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Influence of heat transfer material on the deformability of knitted fabrics

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Abstract

Purpose – To produce a coated fabric, a base fabric may be completely or partially coated with a polymer layer, which changes the properties of the new system relative to the base fabric. The purpose of this paper is to analyze the influence of the thermal transfer material and its shape on the deformability of knitted fabrics during the uniaxial extension and to determine the residual deformation of the thermoplastic transfer element of coated fabrics after unloading.

Design/methodology/approach – Knitted fabrics were partially and entirely coated with heat transfer material. For partial coating, square pieces of three different transfer materials were bonded on the middle of the specimen. They were solid, perforated with either nine circular holes or six rectangular holes. A heat seal press was used to laminate knitted fabrics. The samples were subjected to uniaxial tensile testing. The characteristics such as strain at maximum force, strain at break, and strain at low stress were measured. After stretching and relaxation of the specimens, the residual deformation of the heat transfer element was also investigated.

Findings – The results indicated that coating knitted fabrics with transfer material may decrease their stretchability. The experiments show that the decrease in stretchability and in the degree of residual deformation after stretching and relaxing depend on the knitted structure, the shape of the transfer element, and the degree to which the fabric is coated.

Originality/value – This study examines the influence of heat transfer material which may be not only entirely but also partially joined with knitted fabric layer on the deformability and shape stability of this system.

Keywords Coating, Deformability, Heat transfer material, Knitted fabrics, Residual deformation

Paper type Research paper

1. Introduction

Thermoplastic films are widely used for textiles on purpose to extend their range of functional performance properties and for aesthetical enhancement. The elastomers like PVC, acrylic, synthetic rubbers, silicone, fluorocarbons, polyurethanes, and polyethylene are choosen for clothes decoration, their parts joining and especially for improving the protection against foul weather and any number of other potential hazards (Bemska, 2010; Lomax, 1985; Jakubčionienė and Masteikaitė, 2010).

The systems of fabrics bonded with polymer layers are used in many fields, including technical textiles, geotextiles, protective clothing, and sportswear. The properties of polymeric materials directly influence the durability and performance of the end-product. After fusing onto the fabric surface, the thermal layer becomes part of the base material. In addition to stiffening the fabric, the layer of polymeric material also imparts new characteristics to the base fabric. Base layers for coating and lamination can be of various textile forms, namely woven, knit or nonwoven. Their

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mechanical properties such as elasticity, elongation at break, strength, frictional resistance and dimensional stability are of special importance (Kovačevič *et al.*, 2010). It is desirable that fabrics for active wear be flexible and deform with relatively low levels of stress or loading. Such facile deformability is very important to the comfort of the wearer. The extensibility of fabrics depend on their composition and structure (Gokarneshau and Thangamani, 2012). Knitted fabrics allow better extensibility, recovery and shape retention (Shishoo, 2005). Adding elastane as an ingredient in knitwear of any fiber provides ease of movement and allows the garment to resists bagging and keeps its shape. The first technical criterion by which knitted fabrics are selected also for special application is their deformability; both extensional deformability and deformability in shear are important (Gommers *et al.*, 1998).

Knitted fabrics usually cannot be directly coated because of their stretchiness and open construction. They are generally laminated or transfer coated (Shishoo, 2005). Among the variety of coating techniques, transfer coating yields the softest coating of all in terms of fabric handle (Horrocks and Anand, 2000). Warp-knit fabrics are used most often for functional laminating, while for decorative purposes many more types of knitted fabrics may be chosen. However, despite their advantages, some knitted fabrics pose quality-control problems like dimensional change and deformation; this is especially common for single jersey fabrics. One such problem is fabric spirality, which occurs when the wale is not perpendicular to the course. Because spirality is caused by an imbalance in the structure of the knitted fabric, its occurrence depends on the fabric's structure, tightness, weight, and the conditions of its manufacture (Kurbak and Kayacan, 2008; Değirmenci and Topalbekiroğlu, 2010). Some types of knitted fabrics tend to curl. This is another undesirable deformation caused by unbalanced internal stresses (Singha, 2012; Gommers *et al.*, 1998). In any case, the system consisting of knitted fabric and polymer layer must be flexible, stretchable, and recover its shape after deformation. Though many thermal transfer materials are characterized as soft and stretchable, they may sometimes crack or stiffen during wear. The mechanical stresses to which clothes are subjected during wear renders their coated surface prone to deterioration (Padleckienė and Petrulis, 2010). Even small cracks in the polymer film layer may make a garment unusable though the knitted fabric may be in good state. Therefore, careful consideration is necessary to select both the base fabric and coating polymer.

To achieve reasonably good quality and to predict the durability of such textile goods, it is essential to understand their behavior during wear, and analyze these materials under realistic stresses. Fabrics coated with a thermoplastic film layer may be analyzed in many ways. In the case of fabric laminated for decorative purposes, it is very important that the thermoplastic layer be able to extend to a certain degree and recover its original shape without cracking. For products decoration as color overlay most often the poliurethane with different effects, PVC, viscose flock material are used (BEMIS, 2014; Chemica, 2014). The flexibility of PVC film can be varied by the amount of added plasticiser. However, for most uses plasticiser contents of up to 50 percent are most common. The PVC coatings are resistant to acids and alkalis but organic solvents can extract the plasticiser, making the coatings more rigid and prone to cracking. Polyurethane coatings show outstanding resistance to abrasion combined with good resistance to water and solvents, in addition they offer good flexibility and extensibility (Horrocks and Anand, 2000). The decorative layer can be laser cut to any pattern or shape and then bonded to select panels or assemblies as required.

