PHYSICAL CHARACTERISTICS OF BARITE PLASTER USED FOR X-RAY SHIELDING – PART ONE

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Abstract - Barite plaster has been largely used as shielding material in installations housing gamma radiation sources as well as x-ray generating equipment, in order to minimize exposure to individuals. However, some physical characteristics, such as density, plasticity, resistance to compression and radiation attenuation for the different types of barite plaster commercially available in Brazil are not well known. For this reason, this work was carried out aiming to determine specific density, consistency index (plasticity), resistance to compression and barite plaster composition, as well as the transmission factor and attenuation for x-rays in the ISO 60, 80, 110, 150 qualities for barite plaster produced in Brazil. Barite plaster is a compound of cement, sand, barium sulphate and water mixed in a controlled proportion. The basic ratio of cement to water determines plaster strength. Preliminarily, tests were carried out to determine the best amount of water to be added to manufacture the samples. After determining the quantity of water to be added to the mixture to obtain the optimum consistency index, seven samples (labelled A to G) were prepared by keeping constant the mass ratio of the components (one part cement, five parts sand and five parts barium sulphate). The only variable in the mixture was the barium sulphate, which was obtained from three mining companies located in the states of Bahia, Piauí and Minas Gerais, Brazil. The results obtained for the samples analyzed showed that the best consistency indexes were obtained for a mixture of 200 g of cement to 230 g of water, that is in a 1:1.2 proportion. On the other hand, samples "G" (Bahia) and "B" (Piauí) presented the highest resistance to compression (14.8 and 16.7 MPa, respectively). They were prepared by using a cement/water proportion of 1:1.2. It was also observed that sample "G" presented the highest specific density (2.40 g/cm^3) among all tested samples, with a consistency index of 20.25 cm and a plasticity of 0.049 cm^{-1}.

Keywords – Barite plaster; barium sulphate; x-ray attenuation.

1. Introduction

Barite plaster has been largely used as shielding material in installations housing gamma radiation sources as well as x-ray generating equipment, in order to minimize exposure to individuals. Barite plaster is a compound of cement, sand, barium sulphate and water mixed in a controlled proportion. The basic ratio of cement to water determines plaster strength. The knowledge of the physical and chemical characteristics of both the barite mineral and barite plaster as well as the degree of radiation attenuation provided are very important when dealing with shielding calculations for both medical and industrial installations.

However, some physical characteristics, such as density, composition, granulometry, plasticity, resistance to compression and radiation attenuation for the different types of barite plaster commercially available in Brazil are not well known. For this reason, this work was carried out aiming to determine specific density, consistency index (plasticity), resistance to compression and barite plaster composition, as well as the transmission and X-ray attenuation factors for barite plaster produced in Brazil.

2. Material and methods

2.1. Chemical characteristics of the plaster.

Barium and sulphate concentrations in barite samples from the states of Bahia, Piauí and Minas Gerais, Brazil, were determined by using two different methods: a) the soil sulphur method, based on the use of acetic acid and sodium phosphate for extracting barium and sulphate forming a colourless, crystalline extract. The sulphur content of the solution was determined by absorption spectrophotometry in both the UV and visible regions as well as by atomic absorption spectrometry. b) the gravimetric method [1-4] where the sulphate was obtained by precipitation with barium chloride, and then washed with chloridric acid.

Barium was determined by precipitation following the addition of both chloridric and sulphuric acids. The precipitate was washed with HCl and water (for eliminating Cl^-) and then calcined. The process was repeated six times for each sample and the "Q" test was used for rejecting the results that did not fall in the 90% confidence level. The granulometric composition [5-6] of the barite plaster was determined through the densimetric method, which is based in the sedimentation of soil particles following the addition of a chemical dispersing agent $(NaPO_3)_n$, by measuring the suspension density (total clay concentration). The coarse fractions (coarse and fine sand) were separated by sieving and subsequently weighed. The silt proportion was determined as the difference between the total amount of soil and its (sand + clay) content.

2.2. Physical characteristics of the plaster.

The tests for determining the physical characteristics of the barite plaster were performed at the Civil Engineering Laboratory, Catholic University of Pernambuco, Brazil, according to the ABNT (Brazilian Association for Technical Standards) [7-10] specifications. For the physical tests, different proportions of cement, sand, water and barium sulphate components were used to prepare plaster samples. The initial proportions were chosen according to the supplier's recommendations.

