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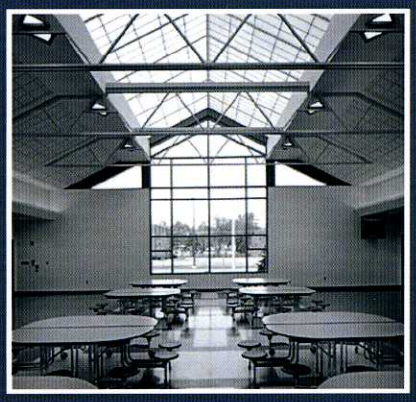

Nanotechnology in eco-efficient construction

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

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As the environmental impact of existing construction and building materials comes under increasing scrutiny, the search for more eco-efficient solutions has intensified. Nanotechnology offers great potential in this area and has already been widely used with great success. *Nanotechnology in eco-efficient construction* is an authoritative guide to the role of nanotechnology in the development of eco-efficient construction materials and sustainable construction.

Following an introduction to the use of nanotechnology in eco-efficient construction materials, Part I considers such infrastructural applications as nanoengineered cement-based materials, nanoparticles for high-performance and self-sensing concrete, and the use of nanotechnology to improve the bulk and surface properties of steel for structural applications. Nanoclay-modified asphalt mixtures and safety issues relating to nanomaterials for construction applications are also reviewed before Part II goes on to discuss applications for building energy efficiency. Topics explored include thin films and nanostructured coatings, switchable glazing technology and third generation photovoltaic (PV) cells, high-performance thermal insulation materials, and silica nanogel for energy-efficient windows. Finally, photocatalytic applications are the focus of Part III, which investigates nanoparticles for pollution control, self-cleaning and photosterilisation, and the role of nanotechnology in manufacturing paints and purifying water for eco-efficient buildings.

Nanotechnology in eco-efficient construction is a technical guide for all those involved in the design, production and application of eco-efficient construction materials, including civil engineers, materials scientists, researchers and architects within any field of nanotechnology, eco-efficient materials or the construction industry.

Fernando Pacheco-Torgal is an investigator in the C-TAC Research Centre at the University of Minho, Portugal, and is the author or co-author of more than 200 publications including 35 articles published in A1 ISI journals. **Maria Vittoria Diamanti** is Assistant Professor in the Department of Chemistry, Materials and Chemical Engineering at the Politecnico di Milano, Italy. **Ali Nazari** is an Assistant Professor in the Islamic Azad University, Iran. He has written 6 books and 140 journal articles as well as registering over 20 national patents. **Claes-Goran Granqvist** is Professor in The Ångström Laboratory at Uppsala University, Sweden.

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Introduction to nanotechnology in eco-efficient construction

F. PACHECO-TORGAL, University of Minho, Portugal

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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

'higher' goals; in particular, the 7th UN Millennium Goal related to environmental sustainability should be a major focus of attention. Consequently, the construction industry should also be at the core of the R&D efforts in nanotechnology: as one of the largest and most active sectors in the world, it will continue to grow at a rapid pace over the coming decades, and most importantly, it has a very high environmental impact, being responsible for the depletion of large amounts of non-renewable resources and for carbon dioxide gas emissions.

Concrete is the most widely-used construction material on Earth, currently used at a level of about 10 km^3/year (Gartner and Macphee, 2011), compared to 2 km^3 for fired clay, 1.3 km^3 for timber, and 0.1 km^3 for steel (Flatt *et al.*, 2012). These astonishing figures show the importance of concrete in the context of material efficiency (Allwood *et al.*, 2011). The main binder of concrete, Portland cement, is responsible for almost 80% of the total CO_2 emissions from concrete, which in turn make up around 6–7% of the planet's total CO_2 emissions (Shi *et al.*, 2011). This is particularly serious in light of current concerns around climate change and, more worryingly still, demand for Portland cement is expected to increase by almost 200% between 2010 and 2050, reaching a level of 6000 million tons/year (Pacheco-Torgal and Jalali, 2011). Nanotech research is therefore crucial in helping to identify methods to make concrete more environmentally friendly.

