WOODHEAD PUBLISHING SERIES IN CIVIL AND STRUCTURAL ENGINEERING

Handbook of recycled concrete and demolition waste

Edited by F. Pacheco-Torgal, V. W. Y. Tam,
J. A. Labrincha, Y. Ding and J. de Brito

WP
WOODHEAD
PUBLISHING

WOODHEAD PUBLISHING SERIES IN CIVIL AND STRUCTURAL ENGINEERING

The civil engineering sector accounts for a significant percentage of global material and energy consumption and is a major contributor of waste material. The ability to recycle and reuse concrete and demolition waste is critical to reducing environmental impacts in meeting national, regional and global environmental targets. *Handbook of recycled concrete and demolition waste* summarises key recent research in achieving these goals.

Part I considers techniques for managing construction and demolition waste, including waste management plans, ways of estimating levels of waste, the types and optimal location of waste recycling plants and the economics of managing construction and demolition waste. Part II reviews key steps in handling construction and demolition waste. It begins with a comparison between conventional demolition and construction techniques before going on to discuss the preparation, refinement and quality control of concrete aggregates produced from waste. It concludes by assessing the mechanical properties, strength and durability of concrete made using recycled aggregates. Part III includes examples of the use of recycled aggregates in applications such as roads, pavements, high-performance concrete and alkali-activated or geopolymer cements. Finally, the book discusses environmental and safety issues such as the removal of gypsum, asbestos and alkali-silica reaction (ASR) concrete, as well as life-cycle analysis of concrete with recycled aggregates.

Handbook of recycled concrete and demolition waste is a standard reference for all those involved in the civil engineering sector, as well as academic researchers in the field.

Fernando Pacheco-Torgal is an investigator in the C-TAC Research Centre at the University of Minho, Portugal. He is the author or co-author of more than 200 publications and has edited seven books. **Vivian Tam** is Senior Lecturer in Quality Surveying in the School of Engineering and Construction Management at the University of Western Sydney, Australia. She is the author of over 200 papers. **João Labrincha** is Associate Professor in the Materials and Ceramics Engineering Department of the University of Aveiro, Portugal, and member of the CICECO research unit. He has registered 22 patent applications, and has published over 170 papers. **Yining Ding** is Professor in the Institute of Structural Engineering at Dalian University of Technology, China. He has published over 100 papers in three languages. **Jorge de Brito** is Professor in the Department of Civil Engineering, Architecture and Georesources at the Instituto Superior Técnico, Technical University of Lisbon, Portugal. He was Head of the ICIST Research Centre from 2009 to 2012.

Woodhead Publishing Limited
80 High Street, Sawston
Cambridge CB22 3HJ
UK

ISBN 978-0-85709-682-1

9 780857 096821

Woodhead Publishing
1518 Walnut Street 1100
Philadelphia, PA 19102
USA

www.woodheadpublishing.com
www.woodheadpublishingonline.com

WP
WOODHEAD
PUBLISHING

Woodhead Publishing Series in Civil and Structural Engineering:
Number 47

Handbook of recycled concrete and demolition waste

Edited by
F. Pacheco-Torgal, V. W. Y. Tam,
J. A. Labrincha, Y. Ding and J. de Brito

WOODHEAD PUBLISHING

Oxford Cambridge Philadelphia New Delhi

© Woodhead Publishing Limited, 2013

1

Introduction to the recycling of construction and demolition waste (CDW)

F. PACHECO-TORGAL, University of Minho, Portugal

DOI: 10.1533/9780857096906.1

Abstract: The chapter starts with an overview on the recycling of construction and demolition wastes (CDW), followed by a brief analysis on the EU 70% recycling target for 2020. The chapter also includes a book outline.

Key words: construction and demolition wastes (CDW), recycling, resource efficiency, waste management, life-cycle assessment (LCA).

1.1 Introduction

The high volume of construction and demolition waste (CDW) generated today constitutes a serious problem. CDW in the United States is estimated at around 140 million metric tons (Yuan *et al.*, 2012). Eurostat estimates the total for Europe to be 970 million tons/year, representing an average value of almost 2.0 ton/per capita (Sonigo *et al.*, 2010). It should be noted that the figures for CDW generation per capita in Europe have a wide geographical variation (e.g. 0.04 tons for Latvia and 5.9 tons for France). These figures must be viewed as lower estimates, as this type of waste is often dumped illegally. The data are also hard to interpret because of the different waste definitions and reporting mechanisms in different countries (Sonigo *et al.*, 2010).

