Construction and Building Materials 80 (2015) 84–91

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effect of powdered activated carbon on the air void characteristics of concrete containing fly ash

Mehrdad Mahoutian, Adam S. Lubell *, Vivek S. Bindiganavile

University of Alberta, Civil and Environmental Engineering Department, University of Alberta, Edmonton, Alberta T6G 2W2, Canada

HIGHLIGHTS

- Study of influence of powder activated carbon on the properties of fly ash containing concrete.
- PAC in fly ash will increase the AEA demand to achieve a specified air content.
- Ink prepared image analysis samples successfully used to determine air void characteristics.

ARTICLE INFO

Article history:
Received 10 September 2014
Received in revised form 14 December 2014
Accepted 4 January 2015

Keywords:
Powdered activated carbon
Fly ash
Image analysis
Air void characteristics
Concrete

ABSTRACT

One of the common methods to reduce mercury vapor emissions from coal-fired power plants involves the injection of powdered activated carbon (PAC) into the flue gases to adsorb the mercury vapor. If the PAC then settles along with the fly ash in the electrostatic precipitator, the ability to use the collected fly ash as a supplementary cementitious admixture in concrete must be established. This study examined the influence of PAC in fly ash on the air void networks and consequent properties of concrete produced with an air entraining admixture. Samples included those with PAC added to the fly ash at the laboratory as well as PAC-containing fly ash collected at a generating station. The air void content, specific surface area and spacing factor of hardened concrete were determined using an image analysis technique on epoxy-impregnated and ink-prepared samples. The PAC-containing fly ash had an insignificant effect on the air void content and spacing factor compared to samples with laboratory-added PAC. Image analysis using ink-prepared samples provided improved reliability of the air void network results compared to epoxy-prepared samples.

1. Introduction

Fly ash has been successfully used as a supplementary cementing admixture in concrete for decades as it is economic, environmentally advantageous and improves the concrete mechanical properties and durability [1–4]. According to the American Coal Ash Association, over 24 million tons of fly ash was consumed as a cement replacement in the United States in 2010 which was a 30% increase compared with 2000 [5]. In Canada, 4.7 million tons of fly ash is produced annually, but only 31% of this quantity is used in construction [6]. However, this value shows a large relative increase in the usage of fly ash when compared to the 21% used in 2002 [6].

All coal-fired electric generating units release mercury into the atmosphere due to the burning of coal. In Canada, regulations [7] governing reduced mercury emissions from coal-fired power plants came into effect in January 2011. One of the common methods to reduce mercury vapor emissions from the coal-fired power plants involves the injection of powdered activated carbon (PAC) into the flue gases to adsorb the mercury vapor. The PAC then settles along with the fly ash in the electrostatic precipitator [8]. PAC is a form of carbon that has been processed to make it extremely porous and thus to have a very large surface area available for adsorption of chemical components such as mercury. Prior research on the effect of carbon on concrete properties has focused mainly on the effects of unburnt carbon in fly ash on the air-void characteristics [9–11]. Carbon in fly ash is suspected to adsorb the surface active admixtures in concrete, in particular the air-entraining admixtures (AEA). Note that very few reports [12] address the effect of PAC or other mercury adsorbents on the AEA demand and consequent properties of the concrete. The influence of PAC may be different than other carbon sources due to its surface properties and the compounds adsorbed from the flue gases. Further, there is no North American standard to govern the use of fly ash containing mercury-adsorbents within concrete,

* Corresponding author. Tel.: +1 604 738 0048.
E-mail address: adam.lubell@gmail.com (A.S. Lubell).

http://dx.doi.org/10.1016/j.conbuildmat.2015.01.019
0950-0618/© 2015 Elsevier Ltd. All rights reserved.

such that blended cements and ready-mix concrete are produced based on guidelines developed for conventional fly ash. This limits the ability to predict the durability and mechanical properties of concrete produced with fly ash containing mercury adsorbents, with possible future repair and life cycle cost implications should the PAC be found to adversely impact these properties. For concrete structures exposed to freeze–thaw cycles, establishing the effects of the PAC on the air void network of concrete is an important aspect of understanding the feasibility of continued blending of cement with fly ash containing mercury adsorbents.

