Experimental Determination of Shear Strength Properties of Lightweight Expanded Clay Aggregates Using Direct Shear and Triaxial Tests

Mahsa Shafaei Bajestani, Mahmoud Yazdani, Aliakbar Golshani

Abstract**—**Artificial lightweight aggregates have a wide range of applications in industry and engineering. Nowadays, the usage of this material in geotechnical activities, especially as backfill in retaining walls has been growing due to the specific characteristics which make it a competent alternative to the conventional geotechnical materials. In practice, a material with lower weight but higher shear strength parameters would be ideal as backfill behind retaining walls because of the important roles that these parameters play in decreasing the overall active lateral earth pressure. In this study, two types of Light Expanded Clay Aggregates (LECA) produced in the Leca factory are investigated. LECA is made in a rotary kiln by heating natural clay at different temperatures up to 1200 °C making quasi-spherical aggregates with different sizes ranged from 0 to 25 mm. The loose bulk density of these aggregates is between 300 and 700 kN/m^3. The purpose of this research is to determine the stress-strain behavior, shear strength parameters, and the energy absorption of LECA materials. Direct shear tests were conducted at five normal stresses of 25, 50, 75, 100, and 200 kPa. In addition, conventional triaxial compression tests were operated at confining pressures of 50, 100, and 200 kPa to examine stress-strain behavior. The experimental results show a high internal angle of friction and even a considerable amount of nominal cohesion despite the granular structure of LECA. These desirable properties along with the intrinsic low density of these aggregates make LECA as a very proper material in geotechnical applications. Furthermore, the results demonstrate that lightweight aggregates may have high energy absorption that is excellent alternative material in seismic isolations.

Keywords**—**Expanded clay, direct shear test, triaxial test, shear properties, energy absorption.

I. Introduction

DIFFERENT types of lightweight aggregates (LWAs) are using in a wide range of applications. The differences of these materials are in their density, texture, composition, and water absorption [1]. Some of these light weight granular materials are formed naturally, others are produced from natural sources or from industrial by-products such as fly ash and slag ashes. One of these LWAs is produced by heating the natural raw material such as shale, clay, and slate. LECA are manufactured in rotary kiln by heating the wet clay up to 1200°C. The productions of this process have irregular shape and inter porosity. Due to inter porosity these LWAs have lower density in comparison of common material. The bulk density of this material is changing between 200 to 700 kg/m^3. The reduction in particle weight causes these materials to be a suitable alternative in geotechnical fills. In addition, these granulated materials have high insulation and thermal inertia.

The response of variety of LWAs under shear tests was similar to a great number of ordinary granular backfill materials. For example, the results of triaxial tests on expanded shale aggregates from different sources showed high internal friction angle that altered in the range of 44.5 to 48° [2]. Other researches also indicated that LWAs have proper shear behavior enabling such materials to solve many geotechnical problems. Utilization of these aggregates as a filling material around a pile can reduce the lateral forces by more than one-half [3]. A laboratory and field study was conducted on the mixture of expanded clay and shale aggregates in order to examine the behavior of these materials as an embankment fill for roadways. The field monitoring showed that the surface settlement of the LWAs fill was lower than the normal material because LWAs have high internal friction angle that helps to increase the stability of the embankment, along with a low compressibility which lessens roadway settlement [4]. The numerical investigation of this highway indicated that the settlement in the long-term can be decreased up to two-thirds [5]. In addition, LECA showed to be a proper energy absorption layer in comparison with other geo-materials such as sand [6].

In this study, two types of expanded clay aggregate produced in LECA Company, Iran were selected to investigate their shear strength properties in order to examine their potential in geotechnical applications.

II. Materials

In this research, two different types of expanded clay aggregate produced in Iran Leca factory including crushed ordinary LECA (OL) and structural LECA (SL) were investigated. The SL material has higher density than the OL due to its lower expansion during the heating process in rotary kiln [7]. In addition, microscopic observations displayed a harder outer shell for SL material. The color of outer layer in OL is light brown, while it is reddish in SL. Table I presents the physical properties of these two aggregates.