For deformability measuring of fabrics coated with a polymer film, the method of uniaxial extension is often chosen. Using this method, the fabric may be extended till break or extended using low stress (Gokarneshau and Thangamani, 2012; Vassiliadis *et al.*, 2007). The fabric's elastic recovery is often determined using low stress as well. Measuring the static elastic recovery of the fabric mainly helps to analyze its dimensional stability, while measuring the dynamic elastic recovery helps to analyze the garment's response to rapid body movements (Senthilkumar and Anbumani, 2011). Extension levels between 20 and 50 percent are often used.

Coated fabrics behavior during deformation differs from uncoated fabrics behaviour. Various authors have investigated the tensile properties of coated fabrics. It was pointed out that coating causes fabric stiffness and more rigid structure therefore its elongation decreases and breaking strength increases (Bulut and Sülar, 2011). Taking into account some structure of knitted fabrics, after their lamination elongation may increase in longitudinal direction and decrease in cross direction (Gregor-Svetec and Bezek, 2005). Also it was determined, that coating agent may reduce the anisotropy of fabric at some degree (Kovačevič *et al.*, 2010). The mechanical destruction of the coated layer may appear after cyclical flexing fatigue (Padleckienė and Petrulis, 2010) and after extension. It was determined that coated fabrics failure using their uniaxial extension may be of three types: instantaneously break of both layers, the distortion of specimen in different surface zones lasts a period of time and the distortion of separate layers not at the same time (Masteikaitė and Sacevičienė, 2005). The failure of more complicated materials, as thermoplastic textile composites may be characterized by numerous mechanisms, such as cusp formation, matrix shearing, matrix cracking, fiber pull-out, resin pockets and fiber bridging (Svensson and Gilchrist, 2000). Loop shape, loop length, and fabric tightness have a large effect on the mechanical properties of knitted fabric composites (Wang and Hu, 2007). A theoretical basis for predicting the elastic properties of knitted fabric composites has been validated by experimental measurements (Ruan and Chou, 1996). Unfortunately, there is a lack of published material devoted to analyze knitted fabrics deformability changes after they are partially coated using heat transfer layer.

The aim of this work was to analyze the influence of the thermal transfer element of various shapes on the deformability of knitted fabrics till break and at low stress and determine the residual deformation and failure of the thermoplastic transfer element after unloading.

2. Materials and methods

2.1 Specimens

Knitting is a very versatile process therefore an infinite range of knitted fabrics exists. Since transfer coating is used for materials of various degree of deformability, the four knitted fabrics with more different structural characteristics and one type of thermoplastic film were used for this work. They were supplied by the sportswear manufacturer LTP UAB (Lithuania). On purpose to investigate the influence of coating on the degree of stretchability the elastic properties of knitted fabrics has the advantage during selection for this experiment. The knitting structure and other geometrical and dimensional properties were also important for clothes deformability therefore they were evaluated during results analysis. The basic characteristics of the experimental fabrics are presented in Table I. As a heat transfer coating, the PVC material Firstmark (Chemica company) with a self-adhesive and transparent polyester

Table I.
Main characteristics of tested fabrics

Symbol	Composition	Course density, cm^{-1}	Wale density, cm^{-1}	Stitch density, loops/cm^2	Mass per unit area, g/m^2	Thickness, mm	Structure
M1	96% CO, 4% EL	20	15	300	160	0.60	Plain weft knitted
M2	71% PES, 29% EL	15	17	255	127	0.46	Double tuck stitch
M3	94% PA, 6% EL	35	20	700	147	0.60	Single tuck stitch
M4	100% PES	25	17	459	146	0.68	Double combined

carrier was used. The thickness of this monocolored material was 0.21 mm and thickness of tested fabrics ranged from 0.46 till 0.68 mm. This characteristic was measured at a pressure of 1.0 kPa, using Textil-Dickenmesser DPT 60 digital instrument. The fabric mass per unit area was determined for each sample in accordance with EN 12127.

In the uniaxial extension tests, five types of specimens were used. For every type of specimen knitted fabrics were cut in lengthwise, crosswise and bias (45°) directions to form rectangular shape with a width of 50 mm and a working zone of 100 mm.

Every square of heat transfer material (50 × 50 mm) was bonded to the middle of the fabric specimen (Figure 1(a)). To investigate the influence of the coated area on the extensibility of the knitted fabrics extensibility, three different shapes of transfer material were chosen. The first shape consisted of a solid square with area $s_1 = 2{,}500\ mm^2$, providing 50 percent coating of the sample (Figure 1(b)). The second shape consisted of a square perforated with nine circular holes ($s_2 = 1{,}645\ mm^2$) providing 32.9 percent coating (Figure 1(c)). The third shape consisted of a square transfer element perforated with six rectangular holes ($s_3 = 124\ mm^2$, providing 2.48 percent coating (Figure 1(d)).

Specimens' without transfer element were used as control and marked as type A. Fabric specimens coated entirely with thermoplastic film were also investigated. These were marked as specimens of type B. Partially coated specimens of the first, second, and third heat transfer elements shapes were marked as C, D and E, respectively. A schematic of the specimen's types is shown in Figure 2.

The heat transfer specimens were cut using Golden laser JG-series equipment. Because polyvinylchloride film is thermoplastic, it can be seamed using various techniques, such as hot air, radio frequency or ultrasonic welding (Lomax, 1985). The heat transfer elements bonding to the knitted fabrics were carried out in a LTP UAB factory using the heat seal press Insta MS728T. The bonding conditions were: temperature 150°C, duration 15 s and pressure 3 bar. The polyester backing was removed after the transfer material had cooled.

