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SUSTAINABLE APPLICATION OF CONSTRUCTION AND DEMOLITION RECYCLED MATERIALS (C&DRM) IN ROAD INFRASTRUCTURES

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ABSTRACT
The use of Construction and Demolition Recycled Materials (C&DRM) in road pavements is envisaged as a solution with environmental and economic benefits. Their application as unbound granular materials in pavement layers (base, sub-base and capping layers) also has the advantage to allow the incorporation of large quantities of those materials, from different origins.
The generalised application of C&DRM in road construction is however still limited by some knowledge gaps, deriving from the lack of information concerning the mechanical and environmental performance of these materials and from the limited experience with their practical application in road construction.
A research project, SUPREMA, aiming to contribute to the sustainable implementation of C&DRM in road pavements, by improving the knowledge concerning the mechanical and environmental behaviour of these materials when placed as aggregates in unbound pavement layers, is being developed by the National Laboratory for Civil Engineering (LNEC), in cooperation with Technical University of Lisbon (IST), over three years.
This paper discusses the detailed objectives and methodology of the research project and presents some of its early results, in particular the ones concerning the C&DRM potential pollution.

Keywords: Sustainability; demolition and recycled materials; road infrastructures

INTRODUCTION
Construction activities usually generate large amounts of waste. The annual overall waste production, among the European Union members, is being estimated in 850 million tons [1]. This waste derives from different sources and processes, namely cleaning of the work site and earthworks, discarded materials during construction and demolition operations, as well as maintenance and rehabilitation of existing constructions.
Due to the increasing shortage of space for landfill implementation and the increased costs associated with waste control regulations, with higher demands for environmental protection, the most desirable alternative is the reduction in construction and demolition waste volumes, by means of their reuse and recycling. According to the new Waste Framework Directive, 2008/98/EC [2] a target of 70% recycling of C&D waste is to be achieved by 2020. In Europe, with an aggregate demand about 3 billion tons/year, only 6% supply come from recycled aggregates [3].
The main purpose of the project SUPREMA – Sustainable Application of Construction and Demolition Recycled Materials (C&DRM) in Road Infrastructures – is to respond to the issues raised by the national and international technical community through the development of the research lines concerning the application of C&DRM as recycled aggregates in road pavement base and sub-base layers and in capping layers. The work plan includes a specific experimental programme, comprising laboratory and in situ tests on a reference natural aggregate and several

selected C&DRM: crushed concrete, crushed mixed concrete, crushed reclaimed asphalt and milled reclaimed asphalt.
This paper presents some early results, namely those regarding geometrical and physical properties of the selected aggregates and in particular the ones concerning the C&DRM potential pollution.

Geometrical and physical assessment

The characterization of C&DRM samples selected in this project was done in accordance with the applicable European Standards, namely for the geometrical, physical and mechanical assessment, and following the Portuguese LNEC Specification E473 [4], applicable to C&DRM recycled aggregates for unbound granular layers. The European Standards EN 933-11 [5] specify the methodology to identify and estimate the relative proportions of constituent materials.

Environmental assessment

Nowadays, regardless the use of C&DRM on road infrastructures could attain a satisfactory mechanical performance, the environmental concern regarding the potential contamination of surface and groundwater forces the appraisal of the release of dangerous substances through evaluation of the leaching behaviour of those materials. To achieve this objective laboratorial and in situ leaching tests were proposed in this project.
Portuguese LNEC Specifications E473 and E474 [8], concerning the use of recycled aggregates in unbound road layers, requires that the release of dangerous substances is assessed through EN 12457-4 [8] LNEC-E474, Guide for the use of recycled materials coming from construction and demolition waste in embankment and capping layer of transport infrastructures, LNEC (2009) (in Portuguese).
[9] and that the limits on leaching comply with those of the Council Decision on the acceptance of waste at landfills, 2003/33/EC [10] (transposed to the Portuguese DL 183/2009 of 10 August) regarding waste for disposal in inert landfill, being these criteria also adopted by other European countries [11].
Leaching tests according to EN 1744-3 [12] were also foreseen in the project owing to the fact that European Standard EN 13242 [13], regarding aggregates for unbound and hydraulically bound materials for use in civil engineering works and road construction, refers that water soluble constituents of these aggregates should be assessed through this procedure. This test was specifically for unbound aggregates and it intend to be used with their real particle size distribution unless it surpasses 32 mm, in which case size reduction must be carried on. For this test there are no defined criteria to assess the leaching results although an approach is to compare it with those obtained with natural aggregates.
The leaching tests according to EN 12457-4 and EN 1744-3 were developed to evaluate the short term release of contaminants. They have similar liquid to solid ratio, 10:1, and leaching time, 24h, but differ on the path used to prepare the test portion, on the particle size distribution, up to 10 mm and up to 32 mm, respectively, and on the type of agitation. The principle behind both tests is that equilibrium or near equilibrium conditions between solid and liquid phases were achieved throughout the test although some controversy exists on this subject [14].
Other leaching tests that will be performed include tests in column with up-flow percolation in accordance to CEN/TS 14405 [15], and in situ test using lysimeters. These tests intend to measure the release of pollutants on real or near real conditions and to compare it with the outcome from the other leaching tests. It should be emphasized that results from leaching tests may be conservative, preventing the recycling of some waste, or non conservative, contributing to pollution of the environment. Comparison of the results of CEN laboratory leaching tests with lysimeter tests indicates that column tests provide the most detailed simulation of the actual leaching behaviour of the waste under normal circumstances [16]. The results of the ongoing project will be an important contribution to assess the adequacy of the current classification on the environmental hazard of some construction and demolition waste flows based on leaching tests conducted in accordance with EN 12457-4.

