

HANDBOOK OF TECHNICAL TEXTILES

Edited by
A R Horrocks and S C Anand



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
Abington Hall, Abington
Cambridge CB1 6AH
England
www.woodhead-publishing.com

Published in North and South America by CRC Press LLC, 2000 Corporate Blvd, NW
Boca Raton FL 33431, USA

First published 2000, Woodhead Publishing Ltd and CRC Press LLC
© 2000, Woodhead Publishing Ltd except Chapter 16 © MOD
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 the publishers.

The consent of Woodhead Publishing and CRC Press 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 or CRC Press 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 1 85573 385 4

CRC Press ISBN 0-8493-1047-4

CRC Press order number: WP1047

Cover design by The ColourStudio

Typeset by Best-set Typesetter Ltd, Hong Kong

Printed by St Edmundsbury Press, Suffolk, England

To the past and present staff members, support staff and students in Textile Studies at Bolton Institute, for their friendship and support over the years.

Preface

Technical textiles are reported to be the fastest growing sector of the textile industrial sector and account for almost 19% (10 million tonnes) of the total world fibre consumption for all textile uses, totalling 53 tonnes in 1997. This figure is likely to increase to 14 million tonnes by the year 2005. Technical textiles are estimated to account for well over 40% of the total textile production in many developed countries and, at the year 2000, account for almost 20% of all textile manufacturing in China (Byrne 1997).

The current volume of the market worldwide for technical textiles is more than \$60 billion. The average annual growth rate of technical textiles worldwide is expected to be around 3.8% for the period 2000 to 2005.

The uniqueness and challenge of technical textiles lies in the need to understand and apply the principles of textile science and technology to provide solutions, in the main to technological problems but also often to engineering problems as well. With the emphasis on measurable textile performance in a particular field of application, this requires the technologist to have not only an intricate knowledge of fibres and textile science and technology but also an understanding of the application and the scientists, technologists and engineers who service it. Thus the producer of geotextiles requires an intricate knowledge of the world of civil engineering, and the medical textile producer, the requirements of consultant, medical practitioner and nurse. This series attempts to provide a bridge between producer and end-user.

The main principles involved in the selection of raw materials and their conversion into yarns and fabrics followed by dyeing, finishing and coating of technical textiles are explored, followed by the raw materials, processing techniques, finishing, specifications, properties and special technical and commercial features of a wide range of specific areas of application.

Each of the chapters has been specially prepared and edited to cover current developments as well as future trends in both the principles of manufacture and the state-of-the-art constructional specifications, properties, test methods and standards of the major product areas and applications of technical textiles.

A team of internationally famous authors has contributed a great deal of time, effort and above all special and significant expertise and experience to the preparation of this handbook. The editors wish to extend their most sincere thanks to all the authors for their important contribution, patience and cooperation. This book once again confirms that enthusiasm and love of the subject are more important than the financial gains.

Special thanks are also given to Patricia Morrison of Woodhead Publishing Ltd, Cambridge for her consistent interest and effort in keeping this project warm for so long and her continued faith in the editors.

Professor Richard Horrocks
Professor Subhash Anand
Faculty of Technology
Bolton Institute
Deane Road
BOLTON
BL3 5AB
UK

List of contributors

Professor S C Anand

Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Professor P Bajaj

Department of Textile Technology, Indian Institute of Technology, Hauz Khas, New Delhi, India

Mr C Byrne

David Rigby Associates, Peter House, St Peter's Square, Manchester M1 5AQ, UK

Dr X Chen

Department of Textiles, UMIST, P O Box 88, Sackville Street, Manchester M60 1QD, UK

Mr W Fung

Collins and Aikman, P O Box 29, Warley Mills, Walkden, Manchester M28 3WG, UK

Dr R H Gong

Department of Textiles, UMIST, P O Box 88, Sackville Street, Manchester M60 1QD, UK

Dr M Hall

Department of Textiles, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Mr E Hardman

Madison Filters (formerly Scapa Filtration), Haslingden, Rossendale, Lancashire, UK

Dr I Holme

Department of Textiles, University of Leeds, Leeds LS2 1JT, UK

Dr D Holmes

Department of Textiles, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Dr M MirafTAB

Department of Textiles, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Dr S Ogin

School of Mechanical and Materials Engineering, University of Surrey, Guildford, Surrey GU2 7HX, UK

Dr M Pritchard

Department of the Built Environment, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Professor P R Rankilor

9 Blairgowrie Drive, West Tytherington, Macclesfield, Cheshire SK10 2UJ, UK

Mr A J Rigby

Department of Textiles, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Professor S W Sarsby

