PREFACE

This book owes its origin to Composite Durability Workshop (CDW) that started between Prof. Yasushi Miyano of Kanazawa Institute of Technology and this editor in 1998 when Yasushi and I submitted a winning proposal to the National Science Foundation on durability of composite materials. It was thought to be a good beginning if we could gather experts in the field to kick off this program. Thus the first CDW was born. It was held in the beautiful conference center of Kanazawa Institute of Technology in Kanazawa, on the north shore of the main island of Japan. Since 1998 we have had 13 workshops, the last one was in Singapore in July 2008.

This book also owes it 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. The latter may have changed business travel forever. 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, printed with yellow trim; and 3) materials and processes and description of tools for design calculations, printed in violet trim.

Actual programs for design tools however are not included as part of the book. We have found the training is required for their use. Thus our frequently offered online composites design tutorials will provide actual design tools and necessary training for each participant. The description of the tools in this book should help the reader to view the formulation and sample problems of the tools. For information on the tutorials please visit compositesdesign.stanford.edu.

This book is intended for students and engineers interested in learning composite materials. It is also intended for professors to adopt for their courses. Our first 2 tutorials in 2007 and 2008 drew over 500 participants. The majority were practicing engineers from industry and government in North America. We would expect greater participation for the 3rd tutorial starting September 2, 2008.

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. The permission to republish these papers granted by SAGE Publications Ltd through its publication editor Wendy Truran is much appreciated.

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. 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. 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 was the 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 5th paper was 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. 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. He proposed the use of an independent shear strength that is different from Prof. Ha's approach based on linear elastic micromechanics. The 7th paper by Prof. Ha covers the generation of master curves, and a standard material. There are differences between Prof. Ha and Prof. Miyano in the generation of master curves although the final results are identical. The standard material 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. There was a congratulatory message of *Journal of Composite Materials* on its 40th anniversary that preceded the six original papers. It is placed as the 8th paper.

In the second section of this book is my *Theory of Composites Design*, originally published by Think Composites in 1992, and subsequently revised in 2002 and 2008.

In the third section of this book, we will have 5 sets of viewgraphs. The first covers materials and processing by Antonio Miravete, a visiting associate professor at Stanford. Other 4 sets cover design tools. The first is a suite of Mic-Mac (Micro- and Macromehanics calculator) compiled and written by Dr. Pranav D. Shah, a postdoctoral fellow with me at Stanford. The second design tool is called Mic-Mac/FEA written by Dr. Jin W. Park of the University of Dayton Research Institute. He provided solutions of many practical examples of using Simulia/Abaqus 6.7 finite element analysis, Student Edition (limited to 1000 nodes). Many problem solutions illustrate for beginners to appreciate the power of FEA to deal with non uniform stress. The third tool is GenLam provided by Antonio Miravete and Carlos A. Cimini. Carlos is a visiting scholar with me at Stanford. GenLam is a useful tool to analyze the stress at a point of a composite material with unsymmetric layup and mixed boundary conditions (any combination of applied stress and strain components.) The last tool is Super Mic-Mac+ developed by Prof. Sung Ha and Kyo Koo Jin of Hanyang University. 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 that can then 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, not generic 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.

We have taken advantage of many blank pages at the end of papers and appendices to show photos of our participation in meetings and working sessions in preparation of this book. We are also proud of sharing with our readers our family members and friends who have supported directly and indirectly our many activities. A listing of all the photos inserted is placed on the last page of this book.

Billy Roeseler of the Boeing Company, and Paul Veers of Sandia National Laboratory were our tutorial keynote speakers on aircraft and wind turbine blades, respectively. We also wish to thank Richard M. Christensen of Stanford for his inspiration in MMF, and Air Force Office of Scientific Research for its support. Extra thanks to Pranav Shah, Jackie Lee, Yuanchen Huang and Younghwan Lee for tireless effort to finish the book; see their photo on p. A-I-6. Finally we thank over 500 participants of our first 2 tutorials. Without them this book would not have been possible.

Stephen W. Tsai
July 2008