An evaluation of usability of warp knitted spacer fabrics as hip protector

G Ertekin and A Marmaralı
Ege University, Faculty of Engineering, Department of Textile Engineering, 35100, Bornova, Izmir, Turkey
gozde.damci@ege.edu.tr

Abstract. The aim of this study is to examine the usability of warp knitted spacer fabrics as a hip protector, in order to eliminate the complaints frequently encountered in the market, due to their higher air and water vapor permeability, thermal conductivity, good compressibility and lightweight. For this purpose, the physical and performance properties of silicone and latex coated warp-knitted spacer fabrics were determined. With an attempt to discuss the effect of coating and fabric structural parameters on the physical and performance characteristics, six warp knitted spacer fabrics were produced by varying thickness (12.5 and 15 mm) and mesh structure (small and large hexagonal mesh). Then, fabrics were coated with silicone and latex by using vacuum infusion process in order to improve the force attenuation capacity of the fabrics. The fabrics were coated with silicone and latex substrates in a 1:1 and 1:½ weight ratios, respectively. Mass per unit area, thickness, air permeability, compressibility, dimensional stability and compression set properties were measured and evaluated.

1. Introduction
As the people are getting older, the incidence of falling, fracture and vulnerability to injury increases due to their decreased physical capabilities. The populations of many countries are both ageing and feminizing, meaning hip fractures now occur in around one in four women and one in eight men. More than 90% of hip fractures result from a fall [1-3]. A sideways fall produces a high-energy impact, which increases six times of the risk of a hip fracture compared to a backward or a forward fall, even in young subjects [4, 5] (Figure 1). Therefore, reducing the rate of falls and the resulting hip fractures is an increasingly important part of healthy ageing.

![Figure 1. Cascade of events leading to hip fracture](https://example.com/figure1.png)
Hip protectors are hard or soft plastic shields embedded into pants or undergarments in proximity of the outside of the hip, just over the trochanter. The aim of hip protectors is to reduce the energy transmitted to the trochanter during a fall below the force causing a fracture, referred to as hip fracture threshold [4, 7]. Mainly, hip protectors can be either “rigid pads” designed for spreading the energy of the impact to the soft tissue of surrounding of the hip or “energy absorbing” soft materials that decrease the force of the impact ultimately transmitted to the bone [8, 9].

Several studies have been indicated that hip protectors are not often used for reasons such as uncomfortable (too tight/poor fit), wearing difficulties, urinary incontinence and physical difficulties/illnesses [10-15]. Attention has been paid to the features of the hip protector garment concerning comfort, appearance and fit. Changes in the design of hip protectors making them more comfortable and acceptable to users justify new studies addressing the effectiveness of hip protectors [16]. The aim of this study is to examine the usability of warp knitted spacer fabrics as a hip protector, in order to eliminate the complaints frequently encountered in the market, due to their higher air and water vapour permeability, thermal conductivity, good compressibility and lightweight.

2. Material and method

2.1. Production of spacer fabrics

Warp knitted spacer fabrics were produced by using a Karl Mayer RD 6 raschel machine with double-needle bars and six yarn guide bars (GB). A 167f48x4 and 334f72 polyester PTY multifilaments were used to create the top outer and bottom outer layers. Polyester monofilament yarns of 0.243, 0.200 and 0.170 mm in diameters were used as spacer yarn to connect two outer layers. The spacer monofilament inclination (shifting one needle distance) was kept constant.

The distance between the needle bars of the machine was set to 12.5 and 15 mm for varying the thickness values of the samples.

Brückner (Vn-Sfp-24/6-Q99) heat-setting machine was used in order to increase the structural stability and to achieve a determined final width (stretching). The samples were horizontally (course-wise) pinned on the sliding aluminum frame pins and heat set at the temperature of 180 °C for time duration of 6 min. The tension applied to the samples during heat-setting was arranged so that the final width of the samples will be 110 and 160 cm. After heat-setting, the fabric samples were allowed to cool down at room temperature for 24 h. The characteristics of the fabrics are given in Table 1.

