Applied Radiation and Isotopes 94 (2014) 8–13

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

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

Prompt gamma ray evaluation for chlorine analysis in blended cement concrete

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HIGHLIGHTS

- New data on chlorine measurements in BFS cement concrete is presented.
- Single chlorine gamma ray was evaluated for chlorine analysis in blended cement concrete.
- 6.11 MeV gamma-rays were found to be optimum one for chlorine analysis in the blended concretes.

ARTICLE INFO

Article history:
Received 16 January 2014
Received in revised form
9 June 2014
Accepted 13 June 2014
Available online 8 July 2014

Keywords:
Single prompt gamma ray evaluation for chlorine analysis
Portable neutron generator
Blended cement concrete samples
Monte carlo simulation

ABSTRACT

Single prompt gamma ray energy has been evaluated to measure chlorine concentration in fly ash (FA), Super-Pozz (SPZ) and blast furnace slag (BFS) cement concrete specimens using a portable neutron generator-based Prompt Gamma Neutron Activation (PGNAA) setup. The gamma ray yield data from chloride concentration measurement in FA, SPZ and BFS cement concretes for 2.86–3.10, 5.72 and 6.11 MeV chlorine gamma rays were analyzed to identify a gamma ray with common slope (gamma ray yield/Cl conc. wt%) for the FA, BFS and SPZ cement concretes. The gamma ray yield data for FA and SPZ cement concretes with varying chloride concentration were measured previously using a portable neutron generator-based PGNAA setup. In the current study, new data have been measured for chlorine detection in the BFS cement concrete using a portable neutron generator-based PGNAA setup for 2.86–3.10, 5.72, and 6.11 MeV chlorine gamma rays. The minimum detection limit of chlorine in BFS cement concrete (MDC) was found to be 0.034 ± 0.010, 0.032 ± 0.010, 0.033 ± 0.010 for 2.86–3.10, 5.72 and 6.11 MeV gamma ray, respectively.

The new BFS cement concrete data, along with the previous measurements for FA and SPZ cement concretes, have been utilized to identify a gamma ray with a common slope to analyze the Cl concentration in all of these blended cement concretes. It has been observed that the 6.11 MeV chlorine gamma ray has a common slope of 5295 ± 265 gamma rays/wt % Cl concentration for the portable neutron generator-based PGNAA setup. The minimum detectable concentration (MDC) of chlorine in blended cement concrete was measured to be 0.033 ± 0.010 wt % for the portable neutron generator-based PGNAA. Thus, the 6.11 MeV chlorine gamma ray can be used for chlorine analysis of blended cement concretes.

1. Introduction

Corrosion of reinforcing steel is mainly caused by the diffusion of chloride ions to the steel surface. These ions either diffuse from the service environment or are present in the mixture ingredients (Maslehuddin et al., 1996; ACI Committee 222, 1989; Al-Amoudi et al., 2001). One preventive measure against reinforcement corrosion is making the concrete dense and impermeable. Pozzolanic materials, such as blast furnace slag (BFS), fly ash (FA), silica fume (SF), Super-Pozz (SPZ) and others, are added to concrete as a partial replacement for Portland cement, to make it dense and impermeable, thereby slowing the diffusion of the chloride ions to the steel surface (Al-Amoudi, 2002; PCI Committee, 1994). The Prompt Gamma Neutron Activation (PGNAA) technique is a non-destructive method that can be utilized to determine the chloride concentration in bulk concrete samples (Saleh and Livingston, 2000; Paul and Lindstrom, 2000; Gardner et al., 2000; Naqvi et al., 2012a, 2012b; Chichester and Simpson Lemchak).

BFS is in itself cement. However, approximately 20 to 40% cement is added to it to enhance its cementing properties. BFS is

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http://dx.doi.org/10.1016/j.apradiso.2014.06.011
0969-8043/

known to significantly reduce the risk of damage caused by the alkali–silica reaction, provides good resistance to chloride ingress, reduces the risk of reinforcement corrosion and provides good resistance to attacks by sulfate and other chemicals. Furthermore, the process of manufacturing Portland cement is costly, and it is a major contributor of greenhouse gases, responsible for approximately 5% of all global carbon dioxide emissions. Minimization of the use of Portland cement in concrete without the loss of concrete strength is highly desirable. As shown in Table 1 (Naqvi et al., 2012a, 2012b), BFS cement is characterized by reduced iron oxide, silica and lime contents and enhanced alumina and MgO contents compared to Type I or Type II Portland cement. It contains SiO_2 (27.70 wt%), Al_2O_3 (12.80 wt%), Fe_2O_3 (1.20 wt%), CaO (44.0 wt%) and MgO (8.80 wt%).

While blended cements are utilized to minimize reinforcement corrosion, a non-destructive technique is required for monitoring the chloride concentration in concrete and thus decreasing the chances of reinforcement corrosion. The PGNAA technique is a non-destructive technique that can be used to analyze chloride concentration in bulk cement concrete samples (Saleh and Livingston, 2000; Paul and Lindstrom, 2000; Gardner et al., 2000; Naqvi et al., 2012a, 2012b; Chichester and Simpson Lemchak). In the PGNAA technique, the sensitivity of chlorine detection is affected by the interference between gamma rays from chlorine and calcium (Naqvi et al., 2012a, 2012b). Concrete containing different calcium concentrations is expected to lead to different chlorine detection sensitivities. As shown in Table 1, replacement of Portland cement with FA, SF, SPZ or BFS to increase the corrosion resistance also changes the calcium concentration in concrete. This in turn may affect the chloride detection sensitivity in blended cement concrete, thereby resulting in different values for the minimum detectable concentration (MDC) of chloride. Therefore, it is of interest to compare the MDC of chloride in blended cement concretes utilizing the PGNAA technique.

