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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-incompressible (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

$$\sigma_m = 3\kappa\epsilon_m, \kappa = \text{infinity}$$

$$\sigma = 2\mu\epsilon, \mu = \text{shear modulus}$$

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.

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

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

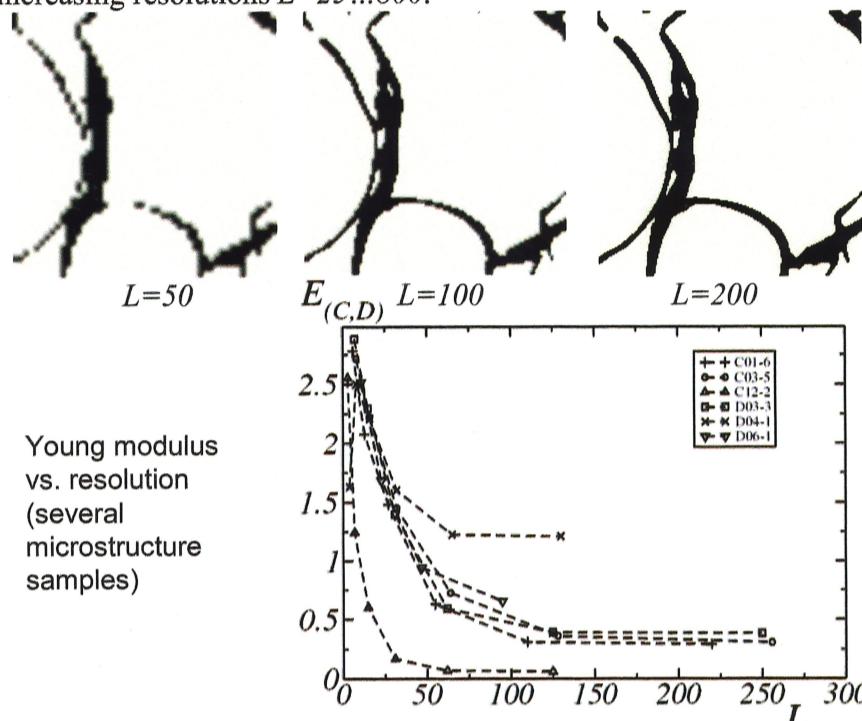
Use of the improved "Augmented Lagrangian method" (Michel et al, 2001) to treat infinitely-contrasted media. Periodic boundary conditions, better suited to numerical homogenization in terms of R.V.E. (Kanit et al, 2003).



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

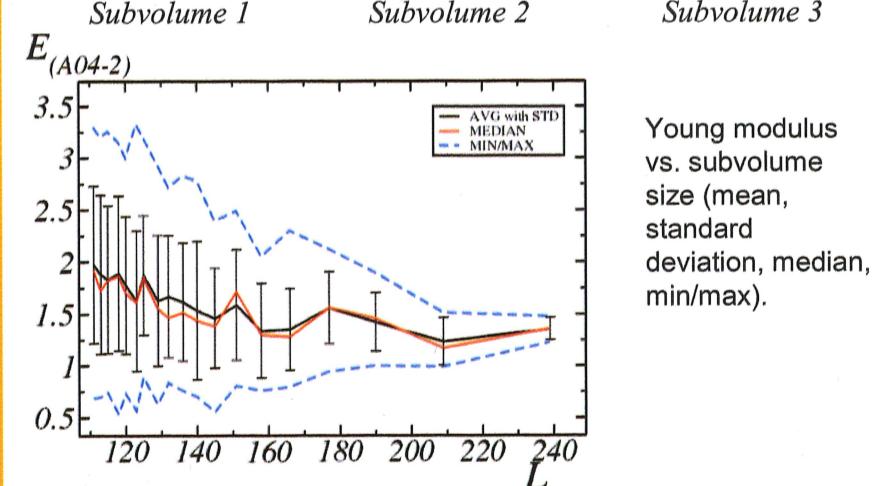
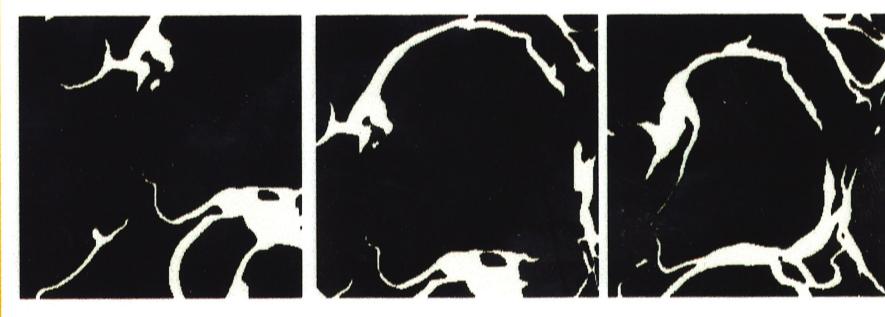
Effect of image resolution

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



Microstructure representativity

Study of size effect: elastic properties of random subvolumes of each sample at various sizes L^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, recovered by FFT numerical estimates.

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

