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

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-629

ECSMGE 24
XVIII EUROPEAN CONFERENCE ON SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

Lignin used as stabilizer in an expansive unsaturated soil

Lignine utilisée comme stabilisateur dans un sol expansif non saturé

S. Orlandi*
Universidad Nacional de la Patagonia San Juan Bosco, Comodoro Rivadavia, Argentina
D. Manzanal, C. Laskowski
ETSI de Caminos, Canales y Puertos, Universidad Politécnica de Madrid, Madrid, Spain
L.G. Libardi, L. Oldecop
Instituto de Investigaciones Antisísmicas, Universidad Nacional de San Juan, San Juan, Argentina
**sandra.orlandi@gmail.com*

ABSTRACT: The most important pathologies that occur in civil constructions are a consequence of the foundations. Expansive soils are among the most problematic soils, being the cause of some of these pathologies. It is possible to design foundations that can resist and restrict the action of expansive soils. One of the alternatives that could be applied to some constructions is to mix the soil with an additive. In this paper, the additive used to modify the swelling properties of an expansive Patagonian soil is lignin, a calcium lignosulphonate (CLS). CLS was analysed considering its influence on the behaviour of the soil. A series of tests were carried out to get a better understanding of the impact the addition of lignin produces on the soil. Tests performed were focused on the physicochemical and microstructure characterization (XR diffractometry, mercury intrusion porosimeter and scanning electronic microscope), volumetric behaviour upon wetting (free swelling), hydraulic behaviour (water retention test using dew-point potentiometer and permeability test) and mechanical behaviour (uniaxial compression test). Time of contact clay-CLS was considered as a variable to analyse the stability of the mixture.

RÉSUMÉ: Les pathologies les plus importantes qui surviennent dans les constructions civiles sont la conséquence des fondations. Les sols expansifs sont parmi les sols les plus problématiques, étant la cause de certaines de ces pathologies. Il est possible de concevoir des fondations capables de résister et de limiter l'action des sols expansifs. L'une des alternatives pouvant être appliquée à certaines constructions consiste à mélanger le sol avec un additif. Dans cet article, l'additif utilisé pour modifier les propriétés de gonflement d'un sol expansif de Patagonie est la lignine, un lignosulfonique de calcium (CLS). Le CLS a été analysé en fonction de son influence sur le comportement du sol. Les essais réalisés ont porté sur la caractérisation physico-chimique et de la microstructure (diffractométrie XR, porosimètre à intrusion de mercure et microscope électronique à balayage), le comportement volumétrique lors du mouillage (gonflement libre), le comportement hydraulique (essai de rétention d'eau à l'aide d'un potentiomètre à point de rosée et de la technique du papier filtre, essai de perméabilité) et le comportement mécanique (essai de compression uniaxiale). Le temps de contact argile-CLS a été considéré comme une variable pour analyser la stabilité du mélange.

Keywords: Expansive clay; calcium lignosulfonate; stabilizing additive; biopolymer.

1 INTRODUCTION

For a long time, the additives have been used as stabilizers in expansive soils. Lime is one of the most common additives, but it has a negative impact over the environment, reason why, nowadays, new, and more eco-friendly biopolymers are being studied to replace it. Some examples of alternative stabilizers being studied are waste tire rubber fibre (Bekhiti et al. 2019), burned olive waste (Attom and Al-Sharif, 1998), seeds and starches (Orlandi et al. 2021), ultrafine palm oil fuel ash (Pourakbar et al. 2015), rice hush ash (Brooks, 2009) and gypsum (Yilmaz and Civelekoglu 2009), among others.

All around the world, the paper pulp industry produces lignin in large quantities, and its disposal has become an environmental global problem (Ijaz and Dai, 2020). Some researchers have been studying this waste as an expansive soil stabiliser for the last decade (Alazigha et al., 2018, Orlandi et al., 2019, Fernandez et al., 2021). Significant advancements have been made in analysing the mechanical and hydraulic behavior of CRclay with varying additions of calcium lignosulfonate (CLS) ranging from 3% to 10%, along with the microstructural changes induced (Orlandi et al., 2019, Fernandez et al., 2021).

This article studies the influence of different curing ages (1 day, 1 month, 3 and 6 months and 1 year) of a Patagonian soil (CRclay) mixed with 10%CLS. The efficacy of the 10% CLS added to CRclay was studied considering the changes in microstructure and the hydraulic and mechanical behaviour. Using 10% CLS was shown to be effective in reducing the swelling potential of CRclay (Orlandi et al., 2019).

