Construction and Building Materials 133 (2017) 459–467

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effects of red mud and Alkali-Activated Slag Cement on efflorescence in cement mortar

Suk-Pyo Kang [a], Seung-Jun Kwon [b,*]

[a] Architectural Engineering, Woosuk University, Jincheon 27841, South Korea
[b] Department of Civil and Environmental Engineering, Hannam University, Daejeon 306-791, South Korea

HIGHLIGHTS

- Quantitative evaluation of red mud effect on efflorescence.
- Various micro observation test results like EDA, XRD, SEM, and TGA.
- The relationship between efflorescence and the results (ion concentration, porosity).
- Verification of efflorescence mechanism through micro observation test.
- Mechanical and durability performance evaluation.

ARTICLE INFO

Article history:
Received 27 June 2016
Received in revised form 1 November 2016
Accepted 21 December 2016

Keywords:
Efflorescence
AASC
Red mud
Alkali activator
Binder effect

ABSTRACT

Recently AASC (Alkali Activated Slag Cement) is utilized for construction materials in order to reduce environmental load like abundant CO_2 emission. Red mud which is a byproduct from Bauxite ores process has a strong alkali component containing 10.0–15.0% of Na_2O, so that it can be used for an alkali activator or retarder for cement hydration. This work presents an evaluation of efflorescence characteristics in cement mortar with AASC and red mud. For the work, OPC (Ordinary Portland Cement) and AASC are used as matrix binder, and varying replacement ratios of red mud (0.0–30%) are prepared. In order to evaluate the efflorescence characteristics in the binders with red mud, analysis of water absorption and porosity are performed. The changing efflorescence areas with weight loss are also measured. The compounds in efflorescence are quantitatively analyzed through various techniques such as EDS, XRD, SEM, TGA, and alkali leaching test. In the work, the accelerated efflorescence mechanism and its characteristics are quantitatively evaluated considering the effects of binder types and red mud replacement ratios.

1. Introduction

Recently, AAC (Alkali Activated Cement) is recognized as a special cement. It can replace OPC (Ordinary Portland Cement) which causes a significant CO_2 emission [1,2]. Many researches have been performed on AASC (Alkali-Activated Slag Cement) which uses GGBFS (Ground Granulated Blast Furnace Slag) as a main binder main and NaOH is usually utilized as an activator. AASC can provide an eco-friendly construction material since the furnace slag is the byproduct obtained from the process of steel manufacturing [3,4]. It also has engineering advantages like early strength development, low hydration heat, and excellent resistance to chemical attack [3–7]. Aqueous solutions of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) which are commonly used as activators for AASC are verified to be effective but using activators in liquid form on-site is very dangerous and uneconomical. Consequently several studies have been performed in order to find another alkali-activators for preventing hard-handling and high cost [8].

Red mud is an inorganic byproduct with pH over 11, obtained from mineral processing of aluminum hydroxide-$Al(OH)_3$ and aluminum oxide-Al_2O_3. Through poly-condensation as slag or alumino-silicate, the minerals in the red mud are dissociated. Red mud containing 10–15% of Na_2O can be used for 1) an alkali activator replacing the previous liquid sodium silicate or 2) a retarder replacing sodium phosphate for construction material. The researches on the system with AASRC (Alkali-Activated Slag-Red mud Cement) can be a representative work for an application of red mud with high alkali to construction material and AASRC is reported to have high strength in early age and better chemical resistance compared with matrix with OPC [9–13].

* Corresponding author.
E-mail addresses: ksp0404@woosuk.ac.kr (S.-P. Kang), jjuni98@hannam.ac.kr (S.-J. Kwon).

http://dx.doi.org/10.1016/j.conbuildmat.2016.12.123
0950-0618/

Efflorescence is the migration of a soluble Ca^{2+} salt to the surface of a porous material. It begin with an aesthetic loss and finally goes to a strength reduction by leaching out the cement hydrates [14,15]. The construction material based on AASC is very vulnerable to efflorescence. The binders with sodium activators are reported to have more severe damage from efflorescence since increasing Na_2O in unreacted state causes a relatively easy movement of sodium ions in the alumino-silicate structure which is a product of the alkali-activated binder [16,17].

This work presents an evaluation of efflorescence characteristics in AASC mortar with red mud, and several tests like porosity measurement, moisture absorption coefficient, and elution analysis are performed considering varying red mud replacement. For analysis of compounds in efflorescence, microscopic analysis like SEM, TGA, and EDS are also performed.

2. Materials and experimental program

2.1. Materials

2.1.1. Binder

The physic-chemical properties of the OPC-noted as C and AASC-noted as NC are compared with those of FA (Fly Ash) and GGBFS (Ground Granulated Blast Furnace Slag) in Table 1. Compared to GGBFS, AASC contains low content of SiO_2 and Al_2O_3, but high content of SO_3. The specific surface area is 4058 cm^2/g and the density is 2.83 g/cm^3, which are similar as those in GGBFS. AASC contains desulfurization gypsum below 10.0% by mass ratio as activator and its main components are CaO (73.2%), SO_3 (21.9%), and SiO_2 (2.27%).

2.1.2. Red mud

Approximately two tons of red mud are produced in sludge with 40.0–60.0% moisture content, when one ton of Al_2O_3 is produced through the Bayer process. An annual production amount in Korea is approximately twenty tons. The photos of red mud sludge are shown in Fig. 1, where Fig. 1(a) and (b) show dumping stage and sludge-typed red mud, respectively. The red mud used in the work is ground granulated powder with red color as shown in Fig. 1(c). The sludge with 40.0–60.0% moisture content is dried to about 10.0%, then ground into granulated type.

2.2. Experimental program

2.2.1. Mix design of mortar and red mud characteristics

The mix proportions for cement mortar are listed in Table 2. The mortar samples are manufactured using a mix ratio of 1:3 (binder: sand). Water to binder (W/B) ratio is fixed as 0.75. OPC and AASC are used as binder, respectively and the red mud replacement ratio is considered from 0.0% to 30%. In order to evaluate the red mud characteristics, the tests of SEM and XRD are performed. Particle size distributions are also carried out for evaluating the mean diameter of red mud.

2.2.2. Compressive strength

Cubic mortar samples with 50 × 50 × 50 mm are prepared and cured for 28 days in the room condition with 25 °C and 60% of R.H. After curing for 28 days, compressive strength is evaluated referred to KS F 2405 [18].

2.2.3. Efflorescence acceleration

After 28 days of curing, the side surface of the sample is sealed with epoxy and about 6.0 mm of the bottom surface is immersed in distilled water for 14 days in the condition of 7 °C of temperature and 50% of R.H. The photos for efflorescence area are taken after 14 days of accelerating period and the area is quantitatively evaluated through software of Paint.NET. The efflorescence grading is evaluated based on the recommendation of As/NZS 6656.6 in Australia.

Table 1
Physical properties and chemical composition of binder.

Type of binder	Specific surface area (cm^2/g)	Density (g/cm^3)	Ig. loss	Chemical composition (%)					
				SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
C	3144	3.15	1.32	21.7	5.7	3.2	63.1	2.8	2.2
NC (AASC)	4058	2.83	2.23	22.1	8.9	1.4	54.9	3.3	5.2
FA	4012	2.13	2.50	49.5	31.9	5.9	2.9	0.9	0.5
GGBFS	4254	2.91	0.23	33.6	14.5	0.7	43.5	5.2	1.4

C: Ordinary Portland Cement NC: Alkali-Activated Slag Cement.

(a) Slurry type of red mud **(b) Dried red mud**

Fig. 1. The photos of red mud.