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Potential reuse of drinking water treatment sludge mixed with additives in landfills covers or other low solicitation applications

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ABSTRACT

Reusing drinking water treatment sludge (WTS) as cover of sanitary landfills can introduce it into the circular economy and partially replace natural soils. However, even after dewatering, WTS water content is very high, and undrained shear strength (s_u) is very low. The incorporation of additives, such as lime (L) or rock powder (RP), can be an alternative to stabilize WTS. This paper presents the s_u of WTS-additive mixtures at different additive contents and investigates the potential reuse of WTS mixed with L or RP as covers of sanitary landfills based on the acceptance criteria for earthworks. Also, it discusses the influence of additive content, curing time, and mixing process on the s_u obtained by vane, fall-cone, and unconfined compression (UC) tests. Results indicated that s_u values obtained for RP are lower than for L addition. Curing time increases s_u; however, s_u does not increase significantly for times longer than 28 days. Depending on the mixing process, two different textures are created: pasty and granular, which are more important than curing time for s_u increase. Generally, granular textures present higher s_u than pasty textures. The acceptance criteria of 10 and 20 kPa were reached for L content of 230% and 300% and RP content of 950% and 1200% (by dry mass basis of WTS). These high values suggest that WTS-L at L content higher than 230% and WTS-RP at RP content higher than 950% can be used in landfill covers provided that a sustainability analysis indicates the carbon footprint decrease.

Keywords: water treatment sludge, waste, reuse, undrained shear strength, cover, sanitary landfills.

1 INTRODUCTION

Reuse of WTS as a construction material for geotechnical works can be a strategy to reduce the consumption of natural soils and to enhance adequate destination for large amounts of WTS. Main geotechnical applications are: landfill liner (Raghu et al., 1987; Rodriguez et al., 2011; Roque & Carvalho, 2006; Silva & Hemsi, 2018), daily cover in sanitary landfills (Castilhos Junior et al., 2012; Kamon et al., 2000; Montalvan, 2021; Rodriguez et al., 2011; Roque & Carvalho, 2006; Marchiori et al., 2022), embankments (Montalvan, 2021; Wang et al., 1992), backfills (Fortes et al., 2006), and road pavement structures (Delgado, 2016). Results suggest that WTS has potential as geomaterial, insofar as treated to abate its fluid-like behavior. When air-dried or oven-dried, WTS turns into a granular material (Basim, 1999; Hsieh & Raghu, 1997; Rodriguez et al., 2011; Watanabe et al., 2011; Xia, 1994), due to the high agglomeration of particles during the loss of water content. At this solid state, WTS may be used as aggregate for civil construction (Costa, 2011; Hoppen et al., 2005; Hoppen et al., 2005; Mañosa et al., 2021; Roque & Carvalho, 2006; Souza, 2010). Drying is time-consuming and expensive. Hence, WTS stabilized with additives can be a promising alternative as a geotechnical material.

Some researches studied the geotechnical behavior of WTS stabilized with additives (Nawagamuwa & Wijesooriya, 2018; Silva, 2017; Wang et al., 1991), WTS-soil mixtures (Ferreira, 2020; Montalvan et al., 2019; Montalvan, 2016; Rodriguez et al., 2011), and WTS-soil-additives mixtures (Lucena, 2012); however, much more investigation is needed to use the WTS stabilized with additives in geotechnical applications. Wang et al. (1991) studied the influence of three additives (lime, fly ash, and soil) at 60% (dry weight of sludge) of additive content on the geotechnical behavior of the Chesapeake WTS: compressibility and shear strength of WTS were improved but not at the point of being used as an embankment material. Silva (2017) tried to determine the lowest additive content to turn WTS into a workable material directly after mixing (i.e., without curing or drying), concluding that a minimum lime content of 68% (dry basis of WTS) is necessary to reach s_u of 10 kPa, which is the limit value for easy

handling sludges in Germany and the Netherlands. Nawagamuwa and Wijesooriya (2018), based on maximum dry density, determined that 30% of fly ash was the optimum additive content to stabilize the Horana WTS from Sri Lanka, and observed that CBR (California Bearing Ratio) of WTS enhanced from 5% to 20% after stabilization with 30% of fly ash and curing time of 7 days; however, the specifications for road construction (CBR>30%) still were not met. Lucena (2012) determined that the addition of 20% soil and 1% asphaltic emulsion to WTS presented the best performance in terms of mechanical behavior and metals leachability, meeting the specifications for road bases and subbases. Montalvan et al. (2019) investigated the geotechnical behavior of mixtures of Cubatão WTS with two lateritic soils largely employed in earthworks, Botucatu sand and Campinas clay, and observed that, respectively, 7.5-10% and 11-15% of WTS can be inserted in the soils without impairing their good geotechnical properties. In some cases, WTS addition can improve the properties of the soils (Marchiori et al., 2022).

