Modelling and predicting textile behaviour

The Textile Institute and Woodhead Publishing

The Textile Institute is a unique organisation in textiles, clothing and footwear. Incorporated in England by a Royal Charter granted in 1925, the Institute has individual and corporate members in over 90 countries. The aim of the Institute is to facilitate learning, recognise achievement, reward excellence and disseminate information within the global textiles, clothing and footwear industries.

Historically, The Textile Institute has published books of interest to its members and the textile industry. To maintain this policy, the Institute has entered into partnership with Woodhead Publishing Limited to ensure that Institute members and the textile industry continue to have access to high calibre titles on textile science and technology.

Most Woodhead titles on textiles are now published in collaboration with The Textile Institute. Through this arrangement, the Institute provides an Editorial Board which advises Woodhead on appropriate titles for future publication and suggests possible editors and authors for these books. Each book published under this arrangement carries the Institute's logo.

Woodhead books published in collaboration with The Textile Institute are offered to Textile Institute members at a substantial discount. These books, together with those published by The Textile Institute that are still in print, are offered on the Woodhead web site at: www.woodheadpublishing.com. Textile Institute books still in print are also available directly from the Institute's website at: www.textileinstitutebooks.com.

A list of Woodhead books on textile science and technology, most of which have been published in collaboration with The Textile Institute, can be found towards the end of the contents pages.

Woodhead Publishing Series in Textiles: Number 94

Modelling and predicting textile behaviour

Edited by X. Chen





CRC Press Boca Raton Boston New York Washington, DC

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

Woodhead Publishing India Private Limited, G-2, Vardaan House, 7/28 Ansari Road, Daryaganj, New Delhi – 110002, India www.woodheadpublishingindia.com

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

First published 2010, Woodhead Publishing Limited and CRC Press LLC © Woodhead Publishing Limited, 2010
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 Cataloging in Publication Data A catalog record for this book is available from the Library of Congress.

Woodhead Publishing ISBN 978-1-84569-416-6 (book) Woodhead Publishing ISBN 978-1-84569-721-1 (e-book) CRC Press ISBN 978-1-4398-0107-9 CRC Press order number N10008

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 elemental chlorine-free practices. Furthermore, the publishers ensure that the text paper and cover board used have met acceptable environmental accreditation standards.

Typeset by Replika Press Pvt Ltd, India Printed by TJ International Limited, Padstow, Cornwall, UK

Contents

Contril	butor contact details	xi
Woodh	ead Publishing Series in Textiles	xv
Preface		xxi
Part I	Modelling the structure and behaviour of textiles	
1	Structural hierarchy in textile materials: an overview X. Chen and J. W. S. Hearle, The University of Manchester, UK	3
1.1	The textile hierarchy	3
1.2	Modelling of fibres from the molecular level	4
1.3	Modelling fibre behaviour	11
1.4	Modelling yarns and cords	14
1.5	Modelling fabrics	18
1.6	Sources of further information	37
1.7	References	37
2	Fundamental modelling of textile fibrous structures S. Grishanov, De Montfort University, UK	41
2.1	Introduction	41
2.2	Fibre classification	43
2.3	Fibre functions in textile materials and composites	43
2.4	Modelling fibre structure	47
2.5	Statistical models of fibre geometry	52
2.6	Modelling mechanical behaviour of single fibres	68
2.7	Viscoelastic properties of fibres	76
2.8	Modelling fibre friction	86
2.9	Modelling fibre assemblies	89
2.10	Conclusions	102
2 11	References	103

