



Influence of the inclusion of synthetic compounds on the plasticity of kaolinitic clays

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Abstract

Clay soil is typically an electrically charged porous tissue whose behaviour is dependent on possible variations in the composition and concentration of the interstitial water. Various complex mechanical impacts can be generated from the physicochemical reactions produced within the compact sets of elongated sheets, often called tactoids. If the chemistry of the used fluids varies appreciably, the natural response to cation exchange is affected, which results in intense physicochemical effects in the soil. In this article, five synthetic agents (Al_2O_3 , Fe_2O_3 , NaCl , CaCO_3 , and $\text{C}_2\text{H}_5\text{OH}$) were included in the kaolin, in different proportions, to explain the influence of the chemistry of these fluids on the chemical-mechanical behaviour of the clay soils. The artificial inclusion of these agents indicated specific changes in the material structure and the known paths of the fundamental Atterberg constants, ranging from the substantial reduction in plasticity according to the oxidizing agents to the considerable increase of this property monohydric solution.

Keywords Atterberg limits · Specific surface · Electrochemical attraction · Diffuse double layer

Introduction

The primitive morphology of soils, their classification, and characterization have covered the initial structure of research on soil behaviour for decades, providing possible solution predictions that are pretty accurate on their response framework (Ponzoni et al. 2014; Xu and Coop 2017). It is relevant to understand that, to generate these theoretical analyses about their performance under specific conditions, it is necessary to place the physical and chemical characteristics of the soil within narrow limits (Odell et al. 1960). It is feasible to build

a correlative framework in which the mechanical properties of soils are directly related to their physicochemical skeleton (Smith et al. 1985). Studies between physicochemical (Banin and Amiel 1970), hydraulic, and mechanical properties (Mortland 1954) expose a strict codependence between particular parameters of the soils. Volumetric change is a function of the shear strength at the level between particles (Sridharan and Rao 1973). The attractive forces operating in a clayey water system affect the physical components that influence the swelling behaviour of the clays. These physicochemical mechanisms contribute substantially to the shear strength of kaolin. However, it is possible to experimentally cause variations in these forces by changing the water solution.

The increase in water content in soil with a fine granular structure brings a transformation of state: semi-solid to plastic and finally to liquid. The existing boundary between the semi-solid and plastic states is called the plastic limit, and the border between the plastic and liquid consistency corresponds to the liquid limit (Jong et al. 1990). The collective name of this pair is known as Atterberg's limits. The Atterberg limits were used in the first investigations on soil tillage (Dolinar et al. 2007), where the liquid limit was prescribed in parametric terms of the crop. However, the primary use of Atterberg limits has been within the classification of soils for engineering purposes.

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The central importance of determining these limits lies in the ease of expressing the interaction between the solid and liquid phases of soils quantitatively. In simple words, it means studying soils employing a standardized classification based mainly on their similar mechanical characteristics (Wesley 2003). In most cases, these limits provide some important information to guess the trajectories of different constitutive parameters of the soil, such as deformability, hydraulic conductivity, mechanical resistance, and swelling. Within the current state of the art of the subject addressed, it is widely known that Atterberg's limits commonly depend on the mineralogical properties of the soil. However, this premise is not applicable in a global setting. Several investigations (White 1949; Farrar and Coleman 1967; Rao and Sridharan 1985) observed the direct relations between the limits and the autochthonous characteristics of certain soils. The results varied considerably and were valid only for limited samples.

The interparticular chemical-mechanical behaviour can estimate the response of soil to variations in chemical compositions or molecular concentrations of interstitial water, producing alterations at the contact interface between the soil matrix and porous hydraulics (Sridharan 2014). This range of alteration describes the physical-mechanical properties of fine-grained soils and strongly influences soil hydromechanics. Currently, the chemical-mechanical spectrum of clay has received considerable attention. Various experimental approaches have been studied on the shear strength paths and volumetric strain of clay soils exposed to different saline solutions (Witteveen et al. 2014; Wahid et al. 2011).

Regarding chemical transport in clays with a high expansivity index, it varies according to the diffusion for anions and cations. Similarly, this phenomenon is related to the porous geometry and tubular dimensions that shape clay-ion interactions (Bourg et al. 2003). The approach addressed by Sedighi and Thomas (2014) evaluates microscopic instability in expansive clays through geochemical formulations of hydration and dehydration between smectite layers. Although significant advances have been made in the mechanics of unsaturated soils, physicochemical effects on the clay laminar matrix are rarely studied.

The physical and chemical properties of any substance depend mainly on the exposed surface area of the contact. In

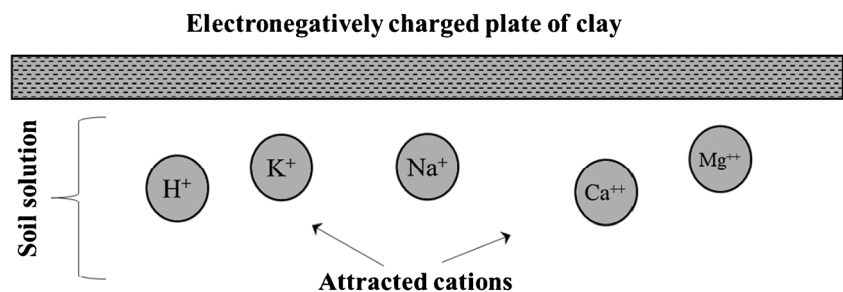
natural soils, properties such as cation exchange capacity (Figure 1) and conductivity are related to the amount and type of clay present, in addition to their specific gravity and porosity, i.e., they are directly related to the specific surface area (SSA) (Mortland 1954). The specific surface area expresses, in a simple way, the reactive potential of clays, being directly proportional to water content, suction, and pore size distribution (Tuller and Or 2005). The relation of Atterberg limits and the SSA can generate a spatial observation of the behaviour of the clay in multiple solution compositions. Since, for a significant number of fine soil types, the water suction values at the liquid limit are similar to each other (Russell and Mickle 1970). This means that the proportion of water adsorbed by the specific surface must be approximately the same at the liquid limit (Dolinar et al. 2007).