Department of the Built Environment, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Dr R A Scott

MOD, Defence Clothing and Textiles Agency Science and Technology Division, Flagstaff Road, Colchester, Essex CO2 7SS, UK

Professor K Slater

Department of Textiles, University of Guelph, Guelph, Ontario N1G 2W1, Canada

Dr P Smith

26 Newhall Park, Otley, Leeds LS21 2RD, UK

Mr W Sondhelm

10 Bowlacre Road, Hyde, Cheshire SK14 5ES, UK

HANDBOOK OF TECHNICAL TEXTILES

Edited by
A R Horrocks and S C Anand



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
Abington Hall, Abington
Cambridge CB1 6AH
England
www.woodhead-publishing.com

Published in North and South America by CRC Press LLC, 2000 Corporate Blvd, NW
Boca Raton FL 33431, USA

First published 2000, Woodhead Publishing Ltd and CRC Press LLC
© 2000, Woodhead Publishing Ltd except Chapter 16 © MOD
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 the publishers.

The consent of Woodhead Publishing and CRC Press 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 or CRC Press 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 1 85573 385 4

CRC Press ISBN 0-8493-1047-4

CRC Press order number: WP1047

Cover design by The ColourStudio

Typeset by Best-set Typesetter Ltd, Hong Kong

Printed by St Edmundsbury Press, Suffolk, England

To the past and present staff members, support staff and students in Textile Studies at Bolton Institute, for their friendship and support over the years.

Preface

Technical textiles are reported to be the fastest growing sector of the textile industrial sector and account for almost 19% (10 million tonnes) of the total world fibre consumption for all textile uses, totalling 53 tonnes in 1997. This figure is likely to increase to 14 million tonnes by the year 2005. Technical textiles are estimated to account for well over 40% of the total textile production in many developed countries and, at the year 2000, account for almost 20% of all textile manufacturing in China (Byrne 1997).

The current volume of the market worldwide for technical textiles is more than \$60 billion. The average annual growth rate of technical textiles worldwide is expected to be around 3.8% for the period 2000 to 2005.

The uniqueness and challenge of technical textiles lies in the need to understand and apply the principles of textile science and technology to provide solutions, in the main to technological problems but also often to engineering problems as well. With the emphasis on measurable textile performance in a particular field of application, this requires the technologist to have not only an intricate knowledge of fibres and textile science and technology but also an understanding of the application and the scientists, technologists and engineers who service it. Thus the producer of geotextiles requires an intricate knowledge of the world of civil engineering, and the medical textile producer, the requirements of consultant, medical practitioner and nurse. This series attempts to provide a bridge between producer and end-user.

The main principles involved in the selection of raw materials and their conversion into yarns and fabrics followed by dyeing, finishing and coating of technical textiles are explored, followed by the raw materials, processing techniques, finishing, specifications, properties and special technical and commercial features of a wide range of specific areas of application.

Each of the chapters has been specially prepared and edited to cover current developments as well as future trends in both the principles of manufacture and the state-of-the-art constructional specifications, properties, test methods and standards of the major product areas and applications of technical textiles.

A team of internationally famous authors has contributed a great deal of time, effort and above all special and significant expertise and experience to the preparation of this handbook. The editors wish to extend their most sincere thanks to all the authors for their important contribution, patience and cooperation. This book once again confirms that enthusiasm and love of the subject are more important than the financial gains.

Special thanks are also given to Patricia Morrison of Woodhead Publishing Ltd, Cambridge for her consistent interest and effort in keeping this project warm for so long and her continued faith in the editors.

Professor Richard Horrocks
Professor Subhash Anand
Faculty of Technology
Bolton Institute
Deane Road
BOLTON
BL3 5AB
UK

List of contributors

Professor S C Anand

Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Professor P Bajaj

Department of Textile Technology, Indian Institute of Technology, Hauz Khas, New Delhi, India

Mr C Byrne

David Rigby Associates, Peter House, St Peter's Square, Manchester M1 5AQ, UK

Dr X Chen

Department of Textiles, UMIST, P O Box 88, Sackville Street, Manchester M60 1QD, UK

Mr W Fung

Collins and Aikman, P O Box 29, Warley Mills, Walkden, Manchester M28 3WG, UK

Dr R H Gong

Department of Textiles, UMIST, P O Box 88, Sackville Street, Manchester M60 1QD, UK

Dr M Hall

Department of Textiles, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Mr E Hardman

Madison Filters (formerly Scapa Filtration), Haslingden, Rossendale, Lancashire, UK

