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Performance of ground improvement projects incorporating sustainable reuse of geo-composite wastes

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ABSTRACT

Green geotechnical construction can have a significant contribution to the sustainability and resilience of infrastructural projects. As the amounts of wastes produced from different construction and mining activities continues to increase exponentially, green geotechnical applications incorporating waste and recycled materials become essential to minimize materials sent to landfill while reducing demand on natural resources. This paper investigates the use of geo-composite admixture produced from recycled materials in ground improvement projects. The developed geo-composite admixture is comprised of coal ash, blast furnace slag, and recycled bassanite to optimize the formation of ettringite within the soil matrix. The geo-composite admixture was mixed with small ratios of cement-soil to retain its stability in wet environment. The effect of geo-composite on the strength of stabilized soil is evaluated through unconfined compressive strength tests. The results demonstrated the effectiveness of the developed geo-composite admixture in stabilizing soft clay soils. As the admixture ratio increased, the soil mixture strength and dry unit weight increased while its water content decreased. The formation of ettringite enhanced as the admixture ratio in soil mixtures increased. The ettringite plays an important role in the permanent strength improvement of stabilized soil. Increasing the morphology of ettringite in soil matrix due to increased length of ettringite needles, which enhances interlocking of soil particles and consequently improves strength of soil mixture. Based on the achieved results, it is recommended to incorporate the developed geo-composite admixture in earthwork structures for more sustainable and resilient construction.

Introduction

Geotechnical engineering has the potential to play an important role in sustainable infrastructure projects. For example, green construction using recycled and waste materials as alternative materials in earthwork structures can contribute to sustainable and resilience society. Therefore, several researchers investigated incorporating waste and recycled materials in ground improvement projects as alternative geo-materials for sustainable construction practices. Examples of these waste and recycled materials are fly and coal ashes, waste tire, plastic waste, recycled crushed concrete, Cement Kiln dust, waste plasterboards, rice husk ash, sludge, lime waste, and others [1–19]. While incorporation of these materials in ground improvement projects has significant economic and environmental benefits, it still has many challenges and issues that need to be evaluated and resolved. These challenges are related to durability, environmental impact, and design criteria. Consequently, it is important to consider these challenges prior to incorporating waste and recycled materials in ground improvement projects. Some of the challenges related to using recycled bassanite, produced from waste plasterboards, in ground improvement projects were investigated in previous works [16,20,21]. It was reported that increasing the solubility of fluorine is considered the main challenge when using recycled bassanite in ground improvement project, and recommended using a binding agent along with recycled bassanite to prevent its solubility [22]. Different types of binding agents were used to improve the geo-environmental properties and durability of soil stabilized with recycled basaanite. Examples of the binding agents used acceptable results in previous works include Portland cement, blast furnace slag cement type-B, and lime [19,20,22,23].

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To further advance green geotechnical construction, a solidification technique was developed by Kamei et al. for fluorine-contaminated bassanite which utilizes different types of waste and recycled materials [24]. This solidification technique is based on the development of ettringite in soil matrix to capture the fluorine on its surface, which improves the mechanical and geo-environmental properties of stabilized soil. The main ingredients for the developed geo-composite were recycled bassanite, blast furnace slag, and coal ash [24]. While Kamei et al. [24] examined the geo-environmental performance of the developed geo-composite, its geo-mechanical properties have not been evaluated and its applicability as a stabilizer in ground improvement projects has not been investigated yet [24]. Therefore, the main objective of this research is to extend the work introduced by Kamei et al. [24] through investigating the performance and sustainability of the developed geo-composite when employed as a stabilizer in ground improvement projects. The geo-composite is utilized for the amendment of very soft clay soil and the geo-mechanical properties and microstructure of the improved soil are investigated.

Table 1
Physical properties of the Kaolin soil used.

