Experimental Study of the Crush Evolution and its Effect on the Expanded Clay Behavior

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Abstract: ***Granular materials forming part of the structural elements for civil engineering, structures such as road embankments, the base of pavement and foundations. Among these materials, there are those where the grains have a brittle behavior: «crushing » It is, therefore important to study the crushing phenomenon of granular materials, because we need to better understand the behavior of this type of materials and provide information on the crushing evolution. The current work is an experimental study of the granular materials behavior subjected to crushing phenomenon. The expanded clay was chosen as a model material thanks to its brittle crushing behavior toward compressive forces. The study of this phenomenon can be very helpful to understand the soil's behavior toward several types of loading. Uniaxial and triaxial compression tests were made to understand the effect of crushing on the grain size distribution, soil's frictional properties and mechanical behavior***

Keywords: Granular materials, expanded clay, particle crushing, coordination number, macroscopic behavior

1. Introduction

Structural elements of civil engineering are constituted in large part by granular materials such as road embankments, pavement structure, railways, and foundations. It is, therefore, necessary to study the crushing phenomenon of granular materials to better understand the behavior of this type of building materials and to provide more information on the fragmentation evolution in favor of improving the structure's design

The crushing results from the particle loading effect for a critical point break into several pieces of different sizes. The crushing phenomenon continues the amount of fine particles increases and the curve of the grain size distribution changes.

According to several authors, the crushing phenomenon is influenced by:

- The particles resistance [1],
- The particle size, Granular distribution [2];
- The confinement degree [3];
- State of stress [5].

Due to the fragmentation of the grain, several material behavior characteristics can be produced;

- The reduction of The void volume [12];
- The reduction of the hydraulic conductivity [12];
- The variation of the internal friction angle [12].

For these reasons and to better understand the fragmentation phenomenon and especially the conditions in which this phenomenon is favorable, an experimental study was made of a granular material whose particles are favorable to fragmentation, namely expanded clay.

Indeed, expanded clay has been used for many years in the form of light aggregates in the construction industry and public works. This material offers numerous advantages: It is natural, solid, easy to implement, and also it has an economic contribution.

Finally, our experimental work consists in studying the expanded clay behavior under uniaxial and triaxial compression tests. These tests are followed by particle size analysis before and after loading.

2. Physical Parameters of Expanded clay

The results of calculating the void ratio, (Table 1), clearly indicate that this is an internal cellular structure the void volume is six times larger than the volume occupied by the solid grains, hence the explanation of one of the expanded clay properties which are its high porosity and its lightness compared to other materials used in civil engineering.

Table 1: Physical parameters of expanded clay

Test	$\gamma_d(\frac{KN}{m^3})$	$\gamma_s(\frac{KN}{m^3})$	$e = \frac{\gamma_s}{\gamma_d} - 1$
1	2.91	21.51	6.392
2	2.87	21.48	6.484
3	2.9	21.50	6.414

3. Experimental study

3.1 Uniaxial compression test

3.1.1 Stress - strain curves

A Proctor mold having a diameter D = 10.16cm was used, wherein we put 160g of intact granules of expanded clay, (See Figure 1). The sample is interposed between two trays of a compression machine. Then we have imposed a displacement speed and we have determined the force resisting variation in every 15 seconds. The measurements are made for two different speeds: 1mm / min and 2mm / min. The result of the experiment is shown in Figure 2.

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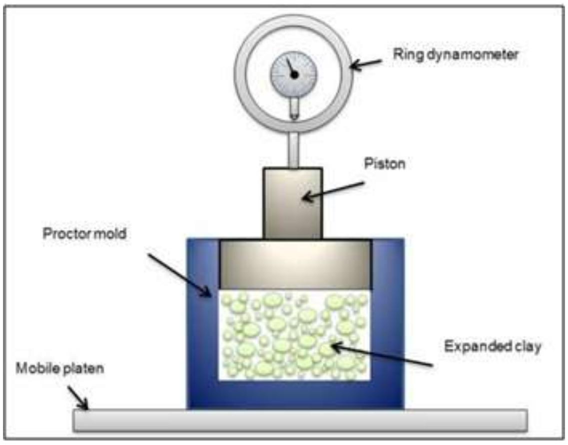

