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Stabilization of Low Plasticity Clay Soil Utilizing Crushed Limestone

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ABSTRACT

Massive quantities of industrial wastes, such as stone industry waste, are obtained yearly. The generated limestone waste that deposits into landfills may be decreased *via* using it in building materials' preparation. In this study, crushed limestone (CLS) was used to enhance the geotechnical properties of low plasticity clay (LPC) soil of Sulaimania governorate, northern Iraq. Consistency, compression and compressibility characteristics were examined and evaluated. CLS was added by 0%, 5%, 10%, 15% and 20% as a replacement from the dry mass of natural soil. Experimental results by using CLS yielded a notable level of improvement of the expansive soils' geotechnical properties. Essential modification in the geotechnical properties was achieved due to the addition of 20% of CLS.

KEYWORDS: Crushed limestone, Stabilization, LPC soil, Geotechnical parameters.

INTRODUCTION

One of the complex issues that exist in the construction of projects is the availability of expansive soils. These soils expand and shrink with water content changes. These characteristics result in severe damages to lightly loaded structures, such as pavements, canal linings, retaining walls and buildings constructed using expansive soil as foundation (Sabat and Mohanta, 2015). In order to obtain an eligible soil foundation for construction projects, its geotechnical characteristics might require some improvement. Hence, for stabilizing purposes, various materials and methods (chemical, mechanical and/or combination of both) were used to improve the weak properties of expansive soil. However, stabilization materials are expensive and/or environmentally insecure (Bhuvaneshwari et al., 2010; Fattah et al., 2010; Abdalla and Salih, 2020; Salih and Abdalla, 2020). Some researchers have used cement and lime, which is one of the undesirable stabilization materials (Ji-ru and Xing, 2002; Al-Rawas et al., 2005; Al-Swaidani et al., 2016; Al-Hadidi and Al-Maamori, 2019; Abdalla and Salih, 2020). Physical and mechanical properties of expansive soil can improve by using industrial by-products, such as rice husk, fly ash, calcium sulphate and silica fume (Sharma et al., 2017; Islam et al., 2018; Gadouri et al., 2019; Mittal, 2021).

A huge amount of crushed limestone (CLS) is produced in masonry factories in Iraq during the cutting and finishing of building stones (Al-Azzo et al., 2009). CLS is found to decrease the plasticity index (P.I.) and change the compaction characteristics (decreasing the optimum moisture content, OMC, whereas increasing the maximum dry density, MDD) (Anu et al., 2016).

Limestone dust (LSD) is a kind of dust formed during the processing of limestone and mostly consists of $CaCO_3$. Approximately 20% of LSD waste is generated through limestone processing (Brooks et al., 2011; Sabat and Muni, 2015). Different studies have been performed using quarries dust and stone powder with/without other materials (Ogila, 2016; Al-Joulani, 2012; Roohbakhshan, 2013) for the purpose of expansive soil improvement. For extremely high expansive soils, swelling percent and pressure can be decreased by the amount of stabilizer increase (Oliga, 2016). Hence, limestone dust has been utilized significantly. It was found to decrease plasticity index and degree of expansion notably (AI-Azzo, 2009;

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Abdalqadir and Salih, 2020). In the same way, it has been revealed that the geotechnical properties of expansive soil can be improved by using limestone dust (Sabat and Muni, 2015), in addition to using limestone powder for improvement of high expansive clay (Pastor et al., 2019). So, the percentage of added limestone dust plays a great role in the improvement purpose. Addition of 20% limestone dust reduces the free swelling ratio to approximately 41.50% and converts swelling soils into non-swelling soils (Memon et al., 2015). Addition of 12% limestone dust reduced the uplifting pressure to approximately 38.36%, while expansion index was reduced from 139% to 82% (Ali et al., 2014). Addition of 30% limestone dust has shown to be the best treatment percentage for high expansive soils (Saygili, 2015).

According to the above-reviewed studies, CLS in various states was utilized. Similarly, in this study, CLS was also used; however, some other geotechnical characteristics, such as linear shrinkage limit, UCS and compressibility index were focused on. Moreover, among the utilized CLS percentages in the literature for stabilization purposes, various percentages up to 20% of CLS were considered, which is notable to find the significance of low and high CLS percentages to improve expansive soils' undesired properties.

MATERIALS AND METHODS

Utilized Materials

Utilized Natural Soil Sample

Sulaimania governorate, northern Iraq, was selected to obtain the required LPC soil samples, which were collected from Bakrajo area (Latitude = 35°34'4.58"N and Attitude = 45°21'47.74"). The soil sample was extracted from 1.0-1.5 m beneath the natural ground level. This depth is for the removal of the effect of agricultural fertilization, because this area has been used for agricultural purposes for many years. The collected samples were undisturbed and disturbed ones. Extreme precautions were taken during soil sampling to maintain the collected soil samples in their natural moisture content and field density conditions (Kalkan and Bayraktutan, 2008; Rashed et al., 2017; Asad et al., 2019). After testing in soil laboratory, the sample was found to be low-plasticity clay, LPC soil according to the Unified Soil Classification System (USCS). The other geotechnical parameters are shown in Fig. 1 and Table 1, respectively. Geotechnical laboratory experiments were conducted according to ASTM standards, as shown in Table 1.