2.2 Uniaxial extension until break

In the case of multilayered fabrics, their properties are determined by both components; the fabric and polymer must be selected by thorough consideration of the desired performance of the finished article (Shishoo, 2005). Since stretchability and recovery are

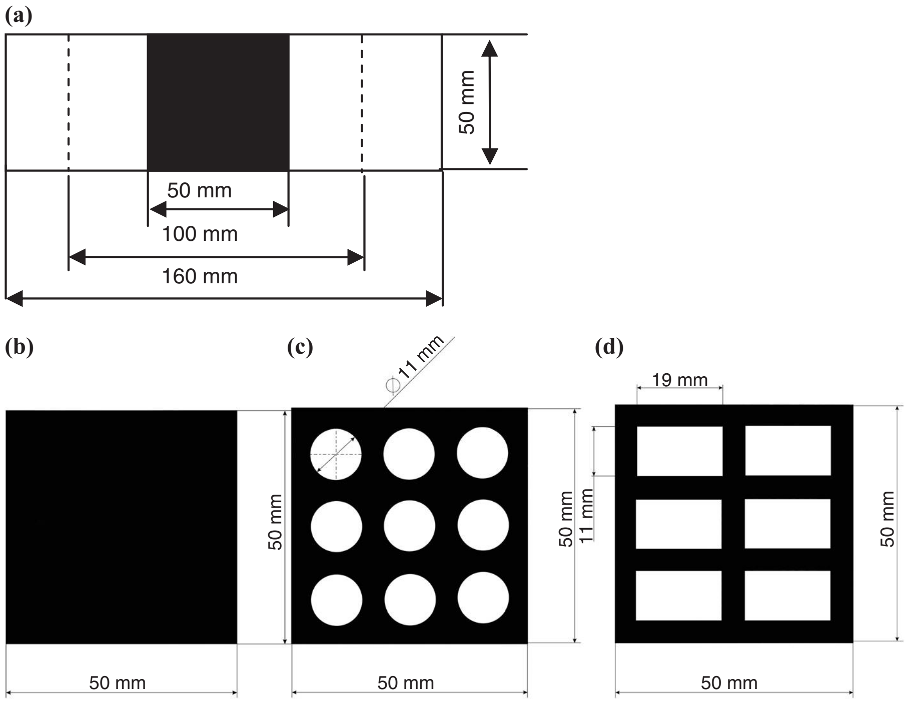
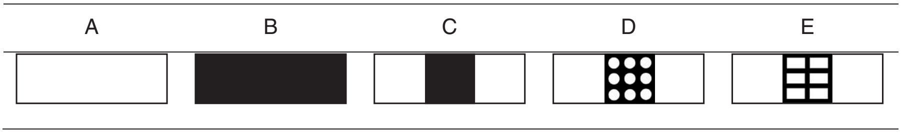


Figure 1. Measurements of the partially laminated specimen (a) and different types of transfer element (b),(c),(d)



Note: The thermal transfer material is marked in black

Figure 2. Types of specimens used in work

important properties that determine the quality of the final coated fabric, we studied the effect of uniaxial extension until break, and up to a controlled degree of stress. Uniaxial tensile testing was carried out using a Tinius Olsen HT10 tension machine. The cross-head speed was kept at 50 mm/s and the distance between jaws was 100 mm. During the first stage of the experiment, specimens were extended until they broke. There are two common types of tensile break: sharp break and percentage break (Hu, 2008). Therefore, the deformation of the specimens during their extension until break was investigated with regard to the strain at maximum force $\varepsilon_{\max}$, and the strain at break ε_n. These values were identified from stress-strain curves (Figure 3(a)). The distortion of the specimens over time was characterized by the value q, which shows the degree of the specimen's further elongation after the maximum load was achieved. The characteristic q was determined using Equation (1):

$$q = \varepsilon_n - \varepsilon_{\max} \tag{1}$$

2.3 Extension at low stress

During normal garment use, fabrics are subjected to stresses that are much lower than the breaking stress. In the case of sportswear and other active sports clothing, which must closely fit the body, the fabric stretch is very important (Hu, 2008). There are two types of stretch: comfort stretch (5-30 percent) and power stretch (30-50 percent) (Lyle, 1977). Preliminary tests showed that the fabrics chosen for this work have low resistance to extension until the comfort stretch limit of 30 percent. The comfort stretch limit was reached at stresses varying from 0.12 to 1.25 N/cm for unlaminated fabric specimens; laminating increased the stress considerably (4.8-9.95 N/cm). Since the aim of this work was to analyze the change in stretchability of the fabrics upon laminating, we determined the extensibility of the tested specimens at low stress. The stress level was chosen in accordance with the recommendations of the Kawabata Evaluation system for Fabrics (Kawabata and Niwa, 1991). This system is used for testing woven and knitted fabrics, and their composites (Gokarneshau and Thangamani, 2012; Svensson and Gilchrist, 2000). To determine the strain ε_1 under low stress conditions, a force of $F_1 = 4.9$ N/cm was used. The values of strain ε_1 were obtained from stress-strain curves as shown in Figure 3(b).

