Cement and Concrete Research 41 (2011) 301–310

Contents lists available at ScienceDirect

Cement and Concrete Research

journal homepage: http://ees.elsevier.com/CEMCON/default.asp

Influence of activator type on hydration kinetics, hydrate assemblage and microstructural development of alkali activated blast-furnace slags

M. Ben Haha *, G. Le Saout, F. Winnefeld, B. Lothenbach

Empa, Swiss Federal Laboratories for Materials Science and Technology, Laboratory for Concrete and Construction Chemistry, Ueberlandstrasse 129, 8600 Dübendorf, Switzerland

ARTICLE INFO

Article history:
Received 24 August 2010
Accepted 23 November 2010

Keywords:
Alkali Activated Cement (D)
Microstructure (B)
Calcium-Silicate-Hydrate (C-S-H) (B)
Image Analysis (B)
Mechanical Properties (C)

ABSTRACT

The hydration of two slags with different Al_2O_3 contents activated with sodium hydroxide and hydrous sodium metasilicate (commonly named water glass) is studied using a multi-method approach. In all systems, C-S-H incorporating aluminium and a hydrotalcite-like phase with Mg/Al ratio ~2 are the main hydration products. The C-S-H gels present in NaOH activated pastes are more crystalline and contain less water; a calcium silicate hydrate (C-S-H) and a sodium rich C-N-S-H with a similar Ca content are observed at longer hydration times. The activation using NaOH results in high early strength, but strength at 7 days and longer is lower than for the sodium metasilicate systems. The drastic difference in C-S-H structure leads to a coarser capillary porosity and to lower compressive strength for the NaOH activated than for the sodium metasilicate activated slags at the same degree of slag reaction.

1. Introduction

In order to reduce the CO_2-emissions related to cement manufacturing, the application of industrial by-products rich in aluminium and silicon oxide in alkaline activated binders is a promising option [1,2]. Materials generally used are blastfurnace slag, fly ash or metakaolin, which are activated by the addition of alkalis like alkali silicates or hydroxides [3–6].

Alkali activated slags (AAS) can have high strength development and using the adequate activators can lead to rapid setting, good durability and high resistance to chemical attack [2–8]. The main hydration products found in AAS are C-S-H with a low Ca/Si ratio related mainly to the composition of the slag and the nature of activators used, hydrotalcite intimately intermixed with the C-S-H in the MgO containing slag and in some cases also an AFm phase, most probably strätlingite [9–13]. The C-S-H produced by alkali activated systems may incorporate a higher content of Al_2O_3 based on the initial composition of the slag [12,14,15]. Many variables influence the reaction of alkali activated slags such as fineness, chemical composition, water/binder (w/b) ratio, temperature or the pH [16–23]. A better understanding of the effects of alkaline activators such as NaOH and hydrous sodium metasilicate ($Na_2SiO_3 \cdot 5H_2O$) on the hydration mechanisms of alkali activated slag could indicate ways to optimise the use of alkaline activators.

An important factor that influences the porosity and thus the compressive strength is the kinetics of the hydration. In Portland cement systems it has been observed that a fast initial reaction as e.g. caused by elevated temperatures or accelerators, results in the formation of a dense hydration product and less reduction of the initial porosity that affects adversely the mechanical properties at later ages [24,25].

This paper investigated the major hydration products formed in alkali activated slags and their composition, morphology and spatial distribution. The study was carried out using two slags with different Al_2O_3 content to investigate the influence of the slag composition on the types of hydrates formed. An image analysis method was adopted to quantify the degree of hydration and the amount of coarse porosity directly from the backscattered electron (BSE) image of polished slag pastes samples. By studying the coarse porosity and degree of hydration using different alkaline activators, the relationship between microstructural properties and compressive strength was established.

2. Materials and experiments

Two ground granulated blast furnace slags (GGBFS) with different Al_2O_3 contents were studied: GGBFS LA exhibits a low Al_2O_3 content of 7.1 wt.%, and GGBFS HA a higher content of 12.0 wt.% Al_2O_3 (Table 1) with a similar particle size distribution. Two types of activators were used: NaOH and hydrous sodium metasilicate $Na_2SiO_3 \cdot 5H_2O$ (labeled here as NSH_5 and commonly referred to as water glass). The dosage of both activators and the amount of water were selected to obtain the same Na_2O content and water content in the two systems. The activators were dissolved in the water prior to the mixing in order to have a homogeneous distribution. The compositions of the pastes are presented in Table 2. All pastes were

* Corresponding author. Tel.: +41 44 823 49 47; fax: +41 44 823 40 35.
E-mail address: mohsen.ben-haha@empa.ch (M. Ben Haha).

0008-8846/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cemconres.2010.11.016