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Polymer Enhanced Clay-Sand Mixture

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Abstract. Using polymers to modify the properties of soils is an area of interest for designing landfills. Landfill closures requires conditions of long-term mechanical and hydraulic stability. This work studies the micro and macroscopic interaction of a fine soil (CRclay), a uniform sand (Sand) and an anionic polyacrylamide (APAM). APAM is a superabsorbent polymer that swells by two orders of magnitude when immersed in water. This paper emphasizes on understanding the interaction between different mixtures of APAM, Clay and Sand analyzing the physical properties, soil-water retention, microstructure by means of Mercury Intrusion Porosimetry (MIP), and volumetric and mechanical behaviour. Results shows an increase on swelling potential and swelling pressure for different Sand-CRclay-APAM mixtures. APAM reduce the microporosity and increase the water retention capacity of the mixtures. For the mechanical behavior, mixtures with APAM present higher unconfined compressive strength and more ductile behavior than mixtures without it (Sand-CRclay). The low hydraulic conductivity of the mixtures with APAM make it viable for its use as part of landfill cover installations.

Keywords. Landfill cover, polyacrylamide, sand-clay mixtures, microstructure, mechanical behavior, hydraulic conductivity.

1. Introduction

Landfill closures often require different set of materials and properties for cover installations than bottom liner installations. In particular; landfill cover design usually presents greater concerns regarding long-term slope stability and admissible differential settlement. Therefore, materials involved in cover installations should work as a hydraulic barrier for rain infiltrations with the required mechanical strength to generate stable slopes.

In the case of compacted soil layers used as part of a landfill cover, clay-sand mixtures could provide greater friction angles while maintaining low hydraulic conductivity. Both hydraulic and mechanical properties can be improved with additions of inorganic additives as lime, cement or fly ash [1-3]. Another option is the use of polymeric additives ([4-7]).

In this work, the influence anionic polyacrylamide (APAM) in the volumetric, hydraulic and mechanical properties of sand-clay mixtures is studied to evaluate the potential use as a cover in landfill installations.

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2. Materials

2.1. Sand, Clay and polyacrylamide

Materials include commercial river sand (Sand), natural clayey soil (CRclay) and anionic polyacrylamide (APAM). CRclay is a high plasticity clay from Comodoro Rivadavia (45°51'56.06"S - 67°28'56.05"W), Chubut province, Argentina. Table 1 & 2 shows main physical properties of Clay and commercial river sand. These results were previously presented by Marti et al. [6], Orlandi et al. [8] and Fernandez et al. [7].

Table 1. Physical properties of the CRclay [6].

USCS	#200 (%)	LL (%)	PL (%)	PI (%)	SL (%)	Clay (%)	$\gamma_{dmáx}$ (kN/m^3)	$\omega_{ópt}$ (%)	S_s (m^2/gr)
MH	96	60	39	21	17.5	90	13	31	220

Table 2. Physical properties of the commercial river sand soil [6].

USCS	#200 (%)	C_u	C_c	D_{50} (mm)	G_s	ϕ_c (°)
SP	5	2.5	1.3	0.38	2.67	30.5

The polymer used is a hydrophilic synthetic superabsorbent polymer called anionic polyacrylamide (APAM), commercially trended as Paipafloc F-AN by Química Paipe S.R.L, Argentina. This APAM has very high molecular weight (10-20 mg.mol^{-1}) and high anionic charge density. Per gram of polymer it can absorb 270 g of water.

2.2. Clay - polyacrylamide mixture

The interaction between CRclay and APAM was firstly studied through the Atterberg Consistency Limits (Atterberg limits, LL, PL) and plasticity index (PI): Both the liquid limit (LL) and plastic limit (PL) of the CRclay and two percentages of APAM (1.5%, 2.5%) was analyzed with both fall cone [11] and ASTM 4318 specification (Table 3). Determination of LL on CRclay-APAM with percentage higher than 1.5% with Casagrande method is not reliable due to two halves of a clay-APAM mixture cake become difficult to flow together for a distance of 12.7 mm along the bottom of a groove. Both LL and PL and PI showed an increase with the increase of 1.5 and 2.5% APAM. This is explained by high water absorption capacity of APAM [8]. The addition of water to the mixture created a continuous network of transparent wires throughout the mixture due to the hydration of the polymer, as shown on Figure 3.