The individual contributions of capillarity and surface forces of adsorption rarely differ in the domain of Atterberg's limits. Generally, the water adsorption processes of clays such as kaolin are closely linked to the structure of the aqueous solution and its interaction with the specific surface. Thus, this research deals with Atterberg's limits in different scenarios, where the electronegative imbalance of the clay sheets is alleviated with the artificial inclusion of cations of different compounds. Such imbalance generated relations with the boundary conditions of the SSA and the attractive forces of the kaolin, which lead to identifying their influence on the plastic properties and the response framework of the material under engineering loads.

State of the art

In most current constitutive models that try to explain the mechanical behaviour of the soil through Atterberg limits (Nagaraj 1986; Wroth and Wood 1978), we can appreciate the shear resistance in the undrained condition in the liquid boundary of clay soils. This resistance can be considered unique and univocal with the plastic limit. If the soil assumes a distinctive state, then the water volume in liquid and plastic limit may also be uniquely related. In basic soil mechanics, the liquid limit is a quantitative indicator to define that soils under this moisture content have approximately the same undrained

Fig. 1 The cation exchange capacity of clays



resistance, around 25 kPa, which is too low (Casagrande 1932). For the most part, these researches have related various physical-chemical properties of clay soils with mechanical reactions in their behaviour to identify the degree of influence on the cation exchange of clays due to the exposure of more exchange positions and a concomitant increase in the SSA (Kelley and Jenny 1936; Reeve et al. 1954).

Multiple researchers have prescribed their results in terms of Atterberg limits, intending to expose soil characteristics more simply. Saikia et al. (2017) predicted the compaction characteristics of fine-grained soils as a function of Atterberg's limits. Al-Khafaji (1987) proposed a simple method to determine the optimal moisture quantitatively based on clay content and liquid limit. Each result is obtained through equations and constitutive models governed by the laws of attraction forces and the magnetic configuration of the clay bodies. In the control of the thickness of the adsorbed water film, the role of Van der Waals forces leads to the related postulation of proportionality between the water content and the specific surface of a certain type of clay (Ross 1978).

The guidance reviewed by Liu (2013) developed a mechanistic model capable of predicting the expansion of bentonite materials saturated in distilled water and dilute solutions. Ma et al. (2016) formulated a conceptual constitutive model to explain the influence of chemistry on clay hydraulics and its effects on the chemical-mechanical behaviour of unsaturated cohesive soils. Research by Gratchev and Towhata (2011) presented a systematic analysis to establish whether acidic pore fluids can affect the osmotic expansion properties of clayey soils. Constitutive models based on clay volumetric differential due to variations in chemical composition have been widely studied (Loret et al. 2002, 2004; Hueckel 2002; Gajo et al. 2002; Gajo and Loret 2003; Guimarães et al. 2007; and Gens 2010).

Studies based on the percentage variations in the expansive capacity of clays under specific aqueous conditions (Nagaraj et al. 1991; Mitchell 1993) express that the hydraulic conductivities of different clays are approximately equal at the liquid limit when the proportionality of the solutions is gradually changed. The plasticity of fine soils in soil mechanics is expressed by Atterberg limits, which have an inverse relation with hydraulic conductivity since increasing plasticity achieves a reduction from this. Nishida and Nakagawa (1969) established that hydraulic conductivity should be predicted from the plasticity index. That means that variations in the solution in which the phenomena of hydraulic conductivity and capillarity (suction) develop to affect the parametric reactions of the Atterberg limits.

Numerous techniques are used for different purposes, improving soil behaviour and the elemental composition and plastic potential (Edil 2003). Soil treatment using synthetic compounds, mainly oxides derived from metal, calcium, and sodium ions, can reduce the expansive response of clay soils.

Chen et al. (2020) studied the influence of calcium carbonate (CaCO_3) on the strength and microstructure of red clay using proportions from 0 to 20% on direct shear tests. On the other hand, Islam et al. (2020) determined the impact of CaCO_3 induction through biologic processes on the plasticity of clays.

Regarding the inclusion of Avant-Garde Materials, Taha and Ying (2010) reported that carbon nanotubes to kaolinite soil increase the plasticity index, results that corroborate what was stated by Taha (2009). Likewise, Majeed and Taha (2012) explored the effects of nanoclay inclusion in proportions of 0.1%, 0.2%, and 0.3%, on the swelling mechanics of organic soils with low plasticity, describing a decrease in the values of the Atterberg limits and the plasticity index (PI). Bahmani et al. (2014) investigated the impact of nano-silica in quantities of 0 to 1% with steps of 2% in the Atterberg limits of clay soils stabilized with cement, showing a reduction of the PI.

