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Evaluation of Aggregates Influence on Reinforced Concrete Rebar Detection by Compton Scattering

A. Iori[1] and E. Boldo[2]

[1]*alexandre_osni@hotmail.com*,
[2]*emerson.boldo@unioeste.br*
Centro de Ciências Exatas e Tecnológicas –
Universidade Estadual do Oeste do Paraná,
R. Universitária, 1619 Cascavel - PR, Brasil
85819-170

1. Introduction

Concrete is formed by cement, coarse aggregate, fine aggregate, water, and additives (if necessary) and is structurally characterized by having high compressive strength, but its tensile strength is low. For this reason, steel is incorporated into the concrete to resist tensile stresses, forming reinforced concrete. Any water infiltration can cause corrosion of the rebar, seriously compromising the durability and strength of the structure as a whole. Severe corrosion alters the diameter of the rebar, so there is a growing need for techniques, preferably non-destructive, that evaluates the location and dimension of these elements inside the structure.

One of the techniques that can be used in this situation is gamma-ray Compton scattering. This phenomenon is one of the kinds of interaction between radiation and matter. It occurs when an incident photon inelastically interacts with an electron belonging to an atom of the target material, being scattered with lower energy than the original.

A typical experiment using this technique consists of focusing a well-collimated beam of gamma radiation on a sample and detecting the energy and amount of photons backscattered by the material. The intensity of the signal captured by the detector is a function of the electronic density of the volume of material intercepted by the beam, among other factors, as shown in the Eq. 1 [1].

$$N_C = I_0 t \varepsilon \, exp\left(-\int_{x_1} \mu_1(E)dx\right) exp\left(-\int_{x_2} \mu_2(E)dx\right) \rho_e \frac{d\sigma_C}{d\Omega} \Delta\Omega V \tag{1}$$

where: I_0 is the intensity of the incident beam with energy E, t is the time in seconds of the counting period, ϵ is the detector efficiency for the scattered photon energy, x_1 and x_2 are the paths taken inside the material by the incident photons and scattered respectively, μ_1 and μ_2 are linear attenuation coefficients for the respective paths taken, ρ_e is the electronic density of the material, $d\sigma_C/d\Omega$ is the electron differential cross-section of the Compton effect, $\Delta\Omega$ is the solid sample-detector angle and V is the radiated voxel volume, defined by the superposition of the solid angles of the beam and detector collimation.

Recently, some works have been using Compton scattering to detect defects and inclusions in concrete [2, 3, 4, 5, 6]. However, the samples studied in these works were made with mortar (cement, sand and water) without adding coarse aggregates. Coarse aggregates, such as gravel, are fundamental components present in the composition of reinforced concrete. These crushed stones, usually of basaltic origin, have in their composition heavy metals such as iron and titanium. These metals can cause high attenuation of the incident and scattered beam in the sample as a function of the incident beam energy, which can affect the exact position determination and dimensioning of the rebar. Therefore, the objective of this work was to evaluate the crushed stone influence in the detection of reinforced concrete rebar, using the Compton backscatter technique, for two incident beam energies. The study was carried out using Monte Carlo simulation.

2. Methodology

To carry out the simulation of the experiment proposed in this work, the Fluka code was used, which is a fully integrated Monte Carlo simulation package that uses sophisticated programming to accurately simulate the interaction and propagation of particles and radiation through matter, whose results obtained have already been evaluated against experimental and theoretical data from other simulation codes showing excellent agreement between them [7, 8].
The sample built in the simulation consists of a concrete column with dimensions of 8.0 x 20.0 x 20.0 cm, with the insertion of a ϕ 1.0 cm diameter rebar centered with a rectangular gravel 2.0 x 1.0 cm as shown in Fig. 1. With this size, the gravel enters the classification of type 1 (24 mm mesh), which is used in various applications (columns, beams and slabs) in the construction of large buildings [9].

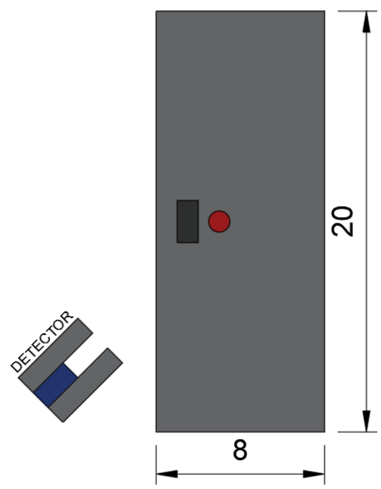

Figure 1: Top view of the pillar. Concrete (light grey), rebar (red) and crushed stone (dark grey). Units in centimeters.

The sources used in the simulation were Americium 241 (59.51 keV) and Cobalt 60 (1170 keV). The choice of these isotopes was based on previous works that indicated better results in the use of these sources for the parameters evaluated in this research [10].
The scan points chosen for the incidence of the cylindrical beam with ϕ 1.0 mm are shown in Fig. 2. At each point, 1.0 x 10^6 photons were emitted. Visualizing a Cartesian plane, with the center of the rebar being its origin, the points on which the beam focused range from 1.5 to -1.5 cm, with a distance of 0.3 cm between each point. In this way, we have at least three points in each material that compose the sample.

