Influence of Elastomeric Finishing on Denim Fabric Properties

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Abstract

In recent years, increasing the demand for more comfortable garments enhanced the use of elastane-containing denim fabrics for casual wear. This study was carried out to investigate imparting new properties on denim fabrics using elastomeric finishing agent. Three types of denim fabrics; one is 100% cotton and the other two are cotton/ elastane (Lycra) blends with different elastane ratios (2 and 5%), were treated with elastomeric finishing agent (amino-functional silicon macro-emulsion) using different concentrations (0, 10, 20 and 30 g/l) to evaluate the most appropriate concentration on denim fabric. The results revealed that elasticity, tensile strength, and elongation of the denim fabrics were considerably improved, due to the increase of elastane content as well as increasing the concentration of the elastomeric finishing agent. Furthermore, as the elastane ratio increased, the absorbency of the cotton denim fabric decreased, which imparts a sort of water repellent property.

Keywords

Cotton, Denim, Elastane (Lycra), Stretch garments, Elastomeric Finishing

1. Introduction

Today, a good design is not enough for garments. Garments should have good mechanical properties during usage. Elasticity plays a dominant role in the behavior of garments during wearing [1]. Cotton garments have very good properties such as water absorbency, comfort to wear and easy to dye [2]. Cotton garments with high functional properties such as elasticity, easy care, softness, antimicrobial, and self-cleaning have great demand in garments market [3]. Denim is a cotton twill woven fabric. It is popular among people of all ages. It is durable, and strong and due to its fabric structure. It is a woven fabric with dyed warp yarns and white weft yarns [4].

Today the most trend in denim garments is customer's need with comfort, fit, flexibility, better dimension stability and special appearance [5,6]. Stretch denim fabrics add a comfort factor to work and casual wear [4,7].

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Stretching performance is very important for the consumer comfort for some parts of body such as the knee, elbow and lower back areas. Garments are required to stretch comfortably in accordance with body movements, and to retain their original shape. Lycra fiber is the brand name of a class of synthetic elastic fibers known as spandex in the U.S., and elastane in the rest of the world. Because of its elasticity and strength, elastane has been incorporated into a wide range of garments, especially in skin-tight garments. Elastane is usually mixed with cotton or polyester, and accounts for a small percentage of the final fabric, which therefore retains most of the look and feel of the other fibers [7].

Adding 1-5% of elastane to cotton will stretch the fabric over the body providing a more comfortable fit. The ratio of elastane had a significant influence on the physical properties of woven denim fabrics [8].

Increasing the amount of elastane in denim fabric enhances comfort properties related to stretch. Core spun yarn can also be used as filling in which core part is Lycra filament and sheath fibers cotton, to improve the elasticity of denim [7,9].

Elastane fibers are a class of synthetic fibers comprising at least 85% by weight of segmented polyurethane characterized by superior stretch and excellent elastic recovery properties. Core spun cotton yarns, with elastane component in the core and cotton in the sheath, have become quite popular in the textile industry. The elastane in the core yarn provides the necessary comfort for aesthetics wearer with good thermo-physiological characteristics [10].

A variety of raw materials are used to produce stretchable elastane fibers. These include pre-polymers, among which two react to produce the elastane fiber polymer back-bone.

One is a flexible macroglycol, such as polyester, polyether, polycarbonate, polycaprolactone which have hydroxyl groups (-OH) on both ends, these molecules are long and flexible so that they are responsible for fabric stretching characteristic. The other pre-polymer used to produce elastane is a polymeric disocyanate which has a shorter chain polymer and (-NCO) groups on both ends. These molecules are responsible for fabric strength as shown in Figure 1.

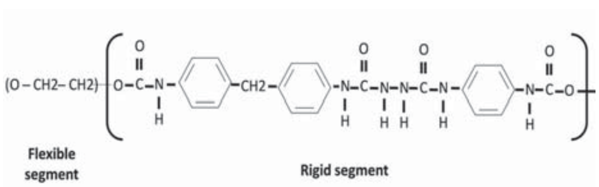

Figure 1. Elastane chemical fiber structure showing flexible segments and rigid segments.

