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MICROMECHANICS BASED DESIGN/ANALYSIS CODES FOR ADVANCED COMPOSITES

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Advanced high temperature Ceramic Matrix Composites (CMC) hold an enormous potential for use in aero and space related applications specifically for propulsion system components. Consequently, this has led to a multitude of research activities pertaining to fabrication, testing and modeling of these materials. The efforts directed at the development of ceramic matrix composites have focused primarily on improving the properties of the constituents as individual phases. It has, however, become increasingly clear that for CMC to be successfully employed in high temperature applications, research and development efforts should also focus on optimizing the synergistic performance of the constituent phases within the as-produced microstructure of the complex shaped CMC part. Despite their attractive features, the introduction of these materials in a wide spectrum of applications has been excruciatingly slow. The reasons are the high costs associated with the manufacturing and a complete experimental testing and characterization of these materials. Often designers/analysts do not have a consistent set of necessary properties and design allowables to be able to confidently design and analyze structural components made from these composites. Furthermore, the anisotropy of these materials accentuates the burden both on the test engineers and the designers by requiring a vastly increased amount of data/characterization compared to conventional materials.

In order to address some of these issues the most cost effective way is to develop validated/verified micromechanics based CMC behavior prediction computer codes that can be run routinely to generate the necessary data for designers/analysts. Micromechanics based codes have unique advantages compared to finite element based or other approaches in that they address the issues pertinent to the smallest scale namely fiber, matrix and interphase etc. Once verified and validated with some experimental data, such codes permit quick trade-off studies involving a variety of constituent level properties, geometrical details, fabrication related parameters and fiber architecture be performed rather routinely. Furthermore, design/analysis tools that allow selection and optimization of the key properties of interest within the physical and chemical constraints of the chosen CMC process are of great help to understand and improve the basic CMC material as well. The present paper addresses micromechanics based modeling issues pertaining to laminated and woven advanced CMC's that are of interest to aero and space communities. Also the presentation will include a description of various computer codes developed in-house with illustrative examples. Specifically the computer codes CEMCAN (Ceramic Matrix Composite Analyzer), W-CEMCAN (Woven Ceramic Matrix Composite Analyzer), and P-CEMCAN (Probabilistic Ceramic Matrix Composite Analyzer) and their derivatives will be presented. Specific examples include strength and property prediction of laminated, plain weave and 5-harness woven CMC's. Also, the current efforts to enhance the codes with capabilities to include 3-D reinforcements such as 3-D orthogonal weaves, and angle-interlock weaves will be described.

The earliest micromechanics based CMC analysis code developed in house is CEMCAN [1]. Figure 1 shows a schematic of the code flow chart. CEMCAN is based upon micromechanics that utilizes a unique fiber substructuring concept. The code simulates all aspects of continuous fiber-reinforced laminated ceramic matrix composites. The details of the code are given in reference [2].

Another computer code that is developed and continues to be under further enhancements is W-CEMCAN (Woven Ceramic Matrix Composite Analyzer). It is an out growth of CEMCAN that was originally developed for continuous filament reinforced laminated ceramic matrix composites. A schematic of five-harness woven CMC and the modeling approach programmed in W-CEMCAN are shown in figure 2. This code was used to analyze composite materials consisting of stacked two-dimensional woven ceramic matrix composites [3,4]. The approach used is quite generic and in fact can be applied to any type of satin weave architectures.

Figures 3, 4 and 5 show typical results obtained from using these micromechanics-based computer codes. When available, measured data is also plotted against the predictions. For most part, the predictions are in good agreement with the data. Similar results for other mechanical and thermal properties are also obtained. These and the calibration procedures to arrive at the in-situ properties of the constituents as a function of temperature will be the focus of the presentation.

References:

1. Mital, S.K. and Murthy, P.L.N.: CEMCAN- Ceramic Matrix Composites Analyzer. User's Guide- Version 2.0. NASA *TM-107187, April 1996*
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3. Mital, S.K., Tong. M. T., Murthy, P.L.N., and DiCarlo, J.A.: Micromechanics-Based Modeling of Thermal and Mechanical Properties of an Advanced SiC/SiC Composite Material. NASA TM-97-206295, Dec. 1997.
4. Mital, S.K.; Murthy, P.L.N.; and Chamis, C.C.: Simplified Micromechanics for Plain Weave Composites. NASA TM-107165, March 1996.

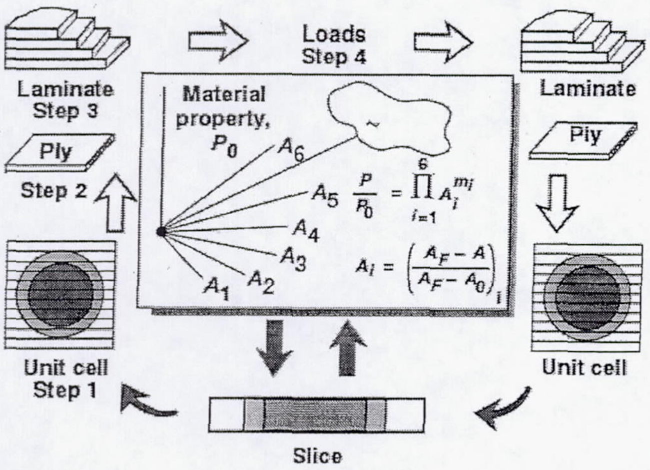

Figure 1. Integrated analysis approach embedded in CEMCAN computer code.