Another relevant aspect of the high environmental impact of the construction industry relates to the high energy consumption in buildings (accounting for approximately one third of the world's energy consumption) which is responsible for a significant proportion of global greenhouse gas emissions. In Europe, buildings are responsible for more than 40 percent of energy consumption and greenhouse gas emissions (Lechtenbohmer and Schuring, 2011), and energy efficiency is an issue of crucial importance. The recasting of the Energy Performance of Buildings Directive (EPBD) was adopted by the European Parliament and the Council of the European Union on 19 May 2010. The recast set 2020 as the deadline for all new buildings to be 'nearly zero energy'; for public buildings, the deadline is even sooner – the end of 2018. Technologies and methods to improve energy efficiency (Clements-Croome, 2011) are therefore required to ensure eco-efficient construction.

1.3 Outline of the book

The key role that nanotechnology has to play in the development of a more eco-friendly type of concrete is the basis for several chapters in the first part of the book, which looks at infrastructural applications (Chapters 2–7). Chapter 2 covers the experimental and theoretical advancements in the field of nanotechnology; these should allow a greater understanding of the

nature of concrete, which in turn will create the scientific basis for the development of more eco-efficient concrete. In Chapter 3, the use of nanoparticles to produce concrete with high strength and high durability is discussed, while Chapter 4 looks at the development of self-sensing concrete with nanomaterials. This feature enables the assessment of strain or stress variations in concrete structures. This not only allows savings in terms of structure inspections but also removes the requirements for conservation processes which are rather expensive. Chapter 5 deals with the use of nanotechnology to improve the bulk and surface properties of steel, which is the most widely used metallic alloy in modern industry, for structural applications. In Chapter 6, nanoclay-modified asphalt mixtures are discussed, showing the importance of nanoclay in improving the stability, resilient modulus and indirect tensile strength of asphalt mixtures. The use of nanoclay allows a superior performance compared to that of unmodified bitumen to be obtained. Finally in Part I, in Chapter 7 safety issues related to nanomaterials are reviewed; this chapter highlights some crucial issues relevant not only to construction industry practitioners but also to health professionals. It covers the potential health hazards of the nanomaterials utilized in construction, describes the lifecycle of nano-enabled structures, and analyses toxicity profiling for nanomaterials.

The importance of energy efficiency in buildings is the subject of Part II (Chapters 8–12). This section opens with Chapter 8 which reviews techniques for producing thin films and nanostructured coatings for energy applications. Chapter 9 covers high performance thermal insulators, namely nanoporous thermal insulators and partial vacuum thermal insulators, while Chapter 10 reviews the use of silica nanogel to produce highly energy-efficient windows and skylights. Switchable glazing technology is the subject of Chapter 11, which also reviews progress in electrochromics and thermochromics. Switchable glazing technology refers to 'materials and devices [that] make it possible to construct glazings whose throughput of visible light and solar energy can be switched to different levels depending on the application of an electrical voltage or on the temperature', which is an important feature in energy efficiency technologies. Chapter 12 closes Part II, and looks at the importance of photovoltaic technology for energy efficiency. It reviews the advantages and limitations of first and second generation photovoltaic cells and also examines the third generation and, most importantly, the role of nanotechnology in the development of highly efficient low cost photovoltaic cells.

Part III (Chapters 13–16) looks at photocatalytic applications. Chapter 13 concerns the photocatalytic capability of concrete, mortar and plaster that contain semiconductor nanoparticles, and reviews their self-cleaning, air depollution, antibacterial and anti-vegetative properties. This chapter describes existing patents and standards relating to photocatalytic cementi-

tious materials as well as pilot projects and field tests, while Chapter 14 looks at self-cleaning and antibacterial tiles and glass. Photocatalytic paints are discussed in Chapter 15 along with an analysis of strategies for the preparation of photocatalytic paints activated by indoor light, and the potential formation of by-products from photocatalytic paints. Finally, Chapter 16 covers the use of nanotechnology for domestic water purification. As the authors of this chapter put it, water 'is the single most essential commodity responsible for the existence and sustenance of life on the planet earth . . . Unfortunately, the most coveted natural resource was already scarce, and is becoming increasingly scarce day by day . . . As emphasized in one of the UN Millennium Development Goals, water scarcity calls for strengthened international cooperation in the fields of technologies for enhanced water productivity'.

I hope that all of those involved in the construction industry can benefit from the knowledge contained in the present book, which was kindly assembled by a number of international experts. Special gratitude goes to my three co-editors whose contributions to the book have greatly enhanced its quality.

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