Synthetic compounds such as CaO used to study the numerical fluctuation of the Atterberg limits are widely reported in the literature. Bozbey and Garaisayev (2010) evaluated the mechanical properties of specimens stabilized with CaO in different amounts. The results showed significant variations in the plasticity index after the application in expansive clays. These clays tend to react readily with CaO, losing plasticity immediately. This behaviour is frequently described in various researches (Akbulut and Arasan 2010; Boardman et al. 2001; Consoli et al. 2011; Dash and Hussain 2012).

The use of oxidizing agents as a means of numerical evaluation of expansivity has been extensively documented. In this perspective, artificial stimulation of clays with aluminium oxide (Al_2O_3) can increase the utilization of clay in the technology and construction industry (Esharghawi 2009). Mesrar et al. (2015) carried out a physicochemical characterization of clay soils after injecting metallic oxides in proportions of 5%, 10%, and 15%. The results indicated a decrease in the plasticity index in percentages of 5% of Al_2O_3 and higher contents (Abdrakhimov and Abdrakhimova 2019), and Abdrakhimov and Abdrakhimova (2017) explored the behavioural spectrum of soils with the presence of iron oxide (Fe_2O_3).

There are still constitutive equations based on functions that need parameters representing the hydraulic conductivity in terms of the SSA of clays to predict the behaviour of Atterberg's limits (Dolinar 2009; Malusis et al. 2003; Roque and Didier 2006; Ilek and Kucza 2014). Many of these equations are based on the assumption that hydraulic conductivity can be predicted from constituent parameters in the mechanical behaviour of clays. These parameters can be used via correlations to interpret the Atterberg limits. At present, reduced investigations attempt to express the overall response of clays through the interaction between the solid and liquid phases.

The diffuse double layer (DDL) behavioural mechanics and its influence on the expansive properties of clay soils are well defined since its principle is to preserve electrical neutrality when an ionic counter-charge is accumulated on the

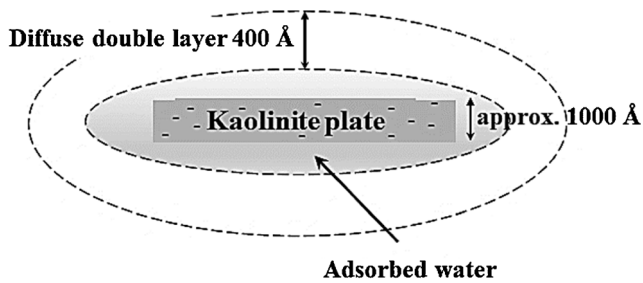


Fig. 2 A particle of kaolinite

surface of the clay (Schmitz 2006). Many response spectra of clays can be explained and analysed based on the DDL. As the thickness of this layer is modified, the cation exchange properties and the internal flow paths fluctuate substantially. The determination of the DDL provides a spatial observation of the degree of expansion in the cohesive soils since it has a close and codependent relation with the SSA (Figure 2) and the Atterberg limits (Dolinar et al. 2007).

During the last two decades, there has been an intense effort to develop models capable of describing the innate response of DDL, under different frameworks, as a way to explain the hydromechanics coupled to cohesive soils (Tripathy et al. 2004; Mitchell and Soga 2005; Likos and Lu 2006; Schanz et al. 2013; Sedighi and Thomas 2014; Bharat and Sridharan 2015; Puppala et al. 2017).

Agus and Schanz (2008) exhibited an approach to predict the volumetric change of bentonites based on thermodynamic relationships between expansion pressure and suction and their influence on DDL thickness. Some assumptions used in this approach were defined in more detail in Tripathy et al. (2004). Microscopic expansivity effects on hydraulic behaviour have also been considered using the DDL approach (Xie et al. 2004).

Approaches centred on DDL theory have long been used to define the expansivity behaviour of clay structure (Komine and Ogata 2003; Schanz and Tripathy 2009). However, most of these models are based on a simplified system of two clay platelets as a physicochemical concept of interaction. The evolution of DDL thickness is directly influenced by both the water

content chemistry and the dry density of a given clay typology, as presented in the manuscript by Baille et al. (2010).

Many of the models that relate the DDL and the SSA use constitutive parameters that are widely studied, such as hydraulic conductivity or void ratio. These parameters, which are currently included in many numerical models, facilitate interpreting results (Mojid et al. 2007). However, the prescription of the constituent models in terms of the DDL depends on materials' mineralogical nature and inherent characteristics. Thus, each numerical analysis must be adapted to different materials using constitutive correlations (Tripathy et al. 2004; Laird 2006).

Materials and methods

Characterization of the material

The estimation of the particle size distribution was carried out employing the integral measurement of the pressure in the suspension (ISP) method to obtain a complete characterization of the physical structure of the kaolin. This method allows determining particle diameters from 0.00001 to 0.002 mm. The results are presented in Figure 3. In addition, the value of the specific gravity of the material is presented.

Kaolin dissociation has been characterized by the X-ray diffraction (XRD) technique, whose application is one of the most used methods to study nanocomposites' structure and identify the character of dispersion of the clay within the polymeric matrix concretely. Table 1 shows the XRD patterns in the kaolin laminar nanostructure.

To obtain an approximate excitation for a wide range of chemical components within kaolin, the use of X-ray fluorescence (XRF) spectral data considers a set of data based on the photoelectric effect that identifies the characteristic orbital paths of a given element and, with the peaks in the spectra, determines the elemental concentrations. The chemical composition is found in Table 2.

