



EFFECT OF CALCINATION ON THE WATER RETENTION CURVE OF CLAY LOAM AND SANDY CLAY SOILS

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Abstract

A laboratory experiment was carried out to study and evaluate the water retention curve of loam soil (sandy clay soil) and sandy clay topped by a clay soil as well as clay soil topped by loam soil with wide moisture range from the minimum moisture content (Q_r) at water soil content of 1,500 kPa up to the higher moisture content (Q_s) near saturation. The water retention curve was estimated and the method of Van Genuchten equation (1980) was used to describe the experimental data mathematically and extracted the equivalence criteria α , n and m . The accuracy of the calculated results and their reliability were evaluated using Van Genuchten (1980) equation by several important statistical criteria. The results showed that the soil moisture content of the soil differed according to the composition of the soil. It ranged from 0.57 to 0.19 cm^3/cm^3 for homogeneous clay soil and volumetric moisture content values between 0.42 and 0.11 cm^3/cm^3 for soil as well as 0.431 and 0.134 cm^3/cm^3 for the loam soil, a (sandy clay mixture) at the bottom and the upper clay layer, and it was between 0.374 and 0.126 cm^3/cm^3 when the bottom layer was clay and the upper layer was loam soil when the tensile strength changes from 0.1 to 1500 kPa.

Key words : Calcination, water retention curve, soils, moisture range.

Introduction

The Soil Moisture Retention Curve (SMRC) was used to describe the relationship between soil moisture content and matric suction (Lal and Shukla, 2004; Malaya and Sreedeeep, 2010; Heshmati and Motahari, 2012). It was one of the important features to determine water movement inside the soil, also it was useful to identify the behavior of unsaturated soil in the water supply of the plant and the extent of moisture retention as well as to identify the different moisture constants such as field capacity, permanent wilt point, especially for the type of soil as the soil water is molten with constant tension forces. These constants were useful in calculating the amount of irrigation water required, and the soil retention function can be expressed in water in different mathematical formats (Sreedeeep and Singh, 2005; Gallage and Uchimura, 2010; Shorafa *et al.*, 2010; Rao and Singh, 2010; Abbaspour *et al.*, 2012). The importance of the moisture retention curve was closely related to the

functions of unsaturated soils (unsaturated and unsaturated water solubility) and the water retention curve of the soil was presented in different ways either by choosing the water content or volumetric water content or the degree of Saturation (Fredlund, 2002; Fredlund *et al.*, 2011). Water content can be used in the practical applications of soil mechanics as well the use of volumetric content in theoretical and agricultural applications, soil density and moisture content are taken into account while the degree of saturation was the percentage of spaces filled with water which indicates soil density, moisture content and the proportion of spaces (Fredlund, 2002).

Numerous mathematical equations have been proposed to describe this curve based mainly on the distribution of pore sizes. These characteristics can describe the properties of soil moisture during specific tensile ranges, the most important of which was the Van Genuchten (1980) formula, which is widely used to describe the water retention curve (Leech *et al.*, 2006),

and even in organic soils (Naasz *et al.*, 2005), where it was possible to obtain a high correlation between measured and predicted data (Cornelis *et al.*, 2005) and the possibility of using it in the prediction of the value of unsaturated hydraulic conductivity, which can calculate the prevalence of water Soil water diffusivity. The Van Genuchten's formula (1980) was:

$$\theta = \theta_0 + (\theta_s - \theta_0) [1 + (\alpha\psi)^n]^{-m} \quad (1)$$

θ - Volumetric content at any tensile value (ψ) ($\text{cm}^3\text{-cm}^3$).

θ_0 - Primary Volumetric Content of Soil ($\text{cm}^3\text{-cm}^3$).

θ_s - Volumetric content at or near saturation ($\text{cm}^3\text{-cm}^3$).

ψ - tensile strength (kPa).

a, n and m are related to the curve (ψ) and the slope of the curve is dependent on the distribution of pore sizes.

