Science of the Total Environment 572 (2016) 77–85

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Characterization of brominated flame retardants in construction and demolition waste components: HBCD and PBDEs

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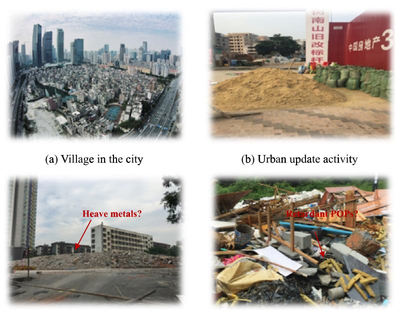
HIGHLIGHTS

- We characterized the hazardous substances (first for BFRs) in C&D waste components.
- High content of HBCD and PBDEs was found in the polyurethane foam scrap.
- It is paramount to develop a classification system to separate harmful materials.
- The results could be beneficial to choose green building materials.

GRAPHICAL ABSTRACT



(a) Village in the city (b) Urban update activity

(c) A demolition site (d) C&D waste mixture

Source: picture (a) is from Feng fei, the others are from authors themselves.

ARTICLE INFO

Article history:
Received 11 March 2016
Received in revised form 23 July 2016
Accepted 23 July 2016
Available online xxxx

Editor: Adrian Covaci

Keywords:
Construction and demolition waste
Hazardous characterization
Persistent organic pollutants
Brominated flame retardants

ABSTRACT

The vast majority of construction material is inert and can be managed as nonhazardous. However, structures may have either been built with some environmentally unfriendly substances such as brominated flame retardants (BFRs), or have absorbed harmful elements such as heavy metals. This study focuses on end-of-life construction materials, i.e. construction and demolition (C&D) waste components. The aim was to characterize the concentration of extremely harmful substances, primarily BFRs, including hexabromocyclododecane (HBCD) and polybrominateddiphenyl ethers (PBDEs). Results revealed extremely high contents of HBCD and PBDEs in typical C&D waste components, particularly polyurethane foam materials. Policies should therefore be developed for the proper management of C&D waste, with priority for POP-containing debris. The first priority is to develop a classification system and procedures to separate out the harmful materials for more extensive processing. Additionally, identification and quantification of the environmental implications associated with dumping-dominated disposal of these wastes are required. Finally, more sustainable materials should be selected for use in the construction industry.

1. Introduction

The construction industry is one of the largest consumers of natural resources, and during the end-of-life (EoL) period of buildings, many of these materials find their way into the waste stream. In China,

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http://dx.doi.org/10.1016/j.scitotenv.2016.07.165

construction and demolition waste (C&D waste) is becoming one of the largest waste streams (Yuan and Shen, 2011). The National Development and Reform Commission (NDRC) estimated the amount of C&D waste generated in China in 2013 at 1 billion tons—approximately six times the amount of municipal solid waste (NDRC, 2014). Most of this waste consists of brick, stone and aggregates; together, these account for 80% of the total C&D waste in China (Duan et al., 2015).

Most construction materials are inert, and can be managed as non-hazardous. During the demolition and disposal phases (EoL) of buildings, however, there are environmental concerns, as many building materials contain hazardous substances. These include asbestos in walls and ceilings, copper and brominated flame retardants (BFRs) in wires and cables, mercury in light bulbs and fixtures, lead paint, and wood preservatives containing heavy metals. In addition, EoL material from buildings that were used for chemical, metallurgical or pharmaceutical processes may have absorbed both inorganic and organic contaminants. Occupational health and safety measures therefore need to be in place for demolition workers during the entire C&D waste management process: sorting, storage, transportation, recycling, and treatment. There is also some risk that inorganic and organic contaminants will be released into various environmental media (e.g. water, sediment, and soil) when hazardous C&D wastes are disposed of by dumping or simple landfilling (Duan et al., 2015).

Yet despite the potentially significant environmental impacts, C&D waste is often overlooked in sustainable building development and environmental management. In China, there are a number of barriers to sound recycling practices, such as high transportation costs and extremely low value of the C&D waste. Similarly, landfill disposal costs are increasing significantly because of the shortage of available land; it is becoming increasingly difficult to find sites for new landfills. Most C&D waste is therefore sent to dumping sites that are not well managed (Duan et al., 2015). However, very few studies have attempted to explore the hazardous characterization of C&D waste: its impacts on human health and various environmental media.

