Micromechanical software enables efficient multiphysics composites modelling

The complexity of engineering systems at the microlevel greatly complicates the analysis of macroscopic behaviour. Direct analysis is computationally intensive and unrealistic. SwiftComp Micromechanics is capable of predicting the effective properties of composites and local fields within the microstructure.


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While composite materials have proved in many ways superior to conventional materials, the increasing complexity of engineering systems at the microlevel greatly complicates the analysis of macroscopic behaviour. This analysis, however, is indispensable for a rational design of these systems. While direct analysis is possible, it is computationally intensive and unrealistic. A new micromechanics code developed at Utah State University addresses these challenging issues. SwiftComp Micromechanics, also known as VAMUCH (Variational Asymptotic Method for Unit Cell Homogenization), is a recently developed micromechanics theory capable of predicting not only the effective properties of composites and other heterogeneous materials, but also the local fields within the microstructure. Utilizing the powerful variational asymptotic method (VAM), SwiftComp is the first truly general-purpose micromechanics software program for composites.

Micromechanics approaches

SwiftComp Micromechanics (VAMUCH), now in version 3.0, is a software program implementing the various micromechanics theories based on VAM to simplify originally heterogeneous materials using effective homogeneous materials, the properties of which are obtained through a micromechanical analysis of a microstructure, commonly called UC (unit cell) or RVE (representative volume element), representative of the heterogeneous material (Figure 1). SwiftComp takes a finite element mesh of the UC including all the details of geometry and material as inputs to calculate the effective properties. These properties are needed for the macroscopic structural analysis to predict the global behaviour. The 3D point-wise local field distribution within the microstructure can also be recovered based on the global behaviour of the macroscopic structural analysis.

In addition to providing a general framework for modelling heterogeneous materials,

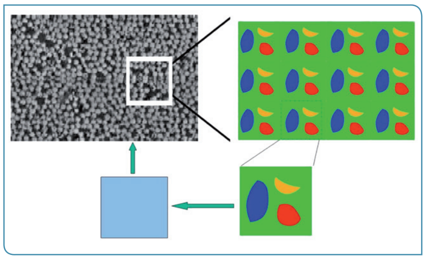

Fig. 1: Micromechanics homogenization

SwiftComp has several unique features in both its theory and application in comparison to other micromechanics approaches. For instance, taking advantage of the smallness of the microstructure of heterogeneous materials, it formulates a variational statement of the unit cell through an asymptotic analysis of the energy functional by invoking only two very basic assumptions of micromechanics. Other convenient assumptions commonly used in the literature are avoided.

Although it is easy to distinguish SwiftComp from other analytical micromechanics approaches, it is often confused as one of the FEA-based micromechanics approaches because the equations of the VAMUCH theory are solved using the finite element technique. FEA-based micromechanics approaches carry out a conventional finite element analysis of an RVE (or UC) with specially designed boundary conditions under specifically designed loads. Although SwiftComp has the same versatile modelling capability as FEA-based approaches, it is dramatically different both in its theory and application.

Theoretical differences

Although there are significant theoretical differences between SwiftComp and other micromechanics approaches, practicing engineers are often more concerned with convenience and efficiency. To this end, we compare SwiftComp Micromechanics and FEA-based approaches. To use an FEA-based approach, one has to carry out multiple runs with different sets of boundary conditions and external loads for predicting different material properties. Post-processing steps such as averaging stresses or averaging strains are also needed for calculating the effective properties. If one is also interested in the local fields within the microstructure, one more run is necessary to predict local stress/strain fields if the global stress/strain state is different from that used to obtain the effective properties. Compared to FEA-based approaches, SwiftComp has the following unique features:

1. It can obtain the complete set of material properties within one analysis without applying any load or boundary conditions, which is far more efficient and less labour intensive than those approaches requiring multiple runs under different boundary and load conditions. It can even obtain the complete set of 3D material properties using a one-dimensional analysis of the 1D UC for binary composites, which is impossible for FEA-based approaches.
2. It calculates effective properties and local fields directly with the same accuracy as the fluctuating functions. No post-processing calculations such as averaging stress or strain fields, which introduce more approximations, are needed.
3. It can recover the local fields using a set of algebraic relations obtained in the process of calculating the effective properties. Another analysis of the microstructures, which is needed for FEA-based approaches, is not necessary.