Cement, lime, fly-ash, steel slag, and other additives have been used to improve or stabilize soils. Stabilization with lime is a well-known procedure to enhance the geotechnical behavior of clayey soils (Boscov, 1990; Consoli et al., 2012; 2009; Thomé, 1994). Literature points out that lime stabilization occurs due to fast reactions, which are responsible for the improvement of plasticity and workability, and slow reactions, which are responsible for cementing soil particles and increasing soil strength (Boscov, 1990; Thomé, 1994). Furthermore, an increase in permeability and a decrease in plasticity, swelling, and shrinkage were observed in clayey soils stabilized by lime (Loch, 2013). Lime stabilization is expected to increase WTS strength and decrease permeability. Also, WTS stabilized by L could reduce the fugitive CO_2 emissions of landfills due to the high carbonatation potential of L, as occurs to basic oxygen furnace (BOF) slags that are rich in L and portlandite (Chetri et al. 2020; Reddy et al., 2019b). However, since the production of L releases CO_2, a sustainability assessment (Reddy et al., 2019a) is necessary to conclude whether the alternative would really be beneficial to decrease the carbon footprint of a sanitary landfill. Another concern is the occurrence of carbonatation of L, that would reduce the formation of cementing secondary aluminosilicates; in soil-L mixtures, these are generated by the reaction of released elements from mineral grains with calcium derived from L, and are responsible for the strength increase along time (Boscov, 1990). However, even the products of carbonatation may improve the very low resistance of WTS at its natural state. RP, a waste to be destined, could also be a potential material to stabilize WTS because of its high friction angle and uniform particle size distribution that may form, together with WTS, a more resistant and permeable structure. Therefore, the stabilization of WTS by L or RP could produce a suitable material in terms of resistance, substituting natural resources as cover of sanitary landfills and introducing WTS into the circular economy.

This paper investigates the potential reuse of WTS mixed with additives (L or RP) as covers in sanitary landfills and other geotechnical applications based on the acceptance criteria from the literature in terms of s_u. Also, it discusses the influence of additive content, curing time and mixing process on the s_u obtained by miniature laboratory vane, fall-cone, and UC tests. The main contribution is the presentation of extensive experimental results and data analysis, which can be useful for reusing drinking water sludge in the field. The hydraulic conductivity (k) and the leachability of metals from the investigated mixtures must meet requirements for the intended applications, but these subjects are focused in another paper and are briefly discussed here.

2 MATERIALS AND METHODS

2.1 Materials and preparation of samples

Cubatão WTS is generated by washing decanters and filters at conventional Water Treatment Plant (WTP), Sao Paulo, Brazil, which uses ferric chloride as coagulant. Samples of dewatered WTS were collected directly from the centrifuges (Tsugawa et al., 2019). A calcium-hydrated lime (Tradical CH-I), produced by Mineraçao Belocal – Lhoist Brazil, Sao Jose da Lapa, Minas Gerais, was investigated. The RP, donated by a mining company next to the WTP, is a byproduct of the production of gravel from milled granite-gneiss rock for civil construction, an inert material at sand particle size. Representative samples materials were obtained (Tsugawa, 2022). WTS is inorganic, composed of quartz, goethite, muscovite, kaolinite and amorphous; it has pH 7, 70% of clay particles, specific gravity of grains (G_s) of 2.9-3.2, plasticity index (PI) of 82-158%, and liquid limit (w_L) of 150-240%. Also, WTS is classified as non-hazardous waste according to TCLP limits (Tsugawa, 2022). L is mostly composed of portlandite and calcite, it has pH 12.2-12.7, G_s of 2.4, PI of 7, and w_L of 44. RP is composed of quartz, feldspar,