The relationship between the m and n structures is as follows:

$$m = 1 - \frac{1}{n} \quad (2)$$

In the heterogeneous soils, water transfer through the layers such as water flow, water distribution, exchange and sedimentation processes were affected. The water is most affected at the boundary and across the layers. This means that water movement and then redistribution and assimilation of soluble matter will be affected (Shokri *et al.*, 2011) and Shokri and Saluvucci (2011) show that the movement of water and its redistribution in homogeneous and heterogeneous soils (soil of different layers of tissue) are related to the state of water and energy balance, the soil ecosystem, studies and research of the movement of water in the fields of soil Qat was a complex studies, so the researchers resorted to the assumption that a homogeneous soil to make it easier to solve the issue of water movement as well as easy to understand sports Alanmozjat ruling on this issue when describing the properties of water and water transport functions in the center Porous homogenized.

Materials and Methods

In this experiment, two samples of soil were taken from the sand dune station to combat desertification located in the Fajr area, 110 kilometers north of the Al Nasiriyah city in the south of Iraq (located between '00' 41° 31', 30' 44° 31' 49° 45' and 30' 53° 45' East). Soil samples were collected from the surface horizon Ap (0-30) cm, aerobic dried, grinded and sifted through a 2 mm diameter sieve. A representative sample was taken to

Table 1 : Some physical and chemical properties of the study soils.

Traits		Quantity	
Clay g/kg ⁻¹		232	572
Gluten g/kg ⁻¹		112	352
Sand g/kg ⁻¹		656	76
Tissue type		Loam	Clay
Virtual density mg.m ⁻³		1.45	1.21
Total porosity cm ³ .cm ⁻³		0.450	0.543
Saturated water conductivity		0.100	0.004
Volumetric moisture content		0.27	0.57
Volumetric moisture content		0.11	0.21
Ready water cm ³ .cm ⁻³		0.16	0.36
Cationic exchange capacity		21.03	31.26
Gypsum		5.3	6.81
Limestone		12.1	16.01
Organic matter		0.62	0.81
Soil reaction degree		7.23	7.35
Electrical conductivity		2.77	7.09
Positive soluble ions	Calcium	12.31	12.31
	Magnesium	15.23	15.23
	Sodium	4.31	4.31
	Potassium	6.21	6.21
Negative soluble ions	Chloride	11.31	11.31
	Carbonates	Nil	Nil
	Bicarbonate	3.12	3.12
	Sulfate	2.28	2.28

estimate some physical and chemical properties of the soil before the experiment according to the methods described by Page *et al.* (1982). Table 1 shows some physical and chemical properties of soil models.

Treatments

Homogeneous sand clay mixture (SCL)

Homogeneous clay (C)

Sand clay mixture-topped by clay soil C-SCL

Clay soil topped by sand clay mixture (SCL-C)

Soil water retention curves were obtained for homogeneous soil treatments by taking moisture content values at different shear strength values between 0.1 and 1500 kPa using 1 cm length rings for homogeneous soil and 2 cm length for tabled spacing. The samples were wet with poetic properties using boiled and cooled

water, there after flooded with water for 24 hours and then exposed to different water shear strength. The Haines-type apparatus used for shear strength 0.1, 2, 4, 6, 8, 10 kPa, and pressure disk drive for shear strength 20, 33, 50, 100, 500, 700, 1000 and 1500 kPa. Determination of moisture content mass at different shear strength and density and then the volumetric moisture content was calculated and the test was performed in three replicates. A fitting match to Van Genuchten's equation (1980) was done for the data of water retention curves and describe the relationship between θ and ψ using equation (1). Volumetric content calculations and corresponding water stress were performed. The water retention curve data for the soil models were computed to calculate the parameters of the water retention curve and to plot the relationship between the measured and computed values and the prepared water calculations using the SWRC Fit program, a program for the nonlinear matching of the water retention data and the relationship between volumetric content and water stress using 6 matching equations and the program runs in GNU Octave and works in a Linux environment.

Statistical criteria used to evaluate the accuracy of the corresponding results

Several important statistical criteria were used to evaluate the accuracy of the calculated results using the Van Genuchten (1980) equation and to evaluate the water transport functions and their salinity and development to predict water retention curves and to assess the accuracy of the measured and identical results and their reliability through several important statistical parameters (Homaei *et al.*, 2002; Khodaverdiloo and Homaei, 2002).

