Study of the Hydraulic Behaviour of Steel Slag and CDW Recycled Aggregates to MSW Landfill Leachate

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ABSTRACT

Laboratório Nacional de Engenharia Civil (National Laboratory for Civil Engineering), in partnership with Faculdade de Ciencias e Tecnologia da Universidade Nova de Lisboa (Faculty of Sciences and Technology, NOVA University of Lisbon), have studied the technical feasibility of applying two recycled aggregates, one processed from electrical arc furnace steel slag and the other from concrete of construction and demolition waste (CDW), in the construction of the leachate collection and removal layer (LCRL) of municipal solid waste (MSW) landfills. In the paper is presented and discussed the hydraulic behaviour of these materials based on results obtained in permeability tests carried out on specimens prepared from grain-size in the ranges 0.25-2.0mm and 2.0-20.0mm, given that, in Portugal, the LCRL is composed by an upper layer of 0.2m thickness constructed with particles in the range of sand and a lower layer of 0.3m thickness constructed with particles in the range of fine gravel. Aiming to test their hydraulic behaviour to more aggressive conditions than those observed in MSW landfills, the leachate used in permeability tests, which was collected at a Portuguese MSW landfill, was acidified with hydrochloric acid to decrease the initial pH from 8.2 to 5.5. As a reference for the results obtained with the recycled materials in contact with the leachate, the same permeability tests were performed with tap water. In general, the hydraulic conductivity of tested materials was higher than the minimum ($1x10^{-4}$m/s) required by Portuguese decree-law in force. Therefore, the results obtained suggest the possibility of applying both recycled aggregates in the construction of the LCRL of landfills.

Keywords: EAF steel slag, CDW, recycled aggregates, hydraulic conductivity, leachate collection and removal layer, landfill

1. INTRODUCTION

The presence of water is usually detrimental to the performance and safety of civil engineering works. The design and construction of appropriate drainage systems are therefore of utmost importance to keep water out of areas where it can cause damage and to control the water that can reach the structure.

The drainage devices in the geotechnical works and transport infrastructures usually contact with water, with the exception of leachate collection and removal layer (LCRL) of landfills.

Traditionally, subsurface and underground drainage devices are built with natural granular materials (sedimentary soils and crushed rocks), unbound. However, current environmental policies severely restrict the extraction of natural materials and encourage the use of recycled materials, thus contributing to the achievement of the overall objectives of sustainable development.

In order to promote recycling of waste, the technical feasibility of using an aggregate resulting from processing steel slags of electric arc furnace (EAF), marketed in Portugal with the acronym ASIC ("Agregado Siderúrgico Inerte para a Construção"; ISAC - Inert Steel Aggregate for Construction) and an aggregate of crushed concrete (CC_{CDW}) resulting from processing construction and demolition waste (CDW), in drainage devices of geotechnical works and transport infrastructures, particularly in LCRL of landfills, has been studied.

Rodrigues et al. (2012) studied the durability of both recycled aggregates to water and leachate from a municipal solid waste (MSW) landfill. The author concluded, in according of classification of Gamble (1971), that both materials presented very high durability. Studies made by Hurd (1988) and Gupta et al. (1994), with steel slag, and Snyder (1995), Arm (2001) and Poon et al. (2006), with CDW, showed that the hydraulic behaviour of recycled materials can be unsuitable to construct drainage structures.

In this context, it was important to assess the hydraulic behaviour of recycled aggregates studied by Rodrigues et al. (2012). Given that, in Portugal, the LCRL is usually composed by an upper layer of 0.2m thickness constructed with particles in the range of sand (0.18/2mm) and a lower layer of 0.3m thickness constructed with particles in the range of fine gravel (2/31.5mm), permeability tests were realized on specimens prepared from these grain-size ranges. Permeability tests also allowed evaluating the influence of two permeants (tap water and MSW landfill leachate), volume of permeant percolated, during testing, and temperature, in the hydraulic behaviour of two recycled aggregates.

