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Thermal conductivity predictions for porous materials via effective medium approximations and cross-property relations

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The effective thermal conductivity of porous materials is determined by all details of their microstructure. Since lower bounds (both Wiener and Hashin-Shtrikman bounds) are not available for porous materials (with vacuous voids), all predictions based on the porosity alone are necessarily model-based and thus tentative. In this contribution we first recall the exact solution of the single-inclusion problem for spherical and spheroidal pores [1], give a comprehensive summary of admissible nonlinear model relations (Maxwell-Eucken relation, Coble-Kingery relation, power-law relation, our exponential relation) [2] and explicitly exclude those model relations that are either redundant (self-consistent / Landauer-Bruggemann model), non-admissible (Spriggs 'exponential relation) or useless (minimum solid area models) [3]. Further it is shown how the exact solution for spheroidal pores (oblate or prolate) is to be implemented into the admissible nonlinear effective medium approximations [1]. In the second part of this contribution we show that the problem of characterizing microstructural details and implementing microstructural information beyond volume fractions can be circumvented via cross-property relations (CPRs). In particular, the knowledge of the relative tensile modulus (Young's modulus) can be used to predict the relative thermal conductivity of porous materials. The CPRs currently available for this purpose are recalled, including the Sevostianov-Kováčik-Simančík CPR [4], our CPR for isometric pores [5] and the recently proposed generalized version of the latter for anisometric pores (spheroidal-prolate and spheroidal-oblate) [6]. Using numerical modeling on a wide range of different computer-generated digital microstructures (convex pores, concave pores, spheroidal pores, foams) it is shown that our CPR provide the best thermal conductivity predictions currently available.

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