2 MATERIALS: CRCLAY - CLS

CRclay is Patagonian expansive soil located in Comodoro Rivadavia (Argentina) classified as MH by Unified Soil Classification System (USCS). Table 1 shows the CRclay properties (Manzanal et al., 2019). CRclay is a soil with a high swelling potential (LL=74.5%, PI= 35.3%, Contraction limit = 24.2%), and high surface area (563 m^2/g). The active clay mineral smectite (Sm), known for its swelling behaviour upon hydration was identified within the XRD diffractogram of CRclay (Fernandez et al., 2021). Additionally, impurities such as calcium (Ca^{2+}) and feldspar (F) were also observed.

Table 2. CRclay properties.

Properties	CRclay
% clay	76.64
% silt	21.4
% sand	1.96
pH 1:2,5	8:51
EC [dS/m] (electrical conductivity)	10.81
Organic matter content [%]	0.6
Carbon content [%]	0.3
Available phosphorus [mg/kg]	11
SO^{4-} [mg/kg]	3608
Ca [meq/100g]	16.0
Mg [meq/100g]	1.5
K [meq/100g]	7.8
Na [meq/100g]	28.5
CEC (cation exchange capacity)	55
XRD mineralogical identification	Mostly smectite

CLS was a commercial biopolymer which was provided by Norlig® which has a degradation temperature of 300ºC, a glass transition temperature, Tg = 80ºC, and 10.33% ash content (Orlandi et al., 2021).

3 METHODS

Utilizing their prior expertise in determining optimal CLS content (Orlandi et al., 2019; Fernandez et al., 2020), this study explores the influence of curing time on CRclay samples and CRclay-10%. All samples were uniformly prepared by static compaction at a dry unit weight of 13 kN/m^3. The natural water content of 18% was maintained for samples of various tests, including free swelling, uniaxial compression, mercury intrusion porosimetry (MIP), and scanning electron microscopy (SEM). Variable Charge Permeameter (VCP) tests were conducted on samples compacted at a moisture content of 33%. Samples were sealed with film to prevent moisture fluctuations and stored under controlled temperature and humidity until testing. Different ages of testing were adopted for each type of test: free swelling tests were carried out on samples of 1 day and 9 months and uniaxial compressive tests were performed over samples with ages of 1 day, 1 month, 3 months, 6 months, 9 months, and 1-year. The microstructure (MIP and SEM) was analysed for samples aged at 1 day and 1 year. Water retention (WP4: dew-point potentiometer), and permeability tests were conducted on samples aged 1 day.

4 RESULTS AND DISCUSSION

The water retention capacity of the unsaturated compacted samples of CRclay and CRclay+10%CLS were obtained using dew-point potentiometer (WP4) as is illustrated in Figure 1. When comparing samples with equal degrees of saturation in terms of water content and dry unit weight ($13kN/m^3$), it was observed that the addition of CLS increases suction in the sample. This trend is more pronounced in samples with saturation degrees higher than 50% (similar to the molding moisture content of 18%). Comparable findings were also reported using other techniques (Fernandez et al., 2021, Orlandi, 2021). The evolution of unsaturated compacted samples at the water content of 18% was evaluated with the VCP test and free swelling test.

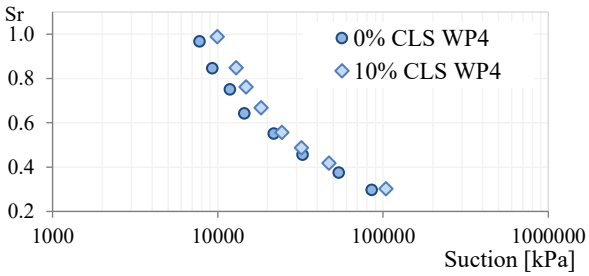

Figure 1. Suction obtained by using WP4 for 0%CLS and 10%CLS.

The VCP test demonstrates that the addition 10% CLS increases the permeability compared to CRclay, as illustrated in Figure 1. This is attributed to the change in inter-aggregate porosity caused by CLS

(Fernandez et al., 2021). Moreover, we note a gradual decrease in VCP permeability over two months of testing due to specimen expansion at constant volume, and the sequential saturation processes of inter-pore, intra-pore, and eventual development of the diffuse double layer (Delage, 2007).

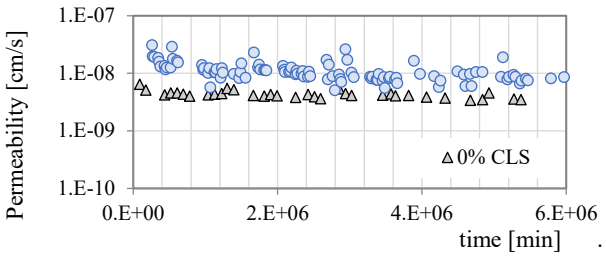

Figure 1. Permeability evolution for 0%CLS and 10%CLS.