phlogopite, amphibole, and kaolinite, it has pH 9.4, G_s of 2.7, and it is non-plastic. For more detail see Boscov et al. (2021), Pereira et al. (2018), Tsugawa (2022), Tsugawa et al. (2022, 2017, 2019a, 2019b). WTS at as-collected water content (w=240%, after dewatering at WTP) and additives at hygroscopic water content (w=0.4%) were prepared by adding the target proportion to the mixing bowl. Mixtures were mixed by a planetary mixer (Hobart type) and a flat beater for 5 minutes, creating a sample with a granular texture (g), or until the complete homogenization, creating a sample with a pasty texture (p). L contents of 5, 10, 25, 50, 75, 100, 150, 350, 400, 450, and 500%, and RP contents of 5, 50, 150, 500, 700, 800, 1000, 1350, and 1700% (by dry mass basis of WTS) were investigated. To assess the influence of curing time on s_u of mixtures with L, samples at 350 to 500% L content were sealed with PVC film and stored in a humid environmental at a desiccator glass container with water on the bottom for 7, 28, and 56-days. All samples were prepared and tested at least in triplicates.

2.2 Laboratory miniature vane tests and fall-cone tests

Vane tests were carried out until a rotation angle of 90° at a constant rate of 50°/min, using the Wykeham Farrance Engineering Ltd. apparatus, with the most flexible spring (30kPa), and a 12.7 per 12.7-mm vane blade. s_u and s_{ur} (residual undrained shear strength) were obtained. Fall-cone tests was performed using 80g cone with 30° apex angle and smooth surface, and the s_u was calculated using the equation presented by Hansbo (1957). w of a samples was determined by oven drying at 105°C for 12 hours. All test procedure was detail described in Tsugawa et al. (2022), which presented results of vane and cone tests performed for WTS-L mixtures at 5 to 150% L content. The experimental value of Hansbo's cone factor (K) of 1.27, determined from calibration of fall-cone with vane results, was used to determine s_u for all fall-cone tests. Samples were tested immediately after preparations, i.e., without curing time (0 days). All samples were supposed to have a pasty texture.

2.3 Unconfined compression tests

UC tests were carried out following ASDTM-D2166-16 at 1.0 %/min strain rate with triplicate specimens of 50 mm diameter and 50 mm height (compacted by mini-MCV equipment) for each mixture. Since the L/D ratio of the specimens was 1, a correction factor of 0.69 was applied to the maximum axial stress in order to obtain the equivalent axial stress for L/D = 2, based on the correction equation suggested by Güneyli & Rüşen (2016). Samples were tested immediately after preparations, i.e., without curing time (0 days) as formerly presented by Boscov et al. (2021). Samples with pasty and granular textures and for curing time of 7-days (7d), 28-days (28d), and 56-days (56d) were investigated. All data were used for a more detailed and comprehensive evaluation of acceptance criteria for geotechnical applications.

2.4 Materials acceptance criteria for use in earthworks

For bottom liner and final cover of sanitary landfills, most environmental agencies recommend (or require) a maximum k of 10^{-9} m/s (Boscov, 2008; NRA, 1998; USEPA, 1993), while, for covers of non-hazardous waste (i.e. horizontal barriers), the k is of 10^{-7} m/s (Bates & Hills, 2015). There are no acceptance criteria in terms of k for daily covers. However, a minimum s_u of 10 to 20 kPa is needed to assure easy spreading and workability of the material in the field (Silva & Hemsi, 2018; Trenter, 2001; Wang et al., 1992). For embankments, a range of 50 to 60 kPa is often considered to be an acceptable value for satisfactory equipment manoeuvring without soil rutting (Trenter, 2001), while Murray et al. (1992) cite a minimum s_u of 40 to 50 kPa as typically required for earthworks. For application as cover in sanitary landfills, WTS must be classified as non-hazardous, and the metal levels must be lower than the TCLP (Toxicity Characteristic Leaching) limits. Some authors have observed the presence of toxic heavy metals in WTS, e.g., Ahmad et al. (2016) observed the presence of Pb, Cr, As, and Ba in concentrations much higher than the TCLP limits in a WTS from Ghaziabad, India. On the other hand, Boscov et al. (2021) identified by X-ray fluorescence: Cu, Cr, and Ni in Cubatão WTS at concentrations higher than the intervention values for agriculture according to Brazilian standards, whereas Tsugawa (2022) classified Cubatão WTS as non-hazardous by TCLP tests, and determined k of 10^{-9}-10^{-8} m/s for WTS-L at L content of 350%, and k of 10^{-8} m/s for WTS-RP at RP content of 1350%, which permits their use as a cover of landfills. The toxicity of WTS should be investigated on a case-by-case basis.

