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Extreme viscoelastic and coupled-field properties of composites containing ferroelastic inclusions

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ABSTRACT

Effective viscoelastic properties of continuum composite systems under the effects of ferroelastic phase transition (FPT) in inclusions are studied with the finite element methods, as well as their effective coupled-field properties, such as dielectric and piezoelectric properties are also studied. The effective effects of FPT can be modeled by assigning negative modulus in inclusions. In this study, it is found that under suitable tuning of the negative modulus, extreme effective properties of such composites may be obtained through finite element calculations. The stability of such systems can also be estimated by the time-domain analysis. Smaller inclusion volume fraction systems may be more stable than larger volume fraction ones. Furhtermore, multi-physical effects, such as electric polarization, may provide a stabilization mechanism in the negative-stiffness systems.

1. INTRODUCTION

Negative-stiffness composites have been experimentally demonstrated to exhibit anomalous effective damping and modulus (Lakes et al. 2001). The unusual behavior of the composites rise from the interaction between the negative-stiffness inclusions and positive-stiffness matrix. Follow-up researches, such as extreme coupled-field properties (Wang and Lakes 2001), have shown tremendous progresses in understanding this exterlibral composites, defined as composite materials containing negative-stiffness phases. Recently, Wang et al. (2015) have reported numerical studies on such systems, showing under some conditions the coupled-field anomalies may be stabilized due to multi-physics effects.

2. MODELING DETAILS

Numerical models of the composite systems are shown in Fig. 1 (a) and (b) for their the effective viscoelastic properties and coupled-field properties, respectively.

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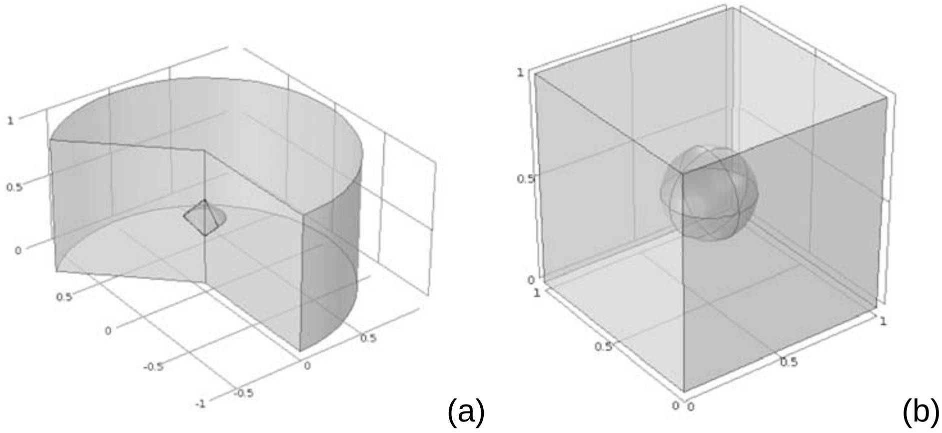
Suitable boundary conditions are applied to calculate effective elastic, viscoelastic and coupled-field properties of the composite systems through volume-averaged field quantities.



(a) (b)

Fig. 1 (a) Viscoelastic model analyzed under the 2D axisymmetric assumptions, and (b) 3D coupled-field model.

Stability boundaries of such systems may be determined by applying small dynamic perturbation in time to the systems through boundary surfaces. If any field variables become divergent in time (equal to 3T, where the period T = 1/ f), then the system is unstable.

3. RESULTS AND DISCUSSIONS

Fig. 2 shows the normalized effective complex modulus of the single cell viscoelastic model that contains a diamond-shape inclusion. As can be seen, smaller inclusion volume fraction gives rise to more stability in the system. The normalized effective bi-axial modulus may be three times more than that of matrix. Due to sampling points, extremely large or small (i.e. singular) effective properties are not seen. However, with finer tuning of modulus ratio, it is expected that extreme properties would be obtained. For viscoelastic composite systems containing small volume fractions, the systems can be stable at a certain driving frequency. Larger inclusion volume fraction reduces allowable negative stiffness in the viscoelastic system, as well as in the coupled-field systems.

Fig. 3 (a) and (b) show the anomalies in effective dielectric and piezoelectric constants of the cubic composite systems. Multiple peaks can be observed for the largeest inclusion volume fraction case. All anomalous peaks found in the coupled-field properties are in the unstable regime, except for the piezoelectric anomalies with electrically insulated inclusions and large inclusion volume fraction. Insulated inclusions may cause charge accumulation at the inclusion-matrix interface and boundary surface effects may serve as stabilizing agents to the composite system.

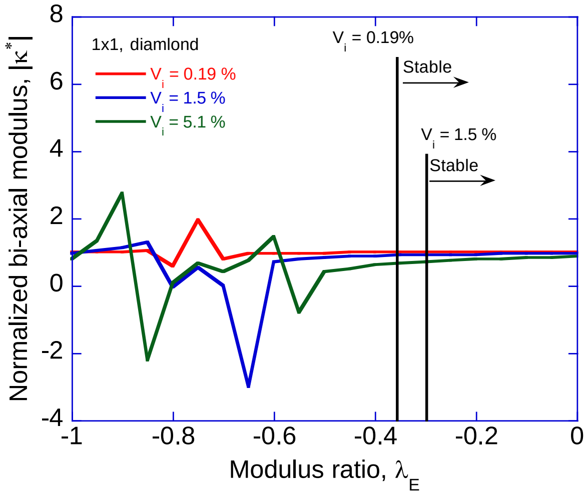


Fig. 2 (a) Effective dielectric constant, and (b) effective piezoelectric constant of the 1x1x1 composite model.

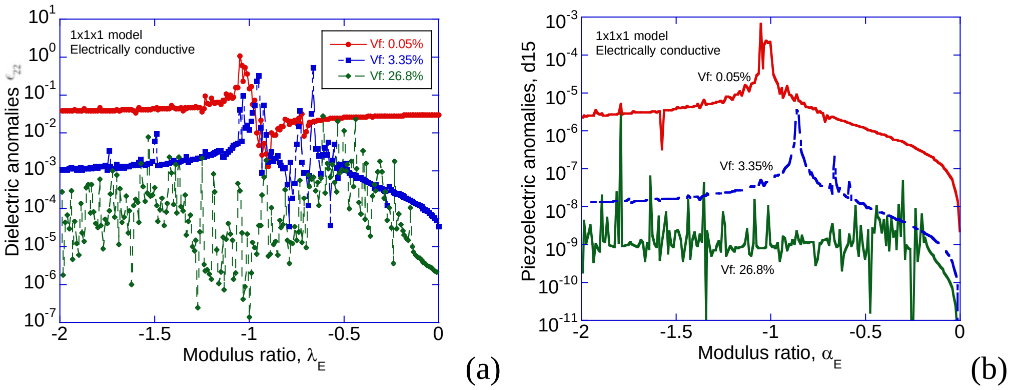


Fig. 3 (a) Effective dielectric constant, and (b) effective piezoelectric constant of the 1x1x1 composite model.

4. CONCLUSIONS

The anomalous phenomena in the effective properties of the negative-stiffness composites for the viscoelastic, dielectric and piezoelectric properties are numerically studied with the finite element methods. Effective properties may be extreme when modulus ratios are finely tuned. Since it is known that negative-stiffness composite is unstable in the purely elastic system in statics, stability enhancement found here in the negative-stiffness systems studied here for the viscoelastic and coupled-field properties may be considered as multiphysics-induced stabilization. Furthermore, all stability studies performed here are for the short-term stability. The long-term stability of the systems requires further studies.

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