1. Determination Coefficient R^2 (a)

$$R^2 = 1 - \frac{\sum_{i=1}^n (\theta_i^m - \theta_i^f)^2}{\sum_{i=1}^n (\theta_i^m - \bar{\theta}^m)^2} \quad (3)$$

(Mohamed and Sahli, 2006; Obiero *et al.*, 2013)

2. Root Mean Squared Error of θ (RMSE) showed the accuracy of the corresponding results. The lower value, the more accurate the results:

$$RMSE_{\theta} = \sqrt{\frac{\sum_{i=1}^n (\theta_i^f - \theta_i^m)^2}{n}} \quad (4)$$

3. Coefficient of Determination (CD) * It is a

measure of the dispersion of values between the corresponding and measured values. The closer the value of the value, the more accurate the results:

$$CD = \frac{\sum_{i=1}^n (\theta_i^m - \bar{\theta}^m)^2}{\sum_{i=1}^n (\theta_i^f - \bar{\theta}^m)^2} \quad (5)$$

4. Modeling Efficiency (EF) is a measure of the comparison of the corresponding values with the mean of the measured values and their values are negative or positive. The negative values indicated that the measured values are the best representation of the water retention data of those corresponding values. Positive values indicated that the corresponding values are best in representing data from the measured values in terms of use of the Van Genuchten model:

$$EF = \frac{\sum_{i=1}^n (\theta_i^m - \bar{\theta}^{om})^2 - \sum_{i=1}^n (\theta_i^f - \theta_i^m)^2}{\sum_{i=1}^n (\theta_i^m - \bar{\theta}^m)^2} \quad (6)$$

5. Coefficient of Residual Mass CRM is the measure of the mathematical model where it is more or less than the corresponding values through its positive or negative values. If the values of the CRM coefficient are positive, it indicates that the measured data is greater than the corresponding data while negative value indicates that the corresponding values are greater than the measured values:

$$CRM = \frac{\sum_{i=1}^n \theta_i^m - \sum_{i=1}^n \theta_i^f}{\sum_{i=1}^n \theta_i^m} \quad (7)$$

6. Error Ratio (ϵ)

$$\epsilon = \frac{\theta^f}{\theta^m} \quad (8)$$

7. Geometric Mean of Error Ratio (GMER) was a measure that shows the average of the matching values and the extent to which they exceed GMER (1) or less (GMER < 1):