| Fabric type | Yarn thickness (dtex/mm/dtex) | Distance between the needle bars (mm) | Mesh size (Finished width of the samples) | Courses/cm | Fabric pattern                  |
|-------------|------------------------------|--------------------------------------|------------------------------------------|------------|----------------------------------|
| 1           | 167f48x4-334f72x3/0.243/     | 12.5                                 | Large (160 cm)                           | 5.25       | Two side open structure          |
| 2           | 167f48x4-334f72x3            | 15.0                                 | Large (160 cm)                           |            |                                  |
| 3           | 167f48x4-334f72x3            | 12.5                                 | Small (110 cm)                           |            | Two side close structure         |
| 4           | 167f48x4-334f72x3            | 15.0                                 | Small (110 cm)                           |            | Face side open/back side close structure |
| 5           | 167f48x4/0.200/167f48x4      | 15.0                                 | 130 cm                                   | 6.5        |                                  |
| 6           | 334f72x3/0.170/334f72x3      | 15.0                                 | 130 cm                                   | 5          |                                  |
2.2. Coating of spacer fabrics
Fabrics were coated with silicone and latex by using vacuum infusion process in order to improve the force attenuation capacity of the fabrics. Silicone substrate with two-components (10:1) from ACC Silicons Company mixed with a laboratory mixer and the mixture was put under vacuum before use to avoid air bubbles [17]. The fabrics were coated with this substrate in a 1:1 weight ratio. Latex substrate were applied in 1:½ weight ratio. The photographs of the coated fabrics are given in Figure 2.

![Figure 2. Surface photos of (a) non-coated, (b) silicone coated, (c) latex coated fabrics.](image)

2.3. Measurements of spacer fabrics
The physical properties such as fabric thickness (measured with a caliper) and mass per unit area (according to EN 12127:1997) of the spacer fabric samples before and after coating process are measured and shown in Table 2.

Air permeability values were obtained by using Textest FX 3300 instrument according to TS 391 EN ISO 9237. The results of the measurements are averages from the values of 10 readings. The performance characteristics of the spacer fabrics such as compressibility, dimensional stability, compression set and air permeability were tested. Compressibility tests were carried out by Zwick Z010 Instrument based on the ISO 3386 standard. 950N was applied to the samples and the set compression rate is 25%. The measurement was performed by using two layers of fabric samples in both course and wale direction. The results are averages of 3 readings in N. Dimensional stability was tested according to the DIN 53377 standard. The samples are cut into square form of 10 x 10 cm and are placed in an oven maintained at 90°C for 1h. The dimensional stability value was calculated according to the Eq. (1):

$$\text{Dimensional stability (\%) } = \frac{l_o - l_F}{l_o} \times 100$$

(1)

where \(l_o\): The original dimensions of the specimen, \(l_F\): The dimensions of the specimen after treatment.

The compression set is the difference between the initial thickness and the final thickness of a test piece of the material after compression for a given time at a given temperature and after a given recovery time and is determined according to TS 2013 EN ISO 1856 standard. The samples (50x50x25 mm) are compressed at a rate of 75% and are placed in an oven maintained at 70°C for 22h. The compression set value was calculated according to the Eq. (2):

$$\text{Compression set (\%) } = \frac{|d_o - d_F|}{d_o} \times 100$$

(2)

where \(d_o\): The original thickness of the specimen, \(d_F\): The thickness value of the specimen waited for ½ h after experiment.

3. Result and Discussion
The mean values of the physical and performance properties are given in Table 2 and 3, respectively.
### Table 2. Physical and air permeability properties of the fabrics

