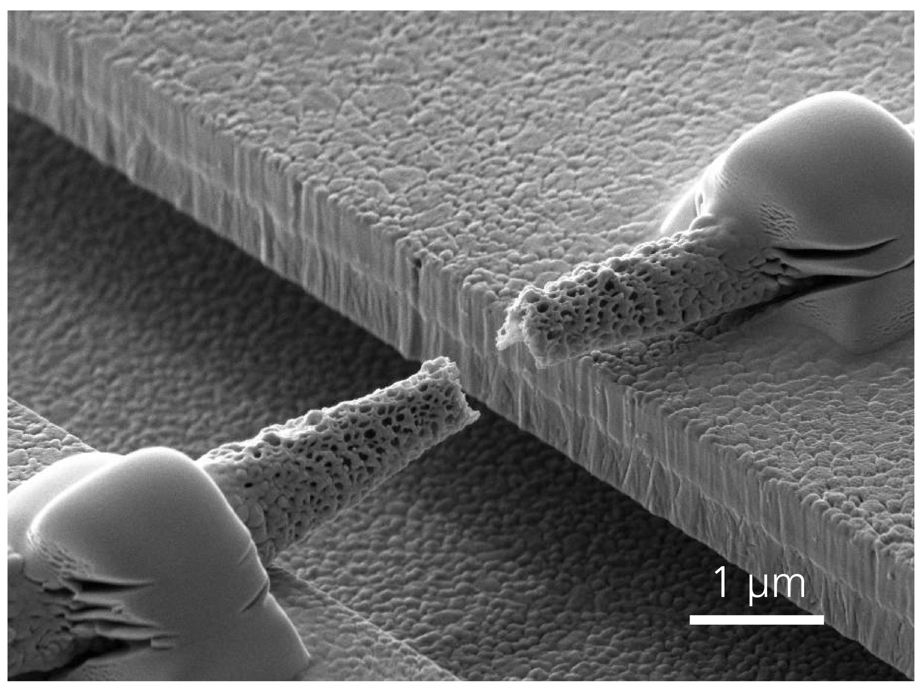
Simulating the Mechanical Properties of Electro-spun Non-wovens

Dominik Jaeger, Raimund Jaeger, Björn Henrichs, Michael Moseler
Fraunhofer Institute for Mechanics of Materials IWM, Wöhlerstraße 11, D-79108 Freiburg

raimund.jaeger@iwm.fraunhofer.de

Motivation and Aim

Electro-spun non-wovens are used as porous scaffolds in Tissue Engineering. Apart from exhibiting a benign cell-biological response, porous scaffolds should have appropriate mechanical properties in order to provide a sufficient stability under mechanical loading and to transmit suitable mechanical stimuli to the developing tissue. Numerical simulations can be used as a tool to study how non-wovens react to external forces and fluid flows which result in local stresses for cells embedded in the non-woven. As a first step, a mechanical model for a non-woven is developed which describes the response of non-wovens to external strains as a function of their degree of orientation.