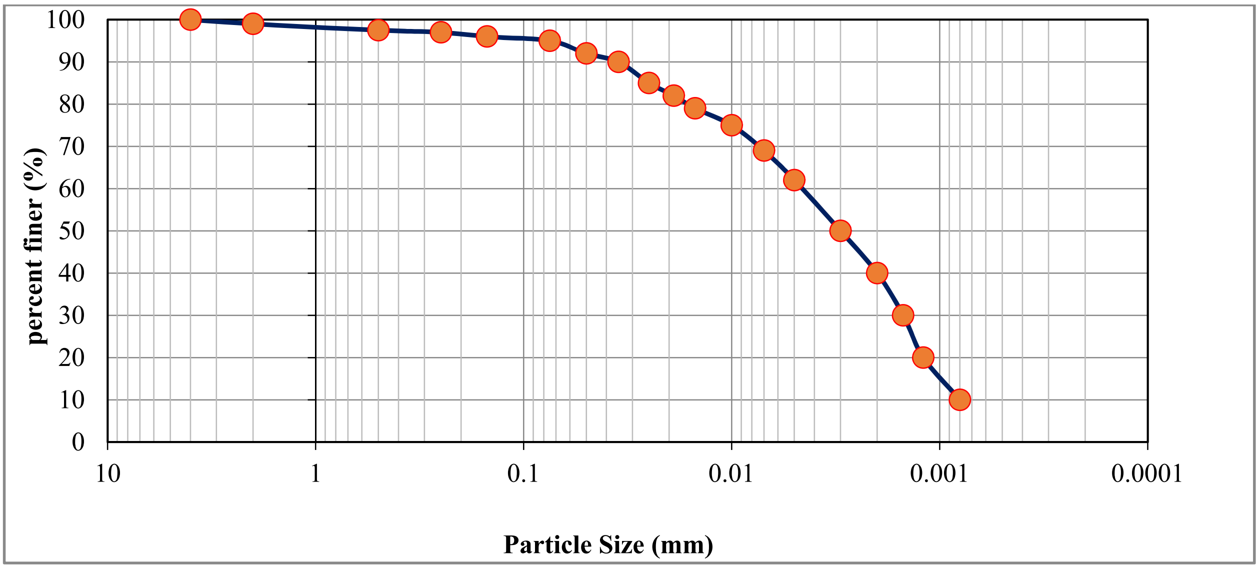

Figure (1): Grain-size distribution for the tested sample (Bakrajo LPC soil)

Table 1. Basic physical and geotechnical parameters for the tested sample (Bakrajo LPC soil)

Property	Value	ASTM Standard
Natural Moisture Content (%) Field Density (gm/cm^3)	14.1 1.6	ASTM D2216 (2010) ASTM D 2937 (2010)
Color	Light Brown	Munsell Color Chart
LL (%)	44	ASTM D4318 (2010)
PL (%)	23	ASTM D4318 (2010)
PI (%)	21	ASTM D4318 (2010)
Linear Shrinkage Limit (%)	15	ASTM C356 (2010)
C_c	0.18	ASTM D 2435 (2011)
C_r	0.02	ASTM D 2435 (2011)
Specify Gravity (G_s)	2.6	ASTM D854 (2014)
UCS (kPa)	312	ASTM D2166 (2010)
UCSC Classification Particle-size Analysis	LPC -	ASTM D2487 (2017) ASTM D 422 - 63 (2007)

Crushed Limestone

The required *in-situ* samples of limestone were obtained from a place (Naopurdan limestone klippe) that covers about 20.0 km^2, located around 32.0 km to the northeast of Sulaimania city, northern Iraq. The collected samples were properly crushed, sieved on sieve no. 40 (0.425 mm); the finer limestone part was utilized for the purpose of LPC soil sample stabilization. The major elemental chemistry of the limestone *in-situ* samples is presented in Table 2.

Table 2. Chemical analysis for the natural samples of the utilized limestone

Chemical Composition	Value
SiO_2	0.25
Al_2O_3	0.44
Fe_2O_3	0.24
CaO	55.08
MgO	0.37
Na_2O	0.06
K_2O	0.08
SO_3	0.02
L.O.I.	42.98
$CaCo_3$ (%)	98.81

EXPERIMENTAL WORK

For the experimental work done in the field, limestone (Table 2) and natural soil (Table 1) samples were collected form two locations, Chwarta and Bakrajo Regions, respectively, in Sulaimania governorate, northern Iraq. Soil samples were collected and saved in plastic bags in order to keep their field intact properties, then they were transported to a soil laboratory to be used for the conduction of the geotechnical laboratory experiments.

