Investigating of Barite Shielding Boards for Radiation Protection

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Abstract. Radiology has seen enormous growth with the latest medical equipment and increase in radiation technology usage. Lead is also used to shield against radiation leakage to diminish harmful effects of radiation dosimetry to human bodies. To save harmful, cost, effective shielding and provide easy installation, a pre-cast board with fiber concrete layers and heavyweight concrete with Barite is developed. The radiation attenuation coefficients for Barite concrete board are calculated and measured in this report. This board can instead of lead for the photon energy around the diagnostic medical areas. The board has been successfully employed in medical hospitals and makes shielding easy and effective.

Introduction

The significant advantage of radiation technology in the medical field has led to rapid expansion in its employment. The advances in the use of radiation in medicine include both diagnostic and therapeutic areas. Iodine-131, for example, is used as a diagnostic tracer and had been developed for use as therapeutic medicine [1]. Radiology, in particular, has seen enormous developments with the latest medical equipment and practices being commonplace in this region [2].

Because of the potential danger to human body, radiation use in medicine must be carefully considered and proper shielding should be used [3]. To provide effective protection from radiation the building should be constructed using a material with higher mass attenuation coefficients (µ). However, some well-known heavyweight materials, such as tungsten or lead, cannot be used directly in building construction. The main material in building construction is still concrete.

Since technology progress expands Radiology usage and National Health Insurance, Taiwan, enlarges on offering from time to time. Hospitals need to re-enhance the radiation shielding of rooms as usage changes to radiation practices. In addition, the shielding of radiotherapy is only considered priori to the hospital construction in Taiwan. The shielding for those non-therapeutic radiology will be arranged after building construction, in general. Since then, medical hospital will decorate or enhance the shielding according to practices of spaces.

Concrete is the main material for building construction. The lead sheet is frequently used in medical hospitals for decoration or enhancing the shielding of rooms. Although, the price of lead went steady recently. However, the current cost of lead is two times to the year of 2005. In 2008, the cost of lead even up to three times to 2016[4].

Recently, heavy-weight materials such as Barite (BaSO4) have been added into concrete as aggregates for shielding more effectively [5]. This material does not have rich earth reserves and must be used judiciously in building construction. Barite is one of the most effective materials used as an aggregate in heavy-weight concrete production. Previous studies were performed on the calculation and measurement of linear attenuation coefficients µ (cm-1) for concrete with Barite. Theoretical calculations of the total mass attenuation coefficients were performed using the XCOM program [5]. The XCOM (Version 3.1) is a program developed by Berger and Hubble [6] to calculate the mass attenuation coefficients for elements, compounds or mixtures at energies from 10-3 to 105 MeV. Their works make attenuation coefficient calculation more accessible.
Esen and Yilmazer measured the energy absorption capability of different amounts of Barite aggregate with concrete [7]. Akkurt et al. tested the shielding properties of concrete including Barite using Cs-137 and Co-60, individually [8]. They measured and calculated radiation shielding abilities for concretes containing various amounts of Barite in their earlier paper too [9, 10]. Barite has been suggested as concrete aggregate to more effectively shield against radiation.

Barite is a good radiation shielding material and it is one of many construction product aggregates in heavyweight concrete. There are other materials, i.e. cement and water, in construction products. The properties of heavyweight concrete produced with Barite depend on the content, grain size and w/c ratio. It is well known that the attenuation coefficient subject to the material density. Material density is depends on the aggregate content [9]. The higher the contents of Barite result in the higher attenuation coefficients [10]. However, a lack of strength risk may exist when the Barite heavyweight concrete was used for building construction.

Topcu examined the different w/c ratios of heavyweight concrete produced with Barite [11]. He found that the compressive strength decreased when the w/c ratio increased. This paper suggests that the mixing duration should be as short as possible and finer aggregate should be using to prevent segregation in heavyweight concretes [11]. The homogeneity of Barite in heavy concrete may be a point of concern. The w/c ratio and strength should be carefully considered [11].

Can we develop anew radiation protection board using Barite as aggregates? The new board model may be used to replace lead in radiation protection if the strength and shielding ability are good enough. The advantages of board will be convenience in shielding, cost save, toxic free, not parts of building structure, easy for decoration. The Barite Shielding Board (BSB) was developed and properties were investigated in this report. The BSB been proved that it can be used to replace lead sheet. The BSB may employ in medical hospitals and radiation facilities.

Materials and Methods

Materials

The BSB has a sandwich construction, with an internal layer for radiation protection and with two outside cover layers, as shown in Figure 1. The fiber concrete is used as cover layers for fixed shape and interior protected. This pre-cast board is constructed in modules to make installation easy. Mixed concrete and water and with Barite as the aggregate are in the middle layer for radiation shielding.

The fiber concrete board density is 1.34 kg/m³ (ρ) and 0.5 cm in thickness. The cement concentration in fiber concrete is around 35% in density. Three types of BSB-002, 003 and 005 were developed, as noted in Table 1. The BSB-002, 003, 005 protection layer thicknesses are 15, 25, 37 mm, individually. The different dimensions and models are used for practices of radiation shielding. For the additive Barite, the concentration of pure BaSO₄ is about 90%—91.2% and density is 4.2g/cm³. The BSB protection layer is mixed using 80% (<3mm) and 20% of fine(<75µm) Barite, for the easy homogeneity. Portland cement is used with a w/c ratio of 0.36.

