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Use of cement based grout with glass powder for deep mixing

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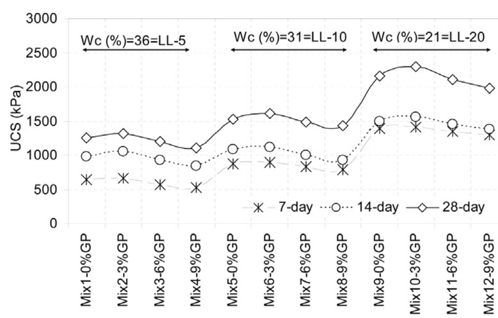
HIGHLIGHTS

- The setting times of the mixture pastes increase with glass powder.
- The bulk densities of soilcrete samples do not significantly change with the glass powder.
- The UCS and UPV increase with decreasing water content as well as increasing curing time.
- 3% replacement of glass powder is more favorable for the strength enhancement.

GRAPHICAL ABSTRACT

The UCS performances of soilcrete samples.



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ABSTRACT

In recent years, the deep mixing technique that utilizes cement-based grout mixtures has become a popular approach, particularly for the enhancement of soft soils. Despite the advantages of deep mixing technique in numerous construction applications, the effort given for this technique still needs to be extended using new material as additive. Thus, this study investigates the use of cement-based grout combined with glass powder to enhance the clay soil via deep mixing technique. An experimental program has been conducted including grout mixtures at different replacements of glass powder (0%, 3%, 6% and 9% by dry weight of binder) mixed with clay having different water contents (36%, 31% and 21%). The Vicat, unconfined compressive strength (UCS) and ultrasonic pulse velocity (UPV) tests have been carried for analysing performances of mixtures. The results indicate that the setting times of the mixture pastes increase, while the bulk densities of the soilcrete samples do not significantly change with the replacement of glass powder. Moreover, due to the use of glass powder, both the UCS and UPV increase alongside decreasing water content as well as increasing curing time. Test results imply that, owing to the replacement of glass powder, all UCS values of the soilcrete samples are applicable for the purpose of deep mixing. However, the replacement of glass powder by 3% produces a more favorable UCS response. Strong correlations exist for the UCS versus elastic modulus ($R \geqslant 0.84$) as well as for the UCS versus UPV ($R \geqslant 0.82$), which practically could be useful for the strength predictions of soil-cement columns. Consequently, the use of cement-based grout with the glass powder replacement could provide a new insight into the deep mixing technique for the treatment of clay. Moreover, the employment of glass powder as a waste material could also benefit the environment and construction costs.

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1. Introduction

Several civil engineering projects have encountered design issues due to the use of soft soils resulting in unfavorable responses, particularly regarding bearing capacity, settlement, and permeability [1]. For instance, large consolidation settlements due to long-term loading in soft clay soils could considerably shrink when dried or significantly expand when absorbing moisture [2]. For years, deep mixing has been internationally acclaimed as a ground improvement technique used to enhance the engineering characteristics of soil. In this technique, enhancement is obtained by mixing soil with binders such as cement and lime utilizing rotary mixing tools, resulting in hardened soil-cement columns. The enhancement of soil occurs mostly as a consequence of pozzolanic reactions taking place between the binder and soil particles. A machine equipped with a mixing blade at the end of a shaft to the borehole inside the soil is used for the deep mixing of the soil. The binder used for soil enhancement could take any of the following forms: i) dry powder or ii) grout (or slurry) both of which are injected into the soil via a nozzle [3–8]. It has been reported that strength development due to deep mixing is obtained via the diminution of initial soil volume. This process involves replacing the fluid in the soil structure with the used stabilizing agent, thereby increasing the contact points between particles and, at the same time, preventing swelling [9]. In terms of the chemistry involved, calcium silicate hydroxide (C-S-H) and calcium aluminate hydroxide (C-A-H) gels are produced due to the reaction between water and calcium silicate/aluminates within the binder. When the pH levels of soil are greater than 10.5, pozzolanic reactions enable these cementitious gels to continue to form over long periods of time [10].

