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# Construction and demolition waste: Comparison of standard up-flow column and down-flow lysimeter leaching tests

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ABSTRACT

Five samples of construction and demolition waste (C&DW) were investigated in order to quantify leaching of inorganic elements under percolation conditions according to two different experimental setups: standardised up-flow saturated columns (<4 mm particle size) and unsaturated, intermittent down-flow lysimeters (<40 mm particle size). While standardised column tests are meant primarily to provide basic information on characteristic leaching properties and mechanisms and not to reproduce field conditions, the lysimeters were intended to mimic the actual leaching conditions when C&DW is used in unbound geotechnical layers. In practice, results from standardised percolation tests are often interpreted as estimations of actual release from solid materials in percolation scenarios. In general, the two tests yielded fairly similar results in terms of cumulative release at liquid-to-solid ratio (L/S) 10 l·kgTS; however, significant differences were observed for P, Pb, Ba, Mg and Zn. Further differences emerged in terms of concentration in the early eluates (L/S < 5 $l \cdot kg^{-1}$TS) for Al, As, Ba, Cd, Cu, DOC, Mg, Mn, Ni, P, Pb, Sb, Se, Si, Zn. Observed differences between tests are likely to be due to differences in pH related to crushing and exposure of fresh particle surfaces, as well as in equilibrium conditions. In the case of C&DW, the standardised column tests, which are more practical, are considered to acceptably describe cumulative releases at L/S 10 $l \cdot kg^{-1}$TS in percolation scenarios. However, when the focus is on estimation of initial concentrations for (for example) risk assessment, data from standardised column tests may not be fully applicable, and data from lysimeters may be used for validation purposes. Se, Cr and, to a lesser extent, $SO_4$ and Sb were leaching from C&DW in critical amounts compared with existing limit values.



## 1. Introduction

In many countries, construction and demolition waste (C&DW) is one of the dominating waste types in terms of weight. In Europe (EU28), C&DW accounts for more than 30% of the waste generation, corresponding to about 900 million Mg annually (Eurostat, 2010). As C&DW primarily consists of mineral materials, such as concrete, it is generally considered to have useful geotechnical properties for utilisation, and be associated with few environmental concerns (Monier et al., 2011). Currently the main end-of-life option for C&DW includes substitution of virgin aggregates in unbound applications, such as the construction of roads, parking areas, and embankments (Tam and Tam, 2006), thereby contributing to potential savings of natural resources (gravel or crushed rocks) and landfill capacity. Ideally, waste collected from construction and demolition activities should be subjected to pre-sorting of potentially hazardous materials (for example, by selective demolition), thereby ensuring that the C&DW consists of mainly unproblematic materials. However, this may not always be the case, as recently documented by Butera et al. (2014), who reported large variations in appearance, composition and leaching determined in batch leaching tests. While relatively few countries have limit values regulating utilisation of C&DW-examples include the Netherlands (Dutch Ministry of Housing Spatial Planning and the Environment, 2007) and the Belgian region of Flanders (Ministry of the Flemish Community, 1997)-existing literature suggests that leaching from C&DW could potentially be critical from an environmental impact perspective (e.g., Butera et al., 2014; Nielsen et al., 2006).

*Abbreviations:* BA, bottom ash; C&DW, construction and demolition waste; DOC, dissolved organic carbon; FA, fly ash; ICP-OES, inductively coupled plasma optical emission spectrophotometer; L/S, liquid-to-solid ratio; LOD, limit of detection; LOQ, limit of quantification; MSWI, municipal solid waste incineration; SI, saturation index; SQD, Soil Quality Decree; TS, total solid.

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Batch leaching tests (e.g., EN 12457-1, 2002) offer a cost-effective basis for compliance testing relative to regulatory limit values; however, batch leaching tests are not designed to reflect the specific leaching conditions in a percolation environment, such as construction works involving C&DW (López Meza et al., 2008). Percolation leaching tests, such as standardised up-flow columns (CEN TS 14405, 2014), as prescribed for basic characterisation in relation to the EU landfill acceptance criteria (European Commission, 2002), may be more appropriate for description of leaching in hydraulically dynamic systems. The scope of standardised column tests does not include the simulation of specific utilisation scenarios, but aims at determining the basic leaching properties of granular materials in equilibrium with the leachant, as a function of liquid-to-solid (L/S) ratio. Nevertheless, in practice results from standard column tests are often interpreted as estimations of actual release from solid materials in percolation scenarios (e.g. due to lack of appropriate full-scale data); in these cases, standard column leaching data are used for environmental assessment purposes. In order to ensure reproducibility, and to allow for harmonization of the results with compliance batch leaching tests, the column leaching test prescribed in relation to the EU landfill acceptance criteria requires crushing of the tested materials to particle sizes for example below 4 mm (CEN TS 14405, 2014). This does not reflect conditions of C&DW as applied in construction, where C&DW is crushed to a particle size range that reflects the needs of the construction sector (in Denmark about 0–40 mm); this is a significantly larger particle size compared with the maximum prescribed in CEN TS 14405 (2014) column leaching test.[1] Prior to its application in construction, C&DW is typically crushed in a recovery facility; misplaced metal pieces may be sorted for recycling. After crushing, the C&DW is typically stored outside until application, during which carbonation and ageing reactions may occur (e.g., Engelsen et al., 2005). Further crushing prior to leaching testing (and after outside storage) may therefore significantly alter the physical properties of the material by exposing new surfaces and potentially alter leaching, compared with a field situation. Standardised up-flow columns also involve saturated flow conditions, again to ensure reproducibility and best possible contact between particles and solution. However, C&DW utilised in construction works is more likely to experience intermittent, down-flow conditions. The importance of these key differences between standardised up-flow column leaching tests and field-scale conditions has not been addressed for C&DW.

