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Resistance of chemically activated high phosphorous slag content cement against frost-salt attack

Ali Allahverdi *, Mohammad Mahdi Bahri Rasht Abadi

Cement Research Center, School of Chemical Engineering, Iran University of Science and Technology, Narmak 1684613114, Tehran, Iran

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ABSTRACT

In the present work, durability performance of chemically activated high phosphorous slag content cement exposed to 1.5%, 3%, and 4.5% of deicing salt solutions along with repeated cycles of freezing and thawing was evaluated from mass loss, visual examination, XRD and SEM analyses of concrete test prisms. Concrete prisms of Portland cement of the same 28-day compressive strength class were also used as reference. The results confirm a significantly better resistance for chemically activated high phosphorous slag content cement against frost-salt attack.

1. Introduction

Concrete deterioration caused by the combined effects of frost and de-icing salts is one of the main reasons of repair costs for transportation infrastructures in cold climate countries (Giergiczny et al., 2009). Numerous mechanisms such as thermal shock, osmotic pressure, water saturation of concrete caused by deicing salts, etc. were suggested for salt scaling damages, but none of them could respond to all the features of this phenomenon (Scherer and Valenza, 2005; Valenza and Scherer, 2006, 2007). Recently, the glue spall mechanism was proposed as the main and primary cause of frost-salt attack by Valenza and was successful in justifying all the specifications of this phenomenon (Valenza and Scherer, 2005; Valenza and Scherer, 2007). This mechanism is based on the unequal thermal expansion coefficient of concrete and ice. The glue spall mechanism is an absolute physical theory. According to the glue spall mechanism, crack resistance and tensile strength of concrete play important roles on the durability of concrete against salt scaling (Valenza and Scherer, 2005).

The microstructure and behavior of any concrete against aggressive agents significantly depend on the kind of cement used (Scherer and Valenza, 2005). On the other hand, the production of environmentally friendly and less energy-intensive cements attracted industries to the use of industrial wastes or by-products with latent hydraulic property and/or pozzolanic activity. Phosphorous slag is an industrial by-product from yellow phosphor production industry. It is mainly composed of calcium oxide and silicon dioxide and thus could be applied as a suitable cementing material for blended cement production. Phosphorous slag, however, has relatively weak cementing properties and can adversely affect the early-age strength of Portland cement when used at high replacement levels.

Attempts, therefore, have been made to increase its reactivity using auxiliary activation techniques (Allahverdi and Saffari, 2011; Dong-xu et al., 2002; Sajedi and Razak, 2011a,b). The most common activation techniques that have been applied include: thermal, chemical, and mechanical (Sajedi and Razak, 2011a,b). Thermal activation or curing at elevated temperatures can increase the rate of strength gain, but at the same time may diminish the ultimate strength (Sajedi and Razak, 2011a,b). Chemical activation refers to the use of chemicals to impart cementing properties and/or to activate latent hydraulic properties (Allahverdi and Saffari, 2011; Bellmann and Stark, 2009; Sajedi and Razak, 2011b).

There are two types of chemical activation (Li et al., 2010; Pacheco-Torgal et al., 2008a,b; Sajedi and Razak, 2010); strong and mild alkali activations. Experiences have shown that aluminosilicate materials with no latent hydraulic or cementing properties can be activated only by strong alkali activators (Pacheco-Torgal et al., 2008a,b). For industrial slags exhibiting cementing properties, however, mild alkali activators are also applicable (Allahverdi and Saffari, 2011; Dongxu et al., 2000).

Research works (Allahverdi and Ghorbani, 2006; Allahverdi and Rahmani, 2009; Allahverdi and Saffari, 2011; Dongxu et al., 2000) have recently introduced a compound activator that can effectively activate supplementary cementing materials. This solid activator is based on Portland cement and contains a blend of different solid chemical activators including anhydrite and sodium sulfate. This alkali activator is of the mild-type and the only alkaline constituent of which is Portland cement and the other constituents do not result in alkalinity in aqueous media. Experimental results confirmed that optimum proportions of this relatively low cost solid compound activator may effectively

* Corresponding author. Tel.: +98 21 7724 0475; fax: +98 21 7724 0397.
E-mail addresses: ali.allahverdi@iust.ac.ir (A. Allahverdi), mmbahri@gmail.com (M.M. Bahri Rasht Abadi).

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Table 1
Chemical compositions (wt.%) and physical properties of granulated phosphorous slag.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	K_2O	Na_2O	SO_3	Free-CaO	LOI	Specific gravity (kg/m^3)	Particle size (mm)
38.42	7.65	0.90	45.14	2.60	1.50	0.56	0.43	–	–	1.87	2.74	<2

accelerate the hydration reactions of industrial slags depending on their properties.

