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Monte Carlo Modeling of Gamma Ray Backscattering for Crack Identification in the Aluminum alloy Plate

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Abstract. A Monte Carlo simulation study has been conducted of the Cs-137 gamma ray backscattering in the aluminum alloy plate. This simulation was performed in order to identify the existence of the crack in the aluminum alloy plate, the correlation between the backscattering peak and the crack width. We are able to analyze the absorbed energy distribution in the NaI(Tl) scintillation detector. For the experimental measurement, we are using 5 μ Ci of a Cs-137 gamma source and 2 in. x 2in. NaI(Tl) scintillation detector with the PMT. The aluminum alloy dimension is about 8 cm x 6 cm x 1 cm. The crack model is represented by the slit with the varying width (1 mm, 2 mm, 4 mm, and 6 mm). The existence of a crack is identified by the decreasing intensity of the gamma backscattering energy peak. These predicted results have a good agreement with the experimental measurement.

1. Introduction

Aluminum alloy is a material that mostly used in industry for aircraft, cycling frames, body panel etc. The presence of defects in the material such as invisible crack, holes or local density anomaly gives an effect of the mechanical strength of the material. Investigation of the defect can be conducted by applying the penetrating radiation. In order to develop the one side measurement access of penetrating radiation to the high density material object, gamma ray backscattering is a potential method to be applied.

The presence of crack in a material will be causing a gap in the material and its influences an element volume which probably involve in the scattering interaction. Therefore, it can affect the detected intensity of gamma photon or energy spectrum distribution. Djamal et al. (2013) have investigated the effect of the hole presence in acrylic block to the energy spectrum distribution [1].

As a preliminary study of investigating the presence of crack based on the gamma ray backscattering method, computer simulation is the promising choice to be done. According to the characteristic of the radiation, Monte Carlo (MC) simulation is a probable approach. MC is useful for modeling a large variety of physical situations, prediction of the experimental results, probe/detector design, and performance of an inspection modeling [2,3].



In this work, we investigate the effect of the crack presence in the back of aluminum alloy plate to the gamma ray energy distribution spectrum of Cs-137 based on the gamma ray backscattering measurement. The preliminary investigation was conducted using the MC GEANT4 simulation toolkit.

2. Theory

Intensity of detecting beam in the crack investigation is a result of direct gamma beams and scattering beams from a plate (Figure 1). Mathematically, it's written as the following equation.

$$I_{\text{detected}} = I_{\text{direct}} + I_{\text{scatteringplate}} \quad (1)$$

The scattering interaction of photon beam with an elemental volume of the plate can be described as a result of single scattering or the multiple scattering. According to the single scattering approach (Figure 1), there are three steps process i.e. attenuation process by medium before interaction, the interaction process with an elemental volume, and attenuation of the scattering photon in the movement to the detector.

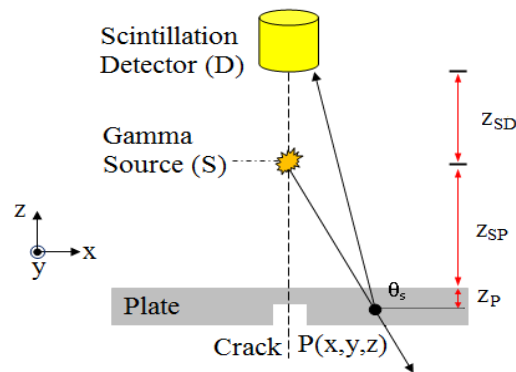


Figure 1. Gamma scattering from the plate model.

Reducing some element volume of the material which described as the presence of crack has an effect on the volume interaction. So, it influences the detected intensity as depicted the detected photon scattering intensity formula in the equation (2),

$$I = \int \left(\frac{Sr_0^2 N_A Z A_d}{8\pi M} \right) \rho \times \frac{e^{-\left(\frac{\mu_1(E)}{\rho}\right)\rho r_1}}{r_1^2} \frac{e^{-\left(\frac{\mu_2(E)}{\rho}\right)\rho r_2}}{r_2^2} \times \quad (2)$$

$$\left(P - P^2 \sin \theta + P^3 \right) \sin \beta \cos \phi dV$$

and it depends on the source activity (S), classical electron radius ($r_0 \sim 2.82$ fm), Avogadro number (N_A), atomic number (Z), detector surface area (A_d), atomic mass of element volume (M), medium density (ρ), element volume interaction (dV), distance photon source, the vertical angle of element volume position (ϕ) and photon scattering to the element volume interaction (r_1 and r_2) and the scattering parameter (P). The scattering parameter P is depending on the photon energy (E) and the scattering angle θ [5].

$$P(E, \theta) = \frac{1}{1 + \frac{E}{m_0 c^2} (1 - \cos \theta)} \quad (3)$$

where $m_0 c^2$ is an electron energy (0,511 MeV) [4,5].

