# *Strength & Life of Composites*

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This innovative book is suitable for education, industry and government personnel interested in composites for aerospace, transportation and wind energy. It provides knowledge and tools to move beyond the penalties imposed by many current practices.

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This book owes its origin to Composites Design Tutorial, an online, on demand training course that has turned out to be timely during the increased interest in composites and the increased cost of fuel. Receiving training without travel now has an added advantage. We emphasize not only new theory of failure based on micromechanics but also tools for designers for enlarging their design envelope and implementing their calculations easily, intuitively and with confidence. Thus, this book has 3 parts: 1) original papers on strength and life based principally on micromechanics of failure, printed in white paper; 2) elementary theory of composites, and basic reference on materials and processing, printed with gold trim; and 3) description of tools for design calculations, printed in burgundy trim.

This book is intended for students and engineers interested in learning composite materials. It is also intended for teachers to adopt for their courses.

The first section of the book covers 7 original papers. The first 6 papers have appeared in a special 40th anniversary volume of *Journal of Composite Materials*. Those in this book are essentially the same as those in *JCM* with some revision and addition.

Sung Ha and his colleagues of Hanyang University in Korea were the authors of the first 3 papers. The first paper was on micromechanics of unidirectional composite plies. It had a comprehensive coverage of unit and multiple cells, the relations between macro- and micro stresses, and effective 3D elastic ply moduli. (Figure 1) The second paper covered random fiber arrays based on a computer simulation of inserting fibers in a given domain. A 60 percent fiber volume fraction was achieved, and the simulation revealed remarkable connection among regular and random fiber arrays. (Figure 2) The 3rd paper covered micromechanics of failure (MMF). A conceptually simple constituent tensile and compressive strengths and interfacial normal and shear strengths were linked to the failure modes of unidirectional plies. Considerable simplification design and testing of composite materials can be realized.

The 4th paper on progressive damage was by Prof. Tong Earn Tay of National University of Singapore. He did a survey of relevant papers on the subject that included strength, damage mechanics and fracture mechanics theories. He also applied his Element Failure Method (EFM) to model progressive damage in practical design problems like a bolted joint. (Figure 3) His paper was followed by time-temperature superposition principle (TTSP) applied to strength by Prof. Miyano Yasushi of Kanazawa Institute of Technology. Prediction of creep rupture and fatigue life of plies and laminates can be linked to master curves of the constituents per MMF. The 6th paper was by Dr. Sangwook Sihn of the University of Dayton Research Institute on an integrated tool that covers MMF, TTSP and progressive damage. It is labeled MAE for Micromechanics of failure (MMF), Accelerated testing methodology, and Evolution of damages. (Figure 4) The 7th paper by Prof. Ha covers the detail in the generation of master curves, and a standard material. The latter has been derived from comparing several epoxies and showed remarkable agreement among them. Such discovery can be used to establish an effective screening test for constituents – a significant savings in time and resource, and increase in confidence in predicting strength and life of composites. (Figure 5)

In the second section of this book we have two prerequisite references on composite materials. Our *Theory of Composites Design*, originally published by Think Composites in 1992, and subsequently revised in 2002 and 2008, covers the mechanics of composites and its application to design.

In the third section of this book, we have five sets of viewgraphs outlining the approaches and numerical examples of design tools. Although software is not provided with the book, it shows what is available. Prof. Antonio Miravete covers materials and processing. The first design tool is a suite of Mic-Mac (Micro- and Macromehanics calculator) by Dr. Pranav D. Shah. The second design tool is called Mic-Mac/FEA written by Dr. Jin W. Park now working for a software company in Seoul. (Figure 6) The third tool is GenLam provided by Antonio Miravete and Carlos A. Cimini. The last tool is Super Mic-Mac+ developed by Prof. Sung Ha and Kyo Koo Jin. The original SMM had many useful features like automatic carpet plots of stiffness, strength, optimum laminate design and controlling load determination from multiple load sets. The current SMM+ covers all original features plus unsymmetric laminates with both in-plane and flexural loading and MMF that features generation of master curves in creep rupture and fatigue. It is an ultimate tool for preliminary design.