3 RESULTS AND DISCUSSION

3.1 Influence of mixing procedure on the texture of WTS-L mixtures

Due to the high agglomeration characteristic of L and the pasty consistency of WTS, mixing WTS and L can be very hard for high L contents and high volumes of material, even using a planetary mixer. While mixing at L contents from 5 to 150% is easy even by hand, it can be very difficult at L content of 350% or higher: L must be stepwise inserted and mixed, and the velocity two of the mixer must be used to surpass the very high mixture resistance. For instance, at this L content, about 10-20 minutes of mixing is necessary after the total volume of L has been inserted to obtain a homogeneous mixture (Figure 1, left), i.e., a "pasty" texture. Otherwise, when L is not stepwise inserted and mixed (i.e., a high amount of L is inserted), and a low time of mixture is applied, the mixture becomes non-homogeneous, and a "granular" texture is formed (Figure 1, right).



Figure 1. *Influence of mixing procedure on the textures of WTS-L mixtures: pasty texture (left), and granular texture (right)*

It is important to highlight that the difficulty of creating a pasty (homogeneous) texture for a WTS-L mixture increases with L content, and for L contents of 450% and 500%, a pasty-texture is almost impossible to achieve even applying high energy for a long mixing time. A possible explanation is illustrated in Figure 2. The laboratory experience acquired by the author suggests that the particles of L encapsulate WTS immediately after mixing begins (t1), forming clods when a high amount of L is inserted and the mixture has not yet been efficiently mixed. As the mixing process is being performed, the clods of encapsulated WTS become smaller (t2 to t4), but are still observable by the naked eye, forming a "granular" texture. If the mixing process is continuously applied, or higher energy is used, L and WTS particles are better mixed and not distinguishable by the naked eye anymore.

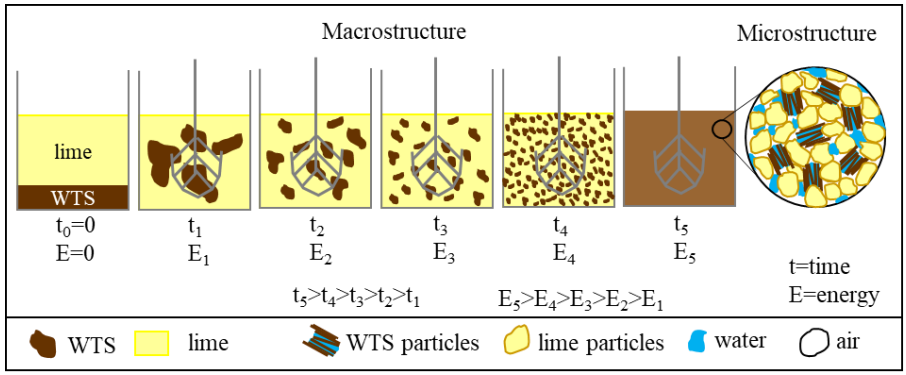

Figure 2. *Effect of mixing procedure on the WTS-L texture*

3.2 Influence of samples texture and curing time on the s_u

Figure 3 (left) shows curves of axial stress versus axial strain for WTS-L350 mixtures with pasty texture (p) and granular texture (g) at curing times of 28 days (28d) and without curing time (0d). The results indicated that the sample texture is much more significant than the curing time for s_u increase. For the WTS-L350 mixture without curing time, the s_u of the pasty mixture is 18 kPa, while the granular mixture is 110 kPa. Also, the sample texture influences on the failure type: samples with granular texture present a fragile (britle) failure, while samples with pasty texture present a plastic (ductile) failure. Figure 3 (right) shows that the higher the L content, the lower the deformation supported by the mixture before the fragile failure occurs. Important to note that the s_u of mixture at 500% L content is lower than the others, suggesting that there is a limit L content of 450%, after which s_u decreases with L content increase.

Results suggest that after curing time of 28-days, s_u does not increase significantly for mixtures at 350 to 450% L content (Figure 4 left). For mixtures at 500% L content, s_u after a curing time of 28-days is lowest (Figures 4 right and Figure 5), suggesting that the addition of L contents equal to or higher than 450% turns WTS into a much more fragile material, decreasing s_u, independent of the texture created (Figure 5). Additionally, other factors can influence s_u, such as water loss during curing time and change in the mass ratio solid particles:water, diminishing the possibility of chemical reactions.

