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Using calcium carbide residue as an alkaline activator for glass powder–clay geopolymer

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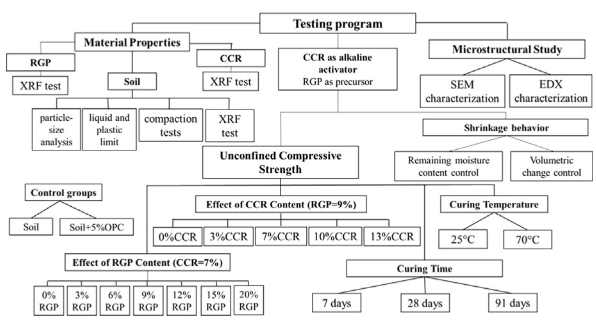
HIGHLIGHTS

- Waste materials: Calcium Carbide Residue (CCR) and Recycled Glass Powder (RGP).
- Stabilization of clay soils using CCR as alkaline activator and RGP as a precursor.
- Strength and microstructural analysis of CCR–RGP geopolymer.
- Analyze shrinkage of the CCR-RGP stabilized specimens.
- Explain the role of curing time and synthesis temperature on strength development.

GRAPHICAL ABSTRACT



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ABSTRACT

This study investigated the viability of using calcium carbide residue (CCR) as an alkaline activator and recycled glass powder (RGP) as a precursor to improve properties of clay soils. The chemical composition of soil, RGP and CCR were determined by XRF. A compressive strength test was run on the specimens to investigate their mechanical behavior. The effect of different factors such as the CCR content, RGP content, initial synthesis temperature and curing time was investigated. SEM/EDX analysis confirmed the formation of a geopolymeric gel. The results show that both CCR and RGP materials can be used to stabilize clay soil.

1. Introduction

Using cement is one of the common methods for improving the bearing capacity, controlling settlement and seismic improvement of problematic soils. The energy consumption and its cost in the cement industry are very significant. In addition, the high emission of greenhouse gases by this industry has caused severe environmental pollutions and other consequences [1]. Therefore, researchers always look for new materials to substitute for Portland cement. In recent decades, industrial and commercial use of alkali-activated aluminosilicate cement, known as geopolymer, has been developed due to appropriate performance and economic-environmental benefits. Geopolymers are a group of inorganic minerals including alkaline activated aluminosilicates [3,4]. The Chemical reactions which are taken place in geopolymerization begins with dissolution of aluminosilicate oxides in MOH solution (M: alkali metal that is M = CaO in this study), diffusion or transportation of dissolved Al-Si complexes from the particle surface to the inter-particle space, formation of a gel phase caused

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by the polymerization between the added alkaline solution and Al-Si complexes, and finally hardening of the gel phase [5–7]. For the poly-condensation occurring during geopolymerization:

$$\mathrm{Al-Si\ material\,(s) + MOH(aq)} \quad \text{(reaction1)}$$

$$\mathrm{Al-Si\ material\,(s) + [Mz(AlO_2)X(SiO_2)y\ \cdot\ nMOH\ \cdot\ mH_2O]\ gel} \quad \text{(reaction2)}$$

$$\mathrm{Al-Si\ material\,(s) + [Ma((AlO_2)a(SiO_2)b)nMOH\ \cdot\ mH_2O]} \quad \text{(reaction3)}$$

Note that, the amount of Al–Si used in reactions (1) and (2) depends on the concentration of the alkaline solution, the extent of Al–Si dissolution and the particle size. The formation of [Mz (AlO_2)x (SiO_2)y .nMOH·mH_2O] gel is based on the extent of alumino-silicate dissolution. Finally, the geopolymer with amorphous structure is formed according to reaction (3). the necessary time for the alumino-silicate solution to create a continuous gel depends on precursor material and processing conditions [5,7]. Furthermore, the performance of geopolymers and geopolymeric materials depends on different parameters, such as the amount and type of base material, the structure of alkaline activator, the curing time, the initial synthesis temperature and the mixture pH [8,9]. In recent years, many studies have been conducted on different waste materials to investigate their applicability in the geopolymerization [10–12]. The CCR and glass powder are of these materials. The CCR is a waste by-product of the acetylene gas production process. In the production process of acetylene gas (C_2H_2), the CCR by-product is produced in form of $Ca(OH)_2$. It seems that this material can be used as an alkaline activator due to its high pH. In recent years, the use of CCR has been considered by researchers due to its high amount of Calcium hydroxide as a soil stabilizer [13,14]. Kampala et al (2013) conducted a study on the engineering properties of CCR-stabilized silty clay [15]. Phetchuay et al (2014) investigated the feasibility of using CCR as an alkaline activator and fly ash (FA) as a precursor to improve mechanical behavior of silty clay. The results of this research showed that CCR can be used as an effective alkaline activator for clay-FA geopolymer [16]. Phummiphan et al (2016, 2017) conducted a research on Marginal Lateritic soil stabilized by CCR and FA geopolymers [17,18].