Additionally, SwiftComp takes full advantage of the finite element technique including versatile discretization capability for arbitrary microstructure, highly efficient linear solvers, and well-developed pre-processing and post-processing capabilities. It is also worth noting that the calculations are conceptually different from automating the multiple runs including post-processing steps of FEA-based approaches using a macro language such as APDL of ANSYS. SwiftComp is not just a different post-processing approach (Figures 2).

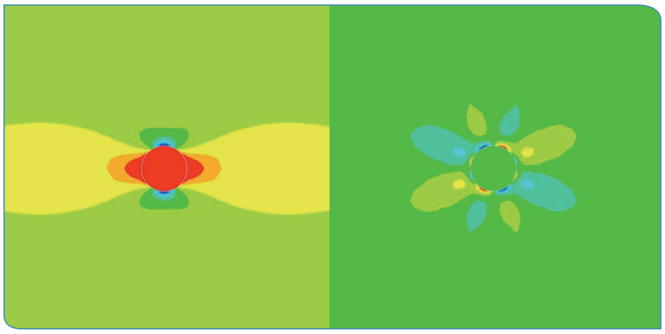

Fig. 2: Micromechanics homogenizations

Several new features

In its latest release, SwiftComp Micromechanics 3.0 incorporates several new important features. Primary among the new features is the program's multiphysics capability. SwiftComp can be used to homogenize heterogeneous materials that have coupled or uncoupled responses to mechanical, electric, magnetic and thermal fields. It not only predicts the elastic, conductive, dielectric, magnetic and diffusive properties of heterogeneous materials, but also coupled properties such as coefficients of thermal expansion, pyroelectric, pyromagnetic, piezoelectric, piezomagnetic and/or electromagnetic properties, as well as the local fields corresponding to these multiphysical responses.

Moreover, the efficiency and capacity of SwiftComp Micromechanics 3.0 has been significantly increased. For instance, it can compute much larger models with many more degrees of freedom in a more efficient way. For some large models, up to one hundred times increase in efficiency is possible.

This newest version can now model UCs with curved edges or surfaces and also relax the restriction that the origin of the coordinate must be at the UC centre. It can also model temperature-dependent materials with or without assuming small temperature variations. For example, a single run can generate a series of temperature-dependent effective properties.

Of course, this means several important advances for engineers dealing with composites and other heterogeneous materials. First, improved product quality is possible, as the program achieves the best available accuracy. Second, drastically reduced engineering time can also be achieved since SwiftComp has the same versatility as FEA, but with a small fraction of the associated computing time. Finally, the learning curve can be minimized since there is no need to apply highly crafted boundary and load conditions or post-process the results.

An interface with ANSYS is also available for taking advantage of the powerful pre-processing and post-processing capability of ANSYS. An evaluation license of SwiftComp Micromechanics (VAMUCH) 3.0, as well as the ANSYS interface, is available for free download on the AnalySwift website for the next several months. ■

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AnalySwift, LLC, is a leading provider of efficient high-fidelity design and analysis software for composite materials and structures, particularly cutting-edge technology for structural modelling and micromechanics modelling. AnalySwift's revolutionary solutions are based on a powerful mathematical approach, providing users a competitive advantage through dramatic reductions in engineering time, without sacrificing accuracy in multiphysics modelling. Utilizing technology licensed from Utah State University, AnalySwift offers the best compromise between efficiency, accuracy and versatility for multiphysics analysis of composite materials and structures. The technology has been supported, in part, by the US National Science Foundation, US Army, US Air Force, Utah Science Technology and Research Initiative (USTAR) and industry.