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Assessment of Environmental Hazardous of Construction and Demolition Recycled Materials (C&DRM) from Laboratory and Field Leaching Tests Application in Road Pavement Layers

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Abstract
A research project aiming to contribute to the sustainable implementation of recycling of Construction and Demolition Waste (C&DW) in road pavements is ongoing. The use of Construction and Demolition Recycled Materials (C&DRM) in road pavements is envisaged as a solution with major environmental and economic benefits. Their application as unbound granular material in pavement layers (base, sub-base and capping layers) also has the advantage to allow the incorporation of large amounts of this type of materials, even coming from different sources. Engineering and environmental performance of these materials are being assessed through laboratory tests and field tests. The evaluation of the environmental hazardous of C&DRM is based in their leachability from compliance (batch test) and basic characterisation (column test and lysimeter test) leach tests. The results already obtained in leaching tests are presented and discussed in the paper. In case of compliance leach test, the results are compared with leaching limit values defined in the Portuguese legislation for waste acceptable at landfills for inert waste.

Keywords: Construction and demolition recycled materials, Road pavement, Unbound granular layers, Leaching

1 Introduction

Construction and Demolition Waste (C&DW) are considered a priority waste stream by the European Union (EU). In 2012, the twenty-eight countries of the EU produced about 820 million tonnes of C&DW (Eurostat, 2015), representing around one-third of the annual production of waste.

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The annual production of C&DW in Portugal was estimated in about 7.5 million tonnes, however, the latest official data of the Portuguese Environment Agency, related to the production of C&DW in 2009, only pointed to 1.7 million tonnes (Vaz and Saldanha, 2015).

According to data collected in 2009, the valorisation rate of C&DW in Portugal was 34% (Vaz and Saldanha, 2015), still well below the target of 70% to be reached by 2020, as it was defined by the Waste Framework Directive 2008/98/EC (OJEU, 2008), in order to move towards a European recycling society.

Recycling of Construction and Demolition Recycled Materials (C&DRM) in unbound granular layers (base, sub-base and capping layers) of road pavements is a solution that allows the incorporation of large amounts of these materials, with important environmental and economic benefits throughout the country.

The application of C&DRM in road pavements is still limited by some lack of knowledge concerning the engineering and environmental performance of these materials and the limited experience with their use in construction.

A Portuguese research project, entitled SUPREMA – Sustainable Application of Construction and Demolition Recycled Materials in Road Infrastructures, developed by the National Laboratory for Civil Engineering (LNEC), in cooperation with the University of Lisbon (UL), aims to assess the feasibility to use C&DRM in the base, sub-base and capping layers of road pavements.

The hazard of release of pollutant substances from C&DRM and the risk it may pose to public health and the environment are main issues and force the evaluation of the leachability of these materials. Portugal, as in the majority of countries in the world, has no specific legislation for environmental classification of recycled materials to be applied in civil engineering works. However, Portuguese Environment Agency is allowing waste recycling when limit values defined in the Portuguese Decree-Law n. 183/2009 of 10 August 2009 (DL 183/2009, 2009) for waste acceptable at landfills for inert waste are not exceeded. This legislation was transposed from the Council Decision 2003/33/EC of 19 December 2002 (OJEU, 2003).

In Portugal, the use of C&DW in unbound granular layers of road pavements is ruled by technical specifications LNEC E 473 (2009) and LNEC E 474 (2009), that have adopted the compliance leach test carried out according to EN 12457-4 (2002), and leaching limit values for inert waste foreseen in the Portuguese Decree-Law n. 183/2009.

Column up-flow percolation tests, carried out according to CEN/TS 14405 (2004), and lysimeter tests are also part of the experimental program, taking into account they are closer to the field conditions than batch tests. Another important issue which justifies the performance of the three leaching tests is the controversy that still exists in the literature on the representativeness of their results (Delay et al., 2007 and Lind et al., 2008).

In this paper, the results of the batch tests are presented and compared with leaching limit values defined in the Portuguese legislation for waste acceptable at landfills for inert waste and with the results of the lysimeter tests existent up to now. The column leaching tests are ongoing and their results will be presented soon.