Recycling of CDW is of paramount importance because it reduces environmental pressure. It prevents an increase in the area needed for waste disposal and also avoids the exploitation of non-renewable raw materials. Environmental impacts caused by the extraction of non-renewable raw materials include extensive deforestation, top-soil loss, air pollution and pollution of water reserves. It should be noted that 40% of all materials are used by the construction industry (Kulatunga *et al.*, 2006). Wang *et al.* (2010) records that construction in China consumes approximately 40% of total natural resources and around 40% of energy. During the last century, the use of global materials increased eight-fold. As a result, almost 60 billion tons (Gt) are currently used per year (Krausmann *et al.*, 2009). It has been forecast that demand for materials will reach at least double the current levels by 2050 (Allwood *et al.*, 2011).

In the context of housing life-cycle assessment (LCA), the environmental gains associated with the recycling of CDW constitute a very small fraction (just 3% in United Kingdom) of the total global warming potential (GWP). Ninety percent of

© Woodhead Publishing Limited, 2013

the GWP relates to the use stage (Cuéllar-Franca and Azapagic, 2012). This situation is not confined to the UK residential sector and applies generally in Europe and in other parts of the world where high energy-efficient buildings are the exception (Pacheco-Torgal *et al.*, 2013). However, the recast of the Energy Performance of Buildings Directive (EPBD), which was adopted by the European Parliament and the Council of the European Union on 19 May 2010, sets 2020 as the deadline for all new buildings to be 'nearly zero energy'. This will dramatically increase the percentage (Pacheco-Torgal *et al.*, 2013a).

The benefits of effective CDW recycling are economic as well as environmental. For example, the Environment Agency of the US (EPA, 2002) states that the incineration of 10 000 tonnes of waste can mean the creation of 1 job, landfill can create 6 jobs, but recycling the same amount of waste can create 36 jobs. The recent report *Strategic Analysis of the European Recycled Materials and Chemicals Market in Construction Industry* records that the market for recycled construction materials generated revenues of €744.1 million in 2010 and is estimated to reach €1.3 billion by 2016 (Frost and Sullivan, 2011). This is a low estimate as it does not take into account a near 100% CDW recycling scenario, which will be the future of construction (Phillips *et al.*, 2011).

During the last 15 years, investigations in the field of CDW have focused on three major topics: generation, reduction and recycling. This is guided by the '3Rs' principle (Lu and Yuan, 2011). However, as it is a more complex issue, zero-waste will demand a much wider approach requiring 'strong industry leadership, new policies and effective education curricula, as well as raising awareness and refocusing research agendas to bring about attitudinal change and the reduction of wasteful consumption' (Lehmann, 2011).

1.2 EU 70% recycling target for 2020

According to the revised Waste Framework Directive 2008/98/EC (WFD), the minimum recycling percentage of 'non-hazardous' CDW by 2020 ('excluding naturally occurring material defined in category 170504 (soil and stones not containing dangerous substances) in the *European Waste Catalogue*') should be at least 70% by weight (Saez *et al.*, 2011; del Rio Merino *et al.*, 2011). This target and also the communication *A Resource Efficient Europe* (COM, 2011) indicates the determination of the EU to emphasise the importance of recycling. As the current average recycling rate of CDW for EU-27 is only 47% (Sonigo *et al.*, 2010), increasing it by 70% in just a decade seems an ambitious goal.

CDW are often used as aggregates in roadfill, constituting a down-cycling option. Worldwide aggregate consumption is around 20 000 million tons/year and an annual growth rate of 4.7% is expected (Bleischwitz and Bahn-Walkowiak, 2011). The environmental impact of primary aggregates includes the consumption of non-renewable raw materials, energy consumption and more importantly, the

© Woodhead Publishing Limited, 2013

reduction of biodiversity at extraction sites. The cost of aggregates is dependent on transport distances and the price per ton doubles for every 30 km (Van den Heede and De Belie, 2012). Extraction operations therefore have to be near construction sites, which increase the number of quarries and the biodiversity impact. More than one-third of aggregate consumption is related to the production of concrete, which is the most widely used construction material, currently standing at about 10 km^3/year (Gartner and Macphee, 2011). By comparison, the amount of fired clay, timber and steel used in construction represents, respectively, around 2, 1.3 and 0.1 km^3 (Flatt *et al.*, 2012).

Although the use of CDW as recycled aggregates in concrete has been studied for almost 50 years, there are still too many concrete structures made with virgin aggregates (Pacheco-Torgal and Jalali, 2011; Pacheco-Torgal *et al.*, 2013b). This is due to their low cost, lack of incentives, low landfill costs and in some cases, a lack of up-to-date technical regulation (Marie and Quiasrawi, 2012). Recycled aggregates also contain impurities which can be deleterious in Portland cement concrete. It is therefore difficult for the concrete industry to use these materials unless uncontaminated recycled aggregates are used. This issue highlights the importance of developing new binders, which are more suitable for CDW recycling. The WFD 70% target increases the need for effective recycling methods and it is the purpose of this book to make a contribution in this area. It also addresses new techniques for the remediation and/or immobilisation of hazardous wastes such as asbestos and for CDW prevention/reduction, which remains the best option (EC, 2006).