| Surface structure | Space distance (mm) | Mesh size | Type of coating          | Mass per unit area (g/m²) | Thickness (mm) | Air permeability (l/m²s) |
|-------------------|---------------------|-----------|--------------------------|---------------------------|----------------|--------------------------|
|                   |                     |           | Non-coated               |                           |                |                          |
|                   |                     |           | Silicone coated          | 525.12                    | 10.51          | 6998.00                  |
|                   |                     |           | Latex coated             | 1125.33                   | 10.02          | 6170.67                  |
|                   |                     |           | Non-coated               | 555.73                    | 12.81          | 6113.33                  |
|                   |                     |           | Silicone coated          | 1168.00                   | 11.61          | 5939.33                  |
|                   |                     |           | Latex coated             | 901.33                    | 13.13          | 5909.33                  |
|                   |                     |           | Non-coated               | 683.57                    | 10.80          | 6024.00                  |
|                   |                     |           | Silicone coated          | 1402.67                   | 10.70          | 5691.33                  |
|                   |                     |           | Latex coated             | 922.67                    | 11.49          | 5665.33                  |
|                   |                     |           | Non-coated               | 737.57                    | 13.02          | 6078.00                  |
|                   |                     |           | Silicone coated          | 1370.67                   | 12.52          | 5654.00                  |
|                   |                     |           | Latex coated             | 1125.33                   | 14.15          | 5634.67                  |
| Two sides open    | 12.5                | Large (160 cm) | Non-coated               | 1117.81                   | 10.49          | 2254.00                  |
|                   |                     |           | Silicone coated          | 2304.00                   | 10.40          | 1135.87                  |
|                   |                     |           | Latex coated             | 1616.00                   | 11.00          | 2183.33                  |
|                   | 15.0                | Large (160 cm) | Non-coated               | 201.12                    | -2             | 33.16                    |
|                   |                     |           | Silicone coated          | 436                       | 0              | 25.34                    |
|                   |                     |           | Latex coated             | 520                       | -1             | 21.38                    |
|                   |                     |           | Non-coated               | 139.04                    | -3             | 38.12                    |
|                   |                     |           | Silicone coated          | 368                       | -1             | 31.80                    |
|                   |                     |           | Latex coated             | 421                       | -1             | 29.80                    |
|                   |                     |           | Non-coated               | 279.84                    | -2             | 32.51                    |
|                   |                     |           | Silicone coated          | 627                       | -1             | 23.08                    |
|                   |                     |           | Latex coated             | 647                       | -1             | 20.95                    |
|                   |                     |           | Non-coated               | 236.64                    | -3             | 37.47                    |
|                   |                     |           | Silicone coated          | 440                       | -1             | 27.10                    |
|                   |                     |           | Latex coated             | 513                       | -1             | 26.65                    |
| Face side open    | 12.5                | Large (160 cm) | Non-coated               | 306.72                    | -2             | 36.48                    |
|                   |                     |           | Silicone coated          | >950                      | 0              | 28.14                    |
|                   |                     |           | Latex coated             | >950                      | 0              | 25.14                    |
|                   | 15.0                | Small (110 cm) | Non-coated               | 271.68                    | -3             | 24.97                    |
|                   |                     |           | Silicone coated          | Not measured              | -1             | 21.20                    |
|                   |                     |           | Latex coated             | 465                       | -1             | 19.20                    |

### Table 3. Performance properties of the fabrics

| Surface structure | Space distance (mm) | Mesh size | Type of coating          | Compressibility (N) | Dimensional stability (%) | Compression set (%) |
|-------------------|---------------------|-----------|--------------------------|---------------------|---------------------------|---------------------|
|                   |                     |           | Non-coated               | Course-wise         | Wale-wise                 | Course-wise         |
|                   |                     |           | Silicone coated          | 201.12              | 193.25                    | -2                  |
|                   |                     |           | Latex coated             | 436                 | 427                       | -1                  |
|                   |                     |           | Non-coated               | 520                 | 518                       | -1                  |
|                   |                     |           | Silicone coated          | 139.04              | 118.11                    | -3                  |
|                   |                     |           | Latex coated             | 368                 | 341                       | -1                  |
|                   |                     |           | Non-coated               | 421                 | 409                       | -1                  |
|                   |                     |           | Silicone coated          | 279.84              | 219.15                    | -2                  |
|                   |                     |           | Latex coated             | 627                 | 539                       | -1                  |
|                   |                     |           | Non-coated               | 647                 | 604                       | -1                  |
|                   |                     |           | Silicone coated          | 236.64              | 218.62                    | -3                  |
|                   |                     |           | Latex coated             | 440                 | 413                       | -1                  |
|                   |                     |           | Non-coated               | 513                 | 508                       | -1                  |
| Two sides open    | 12.5                | Large (160 cm) | Non-coated               | 306.72              | 300.28                    | -2                  |
|                   |                     |           | Silicone coated          | >950                | 0                        | 0                   |
|                   |                     |           | Latex coated             | >950                | 0                        | 0                   |
|                   | 15.0                | Large (160 cm) | Non-coated               | 271.68              | 249.63                    | -3                  |
|                   |                     |           | Silicone coated          | Not measured        | -1                       | 0                   |
|                   |                     |           | Latex coated             | 465                 | 443                       | -1                  |

3.1. Air permeability

The air permeability results indicated that, the highest and lowest air permeability values were observed in the non-coated spacer fabric with a large hexagonal mesh structure and a distance between the needle bars of 15 mm and silicone coated spacer fabric having two side closed structure, respectively. For
determination of air permeability properties, it was observed that, fabric density is the most effective parameter rather than coating, a distance between the needle bars and hexagonal mesh size. Generally, it was examined that, fabrics having a distance between the needle bars of 15 mm and/or large hexagonal mesh structure and/or non-coated have lower density resulting in higher air permeability.

When the effect of surface structure on the air permeability of the fabrics is evaluated, it was determined that the surface structure of the fabric has a dominant effect than the fabric density. As it is expected, fabrics having two sides open structures have higher air permeability followed by face side open/back side close structure and two sides close structure.