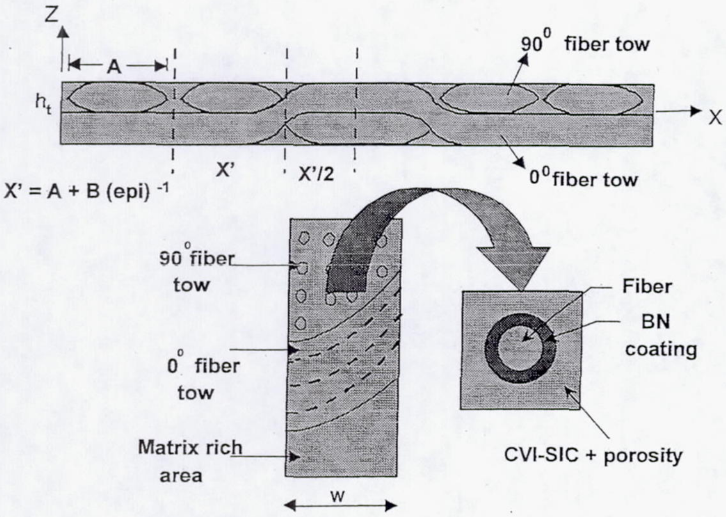

Figure 2. Woven composite analysis modeling details.

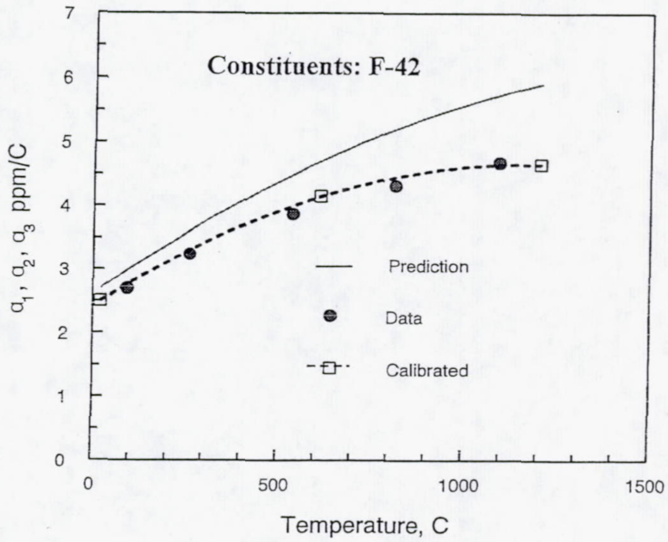

Figure 3. Coefficient of thermal expansion for five-harness SiC/SiC composite.

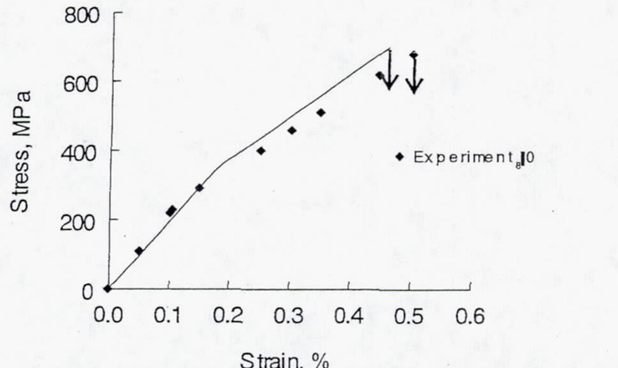

Figure 4. R.T. Stress/strain curve of $[0]_8$ SiC/RBSN composite.

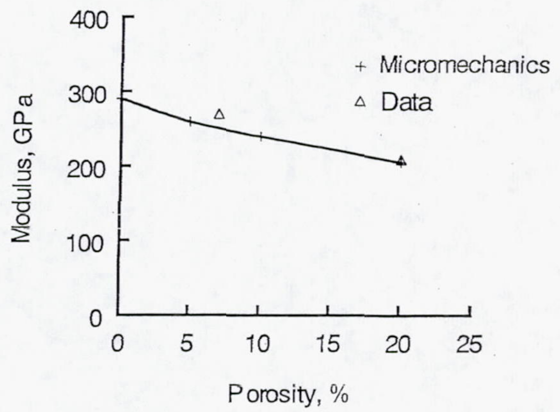

Figure 5: In-plane modulus vs. porosity (SiC/SiC plain weave composite, 0.4 fvr.