2.4 Recovery after load

A fabric's recovery after load is a very important factor for its use in clothing (Hu, 2008; Senthilkumar and Anbumani, 2011; Kovacevic *et al.*, 2010). The recovery after load is the extent to which a fabric returns to its original dimensions after the load is released. As a rule, the addition of elastane increases the level of recovery. However, the addition of a polymer layer may stabilize the knitted fabric structure, and may also restrict its return to original shape. To evaluate recovery of the transfer element, the specimens after rupture were removed from the clamps and allowed to relax on a flat surface under standard conditions in a horizontal position for 24 hours. Then the transfer element's longitudinal and transversal deformation was determined by measuring the width of the narrowest place, x, and its length y. The transfer element's width x and length y after relaxation was compared with initial values ($x_0 = y_0 = 50$ mm) and the percent of these values was calculated as x_a and y_a according to Equations (2) and (3):

$$x_a = \left[(x - x_0)/x_0\right] \times 100 \tag{2}$$

$$y_a = \left[(y - y_0)/y_0\right] \times 100 \tag{3}$$

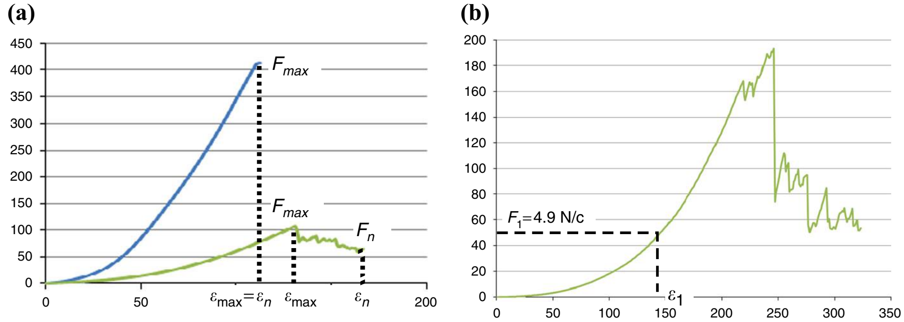


Figure 3.
Stress-strain curves of representative fabric samples showing (a) $\varepsilon_{\max}$, ε_n, and (b) ε_1

Usually a change in the dimensions of knitted fabric samples involves an increase in one direction and a decrease in the other direction.

The shear angle α was determined as the maximum difference between the transfer element selvage and a line perpendicular to the longitudinal specimen's selvage (Figure 4 (a, skewed shape)). The value of α shows the degrees of transfer element skew after extension and relaxation of the specimen.

The transversal deformability, l, of the transfer element (Figure 4 (b, curling)), and the baggy appearance of the surface weaving (Figure 4 (c, surface weaving)) were also evaluated.

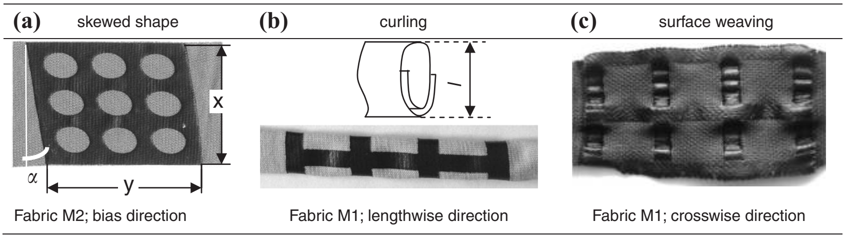
The surface damage of the polymer film after the specimens' extension was identified using only visual inspection to search for cracks, which can be seen with naked eye. A more detailed microscopic analysis was not conducted in this work.

Each test was repeated five times. The relative error in the measurement of the structural parameters was less than 6.5 percent. All measurements were taken after the specimens had been conditioned in standard atmospheric conditions for 24 hours (20 ± 2°C temperature, 65 ± 2 percent RH).

3. Results and discussion

3.1 Effect of uniaxial extension until break

Deformation during extension of knitted fabrics results from the superposition of the bending, elongation and interaction between the yarns (Vassiliadis *et al.*, 2007). At the first stage of extension only loop deformation occurs. Further fabric extension may cause the yarn to slip from its loop structure (Senthilkumar and Anbumani, 2011). The degree of strain at maximum stress in the three cut directions, for all the tested fabrics, is shown in Figure 5. The results show that the $\varepsilon_{\max}$ of the single layer fabrics ranged between 93.8 and 408.0 percent. It is also obvious that most of the specimens exhibited higher extensibility when stretched in the crosswise direction. This is because the loops of the knitted fabrics can more easily deform in this direction. The deformation behavior of a knitted fabric is determined by the areal density of loops and the way the knitted loops are connected to each other (Gommers *et al.*, 1998). The areal density or stitch density of tested fabrics is presented in Table I. The fabric sample M3 is the most elastic, especially in the crosswise direction. It has the largest areal density (700 loops/cm^2) and highest course and wale densities. The thinnest fabric sample, M2, with the smallest areal density (255 loops/cm^2), has the lowest value of $\varepsilon_{\max}$ in the lengthwise. The small course density may explain the low stretchability in this direction. The fabric sample with the lowest degree of stretchability in all cut directions is M4. This is the only fabric sample without elastane in the yarn.