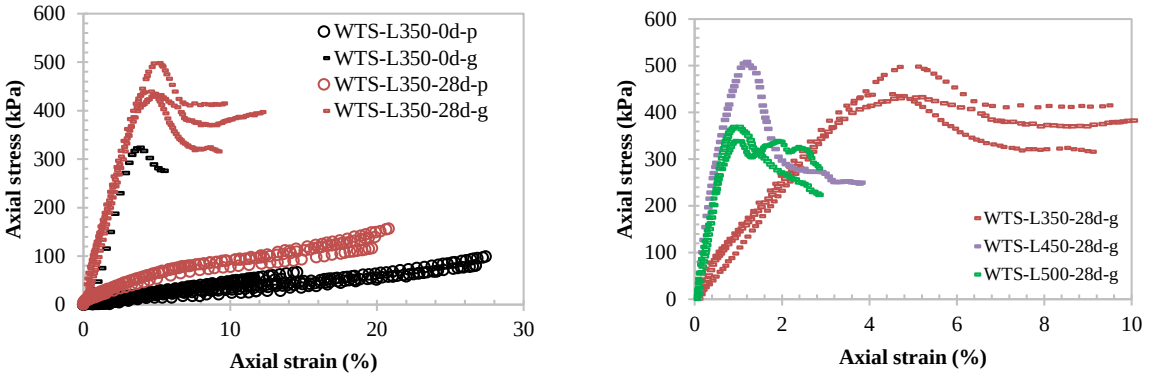

Figure 3. *Comparison between pasty and granular textures (left). Comparison between different L contents with granular texture (right)*

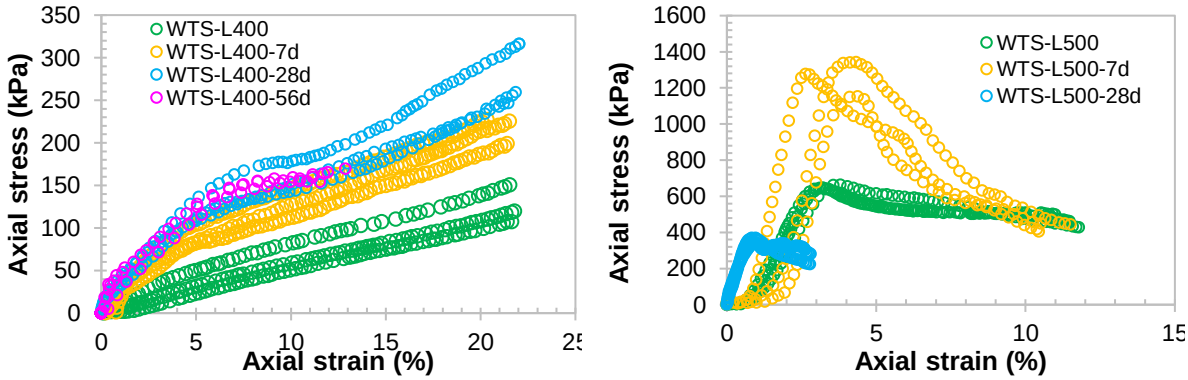

Figure 4. *Comparison between different curing times: mixtures at 400% L content (left), and mixtures at 500% L content (right)*

