Science of the Total Environment xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

Long-term leaching from recycled concrete aggregates applied as sub-base material in road construction

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HIGHLIGHTS

- Leaching from crushed concrete applied as road sub-base has been assessed after >10 years exposure.
- Calcite, gibbsite and magnesite were identified as solubility controlling phases by geochemical modelling.
- These simulated mineral phases were in agreement with the expected degradation products from the carbonation process.
- When field pH changed from 7.4–8.5, leaching of V increased more than one order of magnitude.

ARTICLE INFO

Article history:
Received 19 November 2016
Received in revised form 6 February 2017
Accepted 6 February 2017
Available online xxxx

Editor: F.M. Tack

Keywords:
Leaching
Recycled aggregates
C&D waste
Sub-base
Geochemical modelling

ABSTRACT

In the present study, the metal leaching from recycled concrete aggregates (RCA) used in road sub-base is presented after >10 years of exposure. The released levels of inorganic constituents, the effect of small variation of pH and the use of de-icing salt during winter season were studied. In addition, speciation modelling for the major elements has been provided. The pH varied from 7.5 to 8.5 for the sub-base constructed with RCA whereas the pH of around 8 was obtained for the test section not affected by the traffic and de-icing salts. Despite a small variation in pH, the leachability of Al, Ca and Mg was found to be strongly dependent on pH and fair agreement between the measured and predicted concentrations was obtained. The speciation modelling indicated that gibbsite, calcite and magnesite controlled the solubility of Al, Ca and Mg, respectively, which was in agreement with the expected carbonation products. Due to the larger pH fluctuations in the test sections exposed to the road traffic, increased concentrations were observed for the oxyanions. The same effect was not seen for the trace metal cations Cd, Cu, Ni, Pb and Zn. The distinct pH dependent leaching profile (solubility maximum in the mildly basic pH region) for vanadium could be seen after 10 years of exposure. The simplified risk assessment showed that the released quantities did not exceed the chosen acceptance criteria for groundwater and fresh water. The results obtained for the test section not influenced by road dust and de-icing salts, complied with these criteria even without considering any dilution effects caused by the mixing of pore water with groundwater.

1. Introduction

Safe and sound utilisation of construction and demolition waste (C&D waste) may contribute to a more sustainable aggregate industry. The management practice vary across Europe with respect to pre-sorting rules for demolition, treatment capacity of the generated waste, treatment methods and the level of material recovery. The latter is in much focus today due to the implementation of the Waste Framework Directive (WFD 2008/1998/EC) and due to the included target of achieving minimum 70% material recovery by 2020.

Several recovery scenarios exist for the different fractions (concrete, masonry, wood, asphalt etc.) in the waste stream (Arm et al., 2016). For concrete waste, the use of recycled concrete aggregates (RCA) in road construction seems to be an important user scenario and a number of demonstrations have been reported (Vazquez 2013). However, in many cases the acceptance of RCA in the market seems to be low. The main reasons for this might be the possible fluctuations of physico-chemical (density, grading, cement paste content, leaching properties etc.) and mechanical properties (e.g. bearing capacity, abrasion

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http://dx.doi.org/10.1016/j.scitotenv.2017.02.052

Please cite this article as: Engelsen, C.J., et al., Long-term leaching from recycled concrete aggregates applied as sub-base material in road construction, Sci Total Environ (2017), http://dx.doi.org/10.1016/j.scitotenv.2017.02.052

resistance etc.) due to the fluctuation in the source material, lack of constant supply and easy access of high quality virgin aggregates. Without addressing these challenges adequately, the apprehension for RCA will remain among the end-users.

One of the physicochemical properties addressed in several studies, is the leaching of harmful substances (see for example Butera et al., 2015; Galvin et al., 2014a; Townsend et al., 2004), because RCA is recovered from a waste stream with possible contamination sources. However, it seems evident that the metal leaching properties of RCA are less dependent on the fluctuations in the source material quality provided that sufficient measures are taken prior to and during demolition (e.g. removing building components containing hazardous chemicals before demolition and segregation of the C&D waste fractions). The metals are mostly released from the binder part (hydrated cement paste) in RCA and by addressing the main leaching properties for the main binder types used in construction until today, i.e. lime, Portland cement and cements containing coal based fly ash and blast furnace slag, the characteristic leaching properties can be explained for nearly all existing mortar and concrete types, that are present in most of the today's generated concrete waste (e.g. van der Sloot et al., 2011).

Characteristic constituent leaching patterns with respect to equilibrium and diffusion controlled metal release have been identified extensively and adequately described in many studies (Galvin et al., 2014b; Kosson et al., 2014; Engelsen et al. 2009; Engelsen et al., 2010). Furthermore, the leaching from cement-based materials involves mechanisms like sorption to iron- and aluminium hydroxides, mineral precipitation and complex formation with humic substances (Dijkstra et al., 2004; Van Zomeren et al., 2009). These mechanisms are strongly dependent on pH and therefore the carbonation level (ageing) of the concrete waste. Since carbonation of concrete involves a decrease in the pore water pH from around 13 to 8, due to a series of reaction between the hydrate phases and the carbonate ions dissolved in the pore water (Engelsen and Justnes, 2014), this ageing process influences all equilibrium based leaching mechanisms. Evidence for these processes has been provided by experimental speciation analysis (Mulugeta et al., 2010; Mulugeta et al., 2011) and by geochemical speciation modelling (e.g. Engelsen et al., 2009, 2010).

