WOODHEAD PUBLISHING IN MATERIALS

Nanotechnology in eco-efficient construction

Edited by F. Pacheco-Torgal, M. V. Diamanti, A. Nazari and C-G. Granqvist

WP
WOODHEAD PUBLISHING

Nanotechnology in eco-efficient construction

Edited by
F. Pacheco-Torgal, M. V. Diamanti, A. Nazari and C-G. Granqvist

WP
WOODHEAD PUBLISHING

Oxford Cambridge Philadelphia New Delhi

Published by Woodhead Publishing Limited,
80 High Street, Sawston, Cambridge CB22 3HJ, UK
www.woodheadpublishing.com
www.woodheadpublishingonline.com

Woodhead Publishing, 1518 Walnut Street, Suite 1100, Philadelphia,
PA 19102-3406, USA

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

First published 2013, Woodhead Publishing Limited

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library.

Library of Congress Control Number: 2013931614

ISBN 978-0-85709-544-2 (print)
ISBN 978-0-85709-883-2 (online)

The publisher's 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 publisher ensures that the text paper and cover board used have met acceptable environmental accreditation standards.

Typeset by Toppan Best-set Premedia Limited, Hong Kong
Printed in the UK by MPG Printgroup

Nanotechnology in eco-efficient construction

Related titles:

Eco-efficient concrete (ISBN 978-0-85709-424-7)
Understanding the tensile properties of concrete (ISBN 978-0-85709-045-4)
Handbook of recycled concrete and demolition waste (ISBN 978-0-85709-682-1)

Details of these books and a complete list of titles from Woodhead Publishing can be obtained by:

- visiting our web site at www.woodheadpublishing.com
- contacting Customer Services (e-mail: sales@woodheadpublishing.com; fax: +44 (0) 1223 832819; tel.: +44 (0) 1223 499140 ext. 130; address: Woodhead Publishing Limited, 80 High Street, Sawston, Cambridge CB22 3HJ, UK)
- in North America, contacting our US office (e-mail: usmarketing@woodhead-publishing.com; tel.: (215) 928 9112; address: Woodhead Publishing, 1518 Walnut Street, Suite 1100, Philadelphia, PA 19102-3406, USA

If you would like e-versions of our content, please visit our online platform: www.woodheadpublishingonline.com. Please recommend it to your librarian so that everyone in your institution can benefit from the wealth of content on the site.

We are always happy to receive suggestions for new books from potential editors. To enquire about contributing to our Materials series, please send your name, contact address and details of the topic/s you are interested in to francis.dodds@woodheadpublishing.com. We look forward to hearing from you.

The Woodhead team responsible for publishing this book:
Commissioning Editor: Francis Dodds
Publications Coordinator: Lucy Beg
Project Editor: Cathryn Freear
Editorial and Production Manager: Mary Campbell
Production Editor: Richard Fairclough
Cover Designer: Terry Callanan

Chapter 3

Dr Eng. F. Pacheco-Torgal*
Sustainable Construction Group
C-TAC Research Centre
University of Minho
Campus de Azurem
4800-058 Guimarães
Portugal

E-mail: torgal@civil.uminho.pt

S. Miraldo
University of Aveiro
Portugal

Y. Ding
State Key Laboratory of Coastal and Offshore Engineering
Dalian University of Technology
Dalian
China

J. A. Labrincha
Ceramics and Glass Engineering Department
University of Aveiro and CICECO
Campus Universitário de Santiago
3810-193 Aveiro
Portugal

Chapter 4

Zhipei Chen and Yining Ding
Institute of Structure Engineering
Dalian University of Technology
Dalian 116024
China

E-mail: ynding@hotmail.com

Dr Eng. F. Pacheco-Torgal*
Sustainable Construction Group
C-TAC Research Centre
University of Minho
Campus de Azurem
4800-058 Guimarães
Portugal

E-mail: torgal@civil.uminho.pt

Yulin Zhang
Centre of Mathematics
University of Minho
4700-052
Portugal

Chapter 5

Xianming Shi*
Corrosion and Sustainable Infrastructure Laboratory
Western Transportation Institute
Montana State University
P.O. Box 174250
Bozeman, Montana, 59717-4250
USA

E-mail: xianming.shi@gmail.com

Zhenjian Xiao
Shenzhen Jinzhou Precision Technology Corporation
Longgang High-Tech Industry Park
Shenzhen 518116
China

