

Composites forming technologies

Related titles:

Geosynthetics in civil engineering

(ISBN-13: 978-1-85573-607-8; ISBN-10: 1-85573-607-1)

Geosynthetics are essential to civil engineering and have a multitude of applications. The first part of the book looks at design principles for geosynthetics, their material properties and durability, and the range of national and international standards governing their use. Part II reviews the range of applications for synthetics as well as quality assurance issues. There are chapters on geosynthetic applications as filters, separators and barrier materials, in improving building foundations and landfill sites, and as limited design life materials.

Multi-scale modelling of composite material systems

(ISBN-13: 978-1-85573-936-9; ISBN-10: 1-85573-936-4)

This book focuses on the fundamental understanding of composite materials at the microscopic scale, from designing microstructural features to the predictive equations of the functional behaviour of the structure for a specific end-application. The papers presented discuss stress- and temperature-related behavioural phenomena based on knowledge of physics of microstructure and microstructural change over time.

Durability of composites for civil structural applications

(ISBN-13: 978-1-84569-035-9; ISBN-10: 1-84569-035-4)

This comprehensive book on the durability of FRP composites will make it easier for the practising civil engineer and designer to use these materials on a routine basis. It addresses the current lack, or inaccessibility, of data related to the durability of these materials, which is proving to be one of the major challenges to the widespread acceptance and implementation of FRP composites in civil infrastructure. The book should help further the acceptance of composites for civil structural applications by providing a source for practising engineers, decision makers, and students involved in architectural engineering, construction and materials, disaster reduction, environmental engineering, maritime structural technology, transportation engineering and urban planning.

Details of this book and a complete list of Woodhead's titles can be obtained by:

- visiting our website at www.woodheadpublishing.com
- contacting Customer Services (e-mail: sales@woodhead-publishing.com; fax: +44 (0) 1223 893694; tel.: +44 (0) 1223 891358 ext. 130; address: Woodhead Publishing Limited, Abington Hall, Abington, Cambridge CB21 6AH, England)

If you would like to receive information on forthcoming titles in this area, please send your address details to: Francis Dodds (address, tel. and fax as above; e-mail: francisd@woodhead-publishing.com). Please confirm which subject areas you are interested in.

Composites forming technologies

Edited by
A. C. Long



The Textile Institute



CRC Press
Boca Raton Boston New York Washington, DC

WOODHEAD PUBLISHING LIMITED
Cambridge England

Published by Woodhead Publishing Limited in association with The Textile Institute
Woodhead Publishing Limited
Abington Hall, Abington
Cambridge CB21 6AH, England
www.woodheadpublishing.com

Published in North America by CRC Press LLC
6000 Broken Sound Parkway, NW
Suite 300, Boca Raton FL 33487, USA

First published 2007, Woodhead Publishing Limited and CRC Press LLC
© 2007, Woodhead Publishing Limited
The authors have asserted their moral rights.

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. Reasonable efforts have been made to publish reliable data and information, but the authors and the publishers cannot assume responsibility for the validity of all materials. Neither the authors nor the publishers, nor anyone else associated with this publication, shall be liable for any loss, damage or liability directly or indirectly caused or alleged to be caused by this book.

Neither this book nor any part may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, microfilming and recording, or by any information storage or retrieval system, without permission in writing from Woodhead Publishing Limited.

The consent of Woodhead Publishing Limited does not extend to copying for general distribution, for promotion, for creating new works, or for resale. Specific permission must be obtained in writing from Woodhead Publishing Limited for such copying.

Trademark notice: product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation, without intent to infringe.

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

Library of Congress Cataloguing in Publication Data

A catalog record for this book is available from the Library of Congress

Woodhead Publishing Limited ISBN-13: 978-1-84569-033-5 (book)

Woodhead Publishing Limited ISBN-10: 1-84569-033-8 (book)

Woodhead Publishing Limited ISBN-13: 978-1-84569-253-7 (e-book)

Woodhead Publishing Limited ISBN-10: 1-84569-253-5 (e-book)

CRC Press ISBN-13: 978-0-8493-9102-6

CRC Press ISBN-10: 0-8493-9102-4

CRC Press order number: WP9102

The publishers' policy is to use permanent paper from mills that operate a sustainable forestry policy, and which has been manufactured from pulp which is processed using acid-free and elementary chlorine-free practices. Furthermore, the publishers ensure that the text paper and cover board used have met acceptable environmental accreditation standards.

