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HOMOGENIZATION ESTIMATES FOR THE NONLINEAR TRANSPORT PROPERTIES OF ISOTROPIC PARTICULATE COMPOSITES

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Abstract. Particle fillers are often added to monolithic materials in order to improve and tailor their properties. Predicting the overall transport properties of the resulting composite is specially challenging when such properties are nonlinear and the dispersion of particles is highly disordered. The purpose of this work is to estimate the overall properties in terms of the filler and matrix properties and their geometrical arrangement. The results are particularly relevant to applications involving electronic and ionic composite conductors operating under high field intensities.

New estimates for the overall transport properties of two-phase composites, consisting of a random dispersion of particles in a matrix, are obtained by means of a nonlinear homogenization technique proposed by Ponte Castañeda (Phys. Rev. B 64 (2001), 214–205). In this technique, a suitably designed variational principle is used to express the nonlinear homogenization problem in terms of an auxiliary linear-comparison problem where the linearized properties are “optimally” chosen. A linear homogenization estimate must then be used to solve this auxiliary problem. The variational principle thus generates a nonlinear estimate from an available linear estimate. In this work, use is made of the Hashin-Shtrikman-type estimates of Willis (J. Mech. Phys. Solids 25 (1977), 185–202) for the linear problem. Fairly explicit expressions are obtained for isotropic power-law composites with arbitrary particle concentration, nonlinearity exponent, and heterogeneity contrast. These results are compared with earlier homogenization estimates and numerical simulations, and are used to explore the effect of nonlinearity and other material parameters on the overall response. In addition, estimates are also generated for the first- and second-order statistics of the field distribution in each constituent phase. It is argued that the resulting field statistics are often, but not always, consistent with the expected localization of the fields with increasing nonlinearity.