CONTRIBUTION FOR THE STRUCTURAL CHARACTERIZATION OF THE PARTICLES OF LIGHT WEIGHT EXPANDED CLAY AGGREGATES

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CONTRIBUTION FOR THE STRUCTURAL CHARACTERIZATION OF THE PARTICLES OF LIGHT WEIGHT EXPANDED CLAY AGGREGATES

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SUMMARY

The use of light weight expanded clay aggregates to built road embankments is nowadays a common practice mainly when very soft soil foundations are present. There are good reasons to think that the knowledge of the nature of the structure of the material is an important contribution to the establishment of appropriate constitutive relationships. These relationships are necessary to settlement evaluation that may have a negative impact on road performance during exploration. Another practical aspect is concerned with the construction techniques to be used. This study is inserted in a more general research carried out by the Laboratório Nacional de Engenharia Civil and the Instituto Superior Técnico, funded by Saint Gobain, concerning the mechanical behaviour of embankments of this manufactured material.

The study presented was focused on better understanding the material structure and the role of suction (of the water, in a more broad sense) on the embankment mechanical behaviour. Laboratorial tests were performed including oedometric tests in aggregates for the cases dry and submerged. Crushing strength for different water contents and the water retention curves of single particles of light weight expanded clay composing the aggregate were also measured.

The results found in the study of the aggregate were related, when possible, with the results found for the particle. In a first analysis, it was found that the particles are almost insensitive to water. Nevertheless, the crushing strength of the particles seams to depend on their water content. The aim of this work is to clarify this matter through a deeper experimental investigation.

Key-words: materials, embankments, suction, hydro-mechanical properties, settlements

1- INTRODUCTION

The use of light weight expanded clay aggregates to built road embankments is becoming a more common practice when soft soil foundations are present. Another usual use of the material is to build drainage systems, however in this case it must be ensured that its characteristics do not change in water presence. Concerning the use of this material for road construction, besides the significantly reduction of the self weight of the embankment, the aggregate provides a stiff platform when construction procedure ensures enough density and a good confinement.

The study presented in this paper is inserted in a more general research carried out by the Laboratório Nacional de Engenharia Civil and the Instituto Superior Técnico, funded by Saint Gobain, concerning the mechanical behaviour of embankments of this manufactured material. There are good reasons to think that the knowledge of the nature of the structure of the material is an important contribution to the establishment of appropriate constitutive relationships. These relationships are necessary to the settlements evaluation that may have negative impact on road performance during service.

In a first analysis the aggregate is treated as if it is a set of rock fragments such as a rockfill material. For this type of material settlements occur due fragments rearrangement caused by fragments breakage due to stress concentration at the contacts. This deformation mechanism is strongly affected by water presence, as water increases the rate of breakage process. This process explains the long term deformations observed in embankments built with granular materials with relatively large dimensions (1),(2),(3) and (4).

Another important question is related with the construction process because, apparently, the placement of this light material does not require the addition of water. This procedure is the opposite of the one followed in the construction of embankments made of granular or rockfill materials such as dams, for example (5) and (6), and raises some questions on the need of adding water and on construction control.

The explained above justifies that the study presented in this paper was focused on better understanding the structure of the material of one particle and the role of suction (of the water, in a more broad sense) on the embankment mechanical behaviour. Laboratorial tests were performed where the water retention properties of the material were measured and related with data concerning the porosimetry of the material. Crushing tests, for different water contents, were also performed in single particles of different dimensions, followed by oedometric tests in aggregate, for the cases dry and submerged. The tests and results are described as follows.

2- EXPERIMENTAL DATA

2.1 – TESTS DESCRIPTION AND MAIN PROPERTIES OF LECA PARTICLES

LECA particles are light particles of Light Expanded Clay Agreggate manufactured with clay and additives under high temperatures (7). For Geotechnical engineering purposes, the particles from this fabrication process are more frequently spheres with diameters ranging between 10mm and 32mm (Figure 1).