As the sieve analysis of materials is plotted in Fig. 1, the size distribution of aggregates varies between 0 to 5 mm.

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TABLE I
PHYSICAL PROPERTIES OF LECA

Aggregate Property	Test Method	OL	SL
Bulk density	ASTM D698 [8]	340 kg/m^3	670 kg/m^3
Specific Gravity	ASTM D854 [9]	1.30	1.65

III. EXPERIMENTAL METHODOLOGY

A. Direct Shear Tests

To determine the strength characteristics of the LWAs, several direct shear tests on a square box with dimension of 60×60×22 mm were conducted according to the ASTMD3080 standard for granular materials [10]. Samples were prepared in two different ways: compacted and loose. For preparing loose samples, the LWAs were poured in shear box from a very low height, while for compacted a cylindrical plastic plate with the weight of 445 gr was used to compact slightly the samples in three layers. During sample preparation, special care was taken to avoid crushing of particles. Each material was prepared in both loose and compacted conditions and tested under five normal stresses: 25, 50, 75,100, and 200 kPa. The results of these direct shear tests were illustrated in Figs. 2-7.

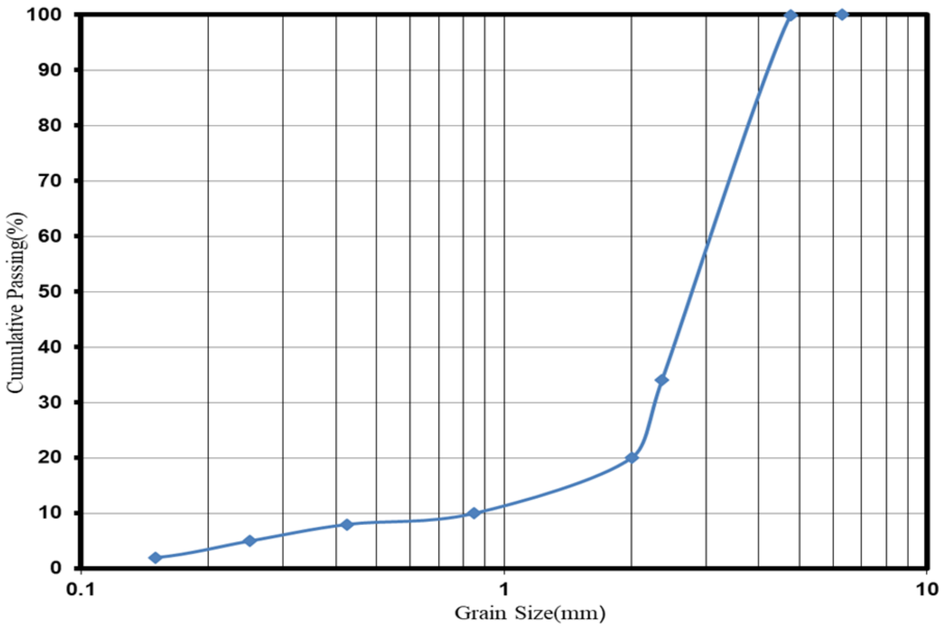

Fig. 1 Sieve analysis of LECA

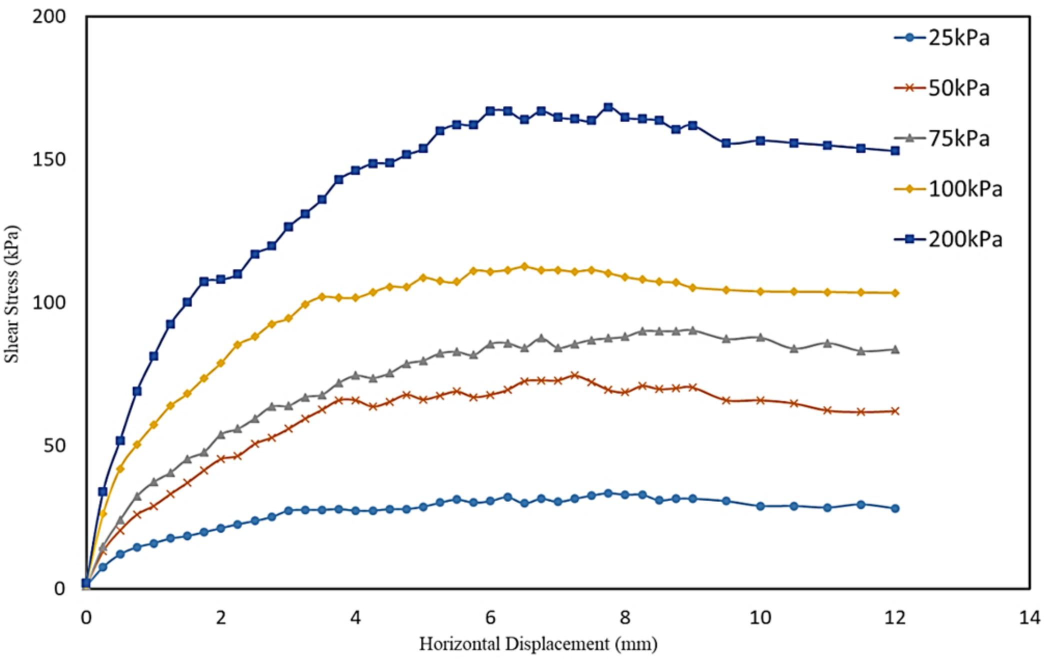

Fig. 2 Variation of shear stress with horizontal displacement for OL in loose condition

B. Conventional Triaxial Test

In this study, conventional triaxial tests on cylindrical specimens with the diameter of 50 mm and the height of 100 mm were also carried out under consolidated-drained (CD) conditions based on EN 15732 and ASTM D7181-11 standard [11], [12]. It should be noted that EN 15732 explains triaxial test method for determination of strength properties of expanded clay LWA. The tests were performed on loose and compacted samples in three confining pressure 50,100, and 200 kPa. From these triaxial tests, in addition to the shear strength parameters, their characteristics of energy absorption were also obtained. The results of triaxial tests were presented in Figs. 8 -11.

