MAPINT 2000

Analysis of the Micromechanics Damage Model Suite

David O'Neal

Computational Scientist

The National Center for Supercomputing Applications
University of Illinois at Urbana-Champaign

oneal@ncsa.edu

Overview

- **Science**
  - What is the Micromechanics Damage Model Suite?
- **Project Team**
  - AFRL Materials Directorate and ASC PET
- **Implementation**
  - Design details and problems
- **Objectives**
  - Project goals
- **Status**
  - Developments and recent insights

What is the MDM Suite?

- Analysis tools for computing stresses and energy release rates associated with fracture mechanics problems in composite bodies
- Set of four stress transfer mechanics models for handling different types of boundary conditions
  - Axisymmetric loading
  - Transverse and shear loading
  - Frictional effects
  - Delamination
- Serves to establish failure criteria used in the design of composite structures for air and space vehicles

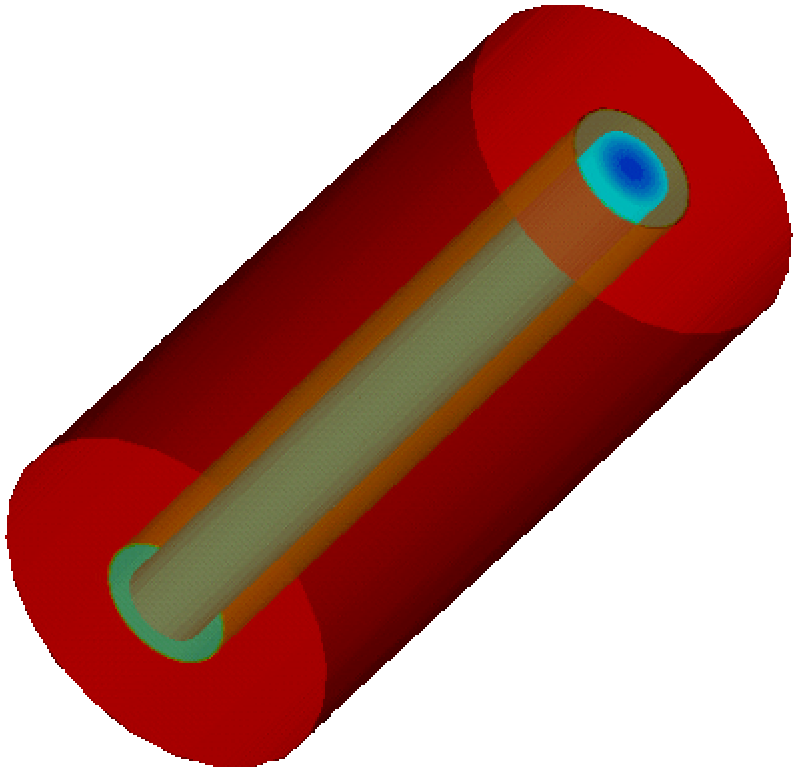
Project Team

- **N. J. Pagano, G. A. Schoeppner, H. W. Brown, III**
  - **AFRL Materials Directorate, Wright-Patterson AFB**
- **G. P. Tandon**
  - **University of Dayton Research Institute**
- **R. Luczak, PET PT/ES**
  - **University of Tennessee at Knoxville**
- **D. O'Neal, PET CSM**
  - **University of Illinois at Urbana-Champaign**

