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METAKAOLIN AS A RADON RETARDANT FROM CONCRETE

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Abstract — Granite aggregates are known to be the radon source in concrete. Recently, metakaolin has been introduced as a partial substitution of Portland cement to produce high strength concrete. It can effectively reduce the porosity of both the matrix and the aggregate/paste transition zone, which suggests its ability to retard radon emission from concrete aggregates. In the present work, radon exhalation rates from concrete cubes substituted with metakaolin were measured using charcoal canisters and gamma spectroscopy, and were considerably lower than those from normal concrete, by about 30%. The indoor radon concentration reduction is estimated as ~9 Bq m^{-3} calculated using a room model, causing a 30% reduction in the indoor radon concentration and the corresponding radon dose. Therefore, metakaolin is a simple material to reduce the indoor radon concentration and the radon dose.

INTRODUCTION

Radon (^{222}Rn) is a naturally occurring radioactive inert gas with a half-life of 3.82 d, and is a decay product of ^{226}Ra which is present in geological materials (rocks, soil, etc.) and concrete at natural levels. While most of the radon gas inhaled will be exhaled, the radon progeny will adhere to the respiratory tract. It is now established that the tracheobronchial deposition of radon progeny in the human body can lead to lung cancers(1,2).

While the main source of indoor radon in single-storey buildings is the soil underneath the building, that for high rise buildings is the concrete used as the building material. Although it was established that radon from concrete effectively came from the granite aggregates(3), up to now, relatively few efforts have been devoted to identifying ways to reduce the radon exhalation from concrete surfaces(4–7).

When a ^{222}Rn atom is formed from ^{226}Ra through α decay within the concrete, several possible fates await it depending on the position of its formation and the particular characteristic medium through which it traverses. It may stop within the originating grain material, traverse to adjacent grains or otherwise stop in the pore system and capillary network of the concrete. Only those atoms which stop in the pore system and capillary network can efficiently leave the concrete by diffusion through the pore system or by transportation within the pore fluids, generally being air or water.

Metakaolin (MK) is a relatively new pozzolan which is gaining popularity due to its superior properties, consistent production and light colour. A pozzolanic material contains silica in a reactive form which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide to form compounds possessing cementitious properties. MK is an ultrafine pozzolan similar in its pozzolanic properties to silica fume(8). It is a thermally activated alumino-silicate produced from kaolinite clay (China clay) through the calcining process. Recent studies(9) have shown that when MK is used as a partial cement replacement in concrete, it gives significantly enhanced early strength and increased long-term strength. This is because it acts as a filler, accelerates initial cement hydration, and in the early stages of curing, it rapidly consumes the hydrated lime produced by cement hydration to produce additional cementitious reaction products. Due to these properties, MK can effectively reduce the porosity of both the matrix and the aggregate/paste transition zone. This immediately suggests its ability to retard radon emission from the aggregates and the radon exhalation from the concrete.

The present work is devoted to studying the difference in the radon exhalation rates between normal concrete (NC) and concrete with MK as a partial cement replacement (MKC).

METHODOLOGY

Cubes of NC and MKC cast in the laboratory were used to study the radon exhalation rates in the present study. The radon exhalation rate of a surface (in units of mBq m^{-2} s^{-1}) is defined as the activity of ^{222}Rn exhaled from a unit area of that surface in a unit time. The approach to measuring radon exhalation rates from concrete follows those of previous studies(10). Standardised charcoal canisters (with diameters of 100 mm and weights of 70 g)(11,12) were used to collect the radon gas exhaled for 2 to 3 d. These were sealed against the con-

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crete surfaces with silicone sealer to stop air leakage. After collection, the charcoal canisters were removed from the surface, sealed, and stored for the radon decay to reach equilibrium. The radon activities inside the canisters were then determined by counting the gamma ray photons emitted by the radon progeny inside at energies 295, 352 and 609 keV using a NaI gamma spectrometer for 10 min.

Eight concrete cubes of side length of 150 mm (in two groups of four cubes, with 0 and 20% MK by weight substitution of Portland cement, respectively), were cast on the same day in the laboratory and were cured for 7 d. Curing is the process of keeping the concrete saturated with moisture to promote hydration of the concrete, until the originally water-filled space in the fresh cement paste has been filled to the desired extent by the products of hydration of cement(13). The date on which curing started coincided with the date of casting. The age of the concrete is defined in this work as the time (t) elapsed after the curing period.

During the course of the experiments, the concrete cubes were kept in a laboratory maintained at a constant temperature of 23°C and a relative humidity of about 60% to avoid effects due to significant changes in the ambient conditions. For each of the concrete cubes, three adjacent surfaces were used for measurement of the radon exhalation rates.