E-mail: dearxiaozj@sina.com

Jianlin Wu
School of Civil Engineering and Architecture
Wuhan Polytechnic University
Wuhan 430023
China

E-mail: forestwjl@yahoo.com.cn

Chapter 6

Dr Saeed Ghaffarpour Jahromi
Department of Civil Engineering
Shahid Rajaee Teacher Training University
Tehran
Iran

E-mail: Saeed_ghf@srttu.edu

Chapter 7

Melissa Spitzmiller and Shaily Mahendra
Department of Civil & Environmental Engineering
University of California, Los Angeles (UCLA)

Dr Robert Damoiseaux*
California NanoSystems Institute
Molecular Screening Shared Resource
University of California, Los Angeles (UCLA)
570 Westwood Plaza
Los Angeles, CA 90095-7277
USA

E-mail: Rdamoiseaux@mednet.ucla.edu

Chapters 8 and 11

Professor Claes G. Granqvist
Department of Engineering Sciences
The Ångström Laboratory
Uppsala University
P.O. Box 534
SE-75121 Uppsala
Sweden

E-mail: claes-goran.granqvist@angstrom.uu.se

Chapter 9

Ruben Baetens
Building Physics Section
Department of Civil Engineering
Faculty of Engineering
KU Leuven
Kasteelpark Arenberg 40 bus 2447
BE-3000 Leuven
Belgium

E-mail: ruben.baetens@bwk.kuleuven.be

Chapter 10

Professor Eng. Cinzia Buratti* and Dr Eng. Elisa Moretti
Department of Industrial Engineering
University of Perugia
Via G. Duranti 67
06125 Perugia
Italy

E-mail: cburatti@unipg.it; elisa.moretti@unipg.it

Chapter 12

Dr Lisa Ann Lamont
Transmission and Distribution Division
Mott MacDonald Ltd
1 Atlantic Quay
Broomielaw
Glasgow G2 8JB
UK

E-mail: Lisa.Lamont@mottmac.com

Chapter 13

Maria Vittoria Diamanti* and MariaPia Pedeferri
Politecnico di Milano
Department of Chemistry, Materials and Chemical Engineering 'Giulio Natta'
Via Mancinelli 7
20131 Milan
Italy

E-mail: mariavittoria.diamanti@polimi.it

Chapter 14

Damian Synnott, Nicholas Nolan, Darragh Ryan, John Colreavy and Suresh C. Pillai*
Centre for Research in Engineering Surface Technology (CREST)
FOCAS Institute
Dublin Institute of Technology
Kevin Street
Camden Row
Dublin 8
Republic of Ireland

E-mail: suresh.pillai@dit.ie

Chapter 15

Carmen del Cacho*
Department of Analytical Chemistry
Faculty of Science
Palacky University in Olomouc
17, Iistopadu 12
CZ-77146 Olomouc
Czech Republic

E-mail: ccacho@quim.ucm.es

Otmar Geiss, Paolo Leva, Salvatore Tirendi and Josefa Barrero-Moreno
European Commission
Joint Research Centre
Institute for Health and Consumer Protection
Ispra (VA)
Italy

Chapter 16

Soumitra Kar* and Professor P. K. Tewari
Desalination Division
Bhabha Atomic Research Centre
Trombay, Mumbai – 400085
India

E-mail: soubiswa@barc.gov.in; soumitra.1stmay@gmail.com; pktewari@barc.gov.in

Contents

Contributor contact details

(* = main contact)

Editors

Dr Eng. F. Pacheco-Torgal
Sustainable Construction Group
C-TAC Research Centre
University of Minho
Campus de Azurem
4800-058 Guimarães
Portugal

E-mail: torgal@civil.uminho.pt

Maria Vittoria Diamanti
Politecnico di Milano
Department of Chemistry, Materials and Chemical Engineering 'Giulio Natta'
Via Mancinelli 7
20131 Milan
Italy

E-mail: mariavittoria.diamanti@polimi.it

A. Nazari
Islamic Azad University
Iran

Professor Claes G. Granqvist
Department of Engineering Sciences
The Ångström Laboratory
Uppsala University
P.O. Box 534
SE-75121 Uppsala
Sweden

E-mail: claes-goran.granqvist@angstrom.uu.se

Chapter 1

Dr Eng. F. Pacheco-Torgal
Sustainable Construction Group
C-TAC Research Centre
University of Minho
Campus de Azurem
4800-058 Guimarães
Portugal

