ARCHIVES OF CIVIL AND MECHANICAL ENGINEERING 16 (2016) 695–701

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Effect of graphene oxide nanosheets on the geotechnical properties of cemented silty soil

Farzad Naseri[a], Mohammad Irani[b,*], Masoud Dehkhodarajabi[c]

[a] Department of Civil Engineering, Electronic Branch, Islamic Azad University, Tehran, Iran
[b] Department of Chemical Engineering, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran
[c] Department of Civil Engineering, University Technology Malaysia, Johor Bahru, Malaysia

ARTICLE INFO

Article history:
Received 26 October 2015
Accepted 23 April 2016
Available online

Keywords:
GO nanosheets
Soil stabilization
Cemented soil
Geotechnical properties
Unconfined compressive strength

ABSTRACT

In the present study, the effect of graphene oxide nanosheets (GO) on the geotechnical properties of cemented soil was investigated. Various concentrations of GO (0.02, 0.05 and 0.1 wt% of cement) were added to the soil to evaluate the influence of GO on the soil's compaction characteristics, consistency limits, unconfined compression strength (UCS) and direct shear parameters. The scanning electron microscopy (SEM) and X-ray powder diffraction (XRD) analysis were used to characterize the structure of synthesized GO and stabilized soil samples. The addition of GO decreased the plasticity and compressibility parameters of the treated soil samples. The tensile and the shear strength of the treated soil samples were increased with an increase in the GO concentration. The unconfined compressive strength was increased as the GO content increased in the cemented soil samples. The obtained results showed that the GO as a stabilizing agent has a considerable influence on the mechanical properties of stabilized soil.

1. Introduction

Many soil stabilization techniques have been used to improve the geotechnical properties of the soil [1–3]. The treatment of soil was developed in the terms of strength, reduced compressibility, and hydraulic conductivity [4,5]. The cementitious additives such as cement, lime and fly ash have been widely used to enhance the geotechnical properties of various soil types [6–9]. Recently, the nano-sized materials including nanoparticles and nanotubes are most commonly used in cementitious composites to improve the mechanical properties. The most common nano-sized materials are SiO_2, TiO_2, Al_2O_3, graphene oxide (GO) and carbon nanotubes (CNTs) [10–15]. Improvement of the properties of cement-treated soil has been mainly attributed to a soil–cement reaction, which produces primary and secondary cementitious materials in the soil–cement matrix [12].

The nanomaterials due to the high specific surface area and surface charges with fine pores, may significantly improve the physico-chemical properties of soil. Chemical stabilization of a soil by adding the nanomaterials into the soil, is one of the techniques that improve the mechanical behavior of cementitious materials-treated soil [16]. The new

* *Corresponding author*. Tel.: +98 021 22590926; fax: +98 021 22600600.
E-mail address: irani_mo@ut.ac.ir (M. Irani).

http://dx.doi.org/10.1016/j.acme.2016.04.008
1644-9665/

stronger and stiffer matrix forms by chemical stabilization compared with original soil.

The most relevant characteristics of cementitious materials-treated soil including particles size distribution, plasticity, chemical composition and pH can be altered by chemical interactions. So, the stabilization of cementitious materials-treated soil can improve by treatment of cementitious materials with reinforcing nanomaterials [17]. The carbon nanomaterials including CNTs and GO nanosheets have been widely used to improve the cementitious material properties [18–22]. Cwirzen et al. [20] suggested adding multi-walled carbon nanotubes (MWCNTs) treatment with polyacrylic acid polymers. The highest increase in the compressive strength was obtained about 50% in cement paste by incorporation of 0.045% of the polyacrylic acid polymer-treated MWCNTs. Figueiredo et al. [16] investigated the influence of CNTs/surfactant on the mechanical properties of stabilized soil. It was verified an improvement up to 77% on the compressive strength of the material and 155% on Young's modulus by good dispersion of CNTs/surfactant into the soil sample. The obtained results indicated that a very small quantity of MWCNT improved the mechanical properties of a soil chemically stabilized with cement. However, the use of CNTs due to the poor dispersion of CNTs and weak bonding between the CNTs and the cement/soil matrix is limited.

Mohammad et al. has been investigated the transport characteristics of GO reinforced cement composites [21]. They found that GO addition to cement matrix can effectively enhance its resistance to aggressive elements by forming a strong barrier that can reduce the movement of aggressive chemicals. GO due to the high specific surface area, high intrinsic mobility and high Young's modulus leads to a remarkable enhancement in mechanical properties of cementitious material matrix [23,24]. GO sheets contain the functional groups such as hydroxyl, epoxide, carboxyl and carbonyl which facilitate the dispersion of GO in cement matrix [23,25]. Therefore, dispersion of cement is much more stable in the presence of GO nanosheets. Most research work to date has been done with GO added to cement pastes and concretes [26–28]; neglecting the study with soil matrixes. Horszczaruk et al. [27] showed that graphene oxide additive in the amount of 3 wt % in cement results in significant enhancement of Young's modulus. Pan et al. [28] studied the mechanical properties and microstructure of a graphene oxide–cement composite. Incorporation of GO led to increase in GO–cement composite compressive strength by 15–33% and the flexural strength by 41–59%, respectively. However, the change in properties of soil by incorporation of GO into the soft soil due to the inherent characteristics of soil is impossible. So, the stabilization of cementitious materials-treated soil can improve by treatment of cementitious materials with GO.

In the present study, the GO nanosheets were added to the cement solution and following the cement/GO solution as a main agent responsible for soil stabilization was loaded into the soil skeleton matrix. Remarkably, only incorporation of 0.02, 0.05 and 0.1 wt% of GO sheets into the cemented soil samples led to increase in compressive strength by 79–127% compared with cemented soil. The mechanical behavior of the new composite materials were more studied by consistency, compaction, unconfined compression and direct shear tests.

2. Experimental

2.1. Soil samples

The soft soil samples were taken from in the Tehran province in the center of Iran. The soil sample was collected at the depth of 2.5 m and was homogenized in laboratory. The soil was composed of silt (2 μm < size < 0.6 mm: 69%), clay (size < 2 μm: 18%) and sand (0.6 mm < size < 2 mm: 13%) particles. The properties of the studied soft soil are presented in Table 1. The unconfined compression strength (UCS) of soil was 136 kN/m^2.

2.2. Synthesis of GO

Graphite oxide was synthesized from pure graphite powder via modified Hummers method [29]. Briefly, raw graphite and $KMnO_4$ were mixed in a flask containing 20 mL sulfuric acid and orthophosphoric acid under stirring at 50 °C for 24 h. The prepared mixture was dispersed into the H_2O_2 (30%) and was immediately precipitated by a centrifuge at 15,000 rpm for 10 min and was washed with HCl, ethanol and deionized water several times. Finally the material was dried at 70 °C for 12 h to obtain the brown GO. The chemical properties of the synthesized GO nanosheets are listed in Table 2.

Table 1 – Properties of the studied soil.

Chemical properties	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	K_2O (%)	pH
	66.3	16.1	6.1	1.3	0.8	2.7	3.7

Compaction properties	Maximum dry unit weight (kN/m^3)	Specific gravity	Optimum water content (%)
	16.21	2.60	6.20

Physical properties	Liquid limit LL (%)	Plastic limit PL (%)	Plasticity index PI (%)	Shrinkage limit (%)
	61	32	31	19

Mechanical properties	UCS (kPa)	Cohesion (kPa)	Internal friction angle (°)
	136	48	33