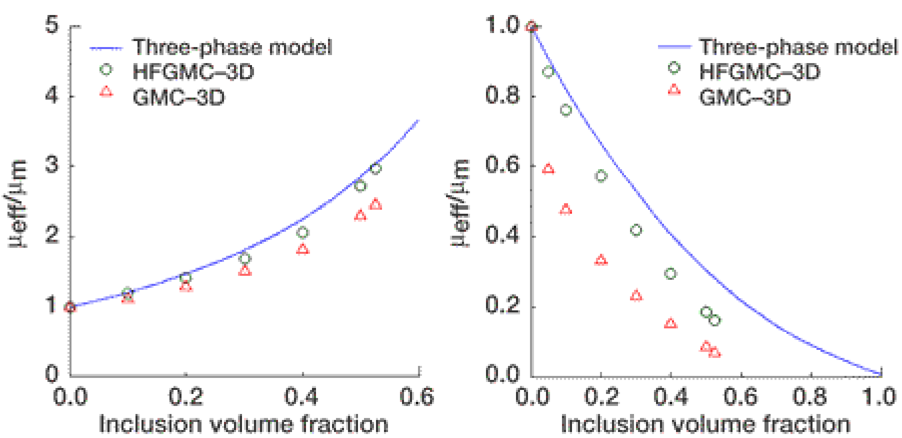
High-Fidelity Micromechanics Model Enhanced for Multiphase Particulate Materials

This 3-year effort involves the development of a comprehensive micromechanics model and a related computer code, capable of accurately estimating both the average response and the local stress and strain fields in the individual phases, assuming both elastic and inelastic behavior. During the first year (fiscal year 2001) of the investigation, a version of the model called the High-Fidelity Generalized Method of Cells (HFGMC) was successfully completed for the thermoinelastic response of continuously reinforced multiphased materials with arbitrary periodic microstructures (refs. 1 and 2). The model's excellent predictive capability for both the macroscopic response and the microlevel stress and strain fields was demonstrated through comparison with exact analytical and finite-element solutions. This year, HFGMC was further extended in two technologically significant ways. The first enhancement entailed the incorporation of fiber/matrix debonding capability into the two-dimensional version of HFGMC for modeling the response of unidirectionally reinforced composites such as titanium matrix composites, which exhibit poor fiber/matrix bond. Comparison with experimental data validated the model's predictive capability. The second enhancement entailed further generalization of HFGMC to three dimensions to enable modeling the response of particulate-reinforced (discontinuous) composites in the elastic material behavior domain. Next year, the three-dimensional version will be generalized to encompass inelastic effects due to plasticity, viscoplasticity, and damage, as well as coupled electromagnetothermomechanical (including piezoelectric) effects.



Effective shear moduli as a function of the inclusion volume fraction for a dispersion of spherical particles in a matrix. Left: m_i/m_m *= 20/1. Right:* m_i/m_m *= 1/200.* m_{eff}*, macroscopc effective shear modulus of the composite;* m_i*, shear modulus of the inclusion;* m_m, shear modulus of the matrix.

The predictive capability of the elastic, three-dimensional version of HFGMC is illustrated in the graphs, where the average shear modulus of a dispersion of spherical particles embedded in a matrix is compared with the predictions of the original GMC model (ref. 3) and the three-phase model (ref. 4). Two extreme shear modulus ratios of spherical particles and surrounding matrix were chosen to provide a high contrast and, thus, a demanding test of the model's predictive capability. In the left graph, the effective shear modulus was determined as a function of the inclusion volume fraction for the case when the inclusion phase is 20 times stiffer than the matrix phase. The right graph shows a case that simulates a matrix with spherical pores whose shear stiffness is 0.005 that of the matrix. The superior predictive capability of HFGMC relative to GMC is a direct result of HFGMC's better local displacement field representation, which produces the so-called shear coupling effects indispensable in accurately capturing locally discontinuous phenomena such as damage, debonding, and material porosity.

References

1. Aboudi, J.; Pindera, M.-J.; Arnold, S.M.: Linear Thermoelastic Higher-Order Theory for Periodic Multiphase Materials. J. Appl. Mech. Trans. ASME, vol. 68, 2001, pp. 697-707.

2. Aboudi, J.; Pindera, M.-J., and Arnold, S.M.: Higher-Order Theory for Periodic Multiphase Materials With Inelastic Phases. Int. J. Plasticity (NASA/TM--2002-211469), 2002.

3. Arnold, S.M., et al.: Micromechanics Analysis Code With Generalized Method of Cells (MAC/GMC). User Guide: Version 3.0, NASA/TM--1999-209070, 1999.

4. Christensen, R.M.: Mechanics of Composite Materials. John Wiley & Sons, New York, NY, 1979.

Glenn contact: Dr. Steven M. Arnold, 216-433-3334, Steven.M.Arnold@nasa.gov
Authors: Prof. Marek-Jerzy Pindera and Dr. Steven M. Arnold

Headquarters program office: OAT
Programs/Projects: RLV, RAC