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Research paper

Utilization of polymer stabilization for improvement of clay microstructures

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ABSTRACT

This article illustrates the application of using polymer stabilization in creating a new nanocomposite material with clay soil. Various tests with different polymer contents were performed to study the effect of using polypropylene as a stabilizing agent on both microstructure and geotechnical clay properties. These experiments showed that the resulting nanocomposites acted as nanofiller materials which decreased the plasticity and compressibility parameters of the treated clay. The initial structural analysis helped in a better understanding of the modified microstructure and the measured size of induced nanocomposites. The constructed inclusions filled the interassembling pores thus notably producing a higher vertical effective yield stress which again reduced the volumetric shrinkage and created isotropic and compressible materials with a lesser extent of desiccation cracks. It also increased the tensile and the shear strength of the stabilized clay with an increase of the nanocomposite size. This technique can be effectively used for road embankments and slope stabilization.

1. Introduction

For all engineering structures constructed on clay soils, these soils cause deformation when exposed to any additional load or external effect. This deformation may cause a significant failure to foundation and structures. Clay soils are mostly found in the middle delta of Egypt. Many problems concerning foundation are related to the consolidation of clay layers as found in different study cases of such deformed road embankments and multi story buildings. These cases show that many problems occur due to the compression of clay layer causing foundation collapse. That is why many researchers employ soil stabilization techniques to improve the geotechnical characteristics of the clay soil to maintain roads, prevent structures from collapsing, control foundation settlement and evade any associated failure. For example, cement was first used as a stabilizing agent at the beginning of the 20th century. It was mixed with soil to form road material and was used in a wide range of applications all over the world. Since then, many other material types, such as lime (Theng, 1982), fly ash (Dermatas and Meng, 2003), organic polymers (Lahalih and Ahmed, 1998) and their mixtures (Indraratna, 1996) have been used as stabilizing agents. Puppala and Musenda, 2000 studied the engineering properties of clay materials reinforced with randomly oriented fibers. Also, several researchers Green et al. (2000); Moustafa et al. (2003); Naeini and Mahdavi, 2009) investigated aqueous polymer applications while others (Daniels and Inyang, 2004; Daniels et al., 2003) provided useful data on the polymer–soil interactions that determine the effectiveness of polymer solution in various applications. All the abovementioned papers were unable to thoroughly explain the technique of nanocomposite formation by using such methods that were chemically explained. Moreover, the nanofiller effect on the geotechnical behavior of stabilized clay by such polymer was not studied. However, this terminology of using a chemical point of view of nanocomposites was adopted in stabilizing swelling soil by the polymer technique, as discussed by Azzam (2012). The modification of the clay microstructure was done with the use of polymers to produce nanocomposite materials with components of clay. Polymers were used in a wide range of applications to improve and reinforce several material properties Liang et al. (2008). Polymers can be reinforced with different fillers to improve the surface textures. The most common nano sized fillers are carbon nano-tubes, nano-sized particles, and intercalated layers. Because nano-particles have significant surface sizes and quantum effects, their incorporation in a polymer matrix improves several material properties. In general, the microstructures of clay/polymer nanocomposites are classified according to the level of intercalation and exfoliation of polymer chains into the clay galleries (Hussain et al., 2006; Kiliaris and Papaspyrides, 2010). The constructed nanocomposites within clay microstructures are analyzed and measured by scanning electronic microscope (SEM) and transmitted electronic microscope (TEM) techniques. Polymer can be dispersed in clay matrix as a filler with clay particles, changing the clay microstructure and producing nanocomposites which are chemically explained by organic onium and ion change process as illustrated in Fig. 1.

Most researches were concerned with the use of polymer to stabilize the soil and to improve its geotechnical characteristics without considering the chemical mechanism of the produced nanocomposites which were extensively applied in the chemical studies.

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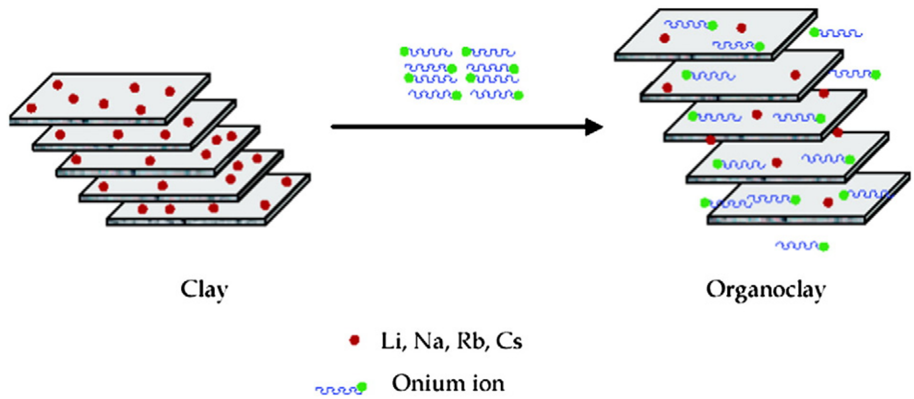

Fig. 1. Scheme of the modification of clay layers by organic onium cations and ion change process.