The ratio of the soft and the hard segment has a great effect on mechanical and elastomeric properties of the elastane fibers blended with natural fibers like cotton [11].

Elastomeric finishes are achieved with silicon-based products which often consist of a terminal silanol (?, ?-dihydroxy polydimethylsiloxane), methyl hydrogen silane and a metal salt catalyst. As the elasticity is durable, an alternative approach to providing fabrics with elastomeric finishes is to incorporate a few amounts of elastic fibers into the yarn of the fabric. Using of elastomeric finishes on fabrics blends with elastic fibers is common in textile industry. To understand the elastomeric mechanism, it has been reported that elastomeric finishing covers the fibers with a thin layer of an elastic material without fiber-to-fiber bonding [12].

Some hydro silane groups can be oxidized by air to silanol groups as shown in Figure 2.

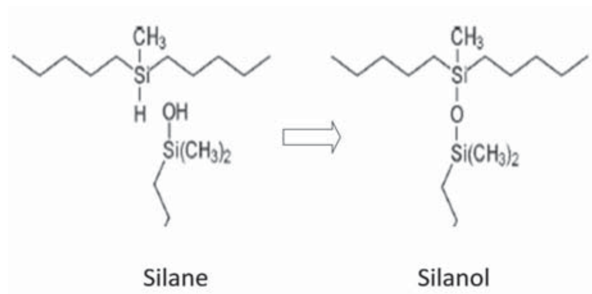

Figure 2. Chemical structure of silane and silanol. Oxidization of hydro silane groups to silanol groups by air resulting in a silicon film as an elastomeric finish.

The resulting silicon film transfers elasticity because of this silicon film effect on hydrophilic fibers such as cellulose. Furthermore, the epoxy groups in silicon react with the hydroxyl groups of cellulose or the amino groups of wool and silk generating stable ether or amino bonds between the silicon film and the fiber surface [12,13].

Amino functional siloxanes, such as polydimethylsiloxane (PDMS) shown in Figure 3 is widely used in textile finishing.

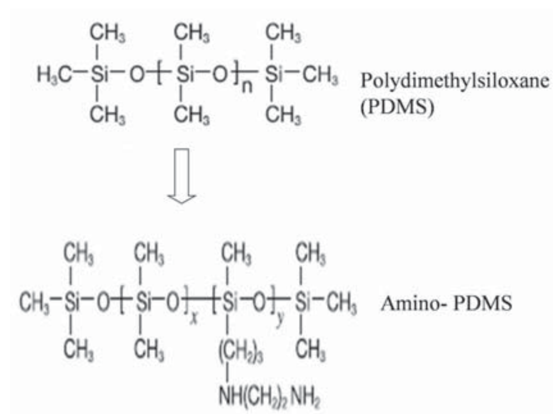

Figure 3. Chemical structure of polydimethylsiloxane (PDMS) and amino-PDMS as a siloxane emulsion used in elastomeric finishing.

Because of the interactions of amino groups with textile fibers, amino functional siloxanes are physically adsorbed onto the fiber surfaces as a thin film covering the fiber and increasing the fiber smoothness. The main disadvantage of Amino-PDMS is the yellowing of white or light-colored fabrics, due to the oxidation of primary amino groups by air, heat or light energy [14].

There is a growing need to study the finishing of denim fabrics, especially when elastane yarns are used in the production of the denim. The main aim of our study was to determine the influence of the elastomeric finishing at different concentrations on the properties of both twill woven cotton fabric produced from 100% cotton yarns and from cotton/elastane yarns. Elastomeric finishing agent based on amino-functional silicon macro-emulsion chemical structure is used in this study. The research work we undertook allows factories to improve the elastomeric properties of this popular kind of cotton fabrics.

2. Material and method

2.1. Fabrics

Three variants of twill woven denim fabrics were used for this study; Twill weaves such as three-up-one-down (3/1) and two-up-one- down (2/1) are predominantly used for denim construction, all the warp yarns are indigo blue dyed cotton, the percent of elastane in the blended denim is (2-5%). The specifications of the fabric variants are presented in Table 1.