$$GMER = \exp\left(\frac{1}{n-1} \sum_{i=1}^n \ln(\epsilon_i)\right) \quad (9)$$

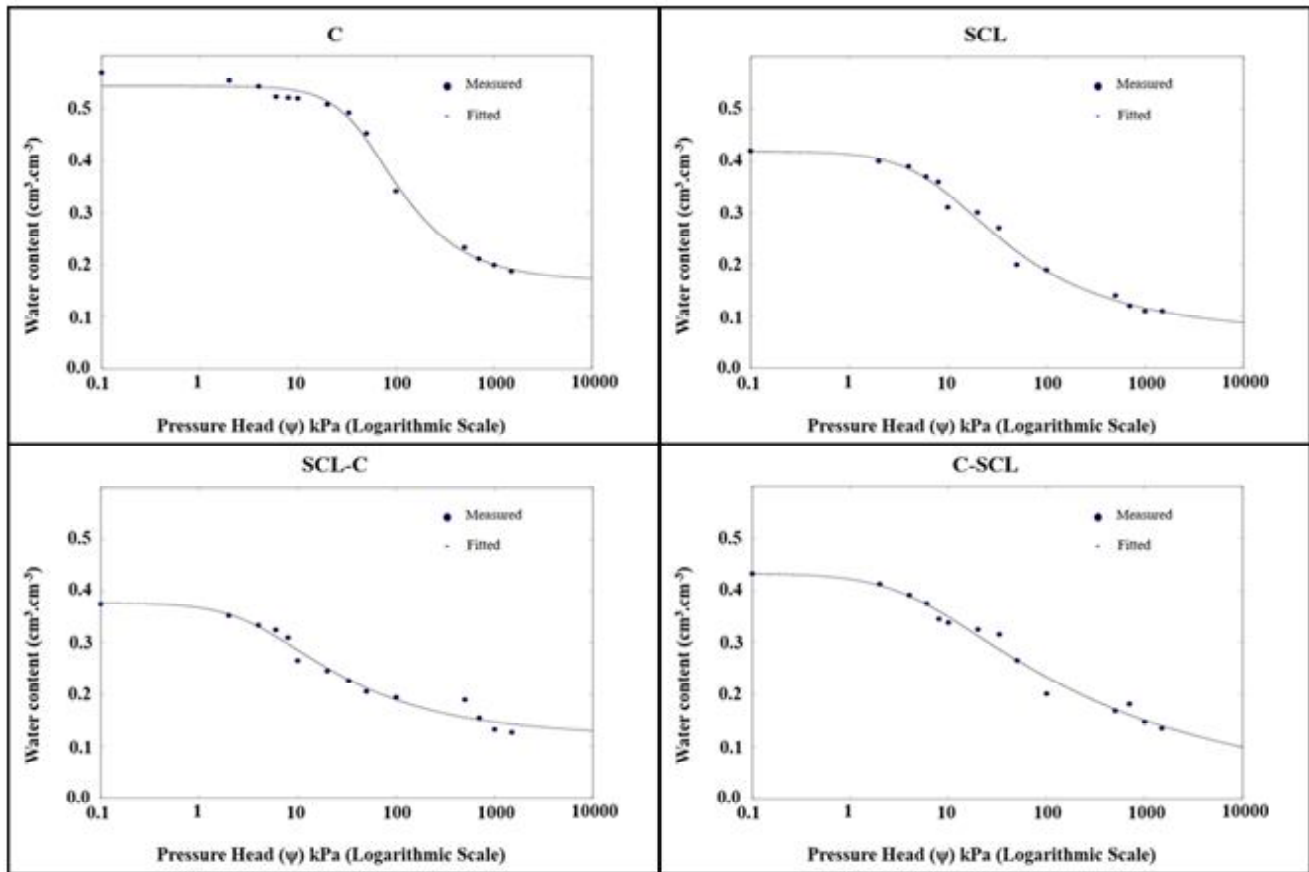


Fig. 1 : Matching the water retention curve data for the soil coefficients using the Van Genuchten equation.

8. GSDER Standard Geometry Standard Deviation of Error Ratio (GSDER), which is a measure of deviation around the mean and increases with deviations from measured values

$$GSDER = \exp \left[\left(\frac{1}{n-1} \sum_{i=1}^n [\ln(\varepsilon_i) - \ln(GMER)]^2 \right)^{1/2} \right] \quad (10)$$

As:

θ^m - Moisture content measured ($\text{cm}^3\text{-cm}^3$).

θ^f - Calculated moisture content values (matching) ($\text{cm}^3\text{-cm}^3$).

n - Number of experimental data.

Results and Discussion

Fig. 1 shows the water retention curve as a relationship between the structural soil effort ψ and the volumetric content for the soil models. The relationship data between ψ and θ was represented by applying Van Genuchten (1980), equation (1) to find the best match between the measured values and the matching values, as well as finding equation constants α , n and m (table

2). Fig. 2 shows the measured experimental data, and the graph represents the best match data promised as expected data. The statistical analysis showed a high correlation between the measured values and the matching values, where the values of the high-concentration parameter were significant while the square root values of the Mean Squared Error of (RMSE), which showed the accuracy of the matching results for small values and for all soil models (Table 2). The differences between measured and identical values and all used soil models and water use were simple and statistically insignificant differences, so that the matching values can be used to predict the water retention curves of homogenous soil treatments using the Van Genuchten (1980) model. These findings were in agreement with Reichle *et al.* (2004), Sepaskhah and Rafiee (2008), Abbaspour *et al.* (2012), Vishkaee *et al.* (2013), Jaiswal *et al.* (2013), Shwetha *et al.* (2013), Zolfaghari *et al.* (2013), Kang *et al.* (2014), Nagy (2014).