Recently, the influence of certain parameters on leaching from C&DW has been evaluated; these include an intermittent flow regime (López Meza et al., 2009), contact time (López Meza et al., 2010), column geometry (Kim et al., 2011), density and compaction (Galvín et al., 2014), and other aspects, such as flow interruptions and saturation (e.g., Sanchez et al., 2002; Wehrer and Totsche, 2008). Crushing itself has been suggested to contribute to an overestimation of leaching (e.g., Kalbe et al., 2008; Kosson et al., 2002; van der Sloot, 2000), both due to the greater surface area and to the fact that fresher surfaces are made available. Galvín et al. (2014) concluded that fine particles contribute to increase the leaching, particularly of Cr and $SO_4$ – two of the most critical constituents from a regulatory point of view (e.g., Butera et al., 2014; Wahlström et al., 2000). In spite of the abovementioned research, a more comprehensive comparison of the standard column leaching tests using lysimeters packed with non-crushed material and subject to intermittent, downward and non-saturated flow conditions has not yet been provided.

For other granular mineral materials, more complete assessments involving large columns, lysimeters and experimental road sections have been conducted. Most of these studies (e.g., Crest et al., 2007; Del Valle-Zermeño et al., 2014; Guyonnet et al., 2008; Kylefors et al., 2003; Schreurs et al., 2000) have focused on various types of ash (for example, boiler ash from fluidised-bed municipal solid waste incineration (MSWI); MSWI bottom ash (BA)). Despite the fact that granular mineral materials share many common characteristics (for example, high pH and overall mineralogy), key properties of these materials may also fundamentally differ (for example, in terms of their porosity, particle size distribution, biological activity, and chemical composition); therefore, the outcomes of the abovementioned studies may not be fully applicable to mineral C&DW. Additionally, these studies have often only included a limited set of elements or substances, or only reached low L/S ratios (Crest et al., 2007; Guyonnet et al., 2008). Delay et al. (2007) conducted a lysimeter study on a C&DW reference material (mixture of various components typical of demolition waste material with a maximum grain size of 4 mm), comparing standard column tests and intermittent down-flow lysimeters, and found good agreement for most analytes; however only few elements were analysed, and only until L/S 0.6 $l \cdot kg^{-1}$total solid (TS), which limits the applicability of the results. Recently, Kosson et al. (2014) carried out an extensive study that focused on laboratory-to-field comparisons of different materials, including C&DW. Redox conditions appeared as a crucial difference between laboratory experiments (typically more oxidised) and field scenario (mild to strong reducing conditions). While field-scale redox conditions are unlikely to be replicated in a laboratory setting, percolation leaching testing which better reflects the particle size distribution and overall flow conditions relevant for field-scale utilisation of mineral C&DW is needed as a basis for assessing the potential release of contaminants from these materials.

The overall goal of the present study was to provide an improved basis for the assessment of leaching from the mineral fraction of C&DW in utilisation scenarios, and evaluate the potential influences from particle crushing and percolation flow conditions in standardised up-flow saturated columns relative to conditions more appropriate for field-scale, represented by downward, intermittent-flow lysimeters. This is relevant in those cases where results from standard column tests may be used as estimation of release in field conditions. Five individual C&DW samples obtained from full-scale crushing facilities in Denmark were subjected to both up-flow column and lysimeter leaching tests, and evaluated in relation to: i) differences in cumulative releases and leachate concentration levels between samples and percolation tests, ii) differences in apparent mineral solubility, and iii) potential critical constituents with respect to selected regulatory limit values.

## 2. Materials and methods

### 2.1. Materials

Five C&DW samples were investigated. The samples were selected based on previous extensive investigations on Danish C&DW (Butera et al., 2014) to represent a wide range of leaching levels, as determined by a batch test at L/S 2 $l \cdot kg^{-1}$TS (EN 12457-1, 2002). Samples CDW1 to CDW4 were sampled from full-scale sorting and crushing facilities that receive materials from demolition sites. Sample CDW1 and CDW2 originated from the same facility, and were constituted of relatively clean, source-separated concrete; sample CDW3 and CDW4, from a second facility, exhibited visible traces of bricks and masonry

[1] CEN/TC 351 is developing a column leaching test for construction products (prCEN/TS 16637-3:2014) which considers the particle size distribution of different "products" (i.e., 0–4 mm, 0–8 mm, 0–16 mm, 0–22.4 mm, 0–31,5 mm, 0–63 mm) and defines rules for crushing of tested material.