For the experimental work done in the laboratory, all the used samples were passed through a 4.75-mm opening sieve. The CLS sample has been prepared to be added at 0%, 5%, 10%, 15% and 20% of the dry mass of the natural soil samples according to the previous determination of soil samples' wet and dry densities and field moisture contents (Table 1). For the purpose of soil treatment, the dry soil was divided into five proportions and the CLS sample was used in percentages of 0%, 5%, 10%, 15% and 20%, being added to the soil proportions in the dry state. Then, all the proportions were mixed and then each testing sample was prepared. The prepared testing samples were left for 24 hours before testing to be matured as time progressed.

The laboratory experiments consist of index properties, classification, shear strength and compressibility. Therefore, field water content, field density, grain-size distribution (hydrometer analysis), liquid limit (LL), plastic limit (PL), plasticity index (PI), linear shrinkage limit (LSL), compressibility and unconfined compression parameters were calculated. These experiments were carried out on intact and stabilized soil samples. The geotechnical laboratory experiments were conducted according to ASTM standards (Table 1).

RESULTS AND DISCUSSION

According to the undesired geotechnical characteristics of the chosen soil sample, such as high consistency properties, in addition to the hope to increase the existing compression capability of the soil sample, the aim of the study was drawn. Crushed limestone (CLS) was selected due to its capability, which was noticed from the literature, to improve fine-grained soils. The following sub-sections present the achieved improvement level for LPC soil by using CLS.

Influences of Limestone on the Consistency Parameters

Linear shrinkage limit and the other consistency parameters' variations before and after the addition of limestone dust are shown in Fig. 2 and Fig. 4. When CLS content increased up to 20%, LL PI and SL decreased noticeably, while PL increased. When 20% of CLS was added, a significant change was observed, where the LL, PI and SL values of the treated soil decreased to 18.89%, 42% and 37%, respectively, as shown in Fig. 3 and Fig. 5.

The achieved decreases in the consistency parameters' values (LL, PI and LSL) were because of the reduction of clay particle layers' thickness. The response of the cation exchange is in charge of the recorded decrease, which causes the attraction force to increase and the subsequent flocculation of particles. The clay minerals' absorbed cations replaced by obtained calcium from the utilized CLS were reduced in the diffuse layers surrounding soil particles. The clay particles were then coated and bonded together with limestone dust (Ahmed et al., 1969; Ene and Okagbue, 2009). Therefore, the available water in addition to the voids among soil particles treated with CLS were reduced. These results are consistent with those results obtained by (Al-Azzo, 2009; Sabat & Muni, 2015; Anu et al., 2016; Kolay & Ramesh, 2016).

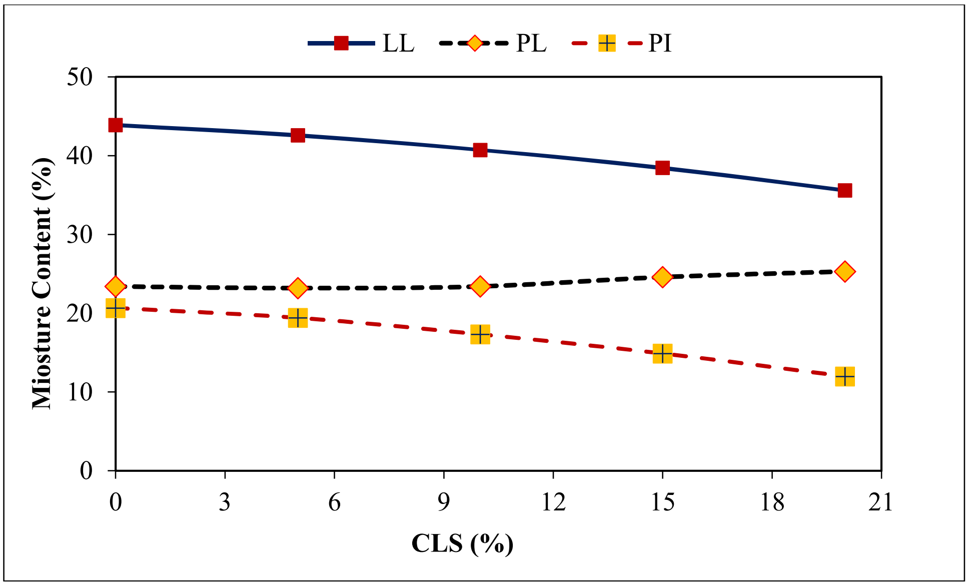

Figure (2): Effect of CLS content on the consistency parameters (LL, PL and PI) of the stabilized LPC soil

