Multi-scale constitutive modelling

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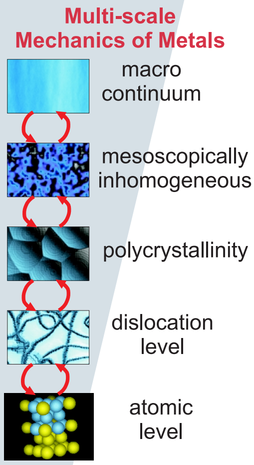
Introduction

Most of the materials produced and utilised in industry are heterogeneous on one or another spatial scale. Therefore, the adequate modelling of the production processes and the product performance requires the solution of a multi-scale problem. For the solution the multi-level micro-macro modelling technique has been developed [1, 2].

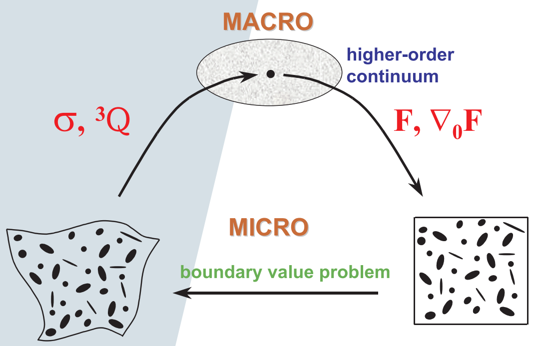


However, the major disadvantage of the existing micro-macro computational approaches is that they rely on the concept of separation of scales and do not incorporate the microstructural size. This significantly limits their applicability e.g. in the fields of micro-technology, metal forming and material design.

The objective is to develop a multi-scale computational procedure that is applicable in miniaturisation and modelling of intense deformations.

Gradient-enhanced framework

The proposed higher-order micro-macro approach is based on the idea to apply the gradient $\nabla_0 \mathbf{F}$ of the macroscopic deformation gradient tensor $\mathbf{F}$ on a Representative Volume Element (RVE), in addition to the deformation gradient tensor $\mathbf{F}$ itself (which is the determining quantity in the conventional micro-macro strategy).

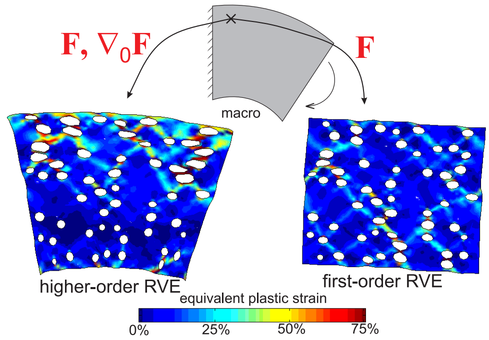


From the solution of the microstructural boundary value problem the macroscopic stress tensor σ and the macroscopic higher-order stress tensor (third-order tensor) $^3\mathbf{Q}$ are obtained. This automatically delivers the microstructurally based constitutive response of the higher-order macro continuum, which deals with the microstructural size in a natural way.

Results

Macroscopic bending

The higher-order approach vs. the first-order approach

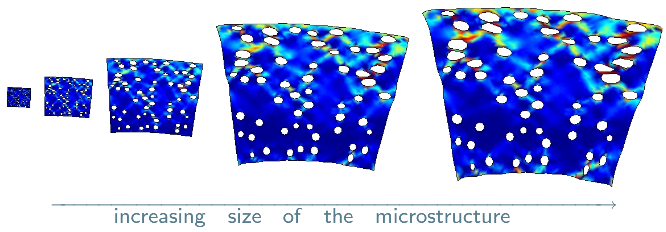


- In the gradient-enhanced approach higher-order deformation modes (e.g. bending) are captured.
- Local deformation patterns differ.

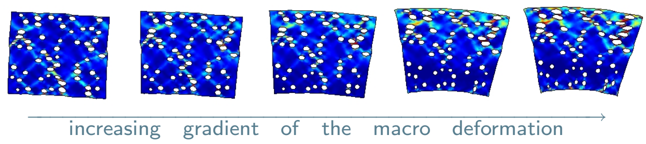
Microstructural and size effects

In the presented gradient-enhanced framework the obtained macroscopic response is directly influenced by

- the size of the microstructure (for given $\mathbf{F}$, $\nabla_0 \mathbf{F}$)



- the value of the prescribed gradient of the deformation $\nabla_0 \mathbf{F}$ (for a given microstructure)



Conclusions

A successful development of this approach enables the analysis of phenomena that are not modelled within the standard micro-macro approach, such as microstructural and size effects and macroscopic localisation.

References:

[1] R.J.M. Smit, W.A.M. Brekelmans, H.E.H. Meijer. *Comput. Methods Appl. Mech. Engrg.*, 155, 181–192, 1998

[2] V. Kouznetsova, W.A.M. Brekelmans, F.P.T. Baaijens. *Computational Mechanics*, 27, 37–48, 2001

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