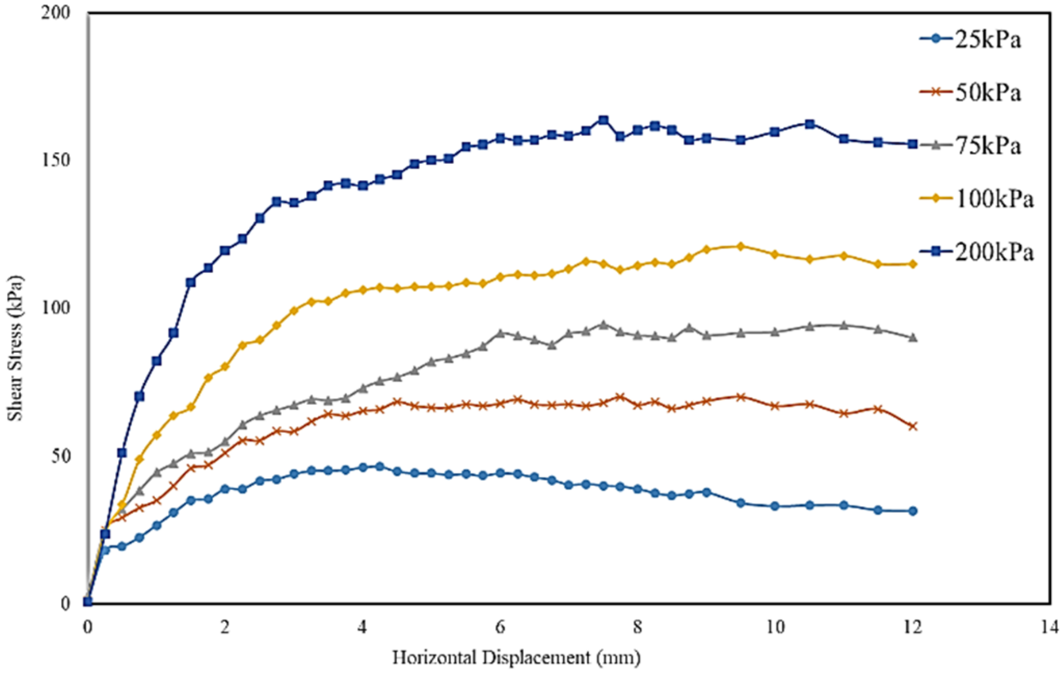

Fig. 3 Variation of shear stress with horizontal displacement for OL in compacted condition

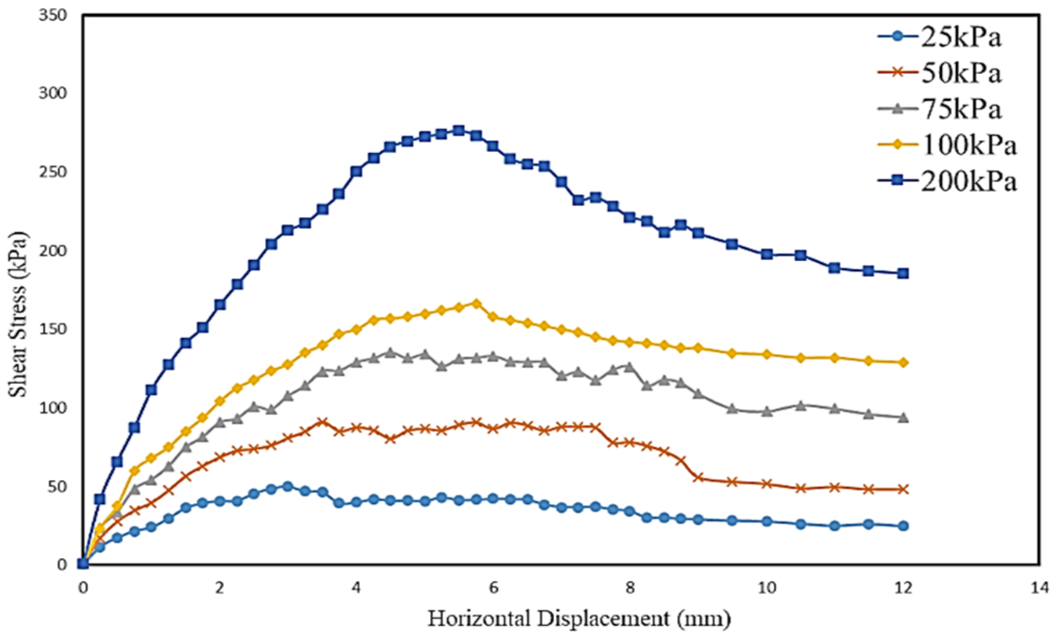

Fig. 4 Variation of shear stress versus shear displacement for SL in loose condition

