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Mechanical Properties of Alkali Activated Slag Pastes and Determination of Optimum Values of Effective Factors

M. Jafari Nadoushan*, A. A. Ramezanianpour

Concrete Technology and Durability Research Center (CTDRc), Department of Civil & Environmental Engineering, Amirkabir University of Technology, Tehran, Iran

ABSTRACT: Geopolymers are alumino-silicate polymer that formed by alkali activation of Si and Al rich materials. This paper describes the effects of different alkaline solution types and concentrations, modulus of sodium silicate and sodium silicate to alkaline solution ratio on the flowability and mechanical properties of alkali activated slag and the optimum activator has been determined for the slag- based geopolymers production.

Results reveal that adding the sodium silicate largely enhances the workability and compressive strength of slag-based geopolymer paste.The optimum modulus of sodium silicate and sodium silicate to alkaline solution ratio to reach the maximum strength are 2.33 and 0.4 respectively. At 91 days of curing, the compressive strength of the optimum mixture of slag- based gepolymer is about 74 % more than the compressive strength of ordinary Portland cement paste.

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1- Introduction

Geopolymers are cementitious binders with three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds that are formed by alkali activation of Si and Al rich minerals and artificial pozzolans such as fly ash, ground granulated blast furnace (GGBF) slag and husk rice ash. Hu et al. [1] prepared three repair materials using cement-based, geopolymeric and geopolymeric containing steel slag binders. The test results showed that the geopolymeric materials had better repair characteristics than cement-based repair materials, and the addition of steel slag could improve significantly the abrasion resistance of geopolymeric repair. Zhang et al. [2] revealed that the presence of GGBF slag have a positive effect on the mechanical and penetration properties of metakaolin based geopolymer binders. Palomo et al. reported that the most effective factors on the mechanical properties of geopolymers are the activator type, time of curing and curing temperature. Bondar et al. [4] revealed that the optimum concentration of KOH solution for the highest compressive strength of alkali-activated Taftan natural pozzolan is between 5 and 7.5 M. Other researchers showed that source material type and its chemical composition, activator type, molarity and dosage, water content and Si/Al molar ratio are effective factors on the geopolymer properties [5-7]. The main objective of this work is to determine the effects of alkaline solution type and concentration, modulus of sodium silicate and sodium silicate to alkaline solution ratio on the flowability and mechanical properties of alkali activated GGBF slag paste. The main factors and optimum values of each factor have been determined.

Corresponding author, E-mail: m_jafarin@aut.ac.ir

2- Experimental Programs

Ground granulated blast furnace (GGBF) slag was used throughout this work to be activated as binder. GGBF slag with a specific surface area of 3383 cm^2/g and an average particle size of 25.97 µm was obtained from a local company. Potassium hydroxide (KOH) and sodium hydroxide (NaOH) pellets were dissolved to produce the 6, 8 and 10 molar alkaline solutions for GGBF slag alkali activation. Sodium silicate was provided by Iran Silicate Industrial Company in the form of solution with silicate modulus of 2.1, 2.33 and 3.13. The silicate modulus of water glass is the weight ratio of SiO_2/Na_2O. The water contents of 2.1, 2.33 and 3.13 modulus sodium silicate are 60%, 52% and 58% and their specific gravities are 1.45, 1.56 and 1.45 respectively.

Four effective factors on the properties of alkali activated slag pastes including alkaline solution type (AS), alkaline solution concentration (Mol), modulus of sodium silicate (Mu) and sodium silicate to alkaline solution (WG/AS) have been investigated. Sodium silicate to alkaline solution ratio (WG/AS) were 0, 0.1, 0.2, 0.3 and 0.4. A total of 90 alkali activated slag paste mixtures were made. The alkali activated slag paste mixtures were prepared with a constant total binder (GGBF slag) content of 1547 kg/m^3 and the activator (alkaline solution+ sodium silicate) to binder ratio in the mixes was 0.4.

In each alkali activated slag paste mixes's name, the initial letters indicate the type of alkaline solution (Na: sodium hydroxide and K: hydroxide potassium), the next number shows the concentration of the alkaline solution, the expression followed by the number indicates the silicate modulus of water glass and the last number shows the sodium silicate to alkaline solution ratio.

