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Radiological safety aspects of utilizing coal ashes for production of lightweight concrete

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Abstract

The present paper reports the results of experiments to develop environmentally and economically friendly structural lightweight concretes utilizing coal ashes and other waste materials. The product complies with national and international regulations setting limits on the activity concentration of natural radioisotopes in building products. The utilization of coal ashes in the building industry carries (in addition to its economic advantages) a fringe environmental benefit. This utilization reduces the potential damage to the environment caused by the radioactivity in the combustion by-products (the ashes) stored in piles and ponds near the power stations prior to their disposal. The study deals with the radiological characteristics of coal ashes and lightweight concretes based on these ashes. The ashes are generated at Israel's power stations from coal supplied from different sources in South Africa, Columbia and Indonesia.

Keywords: Activity concentration index; Bottom ash; Fly ash; Lightweight concrete; Radioactivity

1. Introduction

The utilization of coal ashes in the building industry has economic and environmental advantages. The economic advantages include: the exploitation of non expensive waste materials in civil engineering; the reduction of the amount of ashes that have to be disposed; the possibility to channel coal combustion by-products to the consumer market. The environmental advantage is: incorporating of the ashes in solid material (concrete and other building products) lowering the potential environmental hazard (radioactive air and water pollution) associated with piles and ponds of ashes stored near the power stations prior to their disposal. Therefore this utilization improves significantly the economic and environmental characteristics of power engineering. The incorporation of raw materials containing enhanced concentration of natural radioactivity (such as coal ashes) in the consumer products is subject to legal control due to the inherent potential risk of exposing members of the public to ionizing radiation originated in the product. One of the efficient ways to utilize coal ashes for production of consumer products with an allowable level of radioactivity is their use in the concrete industry. This paper considers the results of research and development of environmentally friendly lightweight concrete based on large quantities of bottom ash and fly ash. The research is distinguished from our earlier studies related to this problem. Firstly, it is based on data collected during systematic and continuous sampling and testing of fly ash and bottom ash produced in Israel's power stations. These utilize coals being supplied from sources located in South Africa, South America (Columbia) and Indonesia. This study supplies therefore more comprehensive data on the variability of the radiological characteristics of coal ashes, especially those of bottom ash. Secondly, in addition to the data on the radioactivity of the coal ashes, we report the results of studying the radioactivity of lightweight concretes based on combined use of two types of coal ashes: bottom ash and fly ash. Thirdly, the methods used for

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controlling and lowering the radioactivity in concrete elements (structures) developed in this study are also reported. Based on these methods, the radioactivity content expected in concrete elements (structures) containing coal ashes from different sources can be predicted. These predictions were confirmed by actual laboratory and field measurements. The evaluation of radioactivity in coal ashes supplied to the building industry enables the prediction of the radioactivity in the building elements (structures) based on these ashes. This has a potential for: (i) the optimal implementation of ashes in concrete technology; (ii) broadening the market of coal ashes for use in the high performance lightweight concrete; (iii) production of environmentally friendly lightweight concrete based on coal ashes while complying with radiation safety regulations.

2. Radiological aspects of generation, storage, and utilization of coal ashes

The amount of coal ashes accumulated at power stations is consistently increasing and posing a significant hazard to the environment. Fly ash and bottom ash, by-products of coal combustion, contain enhanced concentration of the natural radionuclides ^{40}K, ^{238}U and ^{232}Th and their decay products (the level of ^{238}U is usually estimated by the presence of ^{226}Ra) [1]. In addition, the short lived daughters product of ^{226}Ra radioisotope ^{222}Rn (radon gas) must be considered. These radionuclides emit alpha particles, beta particles, and gamma rays, and are therefore a source of ionizing radiation. Exposure to such radiation is considered to pose a hazard to human health. Building products based on coal ashes are classified by the relevant European Commission Directorate for Radiation Protection as materials with enhanced radioactivity [2].

Accumulation of coal ashes stored in piles and ponds can lead to the exposure of the public to ionizing radiation via the following pathways: (i) external exposure of local worker to gamma radiation; (ii) internal exposure of the respiratory tract due to inhalation of radon gas and its decay products; (iii) internal exposure due to inhalation and/or ingestion of coal ash dust particles.

Inhalation of radon gas and fine particles of coal ash is the main route of internal exposure to fly ash. Meij [3] notes that inhalable particles include fly ash particles passing through a 400 mesh (38 μm) sieve. Fly ash complying with the requirement set by ASTM C618-05 [4] comprises more than 55% of such particles. The amount of fine respirable particles in the ash is significantly lower (above 5%). However, these particles are capable of penetrating lung alveoli and they stay in the respiratory tract for a long period of time.

Internal radiation caused by the inhalation of radon gas and radioactive fly ash dust is regarded as a significant health hazard because most of the related exposure is due to high linear energy transfer (LET) alpha particles emitted by ^{226}Ra and ^{222}Rn and by its short lived decay products such as ^{218}Po and ^{214}Po. ^{232}Th also forms alpha emitting radioactive decay products.

Taking into account the radiological characteristics of coal ashes as described above, the requirements for coal ash utilization must include lowering its environmental hazard. For this goal, the following measures can be applied: (i) limiting the amount and the exposure time of coal ash piles to the open environment; (ii) avoiding the spread of coal ash into water, soil, and air pathways; (iii) control of the activity concentration of radionuclides in consumer products based on coal ashes.

One of the effective ways to utilize coal ash while complying with these requirements is to use them in the building industry, i.e. in the production of building materials, predominantly concrete. The advantages of this utilization are:

(i) The possibility to control the concentration of radionuclides in the building products (elements and structures) and lowering it to level below the limitations set by international recommendations and/or national legislations.
(ii) Bonding the fine particles of coal ashes with cement in the concrete, eliminating their spread in water and air and lowering the radon emanation. (It should be noted that utilization of coal ashes in structural fills and beddings of roads and buildings does not exclude totally their spread in water and air).

3. Utilizing coal ashes for the production of lightweight concrete

A novel technology of combined utilization of high volumes of both coal ashes – bottom ash and fly ash – for lightweight concrete production was developed at The College of Judea and Samaria (Ariel, Israel) [5–7]. Characteristics of the lightweight concrete produced and the bottom ash and fly ash used for this production are described below. Among other variables, we studied the radiological characteristics of the coal ashes. The aim of our study was the production of environmentally friendly concrete based on coal ashes with enhanced radioactivity.

3.1. Radiological characteristics of coal ashes used in experiments

3.1.1. Samples of coal ashes

Samples of fly ash and bottom ash were taken from the products of combustion of coals from the main sources supplied to Israel (South Africa, Columbia, and Indonesia). Table 1 presents data on the chemical analysis of the coals. For sampling, one of Israel's power stations with a pulverized dry-bottom boiler was selected. The coal ashes from the different coals were produced using the same coal combustion and transport of coal ash techniques.