Table 1. Specifications of the denim fabrics.

	Denim (A)	Denim (B)	Denim (C)
weave **construction** **warp** **weft**	twill 3/1 cotton cotton	twill 2/1 cotton cotton /spandex 2%	twill 3/1 cotton cotton /spandex 5% (core structure)
Fabric weight (g/m2)	266 g/m2	320 g/m2	340 g/m2
warp/weft density **Fabric thickness (mm)**	30/20 threads/cm 0.630 mm	25/20 threads/cm 0.720 mm	30/20 threads/cm 0.800 mm

2.2. Chemicals

Sodium hydroxide NaOH, wetting agent (triton X-100), acetic acid and anionic detergent were used for scouring and mercerizing, we used α-amylase for desizing. Special finishes were applied on pretreated fabrics using products, (Asumin Elast), Modified poly dimethyl siloxane amine (Amino-functional silicon macro-emulsion), supplied by ASUTEX, Spain. All chemicals are laboratory grade and used without any purification.

2.3. Methods

For pure denim fabric, as well as cotton /elastane denim blends, the warp threads are coated with a substance known as size or starch. It acts as a lubricant and protects the yarn during weaving. After weaving, the sizing agent has to be removed from the cotton fabric. Bio-desizing was carried out using α-amylase as follows: α-amylase 1%, Bath ratio 1:10, temperature at 50^0C for 60 min, and pH at 6.0. After the enzymatic desizing, enzymes were deactivated by immersing the samples for 10 min in hot water (80^0C), rinsing and washing in a solution of anionic surfactants at 80^0C followed by air drying.

Amino-functional silicon macro-emulsion was used as elastomeric finishing by padding the fabrics in (10-30 g/l) Asumin Elast®, acetic acid for adjusting the pH of the finish bath at pH 5, pick up 60-80%, then drying at 150^0C for 3 minutes and polymerization at 170^0C for 1 minute. We compared the influence of elastomeric finishing with different pretreatment processes (desizing, scouring and mercerization) on the properties of denim fabric type A only, which is made of 100% cotton without elastane. For the comparison between the three denim fabric types in elastomeric finishing we chose bio-desizing, as it is the safest pretreatment for elastane and this is applied all over the experiments comparing the three denim fabric types.

2.4. Fabrics measurements

Each sample is tested in the standard atmospheric conditions, 25 ± 2^0C temperatures and 65% relative humidity after conditioning for 24 hrs. The results were expressed as the average of five measurements. All the properties of raw and finished woven fabrics were measured in accordance with the following standards:

2.4.1. Shrinkage

The dimension changes in the weft /warp directions of the raw and treated fabrics were assessed. It is done according to AATCC 96-1997 method.

2.4.2. Fabric weight (g/m²) and thickness

Samples before and after pre-treatment were evaluated according to the standard ISO 3801:2003.
Thickness was determined using standard test method for measuring thickness of textile materials ASTM (D-1777).

2.4.3. Tensile Strength and elongation

Breaking strength and elongation were tested on a universal tensile testing machine- Galdabini Quasar 50KN at the National research centre NRC, Egypt. Fabric samples with 25 mm × 150 mm dimension were used. Tensile Strength and elongation were determined according to Standard test method for breaking force and elongation of textile fabrics (strip method) ASTM (D-5035).

2.4.4. Evaluation of elasticity

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 [7]. We used the Young's modulus of elasticity as an indicator of elastomeric finishes obeying the Hooke's law which can be calculated with the following equation [15].

$$E = \frac{\sigma}{\varepsilon} = \frac{F}{\varepsilon \cdot b \cdot d} \text{ MPa}$$

Where E is the Young's modulus of elasticity which is inversely proportional to the fabric elongation, F is tensile force in N, ε is elongation (%), b is width in mm and d is fabric thickness in mm.