vi	Contents	
3	Yarn modelling R. Ognjanovic, Innoval Technology Limited, UK	112
3.1	Introduction	112
3.2	Yarn construction	113
3.3	Types of models to predict the structure and properties of	115
3.3	yarns	114
3.4	Applications and examples	136
3.5	Future trends in yarn modelling	138
3.6	Sources of further information and advice	139
3.7	References	140
4	Modelling the structures and properties of woven	
	fabrics	144
	E. VIDAL-SALLE and P. BOISSE, INSA Lyon, France	
4.1	Introduction: The importance and objectives of modelling	
	woven fabrics	144
4.2	The mechanical behaviour of woven fabrics	145
4.3	Different approaches for modelling the mechanical	
	behaviour of woven fabrics at different scales	148
4.4	Structure and geometry of the unit woven cell	153
4.5	Specific experimental tests	155
4.6	3D simulation of the deformation of the unit woven cell	
	at the mesoscopic level	161
4.7	Image analyses: Full field digital image correlation	
	measurements and X-ray tomography	172
4.8	Conclusions and future trends	174
4.9	References	175
5	Modelling of nonwoven materials	180
J	N. Mao and S. J. Russell, University of Leeds, UK	100
5.1	Introduction	180
5.2	Constructing physical models of nonwoven structure	182
5.3	Modelling of pore size and pore size distribution in	
	nonwoven fabrics	185
5.4	Tensile strength	189
5.5	Modelling the bending rigidity of nonwoven fabrics	192
5.6	Modelling the specific permeability of nonwovens	193
5.7	Thermal resistance and thermal conductivity	204
5.8	Acoustic impedance	207
5.9	Particle filtration in nonwoven filters	212
5.10	Future trends and sources of further information and	
	advice	219
5.11	References	220

	Contents	vii
6	Modelling and visualization of knitted fabrics Y. Kyosev, Niederrhein University of Applied Sciences, Germany, W. Renkens, Renkens Consulting, Germany	225
6.1	Aim and objectives of modelling knitted structures	225
6.2	Classification of knitted structures	226
6.3	Scales in the structure	228
6.4	Structural elements of knitted structures at the meso-scale	231
6.5	Modelling steps	236
6.6	Model building	237
6.7	Post-processing	256
6.8	Other types of model	257
6.9	Application areas of the simulated fabrics and future	
	trends	257
6.10	Conclusions	258
6.11	References	259
Part II	Case studies	
7	Modelling of fluid flow and filtration through woven fabrics	265
	M. A. NAZARBOLAND, X. CHEN and J. W. S. HEARLE, University of Manchester, UK, and R. Lydon and M. Moss, Clear Edge Group, UI	
7.1	Introduction	265
7.2	Various techniques in modelling fluid flow and filtration	267
7.3	Model design and analysis	271
7.4	Influence of fabric parameters on flow performance	285
7.5	Influence of fluid flow and fabric parameters on filtration	
	performance	299
7.6	Influence of particle properties on filtration performance	306
7.7	Application of fluid flow and filtration modelling	316
7.8	Future trends	317
7.9	References	318
8	Modelling, simulation and control of textile dyeing R. Shamey, North Carolina State University, USA	322
8.1	Introduction	322
8.2	Sorption isotherms	323
8.3	Dye diffusion models	326
8.4	Models relating dyeing parameters to the quality of	
	dyeing	328
8.5	Numerical simulation of package dyeing	347
8.6	Applications	353

viii	Contents	
8.7	Future trends	356
8.8	Acknowledgment	356
8.9	References	356
9	Modelling colour properties for textiles D. P. Oulton, The University of Manchester, UK	360
9.1	Introduction	360
9.2	Types of model used	364
9.3	Case study in colour communication	376
9.4	Future trends in colour modelling	381
9.5	Commercial vendors and their products	384
9.6	References	385
10	3D modelling, simulation and visualisation techniques	200
	for drape textiles and garments F. HAN and G. K. STYLIOS, Heriot-Watt University, UK	388
10.1	Introduction	388
10.2	Review of 3D textile models	389
10.3	Automatic measurement of fabric mechanics	392
10.4	Drape measurement and evaluation	393
10.5	Key principles of 3D mass-spring models	398
10.6	Clothing simulation: strengths, limitations and suggested	
	improvements	403
10.7	Experimental results and discussions	406
10.8	Applications and examples	410
10.9	Conclusions and future trends	418
10.10	References	419
11	Recognition, differentiation and classification of	
	regular repeating patterns in textiles M. A. Hann and B. G. Thomas, University of Leeds, UK	422
11.1	Introduction	422
11.2	Study of pattern: historical precedents	423
11.3	Symmetry in pattern: fundamental concepts	426
11.4	Classification of motifs	430
11.5	The seven classes of border patterns	432
11.6	The 17 classes of all-over patterns	436
11.7	Colour symmetry	450
11.8	Conclusions	452
11.9	References	453