(a) skewed shape

Fabric M2; bias direction

(b) curling

Fabric M1; lengthwise direction

(c) surface weaving

Fabric M1; crosswise direction

Figure 4. Types of residual deformation of transfer element after extension of the specimen extension until rupture followed by relaxation

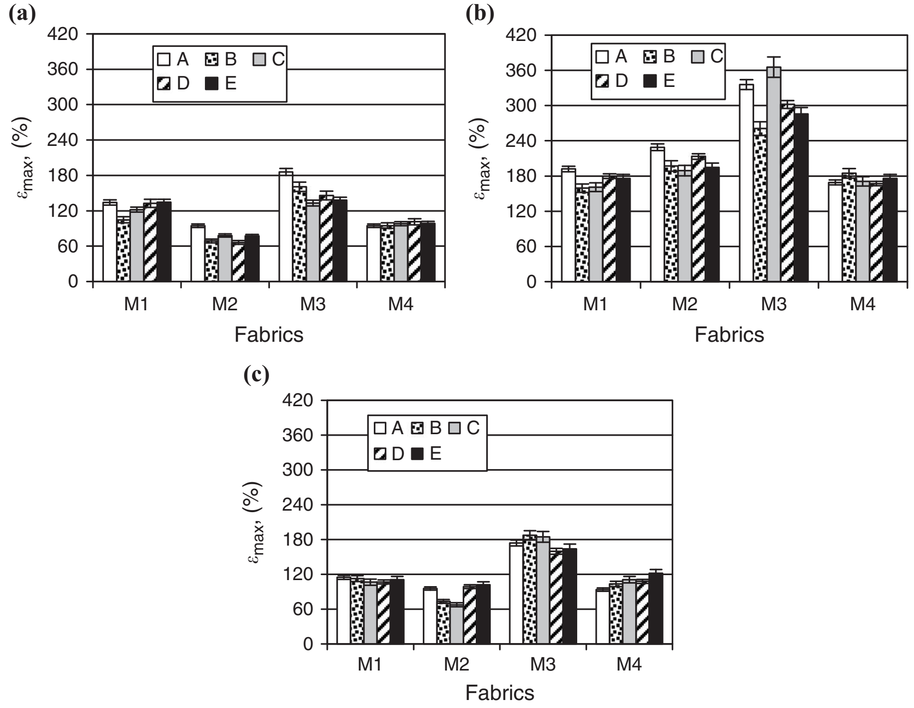


Figure 5.
The strain $\varepsilon_{\max}$ at maximum force $F_{\max}$ of tested fabrics without (A) and with transfers (B),(C),(D) stretched in lengthwise (a), crosswise (b) and bias (c) directions

Most fabrics used for clothes manufacturing are anisotropic. To indicate the degree of anisotropy in a fabric sample, the minimum and maximum values of some property may be used (Gommers *et al.*, 1998). Taking into account that three cut directions were used in this work, the level of anisotropy was determined using the coefficient of variation v. This shows the dispersion of a set of data from its mean. Larger variation in the data indicates higher anisotropy. Among the tested fabric samples, M1 was the least anisotropic ($v = 27.4$). The samples with the highest degree of anisotropy were M2 ($v = 55.2$) and M3 ($v = 51.5$). Fabric M4 had an anisotropy value close to the mean ($v = 36.2$).

Based on these results the fabrics may be characterized as follows. The highest value of $\varepsilon_{\max}$ was observed in the crosswise direction, while the lowest value was observed in the lengthwise direction. The fabric sample M3 with high anisotropy and high stitch density showed greater stretchability. Sample M2, with high anisotropy and low density, has the lowest stretchability only in the lengthwise and bias directions while in the crosswise direction the stretchability only slightly overcomes that of fabrics M1 and M4. Though the density of this fabric is low, the higher stretchability in the crosswise direction may be explained by its high content of elastane (Table I) and its knit structure, a double tuck stitch.

In most cases, coating reduces the stretchability of fabrics (Bulut and Sülar, 2011). Fabrics anisotropy may be reduced, but not eliminated, by addition of a coating agent (Kovacevic *et al.*, 2010). Our results show that coating the fabrics M1-M3 with PVC film (specimens of type B), reduced their stretchability considerably. For specimens cut in lengthwise and crosswise directions their characteristic $\varepsilon_{\max}$ decreased by

13.3 to 56.4 percent. The fabric M4, with average anisotropy, maintained its stretchability even upon complete coating of the surface. The results show that surface coating has the greatest influence on the specimens with higher extensibility.

Testing of the partially coated specimens showed that in most cases upon extension, the fabric itself would rupture but the coated parts would stay intact. As evident from Figure 5, the specimens C-E exhibit intermediate values of $\varepsilon_{\max}$, mostly situated between the $\varepsilon_{\max}$ of single fabric and that of entirely laminated fabric. The value of $\varepsilon_{\max}$ depends not only on the strength of the loops but also on the knit structure of the fabric. The stitch run during knitted fabrics extension explain the large values of $\varepsilon_{\max}$ observed at lower maximum force. The polymer layer strengthens the structure of the fabric and prevents the stitches from running. The stress-strain curves show that during extension, most specimens cut in the lengthwise and crosswise directions broke almost instantaneously, i.e. the maximum strain $\varepsilon_{\max}$ was equal to the strain at break ε_n. The distortion over time was determined for all specimens of fabric M3 cut in the crosswise direction ($q = 34.1$ to 72.0 percent) and for all specimens cut in the bias direction. Figure 6 shows that the characteristic q for these specimens varied from 2.7 to 61.3 percent. Fabric sample M3 has the least stable structure; during its extension, the separate zones of the specimen begin to break. Taking into account its small q, the structure of fabric M1 may be characterized as "all-in-one." These results show that coating may slightly change the characteristic q value of the fabric. The large store changes were determined for the most extensible fabric, M3. The influence of coating on the least extensible fabric, M4, was not notable.