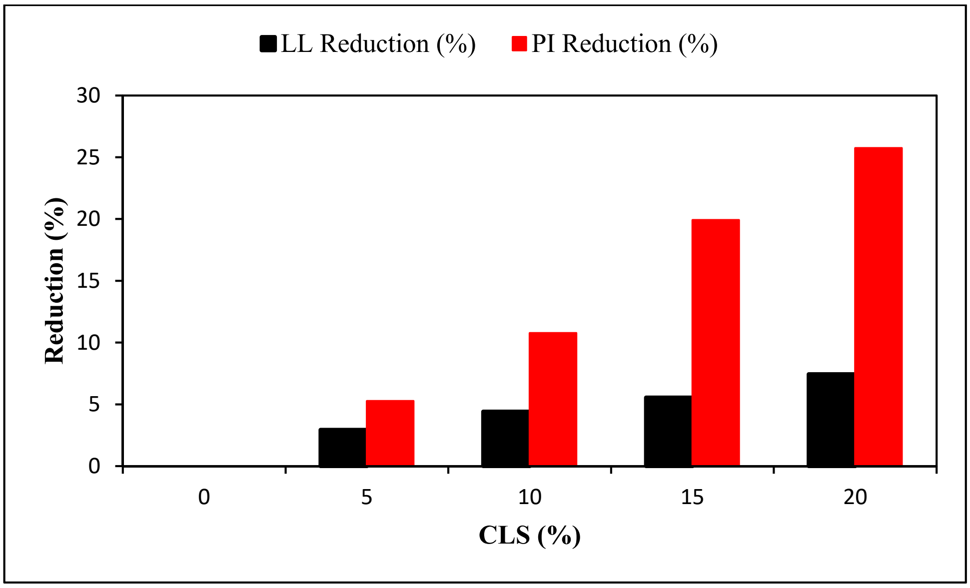

Figure (3): Reduction percentage in LL and PI values after utilizing CLS as a stabilizer for LPC soil

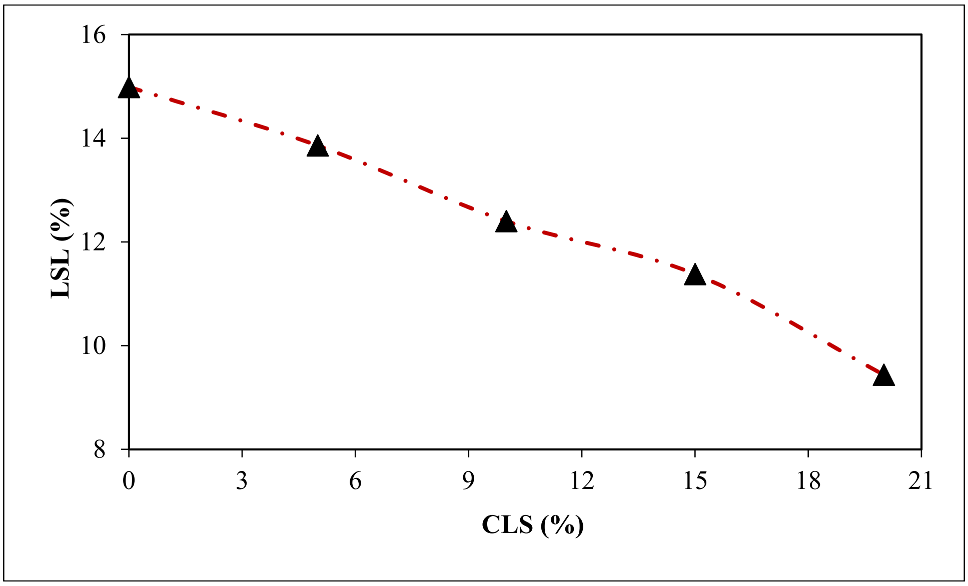

Figure (4): Effect of CLS content on the LSL value of the stabilized LPC soil

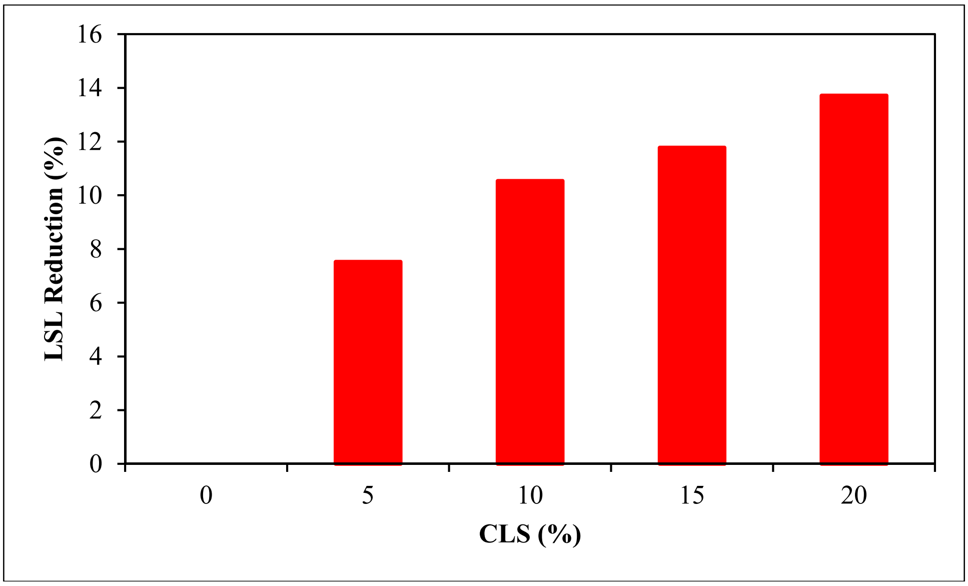

Figure (5): Reduction percentage in LSL value after utilizing CLS as a stabilizer for LPC soil

