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ABSTRACT

The soil stabilisation is employed to construct geostructures as embankments, river levees, road subbases or to backfill excavations, improving the mechanical behaviour and reducing the consumption of extracted primary aggregates. This study is focused on the use of lime/cement treated soils to backfill trenches where high power line cables are buried. Indeed, under these circumstances not only the mechanical properties but also the thermal characteristics of the treated soil are of primary importance.

The effect of changes in suction (soil water content) on the thermo-mechanical properties was investigated on lime-treated and lime-hydraulic binder treated silty soils in the laboratory. The relationship between the Soil Water Retention Curve (SWRC) determined by suction control and measurement techniques, and the thermal properties along the drying path from the Optimum Proctor point (initial state) was analysed. Moreover, to investigate the successive heating/cooling periods induced by the cable, several drying/wetting cycles were applied to analyse their effect on the thermal properties and mechanical behaviour of compacted treated soils. The obtained data showed that increasing the suction from initial state to 3.5 MPa induces a decrease in the thermal conductivity (λ), this diminution becomes more important below 3.5 MPa of suction. An inverse trend was however observed in the change of the thermal capacity (C) with increasing section. The drying/wetting cycles appeared to have a significant impact on the mechanical performances and smaller effect on the thermal properties of the studied compacted treated silty soil.

1. Introduction

The use of soil stabilisation is a convenient way to enhance the mechanical behaviour and to build geostructures as embankments, river levees, road subbases or to backfill excavations, reducing the consumption of extracted primary aggregates [1,2]. Soil stabilisation thus permits to limit the environmental impact of earthwork. The performances of the treated soil need to be tailored as a function of the context of application of the treated soils. This paper is focused on the thermal properties of compacted treated soils that are relevant in several applications like the installation of underground high-power line cables. Indeed, such cables are often buried in the ground, installed within a trench of 1 to 2 m depth and about 1 m wide, most of the time underneath existing low traffic roads. The cables are installed at the bottom of the trench and embedded in concrete. A significant part of the excavated soil is used to backfill the trench, and the road structure is then rebuilt. The backfill is most of the time treated with lime and/or cement to improve its bearing properties to meet the design requirement of the road structure to be rebuilt above. Once the electric cables are operational, their temperature may increase by Joule effect, the energy released varying over the year. The temperature increase of the cables must be limited under a given threshold to minimize the risk of cables failure. The efficient dissipation of the generated energy depends mainly on the thermal properties of the materials around the cables [3–5], including the treated soils installed in the trench. However, the thermal properties of a given soil depend on their moisture content (w%) and density. Some studies showed that the cable temperature increase induces a drying of the soil [6,7], that phase being followed by a progressive rehydration when the temperature of the cable decreases.

Thermal conductivity (λ) and volumetric thermal capacity (C), which describe the ability of a material to conduct heat and its ability to store thermal energy respectively are affected by soil mineralogy, dry density, water content, and particle arrangement [8,9]. Solid particles have a thermal conductivity significantly higher than water, but water has a thermal conductivity of

approximately 30 times of those of air. Consequently, the thermal conductivity of soils increases with their water content for a given density. Similarly, when the dry density of a given soil increases, a significant increase in the thermal conductivity is observed [10,11]. Ekwue et al. investigated the simultaneous effects of dry density and water content of several compacted soils on thermal conductivity along the compaction curve [12]. They showed that thermal conductivity exhibits a similar behaviour with maximum values reached at water contents slightly higher than the optimum water content. Available literature data on the thermal conductivity of compacted treated materials are scarce, while treatments with lime or hydraulic binders modify significantly the soil mineralogy [13,14]. The microstructure of treated soil is also significantly different from the microstructure of the untreated soil [15,16] and is impacted by temperature [17,18]. Moreover, the hydro-mechanical behaviour of treated soils is highly time-dependent due to the processes induced by the presence of lime and/or binder. Wang et al. [15] studied the changes in the thermal conductivity of a compacted lime treated silty soil during curing. They showed that the thermal conductivity of samples compacted on the dry side of the compaction curve decreases slightly with increasing curing time. For the samples compacted on the wet side of optimum, they showed that the effect of curing time on the thermal conductivity is not significant.

In the long term, fluctuations of the cable temperature will induce successive drying/wetting cycles of the soil surrounding the cable. It is well known that successive wetting and drying can alter the characteristics of treated soils [19,20], this alteration being associated to a progressive modification of the treated soil microstructure. Tang et al. [21] studied the cyclic wetting/drying effects of the stiffness of a lime-treated clayey soil by using bender elements. They indicated that an intensive cyclic wetting-drying induces micro-cracks resulting in a decrease in the small shear strain modulus, associated to a decrease of the mechanical performances. Cuisinier et al. [22] also showed the harmful effects on strength and hydraulic conductivity of wetting and

drying cycles on cement treated soil performances. Despite this information on the influence of climatic conditions and cyclic variations of water content on the hydro mechanical performances of treated soils, knowledge on their effect on the thermal properties of soil is still limited.

In this context, the first objective of the study is to provide insights about the changes in the soil thermal properties along the drying path. Several conditions were considered for the soil: untreated, lime-treated or lime-hydraulic binder treated silty soils. The modification of the thermal conductivity, water content and mechanical performances at various curing times were also investigated to complement the analysis. The second objective was to evaluate the possible alteration of the thermal properties after successive wetting/drying cycles.

2. Materials and methods

2.1. Tested materials

The soil tested in this study is a silt taken from the experimental site of Gray, France. Natural soil was first air-dried, grounded and then passed through the target sieve of 2.5 mm. The grain size distribution of the used soil (Figure 1) was determined by the sieving method for particles larger than 80 μm and by the hydrometer method for particles smaller than 80 μm. This silt has a fine fraction (<80 μm) of 40 %. The main geotechnical properties are listed in Table 1. According to the Unified Soil Classification System, this soil is a silt of low plasticity (ML).