3.2 *Effect of extension at low stress*

Due to differences in the behavior of knitted fabrics during extension until break, during the first stage it was difficult to determine an obvious influence of coating on the specimens' stretchability. Therefore, the stretchability of the specimens was further analyzed, during their extension up to a stress of 4.9 N/cm. In all cases, the transfer element decreased the characteristic ε_1 of the fabrics (Figure 7). When the fabric samples M1, M3, and M4 were subjected to low stress, their degree of anisotropy differed from that under maximum stress. A considerable decrease in anisotropy was found for the fabric M3, which has high stitch density. At low stress, its v is equal to 13.8, while at maximum stress $v = 51.5$. Fabric M2, having a lower stitch density, remained greatly anisotropic during both extension conditions: $v = 55.2$ at maximum stress and $v = 55.0$ at low stress. The difference in anisotropy of fabrics M1 and M4 was considered significant. Strenuous movements involved in active sports require stretch

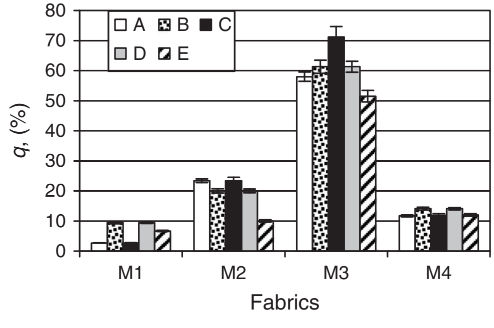


Figure 6.
The characteristic q for specimens cut in bias direction

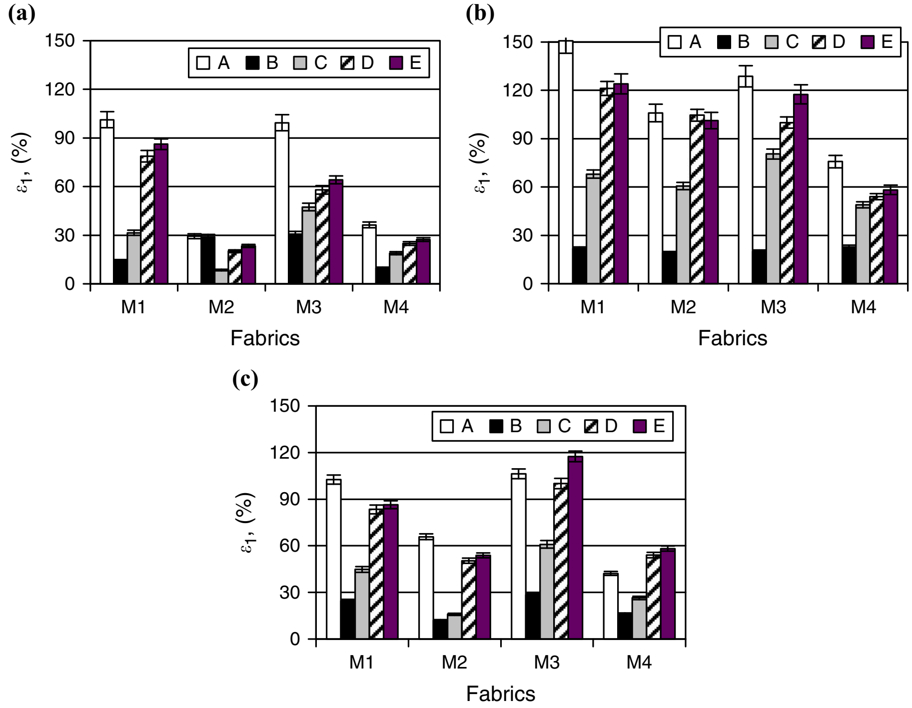


Figure 7.
The strain ε_1 of knitted fabrics specimens without (A) and with transfer elements (C),(D),(E) after their extension in lengthwise (a), crosswise (b), and bias directions (c) up to $F_1 = 4.9$ N/cm

of as much as 50 percent (Hong *et al.*, 2002). In the crosswise direction, almost all specimens exceeded this level of stretch (Figure 7). Fabrics M2 and M4 were more stable, especially in lengthwise direction. A several time decrease in ε_1 was observed for all specimens, especially those with a transfer element of type C.

Transfer elements of types D and E decreased the extensibility of the fabric samples to a lesser extent than in the case of type C, with type E producing a system with slightly higher extensibility than type D. Therefore, the smallest decrease in ε_1 was observed in specimens where the transfer material covered the least area. This indicates that the size of the transfer element must be chosen very carefully even when the knitted fabric has sufficient elasticity in all three directions.

3.3 Failure of the polymer layer

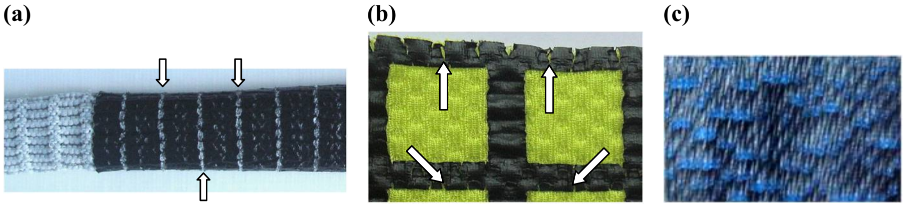
The polymer layer used as the transfer element must be elastic, and should not break during extension. During clothes wear, the acting strain is lower than the strength limit, but it is of interest to characterize the behavior of the transfer element as coated fabric reaches its strength limit. In a static loading situation, the maximum normal stress criterion is one of the most efficient criteria governing the fracture failure of isotropic materials (Huang *et al.*, 2002). Therefore, after applying the breaking load, all the specimens were evaluated visually for cracks. During analysis three types of cracks were observed in the polymer layer: small cracks over the entire surface of the transfer element, cracks in parallel lines, and selvage cracks (Figure 8). The maximum strain of the Firstmark heat transfer PVC material, used in this work, reached 225 percent. This material is thus more extensible than fabrics M1, M2 and M4, but less extensible than specimens of fabric M3 cut in the crosswise direction. The extensibility of these M3 samples considerably exceeds the $\varepsilon_{\max}$ of the transfer material (30.1-36.4 percent).