2 Materials and Methods

Four C&DRM processed from different types of C&DW were selected for the SUPREMA's project: a crushed concrete (CC), a crushed mixed concrete (CMC), a crushed reclaimed asphalt pavement (CRAP) and a milled reclaimed asphalt pavement (MRAP). A natural crushed limestone (NCL) was selected to be used as a reference material in the study. Figure 1 shows the materials studied.

a) b) c) d) e)

Figure 1: Materials recycled and natural selected: a) crushed concrete (CC), b) crushed mixed concrete (CMC), c) crushed reclaimed asphalt pavement (CRAP), d) milled reclaimed asphalt pavement (MRAP), and e) natural crushed limestone (NCL)

Along with the assessment of release of dangerous substances of the selected materials, the experimental research program also evaluated their engineering properties (geometrical, physical, and mechanical), in both instances applying European standards whenever possible. Concerning engineering properties, only the constituents of recycled aggregates, determined according to NP EN 933-11 (2011), and the grain-size distributions of recycled and natural aggregates, determined according to EN 933-1 (2012), are presented in the paper. As mentioned before, the leachability of the recycled and natural materials was studied in laboratory using batch tests, performed according to European standard EN 12457-4 (2002).The field leaching tests, lysimeter tests were performed according to the procedure described hereinafter.

Recycled and natural materials were compacted in a box of High-Density PolyEthylene (HDPE) whose area is 1x1 m^2. The materials were compactied at optimum moisture content as determined from the modified Proctor compaction test (EN 13286-2, 2010). Ultrapure water was used to achieve the optimum moisture content, so that no chemical species were added to the materials to leach. Compaction quality control of the layer was carried out with the sand replacement method (LNEC E 204, 1967) and moisture content test (NP EN 1097-5, 2011).

Reservoirs in PolyEthylene (PE) with a capacity of 65 l were used to collect the leachate. The connection between the HDPE box and the PE reservoir was provided by a PolyVinyl Chloride (PVC) pipe.

All plastic materials were carefully washed before use to eliminate any source of contamination. The wash sequence was: jets of tap water, 10% nitric acid solution, distilled water, and ultrapure water.

To facilitate the percolation of the leachate from the HDPE box to the PE reservoir a drainage layer was built in the base of the compacted layer. Drainage layer comprises a bottom layer in coarse gravel, and a top layer in fine gravel. Coarse and fine gravels were previously washed in this sequence: jets of tap water, distilled water, and ultrapure water.

At the top of the plastic boxes a plastic mesh was applied to protect the deposition of foreign materials into the compacted layer. To prevent entry of local runoff water, the plastic box was laid 0.15m above the level of the natural terrain and its perimeter was surrounded by coarse gravel.

Seven leachates are envisaged to be collected in each lysimeter, corresponding to liquid/solid (L/S) ratios of 0.1, 0.2, 0.5, 1.0, 2.0, 5.0 e 10.0 l/kg dry matter, following the L/S of the technical specification CEN/TS 14405 (2004). The cumulative L/S ratio of 10.0 in the lysimeters is the same as the existing ratio in the batch leach tests (EN 12457-4, 2002).

The chemical components analysed in the leachate are the ones considered in the Portuguese legislation. Nevertheless, this paper only reports the results obtained for heavy metals (Cadmium - Cd, Chromium total - Cr, Lead – Pb, Zinc – Zn, Copper – Cu, and Nickel – Ni), Chloride (Cl^-), Sulphate (SO_4^{2-}), and Dissolved Organic Carbon (DOC). Leachate samples used to determine heavy metals were collected in HDPE plastic recipients and were preserved with nitric acid (pH < 2), and those used to determine Cl^-, SO_4^{2-} and DOC were simply collected to HDPE plastic recipients. All of them were stored at temperatures less or equal to 4 ºC, until they were analysed. The concentration of heavy metals has been determined by mass spectrometry or optical emission spectrometry with inductively coupled plasma, Cl^- and SO_4^{2-} by ion liquid chromatography or volumetry and gravimetry, respectively, and DOC by infra-red detection or wet oxidation.

Measure of the pH and electrical conductivity (EC) in accordance with EN 16192 (2011) of each leachate fraction were also carried out.

3 Results and Discussion

3.1 Constituents of C&DRM

The proportions of the constituents of C&DRM are presented in Table 1.

Constituents	CC	CMC	CRAP	MRAP
Rc (%)	84	60	6.1	0.0
Ru (%)	9.4	24	29	0.0
Ra (%)	0.7	12	64	99
Rb (%)	5.3	3.9	0.9	0.0
Rg (%)	0.0	0.0	0.0	0.0
X (%)	0.6	0.1	0.0	1.0
FL (cm^3/g)	0.0	0.0	0.0	0.0

R_c - Concrete, concrete products and mortars
R_u - Unbound aggregates, natural stone, hydraulically bound aggregates
R_a - Bituminous materials
R_b - Clay masonry units (e.g. bricks and tiles), calcium silicate masonry units and aerated non-floating concrete
R_g - Glass
X - Other: cohesive materials (e.g. clay soils), plastics, rubbers, metals (ferrous and nonferrous), non-floating wood and gypsum plaster
FL - Floating materials in volume

Table 1: Proportion of the constituents in C&DRM

3.2 Grain-size Distribution

The grain-size distribution curve of each recycled material is presented in Figure 2 in comparison with the grain-size distribution range required by Portuguese Infrastructures Administration (IP, 2009).

