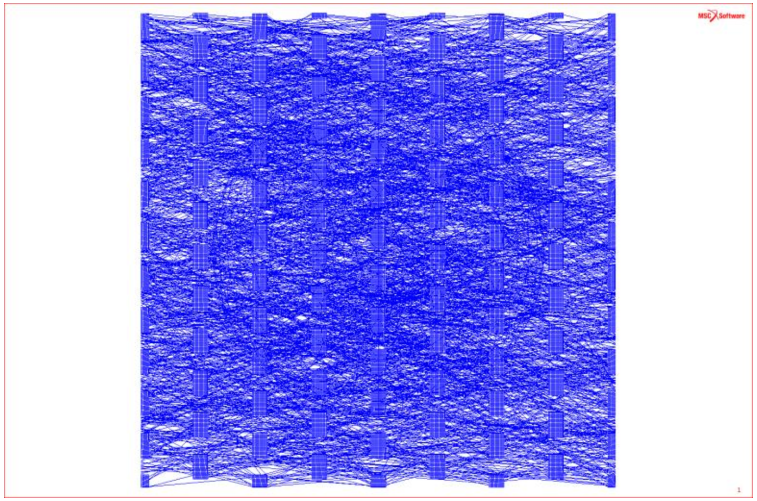




Out-of-plane Loading - a Falling Ball



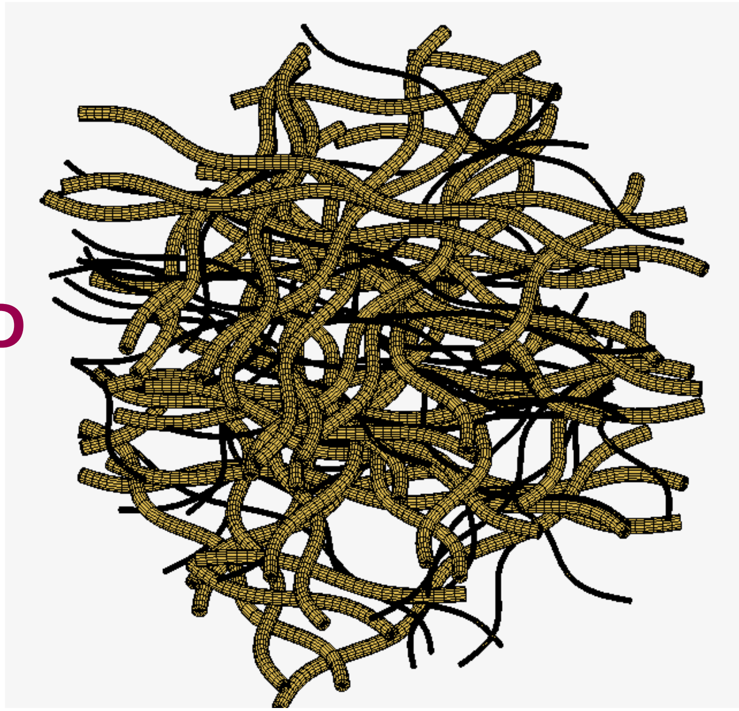


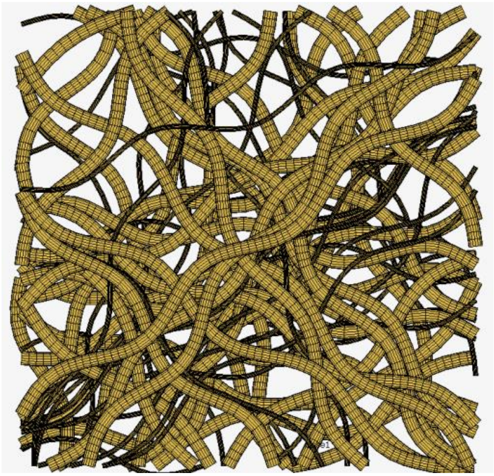


New Parametric 3D Computational Model

50 gsm through air bonded nonwoven model

TD





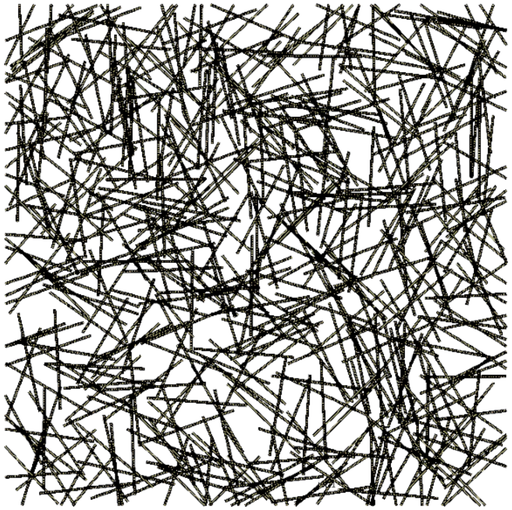
Top view