Implementation Details

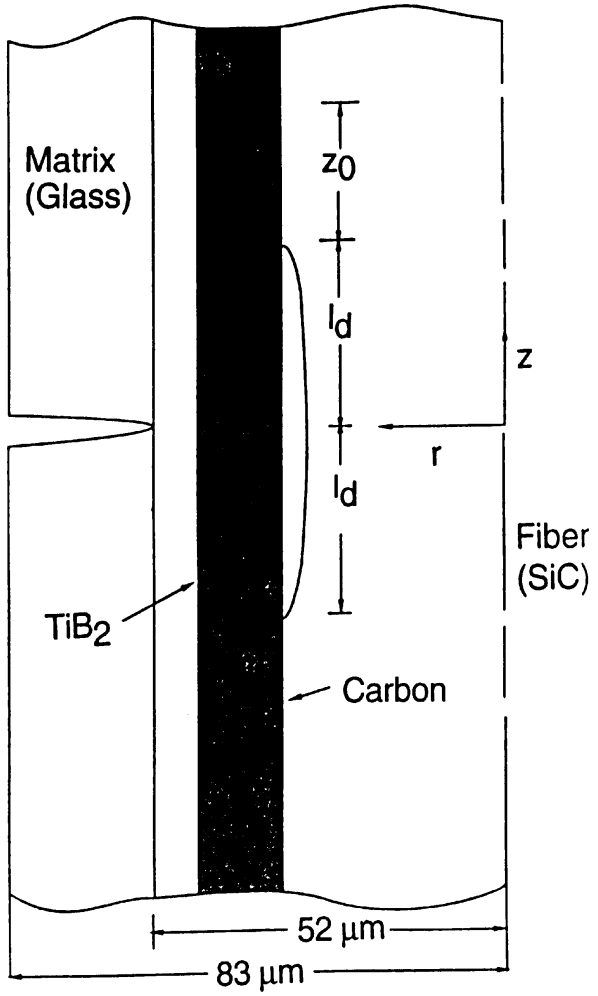
- **Discretizations are based on sets of concentric cylinders that extend into the matrix material that surrounds an individual core fiber**

- **Concentric shell and core cylinders have constant thickness and constant inner and outer radii**

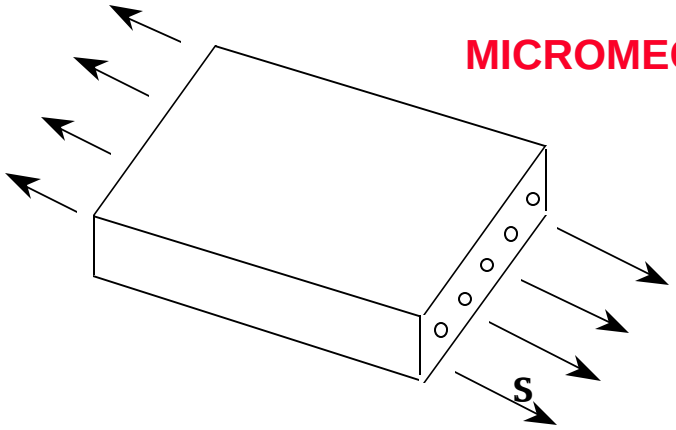


More Implementation Details

- Number of shells and respective thicknesses are dictated by material design, the damage itself, boundary conditions and desired accuracy
- Damage is introduced in the form of annular cracks and/or debonds within or between constituent layers
- Cylinders are further subdivided into section lengths determined by damage locations

