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Evaluating the durability of two recycled aggregates to be used in basal drainage layer of landfills

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Abstract

LNEC, in partnership with FCT-UNL, have studied the durability of steel slag and construction and demolition waste in the presence of a leachate collected at a municipal solid waste landfill, with the main purpose to evaluate the technical feasibility of their recycling in the leachate collection and removal layer of landfills.

The waste durability was studied using the slake-durability test (SDT) proposed by ISRM. In order to test the behaviour of them in chemical and mechanical conditions more adverse than those specified in the mentioned ISRM method, the leachate collected was acidified with hydrochloric acid to decrease the initial pH from 7.6 to 5.5, and more 600 rotation cycles than those foreseen in the ISRM method were applied, respectively. A similar procedure was used to test the materials after their immersion for 15 days in the same acidified leachate. As a complement to SDT tests, a macro- and micropetrographic characterization of two waste as well as a characterization of their physical properties, either before or after SDT tests, were performed.

The paper presents the main results obtained, compares the performance of two waste with the one of two natural geomaterials (basalt and limestone), and concludes with the assessment of the technical feasibility of their recycling in the mentioned application.

Keywords: EAF steel slag; C&DW; Recycling; Durability; Landfill leachate collection layer.

1 Introduction

The large volume of waste generated in various human activities, namely domestic, agricultural, commercial and industrial, and the lack of measures to promote their valorisation, have contributed, to some extent, for the current state of environmental degradation, although today's society intends to reverse this panorama by pursuing a sustainable development.

The durability of the waste is critical to ensure the proper functioning of the public works throughout its lifetime, as was already demonstrated for the natural geomaterials. However, in the bibliography compiled by the authors were not referenced studies on waste durability, which can be explained by the fact that its usage in public works is still a relatively new advancement as compared with the extended practice with natural geomaterials. Therefore, in Portugal, the Laboratório Nacional de Engenharia Civil (LNEC), in collaboration with the Faculty of Science and Technology (FCT), University NOVA of Lisbon (UNL), has decided to perform a study to assess the durability of waste with mechanical and environmental characteristics suitable for their using as recycled aggregates in transportation infrastructure and geotechnical works, considering that their increased use is expected in the future.

This communication evaluates the durability of a crushed concrete aggregate (CC), reclaimed from construction and demolition waste (C&DW), designated hereafter as CC_{CDW}, and also of an inert siderurgical aggregate for construction (ISAC), processed from electric arc furnace (EAF) steel slag, designated hereafter as ISAC.

A high volume of those materials can be recycled in the construction of leachate collection and removal layer of the basal containment system of landfills. Because of this and the increasing number of these infrastructures that will continue to be constructed or expanded, it is justified to study the durability of these materials in contact with leachates produced in landfills. In order to subject the two materials to more adverse chemical conditions than those usually ongoing in landfills, a leachate collected in a municipal solid waste (MSW) landfill was acidified in laboratory to decrease the initial pH from 7.6 to 5.5. The experimental program also assessed the durability of selected recycled materials in presence of tap water, with these two aims: a) to be used as reference values to the ones obtained in tests performed with the leachate and to the ones referenced in bibliography for natural geomaterials, and b) to evaluate the durability of two recycled aggregates in the aqueous medium more common in civil engineering works, namely in the case of surface rainwater drain of the landfill final cover.

The durability study of CC_{CDW} and ISAC was studied using the Slake-Durability Test (SDT) proposed by International Society for Rock Mechanics (ISRM, 1977). The first set of recycled aggregate samples was tested according to ISRM method. The second set was also tested according to ISRM method, but in this case the specimens were previously immersed in acidified leachate for 15 days. For both of these sets, in addition to two slake-durability cycles, which are foreseen in the ISRM method, the specimens were also subject to a third slake-durability cycle of 600 rotations (total of 1.000 rotations). The previous immersion of specimens in the aqueous solutions used in the tests and the increase of the number of rotation cycles, intended to subject the two recycled materials to a longer contact time with both aqueous solutions and to a longer period of mechanical actions. As a complement to SDT test, a macro- and micropetrographic characterization of two materials, as well as their physical characterization (density, porosity and water absorption) were also carried out, both before and after SDT tests.