Chemical activation is not within the scope of this work. The main focus of the current paper is the resistance of chemically activated high phosphorous slag content cement (Allahverdi and Saffari, 2011; Dongxu et al., 2000) against frost-salt attack.

2. Materials and experimental procedure

2.1. Materials

2.1.1. Phosphorous slag

Granulated phosphorous slag (PHS) was obtained from a phosphoric acid plant located in south east of Tehran (Iran). The granulated PHS was characterized by determining its chemical composition (in wt.%) in accordance with ASTM standard C311. Table 1 represents the chemical composition of PHS. The density and particle size of granulated PHS were determined according to ASTM standards C188 and C204, respectively.

Fig. 1 shows the X-ray diffractogram of phosphorous slag. As seen, only the peaks of MgO have appeared in the diffractogram. The phosphorous slag, therefore, has basically amorphous character.

2.1.2. Portland cement

Type II Portland cement (PC), in accordance with ASTM standard, was used. The chemical composition and physical properties of PC are presented in Table 2. The density and Blaine fineness of PC were determined according to ASTM standards C188 and C204, respectively. Table 3 represents the corresponding Bouge's potential phase composition of the PC.

2.1.3. Compound chemical activator

The compound chemical activator was selected according to some recent research works (Allahverdi and Ghorbani, 2006; Allahverdi and Rahmani, 2009; Allahverdi and Saffari, 2011; Dongxu et al., 2000). This activator was composed of Na_2SO_4 (2 wt.%) and anhydrite (4 wt.%). Sodium sulfate was purchased from Merck. The chemical composition of anhydrite (in wt.%) was as follows: CaO-36.00, SO_3-54.38, and SiO_2-5.88.

2.1.4. Aggregate

Standard aggregates, complied with ASTM C33 were used. The aggregates were of three size fractions, consisting of natural sand (0–5 mm), crushed coarse aggregate (10–25 mm) (gravel 1) and fine aggregate (5–10 mm) (gravel 2). The characteristics of the aggregates are presented in Table 4.

2.2. Experimental procedure

2.2.1. Preparation of chemically activated high phosphorous slag content cement

Chemically activated high phosphorous slag content cement (CAPHSC) was prepared by inter-grinding a proportioned mixture of granulated PHS (80%), Type II PC (14%), and compound chemical

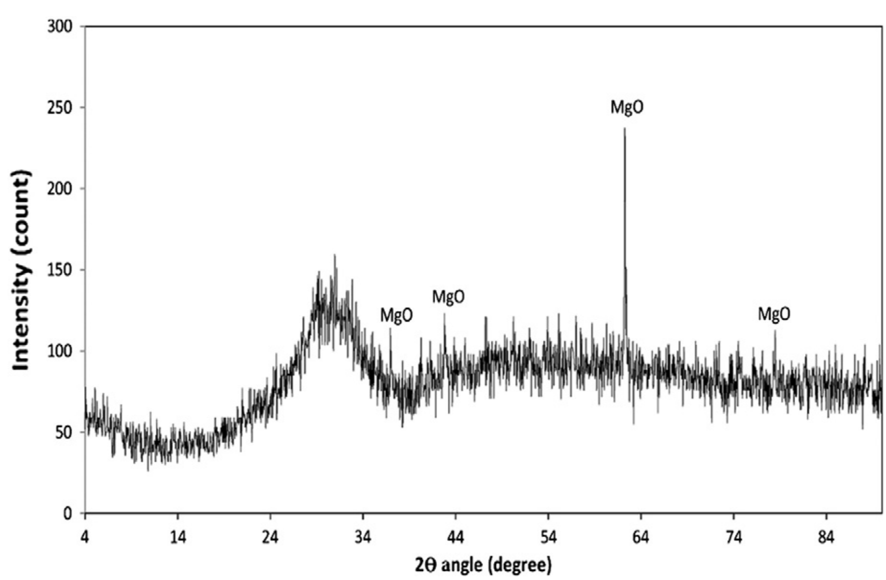

Fig. 1. X-ray diffractogram of phosphorous slag.

Table 2
Chemical compositions (wt.%) and physical properties of Portland cement.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	K_2O	Na_2O	SO_3	Free-CaO	LOI	Specific gravity (kg/m^3)	Blaine fineness (m^2/kg)
22.50	4.15	3.44	63.26	3.25	–	0.65	0.20	1.80	0.72	0.61	3.12	302