Lime and hydraulic binder were used as treatment products. As indicated above, treatment is essential to improve the soil mechanical properties. Lime and/or hydraulic binder treatment is a widely used technique. In the short term, lime (CaO) reacts with the free water to produce hydrated lime, known as portlandite $Ca(OH)_2$. This first reaction leads to a consumption of large amount of water content and a significant heat release. The followed dissociation of the portlandite provides sufficient Ca^{2+} and HO^- ions. Then, the increase in pH and calcium

concentration leads to soil flocculation/agglomeration [23,24], which results in significant decrease of the soil plasticity and changes of the soil engineering properties [25]. In the long term, pozzolanic reactions result in the production of cementitious gel, such as calcium silicate hydrates (C-S-H), calcium aluminate hydrates (C-A-H) and calcium alumino silicate hydrates (C-A-S-H), which play the major role in improving soil mechanical behaviour in terms of compressive strength, cohesion and friction angle and compressibility [26–31].

The selected lime contained more than 94% of quicklime (CaO) on a dry-weight basis. The used hydraulic binder (CEM II/B-M (LL-V) 32.5 R CE) contained 65 % of clinker, 35 % of calcareous material and fly ash. Two types of treatment were considered in this study: lime treatment of 2%, and combined lime-hydraulic binder treatment, with the addition of 1% of lime and 4% of hydraulic binder. These contents were selected with references to current practices in soil treatment in France. Preliminary tests showed that they are sufficient to get satisfactory improvement of soil mechanical properties. The untreated soil was also tested as a reference to evaluate the changes in the thermal and mechanical properties arising from the treatment.

2.2. Samples preparation

The compaction characteristic curves were determined for each type and percentage of treatment according to the standard ASTM-D 698. The soil was left in an airtight container for at least two days to reach moisture equilibrium. The soil and the treatment product were then mixed up in a mechanical mixer for five minutes approximately. After the lime treatment, the mixture was left for 1 hour in an airtight container before compaction. When the cement treatment was used, compaction was carried out within a few minutes (maximum of 30 min) after treatment to account for the setting time of the cement. **Figure 2** shows the influence of the different treatments on the compaction characteristics of the tested soils. As expected, the data show that the addition of treatment induced an increase of the optimum water content, and

a decrease of the maximum dry density (**Table 2**), in line with other works on soil stabilization [24,32].

The soil samples, untreated and treated, were statically compacted by static axial compression in a cylindrical mould to the target dry density [33]. Once the soil was air-dried and sieved with d_{max} = 2.5 mm, its water content was adjusted up to the optimal Proctor water content (determined form the Standard Proctor Test). This mixture was left in an airtight container for one hour prior to compaction to allow the development of immediate reactions. Cylindrical specimens of 50 mm in diameter and 100 mm in height were then prepared for thermal conductivity tests. The samples employed for the thermal measurements were larger to comply with the dimension of the testing device employed (see section 2.4). The specimens for the unconfined compression tests were 35 mm in diameter and 70 mm in height. Immediately after compaction, the specimens were wrapped with plastic-aluminium foil to prevent any exchange with the atmosphere, and stored at 20°C until testing time.

2.3. Suction control and measurement

The initial total suctions were determined by the chilled-mirror dew-point technique using the WP4C dew point potentiometer device (Decagon). More details on the water potential measurements can be found in [34].

To impose different suctions to the soil samples, two suction control techniques were employed. (1): Pressure plate device was used to impose suction values below 1 MPa, while vapour equilibrium method was employed for suction values higher than 3.5 MPa. The pressure plate device principle is based on the axis translation method, imposing a positive air pressure inside the sample and controlling the water pressure [35]. (2): The vapour equilibrium technique which consists in placing the specimens (cylinder of 50 mm in diameter and 75 mm in height) into desiccators containing saturated saline solutions was employed [36,37]. The lowest suction imposed with a saturated saline solution (3.5 MPa) was obtained by using $CuSO_4$. The highest

suction (150 MPa) was imposed with a saturated saline solution of $MgCl_2$. Samples were then left in the desiccators until reaching mass stabilization, checked by periodic weighing. Once this stabilization obtained, the imposed suction was controlled with Decagon WP4®. The moisture content was then determined by oven drying. The dimensions of samples were also measured at each step.

2.4. Thermal conductivity measurements

The thermal conductivity was measured using a handled apparatus named *KD2 Pro* Thermal Properties Analyser (Decagon Devices Inc.). This device complies with the requirements of ASTM Standards [38]. A dual needle (1.3 mm in diameter and 30 mm in length) was used to measure the thermal conductivity of the compacted silty soil through the principle of hot-wire transient method. Its accuracy is ±10% in the range of 0.2-2 W/(m·K) and ±0.01% for 0.02-0.2 W/(m·K).

Penetration of needles is not possible in hardened soils. Thus, two holes of 1.3 mm in diameter and 30 mm in length were drilled in the central part of the upper section of each tested sample to ease the insertion of the dual needle sensor. A thin layer of a thermal conductive paste was applied on the surface of the sensors to ensure good contact with the soil. The dual needle was then placed inside the specimen and left for about 5 minutes to reach the temperature equilibrium between the soil and sensors. Then, the test started, 2 minutes were needed for one measurement. The samples remained wrapped in the plastic foil during the measurement to minimize any possible loss in moisture content. The mass of the sample was checked before and after thermal conductivity measurements to control water content variations.

