ARTICLE IN PRESS

Waste Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Concrete drill core characterization finalized to optimal dismantling and aggregates recovery

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ARTICLE INFO

Article history:
Received 27 June 2016
Revised 2 September 2016
Accepted 8 October 2016
Available online xxxx

Keywords:
Demolition waste
Micro X-ray fluorescence
Hyperspectral imaging
Recycling
End-of-life concrete

ABSTRACT

An innovative strategy, based on micro X-ray fluorescence and **H**yper**S**pectral **I**maging in the short wave infrared range (1000–2500 nm), was developed in order to characterize drill core samples collected from **E**nd-**o**f-**L**ife concrete. Micro X-ray fluorescence maps were realized to check the drill cores chemical composition, to develop the best approach for HSI analyses and to verify the correctness of the obtained HSI results. HSI analysis was carried out in order to recognize and classify aggregates and mortar paste in concrete. A morphological and morphometrical analysis of aggregates was also carried out on the prediction maps.

Results showed as the proposed approach can be profitably applied to analyze and characterize demolition waste materials before dismantling. Starting from an efficient *in-situ* characterization of the objects to dismantle, demolition actions can be optimized in order to maximize the EOL concrete derived materials, minimizing the final waste.

1. Introduction

Eurostates estimated a total production of 970 million tons/year of **C**onstruction and **D**emolition **W**aste (CDW), representing an average value of almost 2.0 ton/per capita only in Europe (Pacheco-Torgal, 2013). This waste is becoming more and more a problem to manage and solve.

CDW recycling is of paramount importance because it allows to recover raw materials otherwise lost (i.e. recycled aggregates), reducing environmental pressures, preventing the increase of land use for the end-of-life concrete disposal in landfills and also avoiding the environmental impacts linked to natural resources exploitation, in a perfect **U**rban **M**ining (UM) logic. UM concerns all the activities allowing the recovery of materials, energy and end-of-life products (Baccini and Brunner, 2012), moving the waste management from a linear approach, where materials are definitively disposed after use, to a circular approach (Cossu et al., 2012; Cossu, 2013; Cossu and Williams, 2015). In this perspective, the need for raw materials is combined with the waste reduction, solving both the problems at the same time.

The possibility to develop and implement an efficient recovery of aggregates from **E**nd-**o**f-**L**ife (EOL) concrete buildings dismantling/recycling is one of the main targets in the CDW sector (Lotfi et al., 2015). Moreover, materials characterization is a crucial step in order to set up correct recycling actions finalized to maximize CDW conversion into useful secondary raw materials (Serranti et al., 2015). Therefore, the possibility to utilize efficient, reliable and low cost sensing technologies able to detect and control materials during all the recycling stages is very important.

Starting from a punctual *in-situ* characterization of materials to dismantle, an ad-hoc demolition process and a following recycling treatment can be developed. The identification of systems for quality measurement and control of CDW during all the recycling stages, from demolition to "new" recycled concrete production, could help to set up better recycling strategies, fulfilling the goal of an optimal CDW recycling. Furthermore, the possibility to implement *on-line* control methodologies allows to obtain a certification of products resulting from CDW processing (Bonifazi et al., 2015; Palmieri et al., 2014).

The main aim of this study was to develop a strategy for CDW characterization by optical sensors, starting from the analysis of concrete drill cores collected from a building to be demolished. The developed recognition/classification method is based on the application of micro X-ray fluorescence (micro-XRF) and **H**yper**S**pectral **I**maging (HSI) working in the Short Wave InfraRed -region (SWIR, 1000–2500 nm). The chemical maps obtained by micro-XRF were compared with the acquired hyperspectral images in order to validate the results, obtained by optical sensing.

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http://dx.doi.org/10.1016/j.wasman.2016.10.008
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Please cite this article in press as: Bonifazi, G., et al. Concrete drill core characterization finalized to optimal dismantling and aggregates recovery. Waste Management (2016), http://dx.doi.org/10.1016/j.wasman.2016.10.008

2. Materials and methods

2.1. Concrete samples

Two different typologies of concrete drill core samples were investigated: Portland cement drill core and blast furnace slag (CEM III/B) cement drill core (Lotfi et al., 2014). The core samples were drilled and collected by Strukton Company (The Netherlands) from two different towers, to be demolished, built in 70s–80s, located in Groningen (The Netherlands) (Di Maio et al., 2012). More in detail, the two core samples came from two different buildings (i.e.: the blue and the yellow towers) and both were drilled from the floor.

In order to perform the analysis, the two cores were cut in two halves and every half core was cut in slices. A portion (about 8 × 8 cm^2) of a selected slice for each drill core was investigated by micro-XRF to evaluate the presence and the spatial distribution of the different chemical elements. The micro-XRF analysis was finalized to perform the correct strategy for the HSI analysis and to check the HSI efficiency.