E-mail: torgal@civil.uminho.pt

Chapter 2

Dr Georgios Constantinides
Research Unit for Nanostructured Material Systems
Department of Mechanical Engineering and Materials Science and Engineering
Cyprus University of Technology
Lemesos, 3041
Cyprus

E-mail: g.constantinides@cut.ac.cy

1

Introduction to nanotechnology in eco-efficient construction

F. PACHECO-TORGAL, University of Minho, Portugal

DOI: 10.1533/9780857098832.1

Abstract: This chapter provides a brief overview of some important aspects of nanotechnology starting with its earlier steps and how countries are trying to establish an advantageous position in this field. China deserves a special mention because it is already the second largest producer of nanotechnology papers after the United States. The need for nanotechnology in the construction sector is emphasized. An outline of the book is given.

Key words: nanotechnology, eco-efficient construction, UN Millennium Goal, concrete, energy efficiency.

1.1 Introduction

Nanotechnology is a hot topic in current research, defined by Drexler (1981) as the manufacture of products using dimensions and precision of between 0.1 and 100 nm (1 nm = 1×10^{-9} m). It should be noted, however, that two decades prior to Drexler's work, the physicist Richard Feynman made a speech entitled 'There's plenty of room at the bottom' at a 1959 meeting of the American Physical Society at Caltech; this is considered to be the beginning of the era of nanotechnology era (Feynman, 1960).

In 1981 an expert group appointed by the European Commission was not able to agree on a firm definition of nanotechnology, but did arrive at a working definition for nanoscience and nanotechnology (NST) as 'the manipulation, precision placement, measurement, modeling or manufacture of sub-100 nanometer scale matter' (Glänzel *et al.*, 2003). The rapid evolution of research in this area is demonstrated by the growth rate of papers published with the 'nano-' prefix in the title in the period between 1992 and 2001, which increased exponentially with a doubling time of 2 years (Glänzel *et al.*, 2003). Economic estimates regarding advances in nanotechnology are still more striking: it is predicted that products and services related to nanotechnology could reach several hundred billion euros by the end of the decade (NSF, 2001; Compañó and Hullmann, 2002).

Dozens of countries already have national strategies in place and have begun to implement national nanotechnology plans (Rieke and Bachmann, 2004; Soltani *et al.*, 2011). According to Arnall and Parr (2005), countries

are trying to establish an advantageous position 'so that when nanotech applications begin to have a significant impact in the world economy, countries are able to exploit these new opportunities to the full'. Europe has assigned 4.865 billion euros to 'Nanosciences, Nanotechnologies, Materials and New Production Technologies' as part of the 7th Framework Programme for the 2007–2013 period. In the United States, a dedicated nanotechnology act was signed into law, which set aside 3.679 billion dollars of funding for the 2005–2008 period (Salerno *et al.*, 2008). China has identified nanotechnology as a priority area in its national agenda of science and technology development, and has increased R&D investment in the field. China has consequently emerged as one of the key global players in nanotechnology, producing the second largest number of nanotechnology papers after the United States (Wang and Guan, 2010, 2012).

Of course, nanotechnology is not entirely risk-free, with issues already raised with regard to the potential toxicity of nanoparticles and a new problem of the disposal of nanowastes (Bystrzejewska-Piotrowska *et al.*, 2009; Tyshenko, 2010). Despite these risks, however, Arnall and Parr (2005) quote Mihail Roco, the senior advisor for nanotechnology to the NSF, who stated that 'early payoffs will come in electronics and IT, and medicine and health'. Malanowski and Zweck (2007) also report that although almost all fields of industry are expected to be affected by nanotechnology by 2015, the areas most affected will be 'chemistry, life sciences and electronics'.

1.2 The need for nanotechnology in the construction sector

Very few nanotech applications are currently used in the construction sector, which in fact seems to have been somewhat neglected by nanotech research to date. A search for the terms 'nanotechnology' and 'eco-efficient construction' in journals listed in Scopus revealed only five papers, all related to cement and concrete. Of course, many more papers examining the role of nanotechnology in cement and concrete have been published; however, the number is very low compared to other major areas of current research. Moreover, much more work on standardization is required to ensure that high quality investigations into the use nanotechnology in cement and concrete applications can reach the global market (Sanjuan *et al.*, 2011).

It is understandable that nanotech research in today's economically driven society has so far been focused mainly on high profit areas such as those mentioned above. It is rather strange, however, that the same society so easily forgets the economics of environmental problems such as the probable meltdown of the world economy associated with global warming (Stern, 2006). Nanotechnology priorities should therefore be driven by