Fig. 3 Particle size distribution curve of the kaolin

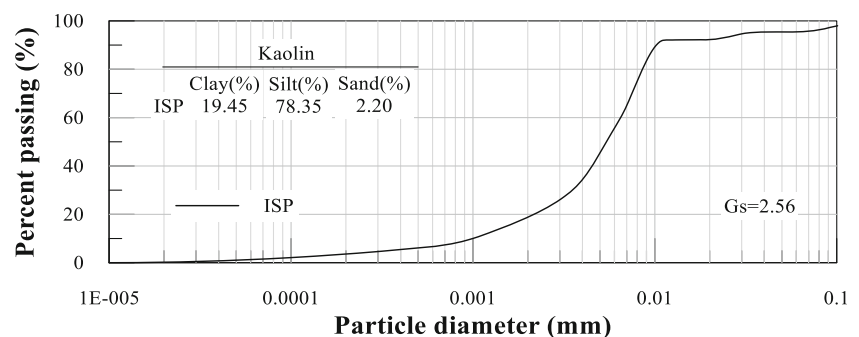


Table 1 Mineralogical composition by XRD

Minerals	Kaolin (%)
Quartz	52.69
Kaolinite	36.48
Illite	9.75
Montmorillonite	1.08

Table 3 shows the values relative to plasticity in the original material, not including any influence of synthetic compounds.

The configuration of DDL and SSA in kaolin is due to the aqueous solution and its internal composition, reflecting the variations in the thickness of the DDL (Olarte and Ruge 2020). When the thickness of the DDL increases, the adsorption capacity of the clay will grow proportionally. The different current imaging techniques allow a dimensional and spatial approach; in general, it is about the processes that occur in the microstructure of the clay body. Figure 4, in a micro-dimensional approach, shows the contact interface between kaolin and Fe_2O_3 molecules (iron oxide) in a 40% solution, in addition to its mineral construction of large particles in the form of sheets stacked together in agglomerates. The Fe_2O_3 corpuscles inhibit the increase in thickness of the DDL, so the plasticity index (PI) of kaolin shows a tendency to decrease the solution's higher percentage.

The soil particle distribution tends to be randomly narrow in the sample without synthetic disturbances (Figure 4, left). However, it can be seen that the structural assembly loosens when iron oxide is added (Figure 4, right). The figures show that the circular-shaped iron oxide particles and the clayey tactoids have different shapes. When iron oxide is incorporated into the kaolin microstructure, these molecules become embedded in the soil layers, destroying the original laminar layer and reducing the particular plastic configuration of the soil.

Plasticity tests

The geotechnical characteristics of kaolin are identified by measuring Atterberg limits. For this case, through empirical tests based on the standard ASTM D4318-17e1 (2017), both the plastic limit (PL) and the liquid limit (LL) were calculated under different types of solutions (Figure 5).

Table 2 Chemical balance according to the results of XRF

Oxides retained (%)								
SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	Na_2O	P_2O_5	TiO ₂
61.16	18.92	3.71	0.12	1.70	1.67	0.91	0.95	0.53

Table 3 Physical properties of the kaolin

Kaolin	LL (%)	PL (%)	PI (%)
	36.7	23.9	12.7

In the local context, the standards analogous to ASTM are those structured and organized by the *Instituto Nacional de Vías* (INVIAS): INV E-125-13 for “Determination of the Soil Liquid Limit” and INV E-126-13 for “Plastic Limit and Plasticity Index of Soil”. The competence was gradually increased for these solutions, from 10 to 40%, following the procedural standardization regulated. However, for the iron oxide (Fe_2O_3) and the aluminium oxide (Al_2O_3), it was calculated in powder by weight at the same percentage and mixed with kaolin. The proportions of oxygen in these compounds coerce their oxidation, transforming them to their insoluble state. The experimental stage includes the variation of solution percentages (10, 20, and 40%) to identify the behaviour of DDL, which is affected by the dosages used, and the values of Atterberg limits evidence these.

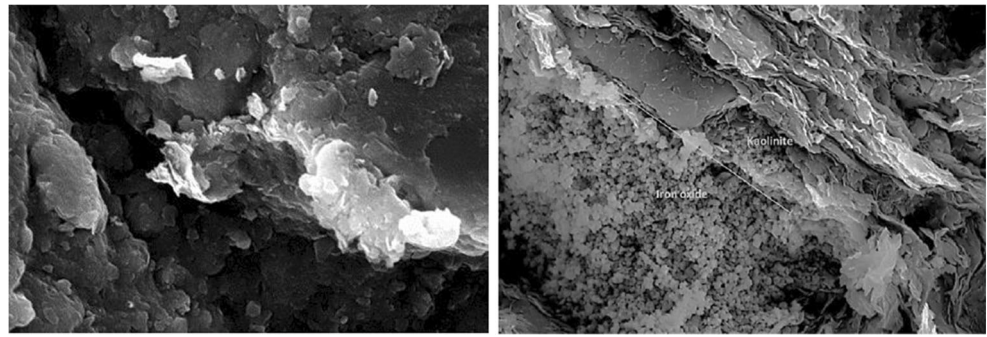
The competence of each synthetic compound in trial-and-error prototypes was gradually increased, from 10 to 40% with steps of 10% in distilled water. For each test of the Atterberg factors, five (5) replicas of each agent were used by percentage to obtain enough information on the plasticity of the kaolin of each one of the controls after the tests (Figure 5).