Jang and Townsend (2001a, 2001b) analyzed soil fines recovered from C&D waste recycling facilities for trace organic pollutants—volatile organic compounds (VOCs), polychlorobiphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs). Their study showed that organic chemicals in recovered soil fines from C&D debris recycling facilities did not present significant risks to human health or groundwater under reuse and contact scenarios. Butera et al. (2014) created a consistent and extensive dataset for the characterization of recyclable C&D waste. Their data included the elemental composition and leaching of major, minor and trace elements; the quantification of critical organic compounds (e.g. PCBs and PAHs); and the identification of the most critical substances from a management perspective. PCBs and PAHs were detected in all samples, albeit in non-critical concentrations. Higher leaching rates of chromium, sulfate and chloride were observed for masonry-containing and partly carbonated samples. This study highlighted the importance of source segregation and management practices.

Brominated flame retardants (BFRs) such as polybrominateddiphenyl ethers (PBDEs) and hexabromocyclododecane (HBCD) have been widely used in a variety of commercial and consumer products (de Wit, 2002). PBDEs and HBCD are currently being considered under the framework of the Stockholm Convention on Persistent Organic Pollutants (POPs) due to their persistence, bioaccumulative capacity, and toxicity (UNEP, 2011; Nie et al., 2015). The last two decades have witnessed growing concern about BFRs from the environmental perspective (Remberger et al., 2004). Furthermore, many congeners of PBDEs are still prevalent in consumer products, and these pose significant threats to both the environment and human health. Most BFR-related studies, however, have focused on PBDEs, and data on the environmental concentrations of HBCD are therefore scarce; very few studies have attempted to examine these POPs in C&D waste. Hexabromocyclododecane (HBCD), as one of the most widely used brominated flame retardants (BFRs), has been used mainly (over 90%) in flame-retardant expanded (EPS) and extruded (XPS) polystyrene foams for insulation in the construction industry, because of its long service life (30 to 50 years) (Li et al., 2016). In contrast, the use of HBCD in textile applications and electric and electronic appliances (high-impact polystyrene) is of a smaller scale (Li et al., 2016). Li et al. (2016) conducted a scenario-based dynamic substance flow analysis, coupled with interval linear programming, and forecast future HBCD emissions in China. They pointed out that during the demolition process C&D waste is manually sorted and crushed on site at destruction sites, and polystyrene C&D materials are separated out from other inert C&D waste such as bricks and concrete. Original HBCD constituent in C&D waste is released into the atmosphere during these sorting and crushing operations, and is assumed to contribute 10% of the atmospheric emissions in the demolition process. Li's study warns of the huge challenges that China could face in attempting to eliminate HBCD contamination in the coming decades.

This study therefore aimed to (i) quantify the content of POP retardants—HBCD and PBDEs—in C&D waste components; (ii) look at and compare the POP concentrations in both inert and non-inert waste; and (iii) reveal the sources of these toxic substances. This information will help in the development of proper management techniques for C&D waste and its components, in order to minimize associated environmental and health risks.

2. Materials and methods

2.1. Sample collection

Following is a component-specific evaluation. Two batches of different types of C&D waste components were collected in 2015, from several new-building construction sites: the first, labeled N1–N9, from a C&D waste recycling plant (recyclers), and the second, labeled M1–M9, from several landfill sites in Shenzhen (see Table 1). The sampling process followed procedures specified in the "Technical Specifications on Sampling and Sample Preparation from Industrial Solid Waste" (HJ/T20-1998, in Chinese). Partial samples were collected manually from several locations, using a shovel, and were placed into the sampling bags. These were sent to the laboratory for further processing. Each individual sample was made up of portions collected from three sampling points within the sampling site, and these portions were then mixed together. All the samples were air-dried at room temperature, cut into

Table 1
Description of the C&D waste component samples.

Sampling site	Label	Category	Description	BFRs	
				HBCD	PBDEs
Landfill site I	N1	Non-inert	Asphalt (pavement)	√	√
	N2		Textiles	√	√
	N3		PUR foam and sponge	√	√
	N4		PUR foam insulating layer	√	√
	N5		PUR foam floor mat	√	√
	N6		Furniture (plastic-wood composite)	√	√
	N7		Plastic hard tube	√	√
Construction sites	N8	Non-inert	Thermal insulation plastic-1	√	√
	N9		Thermal insulation plastic-2	√	√
Landfill site II	M1	Inert	Excavated soil (1)		√
	M2		Excavated soil (1)		√
	M3		Waste sand & concrete		√
	M4		Lime		√
	M5		Recycled aggregate*		√
	M6	Non-inert	PUR foam insulating layer		√
	M7		PUR foam floor mat and plastics mixture		√
	M8		Plastic hard tube (yellow)		√
	M9		Wood		√

* From the recycling plant for the C&D waste, located at landfill site II.