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Comparing the effects of two alkaline activators of sodium hydroxide and calcium carbide residue on geopolymeric stabilization of clay soils

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ABSTRACT: Nowadays, the Ordinary Portland Cement (OPC) industry causes extensive environmental consequences due to consuming huge amounts of fossil fuels. This necessitated researchers to introduce a novel group of binders called "Geopolymer cements" or "Green cements" with higher performance and lower pollution compared to the OPC. Thus, in this research, the effect of using two types of alkaline activators such as sodium hydroxide (NaOH) and calcium carbide residue (CCR), for the stabilization of clay soil (CL) has been investigated. Initially, the chemical compositions of soil, recycled glass powder, calcium carbide residue, and sodium hydroxide were obtained via X-ray fluorescence (XRF) test. Then, the mechanical behavior of different unstabilized, geopolymer-stabilized, and OPC-stabilized samples has studied using the unconfined compressive strength (UCS) test. The effects of several parameters such as the type and concentration of alkaline activators and the curing times (7, 28, and 91 days on the UCS and failure strain of samples have been assessed. Moreover, in order to study the microstructure of samples, scanning electron microscope (SEM) images and energy dispersive X-ray (EDX) analysis of selected samples have been used. Results showed the effective stabilization of soil geopolymer, using both alkaline activators. However, the CCR will be more appropriate if environmental and economic problems are considered.

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1- Introduction

Production of cement products is more than 10 billion tons a year globally [1]. Energy consumption for the production of OPC is too high which causes rising production costs and increases the pollution of this industry too much. Several types of research showed that the production of one-tone cement leads to the production of about one ton of CO_2. Therefore, the cement industry owns 7% of CO_2 produced by humans [2]. Notice that CO_2 has the most effect on the production of greenhouse gases. One of the best alternatives for OPC is using geopolymers. Geopolymeric cement or green cement is a combination of natural geologic materials, silicate and alumina that addition of alkaline activators to them results in geopolymerization and hence it is called geopolymer. These materials have been introduced by French researcher Davidovits for the first time in 1972 [3]. Many researches have been conducted in recent years about the applicability of geopolymeric cements for improving soils; the results showed the high efficiency of these materials to improve the strength behaviors of problematic soils [4, 5]Notice that the type and amount of precursor are highly effective on the strength, physical and chemical properties of geopolymeric products [6, 7]. Another factor that affects the behavior of geopolymers is the type of alkaline activator. Commonly, materials such as SH, SH-Na_2SiO_3, KOH and in some cases CCR are used to provide an alkaline activator. These materials have high pH and they can provide an appropriate alkaline environment for dissolving aluminosilicate particles when dissolved in water [8]. The SH and CCR alkaline solvents have been used in the present research to provide SH-RGP and CCR-RGP geopolymers respectively. The UCS test was conducted to measure the compressive strength of specimens. Moreover, the effect of parameters such as alkaline activator, curing times (7, 28 & 91 days) on UCS and failure strain of the specimens was studied. In addition, the images of SEM and analysis of EDX were used for the infrastructural study of the specimens.

2- Test materials and methods

The main materials used in this study are as follows:
Clay soil with low-Plasticity (CL)
Calcium carbide residue (CCR)
Sodium hydroxide (SH)
Recycled glass powder (RGP)

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Table 1. Name and specification of the specimens

Specimens	CCR (%)	SH (Molar)	RGP (%)	OPC (%)	Curing Time(day)
Soil(control1)	0	0	0	0	7, 28, 91
S-OPC5(control2)	0	0	0	5	7, 28, 91
M1G9	0	1	9	0	7, 28, 91
M2G9	0	2	9	0	7, 28, 91
M3G9	0	3	9	0	7, 28, 91
M4G9	0	4	9	0	7, 28, 91
M5G9	0	5	9	0	7, 28, 91
M6G9	0	6	9	0	7, 28, 91
M7G9	0	7	9	0	7, 28, 91
M8G9	0	8	9	0	7, 28, 91
C0G9	0	0	9	0	7, 28, 91
C4G9	4	0	9	0	7, 28, 91
C7G9	7	0	9	0	7, 28, 91
C10G9	10	0	9	0	7, 28, 91
C13G9	13	0	9	0	7, 28, 91

