# Gamma-ray shielding properties of concrete with different percentages of lead

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**Abstract** In this work, concrete with different percentage leads was used to study gamma-ray shielding properties. The gamma-rays from $^{137}$Cs and $^{60}$Co sources were detected by NaI(Tl) detector and analyzed by multi-analyzer. Linear attenuation coefficients and compressive strength (kg/cm$^2$) of concrete specimens were conducted. Results show that the concrete at the 90% weight ratio of lead to cement can be suitable for shielding gamma-ray.

**Key words** Gamma, Shielding, Concrete, Lead, Attenuation

## 1 Introduction

Radiation protection plays an important role in biologically harmful effect. Shielding properties of many materials have already been studied[1–3]. Concrete is suitable for consuming gamma radiation energy because of its acceptable strength, density for gamma-ray attenuation, easy cast, and low cost. In recent years, some minerals, such as Magnetite, Hematite, Geothite and Ilmenite, were considered as concrete aggregates to improve its radiation protection properties[4–6]. As additive materials, effects of barite and lead on concrete have been investigated[7,8]. Also, different ratio of lime and silica in concrete specimen affects gamma absorption and attenuation coefficient [9–11], because the attenuation property depends on the materials contained concrete, gamma energy, specimen thickness, and density. Photoelectric effect relates with fourth power of atomic number ($Z^4$) for interaction of gamma-ray with material[12]. Lead ($\rho$=11.35 g/cm$^3$) in bricks, sheets and plates is excellent for shielding and attenuating X- and gamma-rays, but should be encased in concrete or protected by heavy coats of paint or drywall because of its toxicity[13]. In this work, the concrete specimens containing lead powder, plate or shots were prepared by ASTM C192 and investigated. The gamma-ray flux was detected by NaI(Tl) detector and analyzed by an MCA analyzer. Their linear attenuations coefficients (LAC) were calculated by using gamma sources of $^{137}$Cs and $^{60}$Co.

## 2 Experimental

The concrete were made of Portland (type I) cement (400 kg/m$^3$) and water. The weight ratio of water to cement is 0.45. About 2.5% plasticizer (*w*:*w*) was used to increase concrete workability. Aggregates were graded by grain size classification of ASTM C136 standards (American Society for Testing and Materials). Lead as additive had three forms of powder, $\Phi$ 2 mm shots, and plate of 10 cm×10 cm×1 mm.

The concrete specimens were molded into cube of 10 cm×10 cm×10 cm within 24 h, removed from molds, placed into water tank for 23 days at room temperature, and dried at ambient temperature for 48 h. Concrete specimens without lead were prepared as the control. The specimen densities are given in Table 1.

Lead plate in cube specimen was located in the middle (Location 1), side (Location 2) and near the detector (Location 3), respectively. On the 27$^{th}$ day, gamma-rays, from a $^{137}$Cs (3.7 MBq) source and a $^{60}$Co (0.296 MBq) source, passing through the specimens were measured by a NaI(Tl) detector (Fig.1). The experimental data were analyzed by the MCA and the Cassy code. All experimental

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equipments were made of LYBOLD Company. Pb shield was used to reduce background radiation. The specimen-to-source or specimen-to-detector distances were 2 cm and 5 cm, respectively.

**Table 1** Densities (in g·cm$^{-3}$) of concrete specimens containing Pb of different physical existences.

| Pb% | Powder | Shot | Plate in middle of concrete (Location 1) | Plate in a side of the concrete (Location 2) |
|---|---|---|---|---|
| 0 | 2.185 | 2.185 | 2.185 | 2.185 |
| 15 | 2.2715 | 2.2715 | / | / |
| 30 | 2.336 | 2.321 | / | / |
| 30.5 | / | / | 2.3362 | 2.3335 |
| 45 | 2.392 | 2.3965 | / | / |
| 60 | 2.445 | 2.442 | / | / |
| 61.35 | / | / | 2.436 | 2.423 |
| 75 | 2.491 | 2.499 | / | / |
| 78.25 | / | / | 2.469 | 2.491 |
| 90 | 2.576 | 2.567 | / | / |
| 110 | 2.5943 | / | / | / |
| 200 | 2.7929 | / | / | / |
| 300 | 2.9397 | / | / | / |

