techtextil symposium

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Simulation Based Optimization of Layered Non-wovens as Acoustic Trims

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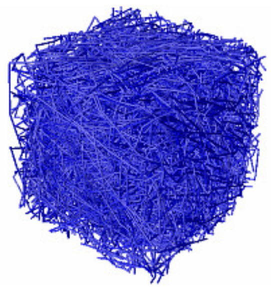


Frankfurt/Main – June 14 2007

Overview

Background and motivation

Virtual acoustic material design in a nutshell

Non-wovens as absorbers – effective material models

Layered structures

Compression simulation

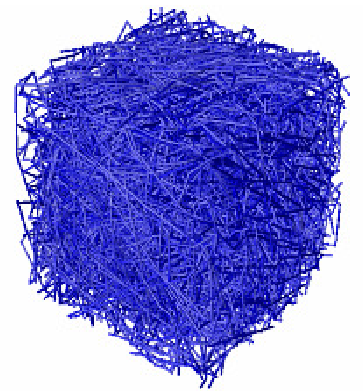
Acoustic properties of compressed non-wovens

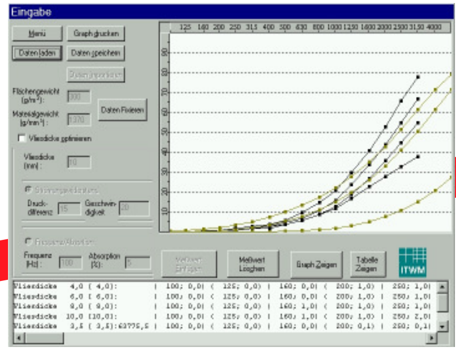
Summary and outlook

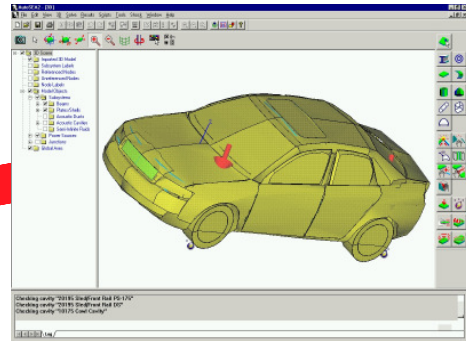
Physical and mathematical formulation of multiscale problems

Material: Parts: System:

Nano- and micrometers Centimeter Meter







Virtual material design versus an empirical process

Empirical process

Material production and testing

(acoustic measurement in impedance tube or alpha cabin)

Disadvantages:

-Prototyping is time consuming and expensive!

-Measurements are demanding

-Instead of an optimisation only small improvements are possible

Virtual material design

•The microstructure (e.g. Non-woven) is generated entirely on the computer

•Determination of effective material parameters by numerical simulation

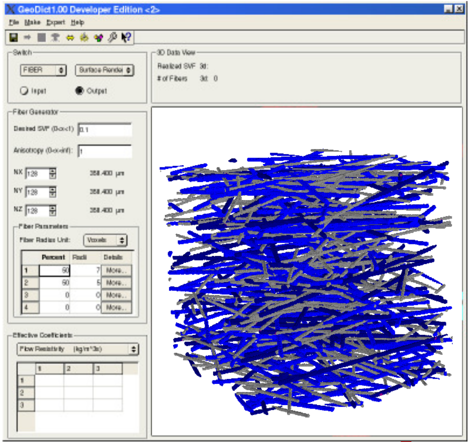
Advantages:

-No prototyping required

-Extensive parameter studies can be done with moderate efforts

-Potential for computer aided optimisation

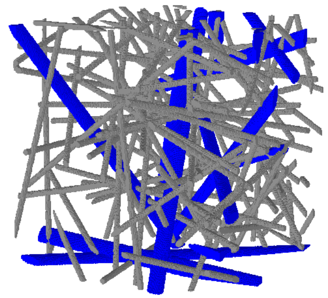
ITWM-Softwaretool GeoDict (***Geo**metry generation and pre**dict**ion*)

