Evaluation of the influence on the variation of the mixture of sand, cement and barium sulphate in the ionizing radiation attenuation result

CHS Sousa, R MVasconcelos, GS Araújo, LGP Filho, RG Azevedo, MCVBalthar, AC Silva, JGP Peixoto

1Universidade do Amazonas
2Universidade Federal do Pará
3Fundação Técnico-Educacional Souza Marques
4Instituto de Radioproteção e Dosimetria
5Universidade Federal Fluminense

Email: chenrique@ird.gov.br

Abstract. Barred mortar is widely used as attenuating barriers for its ease of application and efficiency in attenuating photons. This work presents the evaluation of four different mixtures, aiming at the best use of the product, ensuring the specifications of the barrier thickness required for radioprotection, as well as determining the value of the semiconductor layers of the different traces and attenuation curves. Four molds with different percentages of sand, cement and barite were manipulated. They are then exposed to 70 kVp and 120 kVp X-ray beams, and the air kerma (k) is measured. These values were compared with the specifications for semiconductor and decoder layers by checking the influence of each component of the composition. In conclusion, the physical characteristics of the tests are presented, proving that the handling of the mortar trace does not compromise the safety of the radiative installation.

1. Introduction

Barite is a barium sulfate mineral, whose chemical formula is BaSO4 [1], whose nomenclature has Greek origin barus which means heavy. Due to its high insolubility, it is not considered a toxic material. Much barite production is used in the oil industry to increase the density of thixotropic drilling muds.

The largest producers are the United States (8%), India (27%) and China (32%). Brazil has only 0.3% of world reserves and its production corresponds to 1% of world production, with the state of Bahia being the largest national producer with 95% of the total [2].

Due to its high density, it is widely used as attenuating barriers for ionizing radiation beams. When added to other compounds, such as sand and cement, it also has the advantage of reducing the thickness of the structures used, allowing the increase of the useful area of the room.

Barred mortar is easy to apply and does not require extensive experience in applying the product, making labor-saving easy. The curing time of the mortar is variable, but it is recommended that it be allowed to stand for four days before the finishing phase. The use of fine sand improves the finish during material application as it increases the quality of the structure and aesthetics. Once cured, the finish can be performed as a regular masonry plaster.

Barred mortar can also be applied to drywall sheets in place of masonry walls, taking care to avoid the formation of bubbles in the mass, which would decrease the structural efficiency [3]. Another option is to make blocks of barred mortar instead of baked clay tiles.

The attenuation depends on the attenuating material and the beam energy to be attenuated. For photon-emitting sources of various energies, such as X-rays, different attenuation factors must be
determined, such as the half value layer (HVL) and tenth value layer (TVL) [4], where their relationship to the attenuation factor \( \mu \) is expressed by:

\[
\mu = \frac{0.693}{\text{HVL}}
\]

(1)

In this way we can express the attenuation by:

\[
I = I_0 e^{-\frac{0.693}{\text{HVL}} \frac{x}{\text{HVL}}}
\]

(2)

where \( I_0 \) is the incident beam intensity and \( I \) is the attenuated beam intensity. Table 1 gives the CSR values for some X-ray stresses according to the attenuating material.

| kVp (kV) | Attenuator material (cm) |
|---------|-------------------------|
|         | Pb   | Concret |
|         | HVL  | TVL   | HVL  | TVL   |
| 50      | 0,006| 0,017 | 0,43 | 1,50  |
| 70      | 0,017| 0,052 | 0,84 | 2,80  |
| 100     | 0,027| 0,088 | 1,60 | 5,30  |
| 125     | 0,028| 0,093 | 2,00 | 6,60  |
| 150     | 0,030| 0,099 | 2,24 | 7,40  |
| 200     | 0,052| 0,170 | 2,50 | 8,40  |
| 250     | 0,088| 0,290 | 2,80 | 9,40  |
| 300     | 0,147| 0,480 | 3,10 | 10,40 |
| 400     | 0,250| 0,830 | 3,30 | 10,90 |

2. Material Method

The first phase consisted of making the molds for the tests, where the conditions found by the workers responsible for applying the mortar were first considered (Table 2). Although mass characterization is much more coherent, practice shows that differences in sand, cement and barite volumes are not significant to affect material densities and reproducibilities.

In this way, different amounts of cement, sand and barite were aggregated and samples were made in plate form, to obtain different densities for thicknesses 5 mm and 10 mm. These plates were exposed to photon beams of different energies to measure the beam transmission value and yield of each trace. The cement used was of type CP II F-32 CSN [5].

A 15 cm³ box was designed and built to accommodate and position the test plates, taking care not to suffer interference from scattered radiation. For the measurements, a dosimetric set was used, consisting of a Radcal, model 2026C electrometer and a Radcal model 20x6-60 ionization chamber. The kerma in air (k) measurements due to the small volume and solid beam angle.
Table 2 – List of the mixtures used in the experiment, applied as percentage amounts of aggregates in the planned features.

|        | Sand (x100ml) | Barium (x100ml) | Cement (x100ml) |
|--------|---------------|-----------------|-----------------|
| mortar I | 1,00          | 1,00            | 0,50            |
| mortar II | 1,00          | 1,50            | 0,50            |
| mortar III | 1,00         | 2,00            | 0,50            |
| mortar IV | 2,00          | 1,00            | 0,50            |

The plates were exposed to primary X-ray beams, tabulated between 70 kVp and 120 kVp. Commercial X-ray equipment manufactured by VMI Philips, Compact Plus model was used. The air kerma measurements were recorded in a spreadsheet and distributed in a logarithmic function to determine the 1st. and 2nd CSR, and the barrier thicknesses for the desired attenuations.