Dr I Holme

Department of Textiles, University of Leeds, Leeds LS2 1JT, UK

Dr D Holmes

Department of Textiles, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Dr M Miraftab

Department of Textiles, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Dr S Ogin

School of Mechanical and Materials Engineering, University of Surrey, Guildford, Surrey GU2 7HX, UK

Dr M Pritchard

Department of the Built Environment, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Professor P R Rankilor

9 Blairgowrie Drive, West Tytherington, Macclesfield, Cheshire SK10 2UJ, UK

Mr A J Rigby

Department of Textiles, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Professor S W Sarsby

Department of the Built Environment, Faculty of Technology, Bolton Institute, Deane Road, Bolton BL3 5AB, UK

Dr R A Scott

MOD, Defence Clothing and Textiles Agency Science and Technology Division, Flagstaff Road, Colchester, Essex CO2 7SS, UK

Professor K Slater

Department of Textiles, University of Guelph, Guelph, Ontario N1G 2W1, Canada

Dr P Smith

26 Newhall Park, Otley, Leeds LS21 2RD, UK

Mr W Sondhelm

10 Bowlacre Road, Hyde, Cheshire SK14 5ES, UK

Contents

Preface	xiii
List of contributors	xv
1 Technical textiles market – an overview	1
<i>Chris Byrne</i>	
1.1 Introduction	1
1.2 Definition and scope of technical textiles	2
1.3 Milestones in the development of technical textiles	6
1.4 Textile processes	10
1.5 Applications	11
1.6 Globalisation of technical textiles	18
1.7 Future of the technical textiles industry	19
References	23
2 Technical fibres	24
<i>Mohsen MirafTAB</i>	
2.1 Introduction	24
2.2 Conventional fibres	25
2.3 High strength and high modulus organic fibres	29
2.4 High chemical- and combustion-resistant organic fibres	30
2.5 High performance inorganic fibres	31
2.6 Ultra-fine and novelty fibres	33
2.7 Civil and agricultural engineering	34
2.8 Automotive and aeronautics	36
2.9 Medical and hygiene applications	37
2.10 Protection and defence	38
2.11 Miscellaneous	39
2.12 Conclusions	39
References	40

3	Technical yarns	42
	<i>X Chen and R H Gong</i>	
3.1	Introduction	42
3.2	Staple fibre yarns	42
3.3	Filament yarns	55
	Bibliography	60
4	Technical fabric structures – 1. Woven fabrics	62
	<i>Walter S Sondhelm</i>	
4.1	Introduction	62
4.2	Weave structures	63
4.3	Selvedge	74
4.4	Fabric specifications and fabric geometry	77
4.5	Weaving – machines (looms) and operations	80
4.6	The future	94
	References	94
5	Technical fabric structures – 2. Knitted fabrics	95
	<i>Subhash C Anand</i>	
5.1	Terms and definitions	95
5.2	Weft knitting machines	97
5.3	Weft-knitted structures	105
5.4	Process control in weft knitting	105
5.5	End-use applications of weft-knitted fabrics	110
5.6	Warp-knitting machines	113
5.7	Warp-knitted structures	119
	References	129
6	Technical fabric structures – 3. Nonwoven fabrics	130
	<i>Philip A Smith</i>	
6.1	Introduction	130
6.2	Methods of batt production using carding machines	131
6.3	Air laying	134
6.4	Wet laying	136
6.5	Dry laying wood pulp	136
6.6	Spun laying	137
6.7	Flash spinning	138
6.8	Melt blown	139
6.9	Chemical bonding	140
6.10	Thermal bonding	143
6.11	Solvent bonding	145
6.12	Needle felting	145
6.13	Stitch bonding	148
6.14	Hydroentanglement	150
	Bibliography	151
7	Finishing of technical textiles	152
	<i>Michael E Hall</i>	
7.1	Introduction	152
7.2	Finishing processes	152

