Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-461

Degradation of expanded clay strength after creep tests

Dégradation de la résistance de l'argile expansée après des essais de fluage

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ABSTRACT: After subjecting a material to a constant load maintained over time (creep), it is expected that internal crack growth will occur, resulting in a degradation (decrease) of its strength. This paper analyses the strength of single expanded clay grains after being subjected to constant loads for a period of 40 days. These tests, which, from now on, will be, referred to as creep tests, were performed using three different load magnitudes. To determine whether there is a degradation of the grain strength or not, the results are compared with those obtained in grains tested in simple compression without performing a creep test previously. Expanded clays are a lightweight expanded ceramic aggregate also known as LECA, obtained from heating clay soils in two phases (drying and expanding phases) to high temperatures (above 800ºC and 1100ºC, respectively) in a rotary kiln. The expanded clay obtained is characterized for presenting a very porous and low-density core, and a densely vitrified outer shell, notably more resistant.

RÉSUMÉ: Après avoir soumis un matériau à une charge constante maintenue dans le temps (fluage), on s'attend à ce que des fissures internes se développent, entraînant une dégradation (diminution) de sa résistance. Cet article analyse la résistance de grains d'argile expansée après avoir été soumis à des charges constantes pendant une période de 40 jours. Ces essais, qui seront dorénavant appelés essais de fluage, ont été réalisés en utilisant trois magnitudes de charge différentes. Pour déterminer s'il y a ou non dégradation de la résistance des grains, les résultats sont comparés à ceux obtenus avec des grains testés en compression simple sans essai de fluage préalable. Les argiles expansées sont des agrégats céramiques, également connus sous le nom de LECA, obtenus en chauffant des sols argileux en deux phases (séchage et expansion) à des températures élevées (supérieures à 800ºC et 1100ºC , respectivement) dans un four rotatif. L'argile expansée obtenue se caractérise par un noyau très poreux et de faible densité, et une enveloppe extérieure densément vitrifiée, notablement plus résistante.

Keywords: LECA; strength degradation; creep; breakage.

1 INTRODUCTION

Lightweight expanded clay aggregate (LECA) is an artificial ceramic aggregate that has numerous uses in construction, such as the manufacture of lightweight concrete, lightweight geotechnical backfill on structures, fills over compressible soils, and the manufacture of concrete for the construction of new buildings (Prisco, 2007).

LECA grains have a rather spherical shape and a size that usually varies between 10 and 20 mm, although there are other commercial diameters (Figure 1).

The LECA strength, as for other ceramic materials, presents values with certain variation that can be adjusted by means of a statistical Weibull function. This type of distributions were used for simple compressive strength of different ceramic materials, (Roces-Alonso et al., 2021, Anaya et al., 2022) and for other breakage modes (Lei et al., 2020, Lei et al., 2021).

Figure 1. Intact lightweight expanded clay grains.

Considering that the breakage of a grain is associated with the presence of defects in its interior, it is more likely that a larger volume element will have more and larger defects, so it is common that the strength of the different grains decreases with increasing element size. Thus, it is reasonable to introduce the grain volume, in the Weibull strength distributions of the grain (McDowell et al., 2013).

When a material is subjected to previous stresses or aggressive atmospheres, its strength characteristics degrade significantly. Numerous examples of this phenomenon can be found in literature, for different materials and after different situations, such as: freeze–thaw cycles for rock (Jia et al., 2015), granite (Tan et al., 2011) or concrete (Qu et al., 2023), freeze–thaw and fatigue for marble (Song et al., 2021), sandstone in carbon dioxine atmosphere (Laskowski et al., 2023) or after fatigue for various materials, such as composites (Philippidis et al., 2007) or sandstone (Chu et al., 2022).

In this article, the degradation of the compressive strength of LECA grains after being subjected to a 40-day creep test is analyzed.

2 MATERIAL AND METHODS

2.1 Materials

The expanded clay used for the tests was manufactured by LECA at its plant in Avelar (Portugal). The main components of the expanded clay are silicon oxide (SiO_2) and aluminium oxide (Al_2O_3), which account for more than 75% of the total grain composition (Roces, Muñiz-Menéndez et al. 2021)

The grains tested had an average diameter (obtained as the mean of three perpendicular diameters measured with callipers) between 14 and 18 mm, as it can be seen in Fig 1.