Project managed by Macfarlane Production Services, Dunstable, Bedfordshire, England
(macfarl@aol.com)

Typeset by Godiva Publishing Services Ltd, Coventry, West Midlands, England

Printed by TJ International Limited, Padstow, Cornwall, England

Contents

<i>Contributor contact details</i>	xi
<i>Introduction</i>	xv
1 Composite forming mechanisms and materials characterisation	1
A C LONG and M J CLIFFORD, University of Nottingham, UK	
1.1 Introduction	1
1.2 Intra-ply shear	3
1.3 Axial loading	9
1.4 Ply/tool and ply/ply friction	10
1.5 Ply bending	12
1.6 Compaction/consolidation	14
1.7 Discussion	19
1.8 References	19
2 Constitutive modelling for composite forming	22
R AKKERMAN and E A D LAMERS, University of Twente, The Netherlands	
2.1 Introduction	22
2.2 Review on constitutive modelling for composite forming	22
2.3 Continuum based laminate modelling	29
2.4 Multilayer effects	34
2.5 Parameter characterisation	35
2.6 Future trends	43
2.7 References	44

3	Finite element analysis of composite forming	46
	P BOISSE, INSA de Lyon, France	
3.1	Introduction: finite element analyses of composite forming, why and where?	46
3.2	The multiscale nature of composite materials and different approaches for composite forming simulations	48
3.3	The continuous approach for composite forming process analysis	50
3.4	Discrete or mesoscopic approach	57
3.5	Semi-discrete approach	59
3.6	Multi-ply forming and re-consolidation simulations	70
3.7	Conclusions	75
3.8	References	75
4	Virtual testing for material formability	80
	S V LOMOV, Katholieke Universiteit Leuven, Belgium	
4.1	Introduction	80
4.2	Mechanical model of the internal geometry of the relaxed state of a woven fabric	82
4.3	Model of compression of woven fabric	84
4.4	Model of uniaxial and biaxial tension of woven fabric	89
4.5	Model of shear of woven fabric	93
4.6	Parametric description of fabric behaviour under simultaneous shear and tension	96
4.7	Conclusions: creating input data for forming simulations	111
4.8	References	112
5	Optimization of composites forming	117
	W-R YU, Seoul National University, Korea	
5.1	Introduction	117
5.2	General aspects of optimization	118
5.3	Optimization of composite forming	126
5.4	Conclusions	142
5.5	References	142
6	Simulation of compression moulding to form composites	144
	E SCHMACHTENBERG, Universität Erlangen-Nürnberg, Germany and K SKRODOLIES, Institut für Kunststoffverarbeitung, Germany	
6.1	Introduction	144
6.2	Theoretical description of the simulation	145

6.3	Examples of use of the simulation	161
6.4	Measurement of the material data	172
6.5	References	174
6.6	Symbols	175
7	Understanding composite distortion during processing	177
	M R WISNOM and K D POTTER, University of Bristol, UK	
7.1	Introduction	177
7.2	Fundamental mechanisms causing residual stresses and distortion	177
7.3	Distortion in flat parts	181
7.4	Spring-in of curved parts	186
7.5	Distortion in more complex parts	192
7.6	Conclusions	194
7.7	References	195
8	Forming technology for composite/metal hybrids	197
	J SINKE, Technical University Delft, The Netherlands	
8.1	Introduction	197
8.2	Development of composite/metal hybrids	198
8.3	Properties of fibre metal laminates	201
8.4	Production processes for fibre metal laminates	205
8.5	Modelling of FML	213
8.6	Conclusions	218
8.7	References	219
9	Forming self-reinforced polymer materials	220
	I M WARD and P J HINE, University of Leeds, UK and D E RILEY, Propex Fabrics, Germany	
9.1	Introduction	220
9.2	The hot compaction process	220
9.3	Commercial exploitation	224
9.4	Postforming studies	225
9.5	Key examples of commercial products	232
9.6	Future developments	235
9.7	Acknowledgements	236
9.8	References	236