- Modelling of nonwoven network using fiber deposition and FE methods.
- Multiple fiber types can be generated in the same model (For instance, main and binder fibers)

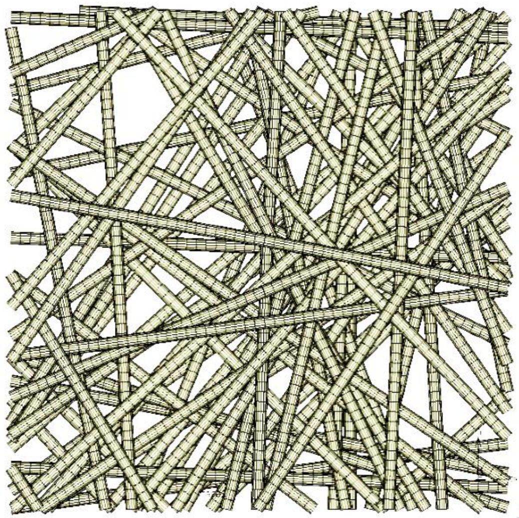
MSC Marc MSC Software Simulating Reality, Delivering Certainty

python

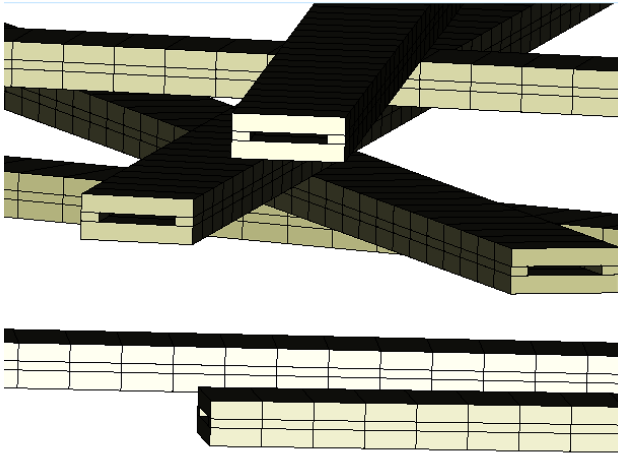
New Parametric 3D Computational Model-Capabilities