Previous studies [11–13] have indicated that cement is often used as a main additive of binders for the enhancement of the soil strength and stiffness through curing time. When the cement is used for soil treatment, the reaction between the cement with soils and water produces a hardened material known as cemented soil. Regarding the mechanical properties of the treated soil, it has been reported that soil-cement columns produce the unconfined compressive strength and elastic modulus, which are typically 10–20% more than those of plain cement [14,15]. Studies have also determined [16,17] that cement enhances soil strength and compressibility in much higher preconsolidation pressure compared to untreated soil. As a result of this high preconsolidation pressure, the permeability and void ratio of the soil decrease sharply. Despite the benefits of native cement use, it has been reported that the strength of soil–cement mixtures could be affected adversely by factors such as organic matter, high water content of soil [18] and pH values [19]. This issue of cement use may sometimes deem the application of deep mixing as impractical; therefore, it is important to support native cement with stabilizers (i.e., additives or admixtures) which could improve the quality of the solidified mixture. In recent study [20], cement added with reactive magnesia (MgO)-carbide slag (CS)-activated ground granulated blast furnace slag (GGBS) has been employed to stabilize natural soil. It has been determined that at a 90-day curing time, unconfined compressive strengths due to the MgO-GGBS and CS-GGBS stabilized soils are respectively obtained as 3–3.2 times and 2.4–3.2 times higher than those of native cement.

Several common stabilizers (e.g., fly ash, cement kiln dust, lime, blast furnace slag, and bottom ash) have been added to cement for ground improvement purposes. Alternative to these stabilizers, glass powder has increasingly been used in various applications [21–26] owing to its environmental benefits as a recyclable material, its increased availability due to industrialization, and its relatively low cost (i.e., replacement with cement) [27]. The most commonly used type of glass is reported to be soda lime glass, which contains 72% silica + 14.2% sodium oxide + 10% lime + 2.5% magnesia + 0.6% alumina. It has been emphasized that, as a waste material, the glass is cohesionless and is capable of enhancing soil quality. In particular, the soda lime glass contained 10% lime is promising for the soil strength when hydrated [2]. The influence of crushed glass waste and plastic high-density polyethylene waste on soil was investigated in past research [28], where it was found that maximum dry density increases while optimum moisture content and Atterberg limits decrease as a result of these materials. The effects of soda lime glass dust as an additive on the improvement of clay soil has also been studied [2], with similar results having been determined in previous study [28]. Additionally, the inclusion of glass dust has been observed as increasing unconfined compressive strength with curing time, while decreasing this strength without curing time. Despite the great attention given by researchers to the use of soda lime glass powder, nevertheless studies utilizing soda lime glass powder in combination with cement-based grout remain insufficient, specifically for deep mixing.

Some existing studies [29–31] concerning use of glass powder have examined the effects of glass powder on the microstructure of cementitious materials. It has been observed [25,29] that the densification occurring in the microstructure of material matrices could be the reason of an increase in the quality of cementitious materials combined with glass powder. Moreover, it has been reported [32] that, due to pozzolanic reactivity, ground glass powder can be utilized successfully for cement replacement. In other previous study [30], the application of different dosages of fine glass powder has been found to model successfully the hydration degree of cement paste. It has also been reported that glass powders with a microscale size distribution are able to improve the strength and transport properties of concrete [27]. However, the above-mentioned contributions of glass powder to cementitious materials require further investigation specific to deep mixing.

This study investigates the use of cement-based slurry grout in combination with glass powder (specifically, soda lime glass powder) for deep mixing purposes via the application of clay soil. Accordingly, different proportions of glass powder replaced with cement in the binder composition (i.e., cement + glass powder) have been tested for the clay soil. The clay *in-situ* is represented by different moisture contents, which are varied from the clay's liquid limit. The experimental study for measuring the quality of treated soil samples (i.e., soilcrete samples) primarily includes the Vicat, unconfined compressive strength and ultrasonic pulse velocity tests. The use of glass powder proposed in this study is significant due its environment-friendly nature as a waste additive, the resulting reduction of cement costs, and its enhancement of soil (clay) quality via deep mixing.

2. Experimental study

2.1. Materials

The cement (PC) used for the binder composition (i.e., cement + glass powder) in the grout mixtures for deep mixing in this study is an ordinary Portland cement with CEM 1-42.5R type of industrial origin that conforms to ASTM [33]. Some chemical and physical properties of cement are given in Table 1.

The glass powder (GP) employed as a stabilizer (i.e., additive or admixture) in the binder composition of grout mixtures in this study is waste soda lime glass powder obtained from green soda lime bottles which have been collected primarily from shops and recycling industry in Gaziantep, Turkey. As noted previously, the waste soda lime glasses have recently become a significant source of waste for the environment. It is known that glass is an amor-