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Proposal of a Novel Approach to Developing Material Models for Micro-scale Composites Based on Testing and Modeling of Macro-scale Composites

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Summary

The Los Alamos National Laboratory's Weapon Systems Engineering division's Advanced Engineering Analysis group employs material constitutive models of composites for use in simulations of components and assemblies of interest. Experimental characterization, modeling and prediction of the macro-scale (i.e. continuum) behaviors of these composite materials is generally difficult because they exhibit nonlinear behaviors on the meso- (e.g. micro-) and macro-scales. Furthermore, it can be difficult to measure and model the mechanical responses of the individual constituents and constituent interactions in the composites of interest. Current efforts to model such composite materials rely on semi-empirical models in which meso-scale properties are inferred from continuum level testing and modeling.

The proposed approach involves removing the difficulties of interrogating and characterizing micro-scale behaviors by scaling-up the problem to work with macro-scale composites, with the intention of developing testing and modeling capabilities that will be applicable to the meso-scale. This approach assumes that the physical mechanisms governing the responses of the composites on the meso-scale are reproducible on the macro-scale. Working on the macro-scale simplifies the quantification of composite constituents and constituent interactions so that efforts can be focused on developing material models and the testing techniques needed for calibration and validation. Other benefits to working with macro-scale composites include the ability to engineer and manufacture—potentially using additive manufacturing techniques—composites that will support the application of advanced measurement techniques such as digital volume correlation and three-dimensional computed tomography imaging, which would aid in observing and quantifying complex behaviors that are exhibited in the macro-scale composites of interest. Ultimately, the goal of this new approach is to develop a meso-scale composite modeling framework, applicable to many composite materials, and the corresponding macro-scale testing and test data interrogation techniques to support model calibration.

The following example further elaborates the proposed approach:

1. Create macro-scale composite specimens using constituents with well characterized mechanical properties (e.g. stiffness, Poisson's ratio) and interaction properties (adhesion, friction)
    - Initially this can be done with materials that exhibit simple responses
    - Other versions can substitute the simple materials with more complicated ones that exhibit responses of interest
2. Test the macro-scale specimen in the same way we might test a composite of interest (e.g. tension, compression, bulk, cyclically, etc.) to produce continuum level data
    - Basic measurements would include applied load and axial and lateral displacements or strains
    - Advanced diagnostics could be employed to collect full-field responses and to quantify behaviors at constituent interfaces
3. Perform a Direct Numerical Simulation of the composite, which will require the known constituent and interaction properties
4. Develop a micro-structurally informed continuum model of the composite material
    a. Calibrate this material model using only the continuum level data (*continuum-calibrated model*)
    b. Also calibrate the material model using the properties of the individual constituents and their interactions (*constituent-calibrated model*)
5. Compare the performance of the two versions of the micro-structurally informed continuum models
    a. Under the loading conditions to which they were calibrated
    b. Under loading conditions that are different from those to which they were calibrated
6. Develop tools and techniques, based on the performance of the two calibrated material models, to bring the performance of the continuum-calibrated model closer to that of the constituent-calibrated model
    a. Perhaps identifying specific continuum level tests that would most efficiently target model calibration of the most important parameters. These might include:
        i. tests on different constituent mixtures
        ii. tests under novel loading conditions
        iii. tests using novel specimen geometries