The results showed that increasing the amount of water held by the clay soil at a specific point of tension was greater than the amount of water held by the soil in a clay loam mixture. Volumetric content values ranged from 0.57 to 0.19 $\text{cm}^3\text{-cm}^3$ for clay soil and volume

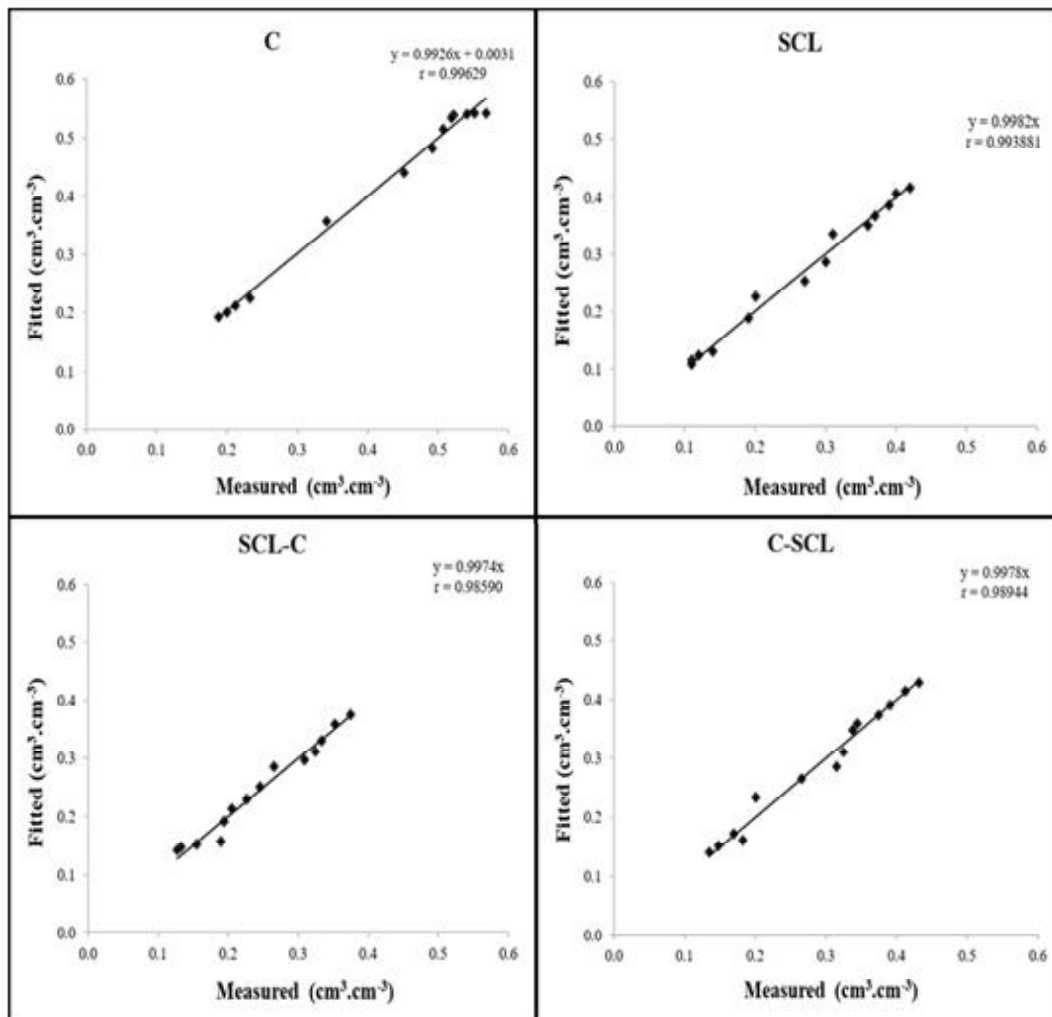


Fig. 2 : The relationship between the measured and calculated values of the water retention curve of the coefficients using the Van Genuchten equation.