1.3 Outline of the book

Part I is concerned with the management of CDW (chapters 2 to 6).

Chapter 2 considers waste management plans, reviews existing methods in several countries and presents the results of a wide survey assessing the effectiveness of the requirements in implementing waste management plans for the Hong Kong construction industry. Attitudes, benefits and difficulties related to the implementation of waste management plans are discussed.

Chapter 3 covers methods of estimating CDW and includes studies and tables to estimate the amount of CDW. Seventeen examples and case studies on the factors affecting such estimates, the improvement achieved in management scenarios and the benefits of its implementation are presented.

In Chapter 4, waste management plants and technology for recycling CDW are addressed. The types and choices of waste management plants are discussed. Particular attention is given to the health and safety of workers.

Chapter 5 covers the use of multi-criteria decision-making methods for optimal CDW recycling facilities.

Chapter 6 reviews the relevant economic issues in the management of CDW facilities.

© Woodhead Publishing Limited, 2013

Part II is concerned with the processing and properties of recycled aggregates from CDW (chapters 7 to 13).

Chapter 7 compares conventional demolition and deconstruction techniques. A local case study is used to perform a thorough economic analysis, which directly compares these two options.

Chapter 8 reviews demolition techniques in the production of CDW.

Chapter 9 discusses the preparation of concrete aggregates from CDW. This chapter contains data on the relevant technological, economic and environmental aspects of operating CDW recycling facilities, which produce average to high-quality recycled concrete aggregates.

Chapter 10 covers mortar/aggregate separation processes for the improvement of quality in recycled aggregates. In addition to classical mechanical beneficiation, it also analyses cases in which thermal, acid and microwave treatments are used.

Chapter 11 addresses the quality control of recycled aggregates.

Chapter 12 discusses compressive strength, tensile splitting and flexural resistance, elastic modulus, shrinkage and creep.

Chapter 13 addresses several durability parameters (carbonation and abrasion resistance, chloride permeability and resistance to freeze/thaw).

Part III (chapters 14 to 18) deals with the applications of recycled aggregates from CDW.

Chapter 14 reviews the use of recycled aggregates in roads and analyses the properties that make them suitable for use as unbound materials and cement-treated materials in road construction.

Chapter 15 looks at the use of recycled aggregates for asphalt materials. Because recycled aggregates may contain 'hazardous wastes, such as adhesives, lead-based paints (LBP), phenols, formaldehyde resins, polychlorinated biphenyls (PCB), polycyclic aromatic hydrocarbons (PAH) and others', their environmental performance must be assessed by a leaching test. This chapter also discusses the appropriate leaching test and its characteristics. It addresses volumetric properties, rutting, stiffness, fatigue, stripping and durability of asphalt materials containing recycled aggregates.

Chapter 16 is concerned with recycled asphalt for pavements, including pavement removal, properties, mix design and recycling methods.

Chapter 17 reviews the current knowledge on concrete made with recycled aggregates, with a special focus on the importance of impurities in rendering aggregates unsuitable for the production of high performance concrete. The potential of geo-polymers in producing high performance concrete based on high volume recycled aggregates is discussed.

Chapter 18 considers the geo-polymerisation of recycled aggregates.

Part IV (chapters 19 to 24) deals with the environmental issues affecting recycled aggregates from CDW.

Chapter 19 describes the environmental and technical problems arising from gypsum contamination and methods for its removal.

© Woodhead Publishing Limited, 2013

Chapter 20 is concerned with the recycling of materials containing asbestos. Among other issues, it analyses the recycling of thermally treated cement asbestos in the production of concrete (Portland cement based as well as geo-polymeric based).

Chapter 21 describes the decontamination processes for wood treated with organic and inorganic preservatives. Recycling this kind of waste requires the prior removal of organic or inorganic preservative agents. The chapter reviews remediation technologies based on inorganic and organic compounds removal by physical, biological or chemical processes.

Chapter 22 analyses the processing of recycled aggregates contaminated with alkali-silica reaction concrete.

Chapter 23 deals with the LCA of concrete with recycled aggregates. It includes results of LCA case studies on two different RCA applications and discusses the potential and limitations of LCA.

Chapter 24 covers assessment of the potential environmental hazards of concrete made with recycled aggregates. It presents 'methodologies for environmental assessment with specific overview on their application to construction materials'. It describes relevant experimental tools dedicated to hazard identification and environmental performances and reviews leaching properties and the chemical behaviour of pollutants in the cement matrix. Several examples related to the leaching behaviour of concrete and of recycled aggregates are presented.