Therefore, this study attempts to apply the technique of polymer nanocomposites from the chemical point of view with geotechnical considerations in order to study the polymer effect on the engineering characteristics of stabilized clay. In this research, the microstructures of stabilized clay soil were investigated to reveal the effect of constructed nanocomposites/nano-fillers through the internal voids of normal clay soil and to show their effects on reducing and mitigating vertical strains at a high stress level. The main aim of this concept research is using polymer to improve the geotechnical properties of clay soil based on the modification of clay microstructures by constructing nanocomposites within the tested clay galleries. This technique can be also effectively used to improve the clay characteristics for installations of road embankments and to stabilize the loaded clay slopes.

2. Materials and experimental procedures

2.1. Soil samples

The clay samples were collected from the delta of Egypt at a depth of 2 to 3 m and at a groundwater level of about 1.5 m below the ground surface. The initial geotechnical properties of these soils were obtained experimentally according to ASTM specification, besides the mineralogical analysis as previewed in Table 1. The tested clay was classified as CH according to unified soil classification.

2.2. Polymer

The polymer used in this investigation was a polypropylene homopolymer (H030SG) obtained from the petrochemical factory in Alexandria, Egypt with a melt flow index of 3. This polymer is commercially available, environmentally accepted, and is used as nanofiller to obtain nanocomposites material with tested clay. The polymer was used in a liquid state and the general properties were: amorphous density at 25 °C: 0.85 g/cm^3, crystalline density at 25 °C: 0.95 g/cm^3 and molecular weight of repeat unit: 42.08 g/mol.

2.3. Preparation of the polypropylene–clay composites

To prepare the polypropylene–clay composites, physical mixing was adopted. According to the testing specification recommendation by AASHTO M 145, the tested samples of the soils were first oven-dried at 120 °C, then graded, pulverized and sieved through a No. 14 (1.2 mm) strainer. According to the dry weight of the soil, the appropriate amount of polymer was added. A kitchen stand blender was used to mix the polymer into the clay with a total mixing time of 5 to 10 min.

2.4. Testing procedures

The amounts of polymer added to the clay soil samples, as a percentage of the dry soil mass, were 0, 3, 6, and 10%. All samples were remolded at their optimum moisture contents (OMCs) and maximum dry densities (MDDs) with the proctor test according to the ASTM (D-1557) specification of the compaction test. The compaction curves for mixes of different plasticity values prepared with different percentages of polymer are shown in Fig. 2. It was noticed that increasing the polymer contents remarkably increased the resulting dry density while the optimum moisture content was decreased.

Table 1
The initial physical and mechanical properties of the tested clay.

Property	Value
Specific gravity	2.64–2.68
Bulk density (kN/m^3)	17.10
Initial average water content (%)	29
Liquid limit (%)	50–48
Plasticity index (%)	27–24
Sand fraction (2 mm — 75i)	0
Silt fraction (75i–2i)	31
Clay fraction (<2i)	69
Natural voids ratio	0.756
Permeability (m/s)	5×10^{-5}
Unconfined compression strength (kN/m^2)	80
Kaolinite (%)	19.5
Montmorillonite (%)	56.5
Illite (%)	24.5

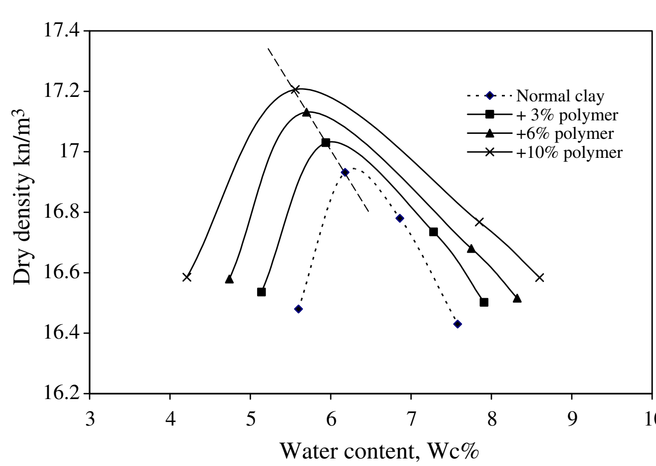

Fig. 2. Compaction curves for clay samples with and without polymer stabilization.