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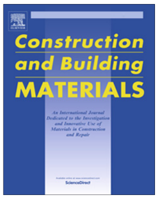

Clayey soil stabilization using geopolymer and Portland cement

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HIGHLIGHTS

- Mechanical properties of geopolymer and OPC treated clayey soil increases overtime.
- Geopolymer treated clayey soil is more efficient in dry curing conditions.
- OPC treated clayey soil is more efficient in wet curing conditions.
- The increase in molarity and content of alkali activator improve the compressive strength.
- The geopolymer specimens show a higher ductility compared with OPC.

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ABSTRACT

This study compares the mechanical performance of clayey soil stabilization using volcanic ash (VA) based geopolymer and ordinary Portland cement (OPC). The effects of curing conditions and time, alkali activator/clay and alkali activator molarity, and VA/clay ratio are determined. The compressive strength of the untreated clayey soil specimens could be increased from 0.2 to 4 MPa and 2 to 12 MPa at the OC and DC conditions, respectively, when the soil partially replaced by 15 wt% of the binders. It is observed that geopolymer treatment is more efficient at the dry conditions (DC) while the Portland cement is superb at the wet environments (OC). This difference is associated with the role of water and pH in the kinetics of geopolymerization and the Portland cement hydration. Moreover, increasing the molarity of alkali activator and alkali activator/clay improve the compressive strength of the geopolymer treated soil. Besides, the higher energy absorption in all geopolymer specimens shows the superior ductility of this material in comparison with OPC.

1. Introduction

Lack of consideration for building and infrastructure construction on weak or soft soils is highly risky due to their poor shear strength and high compressibility. These make them susceptible to differential settlements. Therefore, it is important to enhance the soil properties using stabilization techniques that can respond to increasingly demanding situations.

Currently, chemical stabilization of soft soils is a common method by which binders, such as ordinary Portland cement (OPC) and lime are incorporated into the soil to improve particle interfacial bonds [1]. In geotechnical engineering projects, OPC is the most favored material because of sufficient mechanical properties, availability and cost. Therefore, it is used in numerous stabilization techniques such as deep cement mixing and grouting [2,3]. However, the overdependence on cement has given rise to several environmental concerns, including large CO_2 emission, natural resource depletion and dust generation. The OPC production is an extremely energy consuming process (5000 MJ/t PC) which causes a CO_2 emission of about 0.7–1.1 tonne per tonne of OPC [4–6]. Apart from the environmental drawbacks, OPC often shows a high plastic shrinkage and a reduction of mechanical strength due to the loss of water and incomplete hydration at early ages [7]. This is a big drawback for geotechnical applications, especially in torrid zones, as wet-curing of a big site is not applicable.

In order to reduce the environmental impacts and enhance the mechanical performance, OPC is partially replaced with pozzolanic materials such as fly ash (FA), ground granulated blast furnace slag (GGBS), palm oil fuel ash (POFA), volcanic ash (VA) and red gypsum [1,8]. The partially replaced OPC examples exhibited enhanced mechanical properties, and durability in terms of moisture resistance, water sorptivity and shrinkage [8,9]. However, the

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pozzolanic replacement is often limited to low quantities and the environmental impacts of OPC is still a concern.

Several attempts have been conducted to active the pozzolanic wastes to produce a binder with a similar property as OPC gel. Na_2CO_3 was effectively used to active GGBS to produce binder [10]. While, a similar result was not observed in another experiment [11]. This contradictory was attributed to the different pH environment of the experiments. The Na_2CO_3 hardly created a high pH environment in the clay-water-GGBS system while the rate of activating reactions depended on the pH of the starting solution [12]. Carbide slag, which is mainly composed of $Ca(OH)_2$, was used to activate the GGBS to form a binder, however high water content used in that matrix had a significant impact on the early-age strength development [11].

Geopolymer has been emerging as a potential alternative to Portland cement by converting industrial aluminosilicate rich wastes into a value added binder [13,14]. Apart from the environmental aspects geopolymer stabilized soils have been shown superior properties to meet the requirements engineered clayey soil through compact microstructures, improved mechanical properties and volume stability [15–18]. Different mixing designation have been investigated mechanical performance of geopolymer stabilized clayey soils. It was observed that shrinkage strain of metakaolin-geopolymer stabilized soil is much lower than those of the unstabilized or OPC incorporated ones. This low shrinkage was attributed to the slow evaporation of pore water from the compact structure of the stabilized soil using geopolymer [17]. Also, the compressive strength of lightweight GGBS-geopolymer stabilized clayey soil was improved by 200–350% compared to its corresponding lightweight OPC specimens [19]. Similarly, for the same percentage of binder content, the GGBS-geopolymer stabilized soil indicated 600% mechanical strength improvement compared to the OPC treated specimens over short-term curing time of 28 days [15]. However, FA-geopolymers often show a slower and long-lasting strength development compare with those of OPC at low curing temperatures. A comparison between FA-soil mixtures with and without alkaline activator showed a remarkable increase in strength of alkali activated specimens from 0.3 to 2.8 MPa at 28 days and 5.2 MPa after 90 days [20]. Likewise, it was observed that with comparable 28th day mechanical properties, strength development of FA-geopolymer stabilized samples were in the range of 250–500% after one year, while it was limited to 10–25% in OPC specimens [21]. However, a higher early strength was observed when FA-geopolymer soil was cured at higher temperatures [22,23]. The compressive strength of POFA-geopolymer soil which subjected to hot curing was increased by 112% in comparison with that of cured in the absence of the heating process [24].