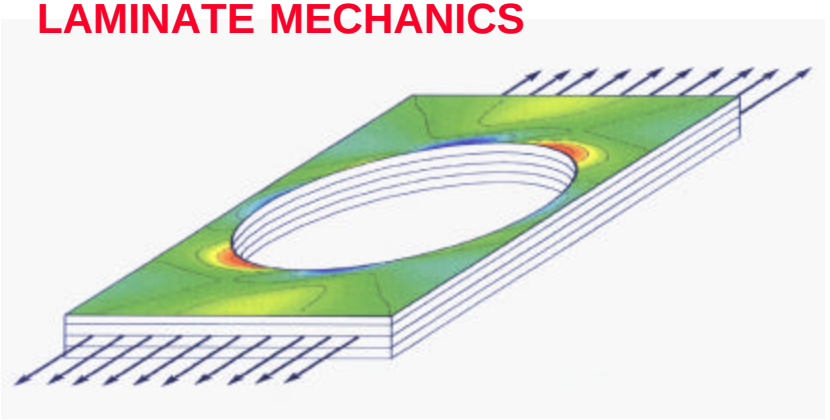


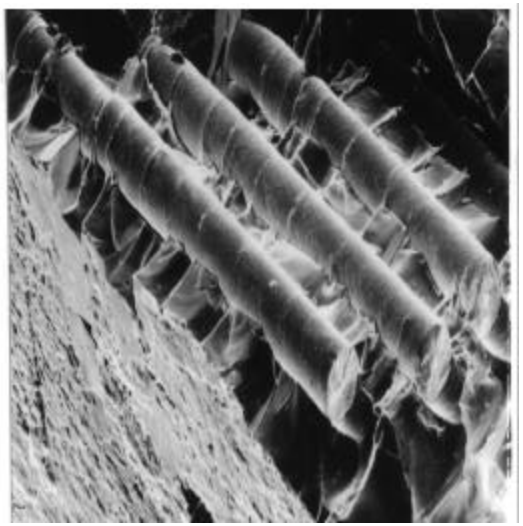
COMPOSITE MICROMECHANICAL FAILURE MODES AND BONDED/BOLTED JOINTS



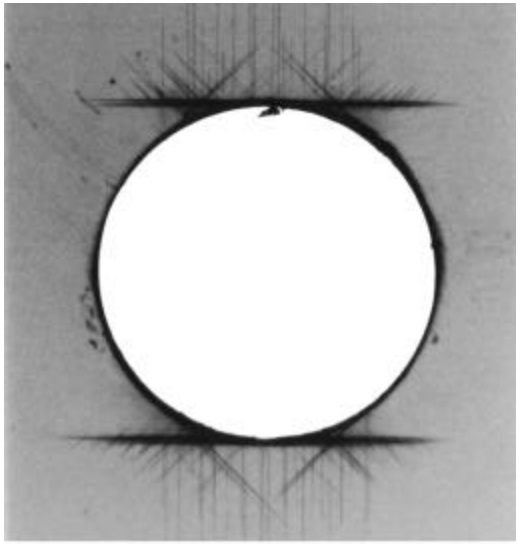
MICROMECHANICS

LAMINATE MECHANICS

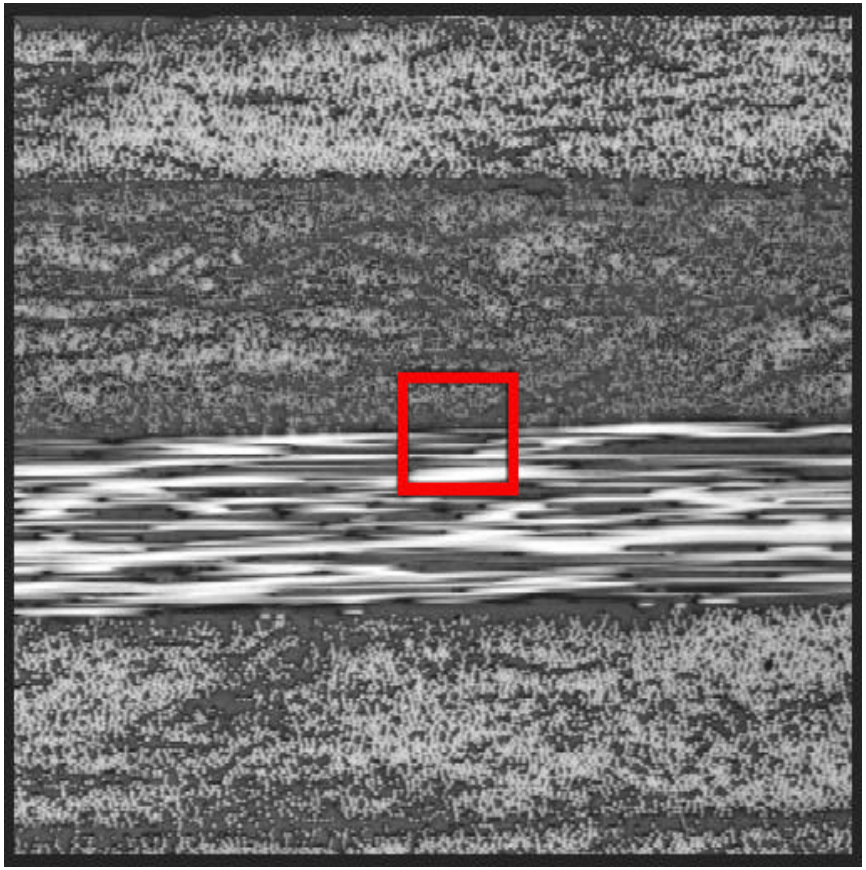


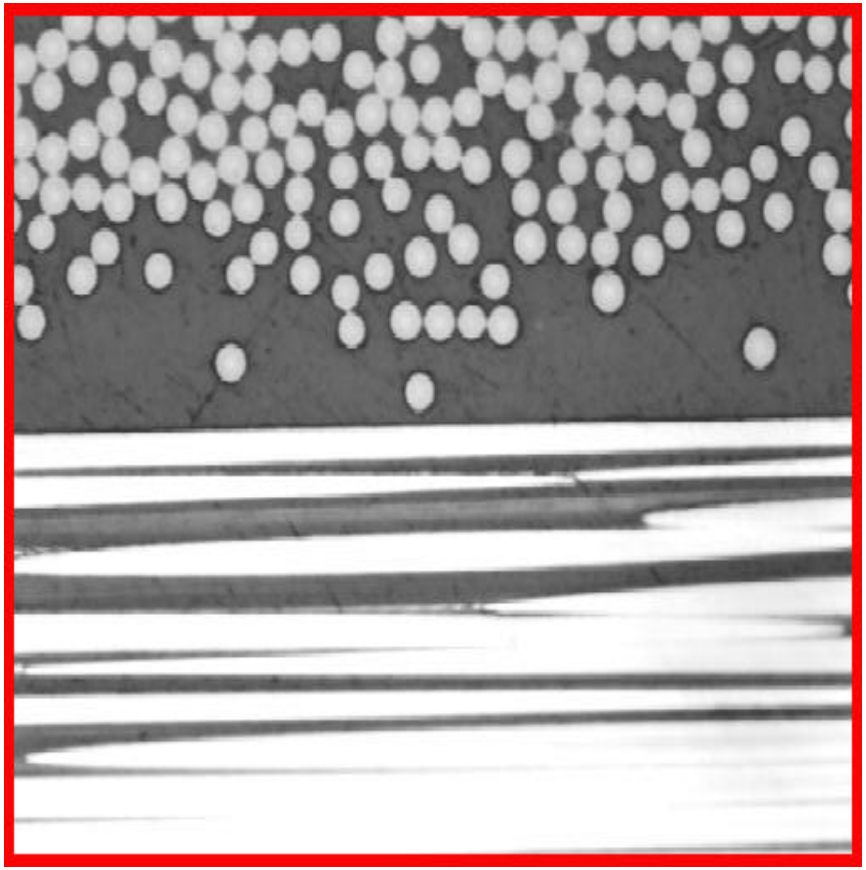


INTEGRATE



LAMINATED COMPOSITE MATERIAL MICROSCOPIC VIEW





Discretization Problem

- **Section lengths associated with debonds can create immediate problems for typical floating point systems**
- **NaN and/or Inf values may occur during evaluation of exponential functions that involve the section length**

  EP = QEXP (LAMBDA * LENGTH)

- **Said functions arise in the general form of the solution vector since the representative differential equations within each material layer are linear**

Portability Problem

- As previously noted, MDM analyses can require an unusually wide range of exponent values
- Sectional lengths can only be scaled with respect to the shell radii, i.e. L/r ratio is fixed
- Production runs have always been restricted to Hewlett-Packard platforms because their quadruple precision floating point system provides an exponent range of -4931 to +4932

Performance Problems

- **Quadruple precision operations are implemented in software**
  - **A full eigenanalysis of a 100x100 real nonsymmetric matrix requires about 200 times as many cycles as an equivalent double precision code (H-P 9000)**
- **User-defined ADD function**
  - **Attempts to control the effects of additive cancellation and round-off error**
  - **Consumes 20% to 40% of the total CPU time for each of our test problems (ranked first or second for all cases)**