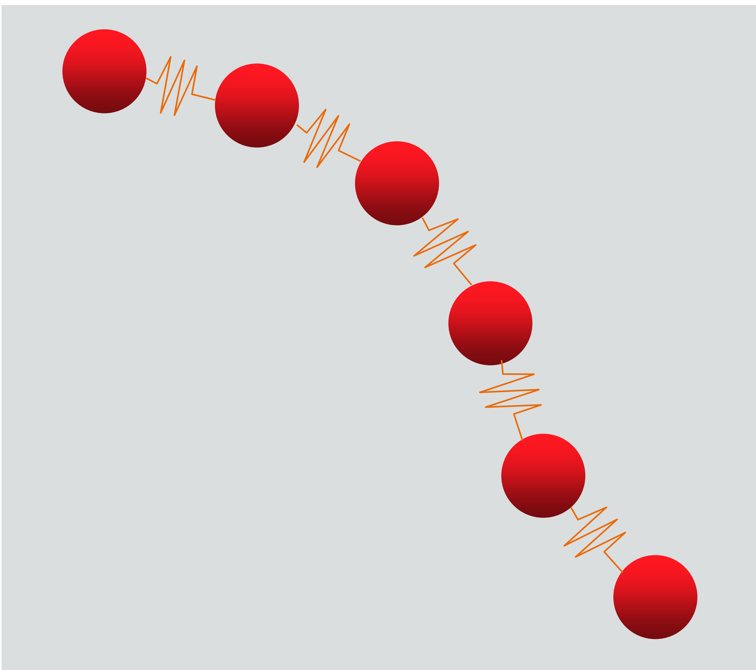
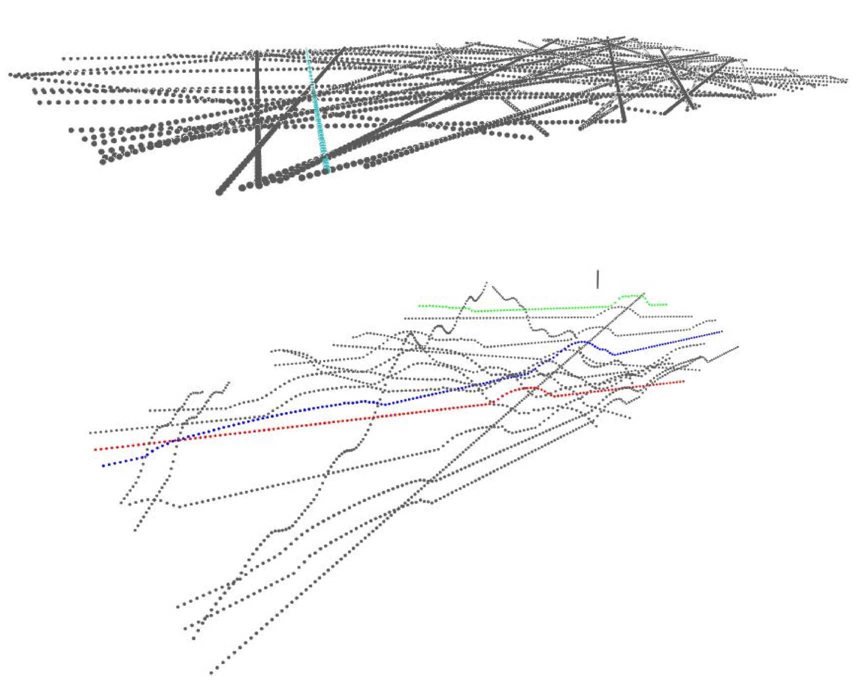


Fig. 1: Micro-mechanical testing of an electro-spun PLLA fiber [1]
Fig. 2: Bead-spring-model of a fiber

Approach

A bead-spring-model similar to models used in molecular mechanics simulations is used to represent electro-spun fibers. The spring constant describes the modulus and the »bond angle potential« determines the flexural stiffness of the fibers. The fiber diameter and adhesion of fibers is described with the interaction potentials acting between different beads. A »structure generator« is used to prepare models of non-wovens with different distribution functions for the orientation of the fibers. Simulations are carried out using approximately 100 000 beads.