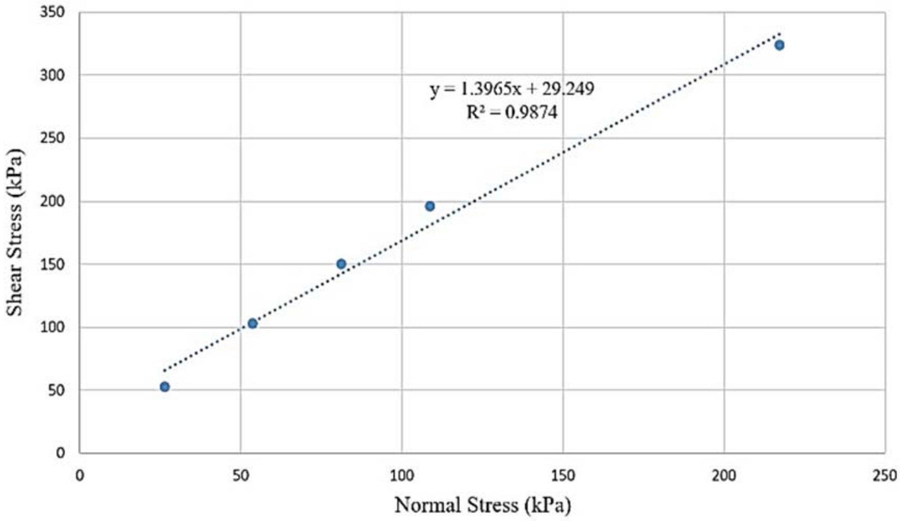

Fig. 5 Variation of shear stress versus shear displacement for SL in compacted condition

IV. Results and Discussion

A. Direct Shear Tests

Fig. 2 illustrates the variation of shear stress versus shear displacement under different normal stresses for OL material in loose condition, and Fig. 3 shows this variation in compacted samples. Similar curves were drawn in Figs. 4 and 5 for SL materials. As it can be seen from Figs. 2 and 3, there is no obvious difference between the shear resistance of OL material in loose and compacted conditions. Meanwhile, the OL samples perform as ductile materials with a prefect plastic behavior in both loose and compacted conditions. However as observed in Figs. 4 and 5, the SL material shows a similar plastic strain softening behavior in both loose and dense conditions but with a clear difference between their shear resistance values.

Fig. 6 presents an obvious difference between the shear behaviors of these two types of LECA material. In this figure a relative clear peak can be observed in curves of structural LWAs.

In order to calculate the peak shear strength parameters, the Mohr-Coulomb failure envelopes of OL and SL materials at loose and dense status were plotted in normal stress-peak shear strength diagram of Fig. 7. It should be noted that in all cases the effective area of shear surface at maximum shear stress was utilized to determine the effective normal and shear stresses [9]-[11].

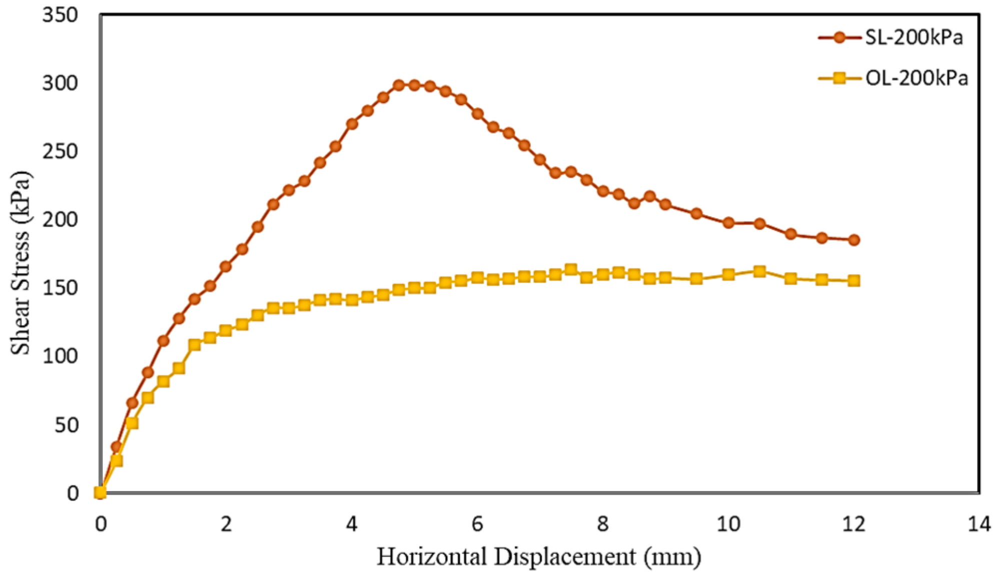

Fig. 6 The comparison between the shear behavior of SL and OL at vertical stress of 200 kPa