Regarding the leaching measured at field site, a few systematic full scale studies have been reported. Engelsen et al. (2012) studied the leaching from RCA used as a road sub-base. Most of the leaching data reported in their study were collected from the exposure period of 4 years. The effect of carbonation at field site was shown and the field leaching observed seemed to resemble the characteristic laboratory leaching patterns as function of pH for some of the metals studied. In another recent field study from USA, Chen et al. (2013) monitored the leaching from RCA (<50 mm) used as a base course in a test section of an interstate highway (Minnesota) and in a parking lot (Wisconsin). The reported data for the base course were collected within a sampling period of around 1.5 years, during which a neutral pH was obtained after 7 month.

Other studies relevant to the practical use of RCA in road construction have also been published recently. Higher released quantities of Cr and SO_4^{2-} were found in percolation tests when the crushed concrete and mortar were tested under compacted conditions (Galvin et al., 2014a,b). Intermittent unsaturated flow and the effect of flow direction have been found to influence the results in column leaching experiments (Meza et al., 2009; Butera et al., 2015). Heavy metal leaching have been included into a life cycle assessment (LCA) framework for road and earth constructions (Schwab et al., 2014) and the suitability of using low quality aggregates from C&D waste in unpaved rural roads has also been reported (Jimenez et al., 2012).

In the present study, the metal leaching from RCA was measured after 10 years of exposure in a road sub-base and was a continuation of an earlier field site study (Engelsen et al., 2012). Effects of small variations of pH and the use of de-icing salt during winter season were studied. In addition, speciation modelling for the major elements have been provided in order to compare the measured results with the expected carbonation products. Long term leaching data of this type combined with thermodynamic modelling have to the author"s best knowledge not been presented before and will form the basis for more a generic assessment of the environmental properties of RCA and increase the confidence among the users.

2. Materials and methods

2.1. Field description

The field site is located at the 4-lane highway (E6) 20 km south of Oslo in Norway. In conjunction with the reconstruction of the highway in 2004, a control station for heavy vehicles (Taraldrud control station) was built by the Norwegian Public Road Administration. The entrance lane from the control station to the north of the highway was used for field leaching studies and was constructed with RCA, foam glass, asphalt and natural aggregates in the sub-base divided into F1–F9, see Fig. 1. The test sections were covered with asphalt except for F7 and F8, which were exposed directly to air and rainfall. Moreover, these test sections were not exposed to de-icing salts as they were located on the side of the test road. Under the asphalt layers, the sub-base was constructed with coarse RCA (20–120 mm) in a layer thickness of 900 mm. Gravel (0–42 mm) with a maximum layer thickness of 50 mm was used as a levelling layer between the sub-base and the asphalt. Below the sub-base, a watertight high density polyethylene (HDPE) membrane was placed. In order to prevent puncturing of the HDPE membrane, a layer of size reduced RCA (8–16 mm) with 100 mm thickness was placed between the sub-base and the membrane. In the reference section (F5), local gneiss (natural aggregates) was used. Test section F2, F4 and F8 were constructed without the HDPE membrane, in order to avoid cross contaminations between the sections and from the surrounding environment. Further details can be found in Engelsen et al. (2012).

2.2. Leachate collection and field site measurements

Leachates were collected from the field site as follows. Watertight HDPE membranes with drains were placed under the section to collect the infiltrated water (leachate), as indicated in Fig. 1. The leachates from the different test sections were led through polyethylene pipes to the collection wells and automatically sampled in separate closed sampling lines (HDPE containers). To protect the instrumentation in the two sampling collection stations, the temperature was kept between 15 and 20 °C. The leachates analysed in this study were collected from F3W, F3E, F5 and F7. They were collected once per each month from October 2014 to June 2015.

Each of the test sections had a separate sampling line inside the collection wells where it was arranged to monitor pH, volume, rainfall and temperature, as described in detail earlier (Engelsen et al., 2012). Regarding the pH measurements, good correlation was achieved earlier between the pH monitored at field site and the pH measured in laboratory for the corresponding leachate samples collected. Thus, since the present study was conducted within a relatively short time period, only the temperature in the test sections was determined on site. For this, copper preserved wood cubes of 50 mm were used as sensor cells and were placed in the sub-base at 3 different levels (top, middle and bottom). Thermocouples from the sampling collection stations were connected to each sensor cell in order to record the temperature

The estimated liquid to solid ratio (L/S) after one year of exposure was 0.30, 0.39 and 0.09 for F3 W, F3E and F7, respectively (Engelsen et al., 2012). Based on data from the meteorological station 15 km further south, the rainfall over a 10-year period has been approximately 1000 mm per year. It was therefore reasonable to assume that the L/S has reached a value of 1 in F7 and 3–4 for F3W and F3E.

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