2.5. Unconfined compressive strength (UCS)

Unconfined compressive strength (UCS) was determined with a displacement rate of 1.04 $mm.min^{-1}$. For each combination of parameters, three samples were tested and the results provided are the mean of these three values.

2.6. Test program

A first series of experiments was performed to investigate the relationship between the soil water retention curves, and the thermal properties for untreated silt (US), lime treated silt (LS) and lime-hydraulic binder treated silt (LHS). To do so, thermal conductivity and volumetric thermal capacity measurements were made by using the KD2 Pro device at initial state and along the drying path from the optimum water content once the suction equilibrium was reached.

A second series of samples was used to evaluate the change of thermal conductivity, water content and unconfined compressive strength (UCS) during curing. Thermal conductivity and UCS tests were performed at 0, 7, 28, 45 and 90 days of curing. Two specimens were tested to check repeatability. The specimens used for the UCS tests were then cut into small pieces to measure their water content by oven drying at each given curing time.

Finally, the effects of drying/wetting cycles on the thermal conductivity and the unconfined compressive strength (mechanical performance) of compacted silty soil were also addressed. To do this, samples at 45 days of curing time were placed in a climatic chamber to simultaneous control of temperature and relative humidity. Thermal properties measurements were carried out at initial state and after 3, 6, 9 and 12 drying/ wetting cycles between 50% and 98% of relative humidity. The UCS tests were performed after the end of a wetting stage under a relative humidity of 98% for 3, 6 and 12 drying/wetting cycles.

3. Experimental results

3.1. Water retention curve – thermal properties

Figure 3 shows the SWRC of the silt, with and without treatments. The drying path of untreated silt is located slightly below the drying path of lime treated and lime-hydraulic binder treated silts. The obtained water retention curves showed that lime and lime-hydraulic binder treatments increased the water retention capacity of silty soils, confirming the previous findings

by some authors [15,39,40]. This can be connected to the impact of these treatments on the soil micro-structure [16,21,41,42].

The thermal parameters determined for each suction upon the drying path were the thermal conductivity (λ) and the volumetric thermal capacity (C). Results are presented in terms of changes of thermal conductivity versus suction and water content (Figure **4**a, b) and in terms of changes in volumetric thermal capacity versus suction and water content (Figure **4**c, d). At initial state, the thermal conductivity of the untreated silt is higher than that obtained with the treated silts (λ = 1.33 and 1.19 W/m·K for untreated and treated silt, respectively). The data also showed that drying from the initial state resulted in a limited change of the thermal conductivity up to a suction of about 3.5 MPa. It decreased by 5.4 % for the untreated silt and by around 15.0 % for both treated silts. Increasing suctions above 3.5MPa resulted in a more significant reduction of the thermal conductivity. Similar conclusions can be drawn from Figure **4**b where the thermal conductivity is plotted with respect to water content changes, with little change in thermal conductivity at water contents between 23.2 and 15% (initial state and 3.5MPa, respectively). The lime treated silt and lime-hydraulic binder treated silt had similar impact on the thermal conductivity, with values below the values obtained on the untreated silt, and almost the same difference at each suction along the drying path (Figure **4**a and b).

Figure **4**c and d present the changes in volumetric thermal capacity of each specimen. The increase in suction from the initial state to 3.5 MPa induced significant changes of the volumetric thermal capacity (76% for US and 86% for LS and LHS). Above 3.5 MPa, the rate of the change in volumetric thermal capacity is less important, unlike what was observed in thermal conductivity change (Figure **4**a and b). At initial state, it can be also observed that the volumetric thermal capacity of the LHS was higher than that obtained for US and LS. However, at high suctions the difference between the three states became negligible.

3.2. Impact of curing time

Figure 5 shows the changes in thermal conductivity, water content of untreated, lime treated and lime-hydraulic binder treated silt versus curing time. It can be observed that, at t = 0 day (initial state), the untreated silt has a significantly higher thermal conductivity than the treated samples. This can be connected to the data observed in the thermal conductivity/suction curve (Figure 4a) along the drying path from the initial state to 152.5 MPa of suction. For the untreated and the treated silts, the curing time seems to have no effect on the thermal conductivity, the values remaining around 1.32 and 1.14 W/m·K for untreated and treated silts, respectively (Figure 5a). Observation of water content versus curing time in Figure 5c indicates that water content slightly decreased. For instance, the water content of the US was about 23.4% at t = 0 day and 22.4% at t = 90 days. The effects of this variation of water content on thermal conductivity changes seems to be negligible.

The UCS of the samples was also determined as an indicator of the development of the setting reactions within the samples. The UCS of the untreated soil was equal to 112 kPa. The treatments improved the mechanical performance of the soil (Figure 5c). For LS, the UCS was about 195 kPa at t = 0 day; then it gradually increased to 243 kPa at t = 90 day. For LHS, the increasing of UCS was much higher. It increased from 167 kPa at t = 0 day to 670 kPa at t = 90 days.

3.3. Effect of drying/wetting cycles

As previously described in Section 2.3, the drying/wetting cycles were applied after a curing period of 45 days to allow a significant improvement of the mechanical characteristics of the treated samples.

The changes in thermal conductivity of the US, LS and LHS versus the controlled relative humidity (50 and 98 %) are plotted in Figure 6 after 3, 6, 9 and 12 cycles. As expected, the data of the US is located above the data obtained on LS and LHS. Interestingly, with an increasing

number of cycles, no effect on the thermal conductivity at 50% of relative humidity was observed (Figure 6). A slight reduction in the thermal conductivity after 3 cycles has been observed, while this difference is actually in the range of the dispersion observed when testing silt specimens. At 98% of relative humidity, it seems also that increasing the number of hydric cycles has a limited effect in the thermal conductivity. For the US and LS, after 3 cycles, we observed a decrease in the thermal conductivity followed by an increase up to a value close to that obtained at 3 cycles for 9 and 12 cycles. For the LHS, no significant change was neither observed in the thermal conductivity up to 6 cycles. Afterwards, the soil thermal conductivity obtained at 9 and 12 cycles is higher than that obtained after only 3 cycles, showing some irreversibility in the thermal properties at higher relative humidity. This set of data will be further commented in the discussion section.