Figure 1: Uniaxial test

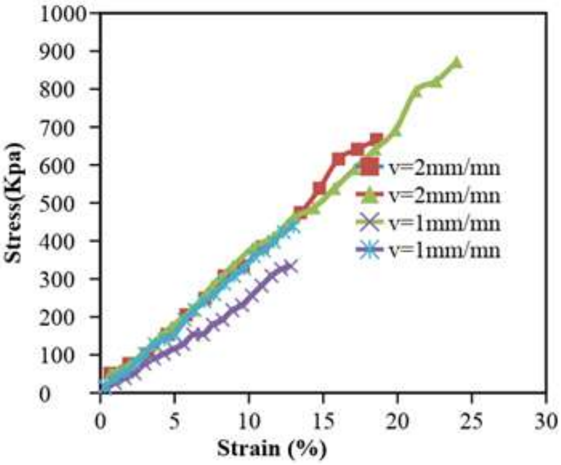

Figure 2: Strain – stress curve of the expanded clay under uniaxial compression test

From the compression-uniaxial strain relationships we can calculate the modulus of elasticity E (Oedometric modulus).Then, E=3, 4 MPa.

3.1.2 Particle size analysis

The sample which has undergone a compression test is examined by a particle size analysis test.

According to the test, it can be said that the fragmentation phenomenon increases the percentage of fines in the sample, which makes the material denser, see (Figure 3).

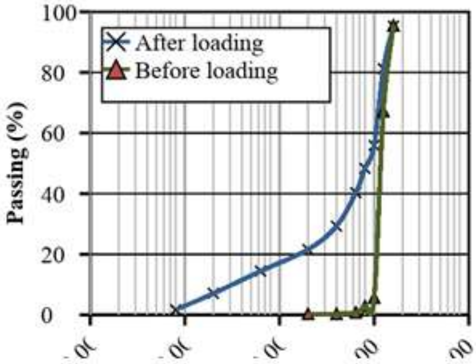

Figure 3: Particle size analysis before and after uniaxial compression test

3.1.3 Statistical approach evaluation of the fragmentation phenomenon.

The aim of the test is to determine the granular fraction most affected by the fragmentation phenomenon after a uniaxial compression test.

The course of the test consists of establishing the granular distribution of 160 g of expanded clay, and then the various granular fractions are colored differently, the operation requires drying in an oven for 24 h, see Photo1.

After drying and before applying the compression force to the sample, the number of grains for each diameter is noted. Then the compression test is applied and we note the number of unfragmented grains. The results described below correspond to two samples of expanded clays. Refer to Figure 4.

Photo 1: Coloration of the various granular fractions

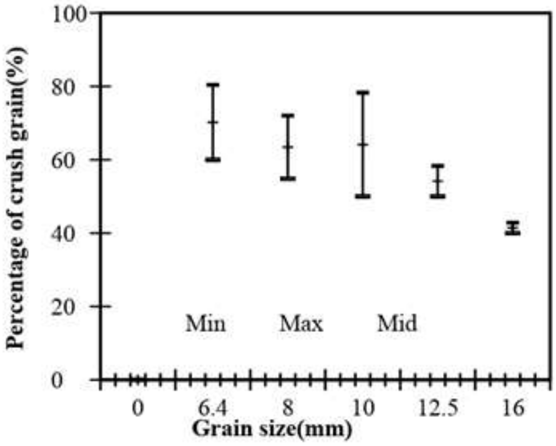

Figure 4: Percentage of grain crush – Grain size curve

The tests show that the fragmentation phenomenon mainly affects grains of small dimensions. Certainly, the grain size is a primary factor in the fragmentation process since it is directly related to the tensile strength of the particle [1]

In fact, a grain can fragment and the other not according to the number of contacts that everyone has. (This number is commonly referred to as the coordination number).

Indeed the coordination number is very important in the crushing process since a particle having a high coordination number does not break easily due to the better distribution of forces [4]

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3.1.4 Crushing phenomena and deformation thresholds.

In order to study the grain fragmentation evolution as a function of the applied stress evolution, is presented below the fragmentation rate obtained during a uniaxial compression test at different thresholds strains.

The study is to conduct uniaxial loading tests with monitored deformations and to stop these tests at different strain thresholds, then establish the particle size distributions obtained.

- The strains thresholds are: 3%; 6%; 8%; 10%; 12%; 15%; 20%.
- The loading speed is set at 2 mm / min.