In addition, LL and PL on CRclay was measured with brine (concentration C=2M) and kerosene, instead of distilled water. Results shows a decrease on consistency limits. These results indicate that pore fluid chemistry is relevant for interparticle interactions [12]. The studies of effect on pore fluid chemistry in the mixtures are ongoing.

3. Testing program

The experimental program consists on evaluate the volumetric, hydraulic and mechanical properties of the Sand-CRclay-APAM. The swelling properties sand-CRclay-APAM for compacted samples to 95% of maximum dry densities of Proctor method were evaluated on the odometric apparatus. The specimens were flooded and free swell was determined under a load of 2 kPa until equilibrium. Then the load is increased until the initial void ratio is reached to determine the swelling pressure. The effect of the polymer in the strength of the material were made by Unconfined compressive tests (ASTM D2166). Three samples for each mixture with moisture content at optimum, dry of optimum and wet of optimum were tested under deformation rate of 1 mm / min. The matric suction of the unsaturated sand-CRclay-APAM composites, compacted at 95 % of the maximum dry density, was measured by the contact filter paper method. The filter paper method used in this study were that proposed by ASTM D 5298. All samples required 15 days to reach equilibrium between the Whatman 42 filter paper and the soil-polymer mixtures. Knowing the calibration curve and gravimetric water content of Whatman 42 filter paper after equilibrium, matric and total suction values were obtained. The hydraulic conductivity in saturated conditions was also measured (ASTM D5084).

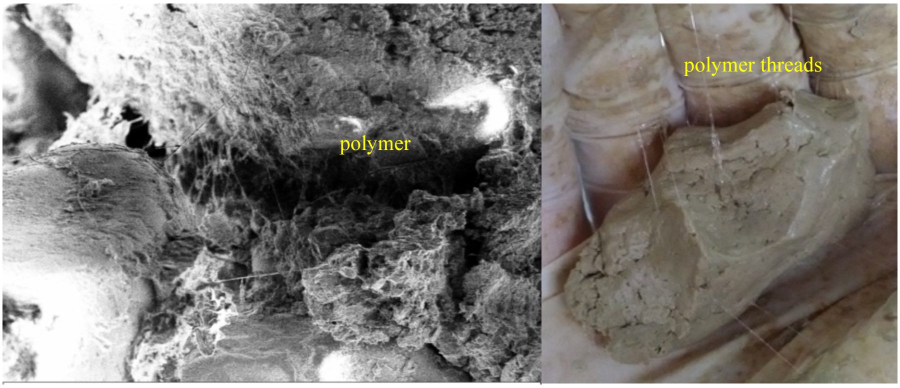

Figure 1. a) Microscopic inspection on soil- polymer mixture by SEM. b) Macroscopic inspection on Clay-polymer mixture after changing its moisture content.

Table 3. Atterberg limits of the CRclay-APAM by fall cone method.

Mixture & fluid	LL (%)	PL (%)	PI (%)
CR clay + 1.5%APAM (d. water)	52	35	17
CR clay + 2.5%APAM (d. water)	47	34	13
CR clay (brine C=2M)	52	35	17
CR clay (kerosene)	47	34	13
CR clay + 1.5%APAM (brine C=2M)	64	43	21
CR clay + 2.5%APAM (brine C=2M)	68	55	13

3.1. Samples preparation

The sand-CRclay-APAM mixture were dynamically compacted according to the standard Proctor test (ASTM D698) at fixed 95% of maximum dry density and three moisture content: the optimum (optimum), the dry of optimum (dry side) and the wet of optimum (wet side).

