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Homogenization in nonlinear viscoelasticity: estimates based on the second moments and fluctuations of the fields

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In this study, we aim at modeling the mechanical behavior of a non linear viscoelastic heterogeneous material having an "inclusions-matrix" type microstructure. The different phases of this material may experience differential shrinkages or swellings (like thermal expansion) and we want to model the internal stresses induced by this loading. Thanks to the theory of homogenization, these internal stresses are correctly estimated when the behavior of the constituents is linear elastic (see in particular [1]) or even aging linear viscoelastic ([2]). However, if the phases obey a non linear viscoelastic behaviour, the determination of internal stresses evolutions remains an open question.

The proposed approach consists in linearizing the (nonlinear) relation between the viscous strain rate and the stress. To obtain a tractable problem, the linearized properties (viscous modulus, stress-free strain rate) are chosen uniform per phase: in each phase, they are computed for reference stresses per phase. Various linearization procedures associated to different choices of these reference stresses (like the first and second order moments or the fluctuations of the stress field) have been proposed in the past (see for instance [3]). Recenty, the improved procedure [4] generates estimates that are exact to second order in the heterogeneity contrast and, contrary to previous second order theories, can be directly extended to nonlinear viscoelasticy (no duality gaps).

The extension of these different linearization procedures to non linear viscoelasticity are first studied from a theoretical point of view. Next, the estimates generated by these different procedures are compared to reference results obtained either by numerical FFT simulations or analytically on a particular microstructure (composite sphere assemblage). As expected, the accuracy of the generated estimates strongly depends on the chosen reference stress in the matrix phase: first-order moments have to be substituted by the second-order ones to obtain realistic predictions while stress fluctuations have to be incorporated into the linearization procedure to yield results quantitatively consistent with the reference ones.

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