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X-Ray Attenuation of Cotton Fabrics Coated with Barium Sulphate

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Abstract

The x-ray attenuation performance of barium sulphate coated cotton fabrics was evaluated. 10-50 wt% barium sulphate/binder mixture was prepared and then coated onto cotton fabrics. For x-ray shielding evaluation, the fabrics with the different layers were tested under the x-ray radiation at 50kV-100 kV energy levels. The results showed that the shielding x-ray radiation were in the range of 1.48-77%, indicating that x-ray attenuation significantly increased with an increase in $BaSO_4$ content. In addition, the number of fabric layers also played an important role. Finally, it was found that $BaSO_4$ coated cotton fabrics exhibited satisfactory durability with respect to rubbing and washing tests.

Key word: Barium sulfate, X-ray, Coating, Attenuation radiation ratio, Shielding

Introduction

With progress of technology, radiation has been used in a variety of different fields. Thus radiation shielding becomes important subject for researcher. Besides normal people especially radiation workers in radiation facilities need extra protection from radiation. In order to be protected from radiation, three different criterias have to be taken into account, these are time, distance, and the shielding. An effective shielding causes a large energy loss on a small distance without emission of more hazardous radiation. In medical centers radiation beams have been used for diagnosis and treatment. In general, the shielding of x-ray radiation used the fabric coating lead.(1) The high toxicity of lead was the disadvantage of lead-shielding product.(2) Many researcher reported the using of materials for the shielding of the radiation such as polymer composite material,(3) inorganicfillers and matrix polymer,(4) bimuth oxide and barium sulphate,(5) metallurgical solid waste containing lead,(6) ultrahigh molecular weight polyethylene fibre/nano-epoxy composites(7) and polypropylene fibre-reinforce concrete.(8)

Barium Sulfate could be used for radiation shielding because barium was a high atomic number element.(9) The radiation shielding of fabric was performed by coating method(10) or by embedded mineral into the fibres.(11) The coating method is the simple technique to conduct and no uses of the expensive equipment. However, the rubbing and washing fastness properties of the coating material may not durable. In the embedding method, the mineral is putted into the fibres during the spinning process. This causes the high durability of the mineral. In contrast with the coating method, this method is necessary to use the complex equipment.

The study of barium sulfate have been reported. Kim and Jung reported that a coating material using barium was as effective as lead in shielding low levels of radiation.(12) The mixing of additive, hardener and barite was coated onto the fabric produced from viscose/polyester blends. The coated fabric absorbed more x-ray radiation than the uncoated one.(13) The ability of the barium sulphate-epoxy mixture to protect gramma ray was studied by Omar et al. The coated fabric could be a good shielding against the gramma ray.(14) Aral et al. investigated the x-ray shielding of the cotton fabric coated with silicone rubber contained tungsten, bismuth or barium sulphate powders. At the same conditions, the bismuth gave better attenuation ratios per thickness in comparison with tungsten and barium sulphate powders(2) Moreover, determination of radiation shielding properties of cotton/polyester blend fabric coated with different barite rate was reported by Kilincarslan et al. The results showed that the barite coated fabrics blocked the radiation. When the barite ratio increased, the amount of absorbed radiation also increased. Also, linear attenuation coefficients increased with the increase of the barite rate on coating.(1)

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In this research paper, the x-ray radiation shielding of modified cotton fabrics was studied. The cotton fabrics were coated with the binder (acrylic emulsion) mixed with barium sulphate at concentration of 10-15%(w/w). X-ray attenuation ratios of the samples were measured at 50 kV, 70 kV, 80 kV, and 100 kV with the different layers of the fabrics. The durability of the coating material on the cotton fabrics was examined. Also, the surface of the fabrics were investigated by SEM coupled with energy dispersive spectroscopy (EDS).

Materials and Experimental Procedure

Materials

Barium Sulfate (mean particle size 1.60-2.00 micron and density1.10 g/cm^3) from Micropowder Industrial (China) was used as received. Thickener (polyacrylate substance) from Durachem Enterprise (Thailand) was used as received. Binder (acrylic emulsion) from Advance Polymer & Chemicals (Thailand) was used as received. Cotton fabric (yarn number 40) was supported by SL Thai Textile (Thailand).