For each portion of the slice, two different areas were selected, thus defining a training and a validation set, used to build and validate the HSI classification model, respectively. In Fig. 1, a flowsheet of the applied procedure is shown.

2.2. Micro X-ray fluorescence

Micro-XRF analyses were carried out at Raw-Materials Lab of the Department of Chemical Engineering, Materials & Environment (Sapienza - University of Rome, Italy).

XRF is a non-destructive technique allowing to perform both the identification of chemical elements and their quantitative evaluation as detected on the investigated surface sample. The analytical method is based on measurement of the intensities of the X-rays emitted by secondary excitation. The primary beam irradiates the specimens exciting chemical elements to emit secondary spectral lines that have characteristic wavelengths for each element and intensities related to their concentration (Lawrence, 2003).

The adopted device is the M4 TORNADO by Bruker. The adopted measurement conditions for the analyses are reported in Table 1.

Table 1
The adopted measurement conditions for the micro-XRF analyses.

Mapping parameters	Width	800 pixels (80 mm)
	Height	800 pixels (80 mm)
	Pixel size	100 µm
	Total number of pixels	640,000
Acquisition parameters	Frame count	2
	Pixel time	10 ms/pixel
	Measure time	12,800 s
	Overall time	15,921 s
Tube parameters	High voltage	50 kV
	Anode current	499 µA
	Vacuum	29 mbar

2.3. Hyperspectral imaging

Hyperspectral images were acquired at Raw-Material Lab of the Department of Chemical Engineering, Materials & Environment (Sapienza - University of Rome, Italy) using the SISUChema XL™ Chemical Imaging Workstation (Specim, Finland), equipped with an ImSpector™ N25E imaging spectrograph (Specim, Finland) working in the short wave infrared range (1000–2500 nm).

The analytical station is controlled by a PC unit equipped with specialized acquisition/pre-processing software (Chemadaq™), to manage the different devices belonging to the platform and to perform spectra acquisition/collection.

The HSI device works as a push-broom type line scan camera, acquiring sample spectral information for each pixel in the line (Hyvarinen et al., 1998). The result of acquisition is often called "image cube" with two spatial dimensions and one spectral dimension.

Calibration for black and white references was automatically performed. The analyzed images were acquired with a 31 mm lens and a field of view of 100 mm. 256 wavelengths were collected.

Spectral data analyses were performed using PLS_Toolbox™ (Version 7.9.3, Eigenvector Research, Inc.) under Matlab® environment (Version 8.4, The Mathworks, Inc.). More in detail, spectral data analysis was carried out in three steps: (i) spectra preprocessing, applied to enhance differences among spectra and to minimize noise; (ii) **P**rincipal **C**omponent **A**nalysis (PCA) applied to perform an exploratory data analysis and, finally, (iii) **P**artial **L**east **S**quares **D**iscriminant **A**nalysis (PLS-DA) to build the classification models.

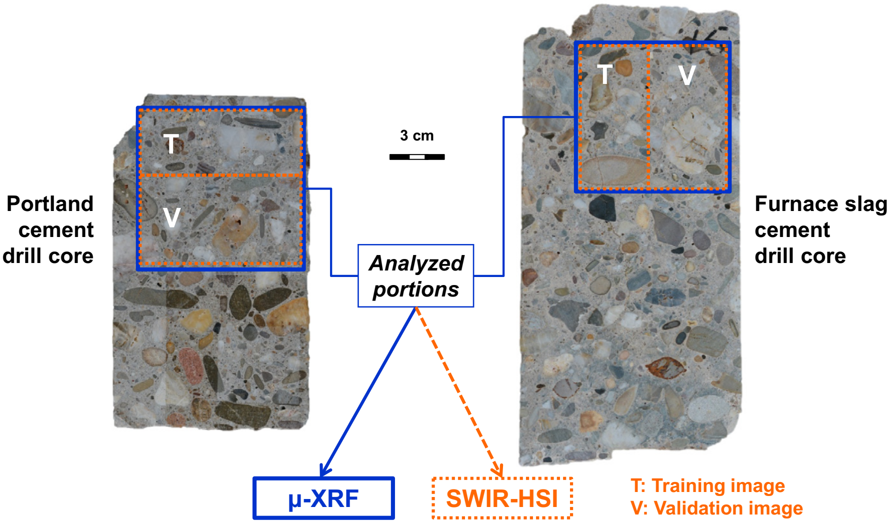

Fig. 1. Layout of the procedure applied on the different portions of the analyzed drill core slices. The square portion was investigated by micro-XRF, whereas Training (T) and Validation (V) areas were selected to build the HSI classification model.

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