10	Forming technology for thermoset composites	239
	R PATON, Cooperative Research Centre for Advanced Composite Structures Ltd, Australia	
10.1	Introduction	239
10.2	Practicalities of forming thermoset prepreg stacks	240
10.3	Deformation mechanisms in woven fabric prepreg	241
10.4	Tape prepreg	247
10.5	Forming processes	248
10.6	Tooling equipment	250
10.7	Diaphragm forming tooling	251
10.8	Potential problems	252
10.9	Process capabilities	253
10.10	Future trends	253
10.11	References	254
11	Forming technology for thermoplastic composites	256
	R BROOKS, University of Nottingham, UK	
11.1	Introduction	256
11.2	Thermoplastic composite materials (TPCs) for forming	256
11.3	Basic principles of TPC forming technologies	262
11.4	Forming methods	264
11.5	Some recent developments	273
11.6	Conclusions	275
11.7	References	275
12	The use of draping simulation in composite design	277
	J W KLINTWORTH, MSC Software Ltd, UK and A C LONG, University of Nottingham, UK	
12.1	Introduction	277
12.2	Zone and ply descriptions	277
12.3	Composites development process	278
12.4	Composites data exchange	281
12.5	Draping and forming simulation	282
12.6	Linking forming simulation to component design analysis	284
12.7	Conclusions	291
12.8	References	292

13	Benchmarking of composite forming modelling techniques	293
	J L GORCZYCA-COLE and J CHEN, University of Massachusetts Lowell, USA and J CAO, Northwestern University, USA	
13.1	Introduction	293
13.2	Forming process and fabric properties	295
13.3	Experimental	297
13.4	Numerical analyses	313
13.5	Conclusions and future trends	315
13.6	Acknowledgements	316
13.7	References and further reading	317
	<i>Index</i>	318

Contributor contact details

(* = main contact)

Editor

A.C. Long
School of Mechanical Materials and
Manufacturing Engineering
University of Nottingham
University Park
Nottingham NG7 2RD
UK

E-mail:

Andrew.Long@nottingham.ac.uk

Chapter 1

A.C. Long* and M.J. Clifford
School of Mechanical Materials and
Manufacturing Engineering
University of Nottingham
University Park
Nottingham NG7 2RD
UK

E-mail:

mike.clifford@nottingham.ac.uk

Chapter 2

R. Akkerman* and E.A.D. Lamers
Construerende Technische
Wetenschappen
Universiteit Twente – CTW
Postbus 217

7500AE Enschede
The Netherlands

E-mail: r.akkerman@ctw.utwente.nl

Chapter 3

P. Boisse
Laboratoire de Mécanique des
Contacts et des Solides
UMR CNRS 5514
INSA de Lyon
France

E-mail:

Philippe.Boisse@insa-lyon.fr

Chapter 4

S. Lomov
Department of Metallurgy and
Materials Engineering
Kasteelpark Arenberg 44
BE-3001 Heverlee
Belgium

E-mail:

stepan.lomov@mtm.kuleuven.be

Chapter 5

W.-R. Yu
Dept. of Materials Science and
Engineering
College of Engineering

Seoul National University
San 56-1 Silim dong
Gwanak-gu
Seoul 151-744
Korea

E-mail: woongryu@snu.ac.kr

Chapter 6

E. Schmachtenberg
Universität Erlangen-Nürnberg
Lehrstuhl für Kunststofftechnik
Am Weichselgarten 9
91058 Erlangen-Tennenlohe
Germany

E-mail: Schmachtenberg@lkt.uni-
erlangen.de

K. Skrodolies
Institute of Plastics Processing at
RWTH Aachen University
Pontstraße 49
52062 Aachen
Germany
E-mail: zentrale@ikv.rwth-aachen.de

Chapter 7

M. R. Wisnom* and K. D. Potter
Professor of Aerospace Structures
University of Bristol
Advanced Composites Centre for
Innovation and Science
Queens Building 0.64
University Walk
Bristol BS8 1TR
UK

E-mail: M.Wisnom@bristol.ac.uk

Chapter 8

J. Sinke
Faculty of Aerospace Engineering
Technical University Delft

Aerospace Materials and
Manufacturing
Kluyverweg 1
2629HS, Delft
The Netherlands

E-mail: j.sinke@tudelft.nl

Chapter 9

I.M. Ward*, P.J. Hine and
D.E. Riley
IRC in Polymer Science &
Technology
School of Physics and Astronomy
University of Leeds
Leeds LS2 9JT
UK

E-mail: I.M.Ward@leeds.ac.uk
p.j.hine@leeds.ac.uk
Derek.Riley@propexfabrics.com

Chapter 10

R. Paton
Cooperative Research Centre for
Advanced Composite Structures
Ltd
506 Lorimer St, Fishermens Bend
Port Melbourne, 3207
Australia

E-mail: r.paton@crc-accs.com.au

Chapter 11

R. Brooks
School of Mechanical Materials and
Manufacturing Engineering
University of Nottingham
University Park
Nottingham NG7 2RD
UK

E-mail:
richard.brooks@nottingham.ac.uk

Chapter 12

J.W. Klintworth* and A.C. Long
MSC Software Ltd
MSC House
Lyon Way
Frimley
Camberley
Surrey GU16 7ER
UK