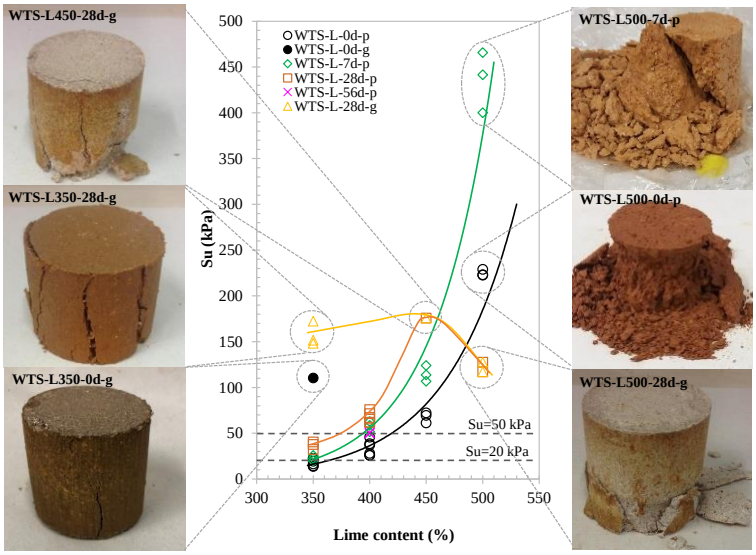

Figure 5. *Influence of curing time and samples texture on s_u*

3.3 Evaluation of WTS-additive mixtures for use in earthworks

Results of s_u obtained by vane and fall-cone tests for WTS-RP mixtures are presented in Table 1. Table 2 shows results of s_u obtained by vane and fall-cone tests for WTS-L mixtures. Table 3 depicts s_u obtained by unconfined compression (UC) tests for WTS-L and WTS-RP mixtures. All results were plotted in a semi-logarithm graph of s_u versus additives contents, as shown in Figure 6. Results suggest that differences in s_u value occur independent of test type. The higher the additive content, the higher is s_u; however, WTS-RP mixtures present much lower s_u than WTS-L mixtures, which may be due to the non-cohesive behaviour of RP. However, it must be highlighted that results could be different if tests were performed with confining pressure.

Table 1. *s_u of WTS-RP mixtures obtained by vane, and fall-cone tests.*

RP content (%) (notation)	Vane s_u (kPa)	s_{ur} (kPa)	Fall-cone W/h²	s_u (kPa)	$w_{mixture}$	SC (%)	w_L (%)	w_P (%)	PI (%)
5	-	-	0.70	0.89	225.4	30.7	-	-	-
(WTS-RP5)	-	-	0.68	0.86	222.4	31.0			
	-	-	0.71	0.91	233.2	30.0			
50	-	-	0.76	0.97	154.9	39.2	79	38	41
(WTS-RP50)	-	-	0.77	0.97	155.0	39.2			
	-	-	0.74	0.94	155.2	39.2			
150	-	-	0.76	0.97	92.8	59.1	64	32	32
(WTS-RP150)	-	-	0.76	0.97	93.0	51.8			
	-	-	0.71	0.90	93.3	51.7			
500	2.49	1.55	-	-	38.2	72.4			
(WTS-RP500)	2.28	1.24	-	-	38.2	72.4			
	2.18	1.14	-	-	38.2	72.4			
800	5.91	1.04	-	-	26.5	79.0			
(WTS-RP800)	7.46	1.66	-	-	26.5	79.0			
	6.11	1.24	-	-	26.5	79.0			
1000	16.58	1.45	-	-	21.3	82.4	29	19	10
(WTS-RP1000)	12.64	1.45	-	-	21.3	82.4			
	7.98	1.86	-	-	21.3	82.4			

Table 2. *s_u of WTS-L mixtures obtained by vane, and fall-cone tests.*

L content (%) (notation)	Vane s_u (kPa)	s_{ur} (kPa)	Fall-cone W/h²	s_u (kPa)	$w_{mixture}$	SC (%)	w_L (%)	w_P (%)	P_I (%)
5[a]	1.04	1.35	0.82	1.04	211.3	32.1	134	76	57
(WTS-L5)	1.24	1.14	0.77	0.98	228.7	30.4			
	1.04	0.93	0.76	0.97	218.9	31.4			
10 [a]	1.04	1.24	0.74	0.94	214.6	31.8	125	75	50
(WTS-L10)	1.04	1.04	0.74	0.94	219.4	31.3			
	1.04	1.04	0.85	1.08	207.1	32.6			
25 [a]	0.93	0.72	0.74	0.94	189.6	34.6	130	78	52
(WTS-L25)	1.86	1.24	0.72	0.91	185.6	35.0			
	1.55	1.35	0.78	0.99	179.5	35.8			
50 [a]	1.14	1.04	0.78	0.99	157.3	38.9	122	76	46
(WTS-L50)	1.14	1.24	0.71	0.90	159.6	38.5			
	1.66	1.24	0.78	0.99	154.1	39.4			
75 [a]	2.28	1.55	1.23	1.56	129.1	43.6	115	72	43
(WTS-L75)	1.86	1.66	0.91	1.16	130.9	43.3			
	1.45	1.04	1.47	1.87	135.8	42.4			
100 [a]	1.86	2.17	1.30	1.65	118.0	45.9	107	70	37
(WTS-L100)	2.17	1.04	2.05	2.60	115.5	46.4			
	1.86	1.24	1.36	1.73	117.5	46.0			
150 [a]	2.07	0.93	2.34	2.97	92.6	51.9	92	61	31
(WTS-L150)	2.28	1.45	1.85	2.35	95.1	51.3			
	2.28	1.24	2.02	2.57	97.0	50.8			
350	-	-	36.30	46.10	46.7	68.2	58	41	17
(WTS-L350)	-	-	54.36	69.04	45.9	68.5			
	-	-	31.10	39.50	44.5	69.2			

