

PROPERTIES IMPROVEMENT OF CLAY SUBSOIL BY ELECTRO-OSMOSIS AND CATIONS EXCHANGE

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1. Abstract

In the presented paper an clay soil and some possibilities of its properties improvement as an electro-osmosis, electro-foresis and cations exchange is discussed. The attention was paid to the clay minerals especially a montmorillonite which has very interesting properties according to its behaviour and practical stabilization possibilities.

2. Clay minerals formation and identification

Soil was created by a physical or chemical destructive process in rock. The physical process may be erosion by the action of wind, water or glaciers. The chemical process change the mineral form of the parent rock due to the action of water (especially if it contains traces of acid or alkali), oxygen and carbon dioxide. Chemical weathering results in the formation of groups of crystalline particles of size less than 0.002 mm known as the clay minerals.

Exact specifying of clay minerals is very difficult according to their small proportions and for identification are applied several methods. As the most commonly used methods for clay mineral identification Gregor [4] presents:

- x – ray methods
- thermal analysis methods
- infrared spectrometry
- electron microscopy and diffraction

Specifying of clay minerals by x – ray methods is based on a dispersion of a short wave electromagnetic radiation dispersion on crystal structure.

Thermal analysis methods allow watch a change of any properties in dependence on temperature and are split to static (changes in dependence on time at constant temperature) and dynamic (changes in dependence on a temperature variation).

Infrared spectrometry is established on a measurement of absorbent spectrum of infrared radiation in range of wave – length 2 - 100 μm , which is caused by oscillation of atoms in clay minerals structure. Absorbed energy depends on a mass of oscillated elements, linkage – relation and their mutual position.

Electron microscopy allows observe subjects big about $5 \cdot 10^{-10}$ m against optical microscopy which can differentiate a maximum only 10^{-7} m. So this method can be used for study of clay minerals with particles less than $1 \mu\text{m}$.

3. Construction of clay minerals

X - ray analysis confirm that for clay minerals is typical a layered structure created by layer of tetrahedrons $(\text{SiO}_4)^{4-}$ and octahedrons $[\text{Al}(\text{OH})_6]^{3-}$ or $[\text{Mg}(\text{OH})_6]^{4-}$. Ideal tetrahedron layers $(\text{SiO}_4)^{4-}$ create a symmetrical hexagonal mesh. Apexes of all tetrahedrons are pointing in the same direction (Figure 1a). The second primary element of layered silicate structures is a layer of octahedrons $\text{Al}_2(\text{OH})_6$ as shown in Figure 1b [4].

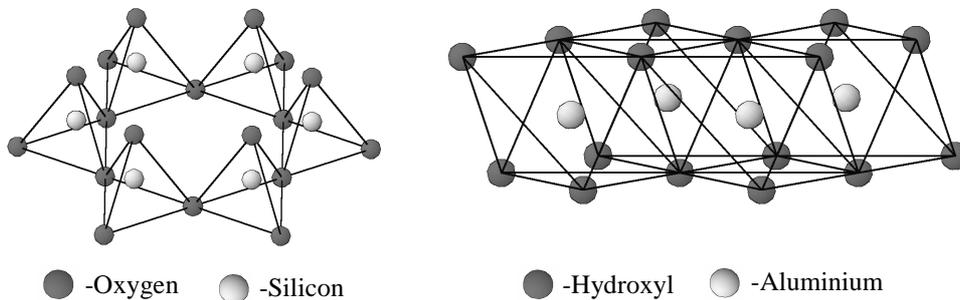


Fig. 1 Tetrahedral sheet and octahedral sheet of clay mineral

The various clay minerals are formed by the stacking of combinations of the basic sheet structures with different forms of bonding between the combined sheets. The structures of the principal clay minerals are represented in Figure 2 [3].

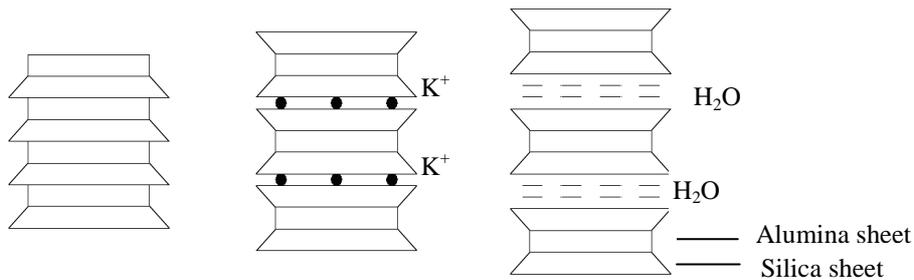


Fig. 2 Clay minerals a) kaolinite b) illite c) montmorillonite

Kaolinite consists of a structure based on a single sheet of silica tetrahedrons combined with a single sheet of alumina octahedrons. There is very limited isomorphous substitution. The combined silica-alumina sheets are held together fairly tightly by hydrogen bonding, a kaolinite particle may consist of over one hundred stacks.

