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Stretch and Bagging Properties of Denim Fabrics Containing Different Rates of Elastane

Abstract
The performance and comfort factors of garments during usage are very important. Generally, the comfortable stretching of fabrics according to body movements as well as recovery after stretching, are good desirable properties. In recent years, due to the demand for more comfortable clothing, which is more adjustable to the body and has stretchable characteristics, elastane-containing denim fabrics for casual wear have been increasingly preferred. In this study, performance characteristics of five different denim fabrics containing various percentages of elastane were compared. After that, mechanical properties such as tensile and tearing strength, bending rigidity, stretching (elongation, maximum elongation, permanent elongation, elastic recovery) and bagging characteristics of the fabrics were tested. The results were evaluated statistically, and the differences between the mean values were found to be significant. The test results revealed that increasing the amount of elastane usage in denim fabric offers enhanced comfort properties.

Key words: *denim fabrics, elastane yarns, stretching, bagging properties, tensile strength, tearing strength, bending rigidity.*

Introduction

The main factors affecting consumers when selecting garments are aesthetic appearance and fashion. However, besides these factors, clothing comfort during usage of the apparel is also quite important. Human skin has the ability to stretch greatly along with body movements. Generally, the wearer also expects to see the same attitude from their clothing.

Clothes are mostly under strain in some parts of the body, such as the knee, elbow and lower back areas [1]. Therefore, stretching is very important for the comfort of the wearer. Generally, fabrics are required to stretch comfortably in accordance with body movements, and also after stretching, to retain their original shape without any deformation. However, if clothes don't have such great flexibility, deformation, dubbed as fabric bagging, occurs.

Gurnewald and Zoll [2] investigated the fabric bagging mechanism. They used a device that had a motion similar to the bending of an arm. They also used a wearer for a period of 50 days and found a good correlation between the experimental results and the ones observed in practice. Yokura et al. [3] used the volume of a bagged fabric as a measure of the bagging propensity and proposed a system to predict an objective evaluation for woven fabric. In their study, the sample is placed on a hemisphere, clamped by chucks, and then loaded with a square frame for five hours. The shape of the distorted test specimen is measured with the moire topographic technique. The volume formed by the bagged fabric is used to evaluate its bagging propensity. Yokura et al. also measured the mechanical properties of fabrics with the KES-FB system and developed an empirical equation to predict the residual bagging volume of fabrics from their dynamic creep and hysterisis behavior in uniaxial tension, bending, and shearing deformation.

Zhang et.al [4] repeatedly deformed their woven fabric samples by a steel ball leading to a high bagging load placed on an Instron tensile tester, and after five load cycles they measured the bagging height, bagging resistance, which depends on the load work in the first cycle, and bagging fatigue, which depends on the change of load work between the first and last cycles. Uçar [5] used a similar type of mechanism to investigate the bagging properties of knitted fabrics.

Zhang et al. [6, 7] studied the mechanism of fabric bagging. They developed a testing procedure for simulating the bagging process and obtaining psychological perceptual ratings. A series of photographs were taken from bagged fabric samples and compared the results with the residual bagging height. Both ranking and rating scales were used as psychological scales. They found that subjective perceptions of fabric bagging are largely based on fabric residual height, and the residual bagging shape is a component of physical stimuli for a subjective perception of fabric bagging and is related to fabric anisotropy. They found a linear relationship between subjective perceptions and the residual bagging height measured. In other research, they investigated the physical mechanism of fabric bagging by developing an equation to describe the fatigue process in terms of the internal energy decay of fabric.

Kisiliak [8] developed a new modified apparatus for testing the spherical deformation of fabric at the elbow and knee. Zhang et al.[9] theoretically investigated the stress distribution in isotropic as well as anisotropic fabrics and related the bagging force to internal stresses in the fabric section. They showed, for an anisotropic fabric, that the internal stresses were distributed non-uniformly between the warp and weft yarns.

Abghari, Najar, Haghpanahi and Latifi [10] investigated the relation of in-plane fabric tensile properties to the bagging behavior of woven fabrics by using a test method simulation of garment bagging formation. The bagging procedure was carried out by evaluating the woven fabric tensile deformations along the warp and weft directions. The experimental results showed that the bagging behavior of woven fabrics is predictable in terms of biaxial tensile properties under low stress.