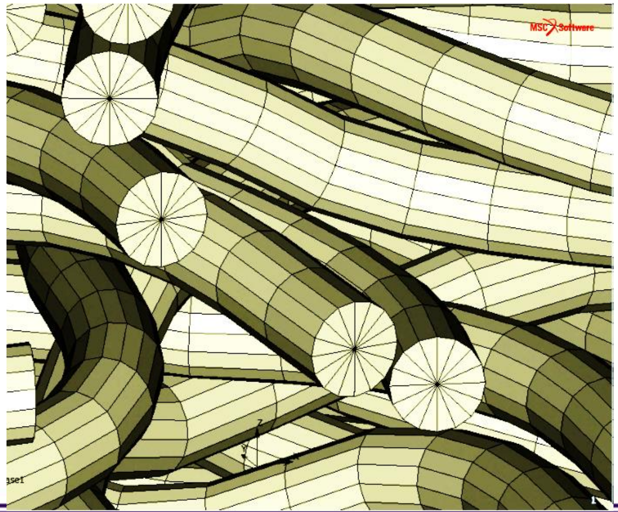
Short Fibers



Continuous Fibers

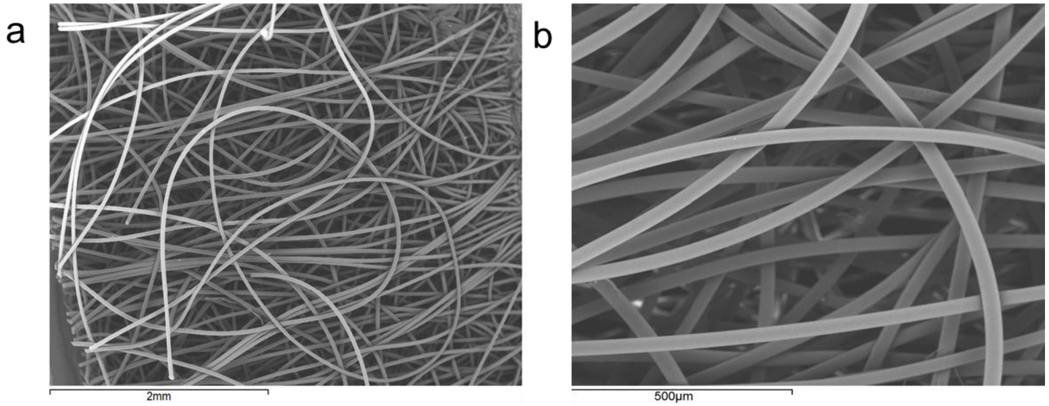


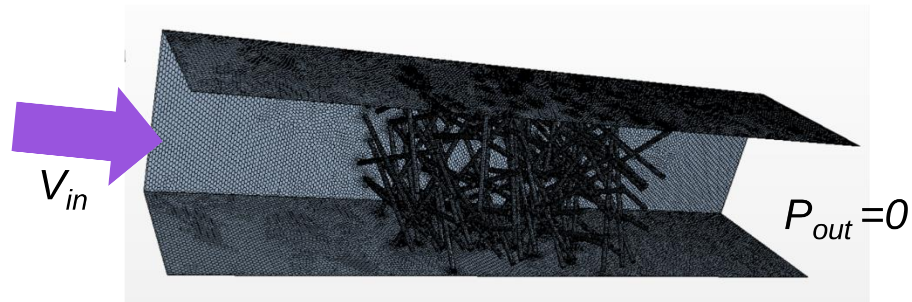
Various fiber cross-sections: rectangular hollow, round, trilobal, 4DG, *etc*



Flow Simulations – a Case Study

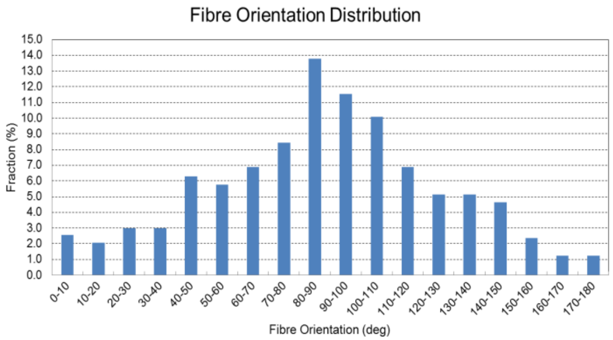
- A through-air bonded nonwoven (90gsm, PP/PE 60:40)