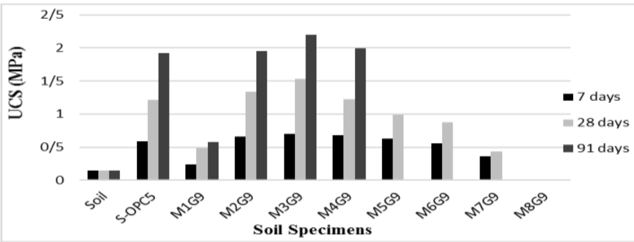

Fig. 1. The UCS of specimens stabilized by SH-RGP

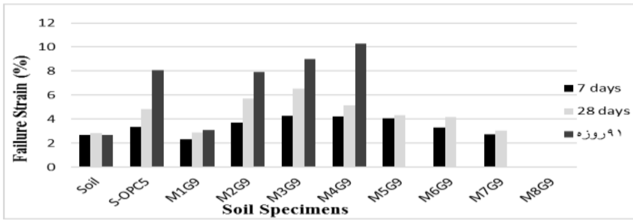

Fig. 2. The failure strain of specimens stabilized by SH-RGP

Two types of alkaline solutions are used in the present research to make geopolymeric specimens: A: NaOH and B: CCR. The evaluation criterion of mechanical properties of the stabilized soil in the present paper is the UCS test. Cylindrical specimens of 76 mm height and 37 mm diameter made by separable metal molds were used in this research. At first, the soil specimens were prepared using specific ratios of soil-RGP or soil-OPC according to table 3. Then, alkaline solutions A and B, prepared by specific concentration, were added to the specimens. Percentages of RGP and OPC in addition to the concentration of alkaline solvents with naming conditions for each specimen are presented in table 1. Three different times (7, 28 & 91 days) were selected for curing the specimens.

After curing time, the UCS test was conducted on all control and stabilized specimens according to ASTM D2166-87 standards and the UCS and failure strain (ε_f) of the specimens were measured [9].

3- Results and discussion

The effect of increasing NaOH concentration on UCS and failure strain of the specimens stabilized by SH-RGP are shown in Figures 1 and 2 respectively.

The studied unstabilized clay soil (control1) has low UCS (0.147 MPa) while the UCS of all stabilized geopolymeric specimens has increased significantly. Figures 1 and 2 show that with increasing the NaOH concentration from 1M to 3M, the compressive strength and failure strain of the specimens increased and for higher NaOH concentrations (5M to 8M), these values decreased. Therefore, 3 M NaOH concentration is required to obtain optimal mechanical properties.

Furthermore, the effect of increasing CCR concentration on UCS and failure strain of the specimens stabilized by CCR-RGP is shown in Figure 3 and Figure 4 respectively.

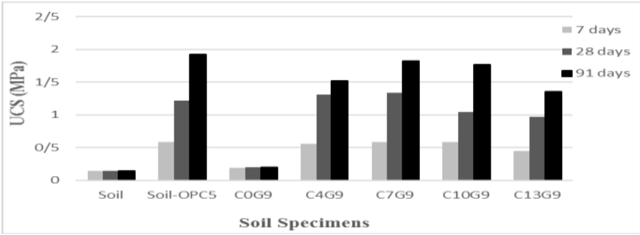

Fig. 3. The UCS of specimens stabilized by CCR-RGP

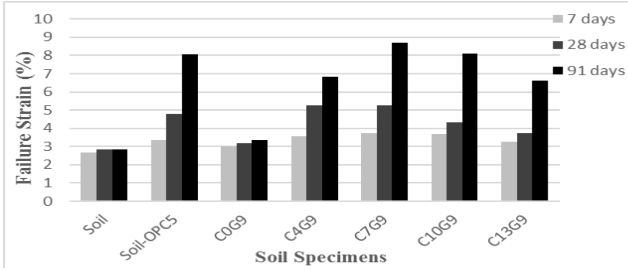

Fig. 4. The failure strain of specimens stabilized by CCR-RGP

Based on Figures 3 and 4, it is observed that by increasing the CCR value from 0% to 7%, the compressive strength of the samples has increased and for higher CCR concentrations (10% and 13%), these values have decreased. The highest compressive strength and failure strain were obtained for 7% CCR.

For both types of studied geopolymers, an increase in curing time increases the UCS of the specimens. Furthermore, the results show that the increase rate of UCS in stabilized specimens within 7 to 28 days was significant while the UCS increased slowly afterward (28 to 91 days). Studying the appearance of the specimens stabilized by SH-RGP geopolymer showed some traces of efflorescence and surface cracks, especially in specimens containing high concentrations of NaOH. The SEM images show that the stabilized specimens have more compacted space and more homogenous structure with less porosity in the surface in comparison with unstabilized specimens.

4- Conclusions

The geopoloymeric stabilized specimens (for both geopolymers) had higher UCS, more deformability and failure strain than unstabilized specimens. Such performance is very useful when the joint effect of high UCS and deformability in the soil is needed.

In order to form more complete geopolymer gels, the optimal concentrations of alkali activator are required (3M for NaOH and 7% for CCR).

The increase rate of UCS was significant during the first 28 days but the rate in 91-day specimens was less than 28-day specimens.

Traces efflorescence and surface cracks on the specimens stabilized by SH-RGP were observed more than that of CCR-RGP significantly.

Studying SEM images and EDX analysis verified the formation of geopolymer gels in the stabilized specimens qualitatively.

Results showed the effective stabilization of soil geopolymer, using both alkaline activators. However, the CCR will be more appropriate if environmental and economic problems are considered

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