400	-	-	148.39	188.46	42.3	70.3	-		-
(WTS-L400)	-	-	93.34	118.54	41.4	70.7			
	-	-	81.69	103.75	41.1	70.9			
450	-	-	107.68	136.75	40.9	71.0	-		-
(WTS-L450)	-	-	60.57	76.92	40.7	71.1			
	-	-	87.22	110.77	39.6	71.6			
500	-	-	545.14	692.33	35.2	74.0	56	38	18
(WTS-L500)	-	-	785.00	996.95	34.6	74.3			
	-	-	400.51	508.65	33.8	74.8			

[a] Data of WTS-L mixture with L content from 5 to 150% were modified from Tsugawa et al., 2022.

Table 3. *s_u of WTS-L and WTS-RP mixtures obtained by unconfined compression tests.*

Additive	**Additive content**	**s_u (kPa) Curing time (days)**				**$w_{mixture}$**	**SC**	**Texture**
	(%)	**0**	**7**	**28**	**58**	**(%)**	**(%)**	
L	350	22.8	22.8	32.4	-	53.3	65.2	pasty
		19.7	25.9	40.7	-			
		22.8	20.0	38.0	-			
		13.8	-	-	-			
		14.5	-	-	-			
		16.6	-	-	-			
	400	25.9	51.8	75.9	50.0	46.5	68.3	
		38.6	58.7	62.1	50.9			
		45.9	63.0	67.3	50.0			
		26.2	-	62.1	-			
		28.3	-	71.6	-			
		37.3	-	65.6	-			
	450	61.4	113.9	176.0	-	33.3	75.0	
		69.7	124.2	[a]	-			
		72.5	107.0	[a]	-			
	500	229.1	400.2	127.7	-	26.5	79.1	
		222.8	465.8	117.3	-			
		223.3	441.6	[a]	-			
RP	700	7.6	-	-	-	37.2	72.9	-
		7.9	-	-	-			
		10.0	-	-	-			
	1000	11.9	-	-	-	20.2	83.2	
		10.8	-	-	-			
		11.1	-	-	-			
	1350	67.1	-	-	-	12.9	88.6	
		68.8	-	-	-			
		68.6	-	-	-			
	1700	41.7	-	-	-	13.6	88.0	
		45.0	-	-	-			
		44.2	-	-	-			

Figure 7 compares s_u obtained by vane, fall-cone, and UC tests as a function of additive contents and the acceptance criteria of s_u in earthworks. WTS-L mixtures at L content of 230% present s_u of 10 kPa, which is the minimum value required to ensure spreading and workability, and could be used as daily and intermediate covers of landfills. A L content of 300% is needed to increase s_u to 20 kPa, which could be suitable for geotechnical applications with low soliciting stresses. And for L contents higher than 375%, s_u reaches the acceptance criterion of 50 kPa, and the mixture could be a good geomaterial for earthwork. WTS-RP mixtures at RP content of 950% present su of 10 kPa, at RP content of 1200% reaches su of 20 kPa, and at 1550% su is 50 kPa. Important to note that the previously drying of WTS from a water content of 240% to 160% increases su from 10 to 90 kPa for the same RP content of 800%.