MATERIALS AND METHODS

Crushed mixed concrete (Figure 2a), crushed reclaimed asphalt (Figure 2b) and milled reclaimed asphalt (Figure 2c) from construction and demolition wastes were used as recycled aggregates and limestone was used as a natural aggregate (Figure 2d). Tests on crushed concrete are still being carried on.

(a) (b) (c) (d)

Figure 1 – Tested materials

The constituents of coarse recycled aggregates were classified according to EN 933-11 by hand sorting particles of different constituents, exception made to the floating particles, and expressing the proportion as a percentage by mass. For the floating particles content the result is expressed as a volume by mass.

The grain size distribution was determined according to NP EN 933-1, by the sieving method with washing aggregate for remove clay particles and others aggregate finer particles, exception made to the milled reclaimed asphalt that was analysed without aggregate washing. Particle density and water absorption were determined according to NP EN 1097-6 [7].

The leaching tests were performed on two replicates of representative samples of the different materials following the methodologies of EN 12457-4 and EN 1744-3. The eluates were filtrated over a 0.45 µm filter and the pH and conductivity were measured and then were acidified with ultra-pure nitric acid before assessing heavy metals concentration by graphite furnace atomic absorption spectrophotometry. Chlorides and sulphates were quantified by titration and gravimetry and dissolved organic carbon was evaluated by wet oxidation.

MAIN RESULTS

Constituents

The constituents of the studied recycled aggregates are listed on Table 1. According to the constituents proportions crushed mixed concrete belong to class C of recycled aggregates covered by the Portuguese LNEC Specification E473. For reclaimed asphalt materials the proportion of constituents does not allow them to fit in any class of this specification.

Table 1– Classification of constituents

Constituents	Crushed mixed concrete	Crushed reclaimed asphalt	Milled reclaimed asphalt
Rc [%]	60	6.2	0.0
Ru [%]	24	29	0.0
Ra [%]	12	64	99
Rb [%]	3.7	0.9	0.0
Rg [%]	0.0	0.0	0.0
X [%]	0.1	0.0	0.8
FL [cm^3/g]	0.0	0.0	0.0

Legend: Rc - Concrete, concrete products, mortar, concrete masonry units;
Ru - Unbound aggregate, natural stone, hydraulically bound aggregate;
Rb - Clay masonry units (i.e. bricks and tiles), calcium silicate masonry units, aerated non-floating concrete;
Ra - Bituminous materials; Rg - Glass; X - Other: Cohesive (i.e. clay and soil), miscellaneous: metals (ferrous and nonferrous), non-floating wood, plastic and rubber, gypsum plaster; FL - Floating particles.

Geometrical and physical tests

The results of grain size distribution performed on C&DRM analysed and the requirements of the Portuguese Road Administration (EP) [17] for recycled aggregates to be used in unbound granular layers are presented on Figure 2.
Grain size distribution of crushed reclaimed asphalt and crushed mixed concrete are similar and are mostly inside the grading envelope presented by the Portuguese Road Administration.
The milled reclaimed asphalt sample presents a grain size distribution outside the envelope, having particles of a smaller size.

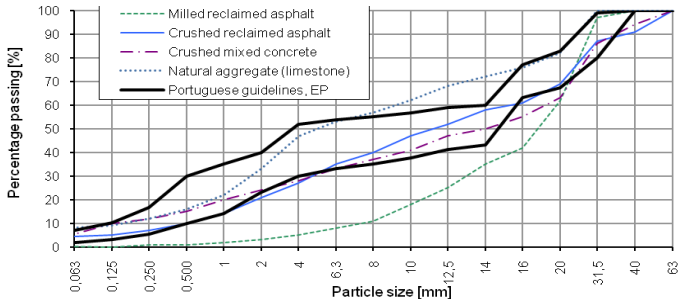

Figure 2 - Grain size distribution for material and Portuguese guidelines for grading [17]

The results of particle density and water absorption tests performed on the three recycled aggregates are presented on Table 2.