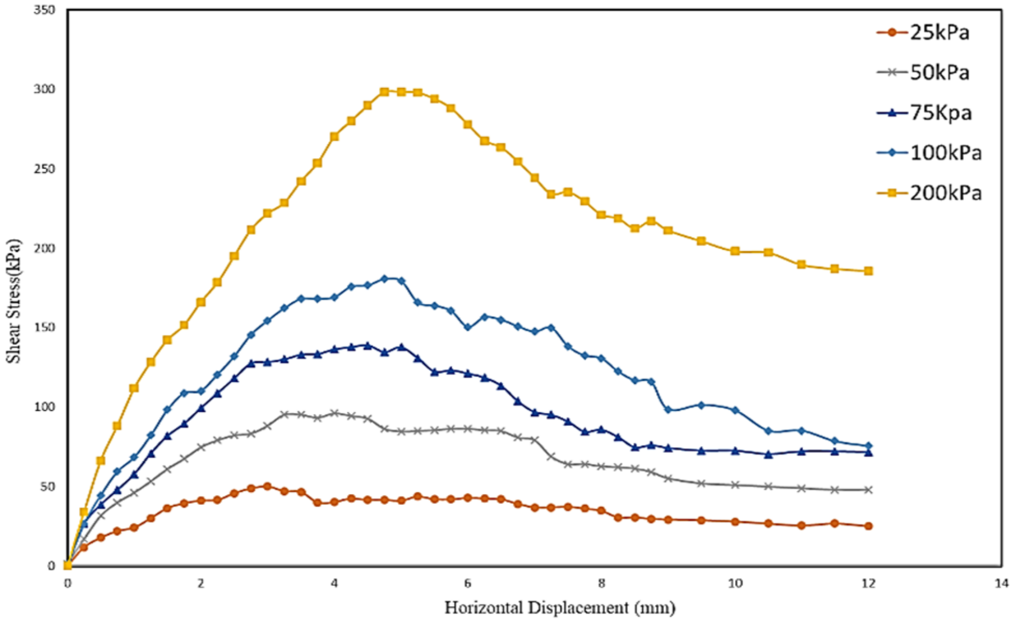

Fig. 7 Mohr-coulomb envelope for SL in compacted condition

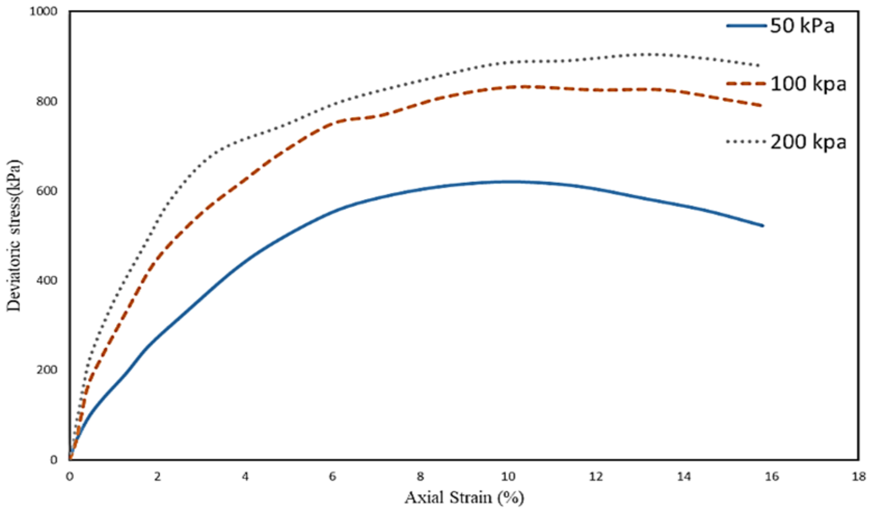

Fig. 8 Deviatoric stress versus axial strain for OL

Table II presents the peak shear strength parameters of frictional angle and cohesion for OL and SL materials in loose and dense conditions.