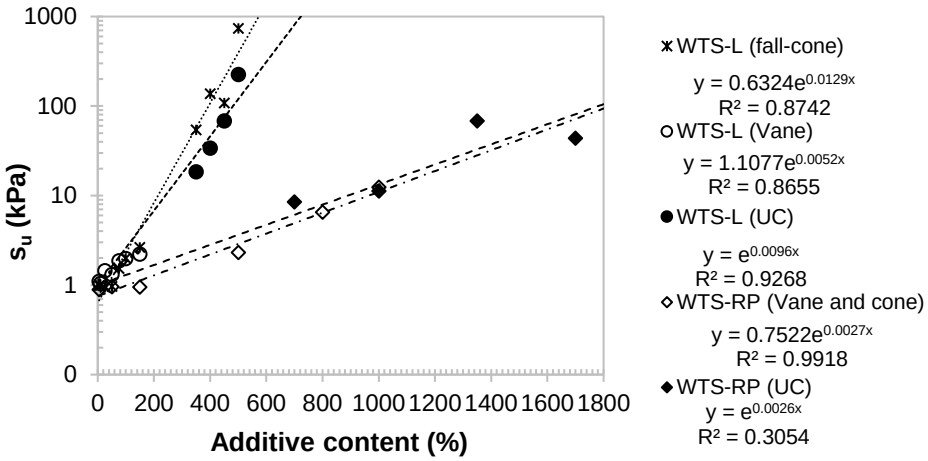

Figure 6. *Unconfined shear strength s_u as a function of additive content for WTS-L and WTS-RP mixtures*

Curing time and texture can enhance s_u of WTS-L mixtures until an optimum L content, above which L increase impairs s_u (Figure 5). After a curing time of 28 days, s_u of WTS-L at L content of 350% increases from 20 kPa (without curing) to 40 kPa. The granular texture obtained for WTS-L350 samples was remarkably more important for s_u increase than curing time. s_u of 50 kPa is surpassed without curing only for L contents higher than 400%.

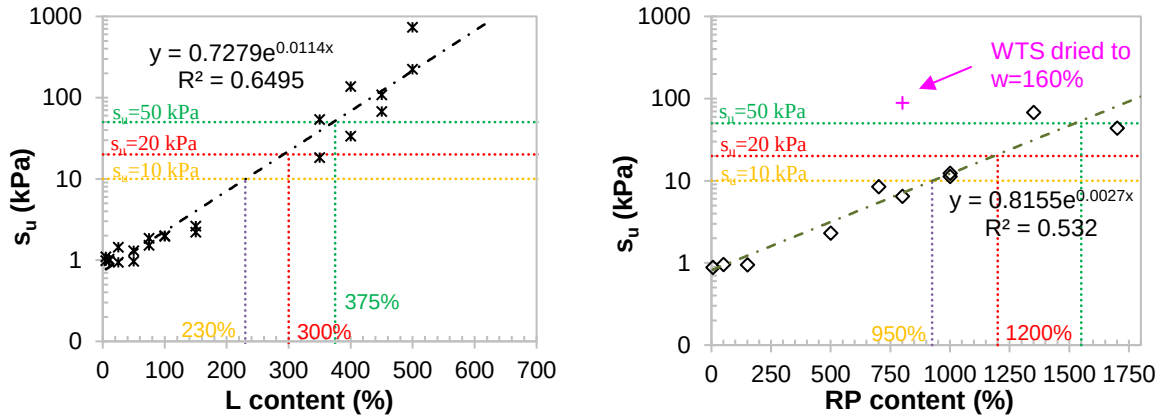

Figure 7. *Comparison between s_u and acceptance criteria for earthworks: fWTS-L mixtures (left), and WTS-RP mixtures (right)*

4 CONCLUSIONS

Results evinced the importance of the mixing process: depending on the mixing procedure, the texture of WTS-L mixtures changes, forming a “pasty” or a “granular” texture, which changes the material’s behaviour in terms of shear strength. s_u values obtained for RP are lower than for L. WTS-L mixtures at L content of 230% and 300% can reach s_u of 10 and 20 kPa, respectively, and could be used as daily covers of landfills or other low solicitation applications. At L content of 375%, s_u reaches the acceptance criterion of 50 kPa, and the mixture could be a good geomaterial for earthwork. The interest in applying such high L contents depends on an overall analysis of sustainability for each particular case. WTS-RP mixtures at RP content of 950% present s_u of 10 kPa, at RP content of 1200% s_u reaches 20 kPa, and at 1550% s_u is 50 kPa. Such high RP contents suggest that the reverse ratio between materials should be evaluated, i.e., which WTS contents would make RP a good geotechnical material, bringing cohesion and conveying a denser packing of particles. Results also suggest that the previous drying of WTS (before mixing with additives) can considerably increase s_u, which could be applicable for WTPs with available operational areas; however, further investigation is needed. Curing can contribute to reducing L content; however, curing time higher than 28-days does not increase s_u significantly. Also, there is an optimum L content, above which L increase impairs s_u. Further research is needed to investigate if a L content lower than 350% can produce better cost-benefit material. Besides, an investigation into the

potential of WTS-L mixtures to reduce the fugitive CO2 emissions from landfills when used as final covers is recommended for further research.

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