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Comparison of Homogenization Schemes to Periodic and Random Simulations

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Assessment of the efficiency of the Interaction Direct Derivative homogenization scheme by comparison to Finite Element Simulations.

Average properties

At a macroscopic scale, for a porous medium with one pore family loaded with pressures \( p \), the constitutive law writes \([1]\):

\[
\begin{align*}
\sigma &= C_{\text{hom}} \varepsilon - pB \\
\theta &= f \mu\varepsilon + \beta M
\end{align*}
\]

Where we call \( C_{\text{hom}} \) the homogenized stiffness tensor, \( \beta \) the Biot coefficient, and \( M \) the Biot modulus (inverse of the usual Biot modulus \( N \)).

Simulations using FreeFem++

We create a volume with pores in a 2d plane strain model, and apply:

- external loadings
- pressure in the pores using periodic B.C., to determine the poroelastic constants by measurement of strain and stress averages.

Fig. 1: Elliptical inclusions on an elliptical grid, periodic simulation
Fig. 2: Circular inclusions in a random simulation

Estimates

- Mori-Tanaka: MT (Inclusion embedded in the matrix, averages computed on a domain of the same shape as the inclusion, respecting volume fractions)
- Interaction-Direct-Derivative: IDD (Convenient simplification of the generalized self-consistent scheme, in which the inclusion is embedded in the matrix atmosphere, which is embedded in the average medium \([2]\)).

Aligned elliptical pores, aspect ratio 0.1

We compare random simulations \( \text{simu} \) periodic simulation with isotropic cell \( \text{perEC} \) and elliptic cell \( \text{perEE} \), to the IDD scheme with circular atmosphere and the MT scheme. The IDD is failing because some coefficient reach their bound (0 or 1) far too early. MT does not show this problem. IDD needs to be used more carefully. \( \text{perEC} \) is accurate but cannot reach high volume fractions, \( \text{perEE} \) gives unsatisfactory results at intermediate volume fractions.

We modify the IDD scheme to improve the results according to a simple geometrical rule and an optimization procedure. The aspect ratio of the atmosphere \( \alpha \) needs to change from 1 to that of the inclusion 0.1 when the volume fraction \( f \) increases.

Fig. 3: Two possibilities for the evolution of the aspect ratio of the atmosphere
Fig. 4: Efficiency of this modification. \((\times):\) simulations, \((\bullet):\) geometrical rule, \((--):\) optimized shape

The geometrical rule is less satisfactory than the optimized shape, but is simpler. We call the IDD estimate built by this modification IDD-A. It is not new \([3]\).

Isotropically oriented elliptical pores, aspect ratio 0.1

Finally we compare three estimates to simulations in the case of randomly oriented pores. The results obtained with IDD-A are very satisfactory.

Conclusion

The IDD scheme, when used with adapted shapes for the atmospheres, gives good results to predict the homogenized properties of crack-like pores, whether aligned or isotropically oriented.

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References