4. Results

The densities found in the various traits used in the experiment are presented in Table 3. The calculated attenuation values for the samples showed deviations below 5%, confirming what is observed in practice. This information assumes importance in the evaluation because important differences or large deviations in concrete traces are usually followed by cracks and structural cracks.

Table 3 - Values of the traits used in the experiment and values of their specific densities (g/cm³).

|        | barium (x100ml) | sand (x100ml) | cement (x100ml) | density (g/cm³) |
|--------|-----------------|---------------|-----------------|-----------------|
| mortar I | 1,00            | 1,00          | 0,50            | 2,20            |
| mortar II | 1,00           | 1,50          | 0,50            | 2,07            |
| mortar III | 1,00          | 2,00          | 0,50            | 1,99            |
| mortar IV | 1,00           | 0,50          | 0,50            | 2,47            |

The k-values measured in milligray (mGy) for each trait as a function of the structural thickness for the 70 kVp beam presented in table 4 were normalized plotted in a beam attenuation graph considering the various traces, observing the behavior of the beam across different densities.

Table 4 - Measured values of kerma in air considering various mixtures for 70 kVp

| 70 kVp | kerma in air (x 10⁻² mGy) |
|--------|---------------------------|
|        | 0 mm | 5 mm | 10 mm | 15 mm | 25 mm |
| mortar I | 557 ± 4,2 | 18,0 ± 0,65 | 4,6 ± 0,14 | 2,1 ± 0,08 | 1,2 ± 0,01 |
| mortar II | 557 ± 4,2 | 16,0 ± 0,35 | 3,7 ± 0,12 | 3,2 ± 0,02 | 2,8 ± 0,05 |
| mortar III | 557 ± 4,2 | 13,0 ± 0,22 | 3,2 ± 0,09 | 2,5 ± 0,11 | 2,0 ± 0,04 |
| mortar IV | 557 ± 4,2 | 4,5 ± 0,12  | 2,8 ± 0,08  | 2,1 ± 0,09  | 1,9 ± 0,08 |

For the incidence of 70 kVp beams, the average values of the CSR and CDR for the different traces are shown in table 5.

Table 5 - Calculated HVL and TVL values for the traces at 70 kVp.

| 70 kVp | HVL (mm) | TVL (mm) |
|--------|----------|----------|
| mortar I | 1,40     | 4,39     |
| mortar II | 1,39    | 4,59     |
| mortar III | 1,38    | 4,56     |
| mortar IV | 1,36    | 4,49     |
For the 120 kVp energy beams, the air kerma values are shown in Table 6. Similarly, the results were plotted and a graph was assembled, normalizing the 120 kVp beam to 0 mm (graph 2).

| 120 kVp | kerma in air (x10^{-2} mGy) |
|---------|-----------------------------|
|         | 0 mm | 0,5 mm | 1,0 mm | 1,5 mm | 2,5 mm |
| mortar I| 1741 ± 2,5 | 140,50 ± 2,1 | 39,80 ± 2,6 | 17,54 ± 0,8 | 4,73 ± 0,6 |
| mortar II| 1741 ± 2,5 | 167,10 ± 3,4 | 41,50 ± 1,8 | 22,78 ± 1,0 | 9,13 ± 0,4 |
| mortar III| 1741 ± 2,5 | 147,20 ± 4,2 | 65,40 ± 2,4 | 34,39 ± 0,9 | 12,33 ± 0,8 |
| mortar IV| 1741 ± 2,5 | 63,50 ± 1,3 | 24,24 ± 1,2 | 10,72 ± 0,7 | 8,02 ± 0,4 |
For 120 kVp beams, the average of the calculated CSR and CDR values for the different traces are shown in table 7.

Table 7 - Calculated HVL and TVL values for the traces at 120 kVp

|          | HVL(mm) | TVL(mm) |
|----------|---------|---------|
| mortar I | 1,51    | 4,98    |
| mortar II| 1,50    | 4,95    |
| mortar III| 1,48  | 4,88    |
| mortar IV| 1,40    | 4,62    |

Thus, considering M the conversion constant to be used to estimate the shielding value in barite mortar, for the specified trait, according to the type of equipment to be installed, we can use the expression below:

\[ M = \frac{HVL_{(Ba)}}{HVL_{(Pb)}} \]  

where HVL (Ba) is the value of the semiconductor layer for barite mortar for the specified energy and HVL (Pb) is the value of semiconductor layer for lead for the same energy specified above.

Therefore, considering the values shown of semiconductor layers of table 1, we can conclude that the M value for the traits used in the experiment are as follows:

Table 8: M values used in the experiment for 70 and 120 kV.

| Energy | Mortar I | Mortar II | Mortar III | Mortar IV | Average |
|--------|----------|-----------|------------|-----------|---------|
| 70 kVp | 8,20     | 8,20      | 8,10       | 8,00      | 8,10    |
| 120 kVp* | 5,40    | 5,40      | 5,30       | 5,00      | 5,30    |

* interpolated value

5. Conclusion

The data listed above show that it is possible to manipulate the barred mortar using other traces, different from those commercially used, provided that the energies of each beam employed are respected. The compression values of the barite mortar (9 MPa), although not close to the compression values of conventional concrete, present no hindrance to its application, since the barite mortar is applied to sidewalls and, in case of In case of ceiling shielding, it will not be constantly compressed, thus allowing its application safely.

Regarding the yield, it is noted that, for each chosen trait, we will have a better use of the “weaker” traits with respect to densities, that is, mortar with lower densities, aggregate more sand and therefore have greater volume. larger, which will make a difference at the time of application, providing greater savings. However, it is worth remembering that the traces of lower density are only recommended for equipment that uses less energy, such as dental equipment, mammography, etc., or in situations where the barrier to be shielded, does not require large measures of radioprotection. such as smaller Occupation Factor walls.

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