Contents	ix	
----------	----	--

12	Mathematical and mechanical modelling of 3D cellular textile composites for protection against trauma	
	impact	457
	X. CHEN, The University of Manchester, UK	
12.1	Introduction	457
12.2	Mathematical description of cellular textile structures	459
12.3	Computer aided design/computer aided manufacturing	
	(CAD/CAM) of 3D cellular woven fabrics	462
12.4	Experimental study of properties of 3D cellular	
	composites	468
12.5	Theoretical characterisation of 3D cellular composites	476
12.6	Discussions and conclusions	490
12.7	Future trends	492
12.8	References	492
13	Development and application of expert systems in	
	the textile industry	494
	R. SHAMEY, W. S. SHIM and J. A. JOINES, North Carolina State University, USA	
13.1	Introduction	494
13.2	System principles	499
13.3	Strengths and limitations of expert systems	507
13.4	Applications of expert systems in the textile industry	509
13.5	Future trends	514
13.6	Sources of further information and advice	514
13.7	References	514
	Index	521

Contributor contact details

(*= main contact)

Chapter 1

Dr Xiaogang Chen* and Professor John Hearle School of Materials The University of Manchester Manchester M60 1QD UK

Email: xiaogang.chen@manchester. ac.uk

Chapter 2

Dr Sergei Grishanov TEAM Research Group De Montfort University The Gateway Leicester LE1 9BH UK

Email: gsa@dmu.ac.uk

Chapter 3

Dr Rade Ognjanovic Innoval Technology Limited Beaumont Close Banbury OX16 1TQ UK

Email: rade.ognjanovic@innovaltec.com

Chapter 4

Dr Emmanuelle Vidal-Salle and Professor Philippe Boisse* INSA Lyon 20, rue Albert Einstein 69621 Villeurbanne Cedex France

Email: philippe.boisse@insa-lyon.fr emmanuelle.vidal-salle@insa-lyon.fr

Chapter 5

Dr Ningtao Mao,* S. J Russell Centre for Technical Textiles University of Leeds Leeds LS2 9JT UK

Email: n.mao@leeds.ac.uk

Chapter 6

Professor Dr Yordan Kyosev*
Department of Textile and Clothing
Technology
Niederrhein University of Applied
Sciences
D-41065 Mönchengladbach
Germany

Email: yordan.kyosev@hs-niederrhein.de

Dipl.-Ing. Wilfried Renkens Renkens Consulting Tittardsfeld 102 D-52072 Germany

Email: W.Renkens@gmx.de

Chapter 7

Dr Mohammad Ali Nazarboland,*
Dr Xiaogang Chen and Professor
John W. S. Hearle
School of Materials
The University of Manchester
Manchester
M60 1QD
UK

Email: Nazarboland@gmail.com xiaogang.chen@manchester.ac.uk

Professor Richard Lydon and Martin Moss Clear Edge Group Knowsley Rd Industrial Estate Haslingden BB4 4EJ UK

Chapter 8

Professor Renzo Shamey North Carolina State University Raleigh NC 27695-8301 USA

Email: rshamey@ncsu.edu

Chapter 9

David P. Oulton School of Materials Sackville St Building The University of Manchester Manchester M60 1QD UK

Email: david.oulton@manchester. ac.uk

Chapter 10

Dr Fan Han*
Middlesex University
London
NW4 4BT
UK

Email: fanhankw@yahoo.co.uk

Professor George K. Stylios Heriot-Watt University Edinburgh EH14 4AS Scotland

Email: G.Stylios@hw.ac.uk

Chapter 11

Professor Michael Hann* and Dr Briony G. Thomas School of Design University of Leeds Leeds LS2 9JT UK