2.4.5. Water absorbency

The test for absorptive capacity and absorbency time were conducted following the principles of test described in ASTM D1117-80. Absorbency time is the time required for the complete wetting of a fabric specimen put on to the surface of the water from a height of the samples of 1-liter measuring glass cylinder, with a stop watch to record the time needed of the fabric to fully sink. For each sample five specimens were tested. Each specimen dimension was 20mmX 20mm. Specimens were tested in distilled water at 20^{0}C. The time taken for the fabric to completely sink below the surface of the liquid was recorded.

3. Results and Discussion

3.1. Influence of elastomeric finishing on shrinkage of denim fabrics

Shrinkage of all raw fabrics is highest in both directions compared to the finished fabrics, for which shrinkage significantly decreased in the warp and the weft directions in Figure 4.

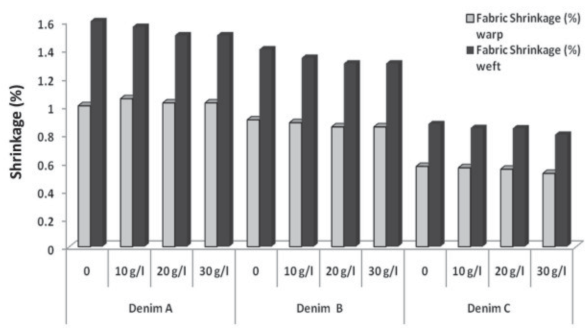

Figure 4. Effect of elastomeric finishing concentrations on shrinkage percentage of denim fabrics. Comparing Shrinkage percentages in all desized denim fabrics.

The shrinkage of 100% cotton denim fabrics after pretreatment was within the range of 1-2%. The shrinkage in the warp direction is lowest. The highest difference between shrinkage of fabrics with starch fabrics made of 100% cotton and fabrics including elastane. The values of shrinkage after finish-ing using different concentration decreased the shrinkage especially in the weft direction.

3.2. Influence of elastomeric finishing on fabric weight (gr/m^2) of denim fabrics

The results of mass per unit area and change in weight (Figure 5) show that all treatments cause changes in the weight loss percent of the denim fabrics.

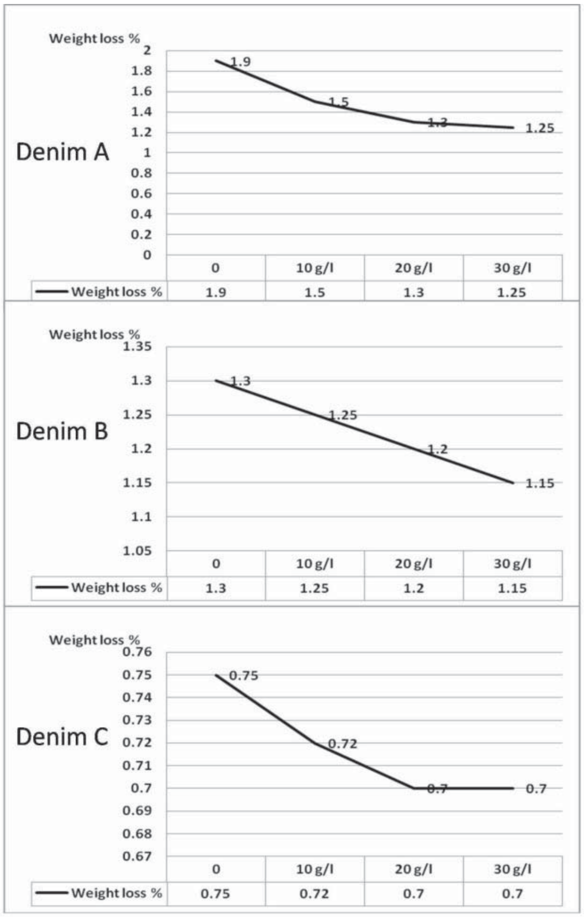

Figure 5. Effect of elastomeric finishing concentration on weight loss (%) of denim fabrics A, B and C.

Desizing with amylase enzyme causes reduction in weight, due to the removal of sizing additives up to the level of 1.9%. Additionally, Special finishes form a layer around fibers increasing the weight of the denim fabric represented as decreasing in weight loss percent.

