Fast solution to determine the elastic behavior of 3D reconstructed biopolymer cellular structures

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Goal

Numerical homogenization vs. experimental results

Investigate the accuracy of the FFT numerical method for predicting the mechanical behavior of complex microstructures, using comparison with experimental data.

Microstructures

Choice of a two-phases (starch+70-90% of voids) biopolymer cellular material most "amenable" to numerical simulations:
- **linear elastic** regime,
- **no imperfect interface** effects,
- starch is **quasi-incompressibile** (Guessasma 2009, Babin et al 2007),
- local behavior depends on only 1 elastic modulus, determined experimentally,
- choice of **several sets of microstructures** with highly-different macroscopic properties, at various density (volume fraction of starch).

Local behavior
Starch
$\sigma_m = 3\kappa\varepsilon_m$, κ=infinity
$\sigma' = 2\mu\,\varepsilon'$, μ=shear modulus
Voids
$\sigma = 0$
Macroscopic behavior
Roughly isotropic:
Young modulus E
Poisson ratio ν

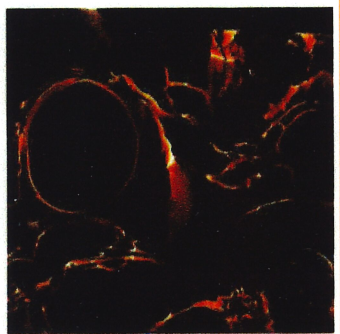
FFT numerical method

Fixed-point algorithm based on the **Lippmann-Schwinger** equations (Moulinec and Suquet, 1994). Directly applied to **microstructure images** (no meshing). Local behavior and fields admissibility taken into account in the real space and Fourier domain respectively.

$$\varepsilon_{ij}(\mathbf{x}) = \varepsilon^0_{ij} + \int d^2y\, G^0_{ij,kl}(\mathbf{x}-\mathbf{y})\,\tau_{kl}(\mathbf{y})$$

$$\tau_{ij}(\mathbf{x}) \equiv \sigma_{ij}(\mathbf{x}) - L^{(0)}_{ij,kl}\varepsilon_{kl}(\mathbf{x})$$

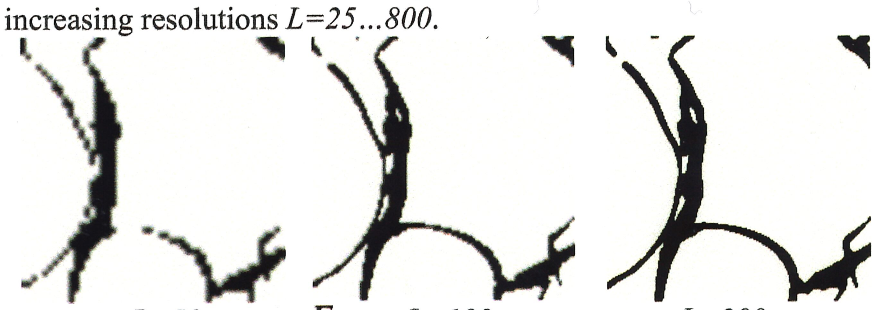
Use of the improved "Augmented Lagrangian method" (Michel et al, 2001) to treat **infinitely-contrasted media. Periodic boundary conditions**, better suited to numerical homogenization in terms of R.V.E. (Kanit et al, 2003).

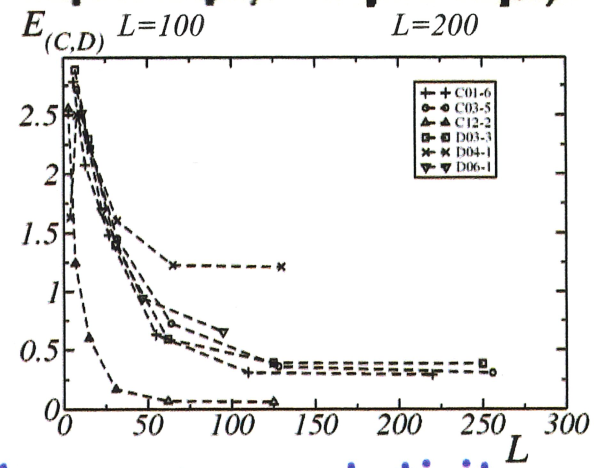


Strongly localized mean strain field, induced by foam-type microstructure

Effect of image resolution

Effect of resolution on the macroscopic elastic behaviour as computed with the FFT method. Same samples discretized over L^3 voxels with increasing resolutions L=25…800.



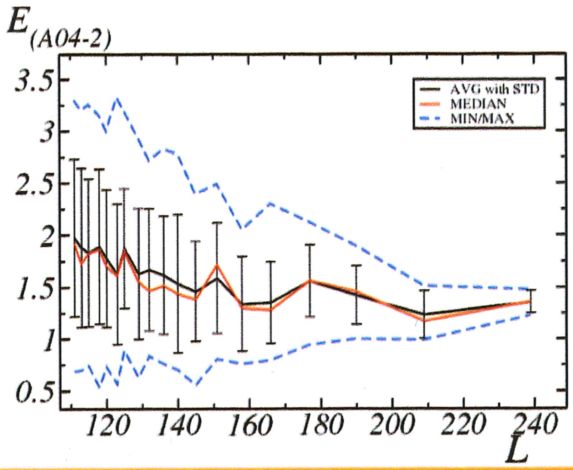


Young modulus vs. resolution (several microstructure samples)

Microstructure representativity

Study of size effect: elastic properties of random subvolumes of each sample at various sizes L^3.

Subvolume 1 Subvolume 2 Subvolume 3



Young modulus vs. subvolume size (mean, standard deviation, median, min/max).

Macroscopic behavior and conclusion

Differing elastic properties of sets A and B, due to distinct microstructures, recoverd by FFT numerical estimates.

For linear elasticity, numerical estimates globally more robust and reliable ; a few aberrant experimental points taken out.