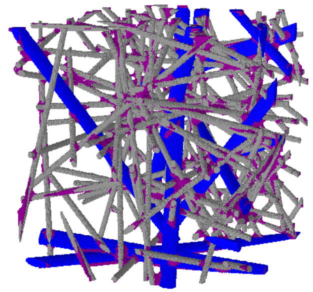


Interactive microstructure generator

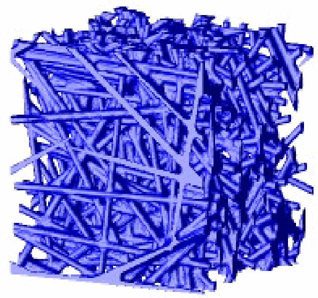
www.geodict.com

80% PET fibers, 7dtex
20% PP fibers, 2.2 dtex
Area weight: 200 g/m²





50% PET fibers, 60dtex, elliptic cross section
50% PP fibers, 8 dtex, circular cross section
95% porosity, with and without binder



Carbon paper, used as gas diffusion layer in a fuel cell
70% porosity

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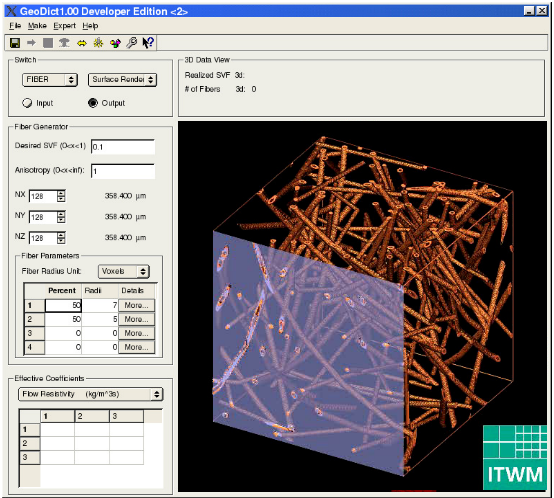
Parameter prediction: GeoDict modules



www.geodict.com

FlowDict: Permeability/Flow resistivity and relative permeability

SatuDict: Capillary pressure-saturation curves

DiffuDict: Gas diffusivity

ThermoDict: Heat conductivity

ElastoDict: Elasticity tensor

FilterDict: Filtration efficiency

AcoustoDict: Acoustic properties

Effective acoustic models

<table>
<tr><th>Parameter</th><th colspan="3">Model and type of absorber</th></tr>
<tr><td>Flow resistivity
σ [kg/m³s]</td><td>Delany/Bazley, Mechel
Highly porous absorbers</td><td rowspan="5">Allard/Johnson
Pride/Lafarge

Porous with rigid frame</td><td rowspan="9">Biot

Porous with (visco-)elastic frame</td></tr>
<tr><td>Porosity, Φ</td><td></td></tr>
<tr><td>Tortuosity, τ</td><td></td></tr>
<tr><td>Viscous charact. length Λ [µm]</td><td></td></tr>
<tr><td>Thermal charact. length, Λ‘ [µ]</td><td></td></tr>
<tr><td>Density, ρ [kg/m³]</td><td></td><td></td></tr>
<tr><td>Young‘s modulus
E [GPa]</td><td></td><td></td></tr>
<tr><td>Poisson‘s ratio, ν</td><td></td><td></td></tr>
<tr><td>Damping loss, η</td><td></td><td></td></tr>
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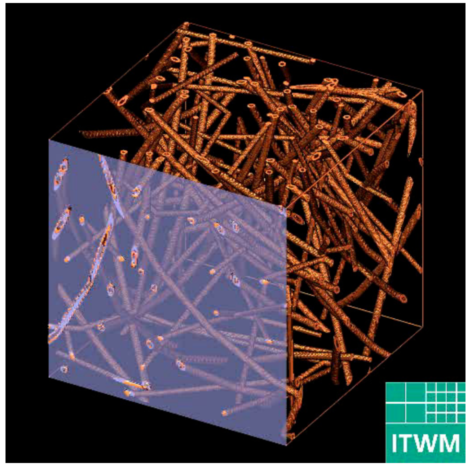
Numerical determination of the Allard-Johnson parameters