Figures 5 to 10 show the particle size distribution of the expanded clay at predefined deformation thresholds

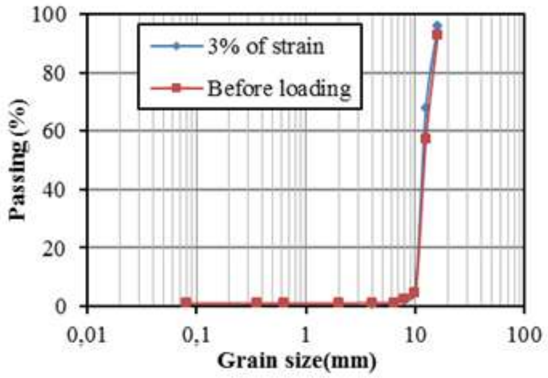

Figure 5: Particle size distribution at 3% of strain

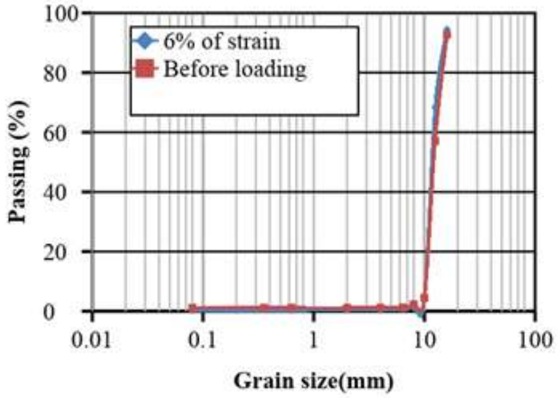

Figure 6: Particle size distribution at 6% of strain

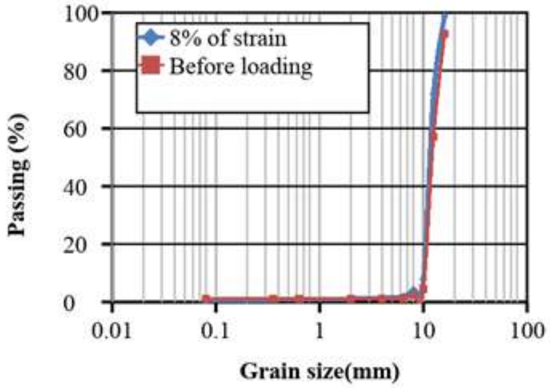

Figure 7: Particle size distribution at 8% of strain

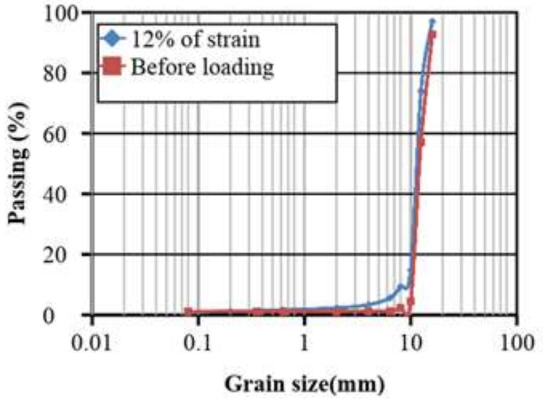

Figure 8: Particle size distribution at 12% of strain

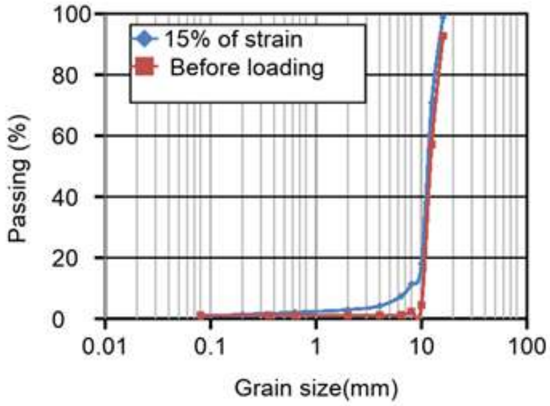

Figure 9: Particle size distribution at 15% of strain

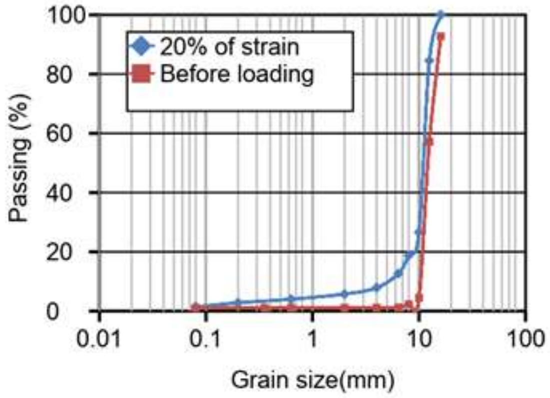

Figure 10: Particle size distribution at 20% of strain

Below 8% strain rate, the fragmentation phenomenon has not yet taken place because the stresses applied to the grains have not yet reached the tensile strength of the particles.