Yeung K W et al. [11] developed a method to evaluate fabric bagging from captured images of bagged fabrics by image processing, and abstracting the criteria to recognize bagging magnitude. They tested a group of sixteen commercial woven fabrics by using a bagging test method developed earlier. At a predetermined time after the fabrics were bagged and the samples photographed. In order to show the anisotropic behavior of bagged samples, they took photographs of bagged fabric samples from both the warp and weft directions. Based on an analysis of the intensity images, eight criteria were extracted to characterise the image features, including bagging height, volume, shape and fabric surface patterns on the bagging appearance. They found out that bagging appearance can be predicted by criteria extracted from images of bagged fabrics.

In order to be able to prevent deformation, reduce bagging and aftermath effects of dimensional changes in different parts of the body; extendable and high elastic recovery fabrics have been introduced to the textile market. In recent years, yarns containing elastane have been used to increase the stretch properties of fabrics. As elastic fabrics can stretch far more than normal fabrics, they are preferred in daily clothes as an attempt to increase comfort and fitting properties. Stretch fabrics have made comfort control, easier movement in shapewear and foundations as well as more fashionable silhouettes possible [12, 13].

Core spun yarns are mostly used to obtain stretch fabrics. In core yarns, there is an elastomeric filament in the core and around it, where staple fibers are located. Consequently, the resultant fabric has all the characteristics of the predominant staple fibre together with the advantages of stretch and recovery [14]. Several studies have been carried out to investigate the properties of core spun yarns, and also to investigate the properties of fabrics embodying core spun yarns.

Satlow et al. [15] studied core spun yarn properties and determined that the strength of PES/viscose core yarn is lower than PES/viscose yarn. Babaarslan [16] compared different core materials, such as lycra, textured PES and textured nylon filaments in the production of PES/viscose core yarn, and concluded that core yarn with lycra has the lowest strength and highest elastic recovery compared to core yarns containing textured filaments.

Meriç B., Gürarda A [17] studied the mechanical properties of fabrics containing elastane and concluded that high elastane content makes the yarn flexible; however, the yarn that will be used with elastane should allow the fabric to move freely and shouldn't cause any deformation in the fabric. Moreover, it was determined that the elastane drafting ratio plays an important role in the tensile and tearing strengths of fabrics and these properties decrease with increasing rates of the elastane ratio within the fabric.

Denim is a specific fabric in which stretch occurs, adding a comfort factor to workwear and casual wear [12]. Because of the advantages of using elastane in fabric structure, elastane has gained much attention for use in woven fabric and also by denim producers. Especially since the 1990's have woven fabrics containing elastane been commonly used in denim based products.

In this study, performance properties such as tensile strength, tearing strength, stretching, bagging and bending properties of denim fabrics, containing different amounts of elastane were compared to each other. Thereafter, the effects of the elastane content on the physical properties of each fabric were comparatively investigated.

Materials and methods

Materials

In this study, five different denim fabric samples (2/1 Z twill structured, with a density of 18 yarns /cm for weft and of 27 yarns/cm for warp, having different amounts of elastane ratios) were used for investigating the performance properties of denim fabrics. The yarn count of the elastane used in the weft yarns was 78 dtex and drafting ratio of elastane in the production of core-yarn was 5.2 %. Table 1 displays the properties of the weft yarns and the warp yarns used in this study.

The outcomes of the yarn tests overtly reveal that the tensile strength values of weft yarns containing elastane are lower than the values of ordinary non-elastane weft yarns, whereas the yarn elongation values of ones elastane consisting are slightly higher. The reason for the low yarn strength may be due to the low fiber control during the production of core-spun yarn and therefore some fibers fail to contribute to yarn strength as mentioned in previous papers [15, 16].

Weft core-yarns were used in different ratios and the layout of the yarns in the fabric structure are given in Table 2.

Methods

The performance properties of the denim fabrics, consisting of different elastane ratios, were examined after the washing and fixation processes of the fabrics. As denim fabrics containing elastane generally shrink too much along the weft and along the warp directions, thermal fixation is required. The stretching properties and dimensional stability values required for the fabrics are obtained with the aid of fixation, therefore it is possible to avoid shrinkages [18].