Given the aforementioned lack of studies on recycled aggregate durability, the obtained results are compared with the behaviour of two natural geomaterials, a basalt (designated hereafter as BAS) and a limestone (designated hereafter as LIM). The laboratory characterization of these natural geomaterials followed the same experimental program applied to two recycled aggregates. For the same reasons mentioned above, the results obtained for the CC_{CDW} and ISAC are also compared to the values published in the literature for natural geomaterials. These comparisons have the advantage of experience gathered on the behaviour of natural geomaterials classified based on the SDT test values applied in public works.

The results obtained with the recycled aggregates, CC_{CDW} and ISAC, as well as the natural ones, BAS and LIM, have showed their technical feasibility to be used in the construction of leachate collection and removal layer of basal containment system of landfills, as well as for most of the transportation infrastructure and geotechnical works, from the point of view of durability.

2 Materials and Methods

2.1 Materials

Two recycled aggregates, ISAC and CC_{CDW}, and two natural aggregates, BAS and LIM, were studied. The aqueous solutions used in the SDT tests were tap water and the leachate collected in a MSW landfill. Figure 1 shows the location of the materials used in the study, which are located up to a maximum radius of 35km around Lisbon.

The ISAC sample, were the maximum size of particles was 100 mm, was collected in a pile stored in industrial facilities of Portuguese Iron and Steel Company (ISC), located at Seixal. The pile height was between 3 and 5 m, and its length was longer than 10 m. The ISAC is processed from EAF steel slag according to the procedures presented by Roque et al. (2007).

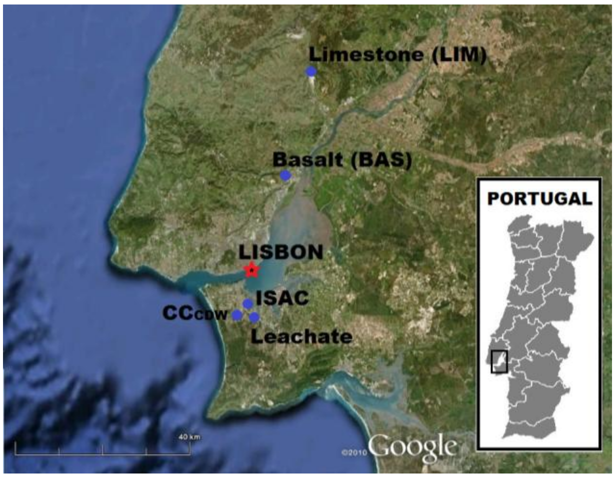

Figure 1. Sampling site of studied materials

The CC_{CDW} sample, with a maximum size of particles of 56 mm, came from a C&DW mobile centre of the Demotri Company, belonging to Ambigroup Group, that was operating at Seixal. The material was collected in a set of piles of about 2 m height and 5 m length, that was a result of different demolition works in an estimated volume of about 2000 m^3. The methodology used for processing the C&DW is described in Almeida (2011).

The BAS was collected in Moita da Ladra Quarry, belonging to Alves Ribeiro Company, located at Vialonga. The blocks of basalt, more than 100 mm size, were sampled in a pile with about 30 m height and 7 m length.

Sampling of LIM was carried out in Vale Grande Quarry, belonging to Agrepor Company, located at Meca. The limestone blocks, larger than 100 mm, were collected at a pile of about 4 to 5 m height and 5 m length.

The sampling process for four materials was undertaken empirically, because it was considered that the quality and representativeness of the samples were not damaged by not following all the recommendations proposed by the CEN/TR 15310:2006. The main reasons for the methodology used were as follows: the nature of the sampled materials, the conditions of the sampling site, the way how the material was stored and the constraints related to the tests performed in the scope of this study, namely the size and shape of the specimens. All materials were transported to LNEC in tagged nylon bags.