Preparation of Fabrics Coated with Barium Sulphate

Coated substrate was prepared by mixing the barium sulphate with the thickener and binder at amounts presented in Table 1. Then, the fabric was coated with the mixing materials by a coating machine. After the coating process, the fabric was dried at temperature of 100ºC for 1 min and cured at temperature of 150ºC for 1 min.

Table 1. Content of the coating material on the cotton fabric

Substance	Formula / Content (%w/w)				
	1	2	3	4	5
Water	41	31.9	22.8	13.5	4.2
Binder	45	45	45	45	45
Barium Sulphate	10	20	30	40	50
Thickener	4	3.1	2.2	1.5	0.8

Characterizations

Thickness measurement

The coated fabric were measured by using micro caliper, Peacock Model:PDN12 Type : SIS-6 No.940147, in 5 positions, up-right, up-left, bottom-right, bottom-left, and center. Also, the average values were reported.

Washing and rubbing fastness tests

The washing fastness of the coating material on the cotton fabric was based on "AATCC Test Method 124-1996, Appearance of Fabrics after Repeated Home Laundering" and the rubbing fastness analysis was carried out using "AATCC Test Method 8-1996, AATCC Crockmeter Method".

Surface morphology and elemental analysis

The surface morphologies of samples were observed with a scanning electron microscope (SEM, JEOL JSM-6610-LV, Tokyo, Japan). Also, the elements on cotton fabric were analyzed by SEM coupled with energy dispersive spectroscopy (EDS Oxford Instruments Model X-Max^{nn}50, UK)

Measurement of X-ray attenuation

The radiation absorption analysis was measured at the x-ray energy levels of 50 kV, 70 kV, 80 kV and 100 kV obtained from general x-ray machine (X-ray Toshiba Model Quantum Medical Imaging).

X-ray attenuation properties of a material are described by exponential attenuation law. The relation between x-ray and matter is given by Equation 1.(15)

$$I/I_o = e^{-\mu t} \qquad (1)$$

I = the intensity of the attenuated beam
I_o = the initial intensity
t = the thickness of the shielding material (cm)
μ = the attenuation coefficient of the shielding material (1/cm)

In practical terms, I is the intensity of x-ray radiation after interaction with the shielding material, and I depends on I_o, material thickness, and attenuation coefficient. Attenuation coefficient (μ) is a characteristic property of the material which varies with the x-ray energy level.

The shield performances of the fabrics were reported in term of the radiation attenuation ratios (RAR) which were calculated by Equation 2.(15)

$$\text{RAR (\%)} = [(I_o - I) / I_o] \times 100 \qquad (2)$$

Results and Discussion

Surface morphology and EDS analysis

The thickness of the uncoated and fabrics coated with barium sulphate at concentrations of 10% (w/w) and 50% (w/w) are shown in Table 2. For the high concentration of barium sulphate, the thick film was slightly higher when compared to those of lower concentration coating.

Table 2. The thickness of uncoated and coated fabrics with barium sulphate at concentration of 10% (w/w) and 50% (w/w)

Type of Materials	Thickness (mm)		
	0%(w/w) $BaSO_4$	10%(w/w) $BaSO_4$	50%(w/w) $BaSO_4$
Uncoated fabric	0.210	-	-
Coated fabric (fabric + coating materials)	-	0.227	0.294
Thickness of coating material	0	0.017	0.084

The SEM micrographs of coated fabrics are shown in Figure 1. It can be seen that barium sulphate is present on surface of coated fabrics. Also, the thick binder film is observed in case of high concentration coatings.