Goals

- **Our first priority is the creation of a portable code capable of producing acceptable levels of accuracy**
  - **Proliferation of the MDM Suite and the semi-analytical methods it represents is constrained by the availability of Hewlett-Packard platforms**
  - **AFRL would prefer to have the option of using other resources too**
- **Performance enhancement is also an important, but secondary, consideration**
  - **Development of a double-precision code will almost certainly yield a significant performance improvement as a sort of side-effect of the primary objective**

Status

- A suitable environment for constructing and testing multiple executables from a single source code has been established
  - The current installation supports multiple HPUX and IRIX builds
- New Makefile system completed
  - Integrated array of original makefiles
- A set of eight increasingly challenging problems for the floating point system have been designed
  - Various shell and section counts/configurations

Validation Testing

- H-P and IRIX executables were built on the Exemplar X-class and Origin 2000 systems at NCSA
- Output from our HPUX runs was directly comparable to AFRL datasets produced at SPAWAR
- Comparison between platforms was complicated by dissimilar formatting
  - Use of the H-P compiler's E4 option facilitated comparison with IRIX outputs
  - xdiff utility was invaluable for examining cases characterized by varying levels of disagreement

Eigensolver

- Guidance suggesting that overflows and underflows originate in the eigenanalysis
- Replaced 128-bit SLATEC sources with equivalent 64-bit codes
  - HQR, HQR2, BALBAK, ORTHRES, etc.
- Copied 128-bit data into 64-bit arrays prior to calling the double precision routines and prior to exiting, the 64-bit arrays were copied back into the quad-precision arrays and the normal execution path was continued
- Final results agreed to at least 10 digits

Detecting Floating Point Errors

- Subroutine used to check for the presence of NaNs was based on the use of a formatted output file
- After writing out selected arrays of floating point data, the file was reopened and read back in as character strings using the specified width of the output field
- Strings were then checked for the presence of “N” characters
- The IRIX port revealed that overflows and underflows were not trapped by the CHKNAN routine
- IRIX platforms report “nan” and “Inf” values

More on Floating Point Errors

- Portable alternative based on the use of the ANSI C function “finite” contained in libm.a was created
- The “finite” function checks two specific bits located in the MSB of floating point variables
- Fortran wrapper was written around the call to the library routine and added to the system Makefiles
- Subroutine CHKNAN was rewritten to check the specified data arrays directly
- A new subroutine capable of checking any given real scalar value or array of values was also added

Boundary Conditions

- **Radial boundary conditions prescribed between concentric cylinder surfaces**
  - **Eigenanalysis of ODE equations**
  - **Evaluation of exponentials not involved here**
  - **No contradictions with respect to our original plan**
- **Axial boundary conditions are prescribed externally at the ends of a specimen and internally between sections.**
  - **Current focus on this specific aspect of the problem**
  - **Resolving internal BCs requires decomposition and solution of a system of linear equations**

Solution Alternatives

- Replace semi-analytical method with an entirely numerical scheme
  - For models consisting of a single section, many boundary value problem solvers would work (this was our original plan)
  - But the handling of multi-section models presents a more complicated set of conditions
- Implement something resembling the current semi-analytical method using a symbolic mathematical library
  - MSSRC ExprLib

Review

- Working environment established
- Validation problem designs completed
- H-P and IRIX validation runs completed
- Analysis of output files used to rank problems in terms of their dependence on extended range of exponent values completed
- Replacement of eigensolver routines with equivalent 64-bit routines demonstrated that FP problems generally originate eigenanalysis results
- Located typical points of origin of overflow and underflow problems (axial BCs)
- Currently evaluating alternative approaches

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- Bai, Z. and Tang, P., *Quadruple Precision FORTRAN Routine for Eigenanalysis of Real Nonsymmetric Matrices*, Dept. of Mathematics, University of Kentucky (1996)
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