The leachate was collected in the MSW landfill of Amarsul Company, belonging to AdP Group, in Seixal. The cell where the leachate was sampled, began to be exploited in 2001, and its closure is previewed to 2020. In December 2011, the total volume of waste disposed of in that cell was 1 861 954 m^3, corresponding to a height ranging from 16 to 24 m. In the leachate sampling was used a pump to extract it from the leachate collection and drainage system of the landfill. Afterwards, the leachate was transported to LNEC, in polyethylene containers with a volume capacity of five liters, where they were stored at 4°C until use in the projected SDT tests. Throughout the sampling procedure, latex gloves were used to avoid contact with the leachate.

The pH of sampling leachate was 7.61. Whereas the leachates from MSW landfills can have lower pH values, namely 7.0, and because it was decided to test the behaviour of the recycled materials to more aggressive chemical conditions than those usually observed in this type of infrastructures, the sample was acidified in laboratory with hydrochloric acid to decrease the pH to a value of 5.5.

2.2 Methods

2.2.1 Petrographic analysis

Macropetrographic study of materials was carried out according to the procedure presented in NP EN 932-3:2010, in the case of ISAC, BAS and LIM, and according to ASTM C856-11, in the case of CC_{CDW}.

The micropetrographic study, performed with an optical microscope on thin section, was carried out following the procedures described in EN 12407:2010 for ISAC, BAS and LIM, and the aforementioned standard of ASTM for CC_{CDW}.

2.2.2 Physical characterization

The tests for evaluating the bulk (ρ_b) and real (ρ_r) densities, porosity accessible to water (P_e) and water absorption under vacuum conditions (w_{max}) of aggregates, followed the procedure described in RILEM (1980). In each test performed, six samples were always used.

The execution of each test included three steps described below.

Firstly, the specimens were placed inside a desiccator, where a pump gradually applied vacuum, until a pressure of 1bar was reached. The vacuum pressure was maintained for a period of time of about 24h to ensure the removal of the air contained in the pores of the aggregates. Afterwards, demineralized water was introduced within the desiccator at a rate such that 15min after its start, the specimens were completely immersed. The vacuum was maintained at this stage for another 24h. Then, the vacuum pump was switched off, to restore the atmospheric pressure inside the desiccator, maintaining the specimens under these conditions for further 24h.

At the beginning of the second stage, the immersed specimens were transferred off the desiccator into a plastic container with demineralized water to a level that guaranteed the immersion of specimens. This procedure was necessary since it was impossible to weigh the specimens inside de dessicator. Initially, the weighing of the submerged mass of each specimen was executed, and therefore, each one was placed in a basket, immersed in water and suspended in a balance of centesimal precision. Later, after drying the faces of each specimen with a clean dry cloth, their saturated mass were determined.

In the last step of the test, the specimens were dried in a stove at 105 ± 2ºC for 24 ± 2h, and then placed in a desiccator to cool, for a period of time of at least 40min. Afterwards, the dry mass of each specimen was determined in the balance of centesimal precision. Knowing the submerged, saturated and dried masses of specimens, the values of ρ_b, ρ_r, P_e and w_{max} were calculated.

For the calculations of the values of ρ_b and ρ_r, the following expressions were applied:

$$\rho_b = \frac{M_1}{M_1 - M_2} \text{ x } 100\% \qquad [1]$$

$$\rho_r = \frac{M_1}{M_3 - M_2} \text{ x } 100\% \qquad [2]$$

the value of P_e was calculated from the expression:

$$P_e = \frac{M_3 - M_1}{M_3 - M_2} \text{ x } 100\% \qquad [3]$$

and the value of w_{max} based on the expression:

$$w_{max} = \frac{M_3 - M_1}{M_1} \text{ x } 100\% \qquad [4]$$

where, M_1 is the mass of the dried specimen, M_2 is the mass of the specimen saturated with water under vacuum, weighed in water, and M_3 is the mass of the specimen saturated with water under vacuum, weighed in air.