Influences of Limestone on Unconfined Compressive Strength

The natural and treated Bakrajo LPC soil samples by CLS were selected to be tested for UCS determination. The treated samples prepared by utilizing different percentages of hydrated lime are shown in Fig. 6. Measured UCS of the CLS-treated samples changed rapidly with increasing hydrated lime percentage until the optimum CLS content was reached. The added optimum percentage of CLS to the natural soil sample further increased its UCS value from 312 kN/m^2 to 608 kN/m^2 and then, the achieved improvement in the UCS value is 95% for the treated sample with 20% CLS, as shown in Fig. 7. Similar results have been observed by various researchers who studied soil's UCS properties (Anu et al., 2016; Pastor et al., 2015; Sabat and Muni, 2015). The addition of CLS might generate bonds among soil particles, which strongly bind the particles closely together and resist any externally applied forces. This effect is indicated by the increase in the UCS value after the addition of 20% hydrated lime.

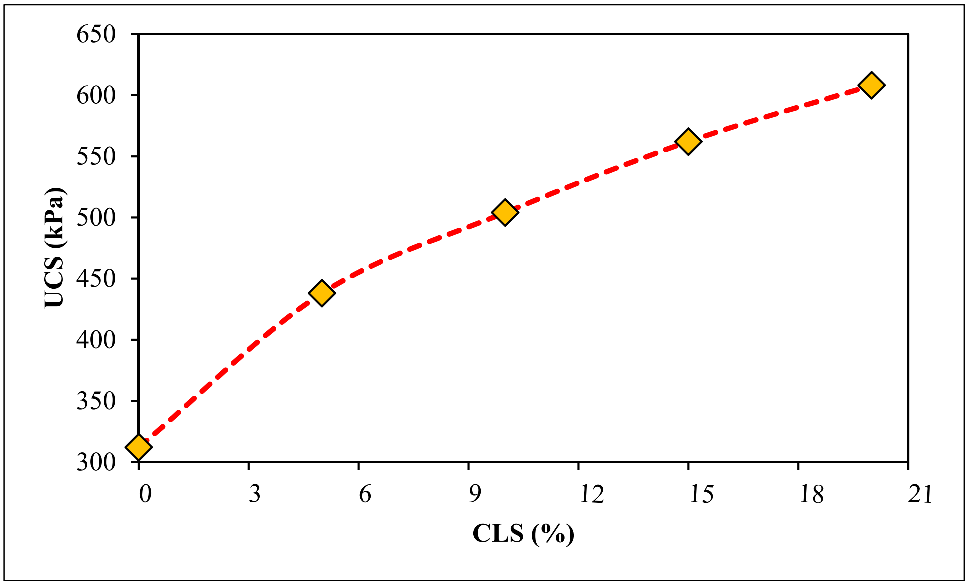

Figure (6): Effect of CLS content on the UCS value for the stabilized LPC soil

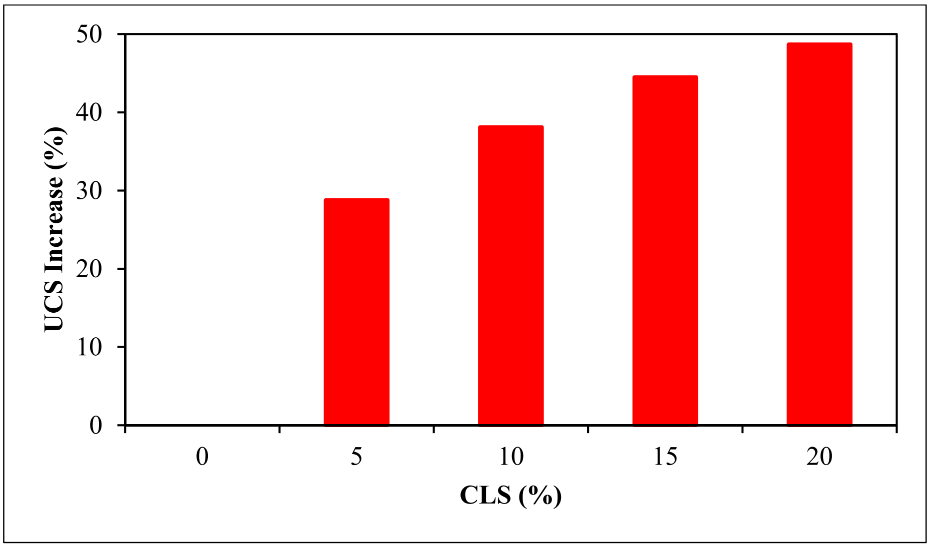

Figure (7): Increase percentage in UCS value after utilizing CLS as a stabilizer for LPC soil

Effect of Limestone on Compressibility Characteristics

The natural and treated Bakrajo LPC soil samples by CLS were selected to be tested for compression index (C_c) and swelling index (C_r) determination as, shown in Fig. 8 and Fig. 9. C_c and C_r for the natural soil sample were 0.187 and 0.0214, respectively. The C_c value decreased from 0.187 to 0.124 and the C_r value decreased from 0.0214 to 0.00794 as the CLS percentage increased from 0 to 20%. Decreases in compressibility indices after the addition of 20% CLS were due to the recorded reduction in the LL value and the subsequent decrease in the compressibility of soil. So, CLS works as a bonding agent for the soil particles in addition to resisting load application. Hence, both mentioned actions performed by CLS are significantly helpful in decreasing compressibility parameters. Fig. 10 represents the obtained reductions in C_c and C_r values after utilizing CLS as a stabilizer for the LPC soil sample. The studies of Pastor et al. (2019) and Saygili (2015) showed similar outcomes.