Methods

The theoretical calculation for the total BSB mass attenuation coefficients is performed using the XCOM code and data based at photon energies from 1 kV to 100 GeV. This program runs on a PC and uses the material chemical structures as the input. For concrete, Portland cement typical constituents are used and for Barite, 92% BaSO₄ with 6% water were used with the impurities ignored.

The attenuation properties of three BSBs were determined using TÜV NORD Sys Tec GmbH & Co. KG, German (Energy and Systems Technology). BSBs were irradiated with X-rays from an X-ray tube (Type MXR 920/26/Y) with 100 kV, 150 kV, 200 kV, 250 kV, and 300 kV voltages, respectively, and with gamma-rays from a Cs-137 and a Co-60 source. The ambient dose equivalent H*(10) was measured behind the boards as well as without the boards in a suited geometry. With these results, the F=H*(10)with board/H*(10)without board attenuation factor was determined. The
irradiations were also performed with lead boards of different thicknesses. The attenuation factor $F$ for the BSBs and lead boards were compared to determine the equivalent lead thickness for each BSB.

Figure 1. A crosssection view of BSB.

Figure 2. The calculated $\mu (\text{cm}^{-1})$ for BSB and comparison with the measurements.

Results

The equivalent lead thicknesses for BSBs in mm Pb for the irradiation with various X-ray energies and gamma-rays are shown in Table 2. For the most diagnostic X-ray energy areas (around 100 kV), BSB-002 can replace 2 mm Pb, lead equivalent thickness of 003 is better than 3 mm Pb, 005 is equivalent to 5 mm Pb, as noted in Table 2. In addition, it is obvious that the lead equivalent thickness of BSB-002, 003, 005 are superior to 2, 3, 5 mm Pb, individually, in the energy areas of Cs-137 and Co-60 gamma-ray.

The calculated $\mu (\text{cm}^{-1})$ results were also compared with the measurements obtained at the various X-ray and gamma-ray energies, as shown in Figure 2. A reasonable consistence was found between the measurements and calculations. The $\mu$ measurements are in good agreement among the different BSB thicknesses.

Discussions and Conclusions

Lead, iron and heavy concrete are the traditional majority adapted materials for radiation shielding. However, the costs of iron and lead, toxicity of lead and non-homogeneity or strength concerns with heavy concrete constructions are factors in their usage. BSBs are obviously superior to these materials in radiation shielding.

BSB saves up to 70% of the cost in comparison with traditional Pb shields. Pre-cast board with fiber concrete layers for cover furnish constructed in modules make installation easy. BSB can be fixed onto C-runners using self-tapping screws and may be painted in colors or variable decoration materials can be pasted onto the surface. Figure 3 shows a BSB installation in a Taiwan hospital. The worker sets up the C-runner first in Figure 3(a), then installs and fixes BSB in Figure 3(b). The BSB is used for a compartment or put onto the wall so the strength consideration is not important.

The Barite mixed in the BSB attenuates photon radiation effectively. However, the radiation therapy and cyclotron facility may produce neutrons. For neutron shielding, the Colemanite and Ulexite, for example, plan to mix with borate BSB. The borate BSB may be able to attenuate both photons and neutrons.

<table>
<thead>
<tr>
<th>Model No.</th>
<th>BSB-002</th>
<th>BSB-003</th>
<th>BSB-005</th>
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<tbody>
<tr>
<td>Size (cm)</td>
<td>W61×H220</td>
<td>W61×H220</td>
<td>W61×H220</td>
</tr>
<tr>
<td>Thickness (mm)</td>
<td>15</td>
<td>25</td>
<td>37</td>
</tr>
<tr>
<td>Density (kg/m$^3$)</td>
<td>3.4</td>
<td>3.4</td>
<td>3.4</td>
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<tr>
<td>Anti-bending Strength (kgf)</td>
<td>381</td>
<td>545</td>
<td>733</td>
</tr>
</tbody>
</table>
Table 2. Equivalent lead thickness of the BSBs in mm Pb for the irradiation with different X-ray energies and gamma-rays from Cs-137 and Co-60.

<table>
<thead>
<tr>
<th>Voltage/ Source</th>
<th>100 kV</th>
<th>150 kV</th>
<th>200 kV</th>
<th>250 kV</th>
<th>300 kV</th>
<th>Cs-137</th>
<th>Co-60</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSB-002(Pb)</td>
<td>2.5 mm</td>
<td>1.3 mm</td>
<td>&lt;1 mm</td>
<td>&lt;1 mm</td>
<td>1.0 mm</td>
<td>2.5 mm</td>
<td>3.9 mm</td>
</tr>
<tr>
<td>BSB-003(Pb)</td>
<td>4 mm</td>
<td>2.0 mm</td>
<td>1.7 mm</td>
<td>1.7 mm</td>
<td>1.8 mm</td>
<td>4.0 mm</td>
<td>6.2 mm</td>
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<tr>
<td>BSB-005(Pb)</td>
<td>5 mm</td>
<td>2.7 mm</td>
<td>2.2 mm</td>
<td>2.4 mm</td>
<td>2.5 mm</td>
<td>5.8 mm</td>
<td>8.6 mm</td>
</tr>
</tbody>
</table>

Figure 3. (a) set-up C-runner, (b) installed and fixed BSB.

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References