7.3	Mechanical finishes	153
7.4	Heat setting	161
7.5	Chemical processes	164
	References	172
8	Coating of technical textiles	173
	<i>Michael E Hall</i>	
8.1	Introduction	173
8.2	Chemistry of coated textiles	173
8.3	Coating techniques	179
8.4	Fusible interlinings	183
8.5	Laminating	185
	References	186
9	Coloration of technical textiles	187
	<i>Ian Holme</i>	
9.1	Introduction	187
9.2	Objectives of coloration	187
9.3	Coloration of technical textiles	188
9.4	Dye classes and pigments	192
9.5	Mass coloration of artificial fibres	200
9.6	Conventional dyeing and printing of technical textiles	204
9.7	Total colour management systems	208
9.8	Dyeing machinery	211
9.9	Printing	215
9.10	Colour fastness of technical textiles	217
	References	219
10	Heat and flame protection	223
	<i>Pushpa Bajaj</i>	
10.1	Introduction	223
10.2	What constitutes flammability?	224
10.3	Thermal behaviour of fibres	224
10.4	Selection of fibres suitable for thermal and flame protection	229
10.5	Fire-retardant finishes	246
10.6	Flame-retardant test methods	252
10.7	Summary	258
	References	259
11	Textile-reinforced composite materials	264
	<i>Stephen L Ogin</i>	
11.1	Composite materials	264
11.2	Textile reinforcement	265
11.3	Woven fabric-reinforced composites	270
11.4	Braided reinforcement	273
11.5	Knitted reinforcement	274
11.6	Stitched fabrics	277

11.7	Conclusion	279
	References	279
12	Waterproof breathable fabrics	282
	<i>David A Holmes</i>	
12.1	What are waterproof breathable fabrics?	282
12.2	Types of waterproof breathable fabric	284
12.3	Assessment techniques	294
12.4	Performance of waterproof breathable fabrics	303
	References	314
13	Textiles in filtration	316
	<i>Edwin Hardman</i>	
13.1	Introduction	316
13.2	Dust collection	317
13.3	Fabric construction	326
13.4	Finishing treatments	328
13.5	Solid-liquid separation	333
13.6	Yarn types and fabric constructions	341
13.7	Fabric constructions and properties	347
13.8	Production equipment	351
13.9	Finishing treatments	352
13.10	Fabric test procedures	355
	References	357
14	Textiles in civil engineering. Part 1 – geotextiles	358
	<i>Peter R Rankilor</i>	
14.1	Introduction to geotextiles	358
14.2	Geosynthetics	360
14.3	Essential properties of geotextiles	362
14.4	Conclusions	370
	References	371
14	Textiles in civil engineering. Part 2 – natural fibre geotextiles	372
	<i>Martin Pritchard, Robert W Sarsby and Subhash C Anand</i>	
14.5	Introduction	372
14.6	Development of natural materials as geotextiles	372
14.7	Natural fibres	374
14.8	Applications for natural geotextiles	378
14.9	Engineering properties of geotextiles	391
14.10	Present state and uses of vegetable fibre geotextiles	392
14.11	Performance of natural fibre geotextiles for soil strengthening	393
14.12	Geotextile structure forms	395
14.13	Frictional resistance of geotextiles	400
14.14	Conclusions	405
14.15	Relevant British standards	405
	References	406

15	Medical textiles	407
	<i>Alistair J Rigby and Subhash C Anand</i>	
15.1	Introduction	407
15.2	Fibres used	408
15.3	Non-implantable materials	410
15.4	Extracorporeal devices	412
15.5	Implantable materials	415
15.6	Healthcare/hygiene products	420
15.7	Conclusions	423
	References	423
16	Textiles in defence	425
	<i>Richard A Scott</i>	
16.1	Introduction	425
16.2	Historical background	425
16.3	Criteria for modern military textile materials	427
16.4	Incompatibilities in military materials systems	427
16.5	Textiles for environmental protection	430
16.6	Thermal insulation materials	432
16.7	Water vapour permeable/waterproof materials	435
16.8	Military combat clothing systems	436
16.9	Camouflage concealment and deception	439
16.10	Flame-retardant, heat protective textiles	448
16.11	Ballistic protective materials	452
16.12	Biological and chemical warfare protection	457
	References	458
17	Textiles for survival	461
	<i>David A Holmes</i>	
17.1	Introduction	461
17.2	Short term (accident) survival	463
17.3	Long term survival	466
17.4	Conclusions	488
	References	488
18	Textiles in transportation	490
	<i>Walter Fung</i>	
18.1	Introduction	490
18.2	Textiles in passenger cars	497
18.3	Textiles in other road vehicles	516
18.4	Rail applications	517
18.5	Textiles in aircraft	519
18.6	Marine applications	521
18.7	Future prospects for transportation textiles	523
	Acknowledgements	523
	References	524
19	Textiles and the environment	529
	<i>Keith Slater</i>	
19.1	Introduction	529

xii Contents

19.2	Degradation	530
19.3	Resource depletion and pollution	531
19.4	Textile sources of environmental harm	532
19.5	Textile sources of pollution	533
19.6	Effects on the environment	537
19.7	Environmental harm reduction	538
19.8	Future prospects	539
	References	542
Index		543