While conducting the permeability tests, the measurements of pH and electrical conductivity (EC) in the effluent were performed, to observe the variations through the testing and assist in examining the hydraulic behaviour of two recycled materials. For the same purpose, before and after permeability tests, the grain-size distribution and dry mass of each material was compared.

2. MATERIALS AND METHODS

2.1 Materials

Recycled aggregates, ISAC and CC_{CDW}, and the MSW landfill where the leachate was collected, are located at south of Lisbon, within a distance of about 20km (Figure 1).

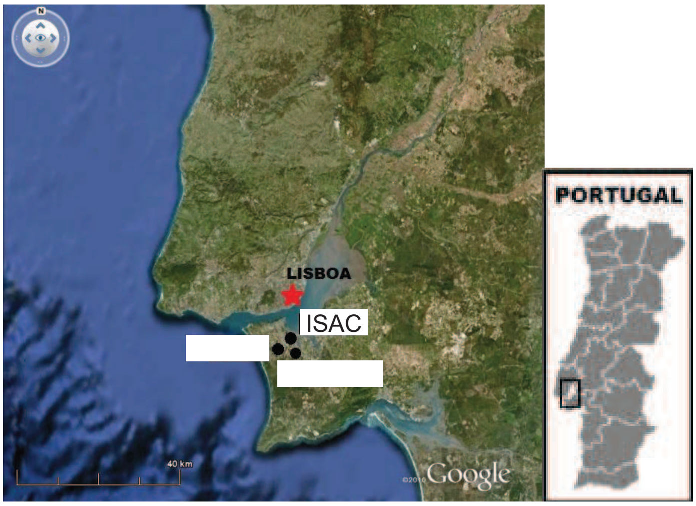


Figure 1. Location of materials

ISAC was collected at the Portuguese Iron and Steel Company, in the following grain-size ranges: 0/6mm, used in the preparation of test specimens of sand, and 0/40mm for the test specimens of fine gravel.

In the case of CC_{CDW}, concrete blocks of CDW, whose dimensions were less than 100mm, were crushed in the amount necessary for the preparation of specimens of sand and gravel. The concrete blocks of CDW were collected at the Demotri Company, which is the entity responsible for the area of demolitions in the Ambigroup Group.

The leachate used as permeant in the permeability tests was collected at the MSW landfill of Amarsul Company (AdP Group). At the moment of sampling, the pH and EC of the leachate were 8.2 and 55 mS/cm, respectively. Until use, the leachate was stored at 4°C.

2.2 Methods

2.2.1 Preparation of materials and specimens

The preparation of granular materials for the study of their hydraulic conductivity, k, was based on the grain-size characteristics of the materials commonly used in the LCRL of Portuguese MSW landfills: sand, in the range of 0.18/2mm, to the top layer of 0.2m thickness; and fine gravel, in the range of 2/31.5 mm (Figure 2), to the bottom layer of 0.3m thickness.

The percentage of different grain-size fractions constituting the sand and gravel used in the preparation of the specimens are shown in Table 1, and the grain-size distribution curves in Figure 2. The maximum diameter of gravel was truncated to 20mm in order to comply with the minimum condition of the relationship "diameter of the permeameter column (90mm) / grain-size diameter (20mm)" equal to or greater than 5.