The maximum dry density of the mixture (sand-CRclay-APAM) was obtained by changing the percentage by weight of oven dried CR-clay and APAM from a series of standard Proctor tests (Figure 2). This was established in Marti et al. [6] who obtained 85.0% sand + 15.0% CRClay-APAM mixture. Distilled water was used for all tests. Mixtures were cured on a moisture room during 12 hours for all the performed tests.

Standard Proctor test of the mixture with and without APAM is presented in Figure 2. It shows a slight variation on the maximum dry unit weight and optimum water content [9].

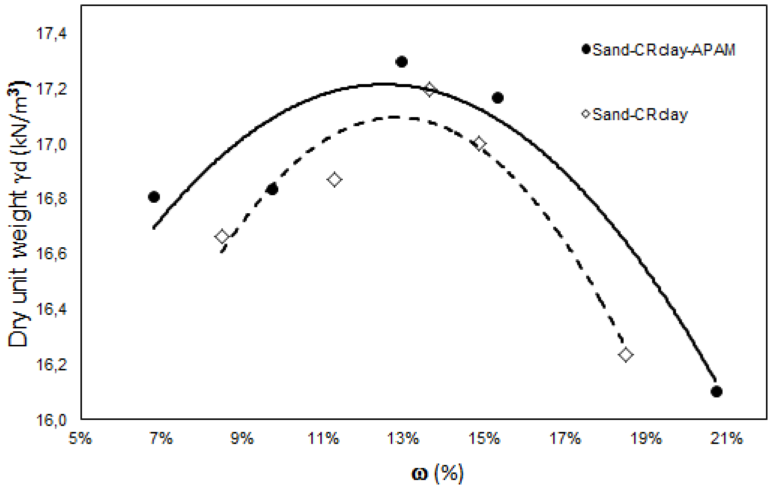

Figure 2. Standard Proctor test on sand-CRclay and sand-CRclay-APAM.

3.2. Volumetric behaviour

The volumetric behavior of the Sand-CRclay-APAM mixture with three different APAM percentages (1.5%, 2.5% and 3.5%) were studied with a series of oedometric test. Table 4 shows results of free swell-swelling pressure test (ASTM D 4546) in mixtures of sand-CRclay-APAM for compacted at 95% of the maximum dry density on dry, optimum and wet side of compaction curve.

Swelling pressure in the sand-CRclay increase with addition of APAM from 0 kPa to 65kPa. APAM addition caused an increment on free swell due to its high water absorption capacity. Compression (Cc) and recompression (Cr) index did not present significant changes and maintained values close to 0.3-0.4 and 0.07-0.1 respectively for the different mixtures studied.

Table 4. Free-swelling and swelling pressure experimental results for CRclay, CRclay-APAM and sand-CRclay-APAM mixtures.

Sample	**γ_d (kN/m^3)**	**S_{r0} (%)**	**$\Delta H/H_0$ (%)**	**σ_{sp} (kPa)**	**C_c (-)**	**C_s (-)**
Sand-CRclay	16,97	56,7	<0,02	< 10	0,27	0,09
Sand-CRclay -APAM 1.5%	17,61	40,1	0.182			
	16,04	56,4	0.158	< 10	0,33	0,10
	16,41	75,5	0.158			
Sand-CRclay -APAM 2.5%	16,98	56,5	0.579	65	0,40	0,09
	15,93	57,4	0.505	< 20	0,36	0,10
	16,40	73,6	0.368	< 10	0,30	0,10
Sand-CRclay -APAM 3.5%	16,95	57,3	0,726	45	0,39	0,07

3.3. Unconfined compressive test

Unconfined compressive tests (UCS) were done to evaluate the effect of the polymer in changes on mechanical behavior on sand-CRclay-APAM mixtures. Four mixtures with different APAM percentages, with moisture content at optimum, dry of optimum and wet of optimum were tested under monotonic load and deformation rate of 1.0 mm/min. The results are shown in Table 5. Figure 3 shows UCS curves on group of samples sand-CRclay-APAM on dry and wet side.

The addition of APAM increased the compressive strength, the ductility and tenacity of sand-CRclay-APAM mixtures. Samples on dry side showed greater strength in accordance with major matric suctions values.