Porosity: Given as input parameter for non-woven generation

Flow resistivity: From the flow field as the solution of the Stokes equation

Tortuosity: Evaluation of the path length of the streamlines

$$\tau = \frac{< |\vec{v}| >}{< \vec{v}_x >}$$

Thermal characteristic length:

$$\Lambda' = \frac{2 \cdot \text{pore volume}}{\text{fiber surface}}$$

Viscous characteristic length:

$$\Lambda \approx 0.5 \cdot \Lambda'$$

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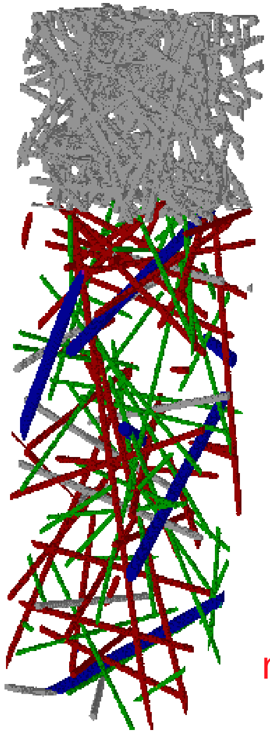
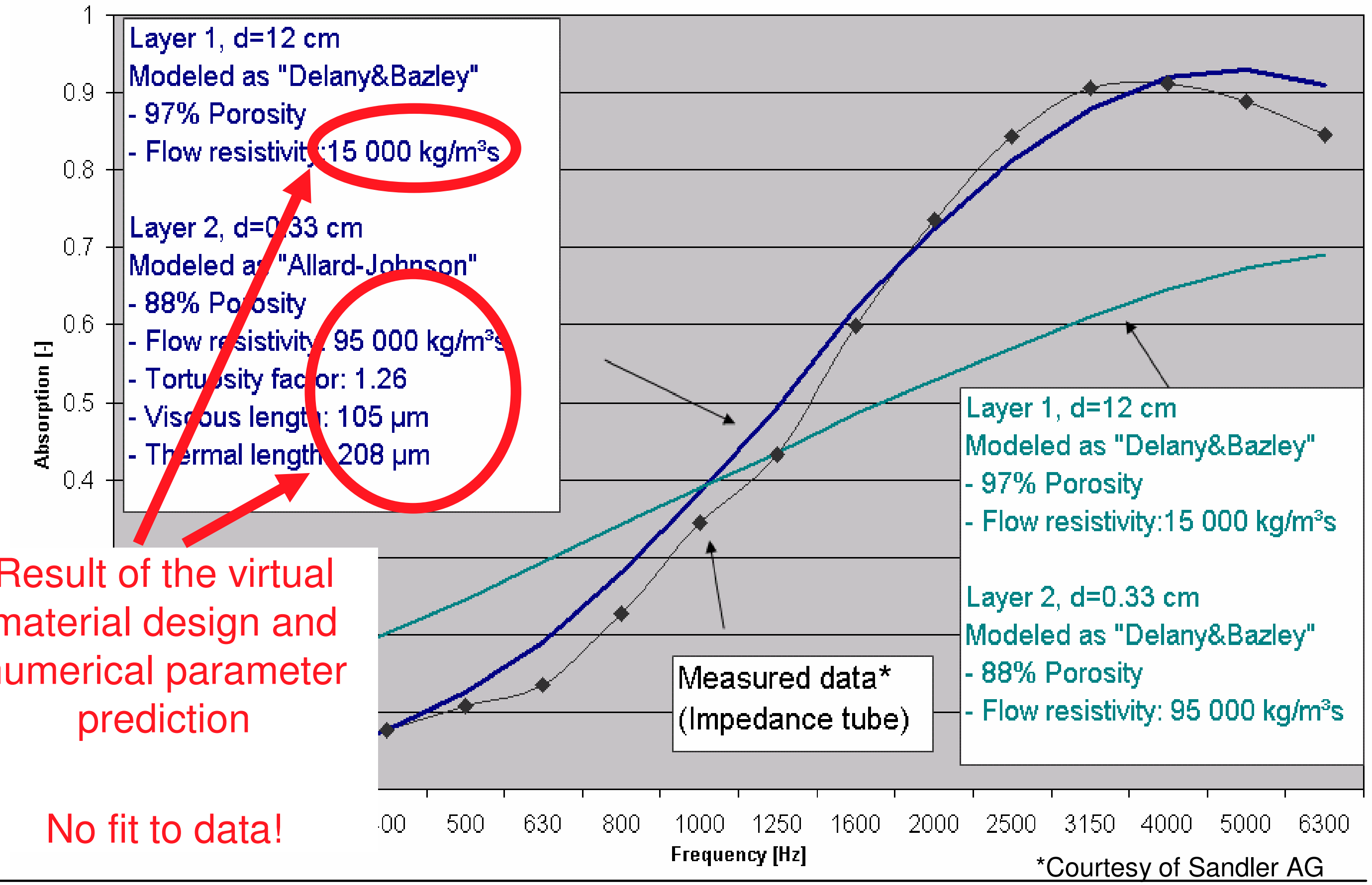
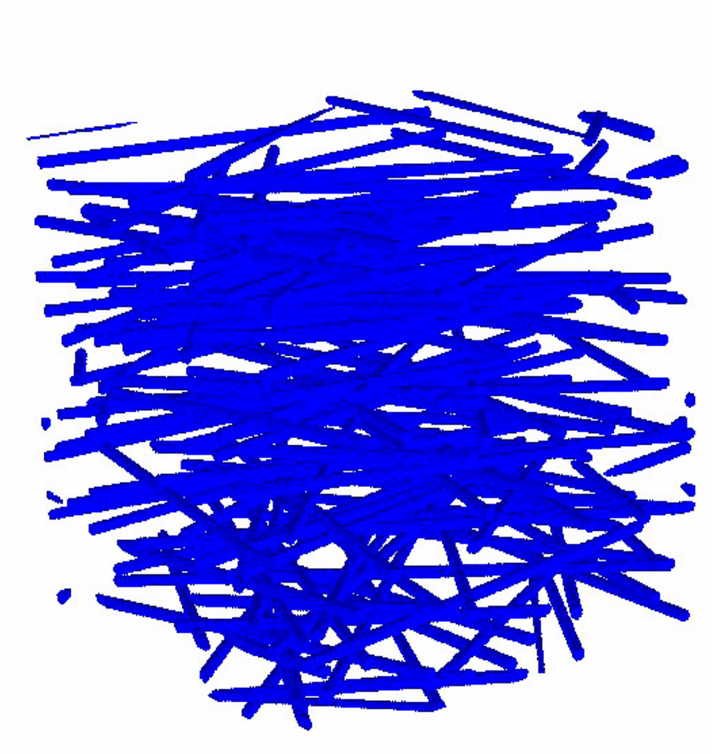
How good is our prediction?





Compression study

Compression of the non-woven can be used to modify the material properties in a controlled way



Example: non-woven

PET fibers, 12.15 dtex

Initial thickness 13.13 mm

Area weight 900 g/m²

How does the microstructure change when it is compressed?

How do the material properties change under compression?