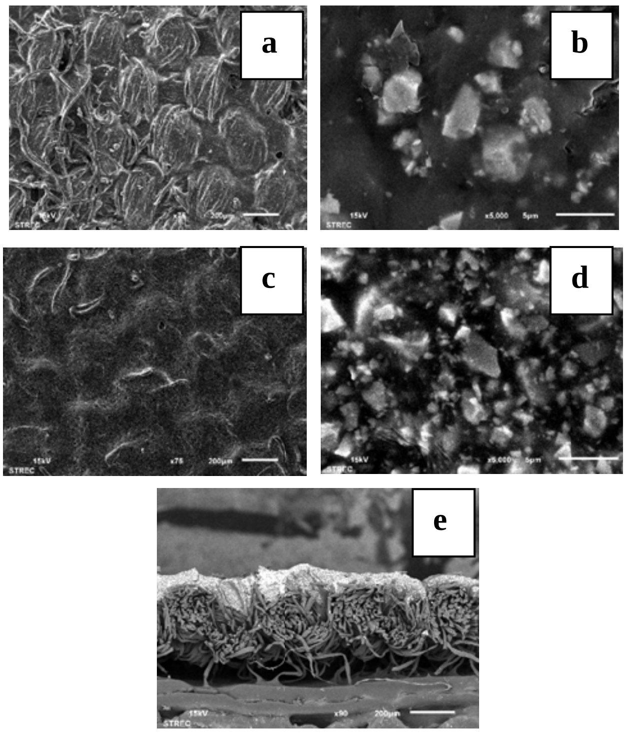

Figure 1. SEM micrographs of the coated fabrics with barium sulphate at different concentration: (a-b) 10% (w/w); (c-d) 50% (w/w) and (e) cross section of the fabric coated with 50% (w/w).

The EDS analysis was conducted to determine the elemental constituents of the coated fabrics. The barium content in the coated fabrics is shown in Table 3 and Figure 2-3.

Table 3. The barium content in coated fabric

$BaSO_4$ concentration (%w/w)	$BaSO_4$ content (wt%)
10	19.42
50	43.59

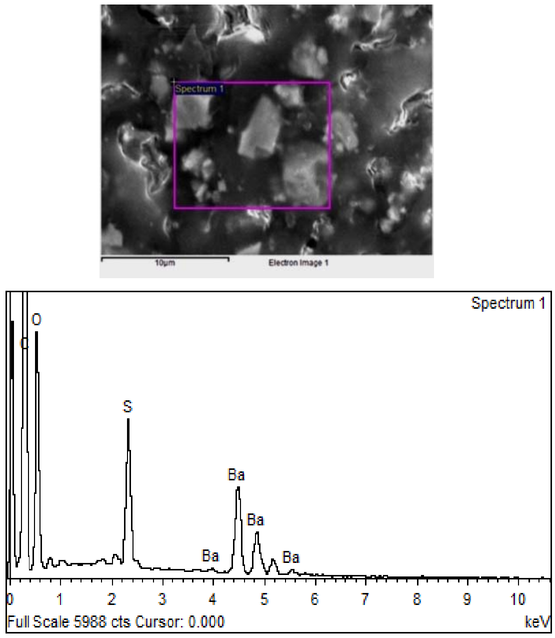

Figure 2. EDS spectra of the coated fabrics with barium sulphate at concentration of 10% (w/w).

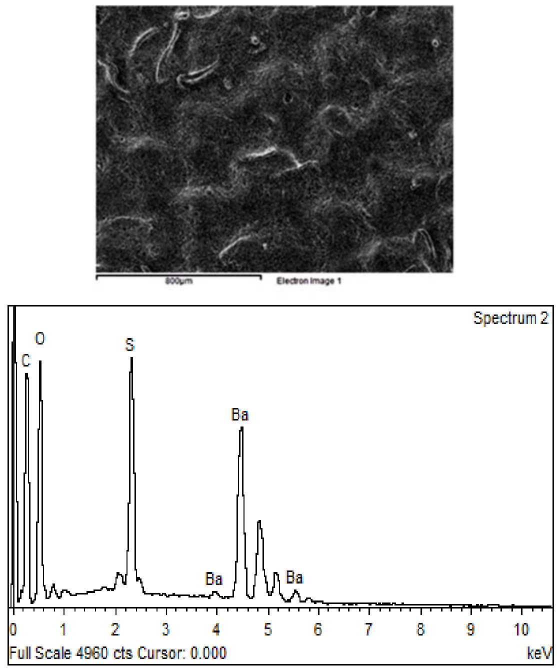

Figure 3. EDS spectra of the coated fabrics with barium sulphate at concentration of 50% (w/w).

The result showed that increasing the concentration of the barium sulphate increased the %Ba content in the fabric. In addition, other elements such as C, O, and S were founded on the cotton fabrics. The mapping of each element on the coated fabric was shown in Figure 4. It can be seen that the mapping of the Ba element showed the dense packing.