Visual inspection of the specimens reveals that, during the extension of all transfers bonded to fabric M3, serious cracks appeared in parallel line formations perpendicular to the lengthwise direction. The failure of the polymer films bonded to fabric M3 failure is due to the high extensibility and uneven structure of this fabric (Figure 8(a)). Therefore, the characteristic *q* for fabric M3 in the crosswise direction, and especially in the bias direction, is comparably high (Figure 6). Failure of the polymer film during extension was also observed for fabrics M1, M2, and M4 cut in the crosswise direction, but mostly for the transfer types of C and E. The morphology of the distortions was identified as cracked selvage in most cases. This phenomenon may be related to the structure of the knitted fabrics. A possible explanation for the higher elasticity of the D type transfer is the circular shape of the perforated holes, which decreases the concentration of stress. Because the perforated holes in type E transfers are rectangular, after extension not only did the specimen exhibit cracked selvage, but also the inner selvages of the rectangular holes became distorted. During extension of the coated sample M2, which is the thinnest and lowest-density fabric, small cracks propagated on the surface of the polymer layer (Figure 8(c)). The more open structure of this fabric has less direct contact with the polymer layer; therefore, the components of the system do not behave as one. This investigation reveals that the transfer material may crack if it is bonded to knitted fabrics whose maximum strain exceeds 180 percent in the crosswise direction and up to 120 percent in the bias direction.

3.4 Recovery after load

Knitted fabric is easy to deform in both the longitudinal and transverse directions, due to its loop structure. During extension, the acting force may change the wale and course spacing considerably (Mikučionienė *et al.*, 2010). The heat-transferred polymer layer, fused onto the surface of the fabric, does not penetrate deeply into the structure of the fabric and instead remains as a compact material. In the case of two bonded layers under extension, the layers can behave as one system until one of them begins to crack. During relaxation, the layers tend to revert to their original form by changing in the opposite manner as the applied stress. This process depends on the structure of the layers. The knitted fabrics have non-uniform structure and are anisotropic. The elastic polymer film has uniform structure and is isotropic. In the case of a two-layered system, the additional polymer layer between individual threads may reduce yarn mobility and stiffen fabric (Shishoo, 2005).

To evaluate the deformation of the two-layered system after extension and relaxation of the specimens, the following three characteristics were analyzed: residual



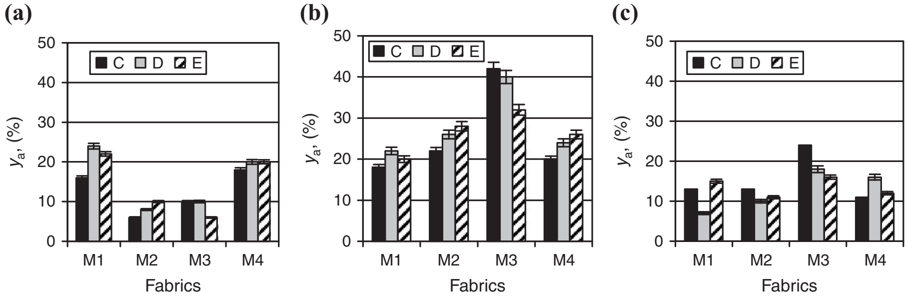
Notes: (a) Parallel line formations (fabric M3); (b) cracked selvage (fabric M4); (c) small surface cracks (fabric M2)

Figure 8.
Failure modes of the transfer element during extension of the specimens until break in the crosswise direction

transfer element deformation in transverse (x_a) and longitudinal (y_a) directions, as well as shear angle α. Transfer element specimens of type C, D, and E were used.

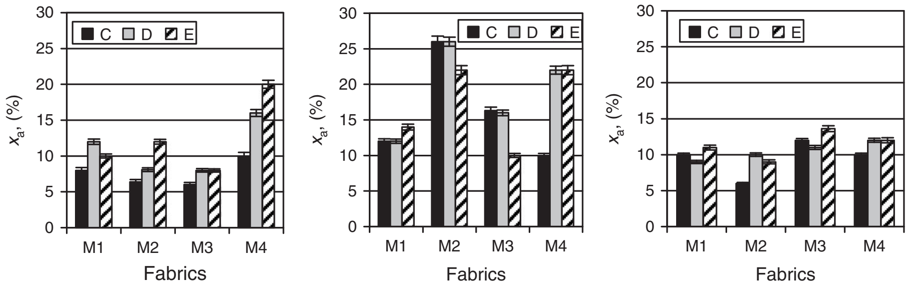
Figure 9 presents the residual deformation of the transfer elements in the longitudinal direction (y_a) after the extension and relaxation of the specimens. All of the specimens exhibit a decrease in their elasticity. The values of y_a vary from 6 to 42 percent. As was expected, the highest values of y_a occurred in the specimens with the largest stretchability. Therefore, with the exception of fabric M3, the specimens with perforated holes (types D and E) were not only more extensible than specimens coated with an intact square of transfer element (type C) but also had a higher degree of residual deformation. Though the specimens coated with perforated transfer elements had higher stretchability, their residual deformation is lower. This was especially apparent for specimens where the area of the polymer layer was the smallest (transfer element with rectangular holes, type E). Relaxation of the M3 fabric specimens was blocked by the numerous cracks in the polymer layer (Figure 8(a)), which appeared during their extension and especially in the crosswise direction. The specimens of type D and E, with a lower coated area, exhibited fewer cracks and therefore slightly higher elasticity.