Furthermore, it will be worthwhile to analyze various types of blended cement concretes utilizing a single energy gamma ray with a common slope. This requires a search for a single gamma ray with a common slope (gamma ray yield/Cl conc. wt%) for all cement concrete types to be analyzed using the specific PGNAA setup. In this study, a single energy gamma ray was sought for the analysis of FA, BFS and SPZ cement concrete specimens using a portable neutron generator-based PGNAA setup developed by the authors. Previously, the chloride concentration in FA and SPZ blended cement concretes was measured using a DD portable neutron generator-based PGNAA setup (Naqvi et al., 2012a, 2012b). In the present study, the chloride concentration has been measured in BFS cement concrete utilizing the portable neutron generator-based PGNAA setup (Naqvi et al., 2012a, 2012b). From the measured chloride concentration data from FA, BFS and SPZ cement concrete specimens, a single energy gamma ray with a common slope for all concrete types has been determined. The two parts of the study are described in the following sections.

2. Prompt gamma ray analysis of BFS cement concrete specimens

The chlorine concentration in BFS cement concrete specimens containing 0.8–3.5 wt% chloride was measured utilizing a portable neutron generator based-PGNAA setup that has been described in detail elsewhere (Naqvi et al., 2012a, 2012b). For continuity, it will also be described in detail here. The PGNAA setup mainly consists of a portable neutron generator, a cylindrical 25 cm × 8 cm (diameter x height) high-density polyethylene (HDPE) moderator, a cylindrical 25 cm × 14 cm (diameter x height) chlorine-contaminated BFS cement concrete specimen and a cylindrical 5 cm × 5 cm (diameter × height) BGO gamma ray detector. The concrete specimen was placed on one side of the neutron generator target-plane location, with the axis of symmetry aligned at a right angle to the neutron generator axis. The HDPE moderator was placed between the specimen and the neutron generator with its axis of symmetry aligned with the axis of the concrete specimen. The BGO detector views the concrete specimen at an angle of 45° with respect to its axis of symmetry, as shown in Fig. 1. To prevent undesired gamma rays and neutrons from reaching the detector, lead, tungsten, and paraffin, neutron shielding is inserted between the neutron generator, the moderator and the BGO detector, as shown in Fig. 1. The paraffin neutron shielding is made of a mixture of paraffin and lithium carbonate mixed in equal weight proportions. The cylindrical BFS cement concrete specimens were prepared by mixing 20 wt% BFS as a replacement of cement. The BFS cement concrete

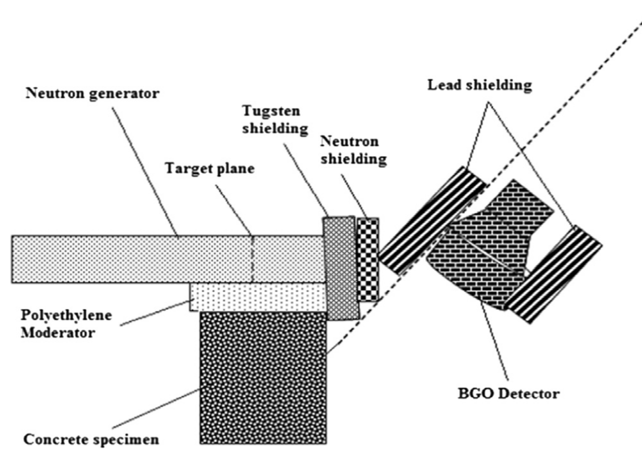

Fig. 1. Schematic of the MP320 portable neutron generator-based PGNAA setup used to measure the prompt gamma-ray yield.

Table 1
Chemical composition (wt%) of Portland and Blended Cements and coarse and fine aggregates Naqvi et al., 2012a, 2012b.

Compound	Type V cement	Type I cement	Fly ash	Blast furnace slag	Silica fume	Superpozz	Fine aggregate	Coarse aggregate
SiO_2	22.00	20.52	52.30	27.70	92.50	53.50	90.70	4.29
Al_2O_3	4.08	5.64	25.20	12.80	0.40	34.3	1.40	0.20
Fe_2O_3	4.24	3.80	4.6	1.20	0.40	3.6	0.48	0.23
CaO	64.07	64.35	10.0	44.0	0.50	4.4	–	–
$CaCO_3$	–	–	–	–	–	–	5.62	93.20
MgO	2.21	2.11	2.20	8.80	0.90	1.0	0.26	0.44
SO_3	1.96	2.1	0.60	3.10	0.50	–	0.2	0.4
K_2O	0.31	0.36	0.10	0.10	0.40	–	0.43	0.09
Na_2O	0.21	0.19	0.10	0.40	0.10	–	0.17	0.03