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The effect of inclusions on macroscopic composite elasticity: A systematic finite-element analysis of constituent and bu

Ferdous Sohag[1*], Akira Yoneda[1]

[1]ISEI, Okayama Univ.

The bulk physical properties of composite systems are difficult to predict ? even when the properties of the constituent materials in the system are well known. We conducted a finite-element method simulation to examine the inclusion effect by substituting an inclusion phase (second phase) into a host phase (first phase). We have organized the simulation results as a function of the elasticity of host and inclusion phases. In this procedure, special attention was paid to the initial change of elastic constants as the inclusion volume ratio was varied. To accomplish this, we introduced a new parameter Dij defined as the derivatives of the normalized stiffness elastic constant over the inclusion volume ratio. We succeeded in obtaining useful systematic formulations for Dij. These formulations are expected to be applicable to the study of composite systems in many disciplines, such as geophysics, mechanics, material engineering, and biology. The present results provide much more effective constraints on the physical properties of composite systems, like rocks, than traditional methods, such as the Voigt-Reuss bounds.

Keywords: composite elasticity, inclusion, finite element method, Voigt Reuss Hill average