moisture content values between 0.42 and $0.11 \text{ cm}^3.\text{cm}^{-3}$ homogeneous sandy clay soil at tensile variation from 0.1 to 1500 kPa . Soil retention increases as the size of minutes of soil separators increases as the tensile required to discharge the pores. When the size of the soil was smaller, the small pores increase and therefore the surface area increases the soil's ability to retain water which requires a greater tensile force to discharge the pores of this soil compared to the loam soil. Pore diameters in these soils are large, resulting in less water retention, so the tensile strength required to discharge these pores was lower than that of clay soils. These results are consistent with those indicated by Mehdi (2002), Qarni (2005) and Yunnan (2008). Hillel (2004) demonstrated that the percentage of water held in the soil increases towards the softness of the soil. Increasing the softness of the soil tissue increases the surface area of the soil and the percentage of fine pores, which increases the soil's ability to hold water in the pores at low and medium shear strength or as water membranes

around the soil atom, at high levels of shear strength. At the high wetlands, wetting changes occur in terms of the amount of water held. Pores are deposited and the water in the soil becomes a thin layer that encapsulates the surfaces of the soil atoms and their concentrations due to the water present in the adsorption phenomenon.

Figs. 3 and 4 shows the water retention curve of the soil. When a soil layer of loam soil presented under a layer of clay soil, the remaining moisture in this layer was higher than the remaining moisture if the layers were reversed. The soil moisture content values ranged between 0.431 and $0.134 \text{ cm}^3.\text{cm}^{-3}$ consisted of loam sandy clay at the bottom and upper clay layer, between 0.374 and $0.126 \text{ cm}^3.\text{cm}^{-3}$ when the bottom layer was clay and the top layer was clay loam mixture. In the first case, the amount of moisture in the upper layer increases with the softness of the tissue in the upper layer. In general, the low tensile values resulted in the discharge of the large pores found in the layer, a lower sandy clay

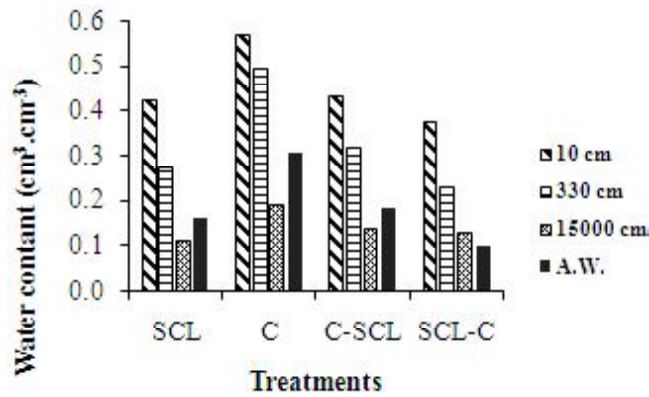


Fig. 3 : Effect of calcification in volumetric content at 0.1, 33 and 1500 kPa and ready-made water.

mixture and a small section of the upper mud layer pores due to the upper mud layer keeps the water in its pores with great force, this requires increasing the tensile tension on the soil sample to remove the water from the pores of the mud layer through the pores of the layer. In the case of the layers, the upper layer becomes a sandy mud-clay mixture. This system of soil leads to the withdrawal of water from the bottom layer clay and water was compensated out of the pores of the bottom layer of water in the layer of clay moss upper sand and continue this process by increasing the exit of water when the increased tensile tension and the moisture in the soil system. The less moisture in the event that the upper layer and the lower layer of mud sand. It is clear from the above that it is necessary to deliver any layer of existing soil to the tensile required to discharge pores, and that the tensile required to reach it increases as the size of soil separators was small, it is also clear that the layer was mixed clay sand when it lies under a layer of clay soil increases soil susceptibility to retain moisture.

Other statistical criteria were used to evaluate the data resulting from the application of the Van Genuchten (1980) model to evaluate the good compatibility of water retention curves and the accuracy of the computed results of the mathematical model and their validity and the reliability of the calculated results. Equations 5, 6, 7, 8, 9, and 10 were used to conduct the statistical assessment of water retention data. The coefficient of the CD definition (5) [a non-traditional coefficient has shown a high moral value, ranging between 1.0075 and 1.0285 (6) [positive values only]. This indicates that the computed values of Van Genuchten (1980) model are best in representing the retention curve data and this indicates that the actual measured values are best in representing the data of water retention curves (Hoomae *et al.*, 2002; Khodaverdiloo and Hoomae, 2011). The values of the remaining mass factor (CRM)