All tests were carried out after the specimens were conditioned in standard

Table 1. *Properties of yarns used in denim fabrics.*

Parameter	Weft yarn without elastane	Weft yarn with elastane (core-spun)	Warp yarn
Yarn count, tex	42	42	74
Twist coefficient, α_m	127	127	136
Breaking strength, N	5.00	4.32	11.3
Elongation at break, %	5.47	12.06	9.84

Table 2. *Properties of denim fabrics.*

Fabric code	The layout of weft core-yarn in fabric	The ratio of elastane, %
D1	2 plain yarn + 1 core-spun yarn	0.50
D2	1 plain yarn + 1 core-spun yarn	0.70
D3	1 plain yarn + 2 core-spun yarn	0.95
D4	1 plain yarn + 3 core-spun yarn	1.05
D5	All weft yarns are core-spun yarns	1.50

atmospheric conditions (temperature 20 ± 2 °C, 65 ± 2% relative humidity). Tensile and tearing strength tests were carried out according to ISO 13934-1 and ISO 13937-2 [19, 20], respectively on a Lloyd trade mark tensile tester. Five samples for each sample were tested, and averages of the test results were calculated.

Stretching and permanent stretching properties were determined according to TS 6071 and ASTM 3107 [21, 22]. A stretch testing instrument, consisting of a frame with separate clamps fixed at the top and at the bottom, was implemented to determine the stretch properties of the fabrics. Sample strips from both weft and warp directions were hung on the apparatus after marking a 250 mm index in the central part of each specimen. A 2250 g load, which was hung according to the fabric weight in the bottom hanger, was applied to the sample three times and after the fourth application; the marked distance was measured. The samples were hung for 30 minutes, and the distance was measured once again. Stretching, maximum stretching, elastic recovery and permanent stretching values were calculated from these measured outcomes.

For stretching and maximum stretching values, the formulas were used.

Stretching in per cent = $(B - A)/A \times 100\%$

Maximum stretching in per cent = $= (C - A)/A \times 100\%$

A: The distance marked between the upper and bottom parts of the fabric (250 mm)
B: The distance between the marked points after the fourth application of the load (mm)
C: The distance between the marked points after hanging the sample for 30 minutes with the load (mm).

Three samples from both weft and warp directions were tested for each sample, and averages of the test results were calculated.

Elasticity is described as the recovery property of a material after deformation. Textile materials cannot retain their original length when they are exposed to a force lower than their tensile strength. To what extent the material would retain its original length depends on the force applied, the duration of the application of the force , the duration allowed for recovery and the properties of the material. The recovery percentage of the material after deformation was calculated by the ratio of elastic stretching to total stretching.

Elastic recovery was calculated by inducing a proportion between the difference in the distance of the marked points of the fabric after hanging it for 30 minutes, and the distance to maximum stretching after 2 hours relaxation time.

Permanent stretching was calculated as follows:

Permanent stretching in % = $= (D - A)/A \times 100\%$

D: The distance between the marked points after 2 hours of relaxation
A: The distance marked between the upper and bottom parts of the fabric (250 mm).

For the woven fabrics, the permanent stretching percentage shouldn't be more than 3 %; otherwise bagging may occur in some parts of the clothes even during normal wearing conditions.

The apparatus that was used (the artificial arm with an elbow joint), improved in accordance with DIN 53860, was modified with an optical component as noted by Prof. F. Bozdogan [2, 23]. In short, this apparatus imitates the human arm in order to measure the deformation occurring at the elbow area. In the statically forced elbow method, the measuring apparatus for bagging has upper and bottom arms. According to Standard DIN 53860, three samples 300 mm × 220 mm in size were prepared from the weft and warp directions of the fabrics [24]. The samples were sewed in a plain sewing machine in such a way that the front parts were placed in the upper part of the apparatus with 5 sewing steps per cm.

Fabric samples, prepared like human arms, were fastened by clamps, then the lower arm was bent to be parallel to the horizontal axis, and next a supporter was placed under the arm (Figure 1). In this position the sample was fixed for 2 hours, and at the end of the testing time the bottom arm was relieved in the vertical position for 12 minutes. After this, the samples were placed on a measuring tube and the deformation height (H_2-bagging) was measured by magnifying the fabric shadow 10 times with an optic lens on a screen. After 24 hours the height of the sample gives the permanent bagging deformation (H_{24}) value. The elastic bagging value was deduced from the difference between the bagging value and the permanent bagging value.