Results and discussion

Figures 6, 7, and 8 show the LL and PL results executed as dictated by ASTM D4318-17e1. This, to capture realistic results in the material evaluated, it was decided to plot the results using two ratios (LL vs PL, LL vs PI) because these charts define the plasticity of the material, as is done in the traditional soil mechanics.

Interestingly, almost all the materials included artificially (10%) produce a slight decrease in LL, except for inclusion with pure ethanol, which is usually known as alcohol (Δ - $\text{C}_2\text{H}_5\text{OH}$). This can be explained logically since the addition of hematite or iron oxide ($\text{O-Fe}_2\text{O}_3$) and alumina or aluminium oxide (∇ - Al_2O_3) is done by a dry path. Adding a granular form material is almost like adding fine sand to the mixture.

Fig. 4 SEM image of the soil studied (left) and SEM image of the soil with iron oxide (right)



This clearly impacts the plasticity of the kaolin, decreasing its LL and LP.

The presence of common salt or sodium chloride (\square -NaCl) in the mixture and its incidence in the decrease of plasticity is clearly explained, due to the sodium which is an element that generates dispersion in clayey materials, even it is used when you want to impose deflocculating in the sample as in hydrometric tests. Similar results were reported by Marks III and Haliburton (1970) and Singh and Das (1999), with reductions of 5% in NaCl contents of 1–5%. The results showed optimal values of NaCl content to modify clays with high plasticity in compaction tests.

Likewise, with the addition of calcium carbonate or calcite (\diamond -CaCO₃), this response was expected since it is a material that is added to stabilize the cation exchange of clays. Regarding ethanol, it is suspected that this inclusion generates an increase inside the clay material within cation exchange capacity (CEC), and ethanol ions become part of the attraction of DDL, causing a slight increase in LL. However, the increase in PL is a little more noticeable.

The amount of the percentage of the solution was gradually increased in each test. This increment can be found in Figs. 7 and 8, where the influence of the components reaches 20% and 40%, respectively. In particular, the behaviour of soil

