Properties of Clays

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The basic component of clay–cement slurries is clays, which give specific properties to viscoplastic bodies. Since there is a whole range of clays with different degrees of crystallization, their properties are variable. This is particularly important because in technological practice, clays found in the area of the hydrotechnical work performed are usually used.

cement clay flowability hydroinsulation barriers

1. Introduction

The construction and maintenance of hydraulic structures, mine workings and parts of buildings require the use of barriers that limit the flow of ground and underground water. The sealing slurries used in hydrotechnics are viscoplastic systems that are prepared by introducing structuring (crosslinking) additives into clay suspensions. Cements and a variety of chemical compounds are usually used as reactionary structuring additives. Various fillers and modifiers are also introduced into slurries. Clay–cement grouts are characterized by the fact that they behave as plastic bodies throughout the setting range and do not form a crystalline structure, which is characteristic of, for example, concrete. As a result, when bonding with the rock, conducting excavation shaft work or other environmental phenomena, they do not disturb its structure. In addition, due to the time-controlled formation of an internal structure with special rheological characteristics, sealing slurries do not wash out of fractures, and the finely dispersed clay fractions contained in them ensure their high tightness [1][2][3][4]. The most effective are clay slurries with a density of 1.2–1.23 g/cm^3, containing cement at 8–10% wt or 90–120 kg/m^3. Various substances and chemical reactants, such as water glass and polyacrylates, as well as pozzolanic compounds (metallurgical slags, ashes, etc.) can be used as rheology-modifying additives [5][6][7][8][9]. In particular, under groundwater conditions, water glass in the amount of 0.8–1.0% is usually introduced as a structuring additive.

The technology for the preparation of sealing slurries includes three stages: the preparation of a suitable clay slurry and the preparation of a cement slurry on its basis, and the introduction of crosslinking additives [10][11][12]. Such a mixture is introduced into the soil or other places requiring technical and construction intervention—mainly hydraulic structures. Using clay–cement binders, programmable sealing systems can be produced in the foundation of water, drainage and hydraulic engineering facilities, as well as in the body and base of embankments that are used for flood control, agricultural reservoirs, dikes and fishponds. These are so-called continuous antifiltration barriers in flood control embankments. They are designed to seal existing engineering structures by introducing a tight wall into their construction to restrict the flow of water through the embankment [3][13][14].

Such barriers are made using various methods, usually by inserting a sealing material through an opening made in the crown of the embankment in such a way that the resulting screen running along the embankment reaches from top to bottom. Such a solution seals the embankment in case the water level rises on the flood side while allowing water to flow under the structure. Excellent sealing properties predispose clay–cement binders also for purposes unrelated to hydraulic engineering but directly related to cutting off the flow of groundwater, such as antifiltration elements protecting construction excavations from water inflow and serving to insulate landfills with vertical sheet piling (such an element achieves a filtration coefficient < 10^{-8} m/s). A special example of the use of clay–cement slurries is their treatment as an immobilizer of hazardous substances. In the case of waterproofing barriers made with soils contaminated with petroleum substances and metals, there is a reasonable risk of these substances leaking into the surrounding soils and groundwater, especially if the barrier is unsealed due to the fact of drying [15][16][17][18].

2. Properties of Clays

The most widely used group of sealing materials are bentonite–cement mixtures. This material is most often a mixture of bentonite, cement, water and fillers—most often fly ash and ground blast furnace slag, sometimes other binding additives, such as lime meal, are also used. The composition of the material is variable, and it is designed to reach a filtration rate of $1 \cdot 10^{-8}$ m/s and a compressive strength of 0.3 MPa after 28 days of maturation. Since the composition of bentonite–cement slurries varies over a wide range, the resulting filtration rate and strength results also vary widely. The proportions of the individual components are 3–7% bentonite, 2–32% cement and 18–43% fillers. Such mixtures obtain filtration coefficient values in the range of $1 \cdot 10^{-9}$ to $3 \cdot 10^{-8}$ m/s and uniaxial compressive strengths at the level of 0.5–3.5 MPa [19][20][21][22]. Slag–alkaline systems are also used as sealing and reinforcing slurries. This binder produced from ground blast-furnace slag has the ability to set and harden, especially in aqueous environments, and its hydration products are hydrated calcium silicates and aluminosilicates with high durability. It is characterized by high sulfate resistance and good strength parameters. Previous studies have shown that sealing slurries based on a slag–alkali binder have compressive strengths of 10–38 MPa and very good resistance to sulfate corrosion (shrinkage within 0.1–0.3) [23][24][25][26]. The basic component of clay–cement slurries is clays, which give specific properties to viscoplastic bodies. Since there is a whole range of clays with different degrees of crystallization, their properties are variable. This is particularly important because in technological practice, clays found in the area of the hydrotechnical work performed are usually used. For this reason, the necessary information on the characteristics of the clay minerals are important. It is generally known that clays do not dissolve in water, and when they are stirred, they change to a colloidal state. Clay grains in suspension have a size from 2 to 100 µm. Due to the packet structure, three groups of clay minerals are distinguished. Minerals with a packet structure (octahedral layer to tetrahedral layer) of 1:1, 1:2 and mixed are shown in **Figure 1**.