3. Methodology

In this work, the simulation modeling using GEANT4 is constructed based on an experimental measurement design as shown in Figure 2. The aluminum alloy dimension is about 8 cm x 6 cm x 1 cm. Aluminum alloy material composition for the simulation based on the EDS test result consisting of Mg 1.09%, Al 94.55% and Cu 4.36%). The crack model was represented by a vertical slit with the varying width (1 mm, 2 mm, 4 mm, and 6 mm) and 0.5 cm height. The position is on the bottom surface of the Aluminum alloy plate at the axis line.

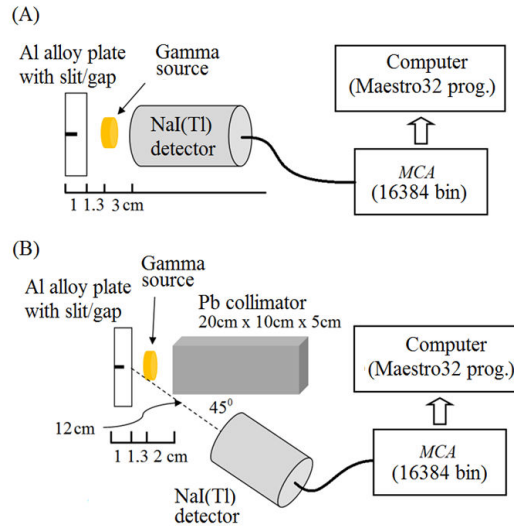


Figure 2. The schematic design of scattering measurement setup.

The number of beamon (history) was used is about 10^7 and a source model of gamma ray in this simulation is a point source. In addition, for the interaction package of MC simulation is *Penelope* (*Penetration and Energy Loss of Positrons and Electrons*). Figure 3 shows ones of the GEANT4 visualization of the measurement design which developed in simulation.

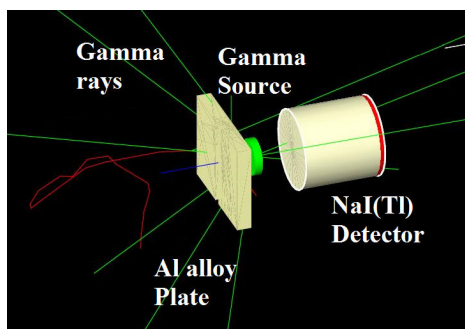


Figure 3. GEANT4 visualization of A type measurement.

For the measurement, a gamma source 5 μ Ci of Cs-137 and the Bicorn 2M2/2 SN IS799 photomultiplier with a NaI(Tl) scintillation detector are used. The high voltage setup of photomultiplier is about 800 V, fine gain and coarse gain amplifications are set in 1.08 and 50 respectively. For data acquisition, MCA with 16384 channel bin is used and it's supported by MAESTRO program.

The optimum counting is chosen based on the recorded spectrum quality. For A type measurement, the counting time is about 5 minutes and 10 minutes for a B type measurement. The recorded energy spectrum will be converted into 400 channel bin using the ROOT program. Therefore, peak curve analysis is conducted to find the peak height of the backscattering energy curve peak.

4. Results and Discussion

The analyze results in the backscattering peak based on Gaussian fitting curve shows that there are reducing the peak height (intensity) in the axis of crack. Figure 4 shows the normalized backscattering (comparison to the backscattering peak of the crack in the central axis).

