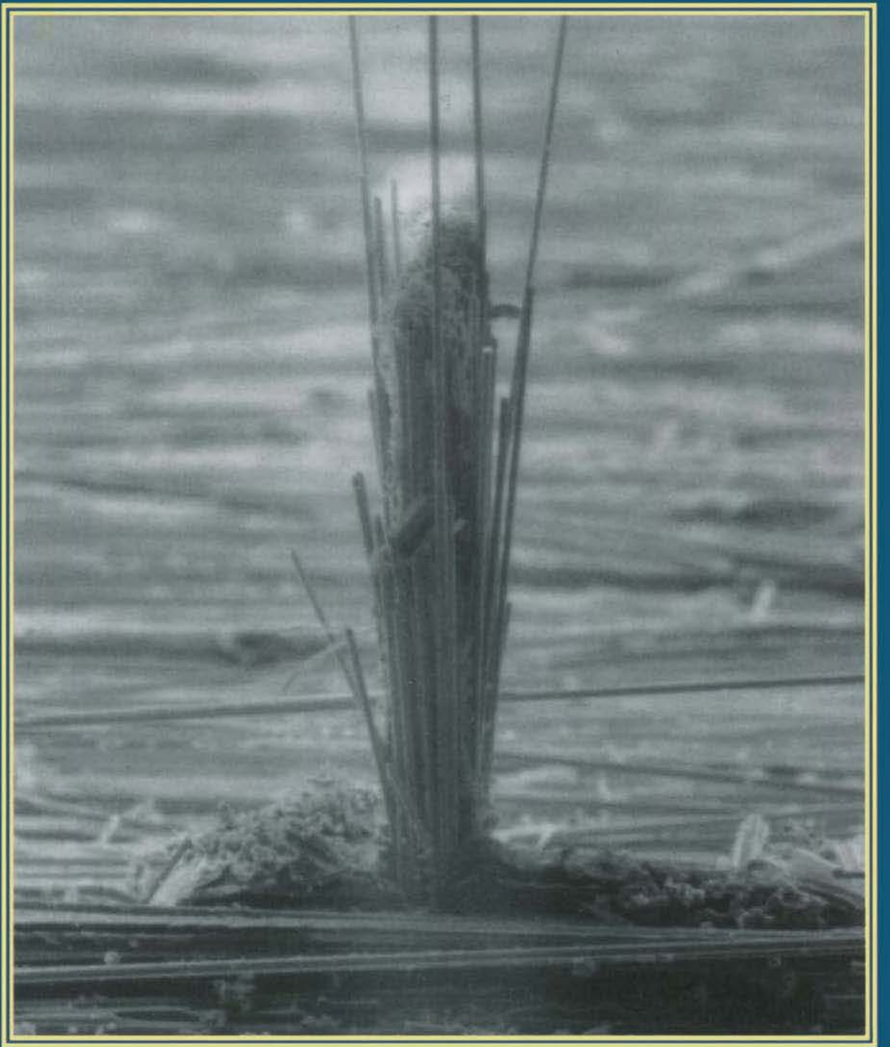

3D Fibre Reinforced Polymer Composites

L. Tong, A.P. Mouritz and M.K. Bannister

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♾ The paper used in this publication meets the requirements of ANSI/NISO Z39.48-1992 (Permanence of Paper).
Printed in the Netherlands.

To my wife Hua and my children Richard and Victoria — L. Tong

To my wife Jenny and my children Lauren and Christian — A.P. Mouritz

To my wife Ruth and my children Lachlan and Emma — M.K. Bannister

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Preface

Fibre reinforced polymer (FRP) composites are used in almost every type of advanced engineering structure, with their usage ranging from aircraft, helicopters and spacecraft through to boats, ships and offshore platforms and to automobiles, sports goods, chemical processing equipment and civil infrastructure such as bridges and buildings. The usage of FRP composites continues to grow at an impressive rate as these materials are used more in their existing markets and become established in relatively new markets such as biomedical devices and civil structures. A key factor driving the increased applications of composites over recent years is the development of new advanced forms of FRP materials. This includes developments in high performance resin systems and new styles of reinforcement, such as carbon nanotubes and nanoparticles. A major driving force has been the development of advanced FRP composites reinforced with a three-dimensional (3D) fibre structure. 3D composites were originally developed in the early 1970s, but it has only been in the last 10-15 years that major strides have been made to develop these materials to a commercial level where they can be used in both traditional and emerging markets.