Each of the grains consisted of a vitrified outer shell and a porous core that gives it its characteristic lightness. The specific dry weight of the grains tested is 5.7 kN/m^3.

2.2 Methods

For the performance of this research, 340 individual grains of expanded clay were tested (121 grains tested under creep loads and 219 tested applying instantaneous loads), according to the following procedure:

- Determination of the weight of each of the grains using a balance with an accuracy of 0.001 g.
- Measurement three of perpendicular diameters (the largest, the smallest and a third perpendicular to the two previous ones) using a calliper of precision 1/50 mm. Grains with an average diameter of less than 14 mm or more than 18 mm were discarded.
- Mechanical test on the grains. These tests were of two types:
  - o Simple compression breakage, using a Point Load type equipment, according to ASTM D5731-16 standard. The maximum breaking load of the grain is recorded.
  - o To perform the creep tests, each grain was mounted on an oedometer-type equipment. This equipment allows a load to be applied by means of weights and maintained over time. In this paper, the testing period chosen was 40 days. The grains that survived this test were further subjected to a uniaxial compressive stress, to determine their residual strength, performing a Point Load Test.

A scheme of these tests is shown in Figure 2. All these tests were carried out at the Laboratorio de Geotecnia-CEDEX in Madrid (Spain).

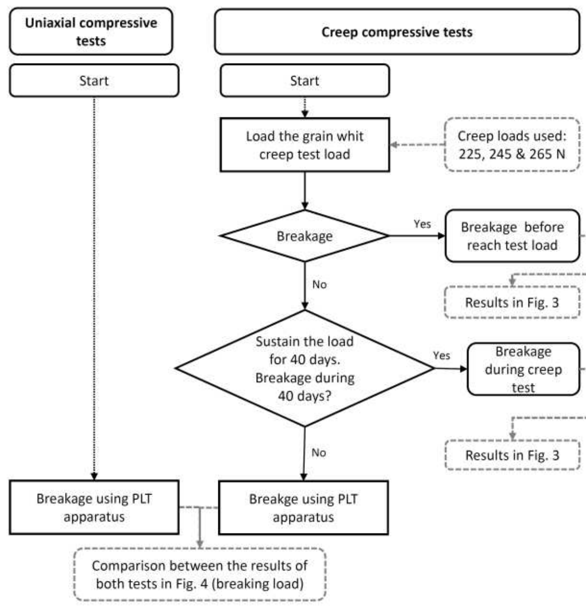

Figure 2. Flowchart of the work carried out.

The stress in a grain subjected to uniaxial compression can be estimated from the following Equation:

$$\sigma = \alpha \cdot \frac{F}{d^2} \qquad (1)$$

Being σ the grain stress, F the force applied to the grain, d the grain diameter (calculated as the arithmetic mean of the three measured diameters) and α a constant. In this study, a value of $\alpha = 1$ will be used as recommended by (McDowell et al., 2000).

3 RESULTS

In Figure 3, the results obtained from performing creep tests over 121 LECA grains are presented. In this plot, the breakage time of each of the grains tested is shown in terms of its average diameter and the constant load to which it was subjected during the 40-day testing period. Those grains that broke before reaching the creep load are indicated as BB. Grains that did not break during the entire duration of the test are indicated as NB. These last were furtherly tested under an instantaneous uniaxial compressive stress, being these results plotted in Figure 4. Finally, the grains that broke during the 40-day period are represented between BB and NB.

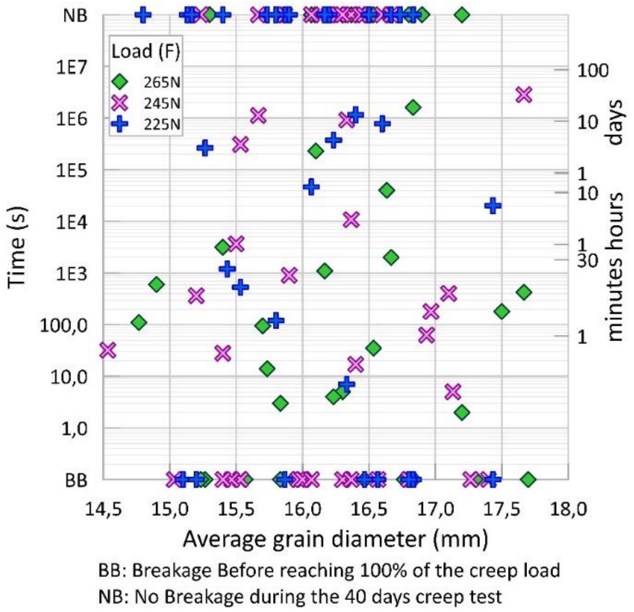

Figure 3. Time required for the breakage of creep-tested grains, depending on their diameter and the load tested.