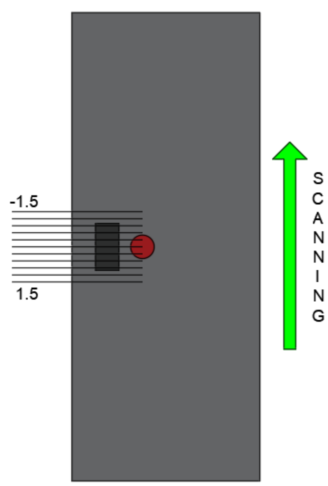

Figure 2: Photon beam incidence positions for each point of the scan on the sample.

3. Results and Discussion

The backscattered photon counts at each position of the scan using the two sources of ^{241}Am and ^{60}Co are shown in Fig. 3. The relative positions of the rebar and crushed stone are also indicated in the figure.

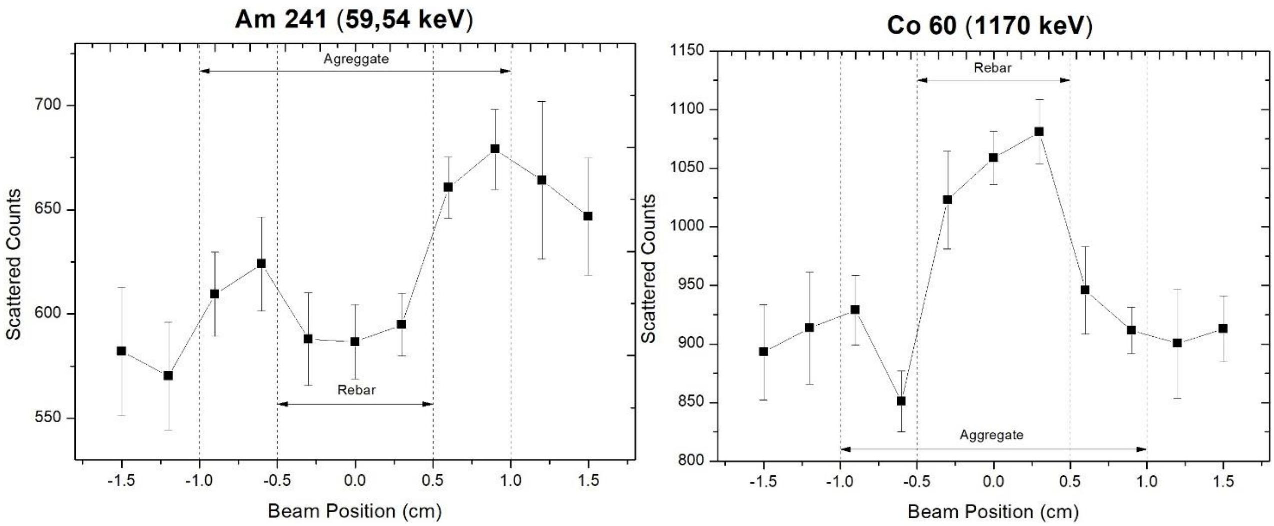

Figure 3: Backscattered photon counts as a function of the incident beam's scanning position (^{241}Am left and ^{60}Co right).

Analyzing the four counting points between the 0.5 and 1.5 cm positions for both energies, we noticed that there was little variation in the number of photons scattered between the concrete and the aggregate. This is due to the low difference between the densities of the two materials (2300 and 2800 kg/m³). Count variation between adjacent values within the same material is attributed only to the statistical fluctuation present in this type of experiment.

For ^{241}Am, when the beam focuses on the rebar region, we see a count drop due to the attenuation effect of the incident and scattered beam within the denser material. Now the technique had the sensitivity to perceive density differences. The three points with the lowest counts provide a good location of the position and size of the rebar, even being behind an aggregate that has a high percentage of Fe_2O_3, a material of high density (5240 kg/m³), in its composition. The low counts of the rest of the points in the most negative positions of the scan can be explained due to the attenuation of the beam that is returning to the detector after suffering scattering within the inspection volume.

In the case of ^{60}Co, the differentiation of densities as a function of the number of scattered photons also happens, but now the higher density rebar generates greater scattering, as can be seen in the three points between the positions - 0.5 and 0.5 cm. Due to the large energy of the beam emitted by ^{60}Co, the scattering phenomenon, in this case, is preponderant regarding the beam attenuation due to the greater weight of the differential electron cross-section of the Compton effect ($d\sigma_C/d\Omega$) concerning the probability of scattering in Eq. 1 [11].

4. Conclusions

It have evaluated the influence of aggregates in the detection and positioning of rebar inside reinforced concrete, using the Compton scattering technique. The investigation was carried out using Monte Carlo simulation. The two analyzed energies were able to detect the rebar hidden by the aggregate with good spatial resolution and contrast values, even with the aggregate having a considerable amount of iron oxide. ^{60}Co was the source with the highest contrast and count values and could be an alternative for inspecting defects further away from the sample surface. The one-sided Compton scattering technique showed to be adequate for the studied problem and may be a very promising alternative for non-destructive analysis of real reinforced concrete structures.

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