An Investigation on Sewability of X-ray Protective Fabrics

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Abstract. In this study, tungsten, bismuth and barium sulphate coated 100% cotton fabrics, which can be used for personal x-ray shielding purposes, were tested in terms of their sewability properties. By doing so, the sewing parameters that would not impair the sewing process and that would not cause or elevate damage on the coated fabrics were determined.

1. Introduction
Radiation used in medical applications with the aim of diagnosis and therapy affects both the patients and the physicians at particular levels [1]. The aim of the personal radiation protection is to preserve patient’s body which are out of the target area and to minimize the radiation level that has a repetitive impact on the physicians. For protection purposes, aprons made of layered thin lead sheets are used. However, the toxicity level of the lead is quite high and it causes some environmental problems during its disposal. Also, due to their non-flexible properties, they have bending problems which ends up with cracking [2,3]. Protective fabrics/sheets with the content of radiopaque materials are used for personal shielding and they might be converted to wearable forms like aprons, collars [4-9]. In the study presented, sewability of x-ray protecting aprons in which lead layers were replaced by layered coated fabrics was investigated. Accordingly, appropriate thread type, needle count and needle type alternatives were studied for sewing x-ray protective fabrics coated with tungsten, bismuth and barium sulphate powders while minimizing the damage on the coated fabrics that may deteriorate the x-ray attenuation performance of protective fabrics. Moreover, forces acting on the needle during the sewing process were measured and SEM images were obtained to evaluate the needle damages on the coated fabrics.

2. Materials and Method
In commercial lead aprons, lead sheets (2) are covered by linings on both sides (1) and a bias tape (3) is used during the sewing operation to combine all the layers (Figure 1).

Figure 1. Schematic structure of lead aprons.
In our study, the lead sheet is replaced by layered coated fabrics. Each layer of the x-ray protective fabric was coated on one side and composed of radiopaque powder-silicone rubber coating and 100% cotton, plain weave fabric as the textile base. Bismuth, tungsten, and barium sulphate powders were used as radiopaque powders in the coatings at the same weight ratio of 60%. The properties of the samples are given in Table 1.

### Table 1. The properties of the coating compounds.

| Sample       | Powder additive | Additive density (g/cm³) | Additive weight ratio (%) | Additive volume ratio (%) | Coating material density (g/cm³) |
|--------------|-----------------|--------------------------|---------------------------|---------------------------|----------------------------------|
| **Bi - SR**  | Bismuth         | 9.8                      | 60                        | 14.41                     | 2.35                             |
| **W - SR**   | Tungsten        | 19.3                     | 60                        | 7.94                      | 2.55                             |
| **BaSO₄ - SR**| Barium Sulphate | 4.4                      | 60                        | 27.23                     | 2.01                             |

Single needle, high speed, 591 D300A model, Singer lockstitch machine was used for the sewing trials. This machine allows working with a variety of needle sizes within a range of #7 to #11. Sewability test (ITV Denkendorf) was performed in order to identify the sufficient force to actualize the sewing process for the coated fabrics. The measurement of the stitching force is a method developed by the ITV-Denkendorf. A needle plate sensor below the needle plate of a sewing machine records the stitching force [10,11]. During the test, Pfaff 1183 sewing machine and DBx1 BP SES NM 80 R type needle were used. 50 needle sinking samples were taken for each of the three tests. Finally, the surface of the coated fabrics after the sewing operation was determined using a Carl Zeiss Ultra Plus Field Emission scanning electron microscope (SEM).

In order to determine a suitable sewing process for joining the coated structures, sewing trials were experienced using different needle and sewing thread types, needle sizes and stitch densities. The thickness of the shielding material is a critical parameter which has an effect on x-ray attenuation. Therefore, the number of fabric layers can be multiplied to reach the required protection levels, where one layer of fabric cannot attenuate the x-rays at needed levels [6,7]. Therefore, the protective coated fabrics were layered and were sewn together. Sewing parameters used during the sewing trials are presented in Table 2.

### Table 2. Sewing parameters.

| Needle Number | Needle Coating                  | Point Type   | Thread Type                        | Thread number (Tex) | Stitch density/cm |
|---------------|---------------------------------|--------------|------------------------------------|---------------------|-------------------|
| 11,9,8,7      | Standard, Gold reinforced Slim   | Spun,Textured, Corespun | 18, 50                             | 2.5, 5              |

At the beginning of the study, the coated layers were sewn using number 11 needles. In order to minimize the needle hole dimensions formed on the fabrics, further sewing trials were performed using finer needles and it was observed that the coated layers could be successfully sewn using number 7 needle.

