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Research paper

Compressive strength and microstructure of soft clay soil stabilized with recycled bassanite

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ABSTRACT

This paper investigates the microstructure and mineralogical compositions of soft clay soil stabilized with bassanite that is produced from gypsum waste materials. Bassanite was mixed in different ratios with cement and lime, as a solidification agent, to prevent the solubility of bassanite. Different amounts of these admixtures were mixed with the tested soil. Scan electron microscopic (SEM) and X-ray diffraction (XRD) were used to identify the microstructure and mineralogical compositions of stabilized soil specimens, respectively while unconfined compression test was used to examine the compressive strength. Test results showed that the addition of recycled bassanite improves the strength of the tested soil. The improvement in the soil strength, based on compressive strength, is in agreement with the SEM and XRD results. The XRD results revealed the presence of various cementation compounds in the soil matrix when recycled bassanite was added. Both the content and ratio of the admixture had a significant effect on the formation of the cementation compounds and the improvement of compressive strength. The formation of ettringite increased with the increase of admixture content in soil mixture for both admixtures used. The ratio of admixture had a clear effect on the reduction of the formation of ettringite in the case of bassanite–cement admixture while it had no significant effect in the case of bassanite–lime admixture. Curing time had a significant effect on the formation of ettringite and the improvement of compressive strength. These results support the suitability of using recycled bassanite produced from gypsum wastes as a low cost and efficient stabilizer material in ground improvement projects.

1. Introduction

The application of recycled bassanite in ground improvement projects is considered as one of the appropriate ways to eliminate gypsum waste materials without cost, reduce the cost of ground improvement projects, and meet the required environmental standards. Although, using of gypsum wastes in ground improvement projects has many economic and environmental benefits, but it also has many challenges. These challenges are related to environmental impacts, durability and unidentified microstructure and mineralogical compositions of stabilized soil gypsum. Durability and environmental properties of stabilized soil gypsum were investigated in previous studies to solve such challenges and reasonable results were obtained (Ahmed and Ugai, 2011; Ahmed et al., 2011b, 2011c; Kamei and Horai, 2008; Kamei et al., 2012, 2013). However, up to the author's knowledge, identification of the microstructure and mineralogical compositions based on SEM and XRD patterns for stabilized soil gypsum was not yet investigated. Information provided by the SEM and XRD patterns are essential to evaluate and understand the behavior of soft clay soil stabilized with recycled bassanite. In general, mixing bassanite with clay soil is associated with several chemical reactions that develop the hardening between the soil particles. The potential of these chemical reactions depends on the soil type, type and quantity of stabilizer material, moisture content, weathering condition, curing condition, and curing time. The physical and chemical properties of waste materials change from one site to another and they depend on the source of waste and seasonal changes. The main objective of this study is to explore the microstructure and mineralogical compositions of clay soil stabilized with recycled bassanite, which is essential to avoid catastrophic failure. Using of the SEM and XRD patterns to identify the microstructure and mineralogical compositions of stabilized soil gypsum is important to recognize the main reasons for the improvement of compressive strength to meet successful results.

Moreover, the objective of this study extends to investigate the influence of some essential parameters on the strength improvement as well as on the microstructure and mineralogical compositions of soft clay soil stabilized with recycled bassanite. These parameters include the content and ratio of bassanite–cement/lime admixture, type of solidification agent which is cement or lime, and curing time. Results obtained from SEM and XRD will be compared with the results of strength obtained from unconfined compressive test.

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Table 1
Mechanical and physical properties of the tested soil.

Engineering property	Value	Engineering property	Value
Specific gravity, Gs	2.46	Silt, (%)	79.50
Water content, Wc%	160	Clay (%) particle size < 0.005 mm	18.90
Liquid limit, LL%	100	D60, mm	0.04
Plastic limit, PL%	61.50	D50, mm	0.022
Plasticity index, Ip	38.50	D30, mm	0.009
Sand, (%)	1.60	D10, mm	–

2. Materials used

Four different types of materials were used in this study: very soft clay soil, recycled bassanite, furnace cement type-B, and lime. The tested soil was brought from a site for embankment construction. Soil samples were taken from a depth of 0.5 m below the original ground level and then placed in plastic containers to avoid any change in water content. The natural water content was determined for different samples and the average value was 160 ± 2%. Soil samples can be classified as clay soil with high plasticity (CH) according to the unified soil classification system (USCS). Mechanical and physical properties of the tested soil were determined and presented in Table 1, while chemical composition of the tested soil is presented in Table 2. XRD results in Fig. 1 showed different peaks for the composition of the tested soil, which includes quartz (SiO_2), anorthite ($CaAl_2Si_2O_8$), kaolinite ($Al_2Si_2O_5(OH)_4$), and hydrated halloysite ($Al_2Si_2O_5(OH)_4.2H_2O$.