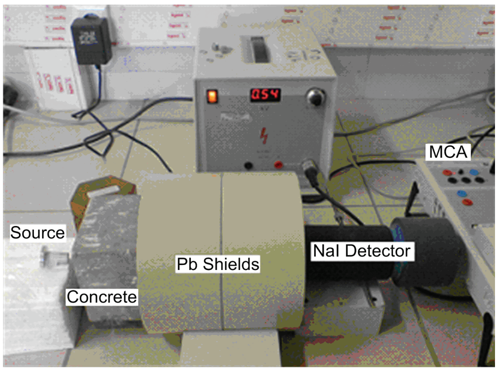


**Fig.1** Photograph of experimental setup.

## 3 Results and Discussion

The $\gamma$-ray energy spectra of the concrete with 90% lead powder, and the control, are shown in Fig.2. To get the linear attenuations coefficient $\mu$, the total counts of the controls ($N_0$), and the total counts ($N$) of the concrete specimens containing Pb in powder, shot, or plate, and the controls, were calculated by $N=N_0Be^{-\mu x}$, where, $x$=10 cm is the concrete thickness, and $B$ is the buildup factor obtained from the buildup factor Table[14], usually $B$ =1 for a good geometry.

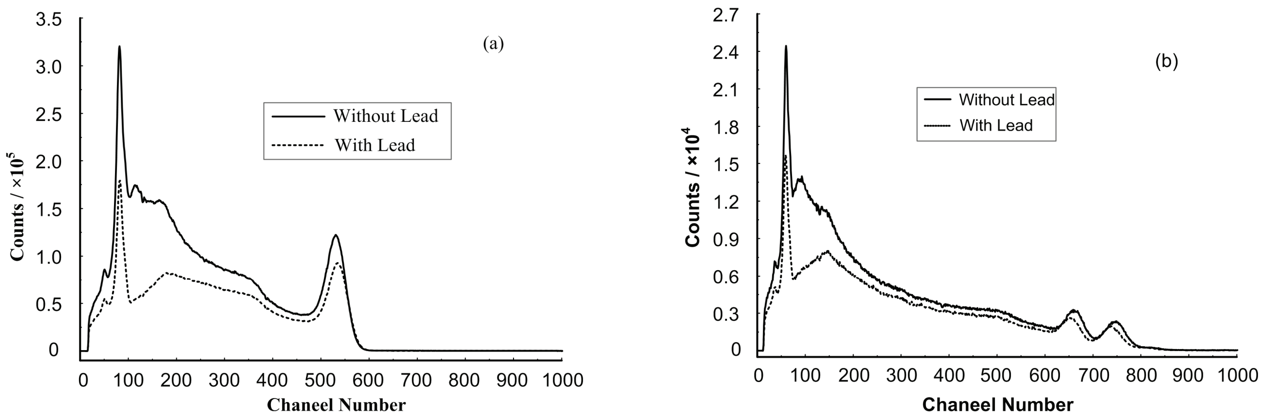


**Fig.2** Energy spectra of the $\gamma$-ray obtained from $^{137}$Cs and $^{60}$Co source for concrete with 90% lead powder and without lead.

As shown in Fig.3, the linear attenuations coefficient, for both $^{137}$Cs or $^{60}$Co gamma-rays, increases with the Pb contents in concrete. The LAC of concrete with lead plate near the detector is the highest of all, but its toxicity is also the highest (not listed in Table 1). The results show that the concrete of lead powder is suitable due to its uniform distribution (Fig.3).

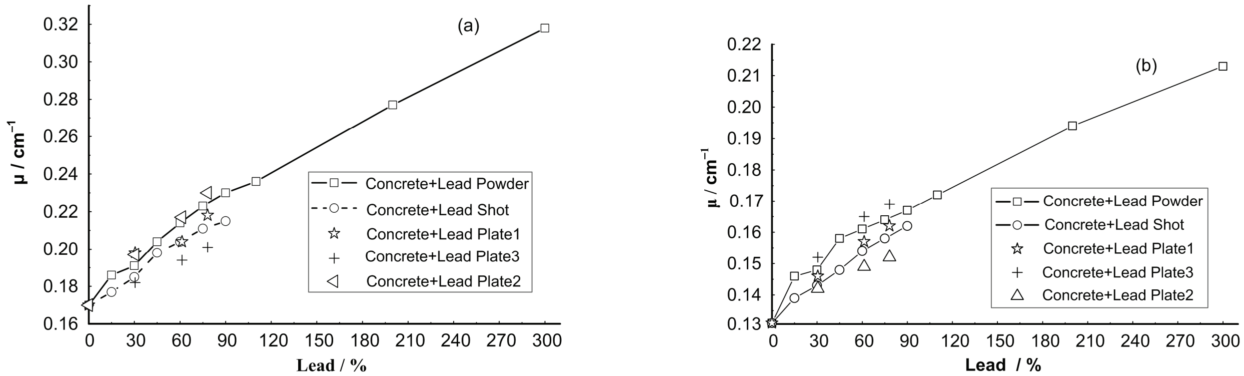


**Fig.3** Linear attenuation coefficients as a function of lead rate in concrete for gamma energies emitted from $^{137}$Cs and $^{60}$Co sources.