E-mail:
john.klintworth@mscsoftware.com

Chapter 13

J.L. Gorczyca-Cole and J. Chen*
University of Massachusetts Lowell
One University Avenue
Lowell, MA 01854
USA

E-mail: Julie_chen@uml.edu

J. Cao
Department of Mechanical
Engineering
Northwestern University
2145 Sheridan Road
Evanston, IL 60208-3111
USA

E-mail: jcao@northwestern.edu

Composite materials are available in many forms and are produced using a variety of manufacturing methods. A range of fibre types is used – primarily carbon and glass – and these can be combined with a variety of polymer matrices. This book concentrates on ‘long’ fibre composites, including fibres from a few centimetres in length (i.e. excluding injection moulding compounds). So the processing methods of interest include compression moulding of thermoplastic or thermoset moulding compounds; resin transfer moulding based on dry fibre preforms; forming and consolidation of thermoset prepreg and thermoplastic sheets; and forming of new material forms including composite/metal laminates and polymer/polymer (self-reinforced) composites.

Whatever the material form or manufacturing process, there is one common step: forming of initially planar material into a three dimensional shape. This is the focus of ‘Composite Forming Technologies’. The book includes descriptions of industrial forming processes, case studies and applications, and methods used to simulate composite forming. This description is intended for manufacturers of polymer composite components, end-users and designers, researchers in the fields of structural materials and manufacturing, and materials suppliers. Whilst the bulk of the text is devoted to modelling tools, the intention is to provide useful guidance and to inform the reader of the current status and limitations of both research and commercial tools. It is hoped that this will form essential reading for the users of such modelling tools, whilst encouraging others to ‘take the plunge’ and adopt a simulation approach to manufacturing process design.

This text may be considered broadly in two halves, with Chapters 1–7 covering the fundamental aspects of modelling and simulation, and Chapters 8–13 describing practical aspects including manufacturing technologies and modern practices in composites design. The first chapter provides a comprehensive introduction to the range of deformation mechanisms that can occur during forming for a range of materials, along with appropriate test methods and representative data. Chapter 2 describes fundamental constitutive models as required for composite forming, including the bases for commercial kinematic (draping) and mechanical (forming) simulations. The latter topic is

continued in Chapter 3, including a detailed description of finite element simulation techniques for forming of dry fabric preforms. The methodology here can be considered similar to that used for sheet metal forming, albeit with a more complex material model. Chapter 4 continues the modelling theme, with a description of 'virtual testing', whereby materials input data for forming simulation are predicted from the material structure. This topic is of particular interest, as it may offer the opportunity to select materials that are fit-for-forming, or even to design new materials with a specific component in mind. Chapter 5 details the use of modern simulation techniques for composite forming within an optimisation scheme, with the aim of selecting materials and process parameters to eliminate such defects as wrinkling or undesirable fibre orientations. Chapter 6 describes the methodology and current status of simulation tools for compression moulding, including applications to sheet moulding compound (SMC) and glass mat thermoplastic (GMT). The following chapter completes the initial treatment of simulation and modelling, with a description of composite distortion – notably the common phenomenon of 'spring-in' – caused by manufacturing induced stresses.

The second half of the book begins with four chapters describing forming technologies for a range of materials. This begins with a relatively new family of materials – composite/metal hybrids – which have recently found applications in the aerospace sector (notably as fuselage panels for the Airbus A380). Another new family is covered next, referred to as 'self-reinforced polymers'. These materials include fibre and matrix from the same polymer material, addressing one of the current concerns for polymer composites – recycling. The next two chapters cover more conventional materials – thermoset prepreg and thermoplastic composite sheet. Prepreg forming technologies are described in detail, from the traditional hand lay-up and autoclave cure approach to current developments in automated tape placement and diaphragm forming. The thermoplastics chapter includes a detailed description of the range of material forms, along with their appropriate forming and consolidation techniques. Chapter 12 describes the current state-of-the-art in simulation software for composite forming within an industrial context, detailing the use of modern software tools to design the material lay-up, and describing how these tools can be integrated within the manufacturing environment. Finally Chapter 13 covers the issue of benchmarking of composite forming. This topic is particularly timely, drawing on current worldwide efforts to compare both formability characterisation tests and forming simulation tools for benchmark materials. It is hoped that this will lead to standardisation of formability testing – a key requirement for more widespread use of analysis tools – and guidelines on the accuracy of the range of simulation approaches that are currently available.