

## **Evaluation of environmental impact of construction and demolition recycled materials (C&DRM) from laboratory and field leaching tests**

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**ABSTRACT:** The management of an important volume of Construction and Demolition Waste (C&DW) in accordance with the applicable legal framework in Portugal and in European Union represents a significant source of concern for the producing companies and for the European countries. A research project aiming to contribute to the sustainable implementation of recycling of C&DW in road pavements is being developed by two Portuguese research institutions since 2010. The main purpose of the project is to respond to the issues raised by the national and international technical community through the development of research concerning the application of Construction and Demolition Recycled Materials (C&DRM) as unbound granular material in road pavements. The research plan includes an extensive experimental programme on several selected C&DRM and a natural aggregate (reference material). According to chemical characterization of waste defined by the Portuguese legislation, two recycled aggregates would have to be disposed at non-hazardous waste landfills. However, either the contents of leached analyses obtained in the compliance batch leaching tests or in the lysimeters tests indicate that C&DRM leachability is under the limit values defined by the Portuguese legislation regarding waste admissible for landfills of inert waste inert.

## **INTRODUCTION**

The annual overall production of Construction and Demolition Waste (C&DW) in Portugal is estimated in about 7.5 million tonnes (Rodrigues, 2012) and among the European Union members in about 850 million tonnes (Fische and Werge, 2009).

The Waste Framework Directive, 2008/98/EC (Official Journal of the European Union, 2008) sets a target of 70%, by 2020, for preparing C&DW for reuse, recycling and other material recovery operations

In the present context of construction activities, the source reduction of C&DW production seems unfeasible, being the most realistic alternatives their reuse and recycling.

The use of Construction and Demolition Recycled Materials (C&DRM) in base, sub-base and capping layers of road pavements is envisaged as a recycling solution with environmental and economic benefits. These applications also have the advantage to allow the incorporation of large amounts of those materials, from different origins.

The generalised application of C&DRM in road construction is however still limited in many countries by some knowledge gaps, deriving from the lack of information concerning the engineering and environmental performance of these materials and from the limited experience with their practical application in road construction.

A Portuguese research project, entitled SUPREMA – Sustainable Application of Construction and Demolition Recycled Materials (C&DRM) in Road Infrastructures, is being developed by the National Laboratory for Civil Engineering (LNEC), in cooperation with the Technical University of Lisbon (IST), with the main purpose of evaluating the technical (engineering and environmental) feasibility of applying the C&DRM in base, sub-base and capping layers of road pavements.

Nowadays, regardless the use of C&DRM on road pavements could attain a satisfactory engineering performance, the environmental concerns regarding the potential contamination of surface and ground waters forces the evaluation of the leaching behaviour of those materials. To achieve this objective, laboratorial (batch tests and column tests) and in situ (lysimeter tests) leaching tests are ongoing in this SUPREMA's project.

Comparison of results of laboratory leaching tests with lysimeter tests in ALT-MAT (2001) have indicated that column tests provide the most real simulation of the actual leaching behaviour of the waste under normal circumstances. The results of the ongoing project will be therefore an important contribution to assess the adequacy of the current classification on the environmental hazard of some C&DRM flows based on the compliance batch leaching test (EN 12457-4:2002) adopted by the Portuguese regulation (LNEC E 473:2009 and LNEC E 474:2009).

However, since there is no Portuguese specific legislation for environmental classification of waste to be applied in civil engineering works, the national regulatory authority, Portuguese Environment Agency, at the present time only allows the waste recycling in civil engineering works when its leachability fits into the category of waste admissible for landfills of inert waste as foreseen in the applicable Portuguese legislation (DL 183/2009, 2009). The chemical characterization or organic parameters of selected aggregates was also studied as provided by the legislation for waste admissible for landfills of inert waste.

In this communication the complete results of compliance batch leaching tests and chemical characterization of aggregates, and the results of the lysimeter tests existent up

to now are presented. The column leaching tests are underway and their results are not yet available to be submitted.

## **MATERIALS AND METHODS**

Four different types of C&DRM were selected for the SUPREMA's project: a crushed concrete, a crushed mixed concrete, a crushed reclaimed asphalt and a milled reclaimed asphalt. For reference material, to provide a comparison with the results obtained with C&DRM, a natural aggregate (limestone) was selected

The characterization of C&DRM and limestone samples was carried out in accordance with the applicable European Standards whenever possible. Concerning engineering properties, only the C&DRM constituents and the grain-size distributions of recycled and natural aggregates are presented. The C&DRM constituents and the grain-size distributions were determined, respectively, according to NP EN 933-11:2011 and EN 933 - 1:2012. In the study of leachability of materials in laboratory the procedure laid out in standard EN 12457-4:2002, a compliance batch leaching test, was adopted where the liquid/solid (L/S) ratio is 10:1 (l/kg dry matter). The exceptions to the use of European Standards were the study of the leachability of the materials in the field given there are no standards for its realization and the dry density of compacted layers in lysimeters, evaluated according to specification LNEC E 204:1967.