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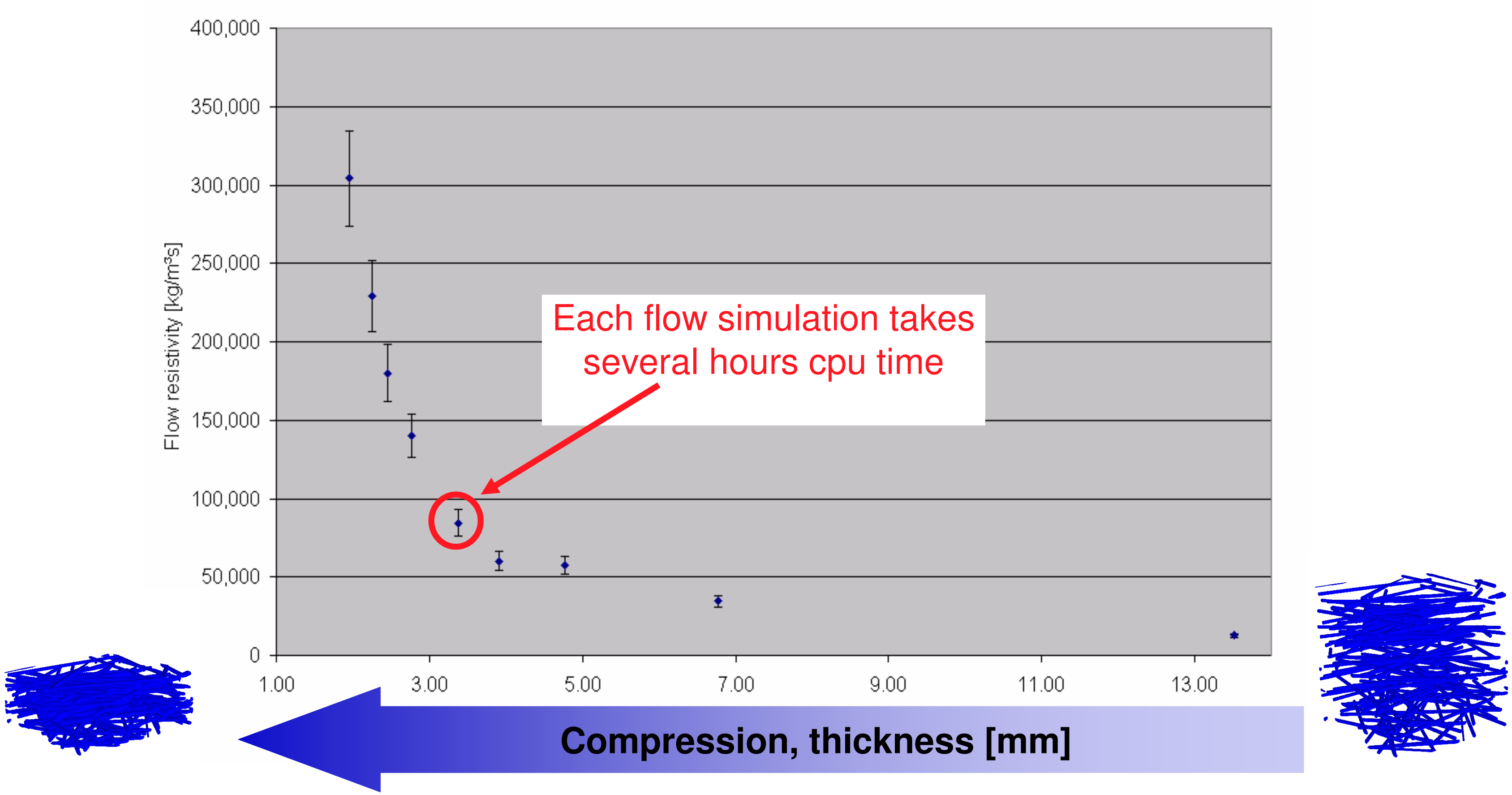
Allard-Johnson parameters versus thickness und compression