Alkali activated slag pastes were prepared by adding alkaline solution (potassium hydroxide or sodium hydroxide solutions) to the raw material and blended for 2 minutes. Then, the sodium silicate was added and mixed for 2 more minutes to form alkali activated slag paste. The resulting paste was transferred to the plexiglass moulds of 20×20×20 mm dimensions. After 24 hours specimens were removed from the mould and cured in the special plastic bags at 23 ± 2°C. Rapid drying should be avoided to eliminate shrinkage cracking.

Flowability of the fresh paste was determined according to the ASTM C 1437 which consists of measuring the increase in average base diameter of the paste mass, expressed as a percentage of the original base diameter [8]. Alkali activated slag paste cubes of 20×20×20 mm dimensions were cast for compressive strength. They were tested for compressive strength after 3, 7, 14, 21, 28 and 91 days maintained in the sealed curing. The specimens were wrapped and insulated in a special plastic bag to prevent evaporation and left at room temperature until the age of the test.

3- Results and Discussions

The flowability of alkali activated slag pastes containing KOH is higher than the identical NaOH. Despite the fact that, because of more molar mass, in the same molarity, KOH solution contains lower water in comparison with NaOH. In the presence of sodium or potassium hydroxide, adding the sodium silicate largely enhances the workability of the alkali activated slag paste. The sodium silicate solution improves the dissolution of raw material in alkaline environment and more dissolved raw materials result in higher workability. Increasing of sodium silicate to alkaline solution ratio from 0 to 0.4 results in the increase of the flow of the alkali activated slag paste, keeping other parameters constant.

The highest compressive strength was obtained for Na6-WG2.33-0.4 and K8-WG2.33-0.4 at 28 and 91 days of curing respectively (145.22 MPa and 169.41 MPa). These results indicate that the optimum value of modulus of sodium silicate and sodium silicate to alkaline solution are 2.33 and 0.4 respectively. As expected, the compressive strength of the geopolymer pastes developed with the curing time. After 3 days of curing, alkali activated slag pastes obtained more than 52% of its final compressive strength which increased to 87% at 28 days of curing. Rapid strength gain rate of geopolymer makes it an ideal material for repairing concrete structures.

Alkali activated slag paste specimens containing potassium hydroxide had higher compressive strength at various ages up to 91 days when compared with the specimens containing sodium hydroxide. For example at 91 days of curing, the mean compressive strength of alkali activated slag paste specimens containing potassium hydroxide is 16.1% higher than specimens containing sodium hydroxide. The ionic size of Na^+ is 116 pm while ionic size of K^+ is 152 pm. The larger K^+ favours the formation of larger silicate oligomers with which Al $(OH)^{-4}$ prefers to bind. Therefore, in KOH solutions more geopolymer precursors exist which result in better setting and stronger compressive strength of the geopolymers than in the case of NaOH [5].

The optimum concentration of alkaline solution is 8 molar. Increasing the alkaline solution concentration from 8 M to 10 M results in reduction of the compressive strength of the alkali activated slag paste. The increase in molarity of alkaline solution causes lower workability, lower compressive strength, more cost and increase in the efflorescence risk.

The activating solution can contain a supplementary source of silica such as sodium silicate, to promote geopolymerization phases. The presence of sodium silicate in the alkali activated slag paste results in increasing the compressive strength. It is clear that increasing the sodium silicate to alkaline solution ratio from 0 to 0.3 causes the increase in the compressive strength about 100 % whereas increasing from 0.3 to 0.4 has a slight effect on enhancement of the compressive strength. Sodium silicate promotes the compressive strength of alkali activated slag paste in two ways: (1) the sodium silicate solution improves the dissolution rate of Si and Al; (2) because the Al-O bonds are weaker than Si-O bonds [9] in the raw material, Al dissolves rapidly in alkali solution. Therefore if Si ion is provided prior to being available through dissolution of raw material, it can increase the degree of geopolymerization and improves the mechanical properties. It has been demonstrated that the optimum modulus of sodium silicate for compressive strength is 2.33.

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