### **Lysimeter testing procedure**

The materials to be leached in the lysimeters were compacted into plastic containers with an area of 1x1 m<sup>2</sup>. Underneath the compacted material a layer of gravel, of equal mass, was placed in all lysimeters, for draining the leachate produced by the percolation of rain water through the materials. The leachate produced in each lysimeter is collected in plastic reservoirs, connected to the plastic containers by plastic pipes, and is periodically sampled. The periodicity adopted was based in the methodology defined in CEN/TS14405:2004, i.e., collecting seven fractions of leachate, the last one corresponding to a cumulative L/S ratio of 10:1 (l/kg dry matter). The same ratio exists in compliance batch leaching test (EN 12457-4:2002).

The recycled aggregates and the natural aggregate to be leached in lysimeters were compacted at the optimum moisture content obtained in the modified Proctor compaction tests (EN 13286-2:2010). Subsequently a compaction quality control including the dry density of the compacted layer by sand cone test (LNEC E 204:1967) and the water content (EN 1097-5:2008) was performed.

At the top of the plastic containers 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 container was laid 0.15m above the level of the natural terrain and its perimeter was surrounded by coarse gravel.

All materials used in the construction of the lysimeters, including gravel, were carefully washed to eliminate any source of contamination.

## RESULTS AND DISCUSSION

### C&DRM constituents

The constituents of the studied recycled aggregates are listed on Table 1.

**Table 1. Proportion of the constituents in C&DRM**

Constituents	Crushed concrete (ARB_R1)	Crushed mixed concrete (ARM_R2)	Crushed reclaimed asphalt (ARA_R3.1)	Milled reclaimed asphalt (ARA_R3.2)
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 <sup>3</sup> /g)	0.0	0.0	0.0	0.0

Rc - Concrete, concrete products and mortars;

Ru - Unbound aggregates, natural stone, hydraulically bound aggregates;

Ra - Bituminous materials;

Rb - Clay masonry units (e.g. bricks and tiles), calcium silicate masonry units and aerated non-floating concrete;

Rg - Glass;

X - Other: cohesive materials (e.g. clay soils), plastics, rubbers, metals (ferrous and nonferrous), non-floating wood and gypsum plaster;

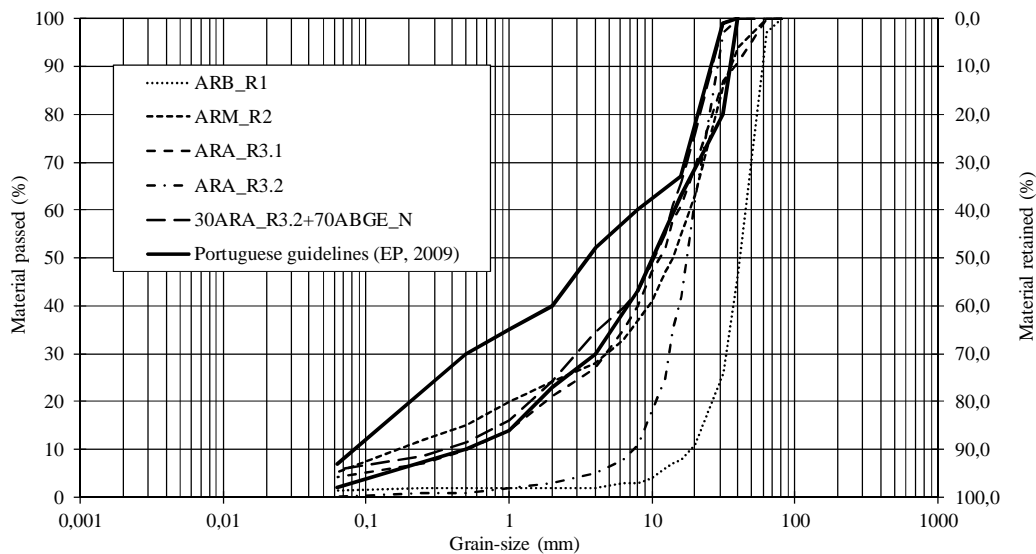
FL - Floating materials in volume.