The impact of the wetting/drying cycles on UCS is presented in Table 3. The results are presented as a function of elapsed time since the preparation of the samples. The detrimental effect of the cycles can be quantified by comparing the UCS together with the data of UCS changes with curing time, and the samples that were cured up to 270 days without being exposed to any wetting/ drying cycle.

The suction of the samples should be considered when doing the comparison. Indeed, suction of the samples after their preparation can be estimated from the retention curve, between 200 and 300 kPa (Figure 3). However, the wetting phases were conducted by applying a relative humidity of 98 %, corresponding to a suction of about 3 MPa. Therefore, the experiments were completed by determining the performance of the soils after a curing under a relative humidity of 98 %. It can be seen that the performance of those samples was significantly higher than the ones kept at constant moisture content. This difference can be explained by the higher suction of the samples cured under a relative humidity of 98 %, as showed for treated soils by De Bel et al. [43].

These results showed that the application of the first three cycles did not altered the performance of the samples, for both treatments. However, subsequent cycles resulted in a significant decrease after 6 and 12 cycles. In both cases, the performance after 12 cycles was significantly lower than the UCS of the samples cured under constant water content. The alteration of the lime-treated samples was much more important than those of the samples treated with the hydraulic binder.

4. Discussion

4.1. Impact of treatments on thermal conductivity

Thermal conductivity and volumetric thermal capacity were measured along the drying path from the initial state for US, LS and LHS. As described in section 1, the thermal conductivity is primarily controlled by the soil texture and structure, defined by soil nature, density, porosity, water content and aggregate size distribution. According to some authors, the maximum thermal conductivity is reached at the optimum moisture content [12,44] and depends on soil microstructure [45]. The thermal conductivity is therefore significantly impacted by the initial compaction level. As shown in Figure 4, the initial thermal conductivity of US is higher than those of LS and LHS. This could be probably due to the higher dry density obtained in the untreated case (Figure 2).

However, Figure 4 shows that US and LHS have different thermal conductivities upon the drying path, despite their similar initial dry densities (Figure 2). Indeed, as reported by various authors, the thermal conductivity of silty soils is around 2.0 W/m·K. This is significantly higher than those of the cementitious compounds (C-S-H; C-A-H) produced during pozzolanic reactions when using lime and/or hydraulic binder treatment. The thermal conductivity of such compounds is comprised between about 0.2 and 1 W/m and is a function of their hydration

density and packing density [46–48]. As a result, the cementitious compounds in the soil may contribute to lower the overall soil thermal conductivity.

Moreover, some authors showed that during the mixing process, the treatment product (lime or cement) is mainly located around soil aggregates, the inner part of the aggregates containing almost no treatment product [49,50]. These authors showed that the cementitious compounds are formed at the contact points between the particles, with a slow diffusion towards the inner part of the aggregates when the curing time is increased. As a result, the conduction process can be significantly altered by the presence of the cementitious compounds at the contact point between the aggregates.

4.2. Impact of suction variation

Figure 4a shows that the changes in terms of thermal conductivity with suction increase were firstly characterized by a limited change between initial state and 3.5 MPa of suction for the three soils. Afterward, the thermal conductivity started decreasing significantly with suction increase. It is well known that the thermal conductivity is largely controlled by the water content, and also by the solid contacts between aggregates (soil density) [45,51]. Because of the soil shrinkage behaviour due to drying, the effect of the water content decrease on the thermal conductivity is certainly combined by the effect of dry density increase at the beginning of drying. Moreover, drying from the initial state (optimum proctor) up to 3.5MPa seems to occur at higher degree of saturation. Consequently, the liquid phase in pores remains continuous and the change in the overall thermal conductivity of soil becomes negligible. Beyond 3.5 MPa, a stabilization of volumetric shrinkage was observed. This means that the dry density could be considered constant, and the significant thermal conductivity change is only governed by the water content decrease.

Upon the drying path from the initial state, the volumetric thermal capacity was also measured. The values are plotted versus suction and water content in Figure 4c and d, respectively. The

results showed that the volumetric thermal capacity seems to be slightly affected by the use of treatment along the drying path. This is in agreement with the data of Eslami et al. [44] who found that the difference between the changes in volumetric thermal capacity versus water content of different soils is not significant. Note that, some differences were observed on the three specimens at the initial state, with a higher volumetric thermal capacity for LHS. For a given soil, it can be assumed that the higher the dry density and the water content, the higher the volumetric thermal capacity. This could explain the higher initial volumetric thermal capacity obtained for the LHS because of its higher dry density (ρ_d =1.52 Mg/m^3) and water content (w = 25%,).

Unlike what was observed in the thermal conductivity change, with a limited change before 3.5 MPa followed by a significant decrease, the volumetric thermal capacity decreases with suction and the decrease rate seems to be more important before 3.5 MPa (Figure 4c). This trend is also in agreement with the results of Eslami et al. [44] who observed that the rate of volumetric thermal capacity increases with water content. Another conclusion that can hence be drawn is that the volumetric thermal capacity is mainly governed by water content, whereas in the range between the initial state and 3.5MPa the drying has occurred at high degree of saturation and consequently with the presence of continuous liquid phase in pores.