Email: m.a.hann@leeds.ac.uk B.G.Thomas@leeds.ac.uk

Chapter 12

Dr Xiaogang Chen School of Materials The University of Manchester PO Box 88 Manchester M60 1QD UK

Email: xiaogang.chen@manchester. ac.uk

Chapter 13

Professor Renzo Shamey,*
Dr W Shim and Professor
J.A. Joines
North Carolina State University
Raleigh
NC 27695-8301
USA

Email: rshamey@ncsu.edu

Woodhead Publishing Series in Textiles

1 Watson's textile design and colour Seventh edition

Edited by Z. Grosicki

2 Watson's advanced textile design

Edited by Z. Grosicki

3 Weaving Second edition

P. R. Lord and M. H. Mohamed

4 Handbook of textile fibres Vol 1: Natural fibres

J. Gordon Cook

5 Handbook of textile fibres Vol 2: Man-made fibres

J. Gordon Cook

6 Recycling textile and plastic waste

Edited by A. R. Horrocks

7 New fibers Second edition

T. Hongu and G. O. Phillips

8 Atlas of fibre fracture and damage to textiles Second edition

J. W. S. Hearle, B. Lomas and W. D. Cooke

9 Ecotextile '98

Edited by A. R. Horrocks

10 Physical testing of textiles

B. P. Saville

11 Geometric symmetry in patterns and tilings

C. E. Horne

12 Handbook of technical textiles

Edited by A. R. Horrocks and S. C. Anand

13 Textiles in automotive engineering

W. Fung and J. M. Hardcastle

14 Handbook of textile design

J. Wilson

15 High-performance fibres

Edited by J. W. S. Hearle

16 Knitting technology Third edition

D. J. Spencer

17 Medical textiles

Edited by S. C. Anand

18 Regenerated cellulose fibres

Edited by C. Woodings

19 Silk, mohair, cashmere and other luxury fibres

Edited by R. R. Franck

20 Smart fibres, fabrics and clothing

Edited by X. M. Tao

21 Yarn texturing technology

J. W. S. Hearle, L. Hollick and D. K. Wilson

22 Encyclopedia of textile finishing

H.-K. Rouette

23 Coated and laminated textiles

W. Fung

24 Fancy yarns

R. H. Gong and R. M. Wright

25 Wool: Science and technology

Edited by W. S. Simpson and G. Crawshaw

26 Dictionary of textile finishing

H.-K. Rouette

27 Environmental impact of textiles

K. Slater

28 Handbook of yarn production

P. R. Lord

29 Textile processing with enzymes

Edited by A. Cavaco-Paulo and G. Gübitz

30 The China and Hong Kong denim industry

Y. Li, L. Yao and K. W. Yeung

31 The World Trade Organization and international denim trading

Y. Li, Y. Shen, L. Yao and E. Newton

32 Chemical finishing of textiles

W. D. Schindler and P. J. Hauser

33 Clothing appearance and fit

J. Fan, W. Yu and L. Hunter

34 Handbook of fibre rope technology

H. A. McKenna, J. W. S. Hearle and N. O'Hear

35 Structure and mechanics of woven fabrics

J. Hu

36 Synthetic fibres: nylon, polyester, acrylic, polyolefin

Edited by J. E. McIntyre

37 Woollen and worsted woven fabric design

E. G. Gilligan

38 Analytical electrochemistry in textiles

P. Westbroek, G. Priniotakis and P. Kiekens

39 Bast and other plant fibres

R. R. Franck

40 Chemical testing of textiles

Edited by Q. Fan

41 Design and manufacture of textile composites

Edited by A. C. Long

42 Effect of mechanical and physical properties on fabric hand

Edited by Hassan M. Behery

43 New millennium fibers

T. Hongu, M. Takigami and G. O. Phillips

44 Textiles for protection

Edited by R. A. Scott

45 Textiles in sport

Edited by R. Shishoo

46 Wearable electronics and photonics

Edited by X. M. Tao

47 Biodegradable and sustainable fibres

Edited by R. S. Blackburn

48 Medical textiles and biomaterials for healthcare