Table 5. Unconfined compression strength on sand-CRclay-APAM mixtures.

Sample	side	ω_0 (%)	ε_f (%)	E_{sec} (MPa)	q_{max} (kPa)
Sand-CRclay	dry	9.28	2.14	1.68	15.7
	opt.	13.11	0.86	1.94	8.1
	wet	16.96	2.59	0.57	6.5
Sand-CRclay-/APAM 1.5%	dry	9.13	1.54	1.77	16.9
	opt.	12.90	1.89	0.81	7.7
	wet	16.15	2.33	0.76	7.7
Sand- CRclay-APAM 2.5%	dry	8.86	1.94	1.89	21.9
	opt.	13.28	2.47	1.37	17.4
	wet	16.68	1.89	1.06	12.5
Sand- CRclay-APAM 3.5%	dry	9.57	2.23	1.93	26.0
	opt.	13.23	2.48	1.47	20.5
	wet	17.52	1.89	1.67	20.4

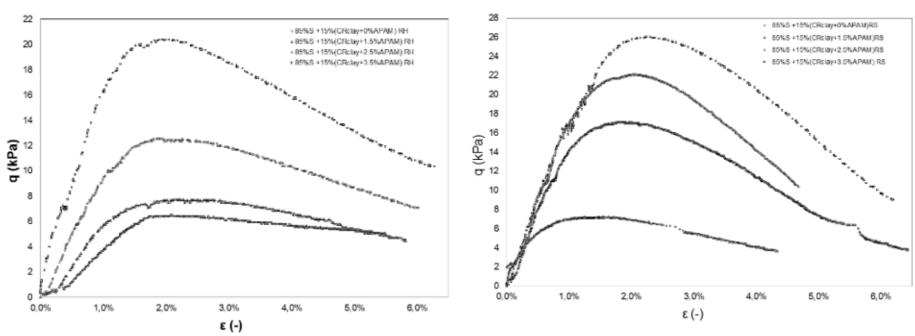

Figure 3. UCS curves for dry (RS) and wet (RH) side on sand-CRclay-polymer mixture. Mixtures vary the percentage of APAM from 0% to 3,5%.

3.4. Hydraulic characterization

The saturated hydraulic conductivity was also measured by falling head method. The results show slight variation with the addition the APAM polymer in both CRclay and sand-CRclay mixtures. The hydraulic conductivity for CRclay is $k_{sat} = 2.0.10^{-10}$ m/s and for CRclay-APAM mixtures it increases to k_{sat} = 1.5.10^{-11} m/s. In the case of sand-CRclay and sand-CRclay- 1,5%APAM mixtures, the hydraulic conductivity is ksat = 9.2 .10^{-8} m/s and k_{sat} = 7.3 .10^{-8} m/s, respectively. APAM addition reduced the hydraulic conductivity of the natural CRclay. However, the reduction is not significant in the case of sand-CRclay [6]. These results in the sand-CRclay composite can be explained by Mercury Intrusion Porosimetry (MIP) tests (ASTM D4404. In Figure 4 it is observed that the variation of the total pores changes slightly due to the increase of APAM for a wet of optimum compacted sample of sand-CRclay and sand-CRclay-APAM 1.5%. Confirming that APAM has an effect on the strength of soil skeleton forming a network of wires as we observed in the previous section, but does not significantly effect on reducing the pores volume and hydraulic conductivity in sand-CRclay mixtures.

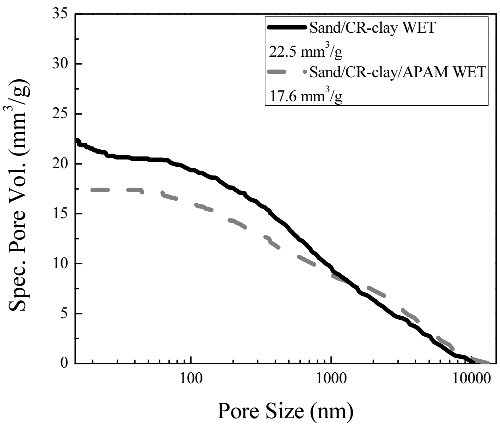

Figure 4. Pore size distribution of sand-CRclay & sand-CRclay-APAM with different moisture.