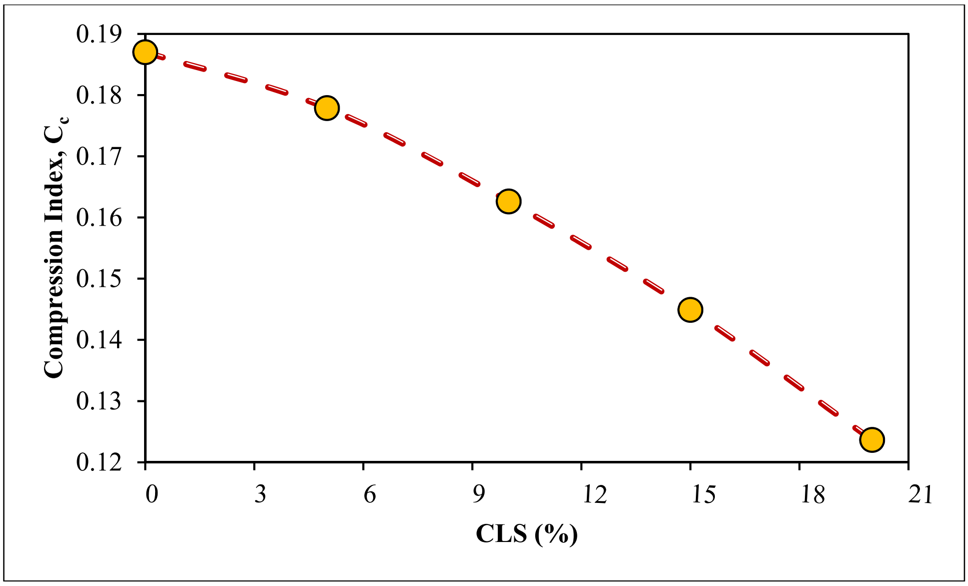

Figure (8): Effect of CLS content on the C_c value for the stabilized LPC soil

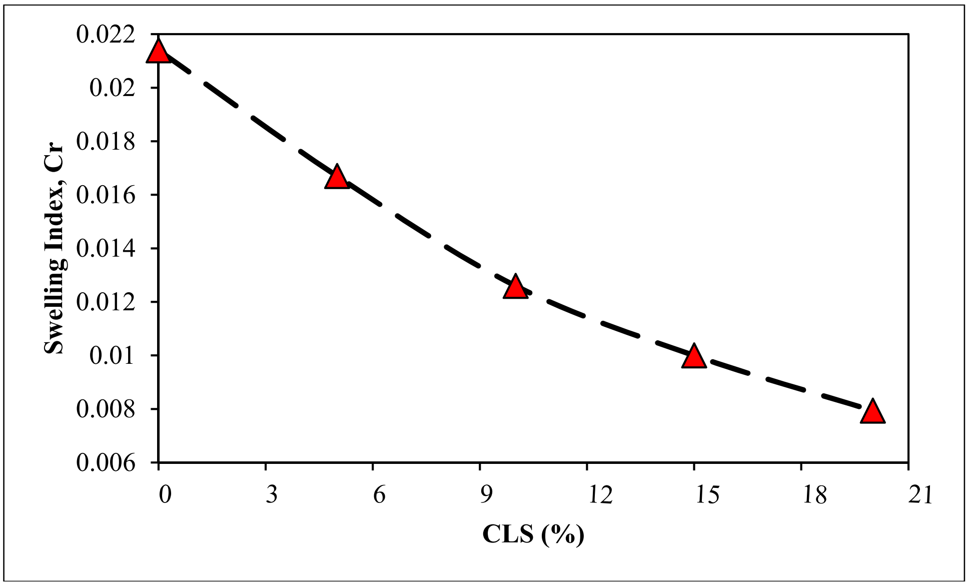

Figure (9): Effect of CLS content on the C_r value for the stabilized LPC soil

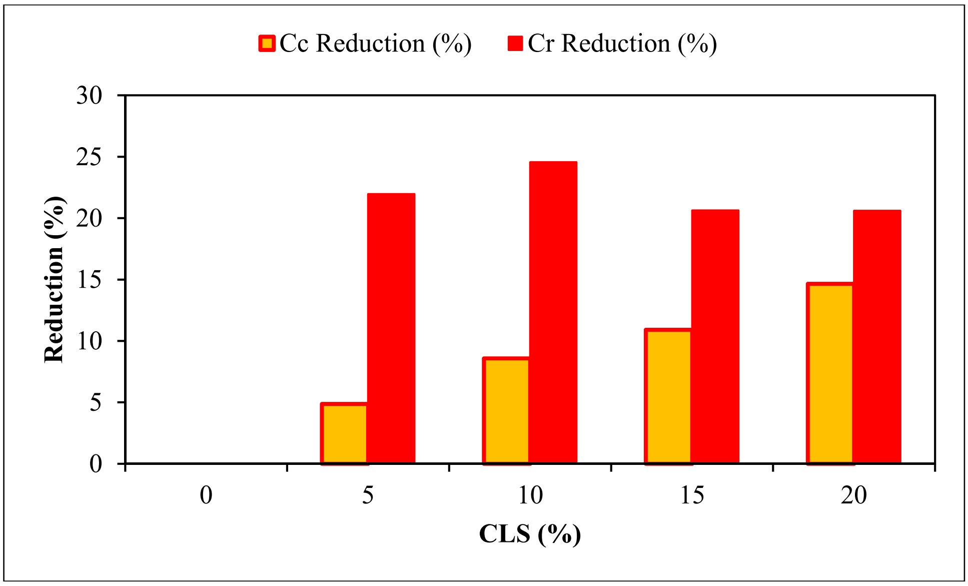

Figure (10): Reduction percentage in C_c and C_r values after utilizing CLS as a stabilizer for LPC soil

CONCLUSIONS

Considering the achieved tests results, the outcomes yielded the following conclusions:

1. Utilization of CLS by percentages ranging from 0% to 20% to stabilize the LPC soil worked significantly to control and decrease the consistency parameters; namely, LL, PL, PI and LSL.
2. Utilization of CLS by a percentage more than 20% to stabilize the LPC soil sample showed significant decreases in the values of LL, PI and LSL by 18.89%, 42% and 37%, respectively.
3. The UCS increased with increasing the percentage of CLS, which yielded an increase of 95%.
4. The addition of CLS resulted in considerable decreases in the compressibility characteristic values (Cc and Cr) of the stabilized LPC soil, which decreased by 34% and 63%, respectively.

Conflict of Interest: The authors declare that there is no conflict of interest regarding this study.

REFERENCES

Abdalla, T.A., and Salih, N.B. (2020). "Hydrated lime effects on geotechnical properties of clayey soil". Journal of Engineering, 26 (11), 150-169.

Abdalqadir, Z.K., and Salih N.B. (2020). "An experimental study on stabilization of expansive soil using steel slag and crushed limestone". Sulaimania Journal for Engineering Sciences, 7 (1), 35-47.

Ahmed, S., Swindale, L.D., and El-Swaify, S.A. (1969). "Effects of adsorbed cations on physical properties of tropical red earths and tropical black earths." J. Soil Sci., 20 (2), 255-268.

Al-Azzo, S.I. (2009). "Treatment of expansive clayey soil in Al-Wahda district at Mosul city with crushed limestone". Iraqi Journal of Earth Sciences, 9 (2), 1-10.