Another parameter for gamma ray shielding is the half value layer (HVL) thickness. As shown in Fig.4, the HVL decreases with increasing Pb contents.

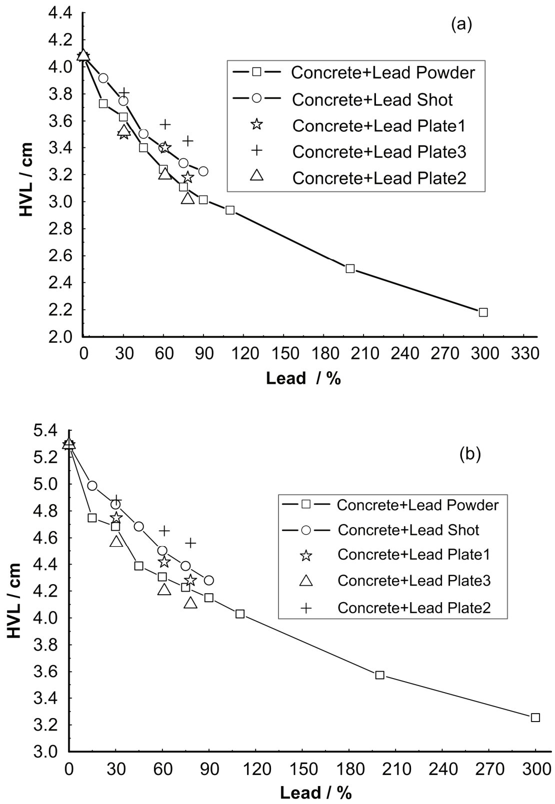


**Fig.4** The half value layer rate as a function of lead rate in concrete for gamma energies emitted from $^{137}$Cs and $^{60}$Co sources.

Compressive strengths of the irradiated concretes with lead powder and shot were measured on the 28th day (Fig.5). The concrete of uniformly distribution lead powder has a higher strength than that of shot. The compressive strength decreases with increasing Pb contents, and reaches a maximum at 90% lead. The improved compressive strength is likely due to forming a larger amounts of calcium-silicate hydrates (Ca-Si-H)[8]. In addition, after filling into concrete micropores, the Pb powder causes the Pb(OH) formation, thus enhancing concrete hydration. Fig.6 shows the XRD patterns of Pb, concrete with 90% Pb and without Pb, indicating lead presence.

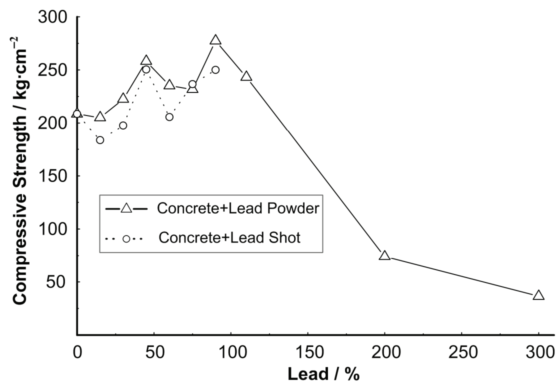


**Fig.5** Variation of compressive strength to Pb%.

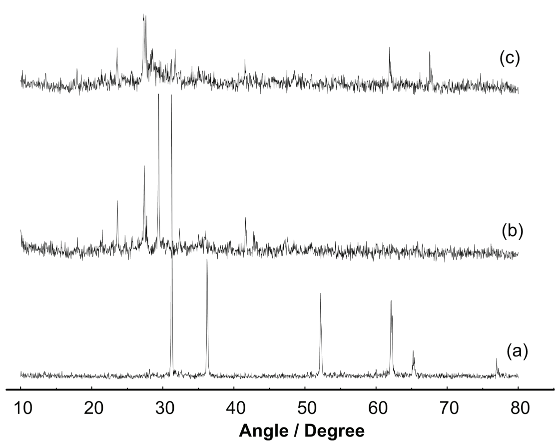


**Fig.6** X-ray patterns of Pb (a), concrete without Pb (b), and concrete with 90% Pb(c).

## 4 Conclusions

After increasing the ratio of lead to cement in concretes from 0% to 90%, their compressive strengths and gamma shielding properties improve. When increasing the ratio from 90% to 300%, their gamma shielding properties increase but compressive strength decreased as so not to be suitable as shielding element. Form $^{137}$Cs and $^{60}$Co sources, the concrete LAC with 90% lead powder is about 1.58 and 1.38 times higher than those without lead, respectively.

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