Composite materials have suddenly emerged as a critical material to meet the high cost of fuel and societal pressure to be green. Engineers who have worked with aluminum have influenced current practices of using 4 ply angles, balanced and symmetric laminates, and design allowable generated from notched specimens. Such constraints must change if composites are to be competitive.

Basic method will be provided so 3 or 2 ply angle can replace the conventional 4 angle laminates. We encourage the use of sublaminates to build a total laminate. Such laminate can be made by continuous stacking. The degree of asymmetry becomes vanishingly small when sublaminate is thin and highly repeated. The resulting homogenized laminate will be strong and tough.

Using notched specimens to generate design allowable is costly and cannot be generalized. Allowable should be derived from smooth specimens of plies and/or constituents. This process is fast, reliable and at a fraction of the cost of testing notched specimens. Design envelope can be increased. The black aluminum influence may finally be put away once and for all.

We see unlimited opportunities in not only fuel efficient airplanes and engines, but also wind turbines and cars. For CFRP we should be able to achieve 50 percent weight savings over aluminum with minimum risk. We are optimistic that with training and innovation composites will serve society well.

Design tools described in the appendices are not included as part of this book.

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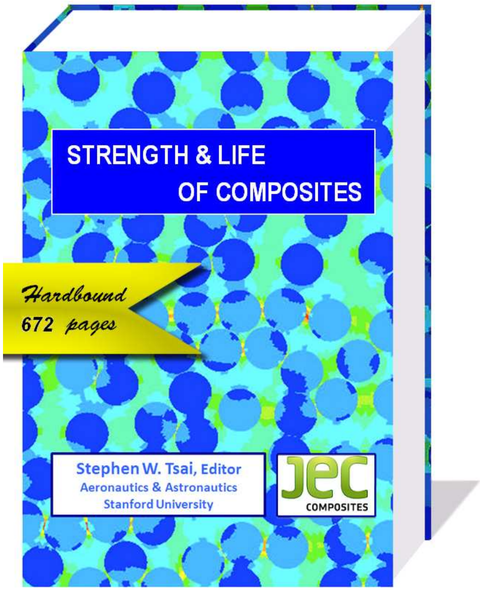


*Strength & Life of Composites* (Hard-bound, 672 pages with colored illustrations)

Illustrations from the book are as follows:

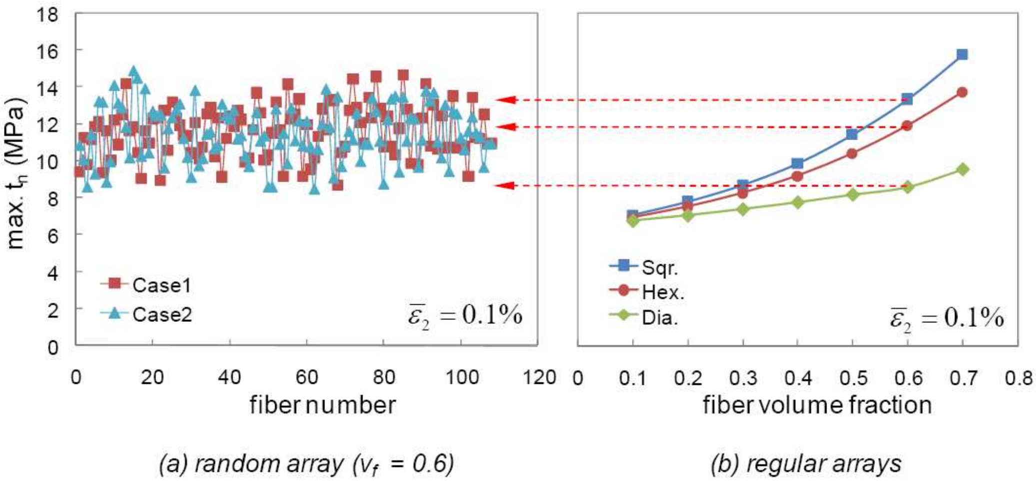


***Figure* 1.** Comparison between maximum interfacial normal tractions in the random and regular arrays due to transverse tension.