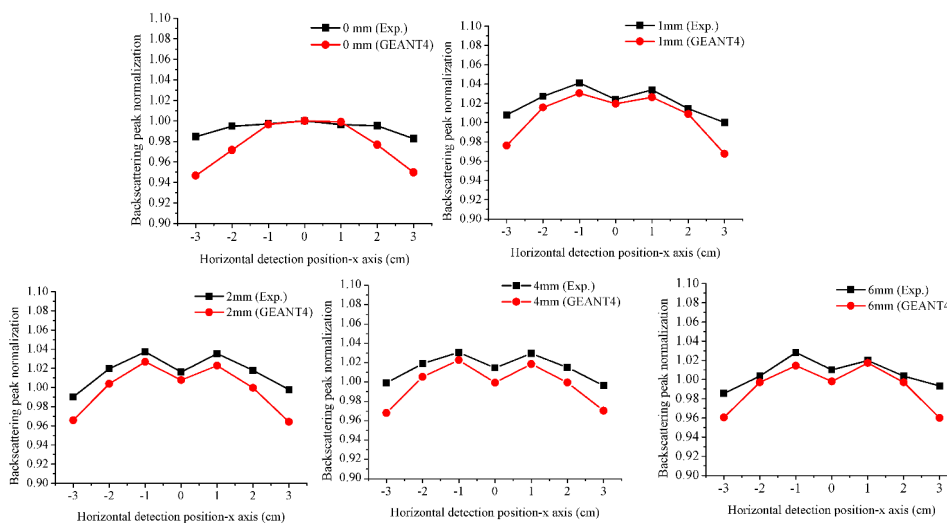


Figure 4. Backscattering peak normalization of A type design.

The similar result is gotten for the B type measurement design as shown in Figure 5. According to these results, the presence of a crack is identified based on lowering backscattering peak height at x=0 detector position compared to the backscattering peak at x = -1 and x=1.

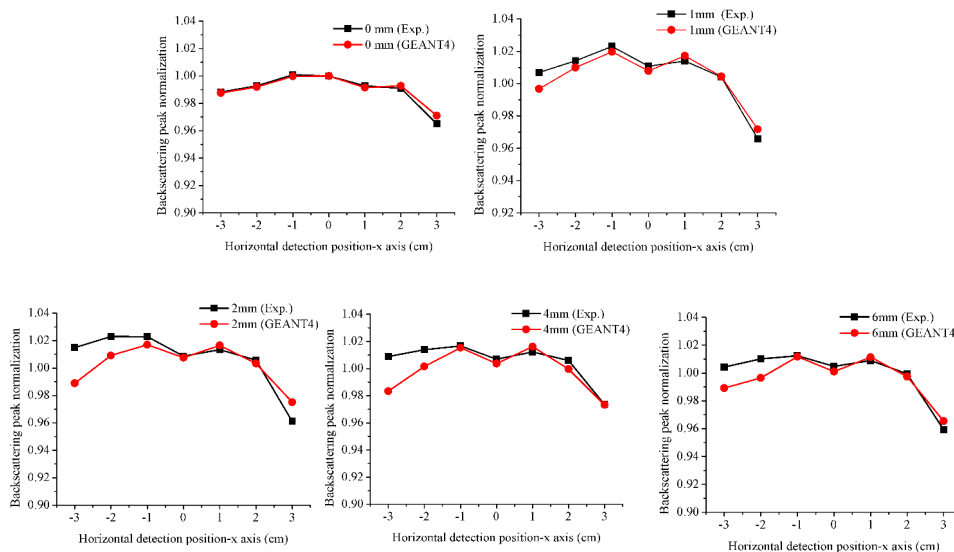


Figure 5. Backscattering peak normalization of B type design.

According to the curve of backscattering peak at $x=0$ detector position shows that simulation result has the same trend to the measurement as shown in Figure 6. Both simulation and experiment show that an increasing of a crack (slit) width leads the decreasing of backscattering peak height.

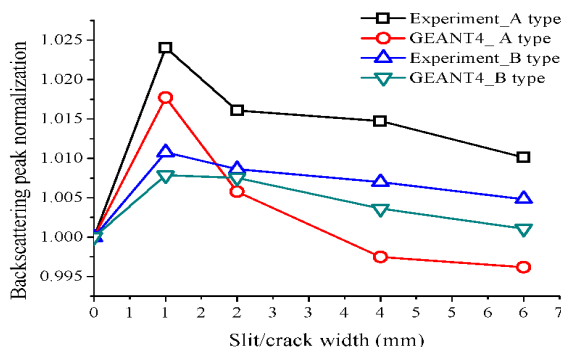


Figure 6. Backscattering peak normalization at $x=0$ detector position.

Comparing the two measurement type model, MC simulation result for B type gets near to the measurement result than A type. In other hand, the detector counting number for the B type measurement is $7.60 \times 10^5 - 8.30 \times 10^5$ less than A type ($2.44 \times 10^6 - 2.56 \times 10^6$). Although the counting time for B type measurement is two times longer than A type measurement. It can explain that the geometry factor of the source – detector arrangement inducing the photon count number. Consequently, this results in an effect to the backscattering peak of the detected energy distribution spectrum.

5. Conclusion

In this study, a Monte Carlo simulation of Cs-137 0.662 MeV backscattering peak was performed in order to conduct preliminary identifying the existence of a crack in the aluminum alloy plate.

The existence of a crack was identified by decreasing intensity of Cs-137 gamma backscattering energy peak. The construction of the source - detector and the crack dimension induce the backscattering energy peak.

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