The Influences of curing condition on properties of concrete

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Abstract—

The effect of curing conditions (sealed and unsealed) on the pore solution composition and carbonation resistance of different binary alkali-activated fly ash (AAFA) and ground granulated blast furnace slag (GGBS) pastes is studied in the study. The studied mixtures were with FA: GGBS ratios of 100:0, 70:30; 50:50, 30:70 and 0:100. Ordinary Portland cement (OPC) (70 wt% of GGBS and 30 wt% OPC) pastes with the same precursor content were also studied to provide a baseline for comparison. Accelerated carbonation conditions (1% (v/v) CO2, 60% RH for 500 days) were considered for evaluating the carbonation resistance of the pastes. The results show a substantial lower [Na+] in the pore solution of the unsealed cured samples compared to the sealed cured samples. It is also found that unsealed curing of the samples leads to a faster carbonation rate. Additionally, it is observed that the carbonation rate decreases with increasing GGBS content independent of the curing conditions. The potential risks with respect to carbonation of the pore solution are studied and discussed.

Keywords— **Curing Condition, Sealed, unsealed, carbonation.**

I. INTRODUCTION

Performance of mortar is drastically affected by carbonation. In alkali-activated materials (AAMS) carbonation received extensive attention. Carbonation is the result of chemical reaction between carbonic acid and cement hydration products that leads to precipitation of carbonation products and decrease in the pH of the pore solution. Carbonic acid is formed in the pore solution by dissolution of gaseous CO2 that diffuses from the environment into the porous structure of the concrete. Carbonation, which is controlled by both diffusion and chemical reaction, is dependent on several factors including relative humidity, tortuosity of the paste, and concentration of CO2 in the environment and chemistry of the binder.

Carbonic acid is formed in the pore solution by dissolution of gaseous CO2 that diffuses from the environment into the porous structure of the concrete. Carbonation, which is controlled by both diffusion and chemical reaction, is dependent on several factors including relative humidity and concentration of CO2 in the environment and chemistry of the binder [5, 8]. Although the carbonation mechanism in AAMs is not yet fully understood, it is expected to be different from that of OPC-based concrete. The fundamental differences in the constituting phases and the physical structure of AAMs in comparison to OPC-based materials are the main reason for such an expectation [11]. While the main reaction products in OPC-based materials are Ca(OH)2 and C-S-H, different types of alkaline gel are formed in AAMs, such as sodium alumino-silicate hydrate (N-A-S-H), calcium aluminosilicate hydrate (C-A-S-H) and calcium sodium aluminosilicate hydrate (C-N-A-S-H) [1–2]. AAMs in contrast to OPC-based concrete, do not contain $Ca(OH)_2$ [15]. The absence of $Ca(OH)_2$, that acts as the main buffering compound in OPC-based concrete, leads to faster decalcification of C-A-S-H/C-N-A-S-H gels and may account for the faster carbonation process in AAMs [6, 7]. The chemical compositions of class F fly ash, slag, silica fume, metakaolin and cement are shown in Table 1. The contents of silica and alumina in metakaolin are approximately 96% of its chemical composition. The silica content in silica fume is approximately 95% of its chemical composition. On the contrary to metakaolin and silica fume, slag contains a high content of calcium oxide. The alkaline solution used in this study was a mixture of SH and SS solutions. The alkaline solution content in all AAFA mixtures was fixed at 40% of the total binder, and the fine aggregate-to binder ratio was fixed at 1.0. No extra water or superplasticizer was added to the mixtures. Regarding the parameter (w/b), the mass of water comes from the water contained in the SS solution and SH solution. The use of highly alkaline activators for reactions of the FA and GBFS provides a high [Na+] leading to high pH levels in the pore solution of noncarbonated AAMs. It has been shown that this ensures existence of sufficiently high [Na+] after natural and accelerated carbonation in alkali-activated systems to prevent corrosion of reinforcement [9]. However, it is not clear whether the susceptibility of AAMs to loss of Na+ ions prior to (or during) the carbonation process can lead to significant decrease of pH or not. The aim of this paper is to address these questions

by investigating the effect of curing conditions on the pore solution chemistry and carbonation resistance of alkali-activated FA/GBFS pastes. Special attention is given to the Na+ loss in sealed and unsealed cured specimens. Five mixtures with different FA/GBFS ratio are investigated. OPC (CEM I) and CEM III/B pastes are considered to provide a baseline and to perform comparisons with the studied alkali activated pastes.