Grain-size distributions of CMC and CRAP materials are similar to each other and they are mostly inside the grain-size distribution range of the Portuguese guidelines. CC and MRAP materials present a grain-size distribution outside the grain-size distribution range of the Portuguese guidelines. In the case of MRAP material a new composition material was produced with the incorporation of 70% of NCL (30MRAP+70NCL).

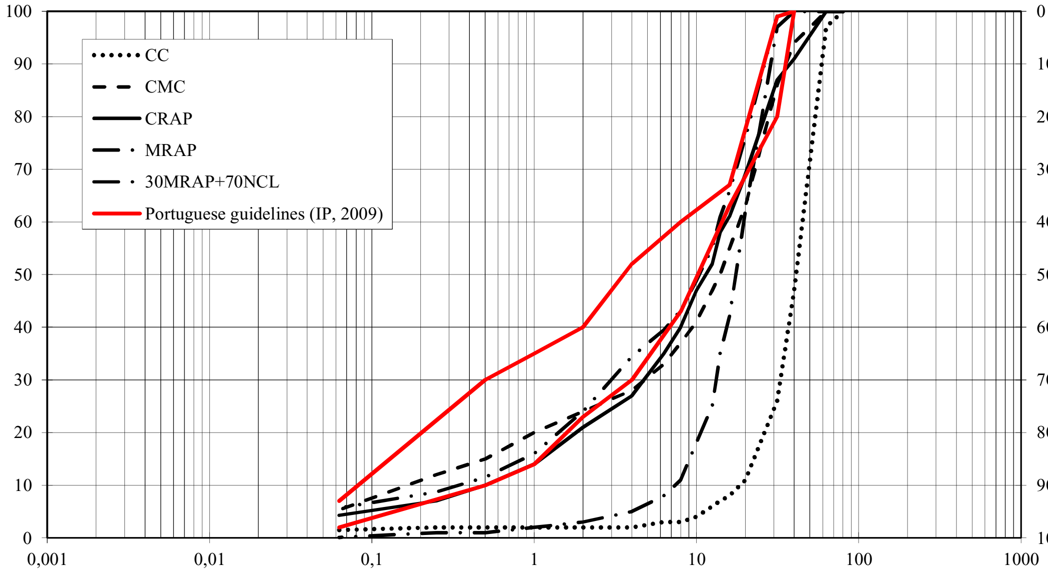

Figure 2: Grain-size distribution curves of C&DRM materials and grain-size distribution range required by Portuguese Infrastructures Administration guidelines

3.3 Leachability

Batch test

The results obtained in the batch tests performed on recycled and natural materials are presented on Table 2. Data from Table 2 show that none of the contents of the evaluated substances are higher than the leaching limit values of the Portuguese Decree-Law n. 183/2009 (DL 183/2009, 2009) for waste acceptable at landfills for inert waste. Only the content of Cr-total in the CMC eluate is closer to the threshold value and even then it is approximately four times lower than the limit.

In these conditions, similarly to the environmental criteria used in other European countries (Böhmer et al. 2008), Portuguese regulation in force (LNEC E 473, 2009 and LNEC E 474, 2009) enables the application of C&DRM studied in the construction of road pavement layers (base, sub-base and capping layers).

Parameter (mg/kg, dry matter)	CC	CMC	CRAP	MRAP	30MRAP+70NCL	NCL	Inert waste threshold
Cadmium, Cd	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.04
Chromium total, Cr	0.239	0.126	0.046	<0.010	<0.01	<0.010	0.5
Lead, Pb		<0.024	<0.024	<0.024	<0.024	<0.024	0.5
Zinc, Zn	0.031	0.010	0.006	<0.006	0.039	0.035	4
Copper, Cu	0.047	0.045	0.030	<0.014	<0.014	<0.014	2
Nickel, Ni	<0.026	<0.026	<0.026	<0.026	<0.026	<0.026	0.4
Chloride, Cl^-	149	44	35	35	26	44	800
Sulphate, SO_4^{2-}	551	267	124	13	50.4	145	1000
Dissolved Organic Carbon , DOC	60	46	71	94	33	71	500
pH	11.99	11.29	10.95	9.67	8.96	7.90	—

Table 2: Results of the batch tests

Lysimeter test

Table 3 summarizes the cumulative contents obtained in the leachates of the lysimeter tests for the six fraction volumes collected (L/S ratio equal to 5.0 l/kg dry matter). In spite of lysimeter tests have begun in June 2011, the rainfall was not still enough to reach the last fraction volume (L/S ratio equal to 10.0 l/kg dry matter). Figure 3 shows, as an example, the variation of the leached cumulative contents for the Cl^-, SO_4^{2-}, and Cu.