Illite has a basic structure consisting of a sheet of alumina octahedrons between and combined with two sheets of silica tetrahedrons. In the octahedral sheet there is partial

substitution of aluminium by magnesium and iron, and in the tetrahedral sheet there is partial substitution of silicon by aluminium. The combined sheets are linked together by fairly weak bonding due to (nonexchangeable) potassium ions held between them.

Montmorillonite has the same basic structure as illite. In the octahedral sheet there is partial substitution of aluminium by magnesium. The space between the combined sheets is occupied by water molecules and (exchangeable) cations other than potassium. There is a very weak bond between the combined sheets due these ions. Considerable swelling of montmorillonite can occur due to additional water being adsorbed between the combined sheets [3]. So one of the most interesting clay mineral is the montmorillonite. Its specific property is a big specific surface, plate shape and electric particle charge. Each particle of montmorillonite is created by a few elementary three – layers and has an external and also internal surface, i.e. a surface of interlayer space. The value of internal surface is about 800 m²/g. The value of external surface is about 30 – 50 m²/g. The big specific surface cause large adsorption capacity of montmorillonite. The montmorillonite is able from environment with 99% humidity adsorb 0,5g H₂O/g and expand its volume about 100%. When is Na – montmorillonite in contact with liquid water then can adsorb about 10g H₂O/g and change its character to thixotropic jelly; its volume expand about twenty times [4].

Layers of water molecules are held round a clay mineral particle by hydrogen bonding and (because water molecules are dipolar) by attraction to the negatively charged surfaces. In addition the exchangeable cations attract water (i.e. they become hydrated). The particle is thus surrounded by a layer of adsorbed water. The water nearest the particle is strongly held and appears to have a high viscosity. The viscosity decreases with increasing distance from the particle surface to that of ‘free’ water at the boundary of the adsorbed layer.

4. Cation exchange capacity

Of all ions adsorbed at clay mineral surfaces, H⁺ and OH⁻ are the most abundant. Monovalent ions, e.g. Na are attached to the crystal surfaces by relatively weak bonds. Bivalent ions such as Ca⁺⁺ and Mg⁺⁺ are held more strongly, and finally the monovalent hydrogen, H⁺, and certain trivalent ions, Al⁺⁺⁺ and Fe⁺⁺⁺, are held by the strongest bonds. Besides the ions, adsorbed, dipolar water molecules may also be tied to both the crystal surfaces and the cations present in the water. The number of the water molecules that can be bonded by a cation depends on the magnitude of the electric charge and on the ionic radius of the cation.

For example, a Ca⁺⁺ ion can bond more water molecules than a Na⁺ ion. On the other hand, two Na⁺ ions can be substituted for every Ca⁺⁺ ion at the lattice surface [3]. The cations adsorbed at clay mineral surfaces have a far-reaching influence on the properties of clays [8].

Not all cations are held by equivalent amounts and the order of strenght of adsorption is shown for most occurred cations in soil after Equation (1) [9].



The quantity of all exchangeable cations is termed the cation exchange capacity as is shown in Table 1 [11].

Table 1. Cation (anion) exchange capacity of clay minerals

clay mineral	Exchange capacity	
	cation (meq / kg)	anion (meq / kg)
kaolinit	30 - 150	60 - 200
halloyzit 2H ₂ O	50 - 100	60 - 200
illit	100 - 400	-
chlorit	100 - 400	-
montmorillonit	800 - 1500	210 - 310
vermikulit	1000 - 1500	40
alofan	-	300 - 600

Cation Exchange capacity (CEC) is highly dependent upon soil texture and organic matter content. In general, the more clay and organic matter in the soil, the higher the CEC. Clay content is important because these small particles have a high ration of surface area the volume. Different types of clays also vary in CEC. Montmorillonit have the highest CEC (800 – 1500 meq/kg), followed by illites (100 – 400 meq/kg) and kaolinites (30 – 150 meq/kg). Examples of CEC values for different soil textures are shown in Table 2 [12].

Table 2. CEC values for different soil textures

Soils texture	CEC (meq / kg soil)
Sands (light - colored)	30 -50
Sands (dark - colored)	100 - 200
Loams	100 - 150
Silt loams	150 - 250
Clay and clay loams	200 - 500
Organic soils	500 - 1000

In general, the CEC of most soils increases with an increase in soil pH. The relative concentration of the cations in soil solution helps determine the degree of adsorption. Very acid soils will have high concentrations of H⁺ and Al⁺⁺⁺. In neutral to moderately alkaline soils, Ca⁺⁺ and Mg⁺⁺ dominate. Poorly drained arid soils may adsorb Na in very high quantities. In contrast to CEC, AEC (anion exchange capacity) increases as soil pH decreases [12].

The cations are attracted to a clay mineral particle because of the negative surface charges but at the same time tend to move away from each other because of their thermal energy. The net effect is that the cations form a dispersed layer adjacent to the particle, the cation concentration decreasing with increasing distance from the surface until the concentration becomes equal to that in the 'normal' water in the void space [3]. The net interparticle forces influence the structural form assumed by clay mineral particles. If there is net repulsion the particles tend to assume a face-to-face orientation, this being referred to as a dispersed structure. If, on the other hand, there is net attraction the orientation of the particles tends to be edge-face or edge-to-edge, this being referred to as a flocculated structure. In natural clays, which normally contain a significant proportion of larger, bulky particles, the structural arrangement can be extremely complex.

