Micromechanics-Based Inelastic Finite Element Analysis Accomplished Via Seamless Integration of MAC/GMC

A critical issue in the micromechanics-based analysis of composite structures becomes the availability of a computationally efficient homogenization technique (see the following figure): one that is

1. Capable of handling the sophisticated, physically based, viscoelastoplastic constitutive and life models for each constituent

2. Able to generate accurate displacement and stress fields at both the macro and the micro levels

3. Compatible with the finite element method

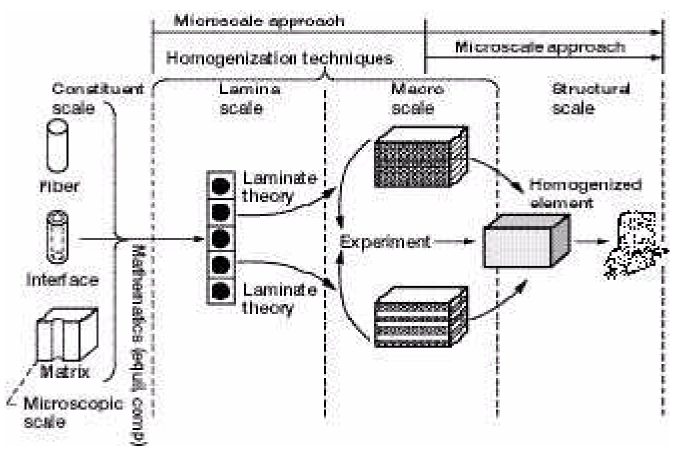


Illustration of levels of scale and approaches for composite analysis.

The Generalized Method of Cells (GMC) developed by Paley and Aboudi (ref. 1) is one such micromechanical model that has been shown to predict accurately the overall macro behavior of various types of composites given the required constituent properties. Specifically, the method provides "closed-form" expressions for the macroscopic composite response in terms of the properties, size, shape, distribution, and response of the individual constituents or phases that make up the material. Furthermore, expressions relating the internal stress and strain fields in the individual constituents in terms of the macroscopically applied stresses and strains are available through strain or stress concentration matrices. These expressions make possible the investigation of failure processes at the microscopic level at each step of an applied load history.

MAC/GMC (ref. 2) enhances the basic capabilities of GMC by providing a modular framework wherein

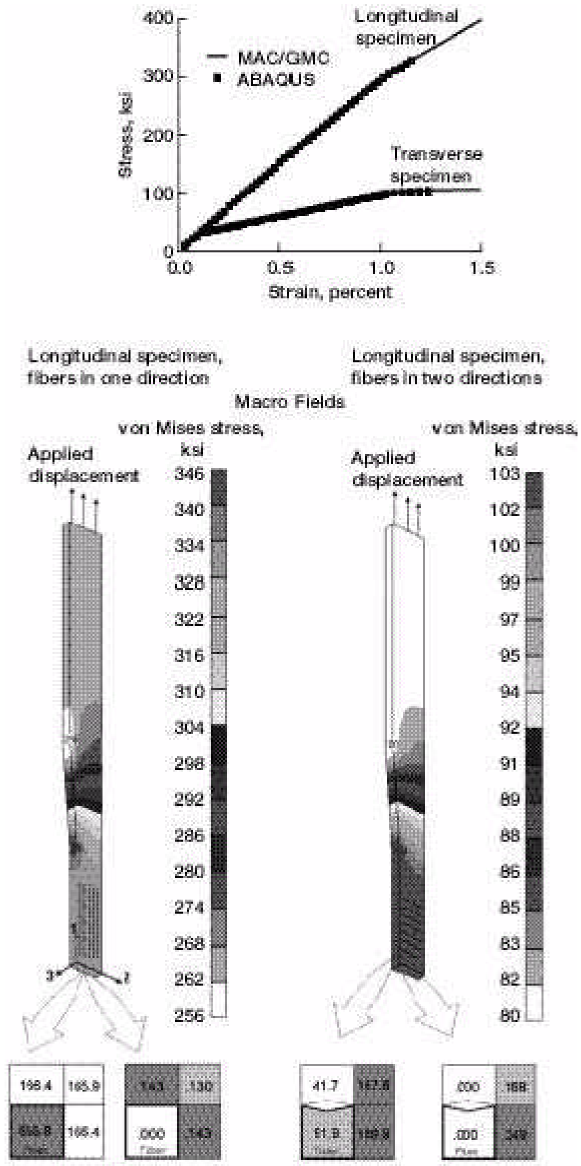
1. Various thermal, mechanical (stress or strain control), and thermomechanical load