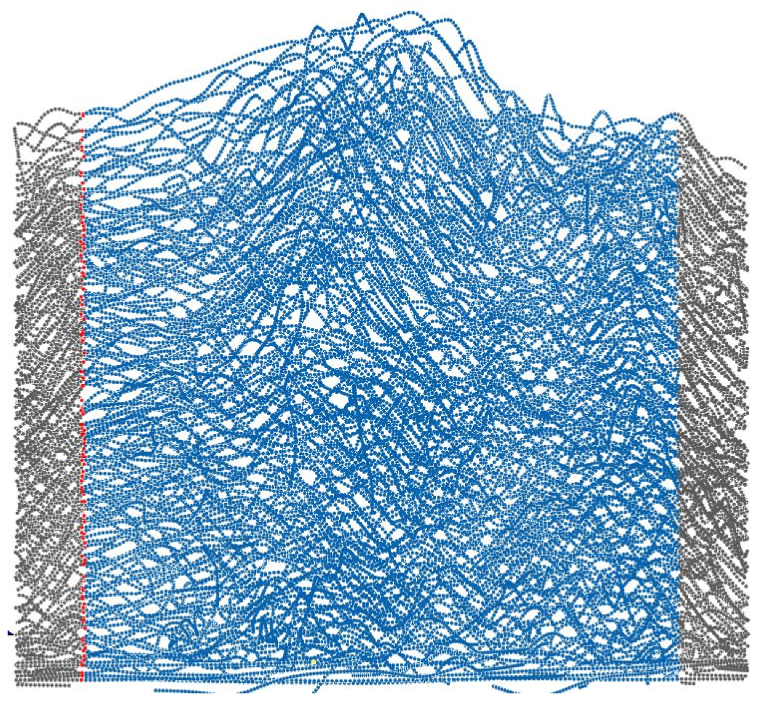
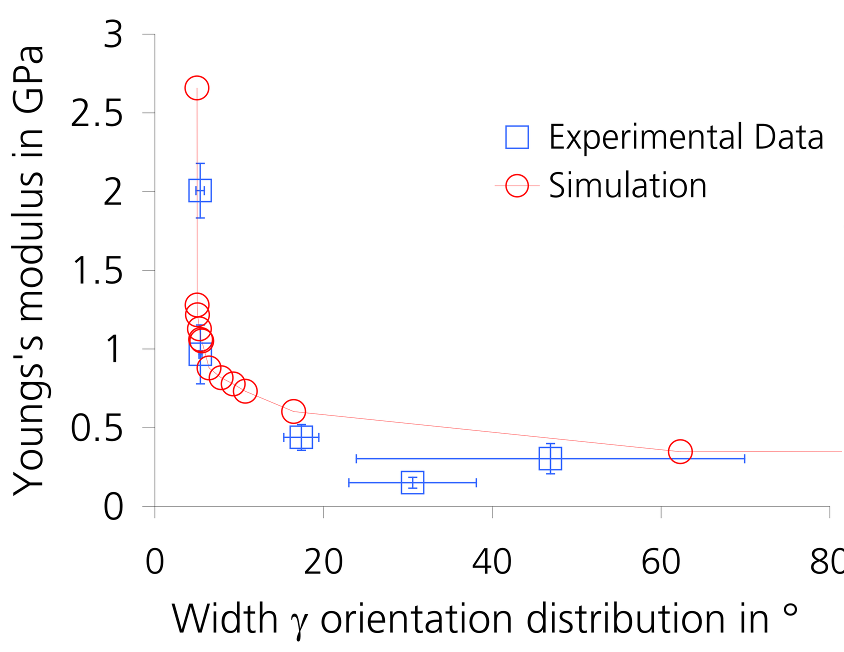


Fig. 3: Structure generator for oriented non-wovens
Fig. 4: Mechanical model of a non-woven

Results

Tensile tests were simulated for non-wovens with different orientation distributions. The degree of orientation is characterized by the width γ of the distribution function (typically a Cauchy function). The results of the simulations are compared with experimental data on the modulus $E(\gamma)$ of electro-spun poly(L-lactic acid) non-wovens. The simulations can reproduce the shape of the experimental $E(\gamma)$-curves; a better agreement would require a more in-detail control of the spinning process and characterization of the non-wovens (e.g. the extent of fiber adhesion). The effect of fiber adhesion can be studied with the model. In a non-woven with adhering fibers, fibers which form a large angle to the loading direction can also »participate« in a tensile test: the modulus for high values of γ increases.