Recycled bassanite was produced from gypsum waste plasterboards by heating. Details about the process of producing recycled bassanite from gypsum wastes were presented in previous works (Ahmed et al., 2011a; Kamei et al., 2007). Recycled bassanite was mixed in a dry state with two different types of solidification agents; furnace slag cement type-B, and lime individually. The suggested mixing ratios for bassanite and cement or lime were 1:1, 2:1 and 3:1. Four different contents of these admixtures of 0%, 7.5%, 15% and 22.5% were mixed with the tested soil. The main objective for the addition of cement or lime to bassanite is to prevent the solubility of soil-gypsum mixture when water is introduced, since bassanite is a soluble material (Ahmed and Ugai, 2011; Ahmed et al., 2011d). Besides, the addition of cement or lime improves both durability and environmental properties of soil-gypsum mixture (Ahmed and Ugai, 2011; Ahmed et al., 2011b, accepted for publication; Kamei et al., 2012, 2013). Chemical compositions of the used recycled bassanite are presented in Table 3. Cement type used in this research is furnace slag cement type-B and its chemical composition is presented in Table 4. Lime used in this study was brought from an industrial lime company. Chemical compositions of the used lime are presented in Table 5.

3. Sample preparation and testing

The sample preparation consisted of four steps. The first step was to mix bassanite with cement or lime in dry state with different ratios. In the second step, specified contents of these admixtures were mixed with the tested soil. Mixing of the admixture of bassanite–cement/lime with the tested soil was done using an automatic mixer to obtain a homogenous sample. In the third step, samples were placed in a specified steel mold in three layers to produce cylindrical stabilized

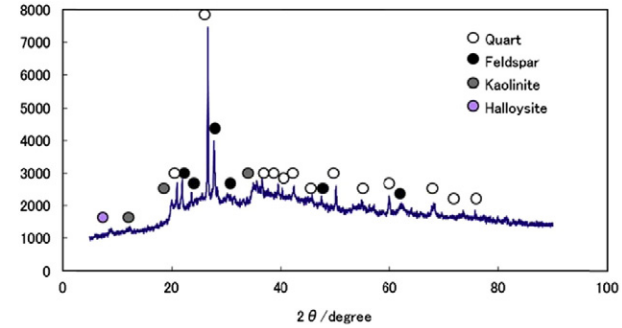

Fig. 1. XRD pattern of the used soil.

soil samples each having a 50 mm diameter and 100 mm height. Each layer was compacted with a static loading method and the sample was then stored in the controlled room at a temperature of 20 ± 1 °C for 24 h. In the fourth step, samples were extracted from the molds and then subjected to curing regime. In this study, the curing regime used was the subject of the tested sample for the required curing time at a temperature of 20 ± 1 °C and 90% humidity. Stabilized soil specimens were subjected to different curing times of 3, 7 and 28 days. The cured samples were then tested for unconfined compressive strength and then examined for SEM and XRD. The compressive strength is considered as one of the appropriate methods used in earthwork projects to identify the strength of soil. Therefore, the unconfined compressive strength test was used in this study to evaluate the strength and behavior of soft clay soil stabilized with recycled bassanite. Unconfined compressive test was conducted in accordance with ASTM 2166-66 (ASTM, 2007). Results obtained from this test were used to evaluate the strength and stiffness of the tested soil in laboratory. While the obtained shear strength parameter (cohesion) from this test can be used to determine the in-site bearing capacity. In this study three replicates were considered to ensure accurate results. Three different identical specimens were tested to represent one sample and the average was considered.

Scanning electron microscope (SEM) and X-ray diffraction (XRD) studies were done on the same samples used for unconfined compression tests. The samples were subjected to the same curing regime used in the unconfined compression tests. When the required curing time for the tested samples was completed, according to the testing program, samples were tested for SEM and XRD. Firstly, after completing the required curing time; samples were immersed in acetone for 24 h to stop the reactions between soil particles and stabilizer materials to stop the hydration. Secondly, the samples were dried for another 24 h and then pulverized to powder. Thirdly, two tiny pieces from the tested sample were mounted on a copper specimen holder and then coated with a thin layer of gold to provide surface conductivity. A special technique was applied to complete the process of installing the two tiny pieces of samples by using a certain vacuum with specified electrical current. Fourthly, the two coated pieces were placed in a JEOL JSM 6580 scanning electron microscopes that were operating at 15 kV. The X-ray diffraction (XRD) tests were performed using a PANalytical X,pert-PRO MPD X-ray diffract meter with a diffracted beam monochromator and a conventional copper target x-ray tube test set to 45 KV and 40 mA. Data obtained by the diffract meter were analyzed with X-ray powder diffraction analytical software JCPDS. The SEM technique was employed to qualitatively identify the micro-structural developments

Table 2
Chemical analysis of the tested soil.

	wt (%)		wt (%)
SiO_2	48	CaO	3
Al_2O_3	20	K_2O	1
Fe_2O_3	8	SO_3	1

Table 3
Compositions of the used recycled bassanite.

	$Ca\ SO_4.1/2H_2O$	$Ca\ SO_4$	$Ca\ SO_4.2H_2O$
wt (%)	92.60	2.10	5.30