This study investigated the effect of PAC and AEA on the fresh and hardened properties as well as the air void characteristics of concrete. Air void characteristics were established by an image analysis technique using both epoxy and inked preparation methods. All mixes contained fly ash at a fly ash-to-cement mass ratio of 1:4, which is typical of some commercially available concrete mixes. In most mixes, PAC was added to the concrete mix in the laboratory at dosages up to 10% by mass of fly ash. One mix used a fly ash that directly contained PAC injected at the power plant ahead of the electrostatic precipitators to allow qualitative understanding of potential differences. This allowed a comparison of the results to those in which PAC was added at similar dosage during the casting of concrete to qualitatively determine if the method of PAC addition into the mix was a relevant consideration for future mix development trials by industry.

The main concrete properties of interest included the fresh air void content, volume of permeable voids, compressive strength, air void content of the hardened samples, spacing factor and specific surface area. The epoxy and inked preparation methods were used for the image analysis technique at two different magnifications to determine the air-void characteristics of hardened concrete. A maximum PAC ratio with an insignificant effect on air void characteristics of concrete was ultimately determined.

2. Research significance

There is growing concern with regard to the continued usage of coal fly ash in concrete due to the carbon content and composition from recent legislation regarding mercury emissions. The presence of PAC in the collected fly ash could potentially interfere with surface active chemical admixtures typically used in concrete. It is therefore essential to understand the corresponding influences on the fresh properties, mechanical characteristics and durability of concrete incorporating fly ash that contains mercury adsorbents such as PAC. This study investigates the influence of PAC dosage on these characteristics in an air entrained concrete with moderate fly ash content. Differences in the PAC effects when added to the concrete mix in the laboratory or injected into the flue gases and directly collected with the fly ash were also considered.

3. Experimental program

The experimental program is briefly explained in this section. Additional details and a complete record of all test results are reported in Mahoutian et al. [13].

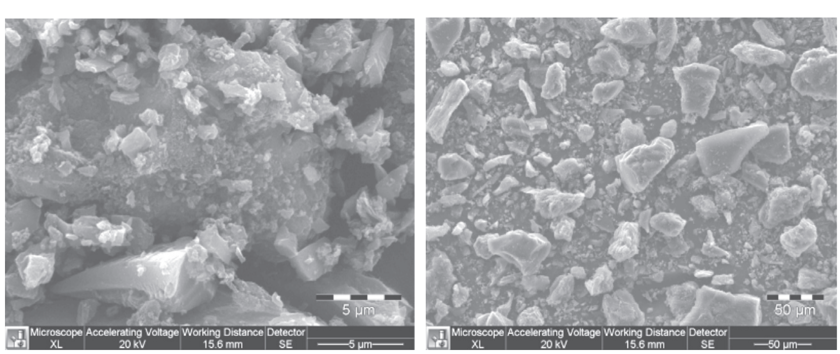
3.1. Materials

The chemical properties of the fly ash and cement are provided in Table 1. Cement Type GU in accordance with CSA A23.1 [14] was used. Most mixes contained a Type F fly ash per ASTM C618 [15] that was sourced from a coal-fired thermal power station in southern Alberta, Canada. One mix used a Type F fly ash sourced from the Genesee coal-fired thermal power plant, herein reinforced to as Genesee fly ash. This plant is located in central Alberta, Canada, and contained equipment to inject PAC into the flue gas ahead of the electrostatic precipitator. The PAC content of the Genesee fly ash was calculated as 2% by mass [13].

A powdered activated carbon (PAC) that is commonly used as the mercury adsorbent in thermal power plants was sourced locally for this study. The moisture content, Iodine number, and apparent density of the PAC were provided by the manufacturer as 8%, 750 mg/g and 0.65 g/cc, respectively. Fig. 1 shows images from a scanning electron microscope at two different magnifications that reveal the high specific surface area of the PAC. The specific surface area was specified by the supplier as 500 m^2/g. The Genesee plant used PAC sourced from a different supplier but the properties were similar to the main PAC used in this study. The manufacturer supplied data for the moisture content, apparent density, specific surface area and particle size of the PAC used in

Table 1
Chemical composition of fly ash and cement (mass%).

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	LOI
Type F fly ash	55.53	23.24	3.62	10.97	1.22	0.24	2.83	0.76	0.68	0.1	0.54
Genesee fly ash	59.40	22.40	3.91	5.91	–	0.11	2.75	1.62	–	–	0.33
Cement	19.87	4.14	2.84	62.24	0.21	2.52	0.21	0.62	0.20	0.07	3.20



a) magnification = 12,000 X b) magnification = 800 X

Fig. 1. SEM images of PAC at two different magnifications.