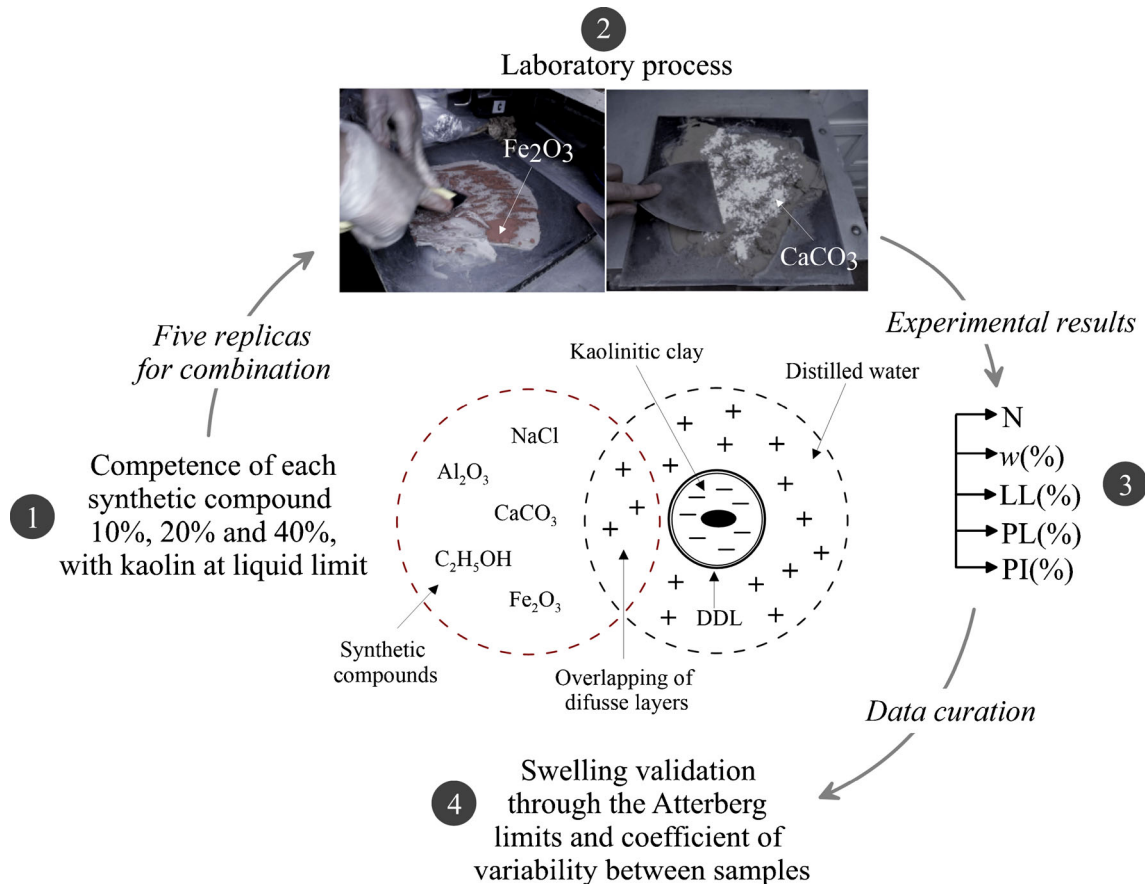


Fig. 5 Methodology for the solution design

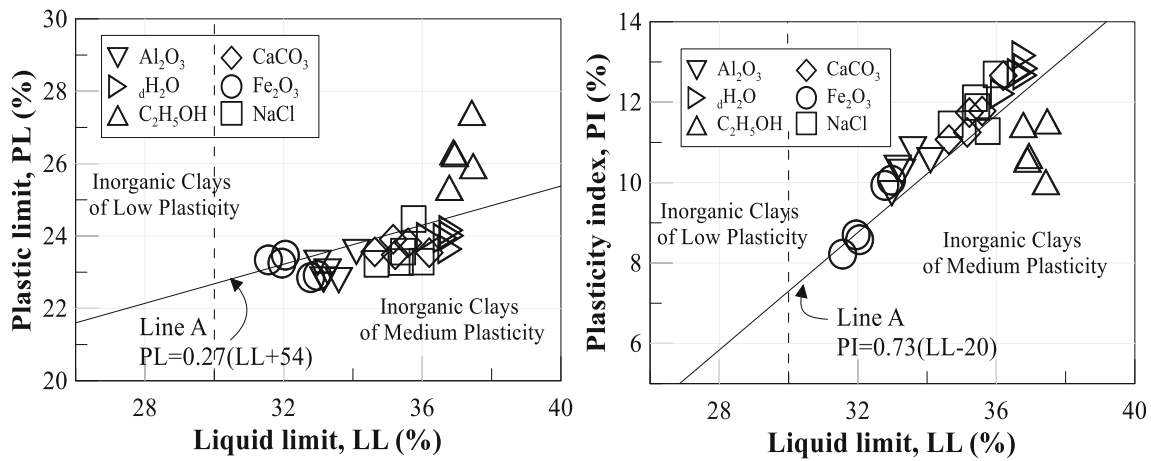


Fig. 6 Results for artificial material content of 10%

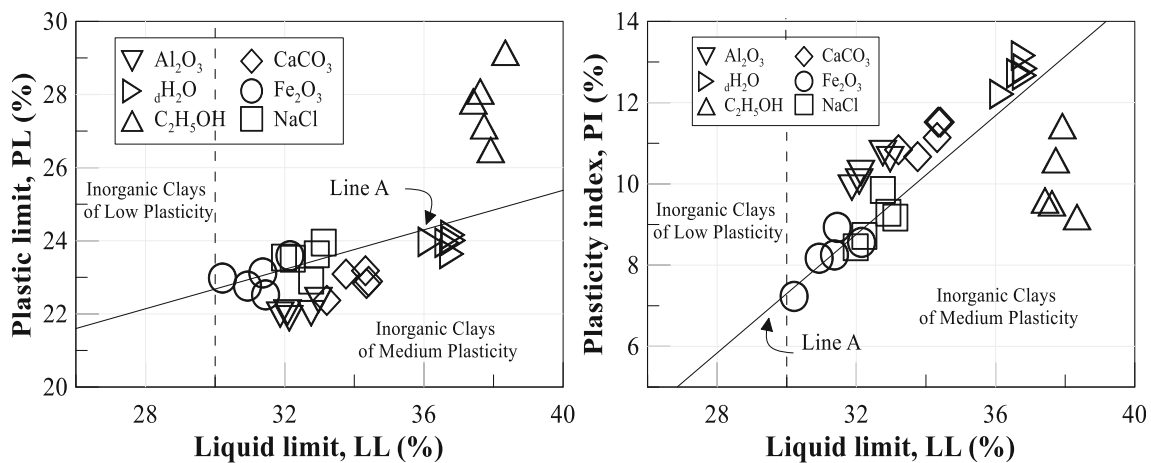


Fig. 7 Results for artificial material content of 20%

located in the frame of the Casagrande plasticity chart moves from a medium to a low plasticity zone. However, this premise does not apply to the solution of ethanol since it is simple monohydric alcohol. In other words, it has only one hydroxyl group, and it responds as the mechanism responsible for the

interlaminar retention of non-ionic polar molecules, which increases the plasticity of the clay.

When the representativeness of the compounds addresses high percentages, the status of clay is potentially affected since the behavioural trend is directed to the low band of line A, where the structural characteristics of the silts predominate. In