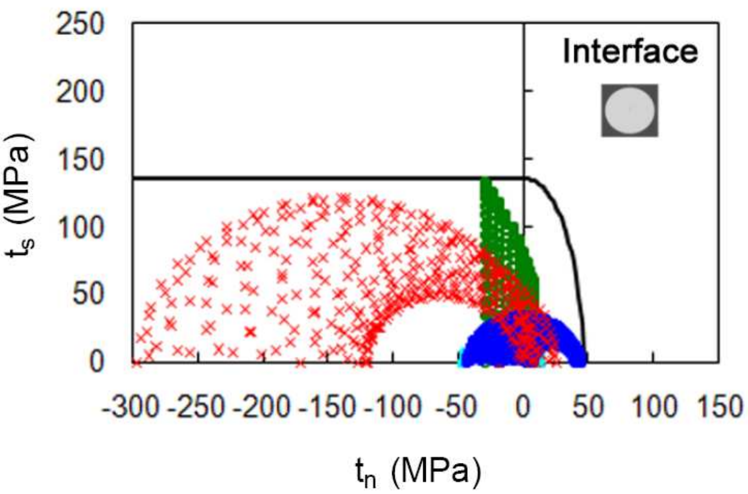


***Figure* 2.** Distribution of tractions at the fiber-matrix interface under macro on-axis ply failure stresses (material: E-glass/MY750; RT: 22$^{o}$C) for square array.

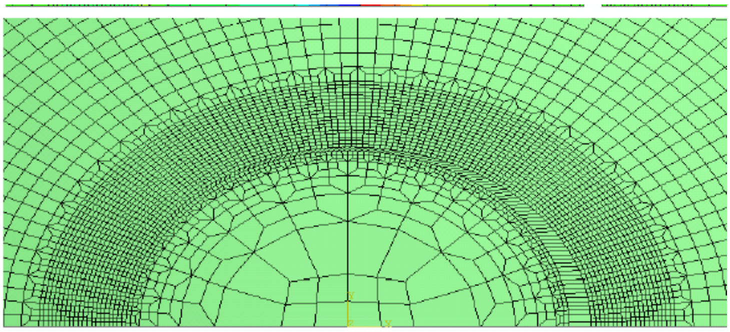

*Figure* 3. Solution with EFM for the pin-loaded plate.

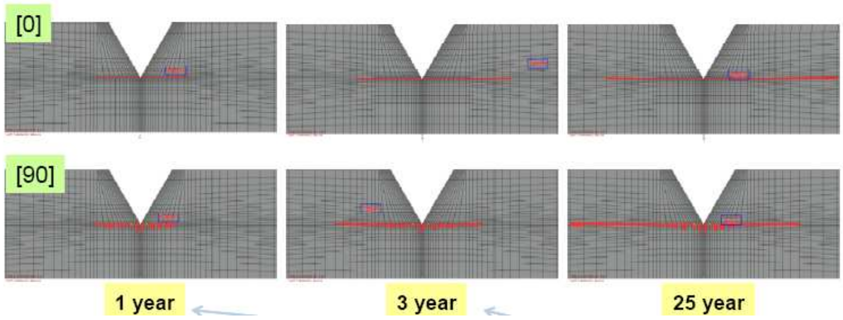


*Figure* 4. Prediction of damage progression of a [0/90]s double-edge notched specimen under tensile creep loading after 1, 3 and 25 years of load durations using the MAE.

