Density and Effective Atomic Number Calculation with Source Weighting Methods Using Dual Energy 90˚ Compton Scattering Experiments

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1. Introduction

In recent years, various researches to develop new inspection system have been performed as the air terrorism has been increased. Generally, the transmission-based inspection system [1] can only get the information about the shapes of the inside objects since it relies on measuring the total attenuation coefficient by penetrated signals. On the contrary, it is known that the scattering-based inspection system can identify the material properties by finding the effective atomic number due to scattering signals and it can give material properties for an object which is arbitrarily located in luggage. Among these scattering-based inspection systems, the 90° Compton scattering inspection system adopted a dual energy method [2] can give the information on the effective atomic number of an unknown object. In addition, the normal density can be estimated by using the X-ray source weighting method reflected on the characteristic of continuous energy [3].

In this paper, the effective atomic number (Z_{eff}) and normal density (ρ) calculations by the source weighting method on the 90° Compton scattering experiment using dual energy X-ray are presented and discussed. On the experiments, highly polymerized compounds whose physical properties are similar to explosive materials are employed.

2. Materials and methods

In this work, the relation between the effective atomic number (Z_{eff}) and normal density (ρ) for two X-ray sources was studied. Among the various ρ-Z related algorithms [4], the numerical method to solve the ρ-Z relation [3] was introduced. The simple experiment diagram is shown in Figure 1.

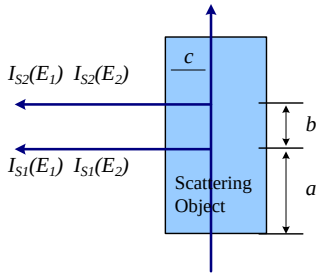

Figure 1. Schematic diagram showing the basic 90° Compton scattering experiment

$I_{Si}(E_j)$ is a scattered signal of X-ray source, where i is the digit to indicate detecting position, and j is the source energy indicator. Using four scattered signals, the effective attenuation coefficient (μ_{eff}) is expressed by

$$\mu_{eff.j} = \int_E \omega(E) k(E) dE, \omega(E) = \frac{S(E)D(E)}{\int_E S(E)D(E)dE} \quad (1)$$

where j is the source energy indicator, $\omega(E)$is the source weighting function, $S(E)$ is the spectral source, $D(E)$ is the detector characteristics, and $k(E)$ is the total attenuation coefficient at dE [3].

To solve the ρ-Z related algorithm, the numerical method originated from the dual energy CT system is employed. Then, according to the effective attenuation coefficient in Equation (1), the relation between the effective atomic number and the effective attenuation coefficient is expressed by

$$\frac{\mu_{eff.1}}{\mu_{eff.2}} = \frac{f_1(Z)}{f_2(Z)} = F(Z), \; f_i(Z) = \frac{\mu_{eff.i}}{\rho} \quad (2)$$

where $f_i(Z)$ is the function of the effective attenuation coefficient and normal density.

$F(Z)$ is a monotonically increasing function of Z for Z=1~20. In Equation (2), the effective atomic number and the normal density can be evaluated. The inverse function ($Z=F^{-1}(\mu_{eff.1}/\mu_{eff.2})$) can be calculated by a numerical interpolation. Then the normal density (ρ) is derived by $f_i(Z)$.

To verify the ρ-Z related algorithm, 90° Compton scattering experiments were performed for simple geometries. To maintain the high count rate for scattering measurements, a 450 kV industrial X-ray tube was used as a radiation source. X-ray beam hardening filters which produce an X-ray source distribution at the specific energy band were fabricated. Two kinds of source spectrum, IN90 and IN150, are obtained. Two spectra are shown in Figure 2.

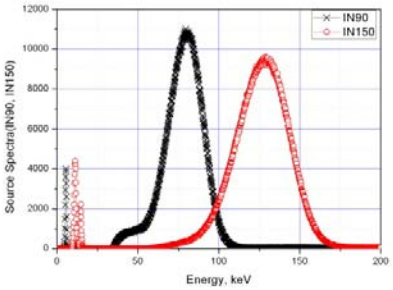

Figure 2. Two X-ray source spectra (IN90, IN150)

4 kinds of highly polymerized compound materials were employed as scattering samples. One is TNT simulant which has the same composition and material properties compared with real TNT, the others are normal polymerized compound materials.

3. Results and Discussions

The effective attenuation coefficients ($\mu_{eff.1}$, $\mu_{eff.2}$) of the experiment object at two source energies, E_1 and E_2, are calculated by using measured scattered spectra. To obtain net counts on measured spectra, ROI(Region of Interest) were determined by the developed ROI calculation equation. [2]

Using the ratio of $\mu_{eff.1}$ and $\mu_{eff.2}$, the effective atomic number and the normal density are then calculated. The effective attenuation coefficient for each material was calculated by using Equation (1). The effective atomic number is then calculated by using Equation (2). The results are presented in Table 1. From the experiment results, it is found that the relative differences were less than 10 % for all the sample sets. In case of the TNT sample, the relative difference of the effective atomic number was 1.48 %.

Table 1. Computed effective atomic numbers for various samples by experiment

Material	Effective Atomic Number		
	Ref. [5]	Cal.	Rel. Diff. (%)
TNT	7.11	7.21	1.48
Acetal	6.95	6.41	-7.80
Urethane	6.70	6.71	0.19
MC	7.26	6.94	-4.39

After calculating the atomic numbers, the normal densities were computed by Equation (2). The calculation results of normal densities are presented in Table 2. As a result, the difference between the reference value and the calculated value is less than 15 %. In case of the TNT sample, the relative difference of the normal density was 9.82 %.

Table 2. Computed normal densities for various samples by experiment

Material	Normal Density (g/cm^3)		
	Ref.	Cal.	Rel. Diff. (%)
TNT	1.63	1.47	-9.82
Acetal	1.40	1.50	7.14
Urethane	1.13	1.21	7.08
MC	1.10	1.26	14.55

From the experiment results, it was demonstrated that the suggested ρ-Z related algorithm can estimate the effective atomic number and the normal density in 90° Compton scattering system as precise as the CT system. From the viewpoint of relative difference fluctuation, the variation of the calculation results were stabilized relatively and it can be acceptable in the system for inspection.

4. Conclusions

According to the 90° Compton scattering experiment results, it is verified that the calculations of the atomic number and the normal density by the source weighting method are valid and acceptable in the X-ray inspection system. Furthermore the normal density calculation using the scattered signal is very significant in the X-ray inspection field because a specific material can be identified by using the normal density information among the various highly polymerized compounds whose effective atomic numbers are very close to each other.

Acknowledgement

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References

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