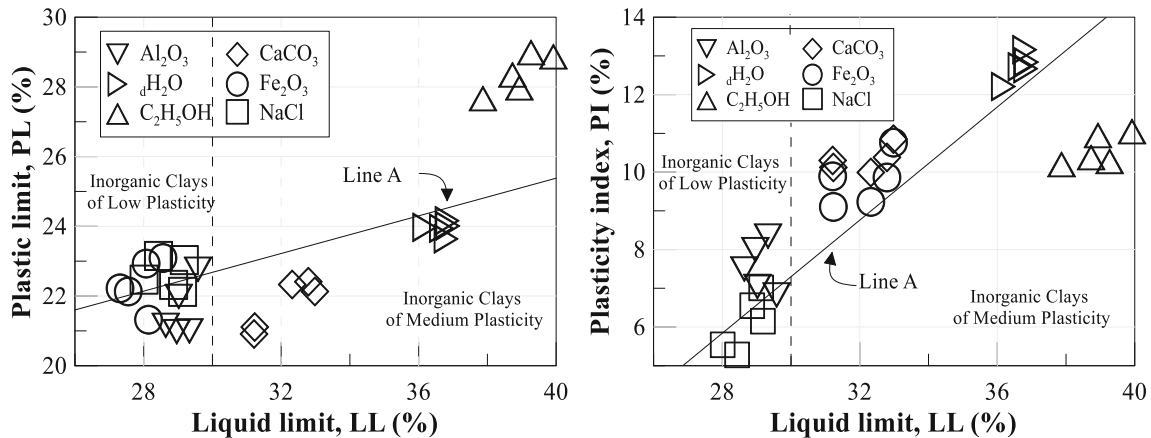


Fig. 8 Results for artificial material content of 40%

the graphs that correlate the LL with LP, as the percentage of CaCO_3 increases, the LL is reduced because the Ca ions displace the fixed ions from the clay surface and trigger, in turn, a reduction of the electrical potential, maintaining the concentrations of the soil solution over the flocculation levels of the clay particles (Keren and Ben-Hur 2003; Montejo et al. 2018).

In high proportions, the Al atom is more efficient than Fe to reduce the expansivity of clays since Fe ions must attack the clayey lattice to diminish the CEC. This can be seen in

Figures 6, 7, and 8 of LL vs PI. In most cases, the LL decreases considerably and, in others, remains constant. Consequently, plasticity decreases. The percentage reduction of approximately 3.5% in the final plasticity index for the samples added with Al_2O_3 is comparable with the reduction obtained by Mesrar et al. (2015) for an Al_2O_3 injection of 5% in Miocene soils.

The relationship achieved between each of the percentages concerning the synthetic is shown in Figure 9. The trend of

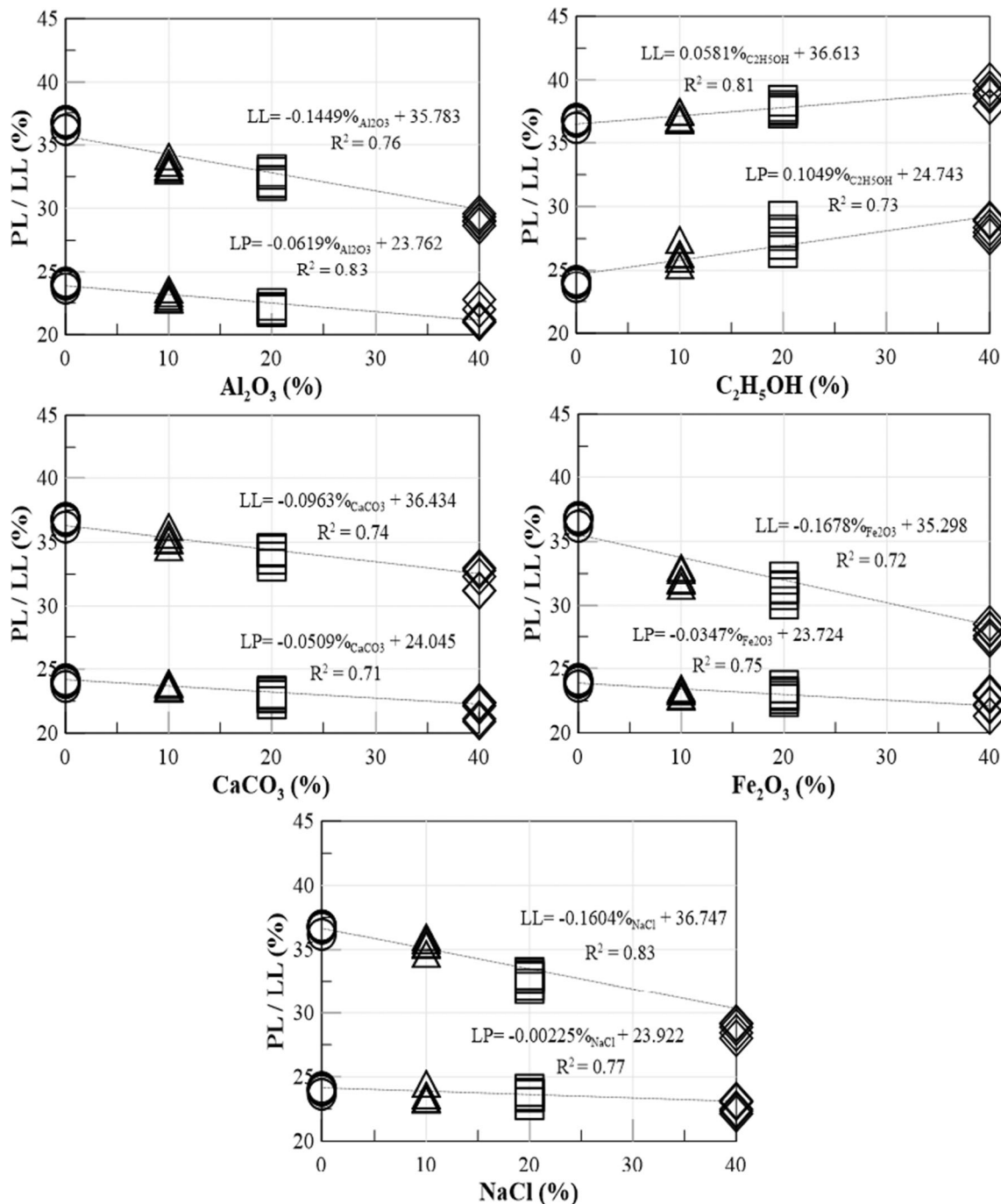


Fig. 9 Trends between relationships LP/LL vs quantity of compounds

decrease in the plastic potential of kaolin in 80% of the synthetic compounds used can be observed by using a descriptive examination. Based on the equations set out in Figure 9, the regression relationships for each compound were evaluated by means of the coefficient of determination, R^2 . The intersection term forced to zero of the results in the comparison points (LL and PL) shows good agreement, with R^2 values greater than 70% in all correlation lines, which indicates that the trend of numerical clustering between replicates for the evaluated Atterberg factors is significantly similar. The appropriate correlation within the data set in each compound can be attributed to the fact that this statistic is determined under the same procedural principle, so that the influences generated by the intrinsic errors of the standard are minimal.