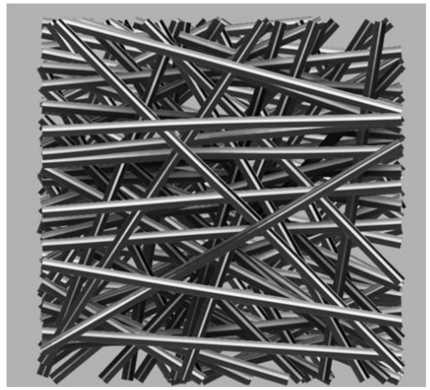


*SEM images

- ODF



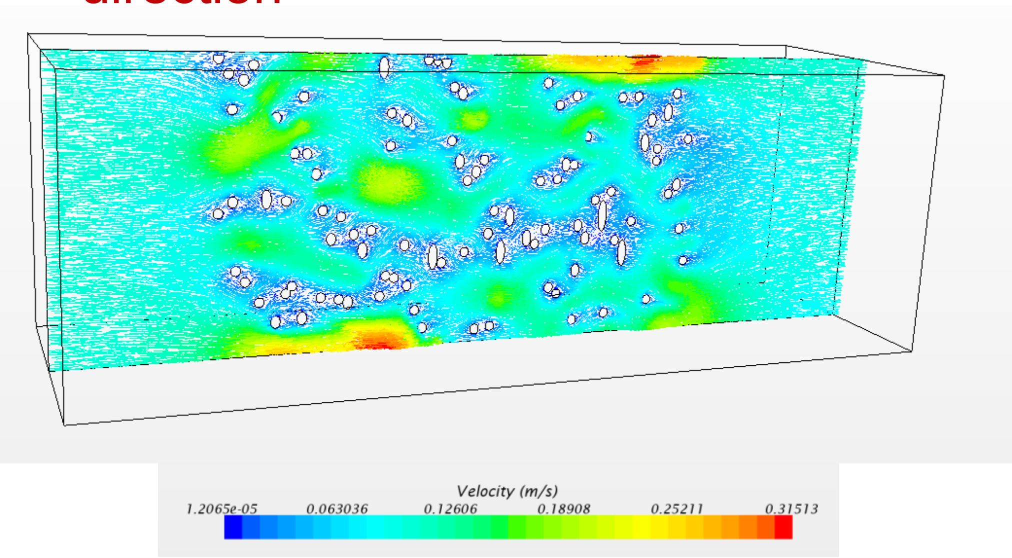
- Nonwoven Model



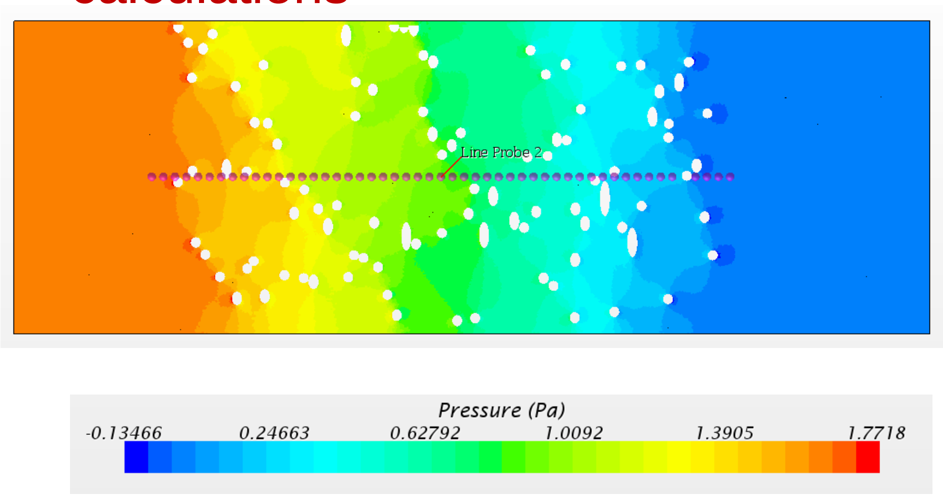
- Star CCM+
- Laminar air flow
- No heat transfer, only continuity equations
- 8-10 millions cells (Polyhedral, tetrahedral elements)
- Inlet velocities: 0.1, 0.25, 0.5, 1.0 m/s
- No-slip on fibers

Flow Simulations – a Case Study

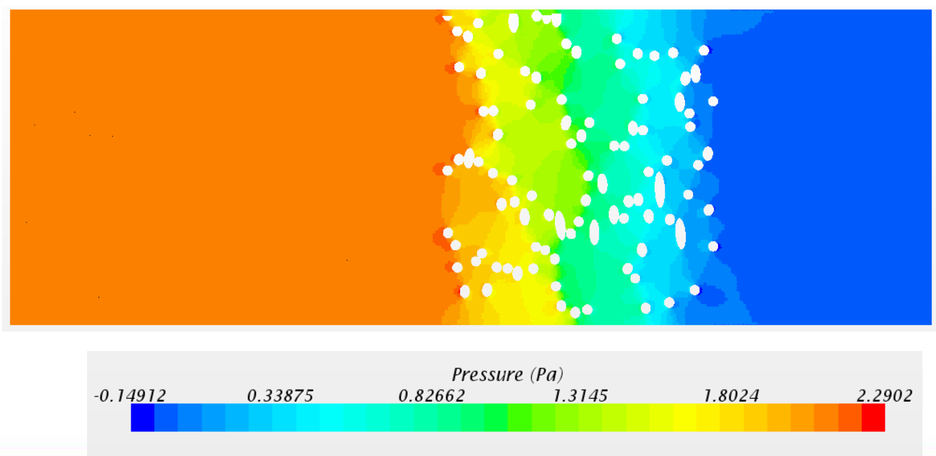
- A section in the middle along the flow direction