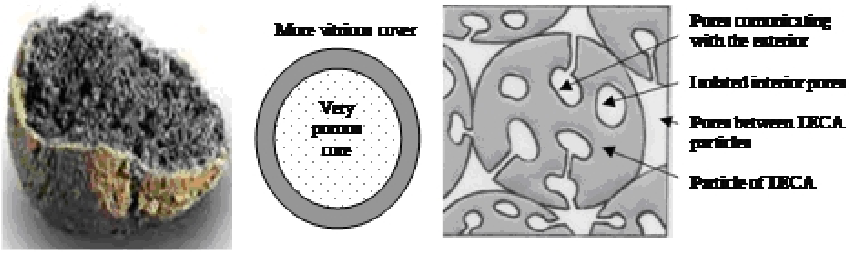

Figure 1 – LECA particle.

The interior of the particles has the two distinct zones identified in Figure 1: the core is a very porous material similar to a volcanic rock and the periphery is a stiff and less porous cover resulting from the vitrification of the clay caused by the fast cooling process and the addition of calcium carbonate. In spite of being diameter dependent, the average porosity is 70% and the saturated water content can reach over 180%. The solid unit mass is 17kg/m^3 and the average dry unit weight is about 5kN/m^3.

Also shown in Figure 1, a significant percentage of the internal pores is not connected with the exterior therefore it is difficult to fully saturate the material. As easily observed in broken fragments, this difficulty is increased by the special shape of the pores having smaller diameter near the surface than in the interior (neck bottle effect). This shape and pore distribution, explained by the formation of the vitreous cover layer, works as almost an impervious layer because water entry in the pores and consequently air coming out are very difficult. Mercury intrusion porosimetry tests were performed in particles with and without the vitreous external layer. The results show the existence of smaller pores when the exterior layer was not removed therefore confirming their bottle neck voids shape.

2.2 – WATER RETENTION CURVE

The water retention properties were measured for LECA particles with and without the external vitreous layer. Both drying and wetting paths were studied. The particles used for the drying cycle were fully saturated in vacuum conditions at the beginning of the test because it is very difficult to saturate them by water addition due to the impervious vitreous cover. This may be explained by the neck bottle shape of the pores, which keep air bubbles inside during the wetting process.

The water retention curves (i.e, the relationship between suction and water content) for 10mm diameter spherical particles are shown in Figure 2. Suction was measured using equipment WP4, following the procedure described in (8). The experimental points from Figure 2 were adjusted using the expression proposed by Romero & Vaunat (9).