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Parameterisation

Allard-Johnson parameters as a function of the porosity Φ

Aw: Area weight

ρ: Material density

d: Thickness

$$\Phi = 1 - \frac{A_w}{\rho \cdot d}$$

Flow resistivity

$$\sigma(\Phi) = \alpha \cdot \Phi^{-\beta}$$

Tortuosity

$$\tau(\Phi) = \gamma \cdot (1-\Phi) + 1$$

Characteristic lengths

$$\Lambda'(\Phi) = \frac{1}{\delta \cdot (1-\Phi)}$$

$$\Lambda(\Phi) = 0.5 \cdot \Lambda'(\Phi)$$

Poroacoustic material parameters, different for each non-woven

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Example: 12.15 dtex PET non-woven under compression

Allard-Johnson parameters versus thickness/porosity

Flow resistivity

$$\sigma(\Phi) = 12{,}834 \cdot \Phi^{-8.3548}\ \mathrm{kg/m^3s}$$

Tortuosity

$$\tau(\Phi) = 0.521 \cdot (1-\Phi) + 1$$

Characteristic lengths

$$\Lambda'(\Phi) = 0.0673^{-1} \cdot (1-\Phi)^{-1}\ \mu\mathrm{m}$$

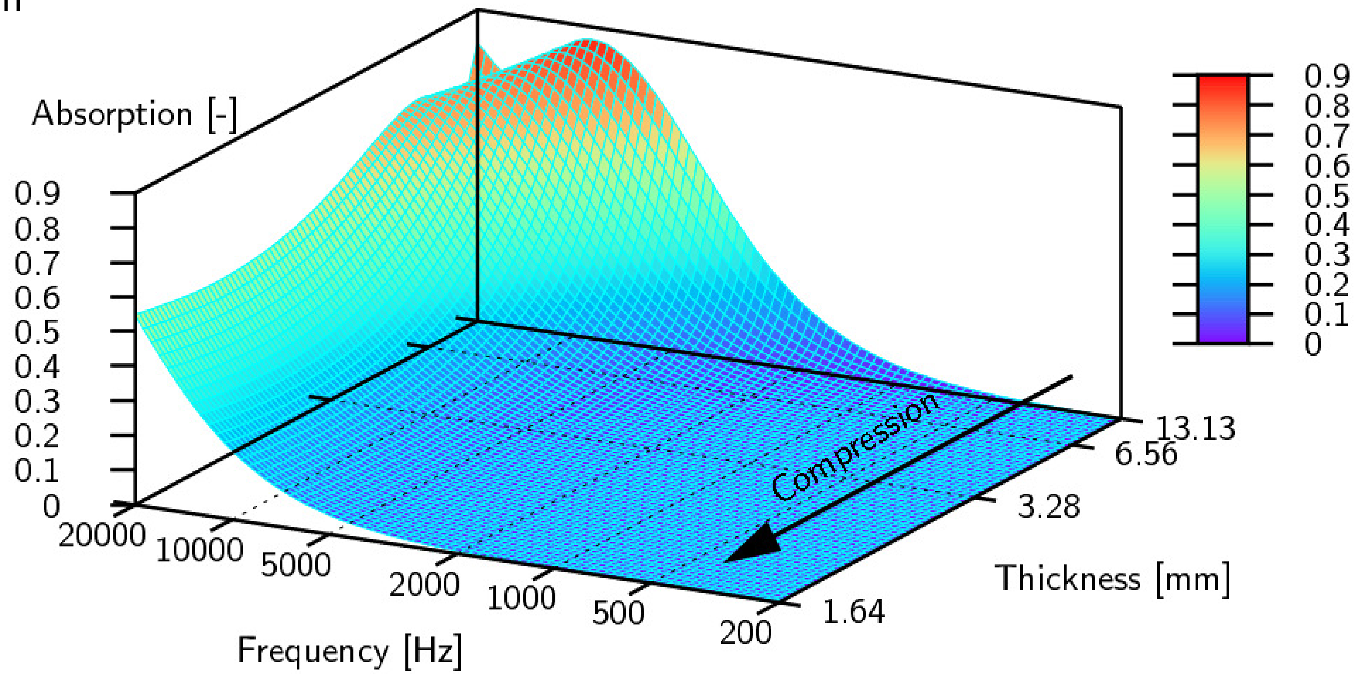
$$\Lambda(\Phi) = 0.5 \cdot \Lambda'(\Phi)\ \mu\mathrm{m}$$