1.4 References

Allwood J, Ashby M, Gutowski T and Worrell E (2011), 'Material efficiency: A white paper', *Resources, Conservation and Recycling*, 55, 362–381.

Bleischwitz R and Bahn-Walkowiak B (2011), 'Aggregates and construction markets in Europe: Towards a sectorial action plan on sustainable resource management', *Minerals Engineering*, 22, 159–176.

COM (2011), 21: *A Resource-Efficient Europe – Flagship Initiative under the Europe 2020 Strategy*, Brussels.

Cuéllar-Franca R and Azapagic A (2012), 'Environmental impacts of the UK residential sector: Life-cycle assessment of houses', *Building and Environment*, 54, 86–99.

del Rio Merino M, Navarro J and Saez P (2011), 'Legal aspects which implement good practice measures in the management of construction and demolition waste', *The Open Construction and Building Technology Journal*, 5(Suppl 2-M2), 124–130.

EPA (2002), *Resource Conservation Challenge: Campaigning Against Waste*, EPA 530-F-02-033.

European Parliament, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives (text with EEA relevance), *Official Journal of the European Union*, 312, 3–30.

European Commission (2006), 'The story behind the strategy. EU Waste Policy', http://ec.europa.eu/environment/waste/pdf/story_book.pdf [Accessed 24 November 2012].

Flatt R, Roussel R and Cheeseman C R (2012), 'Concrete: An eco-material that needs to be improved', *Journal of the European Ceramics Society*, 32, 2787–2798.

© Woodhead Publishing Limited, 2013

Frost and Sullivan (2011), *Strategic Analysis of the European Recycled Materials and Chemicals Market*. Available from: http://www.frost.com/prod/servlet/report-toc.pag?repid—579-01-00-00-00 [Accessed 10 July 2012].

Gartner E and Macphee D (2011), 'A physico-chemical basis for novel cementitious binders', *Cement and Concrete Research*, 41, 736–749.

Krausmann F, Gingrich S, Eisenmenger N, Erb K-H, Haberl H and Fischer-Kowalski M (2009), 'Growth in global materials use, GDP and population during the 20th century', *Ecological Economics*, 68, 2696–2705.

Kulatunga U, Amaratunga D, Haigh R and Rameezdeen R (2006), 'Attitudes and perceptions of construction workforce on construction waste in Sri Lanka', *Management of Environmental Quality*, 17(1), 57–72.

Lehmann S (2011), 'Resource recovery and materials flow in the city: Zero waste and sustainable consumption as paradigm in urban development', *Journal of Green Building*, 6, 88–105.

Lu W and Yuan H (2011), 'A framework for understanding waste management studies in construction', *Waste Management*, 31, 1252–1260.

Marie I and Quiasrawi H (2012), 'Closed-loop recycling of recycled concrete aggregates', *Journal of Cleaner Production*, 37, 243–248.

Pacheco-Torgal F and Jalali S (2011), *Eco-efficient Construction and Building Materials*, London, Springer Verlag.

Pacheco-Torgal F, Faria J and Jalali S (2013), 'Embodied energy versus operational energy. Showing the shortcomings of the energy performance building directive (EPBD)', *Materials Science Forum*, 730–732, 587–591.

Pacheco-Torgal F, Cabeza L F, Mistretta M, Kaklauskas A and Granqvist C G (2013a), *Nearly Zero Energy Building Refurbishment*, London, Springer Verlag.

Pacheco-Torgal F, Labrincha J A, Jalali S and John V M (2013b), *Eco-efficient Concrete*, Cambridge, Woodhead Publishing Ltd.

Phillips P, Tudor T, Bird H and Bates M (2011), 'A critical review of a key Waste Strategy Initiative in England: Zero Waste Places Projects 2008–2009', *Resources, Conservation and Recycling*, 55, 335–343.

Saez P, del Rio Merino M, Amores C and Gonzalez A (2011), 'European legislation and implementation measures in the management of construction and demolition waste', *The Open Construction and Building Technology Journal*, 5(Suppl 2-M6), 156–161.

Sonigo P, Hestin M and Mimid S (2010), *Management of Construction and Demolition Waste in Europe*, Brussels, Stakeholders Workshop.

Van den Heede P and De Belie N (2012), 'Environmental impact and life cycle assessment (LCA) of traditional and "green" concretes: Literature review and theoretical calculations', *Cement and Concrete Composites*, 34, 431–442.

Wang J Y, Yuan H P, Kang X P and Lu W S (2010), 'Critical success factors for on-site sorting of construction waste: A China study', *Resources, Conservation and Recycling*, 54(11), 931–936.

Yuan H, Chini A, Lu Y and Shen L (2012), 'A dynamic model for assessing the effects of management strategies on the reduction of construction and demolition waste', *Waste Management*, 32, 521–531.

© Woodhead Publishing Limited, 2013