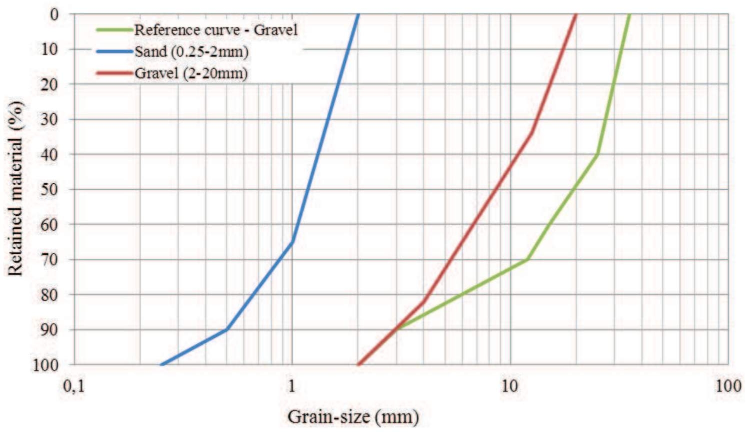


Figure 2. Grain-size distribution curves of sand and gravel, traced from the gravel reference curve used in Portuguese MSW landfills

Table 2: Grain-size fractions of sand and gravel

Sand		Gravel	
Grain-size (mm)	Retained material (%)	Grain-size (mm)	Retained material (%)
2	0	20	0
1	65	16	16
0.5	90	12.5	34
0.25	100	4	82
		2	100

The different grain-size fractions of sand and gravel for each material were carefully mixed in a tray to form a homogeneous mixture (Figure 3).

Prior to specimen production, the material was dried in an oven at 60°C, for a minimum of 24 hours, followed by cooling in a desiccator, in the time required to reach room temperature.

The permeameter column, 25cm in height and 9cm in diameter, was filled with the maximum dry weight of sand and gravel, as it is illustrated in Figure 4. The column and the base of the permeameter were placed in a frame to prevent movement of two pieces (figure 4a.1), and the ensemble was weighed. The recycled material (figure 4a.2) was transferred with a spoon (Figure 4a.3) to the column (Figure 4b). Then, with the aid of a bundle of wood (Figure 4c), densification of the particulate medium was promoted. The set was weighed and the weight of added material was registered. Figure 4d shows the top of the CC_{CDW}/gravel specimen.

The leached collected was acidified with hydrochloric acid (HCl) until the value selected for the permeability tests was reached, that is 5.5. This acidification aimed to perform the tests in more aggressive chemical conditions than those exist in MSW landfills.

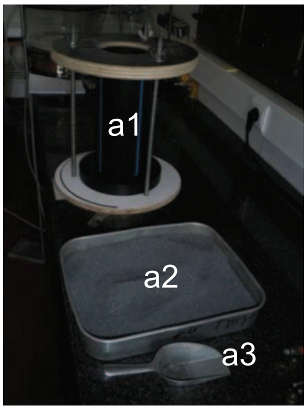
a)

b)

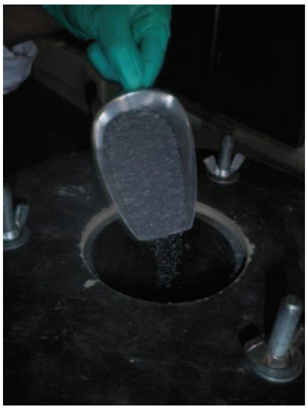
c)

d)

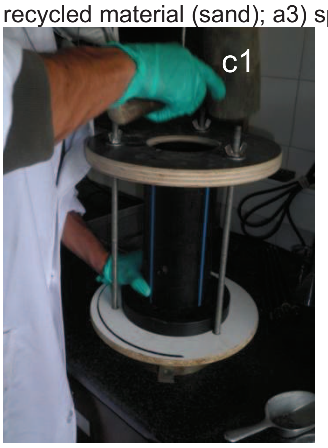
Figure 3. Homogeneous mixtures of sand and gravel of ISAC and CC_{CDW} recycled materials



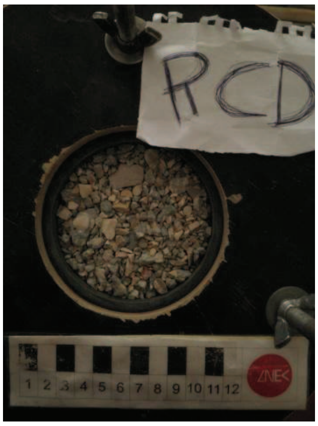
a1) Column and base of permeameter, and frame; a2) recycled material (sand); a3) spoon



b)



c1) Bundle of wood



d)

Figure 4. Procedure adopted for filling the columns of permeameters

2.2.2 Permeability test

The permeability tests were performed on a rigid-wall permeameter, at a temperature of 20±3°C. An upward flow was imposed by applying a constant head of 30cm, corresponding to a hydraulic gradient of 1.25. Hydraulic gradient of this magnitude is usually recommended in the landfills.