For deformations thresholds larger than 15%, the effect of the fragmentation phenomenon is remarkable on the particle size distribution curves of expanded clay. Beyond these deformation rates, and because of the densification of the sample, the grain crushing phenomenon begins to decrease due to the number of coordination which becomes important.

3.2 Triaxial compression test

The purpose of this test is to investigate the sensitivity of the shear strength properties of expanded clay, such as the

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internal friction angle, this macroscopic parameter affects the local resistance properties.

A cylindrical sample of dry granular material is placed between two plates and an envelope of a flexible and impermeable membrane (See Photo 2). A surrounding fluid (water) makes it possible to apply a confinement pressure σ3.

The sample is affected with axial load which caused axial stress σ1, a Mohr's Circle can be drawn. This procedure is repeated for different values of σ3

The line tangent to these circles is the failure envelope of the material; it makes it possible to calculate the internal friction angle. The cohesive stresses is zero because it is a non-cohesive material

Photo 2: Cylindrical sample of expanded clay

3.2.1 Confine shear test

The tests were performed on two samples of expanded clay. The deviator stress-axial strain curves are presented in Figures 11, 12 and 13.

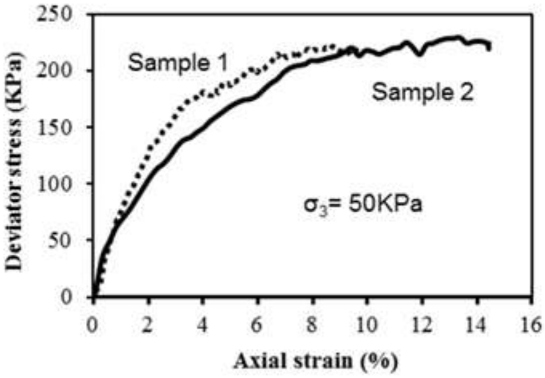

Figure 11: Deviator stress-axial strain curves for σ3= 50KPa

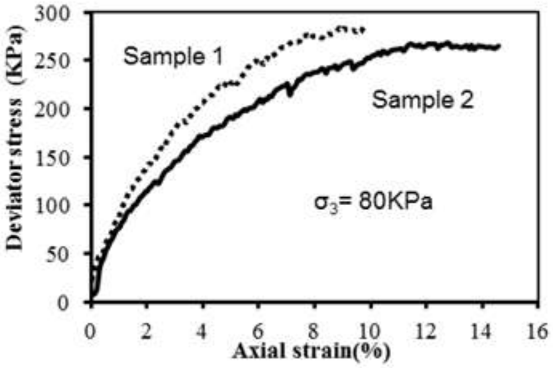

Figure 12: Deviator stress-axial strain curves for σ3= 80KPa

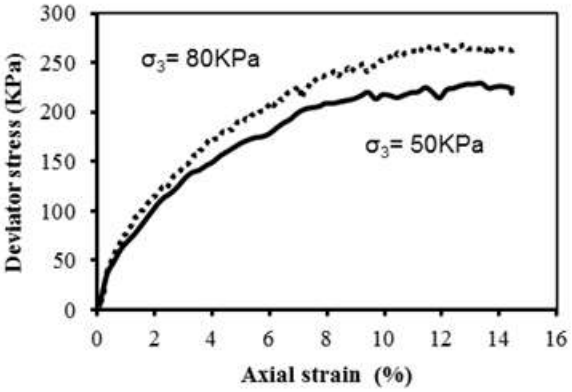

Figure 13: Deviator stress-axial strain curves for σ3= 50KPa and σ3= 80KPa

A Mohr-Coulomb failure envelope was calculated independently. The Mohr's Circles are presented below in Figure 14

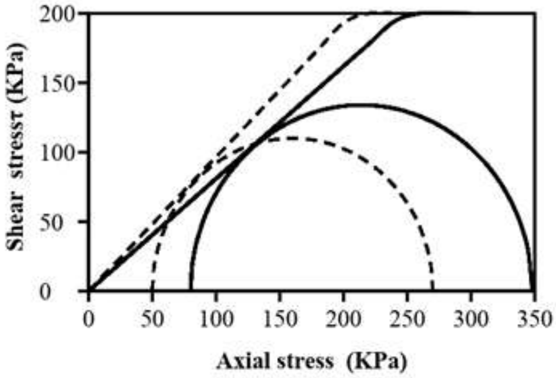

Figure 14: Mohr's Circles for σ3= 50KPa and σ3= 80KPa

For σ3=50 KPa the corresponding internal friction angle = 44° then for σ3=80 KPa the internal friction angle = 39°.