3.3. Influence of elastomeric finishing on tensile strength and elongation of denim fabrics

In a biaxial woven structure two main directions are defined: longitudinal (warp) and transverse (weft) [15]. Because elastane was used in the weft direction, the assessments were carried out for only the weft direction. We observed that the tensile strength of the fabrics gradually increased with the elastane content as shown in Figure 6.

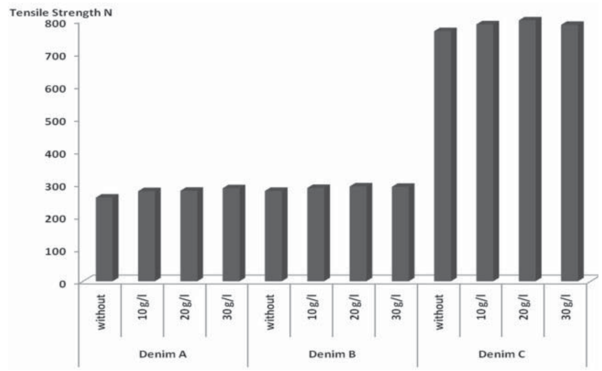

Figure 6. Effect of elastomeric finishing concentration on tensile Strength N of denim fabrics.

The figure showed that the tensile strength of the denim fabrics treated with elastomeric finishing was enhanced, especially denim C with the highest elastane ratio, maybe due to the fact that finishing made the fabric flexible and for this reason tensile strength was increased [16]. In addition, other studies revealed that silicon reduces abrasion, increases tearing strength and crease recovery [13].

These results are associated with the chemical and physical modifications of cellulosic fibers that occur throughout chemical treatment. As expected, the denim which included elastane in the weft of the fabric resulted in high elongation, as shown in Figure 7, and denim C was higher than denim B because it has more ratio of elastane.

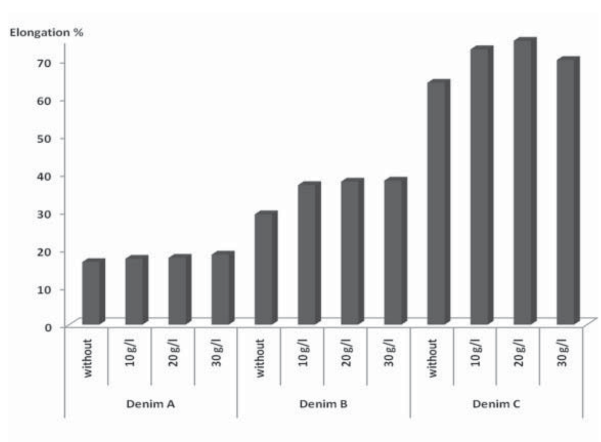

Figure 7. Effect of elastomeric finishing conc. on Elongation % of denim fabrics.

3.4. Influence of elastomeric finishing on Modulus of elasticity in millipascal (mPa) of denim fabrics

Denim fabrics treated with amino-functional silicon macro-emulsion (0, 10, 20 and 30 g/l) as an elastomeric finishing are shown in Figure 8.