Properties		Value
Physical properties	Density – ρ – (g/cm^3)	2.68
	Liquid limit – LL – (%)	73.10
	Plastic limit – PL – (%)	36.70
	Plasticity index – PI – (%)	36.40
Physical compositions	Sand, %	0.00
	Silt, %	35.30
	Clay, %	67.70

Table 2
Chemical compositions for the used furnace cement type B and Kaolin soil.

Substance	Content, %	
	Cement	Soil
SiO_2	26.30	68.10
Al_2O_3	8.70	24.80
Fe_2O_3	1.90	0.14
CaO	54.10	0.02
MgO	3.70	0.02
Na_2O	0.26	0.56
K_2O	0.42	1.54
TiO_2	0.69	0.15
SO_3	2.00	–
P_2O	0.08	–
MnO	0.28	–
R_2O	0.54	–
Ig.loss	0.80	–
Insol.	0.20	–

Materials and testing

Materials used

Three different materials were used in this work: clay soil, admixture (geo-composite), and blast furnace cement type-B. To produce the clay soil specimens, dry kaolinite clay was mixed with enough amount of water to achieve 140% of water content in order to represent the state of very soft soil similar to marine clay [25]. In addition, this facilitates comparing the results obtained from this study with results from previous studies that used the same soft soil [21]. Table 1 presents the physical properties of the test soil while chemical properties are presented in Table 2. Based on the unified soil classification system, the test soil can be classified as clay soil with high plasticity (CH).

Blast furnace slag cement type-B was used in this study in limited amounts to prevent the solubility of bassanite in wet environment [14,19,21]. Chemical compositions of the used cement type are presented in Table 2 as provided by the supplier (DC Cement Ltd., Tokyo, Japan).

The bassanite-admixture (geo-composite) comprised recycled bassanite, coal ash, and blast furnace slag. The preparation of the geo-composite was presented in details in previous work [24]. The mechanical properties of the geo-composite and recycled bassanite are presented in Table 3. Also, chemical compositions of coal ash, and blast furnace slag used in the production of the geo-composite are presented in Table 4. Furthermore, Fig. 1 shows the grain size distributions for the used soil and geo-composite (admixture).

The recycled bassanite used in the present study was produced from waste plasterboards by heating. The production procedure of recycled bassanite from waste plasterboards is provided in previous work [15]. For completeness, the production procedure is as follows: the waste plasterboards waste was air-dried then crushed and sieved to remove any impurities. The sieved waste plasterboard, which called calcium sulphate hydrate, was heated and then bassanite (i.e. calcium sulphate hemi-hydrate) was produced according to the following formula:

$$CaSO_4 \cdot 2H_2O \overset{140-160\,^{\circ}C}{\longrightarrow} CaSO_4 \cdot 1/2H_2O + 3/2H_2O \qquad (1)$$

The coal ash used in this study was brought from a local power plant. The coal ash is classified as F-class type, based on its chemical composition presented in Table 5, in accordance with ASTM C 618-78 [26]. The blast furnace slag type-B used in this study was brought from local steel producer, and its chemical composition is presented in Table 4.

Sample preparation

Different ratios of admixture-soil (A/S), 0, 10, 20, and 40% by weight of tested soil, were used in this study. For each

Table 3
Mechanical properties for the used geo-composite (admixture) and recycled bassanite.

Property		Density, gm/cm^3	D_{10}, mm	D_{30}, mm	D_{50}, mm	D_{60}, mm	Coefficient of uniformity (U_c)	Coefficient of curvature (U_c)
Geo-composite	Value	2.67	0.026	0.042	0.062	0.073	2.81	0.929
Recycled bassanite		2.64	0.22	0.37	0.50	0.60	2.73	1.04

Table 4
Chemical compositions of the used coal ash and blast furnace slag.

Substance		SiO_3	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	TiO	MnO	Ret.#325	LOI
Content, %	Blast furnace slag	33.60	14.30	0.20	42.50	7.30	0.90	1.20	20.00	–	0.90
	Coal ash	58.30	27.60	4.20	2.80	1.10	–	–	–	20	2.20