Poroacoustic material parameters:
Complete description of the acoustic properties of the compressed non-woven

Acoustic absorption

12.15 dtex PET

Area weight 900 g/m²



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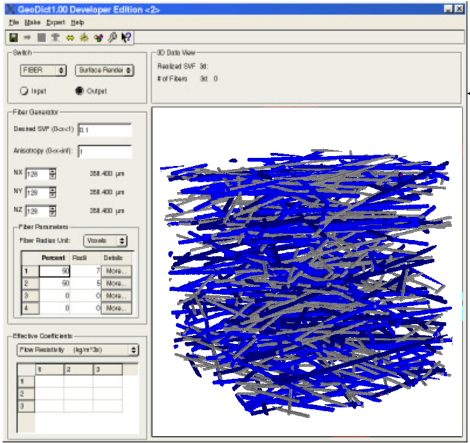
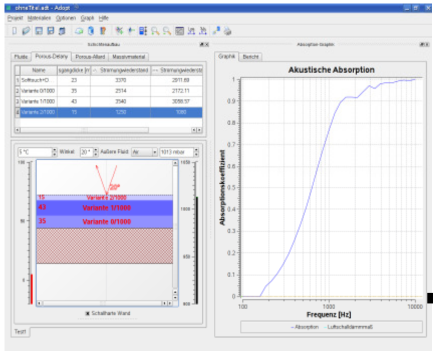
AdOpt: Acoustic database and optimization tool

GeoDict+AcoustoDict



AdOpt



Prediction of acoustic

•Impedance

•Transmission Loss

•Absorption

for **layered** materials

Material database

•Fiber parameters

•Poroacoustic material parameters

Optimal material selection

Export to acoustic simulation software:

•AutoSEA2, Ansys, SysNoise, ...

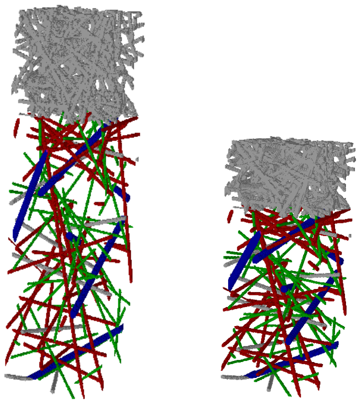
Summary

Without prototyping we predict the acoustic properties of uncompressed and compressed layered non-wovens

Step 1: **GeoDict**

Microstructure generation based on

- Fiber diameters
- Area weight
- Anisotropy
- …



uncompressed compressed

Step 2: **AcoustoDict**

Numerical determination:

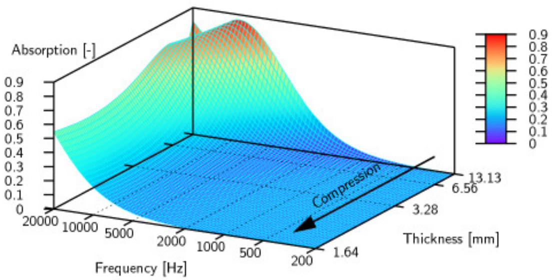
- Flow resistivity
- Tortuosity
- Characteristic lengths

⇒ Poroacoustic material parameters

Step 3: **AdOpt**

Prediction of acoustic absorption, transmission loss, etc. for layered structures