The contents of the heavy metals presented have very low concentrations, sometimes below the reporting limits of the method used. Considering the cumulative contents achieved for all substances in the leachate corresponding to L/S ratio equal to 5.0 l/kg and the decrease of their concentrations in the leachate over time it is unlikely that the leaching limit values for inert waste are achieved with the last fraction volume (L/S ratio equal to 10.0 l/kg). SO_4^{2-} can become an exception for C&DRM from C&DW with cementitious matrix, although this statement could only be confirmed after analysis of the last leachates

In the recycled materials, the cumulative contents for Cl^- and SO_4^{2-} are higher than their contents in the batch tests (Table 2) where L/S ratio is equal to 10.0 l/kg. In the case of DOC it was observed the opposite possibly due to temporal degradation of these compounds, since the time elapsed between the production of leachate and its analysis is much longer in lysimeters.

The pH values of the leachate in the recycled and natural aggregates are neutral and remained approximately constant over the six fraction volumes. Comparing with the pH values of the eluates from the batch tests, it is lower in recycled aggregates and higher in natural aggregate. Electrical conductance (EC) of the leachate decreased gradually over the six fraction volumes collected, consistent with the gradual reduction of release of the species analysed.

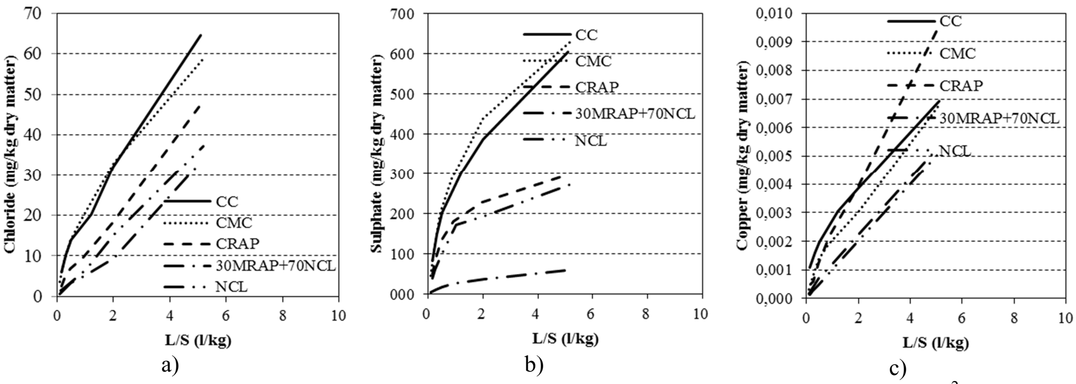

Figure 3: Cumulative contents for six fraction volumes (to L/S ratio equal to 5.0 l/kg): a) Cl^-, b) SO_4^{2-} and c) Cu

Parameter (mg/kg, dry matter)	CC	CMC	CRAP	30MRAP+70NCL	NCL	Inert waste threshold
Cadmium, Cd	0.003	0.003	0.003	0.003	0.003	0.04
Chromium, Cr	0.114	0.083	0.03	0.03	0.03	0.5
Lead, Pb	0.006	0.005	0.005	0.005	0.005	0.5
Zinc, Zn	0.011	0.011	0.010	0.011	0.018	4
Copper, Cu	0.007	0.007	0.009	0.005	0.005	2
Nickel, Ni	0.015	0.016	0.015	0.015	0.016	0.4
Chloride, Cl^-	64.63	58.43	46.91	32.45	37.27	800
Sulphate, SO_4^{2-}	603.83	626.59	294.71	57.32	271.79	1000
Dissolved Organic Carbon, DOC	13.37	21.04	36.74	14.31	6.75	500
pH (-) (min. and max. values)	7.23-8.13	7.20-7.63	7.35-7.66	7.33-7.74	7.27-7.76	—
EC (µS/cm) (first and last values)	1540-302-	1374-266	858-186	247-147	721-180	—

Table 3: Lysimeter test results for six fraction volumes collected (L/S ratio equal to 5.0 l/kg)

4 Conclusions

The hazard of release of pollutant substances from C&DW and the risk it may pose to public health and the environment force the evaluation of the leachability of these waste before recycling in civil engineering works. The results in the batch test, a compliance leach test, highlighted the feasibility of using the studied recycled aggregates in the construction of road pavement layers as the levels of substances released are far below the leaching limit values for waste acceptable at landfill for inert waste.

Regarding the release of the substances in the batch and lysimeter tests, it was observed that the concentration of Chloride and Sulphate are lower in the batch test than in the lysimeter test, but with the Dissolved Organic Carbon the opposite occurs. Therefore, this finding does not allow concluding if a method is more conservative than the other.

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