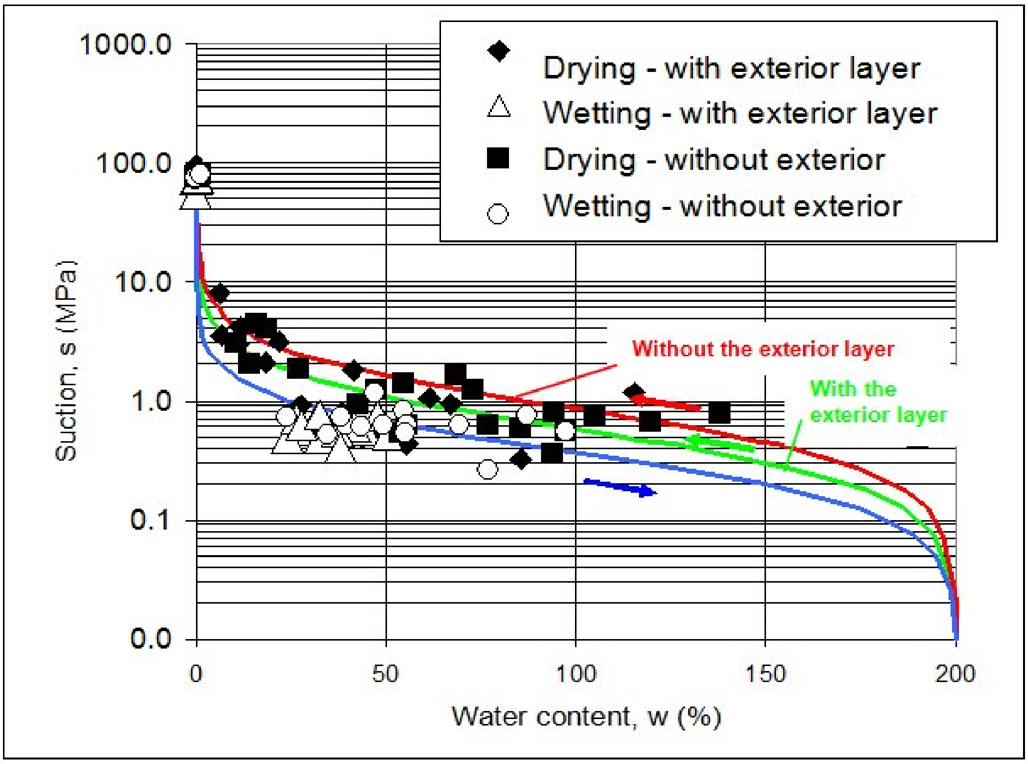

Figure 2 – Water retention curves of 10mm diameter spherical particles.

As observed in Figure 2, the wetting paths are very similar for the particles with and without the cover. The drying curve of the samples with the cover is below the curve of the samples without the cover however. This shows that drying is easier for the samples without the cover, a result explained also by the bottle neck shape of the pores that difficult water exit. Different diameters were analysed because the influence on hydraulic properties of the vitreous layer is different accordingly with the scale. Similar results were measured for larger particles confirming this mechanism.

2.3 – CRUSHING TESTS OF SINGLE PARTICLES

The compressibility of granular materials strongly depends on fragments breakage. This process is strongly affected by water because water reduces the toughness of the material which is the resistance to crack opening (4). The strength of the particles was evaluated through crushing tests illustrated in Figure 3.a) considering different water contents/ suctions.

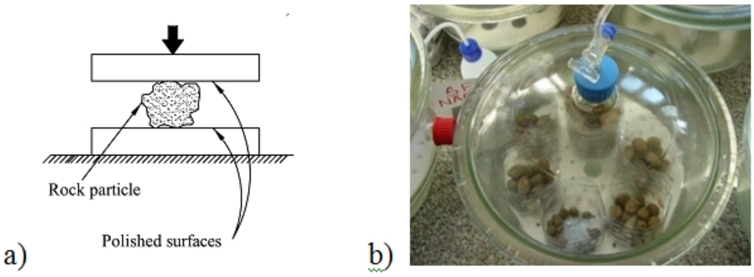

Figure 3 – Crushing tests of particles with different relative humidity: a) crushing test scheme (from (10)); b) vapour equilibrium used for suction application.

Figure 3.b) shows one of the chambers used to apply a known suction by using vapour equilibrium technique, which is the maintenance of a constant relative humidity RH in the air surrounding the fragment. The fragments were tested considering the RH of 85%, 75%, 100% (full saturated) and 50% (dry in the laboratory environment). The tests were performed on particles with different diameters (10, 20 and 32mm) because crushing strength depends on particle size. The results of the tests are in Figure 4, where P is the crushing force and D is the diameter.