The soil water retention curves (SWRC) of the unsaturated CRclay-APAM and sand-CRclay-APAM mixture samples, compacted at 95% of the maximum dry density, was carried out by means of the contact filter paper method ASTM D 5298 [13] [14]. All samples required more than 7 days to reach equilibrium between the filter paper and the soil-polymer mixtures. The experimental results of suction and degree of saturation for sand-CRclay and sand-CRclay-APAM mixtures with three percentages of APAM (1.5%, 2.5% and 3.5%) are presented in Figure 5. Experimental results were fitted with the van Genuchten equation (vGF) [15]:

$$S_e = \left(1 + \left(\frac{s}{s_{ae}}\right)^{\frac{1}{1-\lambda}}\right)^{-\lambda} \quad (1)$$

where s_{ae} is air entry value, S_e is effective saturation degree and λ is a parameter of pore size distribution index. From Figure 5, the APAM addition displaced vGF´s to the right. From Figure 5, vGF slopes tend to increase for sand mixture, suggesting an increase in the rate of the saturation degree changes with respect to matric suction changes. All Figures showed an increase on s_{ae} with an increase of APAM. On sand-CRclay-APAM mixtures, pore size distribution index was reduced with the increase of APAM. Basic parameters of vGF are presented on Table 6.

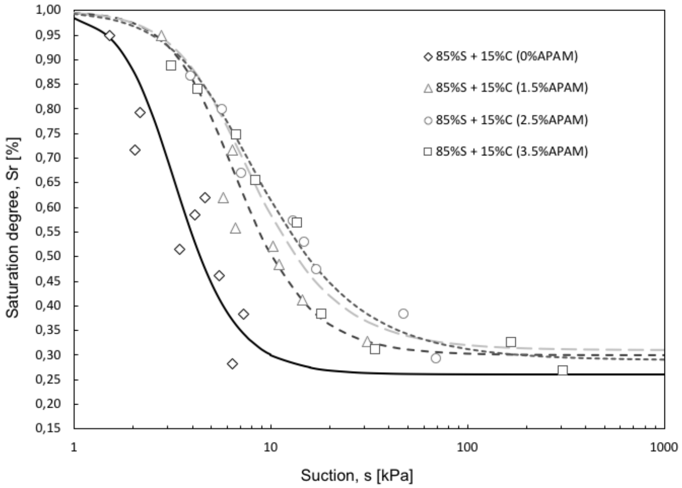

Figure 5. Experimental values of suction and saturation degree for different polymer content in sand – CRclay mixtures (dot) and calibration of van Genutchen equation (lines).

Table 6. van Genuchten model parameters for soil-polymer mixtures.

Mixture	λ (-)	s_{ae} (kPa)	S_{res} (%)
Sand-CRclay	0.70	3.5	23
Sand-CRclay-APAM 1.5%	0.65	5.5	25
Sand-CRclay-APAM 2.5%	0.60	6.0	31
Sand-CRclay-APAM 3.5%	0.55	6.0	29

4. Final remarks

The present work studied a mixtures constituted by natural clay of marine origin (CRclay), a river sand (Sand) and anionic polyacrylamide (APAM) for improving the hydro-mechanical behavior of an upper cover for municipal solid waste.

The addition of polymer increases the shear resistance and ductility of the mixtures. APAM addition changes significantly the air entry value of the water retention curve. Thus, the water retention is much higher with the addition of APAM, and the desaturation will be very slow. This parameter is of great importance for permeability of unsaturated soils. From MIP tests, decrease of the pores volume of the system with APAM is observed. It is also addressed from the water retention curve, since λ (pore distribution parameter from van Genutchen model) slightly decreased with APAM addition.

Further investigations on unsaturated hydraulic permeability behavior and measurements on the shear strength properties are being done in order to fully characterize the system.

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