2.2.3 Slake durability test

The SDT test is a testing commonly used to evaluate the durability of natural geomaterials when subjected to standard cycles of drying-soaking and mechanical action (Moon & Beattie, 1995, Gokceoglu, 1997, Koncagul & Santi, 1999, Gokceoglu et al., 2000, and Sadisun et al., 2005 cited by Erguler & Ulusay, 2009).

To perform the test was used an equipment (Figure 2) identical to that recommended in “Suggested method for determination of the slake-durability index” (ISRM, 1977), except in the number of drums, which were, in this case, of four drums (Figure 2a), instead of two mentioned in the ISRM method.

a) b)

Figure 2. Equipment used for SDT tests: a) general view and b) detail of one of the stainless steel drums

From each sample of CC_{CDW}, ISAC, BAS and LIM, 40 specimens were prepared and equally distributed among the four cylindrical drums of stainless steel (Figure 2b). Each specimen had a mass of 40 – 60 g, and thus each set of ten specimens weighed a total of 400 to 600 g. Specimens of CC_{CDW}, BAS and LIM were prepared with a subangular shape, contrary to the stated in the ISRM method, which recommends a roughly spherical shape. This amendment intended to increase the exposure of the specimens to mechanical action induced by the test. In the case of ISAC, the inability to preparing test specimens of subangular shape due to the intrinsic characteristics of the material itself, led to preparing them with a more rounded shape, but not completely spherical.

The molded specimens were introduced into each of the four drums and then assembled in the four reservoirs, two of them filled with tap water (these specimens will be identified as SDT_W) and the remaining two with the acidified leachate (these specimens will be identified as SDT_L). For those SDT tests in which specimens were previously immersed in water and in the acidified leachate for 15 days, the specimens will be identified as SDT_I_W and SDT_I_L, respectively. The four drums with the specimens were subjected to three slake-durability cycles. The first two were run under the conditions recommended by the ISRM method, that is in a constant speed of 20 rpm for 10 min, for a total of 200+200 rotations. For the third cycle, not stipulated by the method, the samples were subjected to more 600 rotations, in a total of 1,000 rotations. The samples were always dry at 105±2ºC for 24h before the test and also immediately after each slake-durability cycle, and thus their respective dry mass were determined.
According to the ISRM method, the SDT result, expressed as a durability index (I_d), corresponds to the relation, expressed as percentage, of the dry mass of the material retained inside of the drums at the

end of the second cycle (I_{d2}) to the dry mass of the specimens at the beginning of the test. The I_{d2} value, relating to two first slake-durability cycles, was calculated using the following expression:

$$I_{d2} = \frac{C - D}{A} \text{ x } 100\% \qquad [5]$$

where *A* is the initial dry weight of ten specimens, *C* the dry weight of ten specimens after the second slake-durability cycle and *D* is the mass of the drum.

3 Results and discussion

3.1 Petrography

The extension of the text of the petrographic analysis, including figures, combined with limited number of pages, permit only to present a summary of the main changes observed in the specimens after the SDT tests.

The macroscopic study has showed that no significant changes have occurred in the specimens of CC_{CDW}, ISAC, BAS and LIM after the SDT tests carried out. Still, signs of oxidation were identified in the iron minerals and olivine minerals, respectively, in all tests performed with ISAC specimens and in the BAS_SDT_I_W specimens. It was also observed a thin film of organic material, with a moss green tonality, in the surface of material in all SDT tests performed with CC_{CDW} and ISAC specimens, that is either in water or leachate, and in the SDT tests performed with BAS_SDT_I_L and LIM_SDT_I_L, that is in the leachate after previous immersion in the leachate for 15 days.