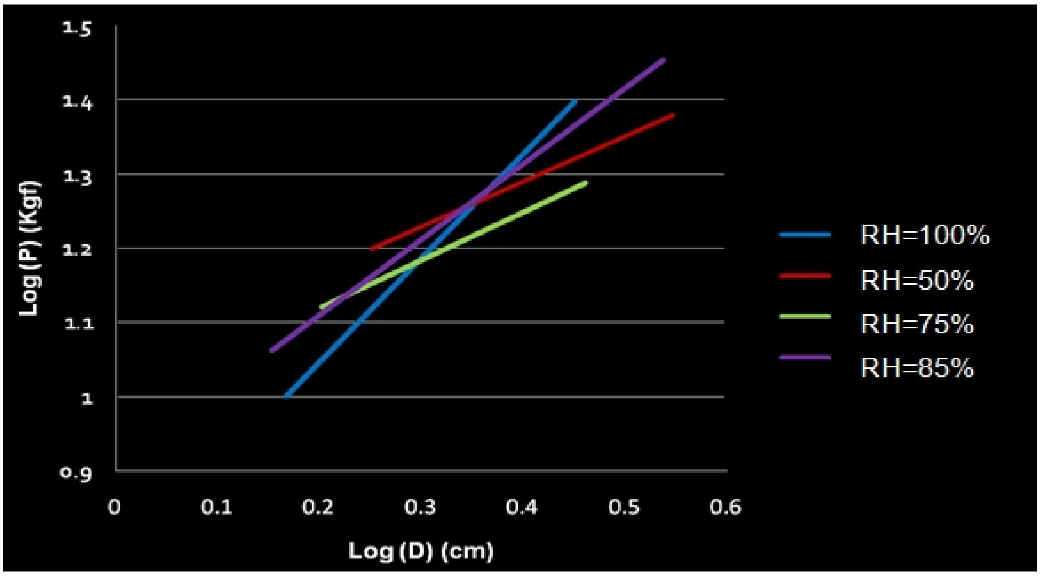

Figure 4 – Results of the crushing tests (11).

As expected, in Figure 4 strength increases linearly with diameter (in a bi-logarithmic scale). It can also be observed different relationships for the RH studied but apparently their slopes are not correlated with relative humidity because it would be expected higher strength for the lower RH as it is observed for rock fragments. This subject requires further study and a higher number of tests because a large dispersion was found, possibly because many particles have small flaws not detected before the tests and have different contact areas with press.

2.4 – OEDOMETER TESTS

Oedometer tests were performed with samples prepared with relatively uniform grading size distribution (diameters ranging between 10 and 20mm). Some particles were broken before the test, as observed in Figure 5.a). The samples were vibrated in a 0.35m diameter oedometric cell presented in Figure 5.a) to reach a final dry unit weigh of 2.92kN/m^3. The cell used is a special cell that minimizes friction in the lateral walls (3).

Two different samples were prepared: one was loaded in dry conditions and the other was loaded after being submerged. The comparison between the two tests allows comparing the effect of saturation of the material. Larger differences would be expected if the material would behave as a common rockfill material. The results of the tests are presented in Figure 6.

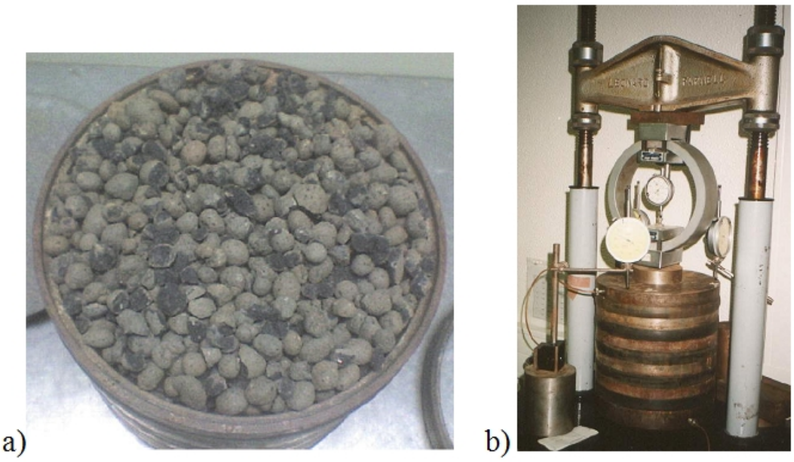

Figure 5 – Oedometer tests: a) sample before the test; b) experimental setup.