Table 2 - Density and water absorption results

Parameter		Size particle	Crushed mixed concrete	Crushed reclaimed asphalt	Milled reclaimed asphalt
Apparent particle density	[Mg/m^3]	4.0 / 31.5	2.604	2.501	2.502
Particle density on a saturated and surface-dried basis			2.443	2.456	2.470
Particle density on an oven-dried basis			2.343	2.426	2.448
Apparent particle density	[Mg/m^3]	0.063 / 4.0	2.496	2.324	2.403
Particle density on a saturated and surface-dried basis			2.396	2.272	2.344
Particle density on an oven-dried basis			2.329	2.234	2.303
Water absorption	[%]	4.0 / 31.5	4.3	1.2	0.88
		0.063 / 4.0	2.9	1.7	1.8

The obtained values for particle density are slightly lower than those usually obtained for natural materials, especially those in the 0.063/4.0 size particle. Regarding the water absorption, the values obtained for the reclaimed asphalt aggregates, are within the range of values usually observed for the natural materials. The values obtained for the crushed mix concrete are higher than those obtained for natural materials.

Leaching tests
The results of leaching tests performed on the studied materials are presented on Table 3 along with the waste acceptance thresholds for disposal of waste in landfill for inert waste of the Council Decision 2003/33/EC.
None of the evaluated contaminants content is superior to the limits of the acceptance criteria. For the metallic determinants, all belonging to List I and List II of dangerous substances of the Directive 2006/11/EC [18], the results were far below the targets for inert waste, exception made to chromium on crushed mixed concrete that is approximately 4 times lower than the limit. It should

be emphasized that the very low release of the contaminants on the short term for the different C&DRM evidence the feasibility of their use as alternative materials in road construction.

Table 3 – Leaching results

Parameter [mg/kg, dry matter]	Crushed mixed concrete	Crushed reclaimed asphalt	Milled reclaimed asphalt	Natural aggregate	Inert waste threshold
pH	11.29	10.95	9.67	7.90	–
Cadmium, Cd	<0.005	<0.005	<0.005	<0.005	0.04
Chromium, Cr	0.126	0.046	<0.01	<0.01	0.5
Lead, Pb	<0.024	<0.024	<0.024	<0.024	0.5
Zinc, Zn	0.010	<0.006	<0.006	0.035	4
Copper, Cu	0.045	0.030	<0.014	<0.014	2
Nickel, Ni	<0.026	<0.026	<0.026	<0.026	0.4
Chloride, Cl^-	44	35	35	44	800
Sulphate, SO_4^{2-}	267	124	13	145	1000
Dissolved organic carbon, C	46	71	94	71	500

Table 4 list the results of the evaluated parameters on the eluates obtained from the four different materials on the leaching test according to EN 1744-3. The release of Cd, Pb and Ni is below the limits of quantification in all aggregates and the contents of Cr, Zn, Cu, Cl^- and SO_4^{2-} are higher on recycled aggregates when compared with natural aggregate, with some exceptions on milled reclaimed asphalt. The own pH of all eluates is lesser in this leaching test and this factor strongly influence the release of chemical species As a general trend Zn, Cl^- and SO_4^{2-} contents in the leaching according to EN 1744-3 are higher in relation to those released on the leaching according to EN 12457-4 while Cr and Cu contents are lower.

Table 4 – Leaching results

Parameter [mg/kg, dry matter]	Crushed mixed concrete	Crushed reclaimed asphalt	Milled reclaimed asphalt	Natural aggregate
pH	9.96	8.12	8.14	6.86
Cadmium, Cd	<0.005	<0.005	<0.005	<0.005
Chromium, Cr	0.103	0.022	<0.01	<0.01
Lead, Pb	<0.024	<0.024	<0.024	<0.024
Zinc, Zn	0.035	0.023	0.053	0.021
Copper, Cu	0.022	0.016	<0.014	<0.014
Nickel, Ni	<0.026	<0.026	<0.026	<0.026
Chloride, Cl^-	53	53	35	35
Sulphate, SO_4^{2-}	343	163	17.5	159

FINAL CONSIDERATIONS

The project SUPREMA, currently underway at LNEC, in cooperation with IST, intends to study the application of C&DRM as recycled aggregates in road pavement base and sub-base layers and in capping layers.

The work plan includes laboratory and in situ tests on a reference natural aggregate and several selected C&DRM: crushed concrete, crushed mixed concrete, crushed reclaimed asphalt and milled reclaimed asphalt.

Some geometrical and physical characteristics have been determined, allowing the framework of the materials under study, to be compared with natural materials.

The first results from laboratorial leaching tests suggest that the construction and demolition recycled materials from this study do not pose an environmental risk, as it is sometimes overstated. Further conclusions on this subject will be withdrawn when all the laboratory and in situ tests, namely the mechanical and the leaching tests, envisaged on this project, were completed.

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