The purpose of this book is to provide an up-to-date account of the fabrication, mechanical properties, delamination resistance, impact damage tolerance and applications of 3D FRP composites. The book will focus on 3D composites made using the textile technologies of weaving, braiding, knitting and stitching as well as by z-pinning. This book is intended for undergraduate and postgraduate students studying composite materials and also for the researchers, manufacturers and end-users of composites.

Chapter 1 provides a general introduction to the field of advanced 3D composites. The chapter begins with a description of the key economic and technology factors that are providing the impetus for the development of 3D composites. These factors include lower manufacturing costs, improved material quality, high through-thickness properties, superior delamination resistance, and better impact damage resistance and post-impact mechanical properties compared to conventional laminated composites. The current and potential applications of 3D composites are then outlined in Chapter 1, including a description of the critical issues facing their future usage.

Chapter 2 gives a description of the various weaving, braiding, knitting and stitching processes used to manufacture 3D fabrics that are the preforms to 3D composites. The processes that are described range from traditional textile techniques that have been used for hundreds of years up to the most recent textile processes that are still under development. Included in the chapter is an examination of the affect the processing parameters of the textile techniques have on the quality and fibre architecture of 3D composites.

The methods and tooling used to consolidate 3D fabric preforms into FRP composites are described in Chapter 3. The liquid moulding methods used for consolidation include resin transfer moulding, resin film infusion and SCRIMP. The benefits and limitations of the different consolidation processes are compared for producing 3D composites. Chapter 3 also gives an overview of the different types of processing defects (eg. voids, dry spots, distorted binder yarns) that can occur in 3D composites using liquid moulding methods.

A review of micro-mechanical models that are used or have a potential to be used to theoretically analyse the mechanical properties of 3D textile composites is presented in Chapter 4. Models for determining the in-plane elastic modulus of 3D composites are described, including the Eshlby, Mori-Tanaka, orientation averaging, binary and unit cell methods. Models for predicting the failure strength are also described, such as the unit cell, binary and curved beam methods. The accuracy and limitations of models for determining the in-plane properties of 3D composites are assessed, and the need for more reliable models is discussed.

The performance of 3D composites made by weaving, braiding, knitting, stitching and z-pinning are described in Chapters 5 to 9, respectively. The in-plane mechanical properties and failure mechanisms of 3D composites under tension, compression, bending and fatigue loads are examined. Improvements to the interlaminar fracture toughness, impact resistance and damage tolerance of 3D composites are also described in detail. In these chapters the gaps in our understanding of the mechanical performance and through-thickness properties of 3D composites are identified for future research.

We thank our colleagues with whom we have researched and developed 3D composites over the last ten years, in particular to Professor I. Herszberg, Professor G.P. Steven, Dr P. Tan, Dr K.H. Leong, Dr P.J. Callus, Dr P. Falzon, Mr K. Houghton, Dr L.K. Jain and Dr B.N. Cox. We are thankful to many colleagues, in particular to Professors T.-W. Chou, O.O. Ochoa, and P. Smith, for their kind encouragement in the initiation of this project. We are indebted to the University of Sydney, the Royal Melbourne Institute of Technology and the Cooperative Research Centre for Advanced Composite Structures Ltd. for allowing the use of the facilities we required in the preparation of this book. LT and APM are grateful for funding support of the Australian Research Council (Grant No. C00107070, DP0211709), Boeing Company, and Boeing (Hawker de Havilland) as well as the Cooperative Research Centre for Advanced Composite Structures Ltd. We are also thankful to the many organisations that kindly granted permission to use their photographs, figures and diagrams in the book.

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Table of Contents