5. Improvement of clay properties by electro-foresis, electro-osmosis and cations exchange

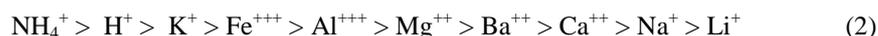
At the electro-foresis under a direct electric current are electric charged colloidal particles moving in disperzion medium towards to the opposite electrode. In soils is particle charge usually negative and water movement towards to cathode. Water movement in porous soil caused by electric current is called an electro-osmosis where also a part of diffusion envelope is moving.

After Grim and Cuthbert (1945) is envelope of hard bound water in Na-montmorillonite robust three molecules and in case Ca-montmorillonite i tis four molecules ($\sim 10 \text{ \AA}$). But at Ca-form clay orientation of water molecules in diffusion envelope reaches only distance 15 \AA and for Na-form of clay water molecules orientation reaches up to the distance 100 \AA . This fact is applied practically for a transformation of slurry Ca-clays into Na-clays by addition salt so before free water is bonded and slurry clay stiffened [9].

Considering the chemical valency can one cation Ca with surface $13,32 \cdot A^2$ substitute two cations Na with surface $2 \times 12,07 = 24,14 \cdot A^2$. So Na-form clay can bond significantly more water than Ca-form of the same clay. In nature Na-clays include more water, they are more plastic, porous than same clay field by Ca cations [7].

Big practical sense of electro-osmosis is that makes possible to drain and stabilize slurry and soft plastic fine-grained soil. As the optimal range of soils right for drain by electro-osmosis is specified for soils with $d_{10}=0.02 \square 0.002 \text{ mm}$ and $d_{60}=0.05 \square 0.005 \text{ mm}$ [9]. Electro-foresis is used for transfer a suitable chemicals into porous soil in order to strengthen and tighten the subsoil.

Járay (1955) has shown the significant effect of the adsorbed cations on the liquid limit of the soil. Their influence on the shearing of the soil was investigated by Sullivan (1939). He transformed a natural clay into a H clay and then, having treated the latter with various cations, he measured the shearing strength at constant phase composition of the soil. With various cations adsorbed, the shearing strength showed a decreasing tendency in the following order:



Plasticity showed a tendency to increase in approximately the same order. The probable explanation for this phenomenon is that the exchangeable cations cause a thin, highly viscous film of water to be adsorbed on the surface of the clay particles. So as a consequence, Li and Na clays, their particles being forced apart by the viscous layer of adsorbed water, are highly plastic and have low shearing strength [8]. The type of exchangeable cations highly affects properties of clay soils so is very important to know the way of changing cations in clays.

6. Practical use of the electrochemical compacting of clay soils

Already in the year 1937 L. Casagrande has strengthened subsoil under bridge column so that he hammered long wooden piles with aluminium jacket into a soft Na-clay and these piles served also as anodes for the direct electric current. As cathodes were used steel rods [7]. By activation the electric current began water flow from the anode to the cathode, soil moisture along piles decreased, friction increased and soil closely fit to aluminium jacket. Piles were long 21 m with diameter 0.3 m. At first after loading piles settled from 7 to 24

mm, but by consumption about 60 kWh was pile settlement only 1 mm and after four months 2 mm.

In Russia were electro-osmosis used for slope support at eastern railway near to station Lagaz – Ail. About 200 electrodes with raster 0.75 m and length only 1.5 m were used. A heavy four tons weight fell on land from 50 cm height and sink into the subsoil 52 mm before a stabilization. After the stabilization the weight sank at the anode and also cathode about only 8 mm. For the slope stabilization was used completely 30 000 kWh.

Cebertovič has used electro-foresis for a saturation small permeable soil by sodium silicate and subsoil has strengthened. The anode was created by perforated pipes filled with the sodium silicate and as cathode were used steel rods. In Hungary have been used this process for stabilization of shifting sand what leak in a shaft. For stabilization were used 4 kW and 6 kg of sodium silicate per one m³. In improved sand was possible to excavate the shaft. Also in Prague during building a tunnel under master rail station was soil grouted by sodium silicate + electrolyte + calcium chloride. But accrued jelly was plastic so the grouted sand had to be partly drained and dried by electro-osmosis and in accrued soft sandstone was possible to realize the tunnel [9].

6. Conclusion

As was shown in this paper the clays are created by clay minerals which have a very small proportions what significantly influence their behaviour in touch with a water and also under a loading. Within most interesting clay minerals certainly belongs the montmorillonite whose behaviour and interaction with interlayer cations influence its properties as a swelling, dimension of clay mineral surface, electric charge of segments and also sort of exchangeable cations. For all that is important to not neglect engineering geological exploration and consider all aspects of clay subsoil behaviour under right boundary conditions.

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