Analytical and numerical investigation on Penalized Micro-Dilatation (PMD) theory based on the macro-micro link concept on porous solid

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In the present contribution, a novel multi-scale continuum model for porous materials based upon the concepts of extended continua is proposed. In addition to classical continua, the extended model takes into account macroscopical dilatancy effects and, additionally, micro-dilatancy effects. Thus, from a theoretical point of view, the model could be compared to the microstretch models of Eringen [1] and the models proposed by Cowin and coworkers [2, 3]. In contrast to the mentioned work, our model is embedded into a rate-dependent, i.e. visco-elastic framework.

The methodology consists of two states field variables: The classical macroscopical displacement field \( u(\mathbf{x}, t) \) and the micro dilatancy field \( s(\mathbf{x}, t) \). That would be capable of describing the micro-structure in terms of porosity change or micro void space variation according to the pore size distribution using the characteristic length scale parameter. To achieve this goal, the constitutive laws should be rewritten with respect to the local positivity of the strain and void energy density including the relevant micro and macro parameters which have not been deeply investigated yet. Consequently our objective is to propose the numerical and analytical approach for determination of the material parameters by a theoretical and numerical homogenization concept based on two simple limit cases:

1. A material incompressible macroscopic bulk material \( (K \to \infty) \). Thus, total dilatancy effects only occur w.r.t. to the material micro-parameter \( (\beta) \). The effective volumetrical response could be linked directly to the volume change of the microscopical void space \((K \neq \text{infinity})\).

2. A material incompressible microscale, i.e. a rigid/incompressible \((\text{void space})\). The effective volummetrical response could be linked directly to the macroscopical dilatancy effect.

Note that for these two limit cases, we are able to decouple the micro- and macroscopical dilatancy effects. Furthermore, the mentioned penalized forms have been also checked by the boundeness property. Moreover, the current methodology would provide a fresh departure in finding the unknown but relevant microscopical and macroscopical material parameters in extended/generalized continuum mechanics. We compare our macroscopical investigations with simple numerical calculations on the scale of a Representative Volume Element (RVE) where we take into account the discrete microstructure of the material, e.g. an elastic bulk material with spherical voids. Therefore, we perform pure volumetrical compressions test and calculate effective material properties and compare the resulting parameters with our macroscopical investigations.
Figure 1: Microscale FEM model of a simplified closed-cell porous material with spherical voids and the corresponding homogenized generalized continuum model

References