Since the value of the breaking stress obtained according to Eq. 1 for LECA grains is not a deterministic function, but a stochastic value, in order to estimate the influence of the creep loads and time on the breaking stress of the grains, distribution functions must be compared. For this purpose, the strengths obtained are sorted and, depending on the number of tests available, the cumulative distribution function (CFD) is performed.

Figure 4 shows the comparison between grains previously creep tested (depending on the creep load used) and the tests carried out on grains without previous creep test.

In order to be able to make this comparison, the following aspects must be taken into account: the weakest grains of those tested at creep have already broken before reaching the creep load (BB in Fig 3) or have broken during the creep test for a time of less than 40 days (Figure 3 shows the grains that have broken during creep). Therefore, it seems logical to shift the CFD of the failure stress of these grains by a value equal to the percentage of grains broken during the creep test. This percentage is determined by summing up both the grains that failed while the creep load was being applied, as well as the ones that failed during the 40-day proposed application period of the constant testing load. Bearing this in mind, as it is indicated in Figure 4, the CFD curve corresponding to the grains tested under an instantaneous uniaxial compressive load after being subjected to a 225 N constant load during 40 days was shifted 57%, while the curves representing the grains that resisted 245 N and 265 N creep loads were shifted 70% and 74%, respectively. In Figure 4, both the CFD curves corresponding to the grains previously tested under constant loads and the ones only tested under an instantaneous uniaxial compressive stress are plotted.

In order to minimize the influence of grain size on grain strength, the results were taken for similar mean diameter values. The mean values for each of the series are shown in Figure 4.

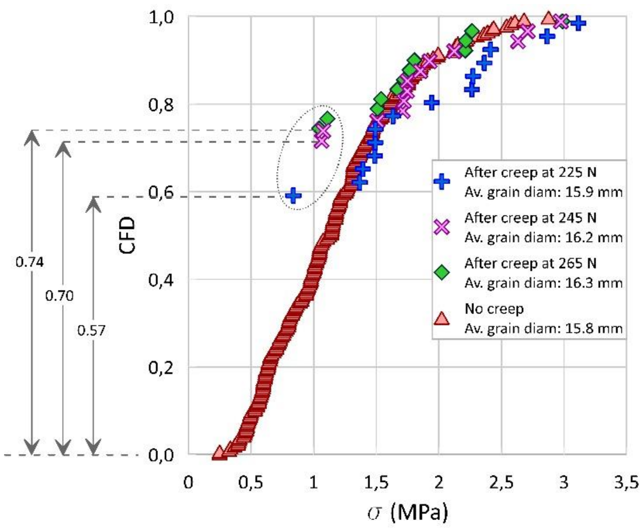

Figure 4. Comparison of breakage stresses of broken grains after creep tests of grains without previous creep test.

Figure 4 shows that there is a great coincidence between the results obtained from performing a point load test on grains previously and not previously tested under creep loads. It can also be seen that the coincidence is not exact, as there are 5 grains from the previously creep-tested group, that don't seem to have the same behavior. These LECA grains, marked in the graph with an ellipse, have a residual strength of approximately 0.5 MPa lower than the expected one. This value is determined by comparing the strength values of the CFD curves obtained for each of the previously creep-tested grains and the CFD curve obtained for the not previously tested grains.

4 CONCLUSIONS

An experimental study was carried out on the failure of expanded clay grains at room temperature, under simple compression, both under sustained and instantaneous loads. The study includes the results obtained from testing 340 grains (121 grains subjected to creep loads and 219 tested under instantaneous loads).

For grains that did not fail after a 40-day period of load application during creep tests and were tested under uniaxial instantaneous compression loading, there was no significant variation between the remaining strength and the original strength. Only in 5 grains marked with an ellipse in Figure 4. a lower strength than that obtained for grains without prior creep test is observed. This decrease in strength could be due to internal crack growth during creep or to statistical variation in the results.

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