The radon exhalation rates from concrete cubes were measured at their ages of 14, 28, 41, 55, 70, 84, 98, 126, 154, 182 and 210 days. The measurements for the two groups were made on the same days for easy and direct comparisons. It is noted that the radon exhalation rate will be affected by the moisture content of the concrete(15–18). Nevertheless, for mature building materials, the variation in moisture will not be very large(19).

RESULTS AND DISCUSSION

The results on the radon exhalation rates for concrete cubes are shown in Figure 1. Each data point in Figure 1 represents the average of 12 data (measurements on three adjacent faces on each of the four identical concrete blocks) and the corresponding error bar represents the standard deviation. The temporal trends for the radon exhalation rates are consistent with the previous finding that the rates of change of radon exhalation rate can be identified for two distinct periods, i.e., the first month following curing and for the period after the first month(16). During the first month, the radon exhalation rate is controlled by exhalation from the superficial pores and the distinct drop in the radon exhalation is due to the rapid drying out of the superficial pores. After this month, the superficial pores are effectively dried out with ^{222}Rn atoms being less likely to be trapped inside the superficial pores, and the exhalation rate will be controlled by the inner pores which are drying out at a much slower rate(14).

The average radon exhalation rates for NC and MKC are calculated from the last five data (i.e., for 98, 126, 154, 182 and 210 days), which are found to be 5.00 ± 0.29 and 3.46 ± 0.13 mBq m^{-2} s^{-1}, respectively. Therefore, a reduction by a factor of 30% has been achieved by using MKC (20% substitution of cement by weight). The radon exhalation rate for NC is lower than the previous value of 8 mBq m^{-2} s^{-1} (7,16,20), which may be due

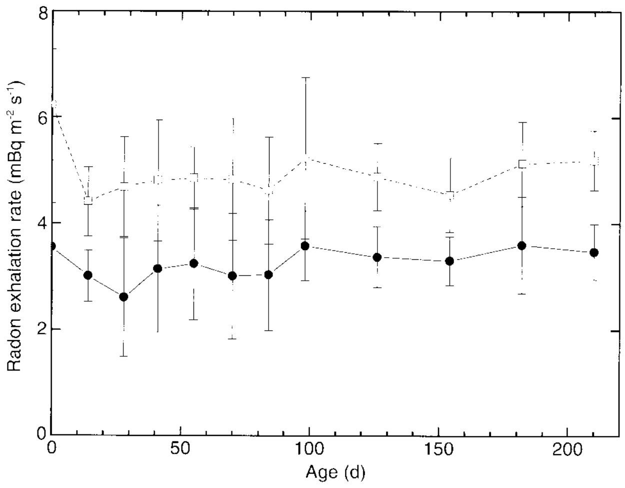

Figure 1. Radon exhalation rates from concrete cubes cured for 7 days. (Open squares: normal concrete; Solid circles: concrete with 20% metakaolin substitution.)

to the different ^{226}Ra contents of the aggregates used for the present concrete cubes.

A room model has been used to assess the indoor radon gas concentrations from laboratory radon exhalation experiments$^{(4,7)}$. The room model was shown to give results in excellent agreement with real measurements$^{(5,6)}$. Using this room model, and assuming that metakaolin only reduces radon exhalation from the walls (i.e., the floor cover is already so efficient that the use of MKC will not further reduce the radon exhalation from the floor, which is the most conservative case), the reduction in the indoor radon concentration ΔC (Bq m^{-3}) by using MKC is $\Delta C = 3.72 \times \Delta\epsilon$ (Bq m^{-3}) where $\Delta\epsilon$ (mBq m^{-2} s^{-1}) is the reduction in the radon exhalation rate from concrete achieved by using metakaolin.

By considering the average radon exhalation rate of 8 mBq m^{-2} s^{-1} for NC in Hong Kong, an average reduction of 2.4 mBq m^{-2} s^{-1} (which is $\Delta\epsilon$) can be expected by using metakaolin, so ΔC is about 9 Bq m^{-3}. Since the average indoor radon concentration is ~33 Bq m^{-3} in Hong Kong$^{(21)}$, the corresponding reduction in the radon dose and the radon induced lung cancer risk are decreased by ~30 %, which is a significant value. At present, MK is more expensive than ordinary Portland cement (OPC), even though its processing involves moderately low temperatures and its overall production cost is significantly less than that of OPC. Wider realisation of the benefits of MK in mortar and concrete will lead to greater demands and this will inevitably drive costs down.

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