### Grain-size distribution

The results of grain-size distribution performed on selected C&DRM and the requirements of the Portuguese Road Administration (EP, 2009) for natural and recycled aggregates to be used in unbound granular layers are presented on Figure 1.

Grain-size distribution of crushed mixed concrete and crushed reclaimed asphalt samples are similar and are mostly inside the grading envelope presented by the Portuguese guidelines (EP, 2009).

The crushed concrete and the milled reclaimed asphalt samples present a grain-size distribution outside the envelope. In the case of milled reclaimed asphalt a new composition material was produced with the incorporation of 70% of limestone aggregate (ABGE\_N) (Figure 1).



**FIG. 1. Grain-size distribution of C&DRM samples**

## **Environmental properties**

### *Laboratory tests*

The characterization of organic parameters in the crushed reclaimed asphalt and in the milled reclaimed asphalt samples evidenced that the values obtained for the petroleum hydrocarbons (C10-C40 fraction) are superior to the minimum requirements defined by the Portuguese legislation regarding waste admissible for landfills of inert waste. According to the legislation, these two materials would have to be disposed at non-hazardous waste landfills.

The determinations made in the eluates of batch leaching tests show that the sulphate contents in crushed concrete and crushed mixed concrete samples are superior to the leaching limit (1000 mg/kg dry matter) of the acceptance criteria. According to the legislation, these two materials would also have to be disposed at non-hazardous waste landfill. However, the reevaluation of sulphate contents in these two recycled aggregates revealed that there had been contamination of samples, probably with gypsum, during their processing in the laboratory. The values obtained in the second eluates were 551 and 267 mg/kg dry matter, respectively, being these values lower than the limit value established for the waste disposal at inert waste landfills.

### *Field tests*

The characteristics of the compacted layers of recycled and natural aggregates in the lysimeters are presented in Table 2 as well as the compaction degree achieved having as reference the results obtained in the modified Proctor compaction test.

**Table 2. Characteristics of compacted layers of aggregates in the lysimeters**

Lysimeter	Aggregate	Bulk (kg)	Layer thickness (cm)	Sand cone test		Compaction degree (%)
				Dry density (g/cm <sup>3</sup> )	Water content (%)	
1	ARB_R1	217.75	14.5	1.802	7.4	95.8
2	ARA_R3.1	196.97	12.5	2.057	6.1	99.9
3	30ARA_R3.2+70ABGE_N	194.51	11.0	2.222	3.6	106.6
4	ARM_R2	195.61	11.0	1.945	9.7	94.7
5	ABGE_N <sup>a</sup>	223.76	14.0	1.988	4.1	87.3

<sup>a</sup> Natural aggregate (limestone).

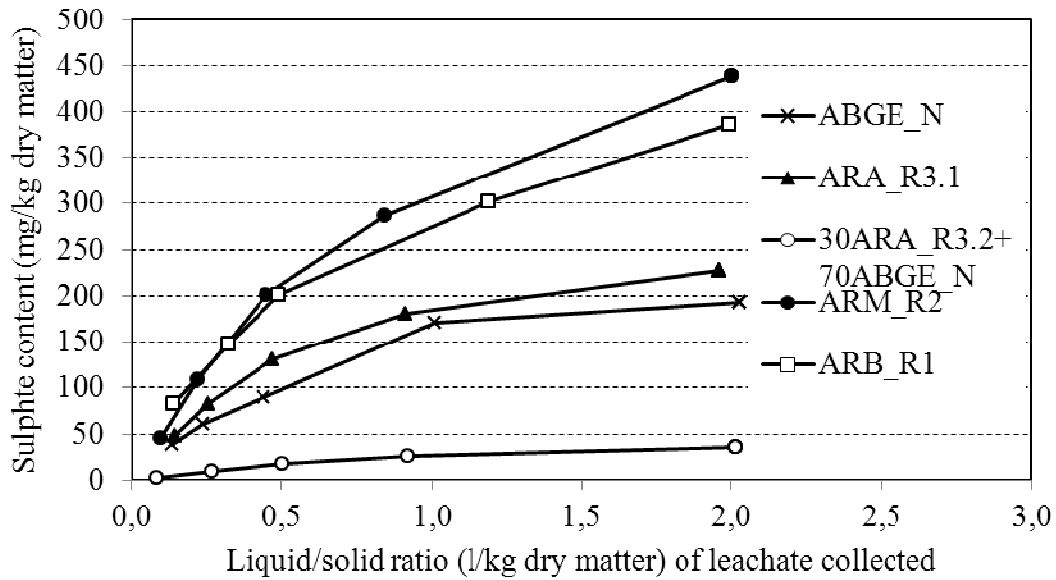
Up to now five of the seven fractions laid out in CEN/TS14405:2004 were collected in all lysimeters corresponding to the cumulative L/S ratio of 2l/kg dry matter. To complete lysimeter tests is lacking the collection of the sixth fraction (cumulative L/S ratio of 5l/kg dry matter) and of the seventh fraction (cumulative L/S ratio of 10l/kg dry matter).