The volumetric behaviour of both CRclay and CRclay-10%CLS samples upon wetting is shown in Figure 2. Results reveal a substantial reduction in free swelling for specimens with CLS, with a decrease of 84% observed for samples tested one day after moulding and 83% for those tested after 9 months, compared to the volumetric behaviour of CRclay.

The time evolution of free swelling depicted in Figure 2 displays three clear periods. The initial swelling is attributed to the saturation of interaggregate porosity, followed by primary swelling associated with the ongoing saturation of intra-aggregate porosity, culminating in secondary swelling once the double-layer expansion is fully saturated.

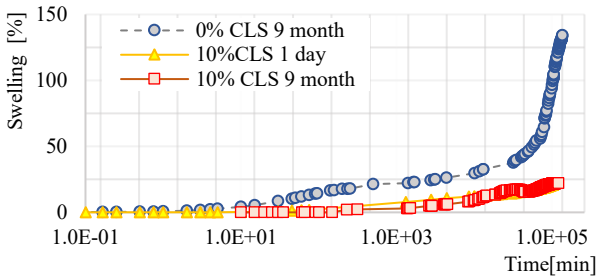

Figure 2. Free swelling for 0% CLS and 10% CLS, at 1 day and 9 months aged samples.

The unconfined compressive stress-strain behaviour of CRclay (Figure 3a) and CRclay-10%CLS (Figure 3b) illustrates the impact of varying sample ages. Overall, the results indicate a slight increase in UCS for samples with the addition of 10% CLS, accompanied by enhanced ductility. The additive does not modify the mechanical behaviour as a function of time but follows the trend shown by the compacted soil.

The variation of stress-strain curves with the age of the sample could be related to gradual water redistribution after the sample compaction stage is finalized. This migration within a sample induces changes in the distribution of interaggregate porosity and porosity with time (Figure 4), which are contingent upon the initial moisture content and dry density of the mixtures. This redistribution may account for the time-dependent fluctuations observed in permeability and simple compressive strength (Delage, 2007, Fernandez et al., 2021).

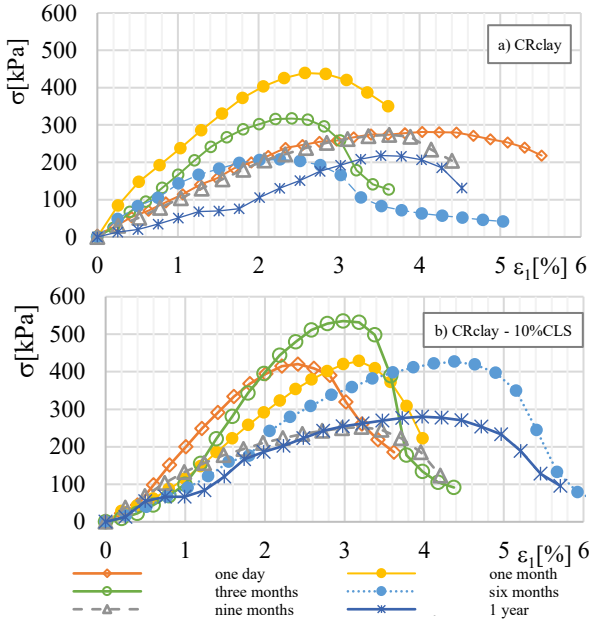

Figure 3. Unconfined Compressive test for nine different curing ages for a) CRclay and b) CRclay-10%CLS samples.

The physicochemical interaction mechanisms between CRclay and CLS are illustrate in Figure 4 (right), revealing the emergence of new lamellar and elongated linear structures within the soil matrix. However, due to the inability to analyse the composition of these structures, assessing their impact on the overall behaviour is not feasible. Furthermore, the presence of spores, known for their natural ability to polymerize lignins, may generate effects which were not evaluated in this study (Orlandi, 2021).

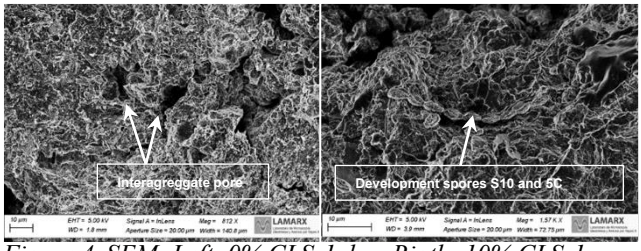

Figure 4. SEM: Left: 0% CLS-1 day. Rigth: 10% CLS-1 year SEM.

Upon further analysis of the influence of sample age on pore distribution using MIP for CRclay-10% CLS samples, we observe significant in the bimodal

distribution between samples aged 1 day and 1 year, with a notable variation in intrapore density increasing with age. Interporosity shows an increase in total pore volume but a decrease in characteristic pore diameter.