Edited by S. C. Anand, M. Miraftab, S. Rajendran and J. F. Kennedy

49 Total colour management in textiles

Edited by J. Xin

50 Recycling in textiles

Edited by Y. Wang

51 Clothing biosensory engineering

Y. Li and A. S. W. Wong

52 Biomechanical engineering of textiles and clothing

Edited by Y. Li and D. X.-Q. Dai

53 Digital printing of textiles

Edited by H. Ujiie

54 Intelligent textiles and clothing

Edited by H. Mattila

55 Innovation and technology of women's intimate apparel

W. Yu, J. Fan, S. C. Harlock and S. P. Ng

56 Thermal and moisture transport in fibrous materials

Edited by N. Pan and P. Gibson

57 Geosynthetics in civil engineering

Edited by R. W. Sarsby

58 Handbook of nonwovens

Edited by S. Russell

59 Cotton: Science and technology

Edited by S. Gordon and Y.-L. Hsieh

60 Ecotextiles

Edited by M. Miraftab and A. Horrocks

61 Composite forming technologies

Edited by A. C. Long

62 Plasma technology for textiles

Edited by R. Shishoo

63 Smart textiles for medicine and healthcare

Edited by L. Van Langenhove

64 Sizing in clothing

Edited by S. Ashdown

65 Shape memory polymers and textiles

J. Hu

66 Environmental aspects of textile dyeing

Edited by R. Christie

67 Nanofibers and nanotechnology in textiles

Edited by P. Brown and K. Stevens

68 Physical properties of textile fibres Fourth edition

W. E. Morton and J. W. S. Hearle

69 Advances in apparel production

Edited by C. Fairhurst

70 Advances in fire retardant materials

Edited by A. R. Horrocks and D. Price

71 Polyesters and polyamides

Edited by B. L. Deopura, R. Alagirusamy, M. Joshi and B. S. Gupta

72 Advances in wool technology

Edited by N. A. G. Johnson and I. Russell

73 Military textiles

Edited by E. Wilusz

74 **3-D** fibrous assemblies: Properties, applications and modelling of three-dimensional textile structures

J. Hu

75 Medical textiles 2007

Edited by J. Kennedy, A. Anand, M. Miraftab and S. Rajendran

76 Fabric testing

Edited by J. Hu

77 Biologically inspired textiles

Edited by A. Abbott and M. Ellison

78 Friction in textile materials

Edited by B. S. Gupta

79 Textile advances in the automotive industry

Edited by R. Shishoo

80 Structure and mechanics of textile fibre assemblies

Edited by P. Schwartz.

81 Engineering textiles: Integrating the design and manufacture of textile products

Edited by Y. E. El-Mogahzy

82 Polyolefin fibres: Industrial and medical applications

Edited by S. C. O. Ugbolue

83 Smart clothes and wearable technology

Edited by J. McCann and D. Bryson

84 Identification of textile fibres

Edited by M. Houck

85 Advanced textiles for wound care

Edited by S. Rajendran

86 Fatigue failure of textile fibres

Edited by M. Miraftab

87 Advances in carpet technology

Edited by K. Goswami

88 Handbook of textile fibre structure

Edited by S. Eichhorn, J. W. S Hearle, M. Jaffe and T. Kikutani

89 Advances in knitting technology

Edited by T. Dias

90 Smart textile coatings and laminates

Edited by W. C. Smith

91 Handbook of tensile properties of textile and technical fibres

Edited by A. Bunsell

92 Interior textiles: Design and developments

Edited by T. Rowe

93 Textiles for cold weather apparel

Edited by J. Williams

94 Modelling and predicting textile behaviour

Edited by X. Chen

95 Textiles for construction

Edited by G. Pohl

96 Engineering apparel fabrics and garments

J. Fan and L. Hunter

97 Surface modification of textiles

Edited by Q. Wei

98 Sustainable textiles

Edited by R. S. Blackburn