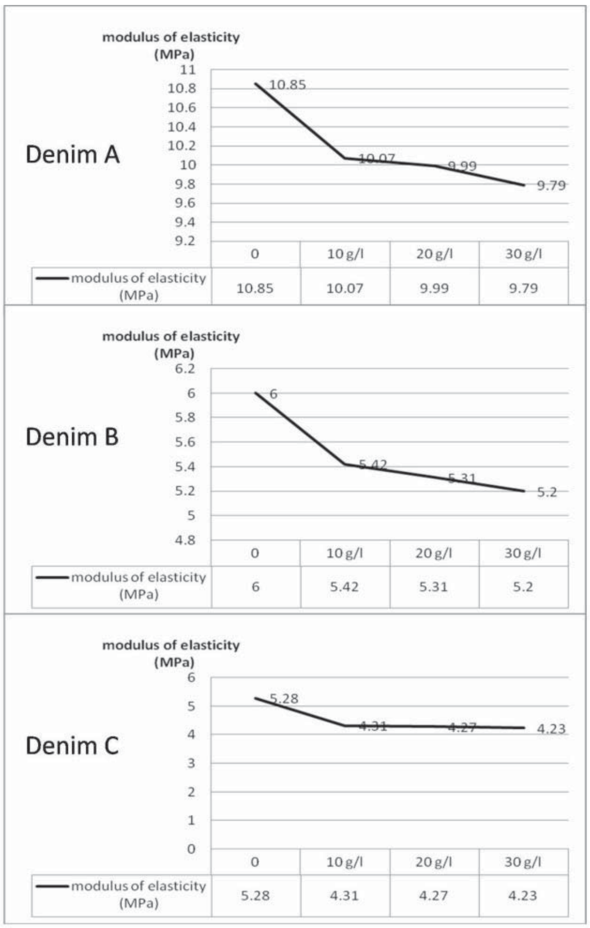

Figure 8. Effect of elastomeric finishing concentration on Modulus of elasticity (mPa) of denim fabrics.

Since lower modulus of elasticity means higher elasticity [15], denim A showed the lowest elasticity (modulus of elasticity 9.79 mPa) compared to denim B and C which were 5.2 mPa and 4.23 mPa, respectively. These values were obtained with the highest concentration of elastomeric finishing (30 g/l).

This finishing agent chemical composition allows it to react with the hydroxyl groups of cellulose generating stable bonds between the silicon film and the surface of cellulosic fibers.

We also observed that the increase in elastane content affected the compressibility and compression recovery properties of the denim fabric samples. As the elastane content increased, fabric compressibility increased. This can be attributed to the spring like behavior of the elastane fiber and its tendency to return to its original dimensions after the load is being removed. The compression recovery of the denim fabrics also showed similar trend as compressibility. In addition, with the increased elastane content, the fabric thickness was increased [9].

3.5. Influence of elastomeric finishing on Water absorbency and repellency of denim fabrics

Figure 9 showed that as the elastane ratio increased the absorbency of the silicon finishing in all denim fabrics A, B and C decreased. This can be explained by the finishing agent composed of silicon imparting hydrophobic properties to the denim fabric, which is considered as a water repellent property [17,18]. The hydroxyl groups of cellulose in cotton fabric made the fabric hydrophilic, but after finishing with amino-functional silicon macro-emulsion, a thin layer of silicon was made onto the fabric, which prolongs the absorption time [16].

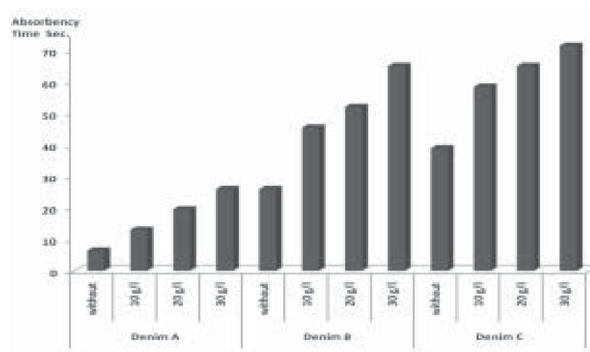

Figure 9. The absorption time of denim fabrics treated with elastomeric finishing.

4- Conclusion

This study focused on the impact of elastomeric finishing using amino-functional silicon macro-emulsion, on the physical and mechanical properties of woven cotton denim and cotton/elastane blend. Elasticity of all denim fabrics after treatments was increased, due to the elastomeric finishing agent reacting with the hydroxyl groups of cellulose generating stable bonds between the silicon film and the surface of cellulosic fibers. Elasticity of the denim fabrics were increased, due to the increase of elastane content as well as increasing the concentration of the elastomeric agent. The results revealed that mechanical properties of denim fabrics, such as tensile strength, elongation were improved after elastomeric finishing, due to the fact that the finishing agent makes the fabric more flexible, thus increasing the tensile strength of the fabric. This finishing improved the properties of denim fabrics.

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