The first test performed aimed to determine the consistency index (parameter that expresses the workability conditions of the plaster). In this experiment, the proportions of cement, sand, and barite were kept constant for all seven samples and the amount of water added was varied in such a way to obtain the best consistency index for the plaster. After determining the quantity of water to be added to the mixture to obtain the optimum consistence index, seven samples (labelled A to G) were prepared by keeping constant the mass ratio of the components (one part cement, five parts sand and five parts barium sulphate). The only variable in the mixture was the barium sulphate, which was obtained from three mining companies located in the states of Bahia, Piauí and Minas Gerais, Brazil. Seven test cylinders were prepared for measuring the compressive strength, specific density and plasticity. These experiments were performed for cylindrical plaster samples, which were cured for seven and 28 days. The specific density was determined by using both the volumetric ring method and the clod method [5-6, 11].

2.3. Attenuation curves

In order to obtain data for the attenuation curves, 20 x 20 cm^2 barite slabs with different thicknesses (1 to 20 cm) were prepared. They were irradiated with x-rays generated by a diagnostic type x-ray equipment (Pantak 250) for accelerating potentials varying between 80 and 150 kV, while keeping the tube current constant at 10 mA (radiation qualities used were ISO 60, 80, 110 and 150). The air kerma rates were measured with a 0.6 cc ionization chamber coupled to a Farmer dosimeter. The focus to detector distance was fixed at 1 meter. Data for slab thicknesses higher than 20 cm were obtained by extrapolation.

3. Results and discussion

Table I presents the results the qualitative analysis for the plaster, as well as the granulometric analysis of the barite mineral (sand +$BaSO_4$) and their respective densities. The analysis of the data on Table I for samples from Piauí and Bahia States show that there are no significant differences in their barium, sulphate and soil content. However, the data for the soil composition show that there are differences in the percent of fine sand, very fine sand and silt and that these differences affect the specific density of the barite mineral. The lower the percent of fine sand, very fine sand and silt the higher the specific density (Bahia: 2.12 g·cm^{-3}; Piauí: 1.60 g·cm^{-3}).

Table I – Chemical characteristics and composition of barite mineral (sand + $BaSO_4$).

Origin	Mineral Composition			Sand Loam Soil Composition						
	%Ba	$\%SO_4$	%Soil	% clay	% silt	% VFS	% FS	% MS	% CS	$\rho(g\cdot cm^{-3})$
Piauí	33.7	24.7	41.6	1	46	35	16	2	0	1.6
Bahia	32.5	24.5	43.0	0	33	16	3	34	14	2.1
$^{+}$*M.Gerais	44.3	31.0	24.7	2	46	46	6	-	-	1.6
$^{+}$M.Gerais	46.2	32.4	21.3	2	47	41	10	-	-	1.9

$^{+}$* Barium sulphate (gray); $^{+}$ barium sulphate (purple); VMS (very fine sand); FS (fine sand); MS (medium sand); CS (coarse sand).

Table II shows the results obtained on laboratory tests performed with barite plaster prepared with barium sulphate originated from Bahia, Piauí, and Minas Gerais states. It can be seen that the best consistency indexes were obtained when water was added to the mixture in a proportion corresponding to 230-235 g. It can be also seen from the data in Table II that the best barite plasters, as far as their physical characteristics are regarded, are "G" and "B", with specific densities of 2.40 and 2.19 $g\cdot cm^{-3}$, resistance to compression of 14.8 and 17.6 Mpa, respectively. Besides, these samples presented good consistency indexes, plasticity and workability conditions.

Table II – Physical characteristics of the barite plaster samples used in this study.

Material		Parameter				
H_2O (g)	Plaster Proportioning	Consistency (cm)	Plasticity cm^{-1}	Density $\rho(g.cm^{-3})$	R Compression (MPa) 7 days cure	R Compression (MPa) 28 days cure
230	A*	21,00	0,0476	2,17	9,70	10,0
	B*	♣	-	-	-	-
	C^{+}	21,25	0,0470	2,13	8,10	9,40
	D^{+}	**19,75**	**0,0500**	214	7,70	13,7
	E^{+}*	22,25	0,0449	2,10	7,90	8,7
	F^{+}*	21,00	0,0476	2,25	9,20	11,30
	G♥	20,25	0,0493	**2,40**	12,30	**14,80**
235	A*	22,05	0,0453	2,16	10,20	11,40
240	A*	22,25	0,0449	2,17	9,10	9,30
245	A*	23,75	0,0421	2,17	10,00	11,10
250	A*	23,75	0,0421	2,13	9,30	10,40
	B*	18,25	0,0548	2,18	16,40	16,70
	H♥	28,75	0,0347	-	-	-
260	B*	20,90	0,0478	2,20	10,60	17,00
270	B*	**21,25**	**0,0470**	2,19	15,10	**17,60**