4.3. Impact of curing time

An important question is the change of the thermal conductivity with respect to curing time. The results obtained here on samples compacted at the optimum showed no significant change in the thermal conductivity with curing time (Figure 5). This is in agreement with the study of Wang et al. [15], who investigated the change in thermal conductivity, suction and water content of a lime treated silt. They observed that the thermal conductivity of samples compacted on the dry side decreases slightly with curing time, while for the samples compacted wet of optimum; the change in thermal conductivity is not significant. Indeed, it is well established

that compaction at different water content results in different micro-structure of the soil. At the optimum water content and on the wet side, the samples present the same microstructure with only one pore population (intra-aggregates) and continuous liquid phase in the pores [52]. It is hence expected to have a similar response in terms of thermal conductivity change with respect to curing time.

As showed by the results in Table 3 the positive effects of lime and/or hydraulic binder treatment on strength are altered by successive wetting/ drying cycles. However, the thermal properties of the tested soils remained almost constant after 12 cycles of wetting /drying process. The mechanical alteration can be explained by the alteration of bonds during the cycles as it has been evidenced by others authors [21,53]. The stability of the thermal conductivity however indicates that the micro-structure of the different material was not dramatically altered by the wetting/drying cycles. The thermal conductivity is primarily controlled by the water content of the samples.

5. Conclusions

This objective of the study was to analyze the impact of two soil treatment products on the thermal performances of a compacted silt, in the short term and the durability of the performances after the imposition of several wetting/drying cycles. The following conclusions can be drawn from the study:

- Lime and hydraulic binder treatments could induce a significant decrease of the thermal conductivity of compacted silty soils. This modification is related to the impact of the treatments on the density of the compacted soil, but it is also a consequence of the micro-structural changes induced by the treatments.
- Moisture content variation, i.e. suction variation, have a major effect on the thermal conductivity of the soil. A drying down to the residual water content can reduce by a factor of two the thermal conductivity of the material.

- The imposition of wetting/drying cycles alter significantly the mechanical performances of lime and hydraulic binder treated soils. However, the thermal characteristics remain constant. The primary effect of the wetting/drying cycles is to alter the bonds, and thus the mechanical characteristics. Such degradation should be taken into account in the design of the road structure in which the cable could be installed.

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TABLES

Table 1. Geotechnical properties of the silt.

Property	
Liquid limit *LL* (%)	61.3
Plastic limit *PL* (%)	36.4
Plasticity index *PI*[2]	24.9
Particle density ρ_s ($Mg \cdot m^{-3}$)	2.95
Methylene blue value (g/100 g of dry soil)	

[a] Unified Soil Classification System.

Table 2. Optimum Proctor compaction characteristics for silt treated with different products.

Soil	Lime content (%)	Hydraulic binder content (%)	w_{opt} (%)	ρ_d^{max} (Mg·m^{-3})
US	-	-	23.2	1.53
LS	2 %	-	25.2	1.47
LHS	1%	4%	24.5	1.52

Table 3. Impact of successive wetting and drying cycles on unconfined compressive strength (the cycles were imposed after 45 days of curing).

Treatment	Quicklime (%)	2	1
	Hydraulic binder (%)	-	4
UCS after 45 days of curing (no cycle) (kPa)		247	690
UCS after 45 days of curing plus (kPa)	3 wetting / drying cycles	260	738
	6 wetting / drying cycles	225	662
	12 wetting / drying cycles	192	552

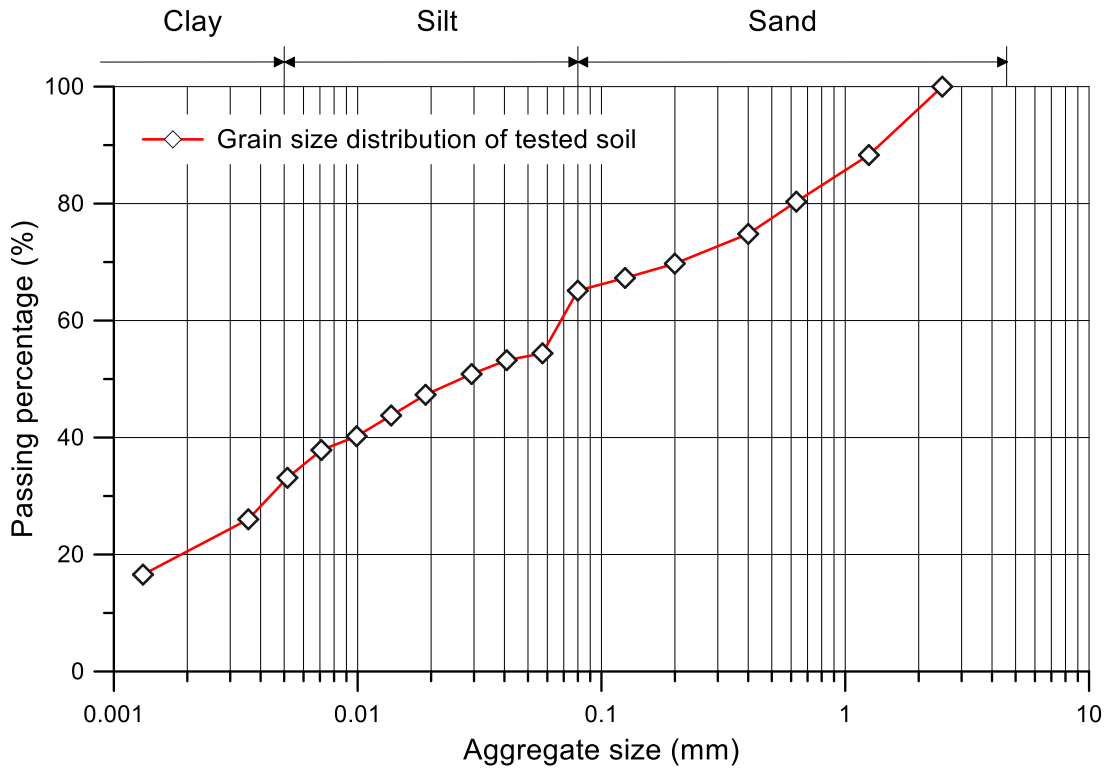

Figure 1. Aggregate size distribution of soil with D_{max} = 2.5mm (dry sieving and hydrometer methods).