During the sewing trials performed using various combinations of needle and thread types, problems such as clogging of the needle eye by the sewing thread, difficulty in handling the material to the sewing region by the operator, sewing thread breakages were observed. Taking these problems into
consideration and with an intention to keep the holes formed on the coated fabrics as small as possible, the sewing parameters were determined as:

- slim pointed type of standard needles with a size of 7,
- 18 Tex corespun polyester yarn,
- 5 stitches/cm stitch density.

3. Results and Discussion
The highest forces recorded during sewing were those that were acting on the needle eye. Mean of three measurements, maximum and minimum forces on the needles when sewing the base fabric, the single layer and the layered samples are presented in Table 3.

| Number of layers | Base fabric | Bismuth (Bi-SR) | Tungsten (W-SR) | Barium Sulphate (BaSO₄-SR) |
|------------------|-------------|-----------------|-----------------|-----------------------------|
|                  | Single layer | Layered         | Single layer    | Layered                     |
| Base fabric      | 234.4       | 1368.0          | 448.9           | 798.2                       |
| Mean (cN)        | 337.7       | 1478.4          | 629.7           | 920.9                       |
| Max. (cN)        | 137.9       | 1278.1          | 459.8           | 721.2                       |
| Min. (cN)        | 65          | 2.3             | 16.8            | 2.6                         |
| CV (%)           | 7.7         | 2.3             | 16.8            | 2.6                         |

As can be seen from the table, Bi-SR coated fabric produced the highest forces while BaSO₄-SR coated one gave the lowest.

The layered coated fabrics were, then, placed between 2 polyester linings (87 g/m²) and using a polyester 2/2 warp rib bias tape they were sewn in the warp direction. After the sewing operation, the needle holes formed on the top layer of the coated fabrics were examined by SEM. Examples of the damages on the coatings are presented in Figure 2.

The damage caused by the sewing needle on the bismuth and tungsten coated fabrics is observed to be in the form of cracks. The dimensions of the opening in the cracks of the tungsten coating were observed to be smaller than those of the bismuth coating, in general. The crack on the tungsten sample proceeded starting from the needle hole at a level close to the coating surface. In case of the bismuth coated sample, however, the damage caused by the needle expanded in such a way that it turned into a much greater hole on the coating. For the BaSO₄ coated fabrics, the damage is in the hole form instead of a crack. The opening on this sample is observed to be bigger than the openings of the other coatings.

The differences between the forces acting during the sewing process and the damages formed on the coatings might be due to the differences in the additive volume ratios on the coated fabrics as well as to the use of different radiopaque powders.

It was stated in the literature that fabrics exhibiting higher penetration forces exhibit sewing damage, however, the inverse statement may not always apply because a fabric exhibiting low penetration forces may not always present less sewing damage [12]. The particle loading of additives also affects the mechanical properties of polymer composites [6]. Although the weight ratio of the additives in all samples is 60%, as may be seen from the Table 1, the volume ratio in the coating is 27.23% for the barium sulphate additive, whilst the bismuth volume ratio is 14.41 and tungsten volume ratio is 7.4%,
due to the differences in their densities. In a previous study by Aral et al. [6] it was found that the barium sulphate embedded silicone rubber coating with higher particle loading showed poor durability against repetitive folding in comparison the tungsten one. This was explained by the fact that the flexible character of the matrix might have been weakened by high powder volume ratio. Weak flexibility of the BaSO4-SR coated sample might have resulted in the formation of the biggest openings.

Figure 2. SEM images of the top layer of the layered coated structure

4. Conclusion
In this study, appropriate parameters for sewing alternative x-ray shielding protective aprons, in which the lead sheets are replaced by layered coated structures, are studied. The test results showed that in order to keep the damage as small as possible, number 7 gold reinforcement needles can be used. The type of the sewing thread should also be determined according to the needle employed. Considering
the forces acting on the coated structures, sewing the BaSO₄ coated fabrics was easier, however they had the biggest openings in the damages caused by the sewing needle. As further studies, sewing trials on samples having coatings with various additive ratios from different radiopaque powders can be suggested. Number of the layers being sewn can also altered accordingly. X-ray penetration through the damages caused by the needles on both alternative aprons and conventional lead aprons can also be compared. Damages on the other layers of the coated structures can be examined.

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