II. MATERIALS AND METHODS

FA was supplied by GBFS was supplied by ORCEM (the Netherlands). CEM I 42.5 N and CEM III/B 42.5 N in compliance with Dutch standard (NEN-EN 197-1:2011 en) were used as references. The chemical composition of raw materials was determined with X-ray Fluorescence (XRF) (Table 1). XRF measurements were done using Panalytical AXIOS Max Advanced XRF spectrometer. XRF analysis of raw materials was performed with fused beads and lithium tetraborate/meth borate as a flux. XRF bead analysis is not suitable for the analysis of sulphur. Therefore, sulfur (S) was determined using Eltra Sulphur analyser. Loss on ignition (LOI) was determined by LECO Thermo graphic Analyser (TGA701). The negative LOI for GBFS (Table 1) was related to the oxidation of sulfur rich species in the GBFS. It should be noted that the LOI was not corrected in the XRF measurements. The activator Na_2O concentration was 4.8 wt% with respect to the mass of precursor (FA+GBFS). For each paste, the activator liquid to binder mass ratio was 0.5. The pastes were produced with the following FA/GBFS ratios of 100:0, 70:30, 50:50, 30:70, 0:100 wt%, named S0, S30, S50, S70, S100, respectively (Table 2). Cement pastes were made with water to-binder ratio 0.5. The precursors were dry-mixed for 2 min and then mixed with the activator. The pastes were cast in two types of cylindrical polyethylene jars, (A) with 35mm diameter and 70mm height, and (B) with 54mm diameter and 100mm height and vibrated for 15–30 s on a vibrating table. The samples denoted as (A) were used for RH measurements, pore solution extraction and alkali loss measurements, while samples (B) were used for mass loss, carbonation depth and pH measurements. The samples were stored in the closed jars (A, B) for 24 h after casting. For unsealed cured conditions, samples were removed from the jars and afterwards cured in a fog room at room temperature and a relative humidity (RH) of ~99% RH (the atmosphere was normal air with 400 ppm of CO2 and the air was internally circulated, however, when opening the curing room, air with CO2 is expected to enter the fog room) for 28 days. For sealed samples, these were kept in the jars in the curing room where unsealed samples were also cured. 2.2. Test programme. The sealed samples were unsealed after 28 days of curing when all the samples were placed in the laboratory conditions at 50–60% RH (0.04% v/v CO_2, 20 °C) for additional 28 days (preconditioning of the samples prior to carbonation). This preconditioning was intended to equilibrate the internal RH of the samples with the environment before performing the accelerated carbonation tests. For unsealed samples, one set was left in the curing room for an additional 28 days, to provide insight into the further alkali loss after first 28 days of curing. During carbonation exposure, the carbonation depth was monitored in both sealed and unsealed cured samples.

III. TEST PROGRAMME

An overview is shown in the Fig. 1 of the test programme followed to investigate the effect of curing conditions and accelerated carbonation on the alkali-activated FA/GBFS pastes. First mass loss, internal RH, pore solution composition and pH are studied for curing under both sealed and unsealed conditions. Additionally, alkali loss was monitored for unsealed cured samples during the first 28 days of curing. The sealed samples were unsealed after 28 days of curing when all the samples were placed in the laboratory conditions at 55–60% RH (0.04% v/v CO2, 20 °C) for additional 28 days (preconditioning of the samples prior to carbonation). This preconditioning was intended to equilibrate the internal RH of the samples with the environment before performing the accelerated carbonation tests. For unsealed samples, one set was left in the curing room for an additional 28 days, to provide insight into the further alkali loss after first 28 days of curing. During carbonation exposure, the carbonation depth was monitored in both sealed and unsealed cured samples.

TABLE I
CHEMICAL COMPOSITION

Material	SiO$_2$	Al$_2$O$_3$	CaO	Fe$_2$O$_3$	S	Na$_2$O	K$_2$O	TiO$_2$	LOI
FA	52	24	5	8	0.2	0.7	1.2	0.9	1.1
GBFS	32	12	35	0.4	0.8	0.3	0.2	0.8	-1.2
CEM I	18.3	4.2	63	1.5	1.3	0.2	0.3	0.1	2.5
CEM-III-B	25	10.3	42.6	1.2	1.5	0.3	0.34	0.8	0.09

This facilitates the Na-leaching process. Water from the curing atmosphere can more readily enter the gel and become self-expelled in paste S50 compared to paste S100. The absolute mass of leached Na+ was measured from the total solution volume which was collected in the plastic container during 28 days of unsealed curing of the samples S50 and S100. It is found that 0.8 g and 0.65 g of Na+ was leached from the samples S50 and S100, respectively. The absolute amount of Na which was initially

used for the activation was 4.62 g. This implies that 17.3% and 14% of this initial Na amount, was leached from the samples S50 and S100, respectively.
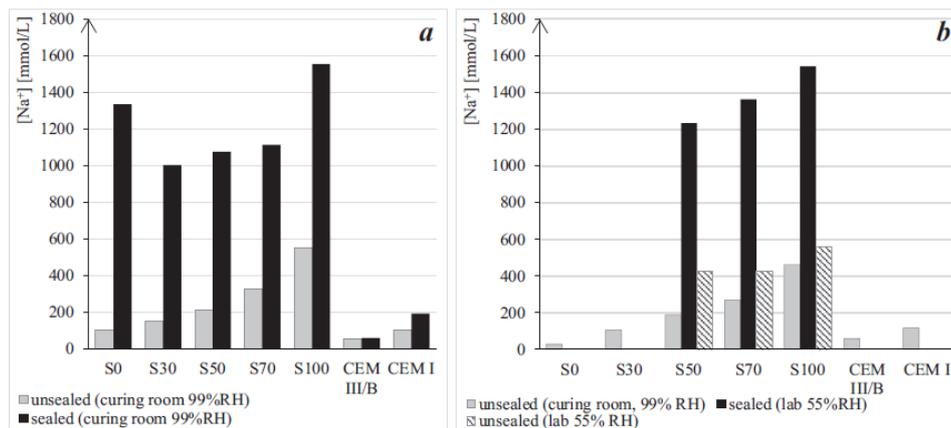

Fig. 1 The effect of sealing on the [Na+] in the pore solution of the pastes at 28 days (a) and 56 days (b).

IV. Conclusions

An alkali leaching mechanism was observed in the unsealed cured specimens. This is most likely the result of several counter-affecting mechanisms. The RH difference between the environment and the specimen, causes a capillary flow from the surface to the interior of the samples and, therefore, an inward movement of the ions (advection). Meanwhile, condensation of water on the surface of the samples leads to dilution of the ions at the surface compared to the interior of the specimens. This causes a diffusive movement of ions from the interior towards the surface of the samples. Here, the diffusive outward movement of ions governed the inward adjective water movement that in total led to a loss of the alkali from the pore

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