Al-Azzo, S., Salih S., and Salim, T. (2009). "Compressive strength and swelling properties of randomly distributed fiber reinforcement of clayey soil". Al-Taghani Journal, 22, 160-166.

Al-Hadidi, M.Th., and Al-Maamori, Z.H.N. (2019). "Improvement of earth canals constructed on gypseous soil by soil cement mixture". Journal of Engineering, 25 (3), 23-37.

Ali, R., Khan, H., and Shah, A.A. (2014). "Expansive soil stabilization using marble dust and bagasse ash". Int. J. Sci. Res., 3, 2812-2816.

Al-Joulani, N. (2012). "Effect of stone powder and lime on strength compaction and CBR properties of fine soils". Jordan J. Civil Eng., 6 (1), 1-16.

Al-Rawas, A.A., Hago, A.W., and Al-Sarmi, H. (2005). "Effect of lime, cement and Sarooj (artificial pozzolan) on the swelling potential of an expansive soil from Oman". Building and Environment, 40 (5), 681-687.

Al-Swaidani, A., Hammoud, I., and Meziab, A. (2016). "Effect of adding natural pozzolana on geotechnical properties of lime-stabilized clayey soil". Journal of Rock Mechanics and Geotechnical Engineering, 8 (5), 714-725.

Anu, K., Deewash, G., Rupesh, S., Lige, L., and Phunstok, N.B. (2016). "Stabilization of soft clay soil using fly ash and limestone dust". International Journal of Scientific and Engineering Research, 7 (5), 18-22.

Asad, A., Hussain, A., Farhan, A., Bhatti, A.A., and Munir, M. (2019). "Influence of lime on low plastic clay soil as subgrade". J. Mech. Const. & Math. Sci., 14 (1), 69-77.

ASTM C356-10. (2010). "Standard test method for linear shrinkage of preformed high-temperature thermal insulation subjected to soaking heat". ASTM International Standards, West Conshohocken, PA, USA.

ASTM D 2216-10 (2010). "Standard test methods for laboratory determination of water (moisture) content of soil and rock by mass". ASTM International Standards, West Conshohocken, PA, USA.

ASTM D 2937-10 (2010). "Standard test methods for density of soil in place by the drive-cylinder method". ASTM International Standards, West Conshohocken, PA, USA.