When a knitted fabric is extended along its longitudinal direction, its width in the transverse direction will be reduced. However, this reduction is limited when the loop structure becomes jammed in the crosswise direction (Hong *et al.*, 2002). The residual deformation of the transfer elements in the transverse direction, x_a, is presented in Figure 10. After relaxation, none of the fabric samples with transfer elements returned



Notes: Direction of extension: (a) lengthwise; (b) crosswise; and (c) bias

Figure 9.
Residual deformation of the transfer elements in the longitudinal direction y_a, after extension and relaxation of the specimens



Notes: Direction of extension: (a) lengthwise; (b) crosswise; and (c) bias

Figure 10.
Residual deformation of the transfer element in the transverse direction x_a after extension and relaxation of the specimens

to their initial width. The values x_a varied from 6 to 26 percent. The largest change in width was observed for the specimens cut in the crosswise direction. The specimens of fabric M2 exhibited especially high residual deformation. In most cases, this undesirable phenomenon was also observed to a greater extent in samples with perforated transfer elements.

Curling of the fabrics edge hinders cutting, sewing and linking. Three of the investigated fabrics (M1, M3, and M4) are not only inclined to curl into a narrow pipe shape during extension, but also remain in this state after relaxation. The transversal deformability l, reached 7.8 to 12.0 mm when the fabric was extended in either lengthwise or crosswise directions. In some cases, transfer elements may stabilize fabrics and reduce their curling. The value of l increases until 36.5-40.5 mm for fabric M3 cut in the lengthwise direction, and until 28.2-35.0 mm for fabric M4 cut in the crosswise direction. It is worth mentioning that specimens of fabric M2 exhibit no curling of the in any cut directions. The transfer elements on fabrics M1, M3, and M4 cut in bias direction also helped these samples to remain flat. These fabrics only exhibited defects in their surface weaving (Figure 4) when they were stretched in the crosswise direction and covered with perforated transfer elements (specimens of types D and E).

This experiment shows that the residual planar shear of the transfer element appears only for specimens cut in the bias direction. This behavior can be explained by the uneven, non-symmetrical structure of the knitted fabrics, which undergo complicated changes during extension of the specimens. The shear angle α of tested specimens reached up to 10.6°. If the shear angle of a knitted fabric usually named as spirality exceeds 5°, it poses an important problem for the quality of the final clothing product (Horrocks and Anand, 2000). Figure 11 shows that the smallest residual shear deformation was observed for fabric M1, while the highest was observed for fabric M3 with all types of transfers, and for fabric M2 with transfers of types D and E.

The degree of residual deformation of the transfer element on a fabric sample is related to the fabric's structure and degree of strain. Larger changes in the transfer element width and length were observed on fabrics with higher extensibility. The weave of the fabric, and its tendency to curl, influences the specimen's transverse measurements (fabrics M2 and M4). Transverse cracks on the polymer layer surface during extension of fabric M3 samples increased the values of y_a for these samples.

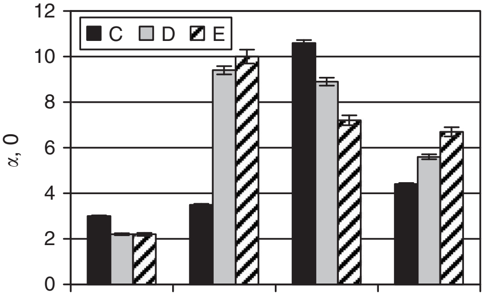


Figure 11. The shear angle α of the transfer element, determined after the specimens' extension in the bias direction, followed by relaxation

4. Conclusion

This paper focusses on the effect of coating on the deformability and coated shape retention of polymer-coated knitted fabrics, after their extension and relaxation. The purpose of these experiments was to establish guidelines for the selection of a heat transfer material for knitted fabrics. Based on the received results the following conclusions were made:

1. In partially coated specimens, the fabric itself ruptures upon extension, but the coated parts stay intact. Two types of breakage in the knitted fabric, and three types of cracking in the polymer layer, were identified. Splitting of the polymer film occurred in three modes: chaotic cracks over the entire surface of the transfer element, cracks in parallel line formations, and selvage cracks. The type of damage depends on the fabric's structure and degree of extensibility, as well as the shape of the transfer element.
2. Extension until breakage of the specimens shows that it is complicated to evaluate the influence of coating area and coated layer shape on the specimens' stretchability, because these results depend on the behavior of the knitted fabrics and polymer layer during extension.
3. Stretching at low stress is a preferable method to investigate the extensibility of knitted fabrics covered with a polymer film. The results of our experiment show that at low stress it is possible to detect a closer relationship between the stretchability of the coated fabric and the degree of its coating with polymer film.
4. After extension until break, the residual deformation of thermoplastic film layer was separated into four types: width and height change, shearing, curling, and surface weaving.
5. The shear phenomenon of the transfer element was observed only for specimens cut in the bias direction. The shape and size of the covered surface have no considerable influence on the shear intensity of the transfer element.
6. The presence of the polymer layer more or less decreases such type of knitted fabrics deformation as curl.
7. Visual analysis has shown that surface of transfer elements with perforated holes may remain wavy after stretching and relaxation of the fabrics. Residual deformation also occurs, which causes the fabric sample to appear baggy.

The results of this research show that to select a suitable transfer element for a knitted fabric, it is necessary first to evaluate extensibility and shape recovery properties of the knitted fabric before choosing a transfer element.

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