Arbitrary parameter variation possible (number of layers, thickness, compression



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Outlook

Extended validation of the method is on the way

Numerical determination of the viscous characteristic length (instead of $\Lambda \approx 0.5 \cdot \Lambda'$)

Application to other porous absorbers such as wovens or metal foams

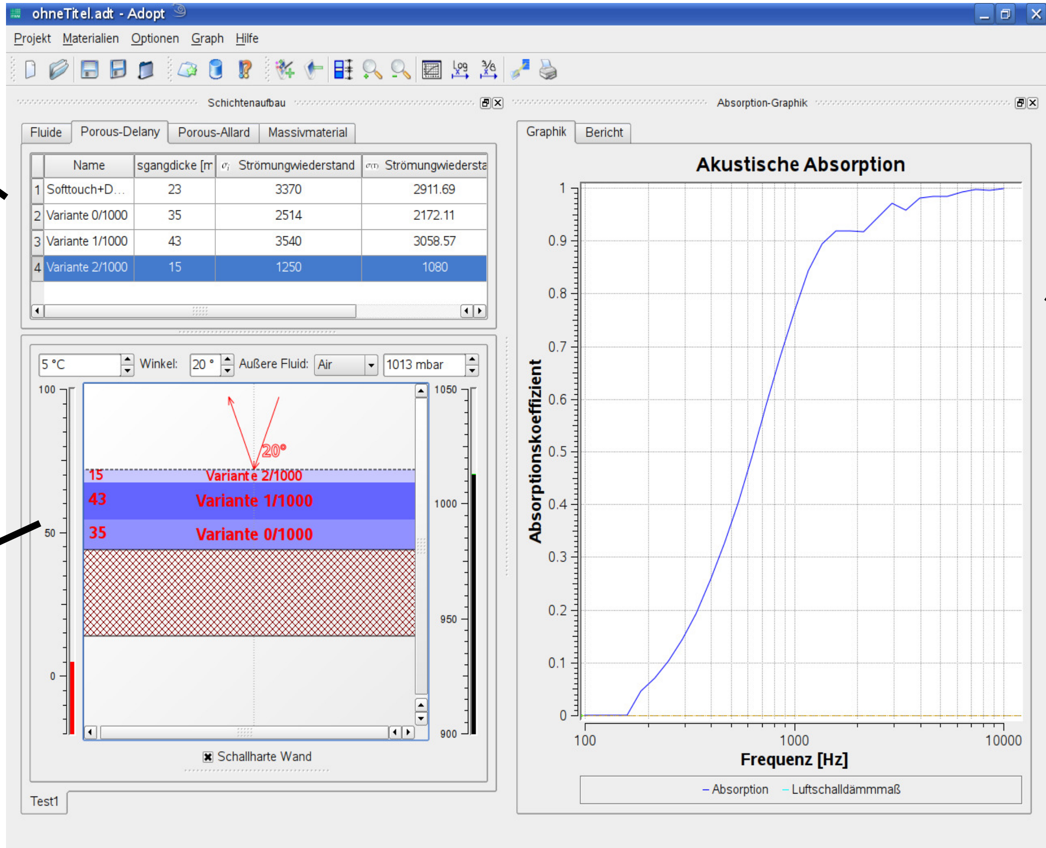
Extension to porous absorbers with (visco-)elastic frame (‚foams‘)
$\Rightarrow$ numerical determination of the Biot parameters

Ongoing software development

AcoustoDict and AdOpt will be available Fall 2007

Material database

Layered trim



Acoustic absorption

AdOpt: Screenshot of the developer version

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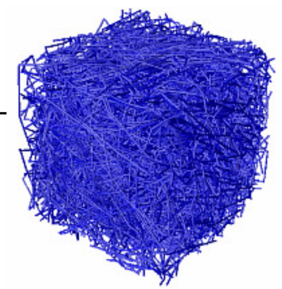

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