The dry expanded clay is a purely granular soil possess no cohesion, for this and after plotting Mohr's Circles corresponding to the confining pressures we have noticed two tangent lines indicating the variation of the internal friction angle. This variation indicates the existence of two different materials; this is explained by the variation of the granular distribution following the particles generated by the crushing. As we know, the internal friction angle in a granular material is dependent on the nature of contacts

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between the grains. The internal friction angle will stabilize at an optimal point when a further increase in stresses no longer affects the granular distribution.

The shear strength properties of the expanded clay are sensitive to the grain crush phenomenon.

3.2.2 Statistical approach evaluation of the fragmentation phenomenon

The idea is to determine the percentage of the crushed grains for each granular fraction after a shear test. At first we start with a particle size analysis of intact expanded clay sample, and then we color the different granular fractions.

The particle size corresponds to a diameter d = 6.4 mm and a diameter D = 16 mm. After staining, the drying step is carried out for 24 h. Afterwards, Grains for each granular fraction will be counted before and after the triaxial test.

The results described in Figure 15 correspond to two samples of expanded clays.

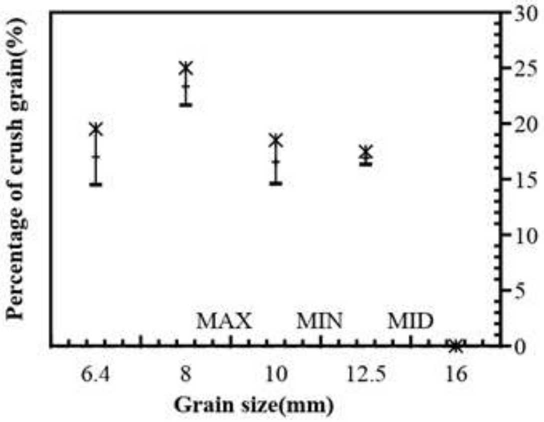

Figure 15: Statistical approach evaluation of the fragmentation phenomenon

The Shear tests have shown that grains with diameter less than 8 mm acquire at most fragile fracture.

This is consistent with the results found after compression tests.

According to the literature [4], it is known that the crushing phenomenon is mainly noticed on the grains with few points of contact. This behavior typically occurs in small grains. For large grains, crushing is more difficult due to their large number of surrounding contacts creating a hydrostatic effect around the grains.

Due to the results found during the compression and shear tests on the 6.4 / 16 mm granular fraction of the expanded clay, it is possible to say that the grains of diameter d <8 mm have minimal coordination numbers.

3.2.3 Crushing phenomena and deformation thresholds.

The aim of the test is to determine the starting point of the fragmentation phenomenon (in terms of deformation) for a sample of sheared stressed expanded clay.

The work consists of performing shear tests on samples of expanded clay with a 4/16 mm granular fraction; during each test, the axial strain is monitored.

For each deformation threshold chosen in advance, the test is stopped and the sample is subjected to particle size analysis in order to test the variation in the initial particle size.

The selected strains thresholds are: 3%.5%; 6.5%; 7.5%; 8.5% and 9.5%.

It should be noted that the confinement pressure is kept constant for all shear tests at a value of 50 kPa with a loading rate of 1 mm / min.