♣ No workability condition; Mixture A - 200 g of cement + 4 parts of sand + 6 parts of $BaSO_4$; Mixture B – 400 g of cement + 5 parts of sand + 5 parts of $BaSO_4$; Mixture C – 200 g of cement + 3 parts of sand + 7 parts of $BaSO_4$; Mixture D – 300 g of cement + 3 parts of sand + 7 parts of $BaSO_4$; Mixture E – 200 g of cement + 3 parts of sand + 7 parts of $(BaSO_4)_{gray}$; Mixture F – 300 g of cement + 3 parts of sand + 7 parts of $(BaSO_4)_{gray}$; Mixture G - 200 g of cement + 5 parts of sand + 5 parts of $(BaSO_4)_{purple}$; Mixture H – 300 g of cement + 5 parts of sand + 5 parts of $(BaSO_4)_{purple}$.

Piaui; + Minas Gerais; $^{+}$ Minas Gerais (gray); ♥Bahia (purple).

The final part of this study consisted in preparing transmission curves for x-rays by using slabs of barite plaster with increasing thicknesses. Figure 1 shows one of these curves, which was obtained for barite plaster slabs with thicknesses varying between 1 and 20 cm, which were prepared by using the same proportions of components as the ones that were used for sample G.

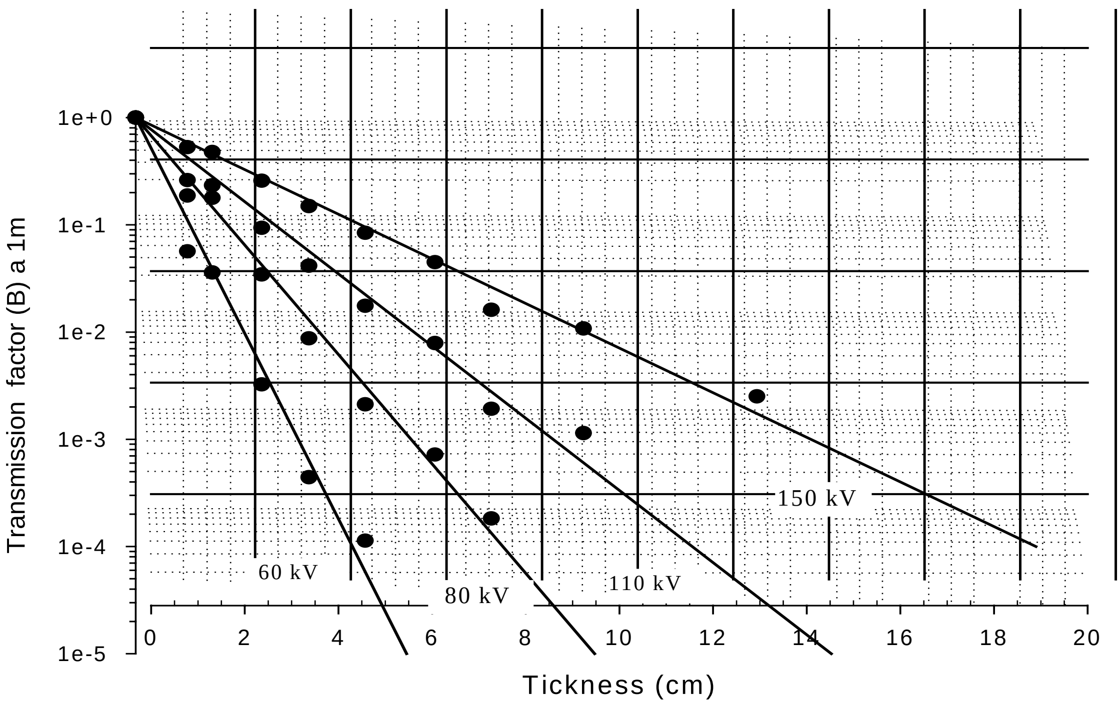

Figure 1- Transmission through barite (specific density 2.19 g·cm^{-3}), of x-rays produced at potentials of 60 to 150 kVp.

4. Conclusion

The results obtained in this study show that: a) the barium content is higher than the sulphate content in the $BaSO_4$ compound regardless of its origin. b) The specific density of the barium sulphate mineral is strongly influenced by its content of silt, fine sand, and coarse sand; c) The composition of soil rather than its proportion in the mixture is an important parameter in determining the specific density of the barite plaster. d) The barite plaster from Bahia State, which presented the highest specific density, was selected as the most appropriate for radiation shielding. e) Both the transmission and attenuation curves obtained in this study present characteristics that are similar to those published elsewhere for other materials.

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