Initially, water (or leachate) was percolated through the specimen until a minimum volume of 250l was collected. For each about 2.5l of effluent collected, the corresponding time was measured. This first phase of testing aimed to collect an estimated volume at about three times the leachate produced in Portuguese MSW landfills during the operation period (12-15 years).

At the end of this step, the permeameter with the sample were placed in the oven for a minimum period of seven days at a temperature of 45°C. After removing the permeameter and before restarting the percolation, the material has cooled the time needed to temperature of 20±3ºC was reached. In this second phase was taken a minimum volume of 30l of effluent. Heating the material at 45°C intended to simulate the temperature that could exist in the LCRL of MSW landfills. Timely, it is intended to carry out all phases of permeability test at a temperature of 45°C.

In sand specimens percolated with leachate, followed a minimum contact time of about 50 days at 20±3ºC, before moving on to the third phase of percolation and collect a minimum volume of 10l of effluent.

Throughout the permeability test, the values of pH and EC of the effluent were measured periodically.

In the tests performed with leachate, recirculation was necessary, given the volume available. Measuring the pH of the effluent allowed to verify if its variation was greater than 5.5±0.3. In almost all recirculation was necessary to acidify the leached with HCl solution.

Concluded the percolation stage, the permeameter was drained, the top cap and porous plate were removed, and a macroscopic description of the top specimen was made.

Subsequently, the specimen was transferred into a tray and visually inspected for macroscopic description. The material was then placed in an oven at 60°C for drying. Once dry, the material was weighed to check for mass loss. The same material was used to perform the sieve analysis and check its adjustment to the corresponding reference grain-size distribution curve.

3. RESULTS AND DISCUSSION

The hydraulic conductivity, k, of the specimens of ISAC/sand, ISAC/gravel, CC_{CDW}/sand, and CC_{CDW}/gravel, percolated with tap water and MSW landfill leachate, are summarized in Table 2 and shown in Figure 5 and Figure 6, respectively. The k values are the average of all values after verifying their stabilization.

The hydraulic behaviour of ISAC/sand was different in tests with water and leachate. In the percolation with water, the k value remained practically unchanged until the introduction of the permeameter in the oven, but decreased significantly after the oven period. In the test with leachate, k gradually decreased to a volume of 160l be collected. From here to the end, the value of k was practically constant.

In ISAC/gravel specimen, the hydraulic behaviour to water and leachate were similar, with values of k practically constant throughout the tests and approximately equals.

The value of k was greater in the gravel specimen than in the sand specimen, as expected, with greater differences in tests carried out with water (9.5 times before oven; 38 times after oven) than with the leachate (3.5 times before oven, 4.7 times after oven).

Table 2: Hydraulic conductivity of recycled aggregates ISAC and CC_{CDW}

Material		Permeant	Test time (days)	Volume of effluent (l)	Hydraulic conductivity ($k \times 10^{-4}$m/s)		
					1st phase (before oven)	2nd phase (after oven)	3rd phase (after long contact)
ISAC	Sand	Water	41	285	2	0.5	-
		Leachate	73	300	4	3	2
	Gravel	Water	28	310	19	19	-
		Leachate	31	290	13	14	-
CC_{CDW}	Sand	Water	42	310	4	3	-
		Leachate	73	298	4	3	2
	Gravel	Water	28	300	25	25	-
		Leachate	31	290	13	10	-

The influence of the temperature in k was only observed in the test of ISAC/sand with water. The extension of the test in the ISAC/gravel specimen with leachate hardly changed the value of k.