differed (7) according to different soil parameters and showed two negative values in SCL and SCL-C which indicates that the computed values were greater than the measured values, while the other parameters showed positive values for the CRM parameter. The measured data was larger than the computed values. As for the error ratio (ϵ), the values were slightly more than 1 but close to 1. The engineering rate of the GMER error ratio (9) [the values were all slightly greater than 1 and this indicates that all the soil models were mean calculated values (matching) are less than measured. Finally, the geometric standard deviation of the GSDER error ratio (10) was all greater than 1. This indicates that all the coefficients were around the arithmetic average by slightly deviating from the value of 1 (table 3). Additionally, fig. 2 shows the relationship between the measured and computed values of the data of the water retention curves at different gradients of different soil treatments showing the high degree of convergence between measured and calculated values using Van Genuchten (1980) model.

Fig. 1 shows a significant difference between the water retention curves of the different soil models due to different parameters, and the volumetric content decreased with increasing ψ and all soil models. At a water voltage of 0.1 kPa, it represents water content in the saturation state θ_s . The values of θ_s differed according to the different treatments. The values of θ_s were 0.420, 0.568, 0.432 and 0.375 cm³.cm⁻³ for treatments SCL, C, C-SCL and SCL-C, respectively. Soil samples lost different amounts of water when the structural soil voltage changed from 0.1 to 33 kPa. The volumetric content which retained soil at 33 kPa, differed from sample to another depending on the change in the coefficients. The amount of water retained at this tensile was 0.270, 0.492, 0.315 and 0.226 cm³.cm⁻³ for soil treatments SCL, C, C-SCL and SCL-C, respectively.

Changing shear strength of soil to 1500 kPa resulted in different residual volumetric content θ_r between different soil treatments. The θ_r was 0.110, 0.188, 0.135, and 0.127 cm³.cm⁻³ for soil treatments SCL, C and C-SCL and SCL-C, respectively. The amount of water in the soil depends on the volume distribution of the soil atoms and the specific surface area. The values of θ_r was increased by the softness of the volume distribution of the soil atoms. This increase was related to the increase of the soil surface quality of the soil separators. Soil in these conditions depends on the absorbance characteristic and therefore the amount of water retained increases with the increase in the surface quality of the soil atoms (Startsev and McNabb, 2001; Chan, 2005). One of the indications of the water retention curve was

Table 2 : Values of the Van Genuchten equation (α , n and m) for water retention curves and residual volumetric moisture content values θ_r , saturation θ_s and values of best match criteria (RMS and R2) for homogeneous soil.

Treatments	$\alpha(\text{cm}^{-1})$	n	m	$\theta_s(\text{cm}^3.\text{cm}^{-3})$	$\theta_r(\text{cm}^3.\text{cm}^{-3})$	R^2	$\text{RMSE}_\theta(\text{cm}^3.\text{cm}^{-3})$
SCL	0.014388	1.4017	0.2866	0.4200	0.1100	0.9879	0.01233
C	0.002014	1.8239	0.4517	0.5684	0.1883	0.9926	0.01228
C-SCL	0.029103	1.1891	0.1590	0.4319	0.1349	0.9794	0.01428
SCL-C	0.031455	1.3633	0.2665	0.3745	0.1268	0.9727	0.01318

Table 3 : Statistical criteria to evaluate the accuracy and the relationship between the measured and expected results.

Parameter						Treatments
$\epsilon_{\text{average}}$	GSDER	GMR	CRM	EF	CD	
1.002585	1.054524	1.001258	-0.000016	0.012112	1.012261	SCL
1.000635	1.027937	1.000283	0.000010	0.007401	1.007456	C
1.003721	1.065246	1.001855	0.000034	0.021029	1.021481	C-SCL
1.005270	1.077465	1.002736	-0.000002	0.027290	1.028056	SCL-C

to know the soil's water retention capacity, which is called water-ready A.W. The water content was 0.160, 0.304, 0.178 and 0.099 $\text{cm}^3.\text{cm}^{-3}$ for soil treatments SCL, C, C-SCL and SCL-C, respectively. Fig. 3 shows the effect of calcination on volume moisture content (the amount of water held by the soil) at 0.1, 33 and 1500 kPa and ready-made water.

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