The Deviator stress-Axial strain curves are presented in figure 16

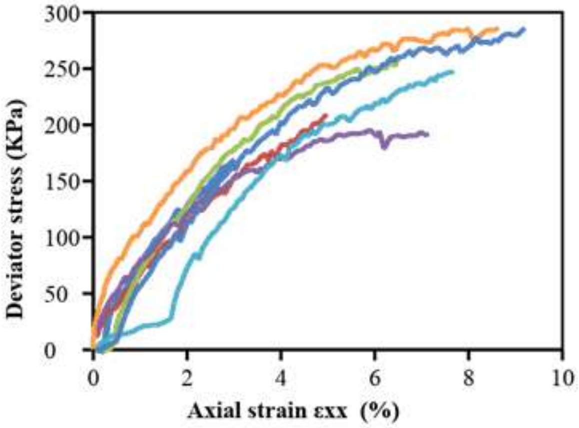

Figure 16: Deviator stress-Axial strain curves

The grains size analyses is presented in Figures 17 to 22

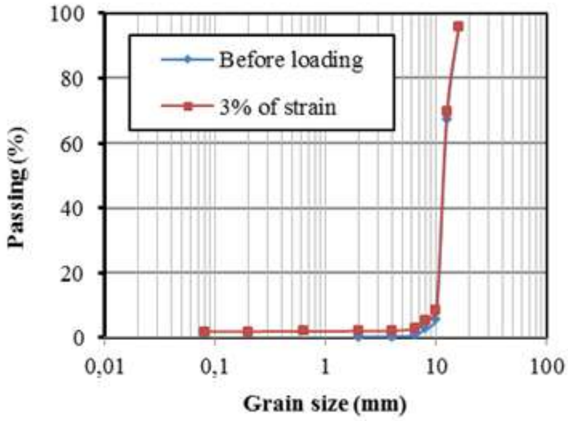

Figure 17: Grains size analyses at 3% of strain

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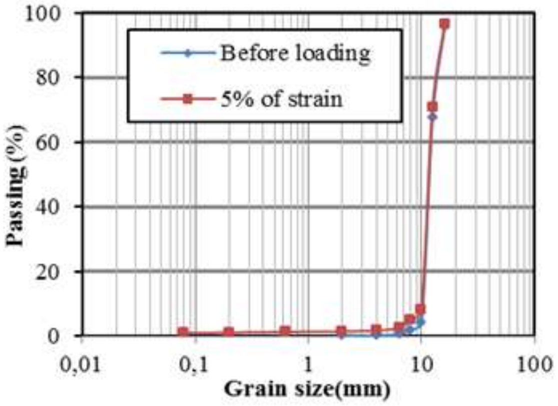