The cumulative contents of the chemical species, in mg/kg dry matter, analysed in the leachate collected up to now in the lysimeters are lower than the limit value established for the disposal at inert waste landfills. As an example the cumulative release of sulphate on the different lysimeters is presented on Figure 2. The levels of nickel and selenium, in particular, were always below the limit of detection so that values considered correspond to the maximum content that could occur considering the value of the detection limit as the maximum value in each leachate collection. As the cumulative L/S ratio of leachate collected in lysimeters is still away from that in the compliance batch leaching tests carried out in this study, is not possible yet to draw conclusions about the released contents of the chemical species. Also it is not possible to draw conclusions about the adequacy of compliance batch leaching tests in the evaluation of environmental hazard of waste intended to be recycled in civil engineering works.

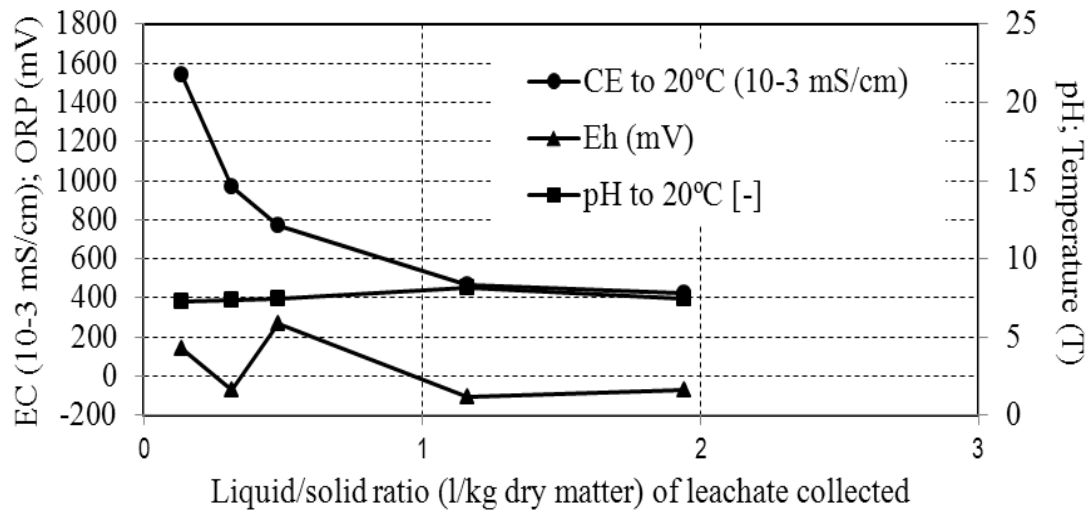
The results obtained in leachate collected in the lysimeters allow affirming, however, that the high contents of petroleum hydrocarbons (C10-C40 fraction) in crushed reclaimed asphalt and milled reclaimed asphalt samples are not easily leachable, since the contents of these chemical species are lower than the detection limit from the first fraction of leachate collected.

The electrical conductivity (EC), the pH and the redox potential (ORP) of leachate were measured in the five fractions of leachate collected (Figure 3). The pH was almost similar in all fractions of leachate collected, i.e. in order of 7.5. The decrease in the electric conductivity value along of five measurements made is common to all leachates and reflects the reduced migration of analytes from the materials under study to the leachate. The greatest decrease in electrical conductivity was observed in the lysimeter constructed with the crushed concrete aggregate and the lowest in the lysimeter

constructed with a mixture of 70% limestone aggregate and 30% milled reclaimed asphalt aggregate.



**FIG. 2. Cumulative sulphate content of the leachate collected in the lysimeters**



**FIG. 3. Electrical conductivity (EC), redox potential (ORP) and pH of the leachate collected in the crushed concrete lysimeter**

## CONCLUSIONS

According to chemical characterization of waste defined by the Portuguese legislation, crushed reclaimed asphalt and milled reclaimed asphalt aggregates would have to be disposed at non-hazardous waste landfills. However, either the results obtained in the compliance batch leaching tests or in the lysimeters tests indicate that C&DRM leachability are lower than the limit values defined by the Portuguese legislation regarding waste admissible for landfills of inert waste inert.

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