The microscopic observation has revealed that the SDT tests only have produced noticeable changes in tests with ISAC specimens corresponding to an increase in the concentration of iron oxides, and in SDT tests with BAS specimens corresponding to different states of weathering of the olivine mineral. Regarding the latter, it was observed that in the BAS_SDT_I_W and BAS_SDT_I_L specimens, the olivine minerals were partially or completely weathered. This phenomenon was characterized by loss of material and a yellow to dark brown tonality.

However, the macroscopic and microscopic changes observed in specimens were not relevant to reflect on the durability of the tested materials.

3.2 Physical characteristics

The results obtained for the bulk and real densities, porosity accessible to water and water absorption under vacuum conditions of specimens of CC_{CDW}, ISAC, BAS and LIM, either before or after SDT tests, are shown in Table 1.

In the scope of four tested materials, it was observed that CC_{CDW} is the less dense, the more porous and presents the highest water/leachate absorption, the ISAC is the denser one, and the BAS has the lowest porosity and water/leachate absorption. The LIM, on the other hand, is characterized by having intermediate results in relation to others. In quantitative terms: a) CC_{CDW} is about 1.2 and 1.5 times less dense than the BAS and ISAC, respectively, b) CC_{CDW} is approximately 1.3 and 38 times more porous than ISAC and BAS, respectively, and c) ISAC is about 1.2 times and 27 times denser and more porous than the BAS. These differences are due to the intrinsic constitution of CC_{CDW}, in particular the cement matrix and the crushed natural aggregates, and in the case of ISAC are due to the presence of iron particles and minerals.

Table 1. Results of physical characterization tests

Material	Specimen	ρ_b (Mg/m^3)	ρ_r (Mg/m^3)	P_e (%)	w_{max} (%)
Recycled aggregate	CC_{CDW}	2.58	2.14	16.88	7.89
	CC_{CDW}_SDT_W	2.62	2.22	15.34	6.93
	CC_{CDW}_SDT_L	2.63	2.27	13.59	5.99
	CC_{CDW}_SDT$_L$_W	2.65	2.24	15.27	6.82
	CC_{CDW}_SDT$_L$_L	2.62	2.27	13.59	6.00
	ISAC	3.77	3.28	12.40	3.83
	ISAC_SDT_W	3.98	3.58	10.00	2.88
	ISAC_SDT_L	3.71	3.28	11.65	3.77
	ISAC_SDT$_L$_W	3.77	3.28	12.32	3.77
	ISAC_SDT$_L$_L	3.78	3.29	12.61	3.90
Natural aggregate	BAS	3.02	3.00	0.45	0.14
	BAS_SDT_W	3.01	2.99	0.48	0.16
	BAS_SDT_L	3.01	3.00	0.38	0.13
	BAS_SDT$_L$_W	3.04	3.02	0.45	0.15
	BAS_SDT$_L$_L	3.00	2.99	0.41	0.14
	LIM	2.72	2.58	5.40	2.20
	LIM_SDT_W	2.74	2.57	6.15	2.41
	LIM_SDT_L	2.72	2.57	5.33	2.09
	LIM_SDT$_L$_W	2.72	2.59	4.70	1.82
	LIM_SDT$_L$_L	2.72	2.56	5.99	2.38

In comparison with other studies already published, the bulk and real densities, porosity accessible to water and water absorption under vacuum conditions presently evaluated for CC_{CDW} specimens fall within the ranges of values reported by other authors. For example, according to Jadovski (2005), the bulk density of CC_{CDW} may vary between 2.12 and 2.43 Mg/m^3, in coarse fractions, and between 1.97 and 2.59 Mg/m^3, in fine fractions. For the water absorption under vacuum conditions, Jose (2002), Katz (2003) and Rao (2005, cited by Rao et al., 2007) and Gómez-Sobero (2002, cited by Martin-Morales et al. 2011), indicated a range of values between 3.0% and 12.0%.