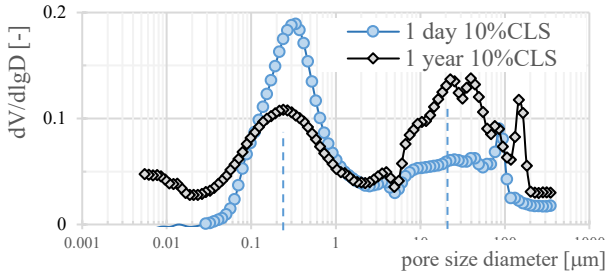

Figure 5. MIP: *Pore size diameter distribution* for CRclay+ *10% CLS* sample.

5 CONCLUSION

The stabilization mechanisms formed between CRclay, and calcium lignosulphonate (CLS) induce mechanical, hydraulic, and microstructural changes in the soil. The incorporation of 10% CLS yields positive effects on soil behaviour, and these changes persist over time. The additive does not alter the mechanical behaviour over time; rather, it mirrors the trend exhibited by the compacted CRclay. This phenomenon could be attributed to the redistribution of water within the soil pores in an unsaturated state.

It can be highlighted:

- The impact on water retention capacity is more pronounced in samples with water content exceeding the natural moisture for the dry unit weights studied.
- The saturation process of the samples in constant volume tests (VCP) and volume change upon wetting confirms the three stages studied by other authors: The initial swelling is attributed to the saturation of interaggregate porosity, followed by primary swelling associated with the ongoing saturation of intra-aggregate porosity, culminating in secondary swelling once the double-layer expansion is fully saturated.
- The effect of time on both CRclay and CRclay+10% CLS samples follows a similar trend in the unconfined compression tests. Variations in porosity observed in SEM and MIP analyses confirm a time-dependent effect in both the CRclay and CLS mixture, signifying an increase in interporosity in the CLS samples, indicating a tendency to disrupt clay aggregation.

The mechanical results should be validated through triaxial tests to verify the contraction-dilatant behaviour of the CLS samples.

REFERENCES

Alazigha, D. P., Indraratna, B. J., Vinod, S. and Heitor, A. (2018). Mechanisms of stabilization of expansive soil with lignosulfonate admixture. Transportation Geotechnics, 14, 81–92. https://doi.org/10.1016/j.trgeo.2017.11.001.

Attom M. F. and Al-Sharif M. M. (1998). Soil stabilization with burned olive waste. Applied Clay Science, 13(3), 219–230.

Bekhiti, M., Trouzine, H., Rabehi,. M. (2019). Influence of waste tire rubber fibers on swelling behavior, uniaxial compressive test and ductility of cement stabilized bentonite clay soil. Const. and Building Materials, 208, 304–313.

Brooks, R. M. (2009). Soil stabilization with fly-ash and rice husk ash. International Journal of Research and Reviews in Applied Sciences.

Delage, P. (2007) Microstructure Features in the Behaviour of Engineered Barriers for Nuclear Waste Disposal. In: Schanz T. (eds) Experimental Unsaturated Soil Mechanics. Springer Proceedings in Physics, vol 112. https://doi.org/10.1007/3-540-69873-6_2.

Fernández, M., Orlandi, S., Codevilla, M., Piqué, T., Manzanal, D. (2021) Performance of calcium lignosulfonate as a stabiliser of highly expansive clay, Transp. Geotechnics, Vol. 27, https://doi.org/10.1016/j.trgeo.2020.100469.

Ijaz, N. and Dai, F. (2020). Paper and wood industry waste as a sustainable solution for environmental vulnerabilities of expansive soil: A novel approach. Journal of Environmental Management, 262.

Manzanal, D., Orlandi, S., Miranda, E., Robinson, M., Barría, J. C. (2019). Swell characterization of expansive clays from Comodoro Rivadavia city. PANAM XVII. Cancún. México 2019. Doi: 10.3233/STAL190107.

Orlandi, S., Manzanal, D. Miranda, E., Robinson, M. (2019). Use of lignin as stabilizer in expansive soils. PANAM XVII. Cancún. México 2019. Doi:10.3233/STAL190295.2291-2298.

Orlandi, S., et al. (2021). Additives based on vegetable biomass to improve the stabilization of expansive clay Soil. Environmental Geotechnics, https://doi.org/10.1680/jenge.20.00066.

Orlandi, S. (2021). Use of calcium lignosulphonate as an expansive soil stabilizer. Doctoral Thesis: Universidad Nacional de la Patagonia San Juan Bosco. (In Spanish)

Pourakbar, S., Asadi, A., Huat, B. B. K., Fasihnikoutalab, M. H. (2015). Stabilization of clayey soil using ultrafine palm oil fuel ash (POFA) and cement. Transp. Geotech, 3, 24–35.

Yilmaz, I., Civelekoglu, B. (2009). Gypsum: An additive for stabilization of swelling clay soils. App. Clay Sci. 44, 166–172.