TABLE II
SHEAR STRENGTH PARAMETERS OF LECA DIRECT SHEAR TEST

Aggregate Property	c (kPa)	φ (◦)
OL-loose	36.7	35.6
OL-compacted	34.4	36.3
SL-loose	10	51.7
SL-compacted	20.2	54.4

The results show that structural aggregates have almost 15° higher friction angles than ordinary materials. It is also obvious that for both OL and SL materials, compacting has very little effects on increasing frictional angles. But, it may remarkably increase the cohesion resistance for SL materials, though has trivial impact in cohesion of OL aggregates. These results are in accordance with the previous research on lightweight granular materials by Valsangkar and Holm and Saride et al. [3], [4].

B. Triaxial Tests

Figs. 8 and 9 show the curves of deviatoric stress versus axial strain for OL and SL materials in loose status. The difference in shear behavior of these two types of aggregates is almost similar to the results of direct shear tests. The peak shear stress is clear in structural aggregates. Another point can be drawn from the OL plot in Fig. 8 is that by changing the confining pressure from 100 kPa to 200 kPa, the shear strength does not increase in proportional to the confining pressure. This may be attributed to the low strength of crushed materials within the mixture of OL aggregates. Hence, the failure envelope of this material is not linear and different shear strength parameters can be obtained in low and high normal stresses.

The peak shear strength parameters of the materials from triaxial tests are presented in Table III.

It can be seen that the results of direct shear and triaxial tests are in a good agreement for SL aggregates but are different for OL. In addition, OL materials present a large cohesion resistance of 260 kPa despite a low frictional angle of 20° at higher normal stresses.

TABLE III
SHEAR STRENGTH PARAMETERS OF LECA TRIAXIAL TEST

Aggregate Property	c (kPa)	φ (◦)
OL-low stress	75	45.5
OL-high stress	260	20.5
SL	28	53

Energy absorption demonstrates the part of energy needed to make deformation in materials. These parameters can be obtained by calculating the area under the stress-strain curve [13]. The energy absorption capacity of structural materials in different confining pressures can be seen in Fig. 10. It can be inferred that these materials can absorb energy properly that caused to be appropriate alternative material in seismic isolations.

The secant stiffness at 10% axial strain was calculated from the data of triaxial tests. The variation of stiffness in different confining pressures is presented in Fig. 11. It is obvious that by applying higher confining pressure, the stiffness of materials is increased. The initial stiffness of structural aggregates is varied between 35 to 45 MPa while for OL materials it is in the range of 14 to 27 MPa.