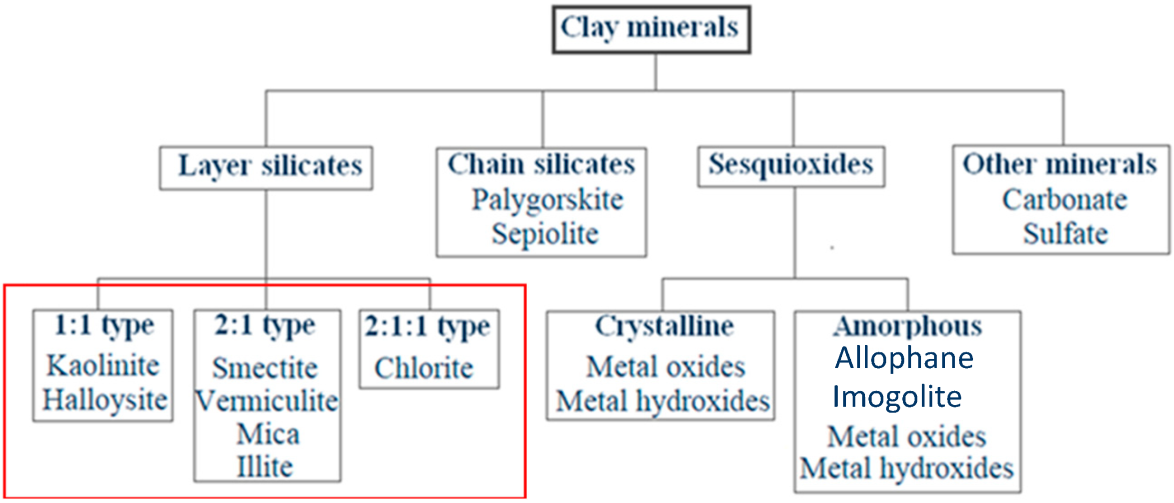

Figure 1. Classification of clay minerals [27][28][29].

Representatives of these groups are kaolinites, smectites and chlorites. Not all clay minerals have equal hydration and dispersion properties in aqueous environments [27][28][29]. Kaolinite and kaolinite-like minerals have a high degree of dispersibility and can achieve good plasticity in aqueous environments. However, kaolinite lacks ion-exchange and hydration properties [30]. Chlorites in some range can be characterized by the above properties. In contrast, the minerals of the smectite group are characterized by all of the above properties. The features of clay rocks depend not only on the size of the clay particles and their quantitative composition but also on their crystallographic structure. The different crystallographic structures of clay minerals affect their different behavior in water in the presence of cations, in particular the rheological properties [31][32][33]. The spontaneous dispersion of clay particles is most common in smectites. Weak bonding between packets of this mineral occurs between exchangeable cations. This bond depends mainly on the type of exchangeable cation and does not interfere with the water penetration and their swelling, as well as the formation of complex packets. The spontaneous swelling and disintegration of the agglomerates into fine particles of minerals, which are included in sealing slurries, cause the structure formulated in this way to strongly restrict groundwater flow. However, sealing slurries based on clay with strong exchangeable properties are not long lasting. Their properties change depending on the moisture content of the system [34]. The clays included in clay–cement grouts are inert with respect to the various types of aggressive groundwater. The most resistant structures in clay–cement slurries are obtained on the basis of polymineral clays of the kaolinitic and chloritic types. Thanks to the specific characteristics of these minerals, a suitable environment is created for crosslinking processes in the slurries. When using clays for the preparation of sealing slurries, it is important to know the granulometric, mineralogical and chemical compositions. The chemical composition of clays determines their ability to form a homogeneous and dispersed suspension under the action of water. The mineralogical composition can determine the nature of clays: calcareous—with a small percent of limestone and calcium carbonate; sandy—with a high quartz content (80–90%). For sealing slurries, clay is recommended to contain the following amounts of oxides: 63–69% SiO_2; 19–29% (Al_2O_3 + Fe_2O_3); 1.6–2.6% MgO; and 0.28–3.29% CaO [2]. The granulometric composition determines the suitability of the clay for sealing slurries in terms of the rheological properties. The content of the sand and colloidal fraction determines such important characteristics of the clay slurry as the static lateral deformation, viscosity and stability. The literature shows that a sand fraction with a content of more than 10% by weight negatively affects the process of internal structure formation. Large and heavy sand particles, having a certain surface electric charge due to the fact of their structure, can entrain charged clay particles behind them and sediment. It is generally recommended that the clay fraction, with a particle size of 0.01–0.05 mm or smaller, should be approximately 89%, and the sand content should not exceed 3–5% [35][36].

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