This reduction varies approximately in a range of 5 to 6.5%, the highest being the one obtained using 40% of CaCO_3 , indicating a significant decrease in the thickness of the DDL. However, in the case of $\text{C}_2\text{H}_5\text{OH}$, this trend is increasing by the growth in the content of $\text{C}_2\text{H}_5\text{OH}$ in the solution, since, during the cation exchange process, the alcohol molecules with a single hydroxyl group are particularly responsible for interlaminar retention of non-ionic polar molecules, which increases the PI, the LL, and the size of the DDL.

The data obtained for the scattering of the samples provided additional information on the expansivity behaviour of the kaolin and synthetic compounds, with values of 5–25% variation for each Atterberg factor. On average, the mechanics of the results ranged substantially for the plasticity index (PI) in each of the solution arrangements, with this being the highest range of variability among all samples. This physicomchanical response of the clay is primarily due to the nature of the porous flow. The higher the percentage injected into the interparticular medium, the greater the variation between synthetic components, and therefore, the scatter between tests increases (Figure 10).

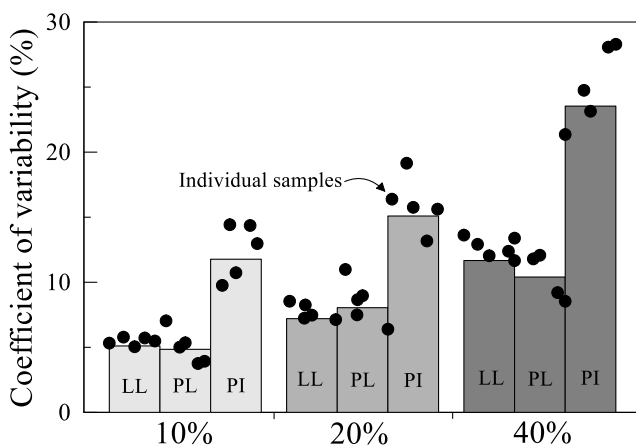


Fig. 10 Coefficient of variability between samples

The replicas for each agent corresponding to the liquid limit, in general, coincided quite well between the values obtained experimentally, so there is low numerical differentiation. Regarding the plastic limit, the degree of variability between repetitions for all percentages was neither the highest nor the lowest but constant, which means that the chemical composition of the flow affects the expansivity in the same proportion, regardless of its level of applicability.

Conclusions

It was effectively evidenced that the addition of artificial materials to a kaolinitic clay produces changes in the microstructure of the DDL, directly influencing the values of physical parameters such as the LL and LP. This was accentuated as the artificiality gradually increased in percentage.

In general, the thickness expansion properties of the DDL tend to be affected because, in the field of interaction, condensation occurs on the surface of the clay; this was a product of hydrolysis at the moment of contact. These coatings in the surface area of the clay body inhibit the proliferation of sufficient ions from carrying out cation exchange. For this reason, when the concentration of the solution increases, the expansive mechanics of the clay decreases, being such a decrease more substantial by these sesquioxides (Fe_2O_3 and Al_2O_3). For this reason, when the concentration of the solution increases, the expansive mechanics of the clay decreases, being such a decrease more substantial by these sesquioxides (Fe_2O_3 and Al_2O_3), due to these compounds present hydrolyzing capabilities that affect in more significant proportion the clayey tissue systems.

The most significant numerical decrease in the plastic potential was obtained using the 40% CaCO_3 solution, reporting a final value of less than 20%, that is, a reduction of approximately 4.5% for the material's value. Choobbasti et al. (2019) recorded a similar behaviour, with a 2.5% reduction in the PI after the addition of calcium carbonate. This significantly reductive trajectory is mainly due to the increase in pH in the solution because of the precipitation of carbonates, behaviour demonstrated by Barbedo (2011), where the plasticity of kaolin clay decreases substantially when the pH increases.

The practical results obtained using different compounds show decreases in the LP. The higher the percentage of addition in the solution, the tendency subtle and without distortion. The decrease in LP has a fundamental importance in engineering practice because it affects the process of mixing the soils, making them less friable, less resistant, and more cohesive. However, the LP of kaolin

with competition from ethanol remains constant under any level of influence.

There is an absolute correlation between the decrease of the LL and the increase in the concentration in the cases studied. When the NaCl solution increases, the surface tension rises, which generates reductions in the LL, in a proportion of 2% for each 10% solution. However, when NaCl is added in large doses, the dissolution process will be more laborious, which crystallizes the corpuscles on the kaolin surface and reduces the concentration of adsorbed and higher valence ions.

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Data Availability Not applicable

Code availability Not applicable

Declarations

No human or animal participant was involved or harmed in any way during this research.

Conflict of interest The authors declare no competing interests.

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