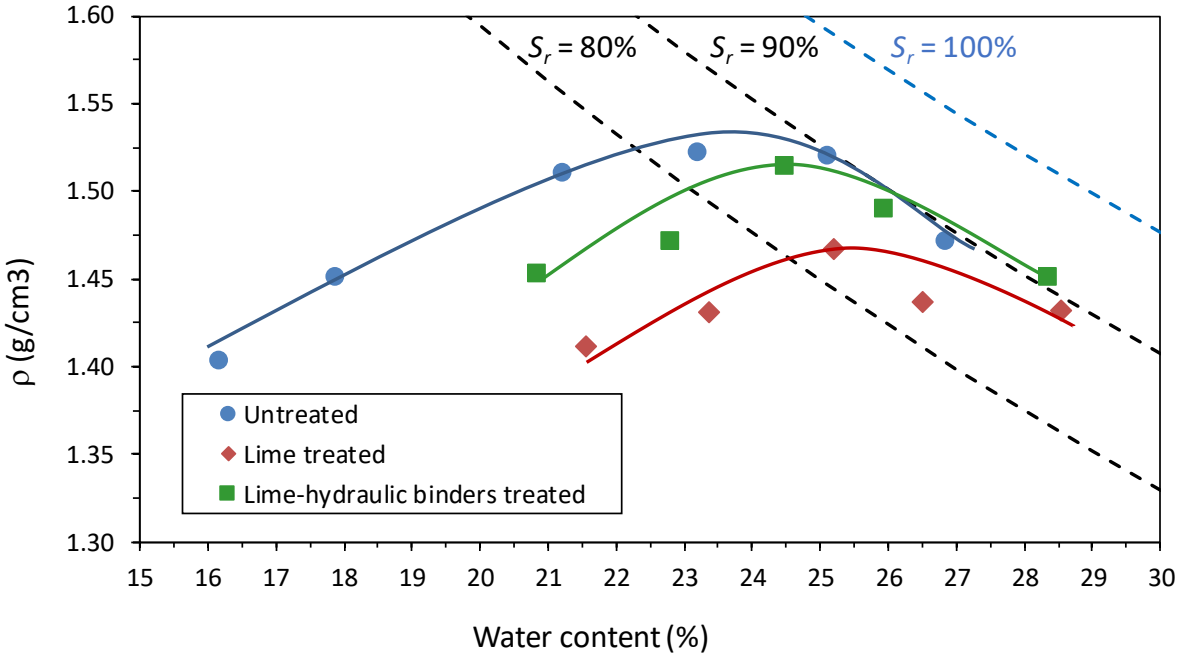

Figure 2. Proctor curves of untreated, lime treated and lime-hydraulic binder treated silt.