In addition to the effects of curing condition and time, it was reported that increasing the binder to soil ratio improves the compressive strength of stabilized soils [22,25]. Also, increasing the sodium silicate/sodium hydroxide ratio or higher alkali activator concentration increase the mechanical strength of the geopolymer soil treated specimens however they reduce the workability [21,26]. In contrary, an increase in strength was reported by decreasing activator/ash ratio. When the Na_2O/fly ash ratio increased from 0.160 to 0.375, the mechanical strength decreased by 50% [21]. The variation in results are due to the type of mixture, curing time and condition of geopolymers. Therefore, further studies on the controlling variables are required.

This study compares the mechanical performance of clayey soil stabilized with VA-geopolymer and OPC and investigates the dominant factors of stabilization process, including: curing conditions, curing time and binder content. The incorporation of both VA and OPC replacement contents varied in the applicable range of 0–15 wt% of the soil. Furthermore, the geopolymer stabilization was optimized by considering the alkali concentration and binder to soil ratio. The experiment carried out at two curing conditions of oven dried and optimum water content to verify stabilizer function at different climates.

2. Materials and methods

2.1. Soil characterization

A locally low plastic available clayey soil was collected from Shiraz-Iran. It contained a trace of sand and fine gravel. Therefore, it was dried and sieved through No. 4 (opening of 4.75 mm) to remove the gravel fraction. The full particle size analysis of the soil used in this study can be observed in Fig. 1. The engineering properties of studied soil in terms of the Atterberg limits, grain fractions, and soil classification was according to the ASTM D 4318, the ASTM D 422 and the Unified Soil Classification System, respectively, as in Table 1. The grain size distribution was obtained by means of sieve analysis coupled with hydrometer testing as per ASTM D 2487.

To determine the maximum dry density (ρ_{max}) and the optimum water content (OWC) of the soil the standard Proctor compaction test was conducted based on the ASTM D 698. The ρ_{max} of 1.74 g/cm^3 and OWC of 14% of untreated soil were determined for the stabilized specimens.

2.2. Binders characterization

The volcanic ash used in this research was collected from the Taftan Mountain, located in the south east of Iran. The as-received material was sieved to 74 μm to remove large particles and impurities. The ordinary Portland cement (OPC) type II was collected from Fars Cement Company. The X-ray fluorescence (XRF) using PANalytical Axios mAX instrument was used to determine the oxide composition of the VA and OPC, as listed in Table 2.

Specific surface area of VA and OPC as measured by nitrogen adsorption according to the Brunauer, Emmett, and Teller (BET) method using NanoSORD92 instrument were 2.424 and 2.003 m^2/g, respectively.

In order to evaluate the efficiency of geopolymer and cement on stabilization of clayey soil, three sets of predetermined concentrations of VA or cement were mixed with the activator for a constant

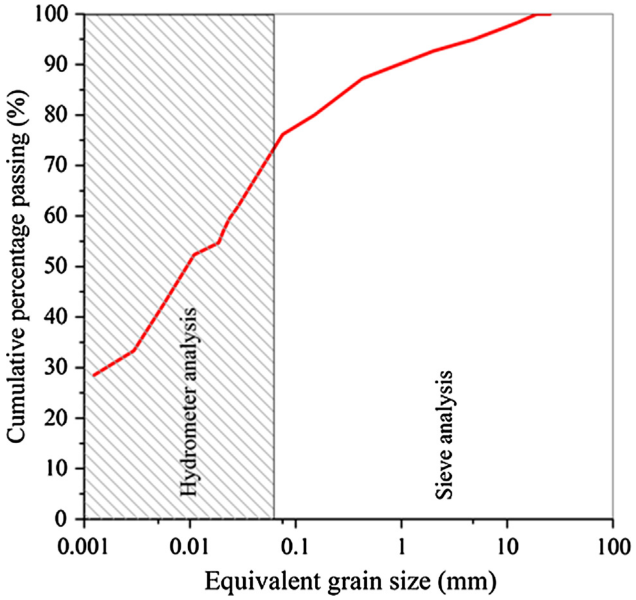

Fig. 1. Particle size distribution of the Shiraz clayey soil.