ASTM D 422-63. (2007). "Standard test method for particle-size analysis of soils". ASTM International Standards, West Conshohocken, PA, USA (Reapproved 2007).

ASTM D 854-14. (2014). "Standard test methods for specific gravity of soil solids by water pycnometer". ASTM International Standards, West Conshohocken, PA, USA.

ASTM D2166. (2000). "Standard test methods for unconfined compressive strength of cohesive soil". ASTM International, West Conshohocken, PA, USA.

ASTM D2435-11. (2011). "Standard test methods for one-dimensional consolidation properties of soils using incremental loading". ASTM International Standards, West Conshohocken, PA, USA.

ASTM D2487. (2017). "Standard practice for classification of soils for engineering purposes (unified soil classification system)". ASTM International Standards, West Conshohocken, PA, USA.

ASTM D4318-10. (2010). "Standard test methods for liquid limit, plastic limit and plasticity index of soils". ASTM International Standards, West Conshohocken, PA, USA.

Bhuvaneshwari, S., Robinson, R., and Gandhi, S. (2010). "Micro-fabric and mineralogical studies on the stabilization of an expansive soil using inorganic additives". Int. J. Geotech. Eng., 4 (3), 395-405.

Brooks, R., Udoeyo, F., and Takkalapelli, K. (2011). "Geotechnical properties of problem soils stabilized with fly ash and limestone dust in Philadelphia". J. Mater. Civ. Eng., 23 (5), 711-716.

Ene, E., and Okagbue, C. (2009). "Some basic geotechnical properties of expansive soil modified using pyroclastic dust". Eng. Geol., 107 (1), 61-65.

Fattah, M.Y., Salman, F.A., and Nareeman, B.J. (2010). "A treatment of expansive soil using different additives". Acta Montanistica Slovaca, 15 (4), 290.

Gadouri, H., Harichane, K., and Ghrici, M. (2019). "Effect of the interaction between calcium sulphate and mineral additives on shear strength parameters of clayey soils". Journal of Engineering Research, 7 (2), 66-88.

Islam, S., Hoque, N., Uddin, M., and Chowdhury, M. (2018). "Strength development in clay soil stabilized with fly ash." Jordan Journal of Civil Engineering, 12 (2), 188-201.

Ji-ru, Z., and Xing, C. (2002). "Stabilization of expansive soil by lime and fly ash". J. Wuhan Univ. Technol. Mater. Sci. Ed., 17 (4), 73-77.

Kalkan, E., and Bayraktutan, M.S. (2008). "Geotechnical evaluation of Turkish clay deposits: A case study in northern Turkey". Environmental Geology, 55, 937-950.

Kolay, P.K., and Ramesh, K.C. (2016). "Reduction of expansive index, swelling and compression behavior of kaolinite and bentonite clay with sand and class c fly ash". Geotech. Geol. Eng., 34, 87-101.

Memon, N.A., Abro, F., Bhutto M.A., and Sumadi S.R. (2015). "Marble powder as stabilizer in natural clayey soils". J. Sci. Int. (Lahore), 27 (4), 4105-4110.

Mittal, A. (2021). "Effect of rice husk ash and stone dust on selecting engineering properties of poor subgrade soil". Jordan Journal of Civil Engineering, 15 (1).

Ogila, W.A.M. (2016). "The impact of natural ornamental limestone dust on swelling characteristics of high expansive soils". Environ. Earth Sci., 75 (24), 1493.

Pastor, J.L., Tomás, R., Cano, M., Riquelme, A., and Gutiérrez, E. (2019). "Evaluation of the improvement effect of limestone powder waste in the stabilization of swelling clayey soil". Sustainability, 11 (3), 1-14.

Rashed, K.A., Salih, N.B., and Abdalla, T.A. (2017). "Correlation of consistency and compressibility properties of soils in Sulaimania city". Sulaimania Journal for Engineering Sciences, 4 (5), 87-95.

Roohbakhshan, A., and Kalantari, B. (2013). "Stabilization of clayey soil with lime and waste stone powder". Int. J. Sci. Res. Knowl., 1 (12), 547.

Sabat, A.K., and Muni, P.K. (2015). "Effects of limestone dust on geotechnical properties of an expansive soil". International Journal of Applied Engineering Research, 10 (17), 37724-37730.

Sabat, A.K., and Mohanta, S. (2015). "Strength and durability characteristics of stabilized red mud-cushioned expansive soil". International Journal of Applied Engineering Research, 10 (10), 25867-25878.

Salih, N.B., and Abdalla, T.A. (2020). "The effect of freeze-thaw cycles on the geotechnical properties of clayey soil treated with lime". Journal of University of Duhok, 32 (2), 454-463.

Saygili, A. (2015). "Use of waste marble dust for stabilization of clayey soil". Mater. Sci., 21, 601-606.

Sharma, S.S., Dutta, R.K., and Parti, R. (2017)."Geotechnical characterization of fly ash-redmud mix stabilized with lime sludge." Jordan Journal of Civil Engineering, 11 (4), 680-697.