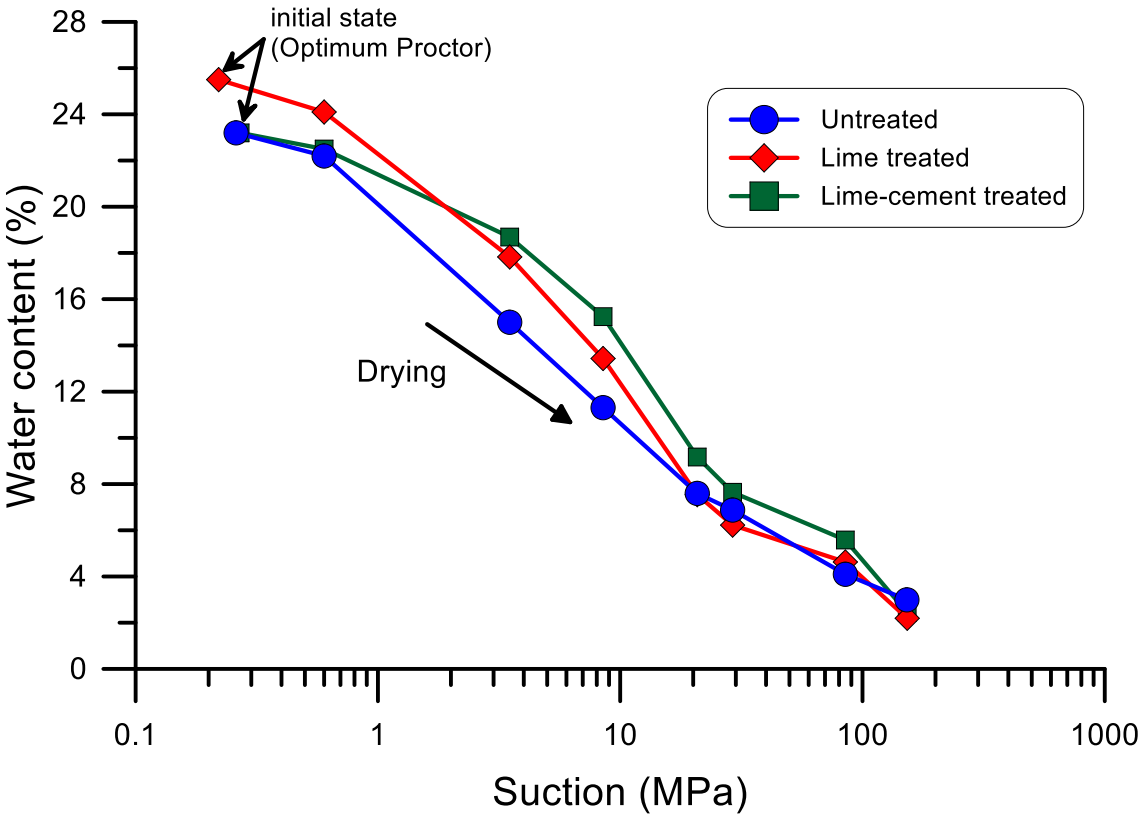

Figure 3. Water retention curves of untreated and both treated soils obtained by suction control and by WP4 measurements (initial state).

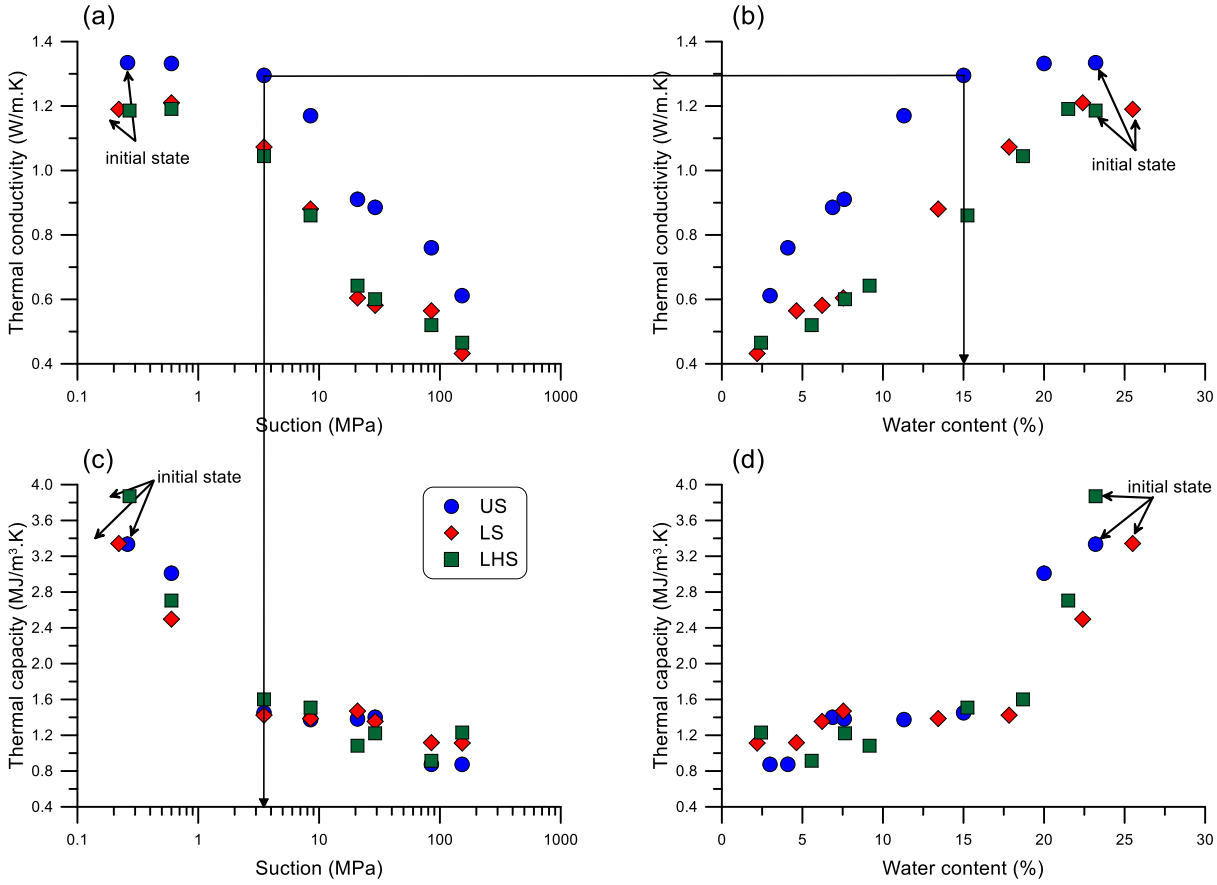

Figure 4. Thermal conductivity and thermal capacity changes with respect to (i) suction changes (a, c, respectively) and (ii) water content (b, d, respectively).