Figure 18: Grains size analyses at 5% of strain

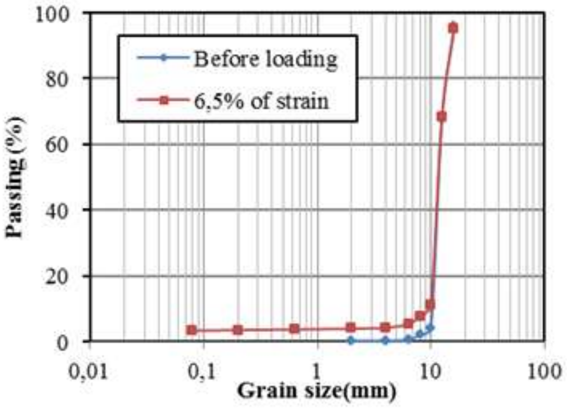

Figure 19: Grains size analyses at 6, 5% of strain

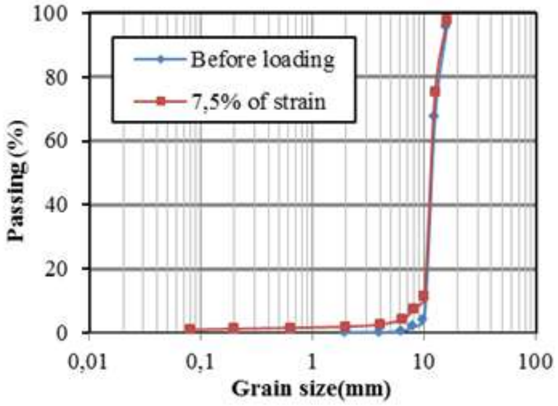

Figure 20: Grains size analyses at 7 5% of strain

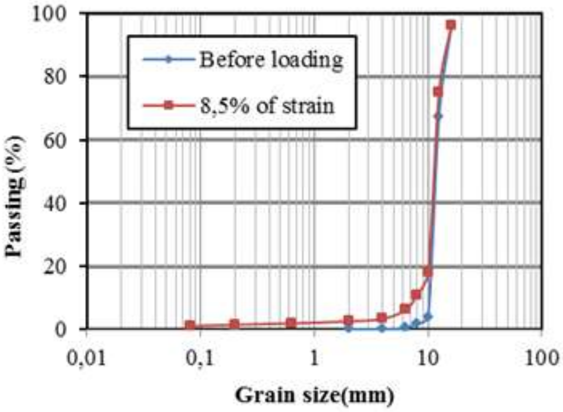

Figure 21: Grains size analyses at 8, 5% of strain

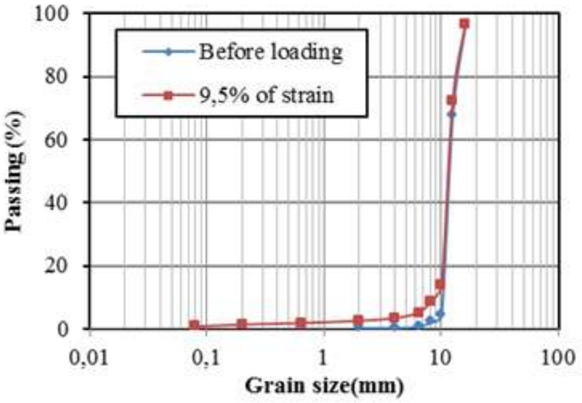

Figure 22: Grains size analyses at 9, 5% of strain

The Triaxial tests with different strain thresholds under constant confinement stress such as 50KPa show that the ragmentation of grains starts from the stress condition corresponding to a strain condition situated in the interval [5%; 7%].

In a triaxial test, with a load application rate of 1 mm / min and a confinement stress such as 50 kPa, the fragmentation of the expanded clay grains starts from a stress threshold of 200 kPa.

Rather we can say that:

- The confinement pressure favors the fragmentation phenomenon.
- Grains with a diameter less than 10 mm are the most affected by the fragmentation phenomenon whereas the large grains don't undergo any change in their grain size.
- The fragmentation phenomenon affects essentially the small grains whereas the others (large grains) undergo practically no change.
- The percentage of fragments found after a triaxial test is greater than that found after a compression test under oedometric conditions.

3.2.4 Isotropic confinement test

It is known that, properties of expanded clay, and therefore his behavior, dependent on ambient conditions, (confining pressure, state of stress, temperature, and load duration).

The tests focused on the relationship between confining pressure and the crushing evolution.

The sample of expanded clay placed in a triaxial cell, is subject to an isotropic confinement pressure.

The Isotropic confinement tests were made with two different confining pressures 50 kPa and 150 kPa.

The grain size distribution clearly changed between the initial, first and second confining pressure. (See Figure 23).

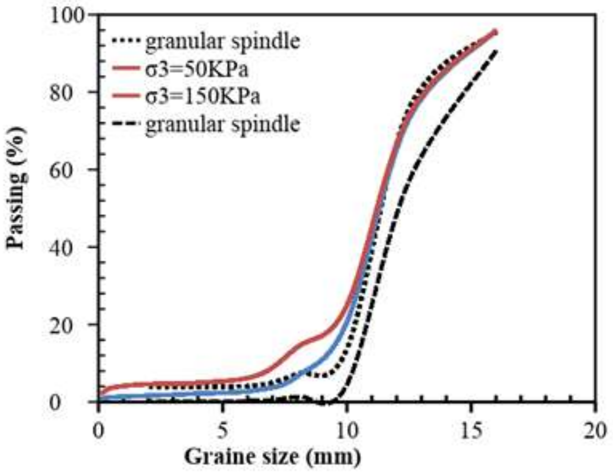

Figure 23: Grain size distribution after isotropic confinement test

4. Conclusions

The uniaxial and triaxial tests show that the fragmentation phenomenon mainly affects the grains of small dimensions. This reminds us of the idea that the coordination number is very important in the fragmentation process since a large particle with a higher coordination number does not easily break because of the better distribution of forces and the imprisonment produced by its neighbors [4], contrary, particles of small diameter are more favored to the fragmentation since their lower coordination number.

Moreover, it has been observed after triaxial tests that the confinement pressure favors the fragmentation phenomenon and that the amount of the fragments is greater than that found after uniaxial compression tests.

According to the results of the tests, it can be said that the mechanical properties of the expanded clay are sensitive to the fragmentation phenomenon.

The modulus of elasticity could change with the compression level and increase with the evolution of the fragmentation phenomenon, still, the internal friction angle reduces considerably because of the particles generated by the crushing.
Under loading, the expanded clay may give different behavioral responses due to the influence of the initial density.

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