3.2. Compressibility

The force necessary to compress a fabric has to overcome the internal stresses of the fibres and the inter-fibre frictional force. A fabric that compresses easily is likely to be judged as soft, possessing a low compression modulus or high compression [18]. Factors affecting compressibility of three-dimensional fabrics are fabric thickness, stitch density, bending behaviour and inclination angle of spacer yarn. According to Table 3, it was observed that as the thickness values increased, the compressibility of the fabrics decreased. As the fabric becomes thicker, it was thought that the fabric becomes softer due to the extension of the spacer yarn and facilitates its deformation.

The compressibility results indicated that, the lower compressibility values in both direction were observed in the spacer fabric with large hexagonal mesh structures and a distance between the needle bars of 15 mm due to its lower stitch density. When the effect of coating on compressibility is examined, it was noted that the coating increased the compressibility of the fabrics and latex coated spacer fabrics had higher compressibility values following by silicone coated and non-coated spacer fabrics.

When the effect of surface structure is investigated, it was examined that, the highest compressibility value was observed in the spacer fabric with two sides close structure, followed by face side open/back side close structure and two sides open structures. The compressibility of the spacer fabric having two sides close structures was higher due to its more stable and rigid structure. As the inclination angle of the spacer yarn decreases, spacer yarn provides better compressibility property. The reduction of compressibility is attributed to the inclination angle of monofilament yarn that can be calculated by image processing of the cross-sectional view of fabrics. The monofilament yarns are placed at nearly right angles in the spacer fabrics having two sides open structure. This led to more easily exposed to bending resulting in a decrease of compressibility.

3.3. Dimensional stability

The dimensional stability characteristics of the fabrics were measured in both directions: wale-wise and course-wise. The results indicated that, no dimensional change in wale direction was observed in all fabrics. The results indicated that, non-coated spacer fabrics with two sides open structures having a distance between the needle bars of 15 mm and non-coated spacer fabric with two sides close structures have 3% shrinkage in course direction. According to DIN 53 377, the acceptable limit value of dimensional stability for both directions is ± 3 %. Additionally, for the non-coated fabrics, as the fabric thickness increased, the shrinkage increased as well. The shrinkage values of the fabrics were 1% in course direction after coating process except fabrics with two sides close structure. The hexagonal mesh size didn’t any effect on the dimensional stability of the fabrics.

When the effect of surface structure is investigated, it was observed that, fabrics with two sides close structure had lower shrinkage values than fabrics having two sides open and face side open/back side close structures.

3.4. Compression set

Compression set value known as aging test is one of the important factors determining the durability and lifetime of spacer fabrics. There is an inverse relationship between the durability and compression set characteristic of the fabrics. The higher the compression set, the lower is the durability of the fabrics [18]. It can be seen from Table 3 that, non-coated fabrics with higher compression set values offered a
shorter lifetime of the fabrics, whereas coated fabrics especially latex coated fabrics had lower compression set values. Additionally, an increase in fabric thickness and/or hexagonal mesh size led to an increase in compression set values resulting in shorter lifetimes of the fabrics. Fabric density has major effect on the compression set properties of the fabrics. The compression set values of the fabrics increase due to the decrease of fibre content per unit area. Spacer fabrics with face side open, back side close structure had lower compression set values than the other fabrics. It was observed that fabric density and surface structure have a mutual effect on compression set characteristic of fabrics.

4. Conclusion
The aim of this study is to examine the usability of warp knitted spacer fabrics as a hip protector. For this purpose, the physical and performance properties of silicone and latex coated warp-knitted spacer fabrics were determined. The results clearly demonstrated that:

– Coating process improved the compressibility property and decreased dimensional stability and compression set. Although coating reduced the air permeability values, no significant decrease in air permeability property was observed after coating. Latex coated spacer fabrics due to their higher compressibility and lower compression set properties provided longer duration and lifetime of the spacer fabrics.

– An increase in thickness values led to decrease in compressibility and increase in compression set values resulting in shorter lifetime of the fabrics. Additionally, for non-coated fabrics, as the thickness increased, shrinkage in % increased as well.

– Fabrics with small hexagonal mesh structure had higher compressibility, and lower air permeability and compression set.

– Fabrics with face side open/back side close structures had moderate air permeability and compressibility properties, whereas their compression set values were lower than the other fabric structures.

To sum up, parameters such as small hexagonal mesh size, lower thickness, face side open/back side close surface structure and latex coating can be preferable for better comfort, longer durability and life time of the warp knitted spacer fabrics which are intended to be used as hip protector.

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