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Homogenization of Heterogeneous Polymers towards Cosserat Media

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1 Introduction

**Experiments:** The microstructure of polymer blends has substantial influence on the macroscopic deformation behaviour.

**Objective:** Determination of macroscopic constitutive equations from microstructural analysis:

- Macroscopic model
- Homogenization
- Closed form constitutive equation
- Microscopic model

2 Macroscopic Model

**Model requirement:** Proper description of strain softening behaviour → non-local models necessary.

**Choice: Cosserat media:**
- **Additional degrees of freedom:** independent rotations.
- **Kinematical quantities:** strain tensor \( \varepsilon_{ij} \) and torsion tensor \( \tilde{k}_{ij} \).
- **Dynamical quantities:** stress tensor \( \sigma_{ij} \) and couple-stress tensor \( \mu_{ij} \).

The constitutive equations are formulated as

\[
\sigma_{ij} = \frac{E}{1 + \nu} \left( \varepsilon_{ij} + \nu \varepsilon_{(ij)} + \frac{\nu}{1-2\nu} \tilde{k}_{kk} \delta_{ij} \right),
\]

\[
\mu_{ij} = \frac{D}{1 + \mu} \left( \tilde{k}_{ij} + \eta \tilde{k}_{(ij)} + \frac{\mu}{1-2\mu} \tilde{k}_{kk} \delta_{ij} \right),
\]

with \( \cdot \) the symmetric, and \( \cdot \) the skew-symmetric part of a tensor.

3 Microscopic Model

**Model requirement:** Proper description of the deformation behaviour of a Representative Volume Element (RVE).

**Choice:**
- PolyCarbonate with microscopic holes.
- Compressible Leonov-model.

4 Homogenization Procedure

**Requirement Boundary Conditions on RVE:** independent variation of macroscopic deformation quantities by using micro-macro definitions → displacement field \( u_i = u_i(\varepsilon_{ij}, \tilde{k}_{ij}) \).

5 Application and Verification

**Application** for a tensile test on a single-edge notched specimen.

**Verification** with 'direct' finite element calculations of the heterogeneous material.

<table>
<thead>
<tr>
<th>Specimen and B.C.</th>
<th>Cosserat FE-mesh</th>
<th>Direct FE-mesh</th>
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<tbody>
<tr>
<td># DOFs: 507</td>
<td># DOFs: 13976</td>
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**Results:**
- \( \sigma_{eq} \) [MPa]:
  - Cosserat FEM, coarse mesh: 50
  - Cosserat FEM, fine mesh: 70
  - Direct FEM: 50

**CPU-time:**
- Cosserat FEM: 2 hours
- Direct FEM: 2 days

6 Conclusions

- Cosserat FEM is capable of describing strain softening (mesh-independent solution).
- Due to the model limitations, the homogenized Cosserat model is correct in a qualitative sense.