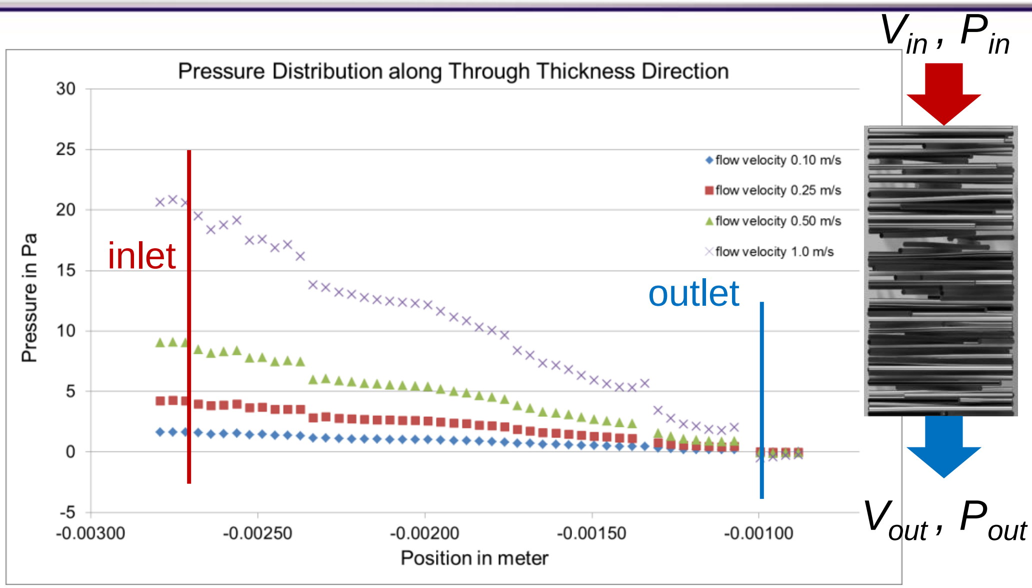
- A line of probes marked for calculations



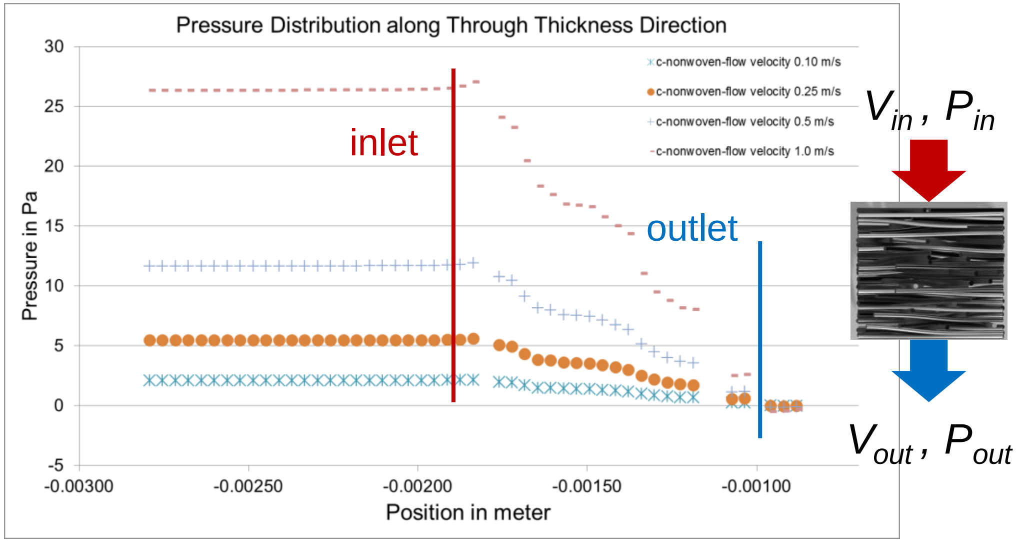
- Nonwoven network was compressed 50% in FE software and flow simulations were repeated.