In relation to ISAC, the values of bulk and real densities and water absorption under vacuum conditions are of similar magnitude to those obtained by Ferreira (2010). The tested steel slag was also processed by the ISC Seixal. The values obtained with the application of NP 581:1969 for bulk and real densities were, respectively, 3.05 and 2.94 Mg/m^3, and the water absorption under vacuum conditions was 3.87%. As for the value of porosity accessible to water obtained, 12.40%, it is about twice the average value of 6.0% obtained by Wu et al. (2006). It should however be noted that the determination of this parameter should be viewed with some reservation, since the porosity accessible to water is one of the physical properties more influenced by the type of processing that the EAF steel slag is subject (Pasetto and Baldo, 2010).

With respect to the values of bulk and real densities and porosity accessible to water of the BAS and the LIM specimens, they fall within the typical values presented by Rocha (1981) and González de Vallejo et al. (2002) for these natural aggregates.

The comparative analysis of physical characteristics of CC_{CDW}, ISAC, BAS and LIM specimens, either before or after SDT tests, shows that no significant quantitative changes have occurred. It is also noted that the use of different aqueous media, in the present case water and leachate, had no significant influence on physical properties of tested materials.

Nevertheless, the values obtained for the porosity accessible to water and water absorption under vacuum conditions in CC_{CDW}_SDT_L and CC_{CDW}_SDT$_L$_L specimens, justify an exception. Specifically for porosity accessible to water, it was observed a decrease of about 3.3% from CC_{CDW} specimens for the specimens tested with the leachate, and a decrease of about 2.0% in the water absorption under vacuum conditions. These differences most likely result from the fact that some of the pores on the surface of the cementitious matrix of the tested specimens were initially accessible to water and after the tests become filled with organic matter.

3.3 *Durability*

The results obtained in the SDT tests with both aqueous solutions, that is water and leachate, are summarized in Table 2. These values correspond to the percentage of material retained in the drums at the end of each cycle (I_{d1} = 200 rotations, I_{d2} = 400 rotations and I_{d5} = 1000 rotations).

Table 2. Results of slake-durability tests

Material	Specimen	Durability index (I_d)	Results (%)	Material	Specimen	Durability index (I_d)	Results (%)
Recycled aggregate	CC_{CDW}_SDT_W	I_{d1}	99.5	Natural aggregate	BAS_SDT_W	I_{d1}	99.9
		I_{d2}	99.1			I_{d2}	99.7
		I_{d5}	98.0			I_{d5}	99.5
	CC_{CDW}_SDT_L	I_{d1}	99.6		BAS_SDT_L	I_{d1}	99.9
		I_{d2}	99.3			I_{d2}	99.8
		I_{d5}	98.3			I_{d5}	99.6
	CC_{CDW}_SDT_L_W	I_{d1}	99.6		BAS_SDT_L_W	I_{d1}	99.9
		I_{d2}	99.1			I_{d2}	99.7
		I_{d5}	97.9			I_{d5}	99.5
	CC_{CDW}_SDT_L_L	I_{d1}	99.3		BAS_SDT_L_L	I_{d1}	99.9
		I_{d2}	98.7			I_{d2}	99.8
		I_{d5}	96.8			I_{d5}	99.6
	ISAC_SDT_W	I_{d1}	99.7		LIM_SDT_W	I_{d1}	99.7
		I_{d2}	99.5			I_{d2}	99.4
		I_{d5}	99.1			I_{d5}	98.7
	ISAC_SDT_L	I_{d1}	99.6		LIM_SDT_L	I_{d1}	99.8
		I_{d2}	99.5			I_{d2}	99.6
		I_{d5}	99.1			I_{d5}	99.0
	ISAC_SDT_L_W	I_{d1}	99.7		LIM_SDT_L_W	I_{d1}	99.7
		I_{d2}	99.5			I_{d2}	99.4
		I_{d5}	99.0			I_{d5}	98.7
	ISAC_SDT_L_L	I_{d1}	99.6		LIM_SDT_L_L	I_{d1}	99.7
		I_{d2}	99.4			I_{d2}	99.6
		I_{d5}	99.0			I_{d5}	99.0

The classification of the durability of the tested materials was defined from the classes shown in Table 3, proposed by Gamble (1971).