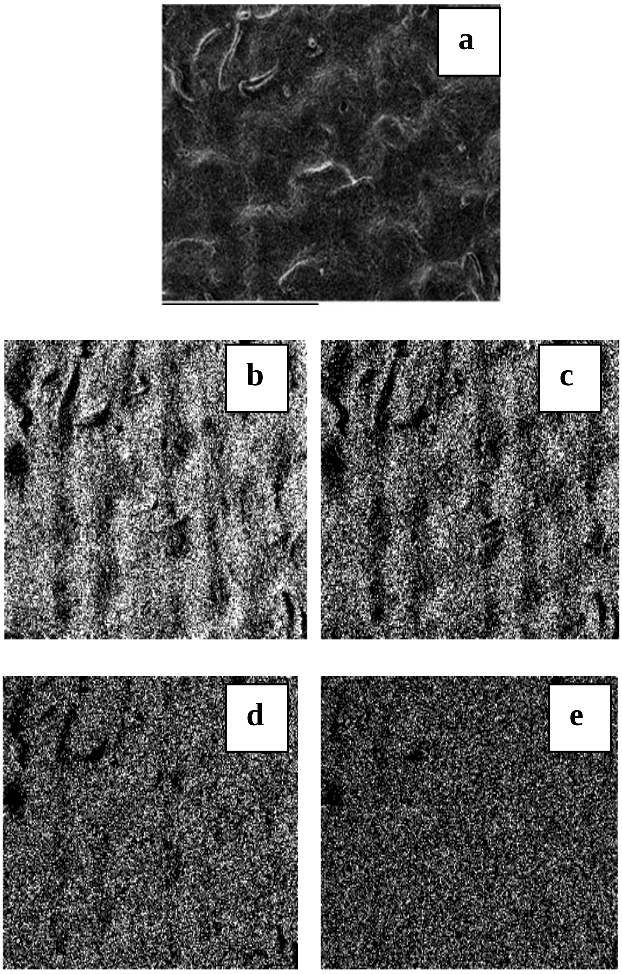

Figure 4. Mapping of elements on the cotton fabric coated with the barium sulphate at concentration of 50%(w/w): (a) SEM micrograph of the coated fabric; (b) mapping of C element; (c) mapping of O element; (d) mapping of S element and (e) mapping of Ba element.

Durability of coating material

The coating fabric with the barium sulphate were tested the rubbing and washing fastness. The weight loss of the fabrics was examined. The results are shown in Table 4. After the rubbing and washing tested, a little bit of the coating material were removed during testing (Table 4 and Figure 5).

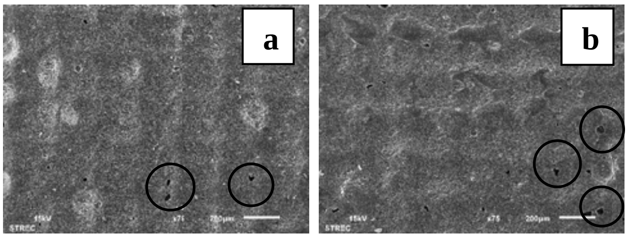

Table 4. The %weight loss of the cotton fabrics after rubbing and washing tested

Testing	Sample	% Weight loss	
		Dry state	Wet state
Rubbing test	Warp direction	0.06	0.15
	Weft direction	0.04	0.17
Washing test	-	-	0.23

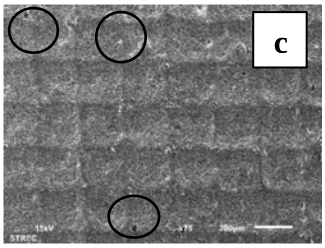

Figure 5. SEM micrographs of coated fabrics with barium sulphate at different concentration of 50% (w/w) after rubbing and washing tested: (a) after rubbing tested in dry condition; (b) after rubbing tested in wet condition and (c) after washing tested.

X-ray radiation measurements

The radiation attenuation ratios of the uncoated and coated cotton fabrics with the barium sulphate at concentration of 10-50%(w/w) and four x-ray energy levels, namely 50 kV, 70kV, 80 kV, and 100 kV are shown in Figures 6-7.