Flow Simulations – Pressure Drop



Zero Compression



50% Compression

Pressure Drop without/with Compression

	Pressure Drop (Pa)	
Velocity (m/s)	No Compression	%50 Compression
0.1	1.64	2.12
0.25	4.23	5.50
0.5	9.09	11.78
1	20.86	26.69

Air Permeability (Darcy Law)

	Permeability	
Velocity (m/s)	No Compression	%50 Compression
0.1	2.17728E-09	8.40586E-10
0.25	2.11155E-09	8.11804E-10
0.5	1.96376E-09	7.57353E-10
1	1.71123E-09	6.68731E-10

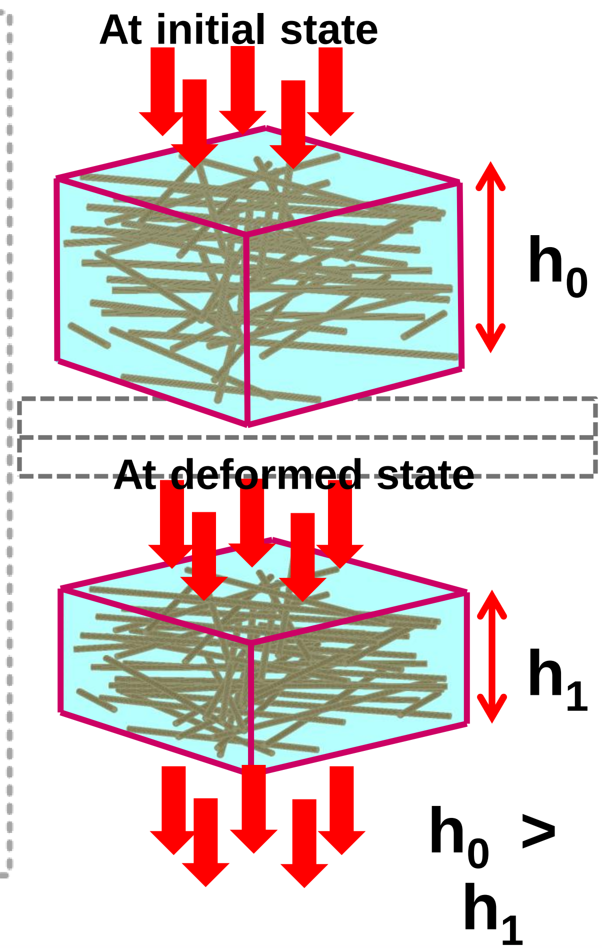
Summary and Conclusions

- A material characterization process in micro and macro scales is necessary to obtain material and geometric properties of nonwovens.
- Tensile performance of nonwovens strongly depends on material properties of fibers and their orientation distributions (ODF's).
- Two dimensional continuous and discontinuous FE models, in which ODF was incorporated into, were presented. Their uses in simulating deformation, damage and out-of-plane loading were shown with sample cases.
- A new parametric 3D finite-element model with fiber curvature and fiber-to fiber interactions was introduced.
- Based on the new parametric model, flow simulations on an uncompressed and 50% compressed nonwoven were conducted. Pressure drop and permeability calculated.
- By compressing nonwovens, a significant increase in pressure drop and a decrease in air permeability were observed.

Future Work – Compression of Nonwoven due to Fluid Flow

Coupling of Structural Analysis with Computational Fluid Dynamics

Method	Domain	Investigated Properties
Computational Fluid Dynamics(CFD)	Fluid Flow in Pores around Fibers	Flow Velocity Pressure Field Permeability Filtration Performance
+		
Structural Analysis	Nonwoven Geometry with all Fiber Interactions	Displacement Field Strain Field Stress Field



Acknowledgement

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- Reicofil GmbH & Co, Germany