Table 3. Classification of materials based on the Gamble durability index

Durability	I_{d1}	I_{d2}	I_{d5}
Very high	> 99	> 98	> 95
High	98 - 99	95 - 98	85 - 95
Medium - high	95 - 98	85 - 95	60 - 85
Medium	85 - 95	60 - 85	30 - 60
Low	60 - 85	30 - 60	20 - 30
Very low	< 60	< 30	< 20

The durability index obtained in the SDT tests is greater than 95.0% in all specimens, so that, considering the classification proposed by Gamble (1971), either recycled aggregates or natural aggregates belong to the category of very high durability. Even so, comparing the values obtained for I_{d5} it appears that they are higher in the BAS specimens, very similar to the ISAC and LIM specimens, and lowest in CC_{CDW} specimens. On the other hand, it appears that the initial immersion of the specimens of ISAC, BAS and LIM in water and leached for 15 days before performing the tests, did not contribute to a reduction in the durability of these materials, since the I_{d5} values, with and without previous immersion of the specimens, were nearly equal. The same can not be said for the CC_{CDW}, since the I_{d5} value obtained in the SDT test carried out after the initial immersion of the specimens for 15 days in leachate, is 1.5 times lower than the one obtained in the test performed without previous immersion of the specimens in leachate.

Since the bibliography compiled by the authors does not reference studies of durability of recycled aggregates tested by SDT test, particularly those processed from EAF steel slag and C&DW, it is not possible to perform a comparative analysis. It was decided, therefore, to obtain values from SDT tests carried out with natural aggregates of similar lithology to the ones tested in this study. Delgado Rodrigues (1986), Jeremias (2000) and Kolay and Kayabali (2006) have performed studies with limestones, and Sharma and Singh (2007), with basalts. Delgado Rodrigues (1986) tested the Mondego limestone specimens to six slake-durability cycles (I_{d6} = 1200 rotations), with and without the presence of water, Jeremias (2000) performed tests with three slake-durability cycles (I_{d1}, I_{d2} and I_{d5}), with water, and Kolay and Kayabali (2006) evaluated the influence of the shape of specimens on durability of clayey limestone (limestone1 and limestone2), with water, over four slake-durability cycles (I_{d1}, I_{d2}, I_{d3} = 600 rotations and I_{d4} = 800 rotations). Sharma and Singh (2007) tested several samples of weathered basalt (the weathering grade was not mentioned by the authors) to two slake-durability cycles (I_{d2}). Considering the values obtained by these authors, it appears that only the Mondego limestone and basalt present durability index similar to those obtained for the CC_{CDW} and ISAC, and that, except for the durability index of Mondego limestone, the oolitic limestone, clayey limestones in the various forms of specimens and weathered basalt have lower durability index than those obtained in this study for the BAS and LIM.

4 Conclusions

In this paper, the technical feasibility of application of two recycled aggregates, CC_{CDW} and ISAC, in the construction of the leachate collection and removal layer of the basal containment system of landfills is evaluated.

The results obtained indicate the following:

- according to classification proposed by Gamble (1977), either the recycled aggregates (ISAC and CC_{CDW}), or the natural aggregates (BAS and LIM), belong to the category of materials of very high durability, even when subjected to mechanical and chemical conditions more aggressive than those provided in the SDT test proposed by ISRM;
- previous immersion of specimens in tap water and in the acidified leachate for 15 days and carrying out three slake-durability cycles did not affect the durability of the materials studied, except in the case of CC_{CDW}_SDT_L_L specimens;
- the results of petrographic study (macro- and microscopic) and physical characterization are consistent with the classification achieved for the four types of aggregates, recycled and natural, since no significant changes occurred in their initial petrography and physical properties;
- the results obtained with the recycled aggregates, CC_{CDW} and ISAC, as well as the natural ones, BAS and LIM, have showed their technical feasibility to be used in the proposed application, as well as in most transportation infrastructure and geotechnical works, from the durability point of view.

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