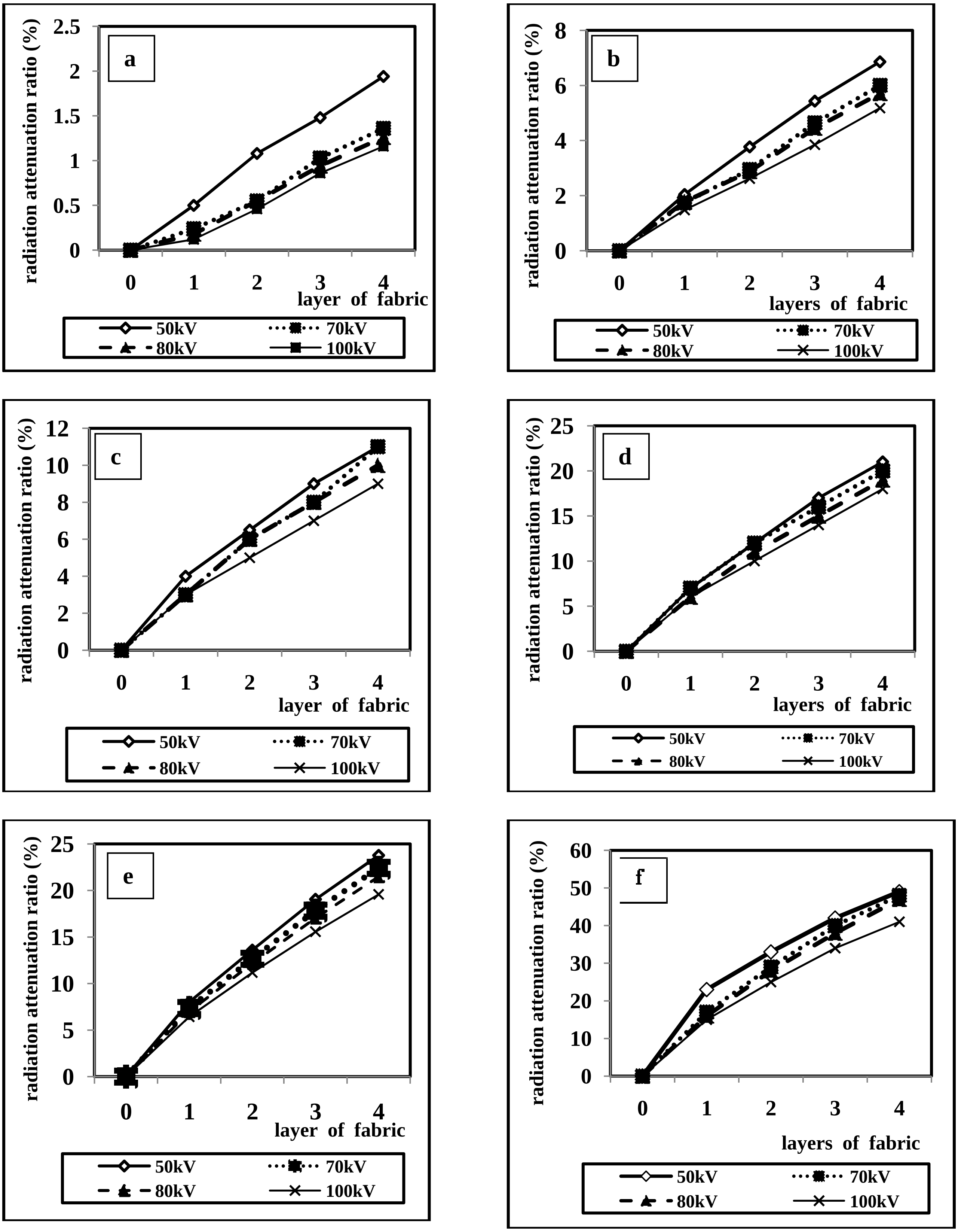

Figure 6. Radiation attenuation ratios of the uncoated (a) and coated fabrics (1-4 layers) with barium sulphate at different concentration (b-f): (b) 10% (w/w); (c) 20% (w/w); (d) 30% (w/w); (e) 40% (w/w) and (f) 50% (w/w).