Figure 5 allows observing that the value of k of ISAC was just below the minimum requirement mentioned in the Portuguese law for LCRL ($k \geq 1 \times 10^{-4}$m/s) in the test of ISAC/sand with water, after oven.

With regard to CC_{CDW} (Figure 6), it was verified that the hydraulic behaviour of the specimen of sand was similar in tests conducted with water and leached, except in the first 20l, wherein the value of k to leachate was lower than the value of k to water.

In the test of CC_{CDW}/grave to water and leachate, it was observed that the value of k remains constant during the two tests, but with k values to leachate slightly lower than the values of k to water.

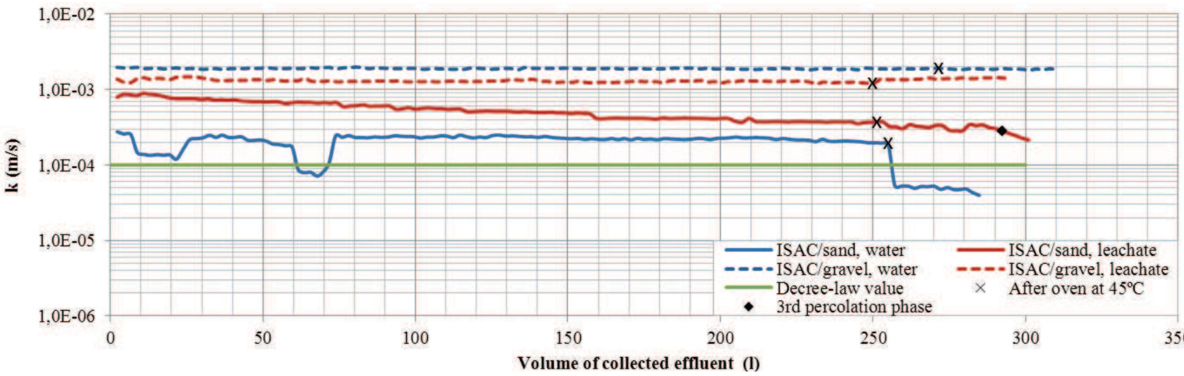


Figure 5. Hydraulic conductivity of ISAC/sand and ISAC/gravel specimens to water and leachate in function of volume of collected effluent

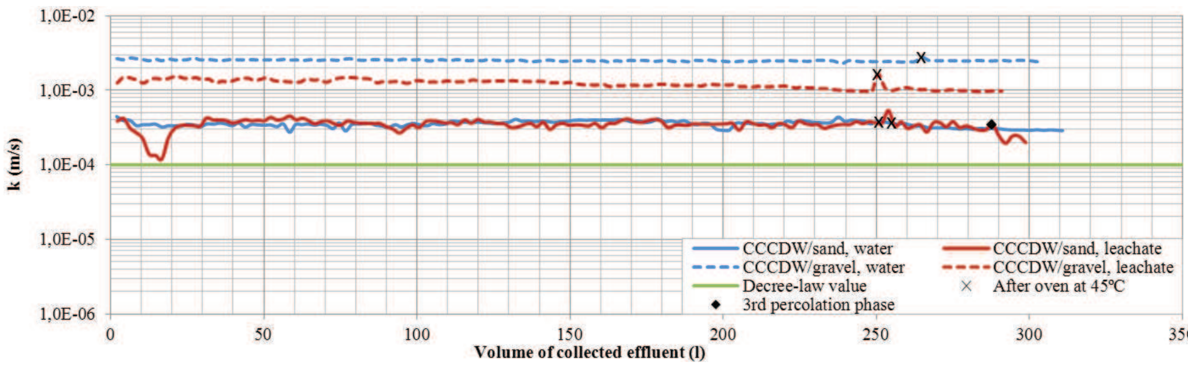


Figure 6. Hydraulic conductivity of CC_{CDW}/sand and CC_{CDW}/gravel specimens to water and leachate in function of volume of collected effluent

As expected and already observed in the ISAC specimens, the k value of gravel was higher than that of the sand, being the major differences in the tests to water than to leachate.