In contrary to other forms of wastes such as paper or organic compounds, the glass wastes remain stable in landfills for a very long time, which causes many environmental and health consequences. Using glass wastes in the production of geopolymers is a new technology considered in construction projects recently [19]. The glass powders obtained from urban wastes are usually amorphous materials and as a rich source of silica, it can be a suitable replacement for sodium silicate in geopolymer production [20]. Some studies that conducted on the capability of glass powder to be used in mortars as a precursor for geopolymers demonstrated that glass powder can be used productively for preparing an alkaline solvent and as a base for a geopolymer due to its alkaline properties and silicate contents [21–25].

Totally, researchers have conducted a lot of research on the application of geopolymers in the civil engineering industry. However, the present research considers environmental problems specifically in which it is tried to use the combination of waste materials: calcium carbide residue (CCR) as an alkaline activator and recycled glass powder (RGP) as a precursor in order to geopolymeric stabilization of clay soil. It is expected that vast use of such geopolymer as an alternative for cement reduces soil stabilization costs in addition to decrease fossil fuels, emission of CO_2, and return of waste materials such as glass and CCR to the industry cycle which results in positive environmental effects. The geotechnical index property tests of natural soil such as gradation, Atterberg limits and standard Proctor compaction test were conducted to identify the used soil characteristics. The chemical compounds of CCR, RGP and soil are determined by X-ray fluorescence (XRF) analysis. The UCS (unconfined compressive strength) is used as a practical indicator to investigate strength development. The volumetric strain was used to quantify the volumetric change of some soil stabilized specimens during the curing process. The parameters investigated in this study are the effect of the CCR content, RGP content, the curing time and the initial synthesis temperature. The scanning electron microscope (SEM) and Energy Dispersive X-Ray (EDX) were used to evaluate the morphology of fractured soil specimens.

2. Materials

2.1. Soil

The soil was collected from the Shahid Bahonar University of Kerman, Iran (30.252°L 57.105°E; 1800 m AMSL) at a depth of 5 m. The clay soil was oven-dried at 60 °C for 3 days and then it was passed through a No.40 sieve. A standard test method for Plastic Limit (PL), Liquid Limit (LL), and Plasticity Index (PI) was conducted on the soil according to ASTM D4318 [26]. The soil liquid limit, plastic limit and plastic index were 20%, 30% and 10%, respectively. Particle size analysis was conducted on soil according to ASTM-D422-63 and ASTM-D2487 standards [27,28]. The particle size distribution curve of the soil is shown in Fig. 1. According to the Unified Soil Classification System (USCS), this soil is classified as low-plasticity clay (CL) [28].

This type of soil is often too soft and weak to support the upper loads of infrastructures in constructions [29]. Therefore, this type of soil was selected for investigating the effect of stabilization by a CCR-RGP geopolymer. The compaction test under standard Proctor energy (ASTM D698) was conducted on the soil to determine the optimum water content (OWC) and the maximum dry density (γ_{dmax}) [30]. According to the standard compaction test, γ_{dmax} = 1.78 gr/cm3 and OWC = 20%. Based on the previous researches and experimental observations, the OWC and γ_{dmax} should remain relatively constant when geopolymer base materials are added [31,32]. Thus, the compaction conditions for unstabilized and stabilized specimens were selected equally. The chemical compounds of the clay soil determined by XRF analysis are listed in Table 1.

2.2. Recycled glass powder (RGP)

The RGP was obtained from waste glass by following a two-steps procedure: first, the waste glass was crushed by a laboratory

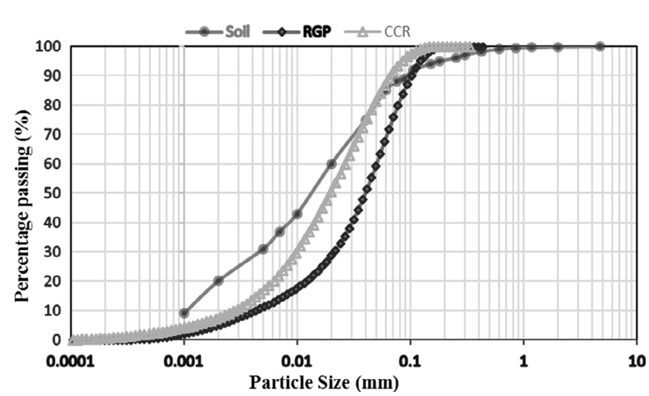

Fig. 1. The particle size distribution curve of soil, RGP and CCR.