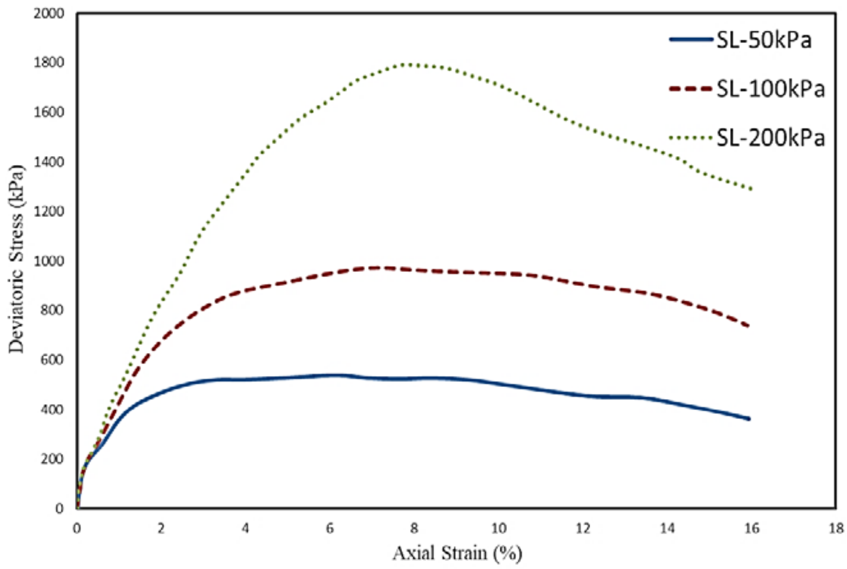

Fig. 9 Deviatoric stress versus axial strain for SL

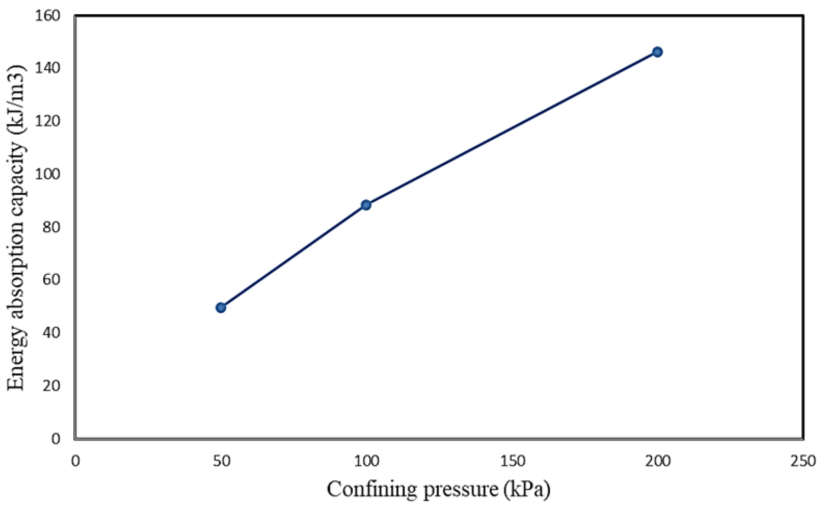

Fig. 10 Energy absorption capacity for SL

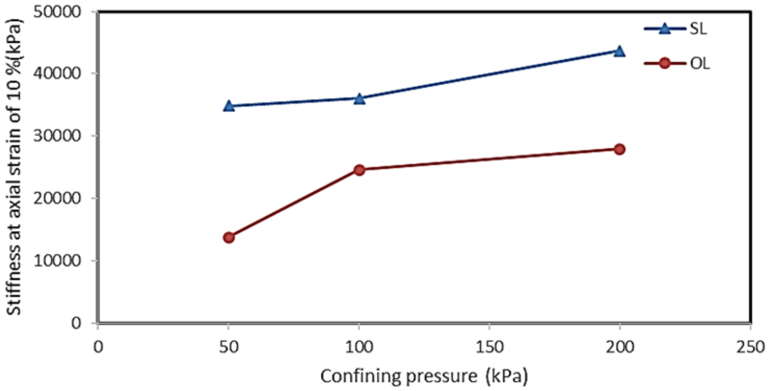

Fig. 11 Stiffness for SL and OL in different confining pressures

V. Conclusion

The results of this study show that LECAs have high frictional angles along with a reasonable cohesion resistance despite their granular shape. These make them as excellent materials in geotechnical applications especially for backfills behind retaining walls. Having such proper parameters beside the inherent lower bulk unit weight can effectively reduce the active lateral pressures imposed on retaining walls. Furthermore, the high energy absorption and suitable stiffness are great characteristics of these materials that may expand their applications for seismic aspects.

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