The heating of the specimens in the oven at 45°C for a period of seven days, did not alter the value of k in any of the tested specimens and the same occurred with the extension of the test in the CC_{CDW}/sand with the leachate.

For all specimens prepared with CC_{CDW}, the k value was always higher than that required in the Portuguese law.

In permeability tests with water, the pH values of the effluent were always higher than pH_0 initial values of the influent. This increase was greater in CC_{CDW} than in ISAC: in CC_{CDW}/sand and CC_{CDW}/gravel, the pH of the effluent was between 10 and 12 and between 9 and 11.5, respectively, and in ISAC/sand and ISAC/gravel between 10 and 11 and 9.5 and 10.5, respectively. The highest pH values in the CC_{CDW} specimens are mainly due to the lime in the cement composition. With regard to higher pH values in specimens of sand than in specimens of gravel, it must be associated, on the one hand, with the largest specific surface of contact between the sand and water than between the gravel and water, and, on the other hand, the longer time of contact between water and sand than between water and gravel.

In permeability tests with the leachate, it is stressed that in the specimens of sand the pH of effluent varied from a minimum of 6.5 to a maximum of 9 and in the specimens of gravel from 5.5 to 9. It means that a value similar to pH_0 (5.5) was reached.

Measurements of EC effluent showed their approach to value of CE_0 of water throughout the test, mainly in the first days of testing. The decrease of CE is due to the leaching of soluble salts present in the material to water, which contribute to the increase of ion concentration in the effluent. For specimens of CC_{CDW}/sand and CC_{CDW}/gravel, the EC decreased from about 2500 and 750μS/cm, respectively, and in the case of ISAC/sand and ISAC/gravel decreased from about 1100 and 360μS/cm, respectively.

Variations of EC values measured in the effluent solutions of the tests performed with the leachate did not lead to any conclusions based on data collected in the study.

At the end of permeability tests, macroscopic examination of the material at the base and top of the specimens was realized. The macroscopic analysis of the material was also performed after being moved into a tray. No significant changes were observed in the material. Just in the case of the specimens of ISAC tested to water was found the presence of iron oxide particles (Figure 7). In the test performed with the leachate it is not observed iron oxides particles due to formation of a film on the surface of particles, probably organic in nature. The same phenomenon was reported by Rodrigues (2012).

The values obtained for the dry weight of the materials at the end of permeability tests showed that the weight loss compared to the initial dry weight was generally less than 1%.

Figure 7. ISAC/gravel after permeability test with leachate

4. CONCLUSIONS

The study presented in this paper aimed to evaluate the hydraulic conductivity of two recycled aggregates, ISAC and CC_{CDW}, regarding to their use in the construction of drainage layers of geotechnical works and transport infrastructures, particularly in the LCRL of landfills.

The obtained results show that:

- percolation with water or leachate has not significantly modified the hydraulic behaviour of the materials, having k values been greater than the minimum requirement in Portuguese law for the LCRL of landfills ($k \geq 1x10^{-4}$m/s) in all tests, except in the ISAC/sand specimen tested to water, after seven days in the oven at 45°C;
- k of gravel was always higher than k of sand in all materials, as expected;
- k of gravel percolated with water was always higher than k of gravel percolated to leachate, but in sand specimens, k of CC_{CDW} to water was similar to the leachate and k of ISAC to water was lower than to the leachate.

5. ACKNOWLEDGEMENTS

The authors manifest their acknowledgement to the Demotri Company (Ambigroup Group), the Iron and Steel Company, the Alves Ribeiro Company, the Agrepor Company, and, finally, the Amarsul Company (AdP Group), for providing the materials used in this study.

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