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The effect of silica fume on durability of alkali activated slag concrete

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HIGHLIGHTS

- Silica fume increased the compressive strength of alkali activated slag concrete.
- Application of silica fume reduced the initial and total water absorption of AAS concrete.
- Application of SF increased the resistance to penetration of chloride ion in AAS concrete.
- Water curing lead to higher compressive strength, lower permeability and higher durability.
- Application of SF significantly reduced the porosity and permeability according to SEM images.

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ABSTRACT

The effect of substitution the slag with silica fume on compressive strength and permeability of alkali activated slag concrete has been examined and analyzed in this study. The use of alkali activated slag concrete is one of the strategies for production of environmentally friendly concrete which is produced through activation of adhesion feature of blast furnace slag in an alkaline solution. Alkali activated slag concrete with a proper mixture shows superior mechanical properties and durability compared to traditional normal Portland cement concrete. For cases in which AAS concrete with higher performance and durability is needed, AAS concrete with silica fume can be considered as a possible alternative. Since the permeability plays an effective role in concrete durability, this research was carried out to examine the effect of using silica fume on permeability of alkali activated slag concrete by substitution of three levels of silica fume including 5 wt%, 10 wt% and 15 wt% of slag. The effects of two types of curing conditions including water curing and curing under plastic cover were also examined. Short-term and final water absorption, penetration of chloride ion and depth of penetration of water were measured to examine the permeability. The effect of these factors on compressive strength was examined and the relation between compressive strength and passing electrical charges and depth of water penetration was also evaluated. To contrast the use of silica fume on internal characteristics of concrete, samples were observed by scanning electron microscopy (SEM). The results showed that the application of silica fume could increase compressive strength and reduce the permeability of alkali activated slag concrete and water curing was the most appropriate type of curing.

1. Introduction

Concrete is among the most important construction materials. Because of increase in usage of concrete, the growing need for cement production and the importance of environmental issues and especial attention to sustainable development, the necessity of reconsideration in concrete production has become more apparent. International Energy Authority (IEA) believes that the cement industry is responsible for approximately 6 to 7 percent of all CO_2 emissions in the atmosphere [1]. One of the methods to produce environmentally friendly concrete is reducing the use of ordinary Portland cements and the use of activated pozzolaic adhesives. Geopolymers are a new type of cement replacement materials which are produced through the reaction of aluminosilicates materials with an alkaline solution [2]. Cement replacement materials are Pozzolans and Cementitious materials. These materials are used to reduce the consumption of cement and increase the strength and durability of concrete [3]. Fly ash, Blast furnace slag, Zeolite, Silica fume and Metakaolin are among cement replacement materials among which the use of slag and fly ash has become more common due to having a high percentage of alumina and silica [4]. The slag itself can be used as a binder in concrete if it is activated by a high pH alkaline solution. Thus, the Alkali Activated Slag

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(AAS) cement can be produced by activation of slag with an alkaline solution such as Sodium hydroxide (NaOH) and Sodium silicate (Na_2SiO_3) [5,6]. Reaction of an alkaline source with a solid material containing aluminum and silica and comparison its performance with Portland cement was presented for the first time by Purdon in 1940 who mentioned that this concrete is suitable for production of concrete and precast elements [7]. The effect of silica fume on mechanical characteristics of geopolymer and AAS concrete is also studied and increase in compressive strength is reported [8–10].

The durability of concrete is among issues which has attracted a large attention of researchers in recent years. It is now well understood that permeability and density of the cement paste and distribution of pores in the cement can have a significant effect on the durability of concrete [11].

Since the performance of alkali activated concrete is strongly influenced by its composition, a lot of studies have been carried out on composition of the slag and other materials to increase its performance [4]. Some researchers have studied the performance of AAS concrete against the attack of sulfates and acids and have compared it with normal concrete. The results have shown that AAS concrete with a proper composition has better performance [12–14].

Permeability is one of the most important factors that affect properties of the concrete. Thus, many researchers have studied and examined different factors such as water-binder ratio, substitution of pozzolans, application of chemical additives, and curing method on the permeability of concrete [15–19]. Some of the researches have studied the effect of application of different pozzolans such as micro metakaolin (mMK), Metakaolin, fly ash and various super plasticizers on mechanical properties and durability of alkali activated slag concrete [20–23] and some of the researchers have examined the effect of curing method on mechanical properties and durability of alkali activated slag concrete [24–27].

This research studied and examined the effect of substitution of 5 wt%, 10 wt%, and 15 wt% of slag with silica fume in AAS concrete mixture and two method of curing, including water curing and curing under plastic covers, on the permeability of alkali activated slag concrete. Tests conducted to evaluate the permeability of AAS concrete samples were water impermeability test, Rapid Chloride Permeability Test (RCPT), initial and final water absorption test. Compressive strength of alkali activated slag concrete specimens were also measured. Imaging method using scanning electron microscopy (SEM) was also used in this research to examine the micro structural changes of cement paste.

2. Experimens

2.1. Materials

Isfahan Steel mill's ground granulated blast furnace slag (GGBFS) with a specific gravity of 2.85 and blain of 4500 cm^2/g was used in this research with Hydration Modulus (HM = (CaO + MgO + Al_2O_3)/SiO_2) equal to 1.66 [28]. Also AZNA Silica fume made by Iran Ferroalloy Company was used as mineral [29]. Chemical compositions are shown in Table 1.

The combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) was used to activate the slag. The used solid Sodium hydroxide was used in from of a solution with purity of 98% dissolved in water. Sodium silicate solution was used with the ratio of SiO2/Na_2O = 2.35 (SiO_2 = % 36.5, Na_2O = % 15.5, H_2O = % 48). Limestone aggregates were prepared from quarries near Isfahan. The sand fineness modulus was 3.05 which is in the range of ASTM C33 standard [30]. Coarse aggregates with a maximum diameter of 12.5 mm, 0.84% water absorption and 2.69 relative density were used in accordance with ASTM C127 guidelines [31].

2.2. Mix design, sampling, and curing

100 × 100 × 100 mm cube molds, 200 × 100 mm cylindrical molds and 120 × 200 × 200 mm prismatic molds were used to prepare the required samples. The prepared samples were kept in conventional laboratory conditions (temperature 23 ± 2 °C) for 24 h and then were taken out of molds and placed under two types of curing condition until the time of experiments. A series of samples

Table 1
Chemical Composition.[25–26]

Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	L.O.I
GGBFS	35.85	13.39	1.06	37.71	9.1	2.52	0.58	0.48	n.a.
Silica fume [25]	88–94	0.6–1.2	0.3–1.6	0.95–1.8	0.95–1.8	n.a.	0.7–1.2	0.7–1.2	0.4–3.5

n.a. = not analyzed.

Fig. 1. Curing condition: 1) water curing, 2) under plastic cover.