histories can be imposed

2. Different integration algorithms can be selected
3. A variety of material constitutive models (both deformation and life) can be utilized and/or implemented
4. A variety of fiber architectures (both unidirectional, laminate, and woven) can be easily accessed through their corresponding representative volume elements contained within the supplied library of representative volume elements or input directly by the user
5. Graphical postprocessing of the macro and/or micro field quantities is made available

Consequently, the availability of MAC/GMC (see http://www.grc.nasa.gov/WWW/LPB/mac) now provides industry, academia, and government engineers and materials scientists with a comprehensive, computationally efficient, user-friendly micromechanics analysis tool that can easily and accurately design/analyze multiphase (composite) materials for a given application. MAC/GMC is also ideally suited for conducting sensitivity/parametric studies (i.e., "what-if" scenarios) in the design and analysis of advanced composite materials (e.g., metal matrix composites, polymer matrix composites, and ceramic matrix composites). Furthermore, MAC/GMC can be interfaced directly with standard linear and nonlinear finite element analysis packages (through their respective user-definable constitutive routines) for cost-effective large-scale component design and analysis. Recently, in cooperation with the University of Akron such a seamless interface was achieved for HKS's nonlinear finite element code, ABAQUS. For clarity, this finite element implementation of MAC/GMC has been given its own unique name, FEAMAC.

To date, over 40 industrial and academic customers have used or are using MAC/GMC for a variety of applications. In particular, FEAMAC is being employed by the Goodyear Tire and Rubber Co. and the NASA Glenn Research Center to understand the influence of cord architecture on the behavior and performance of their tires, and by Glenn and Boeing, Rocketdyne Division, to design and analyze a metal matrix composite (MMC) housing on a large 400,000 thrust class turbopump. For illustration purposes, see the following figure: two 432-element (C3D8) idealizations of a 33-vol % SCS-6/TIMETAL 21S test specimen, longitudinally and transversely reinforced, are analyzed. In the top part of the following figure, a comparison is made of the macro response prediction resulting from MAC/GMC and that coming from the center element within the gauge length (where FEAMAC is providing the viscoplastic material response at all integration points throughout the specimen). Clearly, the agreement is excellent. Furthermore, in the bottom part of this figure, the macro von Mises stress contours for both specimens and the corresponding in situ microstress and inelastic strain field within each constituent are illustrated at the end of the applied tension test. Note that in the transverse specimen, fiber-matrix debonding has been enabled as indicated by the diamond-shaped interface in the bottom part of the figure.



Micromechanics-based structural analysis of two 432-element idealizations of 33-vol % SCS-6/TIMETAL 21S dog bone test specimens, longitudinally and transversely reinforced. Top: Macrolevel stress-strain response. Bottom: Multilevel ABAQUS results using FEAMAC to represent material behavior.

References

1. Paley, M.; and Aboudi, J.: Micromechanical Analysis of Composites by the Generalized Cells Model. Mech. Mater., vol. 14, no. 2, 1992, pp. 127-139.

2. Arnold, S.M., et al.: Micromechanics Analysis Code With Generalized Method of Cells (MAC/GMC) User Guide. Ver. 3.0. NASA/TM--1999-209070, 1999. http://gltrs.grc.nasa.gov

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