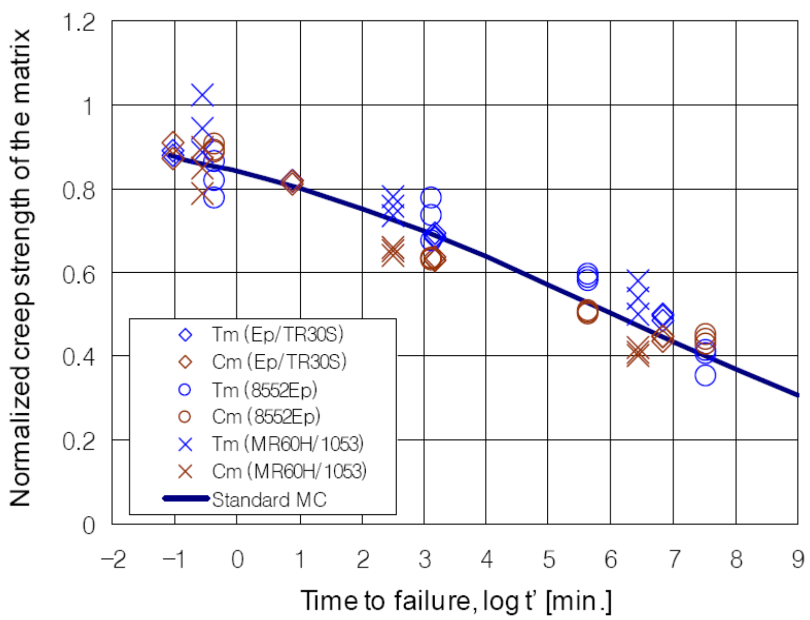


***Figure* 5.** Standard creep master curve of the matrix and corresponding parametes.

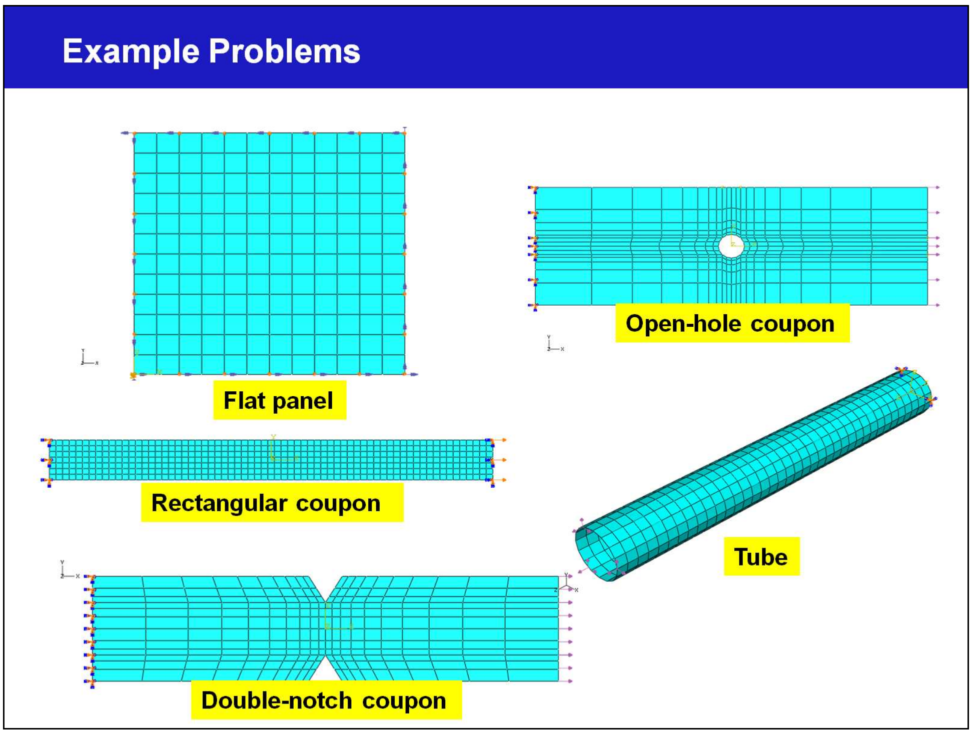


Figure 6. A sample of problems Mic-Mac/FEA tool can solve.