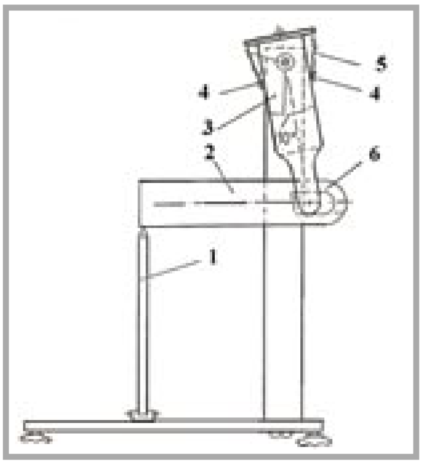

Figure 1. *Apparatus used for bagging testing; 1 - console, 2 - lower arm, 3 - upper arm, 4 - nipper, 5 - coil spring, 6 - joint.*

A circular bending rigidity tester was utilised to determine the stiffness of the fabrics according to ASTM 4032 [25]. The strength required was measured by pushing a fabric of 102 × 102 × 6 mm into a hole of 38.1 mm diameter on the apparatus. To push the fabric into this hole, a cylindrical stick with a diameter of 25.4 mm was applied until the pressure force (measured in cN) that pushed the fabric sample 57 mm down was indicated on a digital screen.

All of the outcomes related to the mechanical properties were also tested for significant differences in means, using one-way anova analysis of variance in a Minitab, separately for each one. To deduce whether the parameters were significant ($p < 0,05$) or not, p values were examined. Significant values from the analysis of variance are given in Table 3.

Table 3. *Significant values (p values) of variance analysis; *statistically significant for α=0,05.*

Tensile strength	Tearing strength	Stretch	Maximum stretch	Permanent stretch	Elastic recovery	Bagging	Permanent bagging	Elastic bagging	Bending rigidity
0.016*	0.707	0.017*	0.010*	0.029*	0.009*	0.001*	0.048*	0.001*	0.56

Results and discussion

Because the elastane yarn was used in the weft direction, which concerned all of the outcomes, there was not a general tendency for the warp direction of the fabrics. Hence, assessments were carried out for weft direction. The tensile and tearing strength values of the fabrics are given in Figures 2 and 3. The outcomes clearly revealed that as the elastane amount in the fabric increased, the tensile and the tearing strength values decreased. Statistical evaluation showed that the difference in means for the tensile strength values were significant, whereas it was not significant for the tearing strength values. This is an expected result, because during the tearing action yarns tend to break one by one or in groups causing highly diverse values for various fabrics, each having a different amount of elastane.

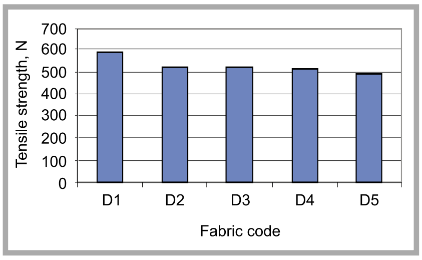

Figure 2. *Tensile strength of denim fabrics.*

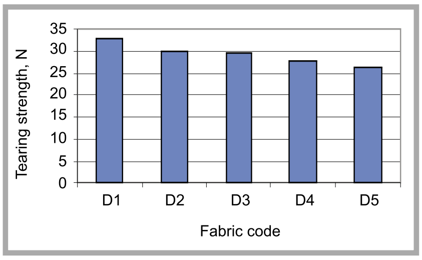

Figure 3. *Tearing strength of denim fabrics.*

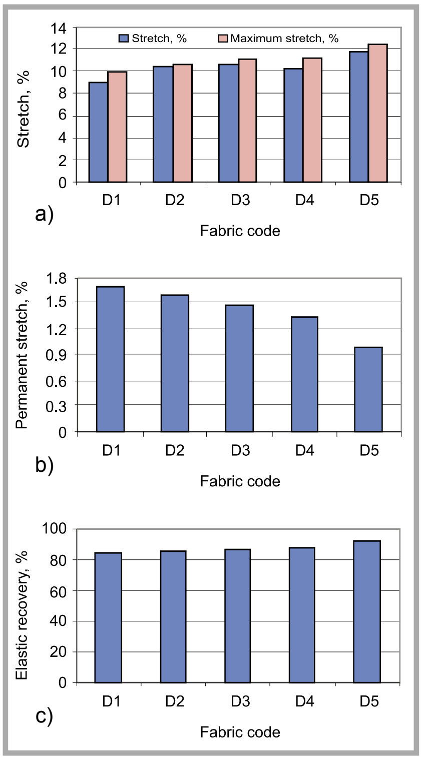

Figure 4. *Stretching properties of fabrics; a) stretching and maximum stretching, b) permanent stretching, c) elastic recovery percentages of denim fabrics.*

Figure 4 displays the stretching, the maximum stretching, the permanent stretching and the elastic recovery values. The outcomes reveal that as the elastane content in denim fabrics increase; the stretching, the maximum stretching and the elastic recovery percentages also increase, whereas the permanent stretching percentages decrease. The differences in means for all the values were found to be statistically significant.