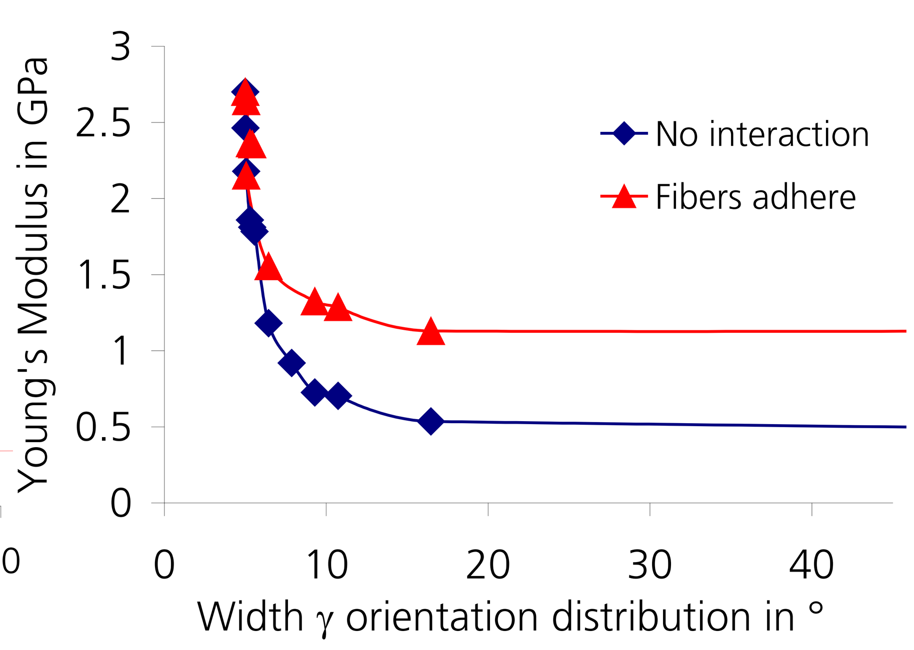


Fig. 5: Experimental and computational results for $E(\gamma)$
Fig. 6: $E(\gamma)$ for non-interacting and adhering fibers

Discussion

The model describes the mechanical interaction of electro-spun non-wovens with their »environment«. The model can be used to study e.g. the interaction of a fluid-flow with the structure of the non-woven (fluid-structure-coupling) or the mechanical stimuli cells experience if external forces are applied to the non-woven. The latter requires, however, a mechanical model for the cell and the cell-adhesion to the fibers.
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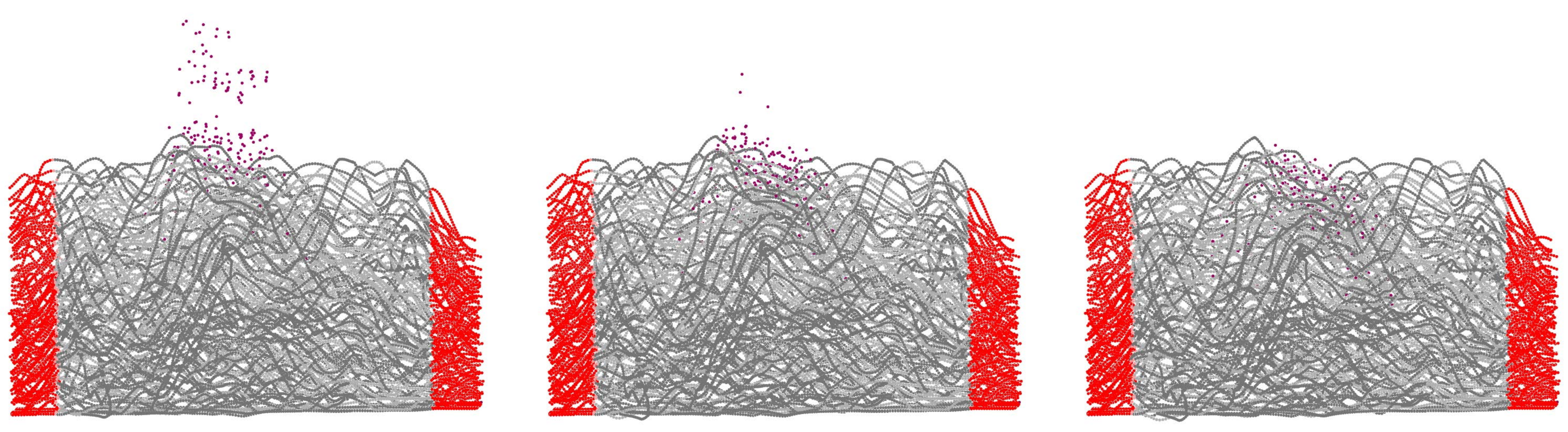

Fig. 7: Cell-seeding

References

[1] Jaeger D, Schischka J, Bagdahn J, Jaeger R. Tensile testing of individual ultrathin electrospun poly(L-lactic acid) fibers. Journal of Applied Polymer Science 2009;114(6):3774-3779.

[2] Jaeger D. Mechanische Charakterisierung und Simulation von elektrostatisch gesponnenen Polymervliesen. Thesis, Freiburg, Albert-Ludwigs-Universität; 2007.