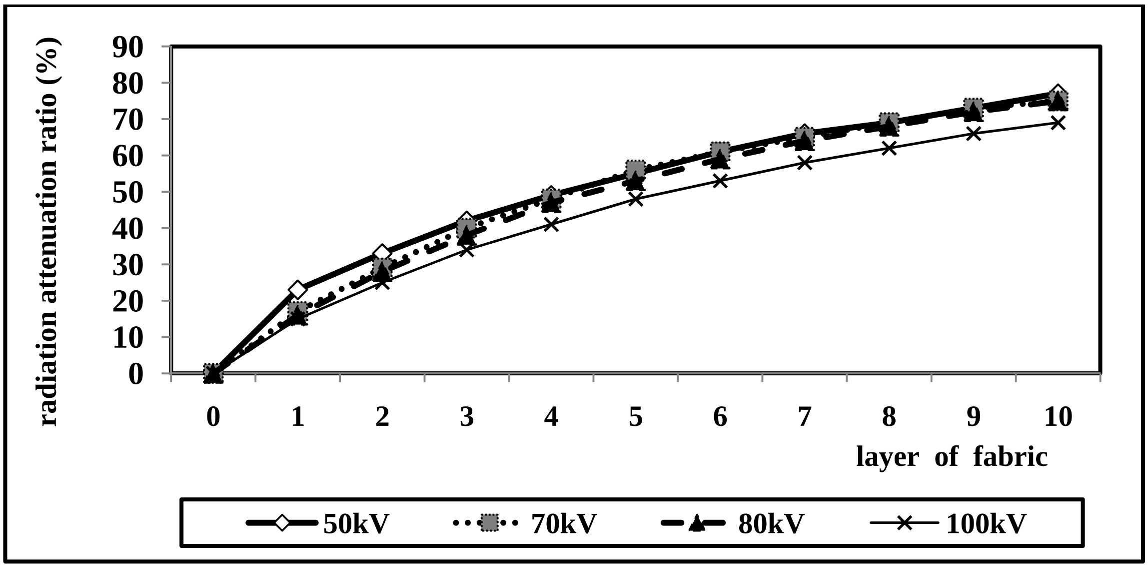

Figure 7. Radiation attenuation ratios of the coated fabrics at 1-10 layers with barium sulphate at concentration of 50% (w/w).

Three parameters were studied in the measurements of the x-ray radiation such as the layer of the cotton fabrics, concentration of the barium sulphate and x-ray energy levels. For the uncoated fabrics (see Figure 6(a)), it had low shielding performance. This indicated that the cotton fabric could not protected the x-ray radiation. Also, the x-ray radiation had the high energy to penetrate through the fabric.

For the measurement of the x-ray radiation shielding of the cotton fabrics, the first factor was the role of the thickness of the cotton fabrics. From Figure 6 and Figure 7, the results showed that increasing the thickness of the coated cotton fabrics increased the percentage of radiation attenuation ratios. It meaned the shielding of x-ray radiation increased with the increasing of the layers of the cotton fabrics. The highest attenuation ratio of the coated cotton fabrics was 77% at the condition of 50% (w/w) barium sulphate, 10 layers of the fabrics and x-ray energy level 50 kV (Figure 7). According to Omar et al., the thickness of the fabric affected the radiation protection. [14]

In the second factor, the effect of concentration of the barium sulphate on the x-ray shielding was investigated. It was found that the increasing of the barium sulphate concentration increased the x-ray radiation shielding (Figure 6). Hence, the shielding of the x-ray radiation was the resulted from the concentration of the barium sulphate. The effect of the barium sulphate concentration was also reported by Akkurt et al.[1]

The last one was the energy levels of the x-ray. The attenuation ratios of the fabrics decreased under increment of the x-ray energy levels. This resulted from the high incident intensities of the high x-ray energy level. A similar observation was reported by Aral et al.[15]. Therefore, the radiation protection of the coated fabrics depended on the energy level of the x-ray.

Conclusion

The barium sulphate coated onto the cotton fabrics had an effect on the x-ray attenuation. The shielding of the x-ray radiation of the coated fabrics was in the range of 1.48-77%. Factor effecting the radiation shielding of the coated cotton fabrics were the concentration of the barium sulphate, layer of the cotton fabric and x-ray energy levels. The coating of the cotton fabrics with the barium sulphate was good durable with the rubbing and the washing tested.

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