The bagging and permanent bagging values of denim fabrics for weft directions are given in Figure 5. The bagging test, carried out to determine the deformations that occurred, especially at the elbow and knee, determined that with an increase of the elastane content in fabric, permanent bagging decreases, whereas elastic bagging increases. The differences in means are found to be statistically significant.

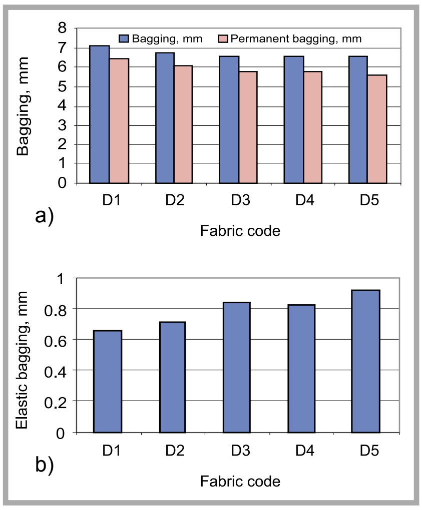

Figure 5. *Bagging properties of fabrics a) bagging and permanent bagging b) elastic bagging values of denim fabric.*

The bending rigidity values of denim fabrics, which were measured by a circular bending rigidity tester, are given in Figure 6. The outcomes suggest that the bending rigidity of denim fabrics increase with an increase in elastane content, therefore it can be stated that the fabric handle becomes stiffer as the elastan ratio in the structure of the fabric increases.

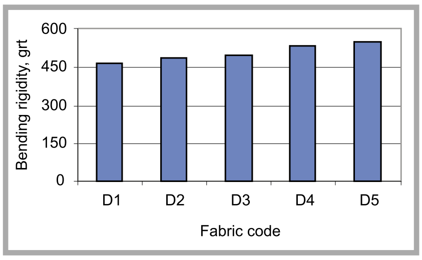

Figure 6. *Bending rigidity values of the denim fabrics.*

Conclusions

The aim of this study was to investigate the effects of elastane content in denim fabrics on the performance properties of the fabrics. For this purpose, the performance properties of denim fabrics, including various amounts of elastane content incorporated into core spun yarns in the weft direction, were measured.

The outcomes of the tests explicitly revealed that the breaking strength of the core spun yarns containing elastane was lower than the breaking strength of non-elastan yarns. Therefore, as the elastane content increases, the tensile and tearing strength values decrease in denim fabrics. The outcomes of the bending rigidity tests displayed that increased amounts of elastane make denim fabrics stiffer.

It was noted that as the elastane content increases, the stretching and the maximum stretching percentages increase owing to the high elasticity of elastane, whereas the permanent stretching percentage decreases due to the rather high recovery properties of elastane. It was also noted that the bagging and permanent bagging values decrease, and the elastic recovery values increase along with an increase in elastane content in the fabric. Therefore, it can be stated that the disturbing appearance, which is formed because of bagging deformation, decreases as the amount of elastane increases.

All of the outcomes and results obtained within this study are consistent with previous studies without any significant exceptions. In short, the outcomes of the tests highlighted the merits of elastan added fabrics. However, the reader should be cautioned that adding a more than enough amount of elastane to the fabric structure introduces a higher degree of stiffness, which would degrade the handling properties of the fabric.

The enhanced aspects of fabrics added with elastane are widely acknowledged and welcomed by the market and consumers. After all, every and each consumer seeks heightened levels of comfort, durability and shape retention. Fabrics with elastane apparently offer these services. On the other hand, elastomer is still an expensive material, and during the manufacturing processes (especially during weaving) it requires more attention and more experience than standard items.

At present, the customers are displaying a conspicuous and steady trend toward appreciating the comfort properties of the garments. To some extent, customers are eager to pay more for comfort. Fabrics added with elastane are still classified as enhanced , as they cost more than standard fabrics. Therefore, there is an increased emphasis on cost reduction and thereupon the major elastan fiber manufacturers are working on innovative developments in their RE-DE departments to be able to offer a cheaper product. However, this is not an easy task and requires time.

It seems that fabrics added with elastane will, to a large extent, maintain their position in the upper middle quality and high quality sections of the textile market, while standard quality, bulk produced items will be waiting for substantial price reductions in elastomer fibers to be able to have an elastane content.

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