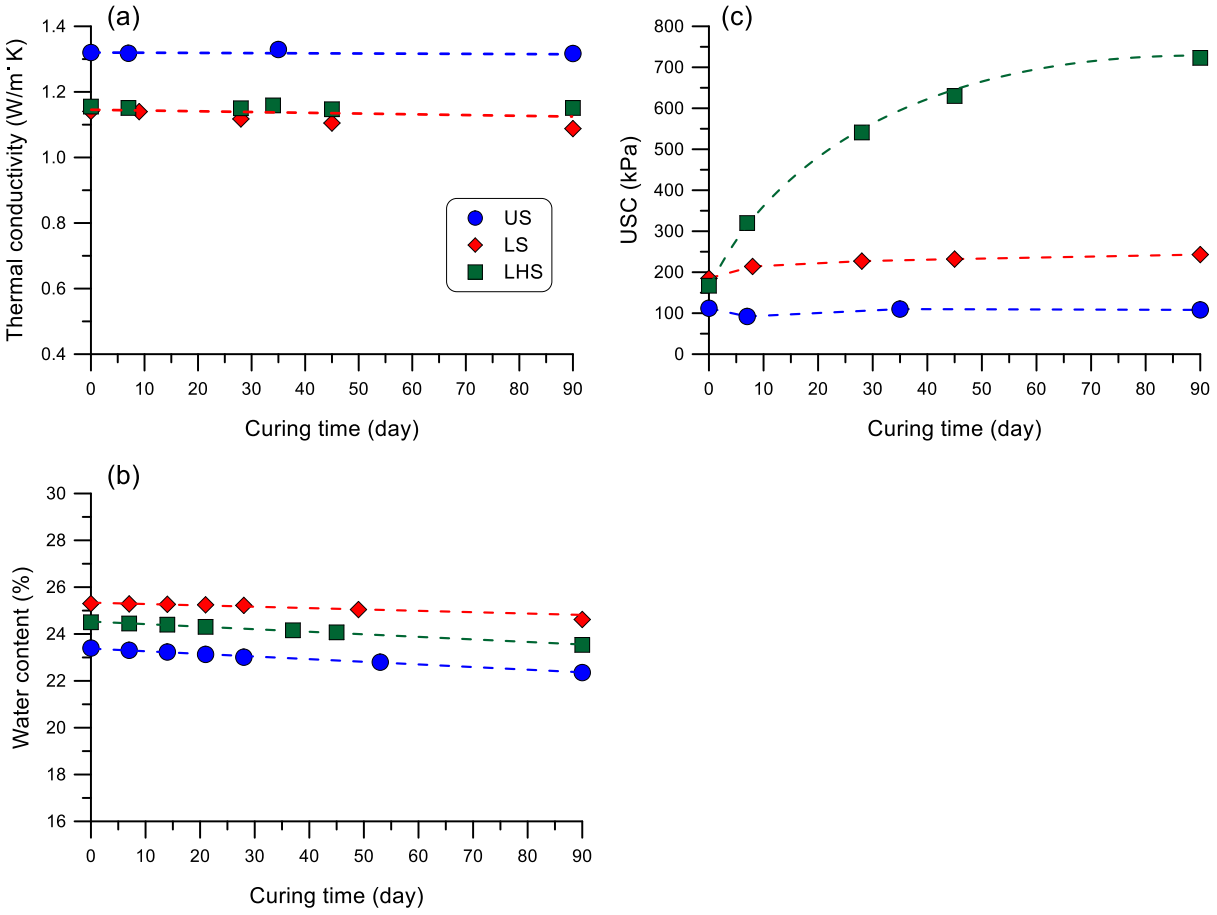

Figure 5. Changes in thermal conductivity, water content and UCS during curing (a, b and c).

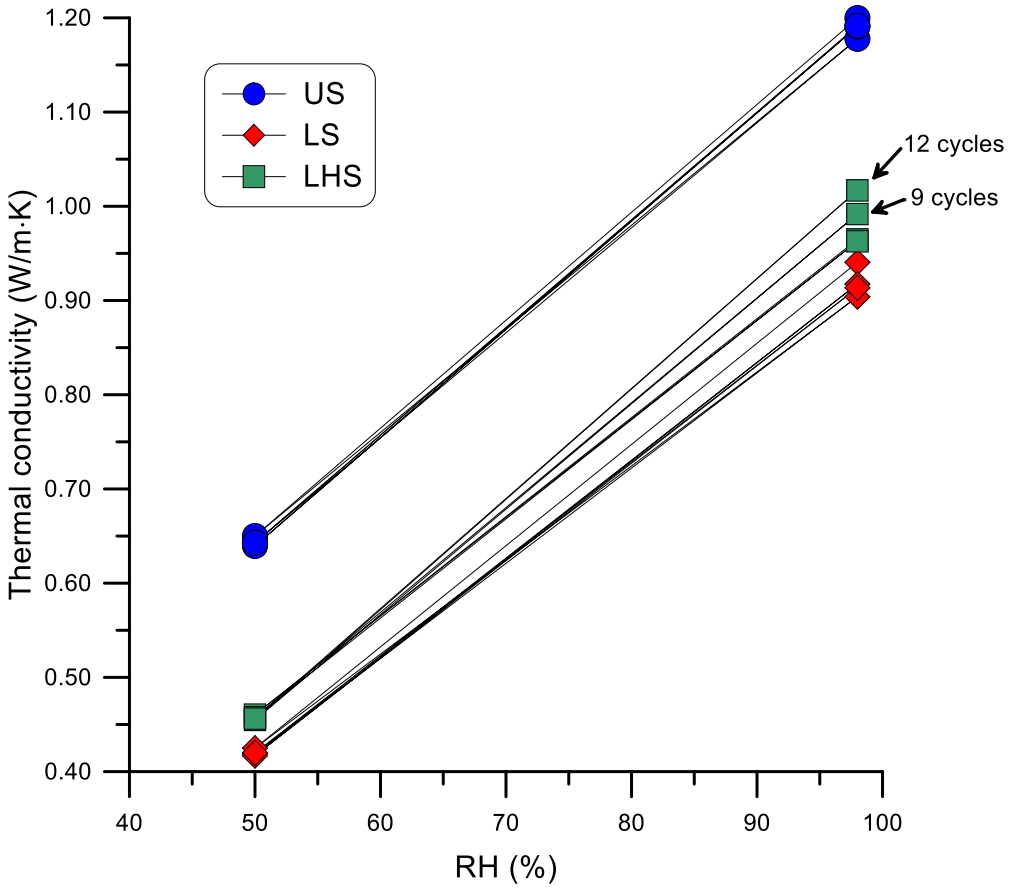

Figure 6. Impact of successive drying-wetting cycles on the thermal conductivity of compacted treated silt.