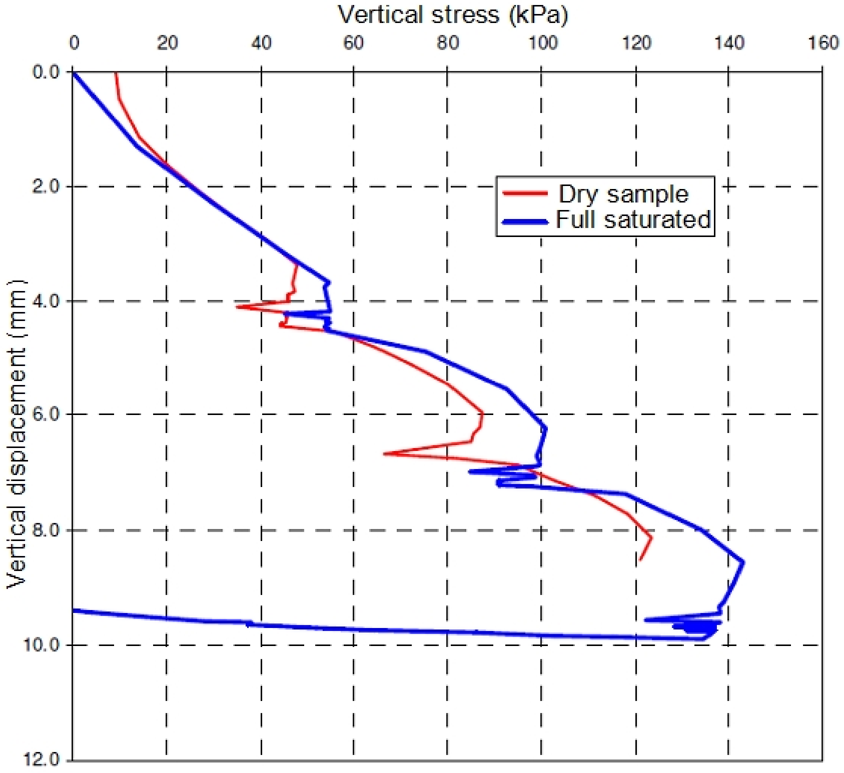

Figure 6 –Results of the tests for the two types of samples analysed.

Maximum vertical stress reached was about 140kPa. This value ranges the maximum average loading values expected in real cases and allowed to observe yielding defined as irreversible vertical deformations (or irreversible particles rearrangement), also shown in the unloading reloading curves from Figure 6.

The elastoplastic compressibility index Cc was measured for the samples, as well as their oedometric modulus M'.

Similar values were found for the two types of samples: for the dry sample - Cc=4.59 and M'=5MPa; for the submerged sample - Cc=5.21 and M'=6MPa. The elastic compressibility index Cs was 0.298, measured in the test on the fully saturated sample.

The small differences found for the two cases studied may be explained by the fact that the fragments were not fully saturated in the sample tested in submerged conditions, as mentioned before. The fact that the grading size distribution curve did not changed significantly after the tests also shows that the particles water content did not significantly changed when submerged or the applied stresses were inferior to the crushing strength of material. This insensitiveness to water may be explained by the geometry of the pores previously mentioned and analysed when the water retention properties were studied.

3- CONCLUSIONS

The results found in the study of the aggregate were related, when possible, with the results found for the particle. In a first analysis, it was found that the particles are almost insensitive to water. Nevertheless, the crushing strength of the particles seams to depend on their water content. A deeper experimental investigation is required to clarify this matter.

Finally, the results show that long term deformations due to climate (mainly wetting caused by rain) are not expected in embankments built with these materials, since breakage measured by particles crushing was not significantly increased with water presence. Moreover, if these results are confirmed, the material can also be used in the construction of drainage systems as its grading size distribution and other mechanical characteristics are not expected to be affected by the presence of water.

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